92-483-332 WR

TEXAS A&M UNIVERSITY
Department of Civil Engineering
Environmental, Ocean and Water Resources Division

March 15, 1994

Stephen D. Densmore
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

Dear Steve:

An unbound copy of the final report is enclosed. We have revised the report in response to the comments you provided. The final report reflects revisions based on our review of the draft as well. Simultaneously with mailing you this copy, I am hand-carrying the originals to the Texas Water Resources Institute for publication in their technical report series. We will send you ten copies of the report as soon as printing is complete, which should be within the next couple of weeks. Additional copies will be available to anyone from the Texas Water Resources Institute upon request.

Please let me know if I can be of further assistance. I will be glad to discuss the model and study findings any time. Best personal regards.

Sincerely,

Ralph

Ralph Wurbs

Copy Furnished:

Wayne R. Jordan, Director
Texas Water Resources Institute

CIVIL College Station, Texas 77843-3136 • (409) 845-3011; FAX (409) 845-6156

RESERVOIR/RIVER SYSTEM RELIABILITY CONSIDERING WATER RIGHTS AND WATER QUALITY

Ralph A. Wurbs
Gerardo Sanchez-Torres
David D. Dunn

March 1994

Texas Water Resources Institute
Texas A&M University

RESERVOIR/RIVER SYSTEM RELIABILITY CONSIDERING WATER RIGHTS AND WATER QUALITY

By

Ralph A. Wurbs
Gerardo Sanchez-Torres
David D. Dunn

The research on which this report is based was financed in part by the Department of the Interior, U.S. Geological Survey, through the Texas Water Resources Institute. The Texas Water Development Board jointly sponsored the project and provided non-federal matching funds.

Technical Report No. 165
Texas Water Resources Institute
Texas A&M University
College Station, Texas 77843-2128

March 1994

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

CHAPTER 1
INTRODUCTION

Statement of the Problem

Effective management of the highly variable water resources of a river basin requires an understanding of the amount of suitable quality water that can be provided under various conditions within institutional constraints. Although much research has been reported in the published literature regarding modeling reservoir system operations and evaluating water supply reliabilities, relatively little work has addressed integration of water rights and salinity considerations in comprehensive water availability studies. However, from a practical water management perspective, these are the controlling factors in many river basins in Texas and elsewhere. The study documented by this report provides expanded capabilities for modeling and analysis of reservoir/river system reliability, with a focus on institutional (water rights) and water quality (salinity) considerations.

Population and economic growth combined with depleting ground water reserves are resulting in ever increasing demands on the surface water resources of Texas. Water rights and salinity represent two particularly important considerations in management and utilization of the surface water resources of the state. With the recent implementation of a prior appropriation permit system, water rights have become a key aspect of reservoir/river system management. Natural salt pollution is also a controlling constraint in utilization of the waters of a number of major river basins in Texas and neighboring states.

Surface water law in Texas developed historically over several centuries. Claims have been recognized to water rights granted under Spanish, Mexican, Republic of Texas, and United States, as well as State of Texas, laws. Early water rights were granted based on various versions of the riparian doctrine. A prior appropriation system was later adopted and then modified. An essentially unmanageable system evolved, with various types of water rights existing simultaneously and with many rights being unrecorded. The Water Rights Adjudication Act of 1967 merged the riparian water rights into the prior appropriation system. The allocation of surface water now has been consolidated into a unified permit system. The water rights adjudication process required for transition to the permit system was initiated in 1968 and was completed in the late 1980s. About 7,700 active permits are now in effect for use of the waters of the 15 major river basins and eight coastal basins of the state. Applications for additional new permits or modifications to existing permits can be submitted to the Texas Natural Resource Conservation Commission at any time. Applications are approved only if unappropriated water is available, existing rights are not impaired, a beneficial use is contemplated, water conservation will be practiced, and the water use is not detrimental to the public welfare.

Water quality in several major river basins in the Southwestern United States is seriously degraded by natural salt contamination. The salt, which consists largely of sodium chloride, originates from geologic formations underlying portions of the upper watersheds of the Arkansas, Canadian, Red, Brazos, Colorado, and Pecos Rivers in the states of Kansas, Colorado, Oklahoma, New Mexico, and Texas. Millions of years ago, this region was covered by a shallow inland sea. The salt-bearing geologic formations were formed by salts precipitated from evaporating sea water. Salt springs and seeps and salt flats in the upper portions of the river basins now contribute large salt loads to the rivers. The natural salt pollution significantly impacts water resources development and management.

The Brazos River Basin provides a case study for the research. A water supply reliability study was performed for a system of 12 reservoirs owned and operated by the Brazos River Authority and U.S. Army Corps of Engineers. The evaluation of the water supply capabilities of the 12-reservoir system reflects the facts that: (1) over a thousand entities, owning about six hundred reservoirs, hold permits to use the waters of the Brazos River and its tributaries and (2) much of the streamflow is unsuitable for most beneficial uses much of the time due to excessively high salt concentrations.

The Brazos River Basin illustrates a general situation which is characteristic of other major river basins as well. A significant need exists for improving modeling and analysis capabilities for performing comprehensive water availability studies. Reservoir/river system reliability analyses support planning studies and management decisions regarding (1) improvements in reservoir system operating policies, water rights allocations, and water supply contracts, (2) facility expansions and construction of new water supply projects, and (3) projects and strategies for dealing with salinity. Formulation and implementation of innovative management strategies for operating reservoir systems, allocating water between multiple uses and users, and minimizing the adverse impacts of natural salt pollution require that a river basin be treated as an integrated system.

Scope of the Study

The objectives of the research study documented by this report are to:

- develop a generalized simulation model for analyzing river/reservoir system reliability which integrates consideration of water rights and salinity,

- develop a better understanding of approaches for increasing multiple-reservoir system yields and reliabilities, formulating associated system water rights permits and contractual arrangements, and dealing with high salt concentrations,

- evaluate the impacts of natural salt pollution on water supply capabilities, and

- perform a comprehensive reliability study for the major reservoir system in the Brazos River Basin operated by the Brazos River Authority and U.S. Army Corps of Engineers.

The primary products of the research are (1) a generalized simulation modeling package and (2) a comprehensive detailed case study analysis. The simulation model consists of a refined and expanded version of the previously developed TAMUWRAP Water Rights Analysis Package. The generalized computer model simulates the management and use of the streamflow and reservoir storage resources of a river basin, under a prior appropriation water rights permit system. TAMUWRAP is generalized for application by water resources planning and management practitioners to essentially any river basin or multiple river basins. TAMUWRAP was applied, in this study, to the Brazos River Basin. The general modeling and analysis approach adopted for the Brazos River Basin water supply reliability study is equally applicable to various types of studies of other river basins in Texas and elsewhere.

The Brazos River Basin simulation study focused on the water supply operations of the Brazos River Authority system, but all the other water rights in the basin were also considered. Surface water availability was evaluated for the overall river basin in general and for the 12-reservoir Brazos River Authority system in particular. In addition to the various analyses reported here, the basic input data files developed are now also available for future studies as well.

Several key aspects of reservoir/river system management and associated water availability modeling were investigated. Water management strategies and modeling premises examined include salinity constraints, multiple-reservoir system operations, reservoir storage rights, reallocation of hydropower storage to water supply, and salt control impoundments. Although the simulation modeling study was performed for the Brazos River Basin, the basic water management and modeling concepts investigated are generally applicable to other river basins as well.

Study Sponsors, Organization, and Documentation

This report is one of several prepared in conjunction with a research project, entitled "Reservoir System Reliability Considering Water Rights and Water Quality," conducted from September 1992 through December 1993 as part of the cooperative federal/state research program administered by the U.S. Geological Survey and Texas Water Resources Institute. The Texas Water Development Board jointly funded the project as the nonfederal sponsor. This research project builds upon and extends a project sponsored by the Texas Advanced Technology Program (TATP) entitled "Natural Salt Pollution and Reservoir System Yield," which was conducted from September 1990 through August 1992. The TATP is administered by the Texas Higher Education Coordinating Board.

The overall investigation is documented by two other technical reports (Wurbs, Karama, Saleh, and Ganze 1993; and Wurbs, Dunn, and Walls 1993) in addition to the present report. Several graduate student dissertations and theses also address various aspects of the study. Wurbs, Karama, Saleh, and Ganze (1993), Saleh (1993), and Karama (1993) developed salt load data and evaluated water supply reliabilities constrained by salinity, without considering water rights. Sayger (1992) investigated surface/subsurface interactions of streamflow and salinity in the Brazos River. Wurbs, Dunn, and Walls (1993) document the TAMUWRAP Water Rights Analysis Package prior to the addition of salinity features. Dunn (1993) applied TAMUWRAP in an analysis of the Brazos River Basin without considering salinity. Yerramreddy (1993) developed a network flow programming version of the TAMUWRAP model, again without salinity features. Sanchez-Torres (1994) and the present report integrate water rights and salinity considerations.

Prior Studies

The present study also builds upon a research project conducted from September 1986 through August 1988 as a part of the cooperative research program of the U.S. Geological

Survey and Texas Water Resources Institute, jointly sponsored by the Brazos River Authority (Wurbs, Bergman, Carriere, Walls, 1988; and Wurbs and Carriere 1988). This study also addressed simulation modeling and water availability in the Brazos River Basin. Storage reallocations and other strategies for enhancing reservoir yields were investigated. The USACE Hydrologic Engineering Center (HEC) simulation models HEC-3 and HEC-5 were used in the study. Salinity was not considered. The original version of the Water Rights Analysis Program (TAMUWRAP) was developed in conjunction with the study.

Brazos River Basin natural salt pollution control studies conducted by the U.S. Army Corps of Engineers (USACE) are documented by a survey report (USACE 1973), environmental impact statement (USACE 1976), and draft general design memorandum (USACE 1983). McCrory (1984) provides a concise overview of the natural salt pollution control studies. Various other agencies prepared reports as input to the USACE managed studies. Alternative plans for addressing the salt problem were formulated and evaluated in these studies. The survey report (USACE 1973) recommended construction of a system of salt control dams to contain the runoff from the primary salt source areas. In the restudy documented by the draft general design memorandum (USACE 1983), the previously recommended salt impoundment plan and alternative plans were found not to be economically feasible based on current evaluation methods and conditions even though natural salt pollution is definitely a serious problem. The U.S. Geological Survey conducted an extensive water quality sampling program from 1964 through 1986 in support of the USACE salt pollution control studies. The contract work of Ganze and Wurbs (1989), accomplished for the USACE, consisted of compiling the USGS data into a readily usable format and performing various analyses. The present study utilized this basic salinity data and includes an analysis of the previously proposed USACE salt control impoundment plan.

Organization of the Report

The Texas surface water allocation and permitting system is outlined in Chapter 2. Chapter 3 describes the TAMUWRAP Water Rights Analysis Package which simulates water management and use within the framework of the water rights system discussed in Chapter 2. Chapter 4 describes the Brazos River Basin including its reservoirs, water use, water rights, and salinity. The TAMUWRAP simulation modeling study of the Brazos River Basin is presented in Chapters 5-8. Development of the basic model input data sets is documented in Chapter 5. The scope and organization of the simulation study are outlined in Chapter 6. The study involved numerous runs of the simulation model reflecting alternative reservoir/river system management approaches and related modeling assumptions. The results of a single base simulation run are presented, in some detail, in Chapter 7. Chapter 7 provides a demonstration of TAMUWRAP modeling capabilities as well as an examination of water availability in the Brazos River Basin. Chapter 8 is an evaluation of key water management strategies and modeling assumptions based on numerous alternative runs of the simulation model. The summary and conclusions of the report are presented in Chapter 9.

CHAPTER 2
THE TEXAS WATER RIGHTS SYSTEM

Water Law

A water right is simply the legal right to use water. Water law is the creation, allocation, and administration of water rights. Getches (1990) provides a general overview of the development and application of basic principles of water law. Rice and White (1987) address water law from an engineering perspective. Davenport (1954) treats the early history of water rights in Texas. McNeeley and Lacewell (1977) and Templer (1981) discuss the evolution of Texas water law, with a focus on the adjudication process instituted by the Water Rights Adjudication Act of 1967. Kaiser (1987) describes the current water rights system.

Water is categorized by where it is physically contained. Water law in Texas, and most other states, recognizes four distinct classes of water: (1) percolating groundwater, (2) underground streams, (3) diffuse surface water, and (4) streamflow. Separate rules of law have been developed for each category of water.

In regard to percolating ground water, Texas courts have followed the common law rule that the landowner has a right to take for use or sale all the water he can capture from beneath his land. The state has little control over the use of ground water. Consequently, conjunctive management of ground and surface waters is extremely difficult. A recent legislative act creating a mechanism for implementing a permit system for the Edwards Aquifer is a major exception to the general rule of essentially unlimited withdrawals. In 1993, the Texas Legislature, in enacting SB1477, created the Edwards Aquifer Authority to administer a water allocation system somewhat similar to the surface water rights system of the state.

The law with respect to ownership of subterranean rivers is not settled in Texas. From a water rights perspective, underground rivers could conceivably be treated similarly to surface rivers. However, the existence of specific subterranean rivers has never been legally recognized in Texas. The Edwards Aquifer has been the focus of debate on this issue. The Edwards is considered by many water management professionals to be a subterranean river and thus subject to state regulation of water use. Proposals to treat the Edwards Aquifer as an underground stream to facilitate regulation of well pumping have been debated for a number of years. However, the proposals to grant to the Edwards Aquifer the legal status of being a subterranean river have not been successful. In 1993, the Texas Legislature, in SB1477, declared the Edwards to be a unique aquifer but not an underground stream. As noted above, a permit system is being developed for this particular aquifer.

Diffuse surface water, often called drainage water or runoff, does not become the property of the state until it reaches a watercourse. A landowner may construct a dam on a non-navigable stream on his property to impound and use diffuse surface water, without a permit, as long as the volume of water impounded does not exceed 200 acre-feet. This provision of the law is pertinent to the management of major reservoirs because construction of numerous small dams in a watershed can reduce the amount of runoff that reaches the main river.

The present investigation is concerned with streamflow. Generally, in the United States, legal rights to the use of streamflow are based on two alternative doctrines, riparian and prior appropriation. The basic concept of the riparian doctrine is that water rights are incidental to the ownership of land adjacent to a stream. The prior appropriation doctrine is based on the concept "first in time is first in right." In a prior appropriation system, water rights are not inherent in land ownership, and priorities are established by the dates that users first appropriate water. Water law in 29 eastern states is based strictly on the riparian doctrine. Nine western states have a pure prior appropriation system. Ten western states, including Texas, originally recognized riparian rights but later converted to a system of appropriation while preserving existing riparian rights. Two other states also have hybrid systems incorporating the two doctrines in a somewhat different manner.

Historical Development of Surface Water Law in Texas

Texas water law recognizes claims to surface water rights granted under Spanish, Mexican, English, Republic of Texas, and United States as well as Texas state laws. Both the appropriation and riparian doctrines have been recognized. The riparian doctrine was introduced into Texas by the Spanish and Mexican governments and then, after independence in 1836, in a somewhat different form by the Republic of Texas. For many years, Texas courts and water agencies ruled that Spanish and Mexican land grants carried extensive riparian water rights, including the right to use water for irrigation. Following more thorough investigations of Spanish and Mexican water law, the courts determined in the Valmont Plantations versus Texas case in 1962 that riparian rights to use water for irrigation did not attach to these land grants, unless specifically included. Few land grants included specific provisions for water rights except in the vicinities of San Antonio and El Paso. Extensive amounts of land, mostly in South and Central Texas, can be traced to Spanish and Mexican grants. Land grants made between 1836 and 1840 by the Republic of Texas also were controlled by Mexican law and have the same water rights. In 1840, the State of Texas adopted the common law of England in which riparian water rights include the right to make reasonable use of water for irrigation or for other extensive and consumptive purposes.

The prior appropriation doctrine was adopted by the state with the Appropriation Acts of 1889 and 1895. After 1895, public lands which transferred into private ownership no longer carried riparian water rights. Water rights are claimed through statutory procedures. At first, appropriation was accomplished through an informal procedure in which a water user simply filed a sworn statement with his county clerk describing his water diversion. Later, certified copies of these claims were recognized by the state, and came to be called "certified filings". Since 1913, more strictly administered procedures have been followed based on a statewide appropriation system administered by a centralized state agency. All appropriation statutes recognize the superior position of riparian water rights. Riparian landowners can also acquire appropriative water rights and may claim both types of rights, each without prejudice to the other.

The complications of having various forms of riparian and appropriative water rights existing on the same stream have been a significant difficulty in managing the surface water resources of the state. As late as 1968, no single state agency had a record of the number of riparian water users in any major river basin, the extent of their claims, or the amount of water they were using. Prior to 1967, several unsuccessful legislative attempts were made to more accurately measure riparian rights. A 1917 water rights adjudication attempt was held unconstitutional. In 1955, the legislature adopted a statute requiring all water users, including riparians, to file a statement each March with the Water Commission stating the amount of water used during the preceding calendar year. However, most riparian water users ignored the law and failed to file reports. Penalty provisions were inadequate and were not enforced.

In 1926, the courts divided streamflow into "ordinary normal flow" and "flood flows". Riparian rights are limited to normal flow and therefore are not applicable to flood waters impounded by reservoirs. The ordinary or normal flow of a watercourse is judicially defined as the flow below the line "which the stream reaches and maintains for a sufficient length of time to become characteristic when its waters are in their ordinary, normal and usual conditions, uninfluenced by recent rainfall or surface runoff". Although the courts and water agencies have found this definition to be extremely difficult to apply in actual practice, it has been the basis for correlating riparian and appropriative rights since 1926.

The Wagstaff Act, enacted in 1931, provides that "any appropriation made after May 17, 1931, for any purpose other than domestic and municipal use, is subject to the right of any city or town to make appropriations of water for domestic or municipal use without paying for the water." The Rio Grande was specifically excluded.

The Water Rights Adjudication Act was passed in 1967 to remedy the confused surface water rights situation. The stated purpose of the act was to require a recording of all claims for water rights which were not already recorded, to limit the exercise of those claims to actual use, and to provide for the adjudication and administration of water rights. Pursuant to the act, all unrecorded claims were required to be filed with the Texas Water Commission. Minor exceptions were made for those using only small quantities of water for domestic and livestock purposes. Claims were to be recognized only if valid under existing law and only to the extent of the maximum actual beneficial use of water without waste during any calendar year from 1963 to 1967, inclusive. The deadline for filing was September 1, 1969, but numerous late claims were received and accepted by the Commission. The base period and filing date were extended to 1970 and 1971, respectively, for some riparians, and the filing deadline was extended to September 1974 for those who failed to file because of extenuating circumstances or for good cause. Statewide 11,600 unrecorded claims were filed claiming more than 7 million acre-feet of water. About 95 percent of the claims were for riparian rights, and the remainder were certified filings which had not been properly recorded previously. More than half the claims were rejected because they showed no water use during the base period. Shortly after receiving the claims, the Texas Water Rights Commission initiated a series of administrative adjudications of water rights on a river segment by river segment basis. The adjudication process was essentially complete in 1986.

Since 1913, a surface water rights system has been administered statewide by a single agency. However, that agency has changed over time. The Board of Water Engineers was established in 1913, reorganized as the Texas Water Commission in 1962, and renamed the Texas Water Rights Commission in 1965 with non-water rights functions being transferred to the Texas Water Development Board which had been previously created in 1957. In 1977, the Texas Department of Water Resources was created by combining the Water Rights Commission, Water Development Board, and Water Quality Board. In 1985, the Texas Department of Water Resources was dissolved, and the Texas Water Commission and Texas Water Development Board became separate agencies. The Texas Natural Resource Conservation Commission was created in September 1993 by merging the Texas Water Commission and Texas Air Quality Board.

The Texas Natural Resource Conservation Commission (TNRCC) is one of the largest and most comprehensive state environmental protection agencies in the nation. The TNRCC consists of three full-time commissioners (former TWC commissioners) appointed by the governor and a professional and administrative staff of almost 3,000 employees. The water rights administration responsibilities of the former Texas Water Commission (TWC) are continued by the TNRCC. Water rights represent just one of many regulatory responsibilities of the former TWC and new TNRCC.

Water Rights Permit System

Water rights are granted by a state license, or permit, which grants to the holder the use of a specified amount of water, at a specific location, and for a specific purpose. Any person, public or private corporation, city, county, river authority, state agency, or other political subdivision of the state may acquire a permit to appropriate water. The Texas Water Code recognizes an appropriator as any person who has made beneficial use of water in a lawful manner. The laws and regulations governing the permit system are recorded in the Texas Water Code and the Rules of the Texas Water Commission. The Texas Water Code is included in Vernon's Texas Codes Annotated. The Texas Natural Resource Conservation Commission (TNRCC) is responsible for administering rights to use the surface waters of the state. The water rights permitting functions of the TNRCC include determining the amount of water available for appropriation, evaluating permit applications, and granting permits. As of September 1993, the TNRCC data base includes a total of 19,188 water rights permits which have been issued, including 7,711 active permits and 11,477 permits which have been cancelled for lack of water use or other reasons.

The Water Rights Adjudication Act applies to permit claims through 1969, which are titled certificates of adjudication. For permits after 1969, a more standard procedure is followed. Applications for permits to appropriate water are formally submitted to the TNRCC. A water use application is approved by the TNRCC only if unappropriated water is available, a beneficial use of the water is contemplated, water conservation will be practiced, existing water rights are not impaired, and the water use is not detrimental to the public welfare. After approval of an application, the TNRCC issues a permit giving the applicant the right to use a stated amount of water in a prescribed manner. Once the right to the use of water has been perfected by the issuance of a permit by the TNRCC and the subsequent beneficial use of the water by the permittee, the water authorized to be appropriated under the terms of the particular permit is not subject to further appropriation until the permit is cancelled. A permit may be cancelled if water is not used during a 10-year period. Cancellation and forfeiture of unused permits, certified filings, or certificates of adjudication are provided for in the Texas Water Code through administrative action by the TNRCC.

Permits may be regular, seasonal, term, or emergency in nature. A regular permit is issued in perpetuity so long as the water is used for a beneficial purpose. Seasonal permits are similar to regular permits except that the use of water is limited to certain months or days during the year. A term permit is granted for a specified number of years, often ten years, and does not give the holder a permanent water right. An emergency permit allows the holder to divert and use water for up to 30 days if emergency conditions exist that threaten public health, safety, and welfare. The TNRCC may also grant permits to impound and store water, then determine the actual diversion and use at a later date. Many permits issued to river authorities fall in this category. At a later date, the river authority may locate a customer for the water. The TNRCC will then issue a water use permit.

A 1985 amendment to the Texas Water Code requires applicants to adopt water conservation practices before they receive a water permit from the TNRCC. The water user must develop water conservation plans and demonstrate that their techniques either will reduce water consumption, loss, or waste, or will increase recycling or reuse of water.

A water permit holder has no actual title to the water but only a right to use the water. However, a water right is a recognized property right in Texas. A water right can be sold, leased, or transferred to another person. A water right can be conveyed automatically with the title to land, unless reserved in a deed, or can be sold separately from the land. In these cases, the water code provides that the written instruments conveying water rights may be recorded in the same manner as a property deed. The Texas Water Code and Rules of the TNRCC place certain restrictions on the transfer of water rights. Transfers must be approved by the TNRCC. A transfer will not be allowed if other water rights would be impaired. The transfer of a water right to another river basin is prohibited if the transfer will materially harm any person in the watershed from which the water was taken. The physical transfer of water from one basin to another is allowed only if there is no prejudice. In this case, the water is transported but not the water right.

The Texas Water Code contains a number of penalties for violations of the substantive and procedural provisions of the law. Violations are considered misdemeanors and are punishable by fines as high as $1,000 or by confinement in a county jail for not more than two years, or both. Examples of misdemeanor violations include: (1) unlawful use of state water without a permit, (2) sale of a water right without a permit, (3) interwatershed transfers, (4) interference with diversion of water on an international stream, (5) willful destruction of ditches, canals, reservoirs, or machinery associated with a water right, (6) allowing Johnson grass or Russian thistle to go to seed on a waterway, (7) throwing garbage into a water canal, (8) obstructing a navigable stream, and (9) willfully wasting water. In addition to the misdemeanor penalties, the Texas Water Code allows a civil penalty to be levied for unlawful use of water. A person who takes state water without a permit, or in violation of a permit, faces a civil penalty of up to $1,000 for each day of the violation.

Water Rights Priorities

The Texas Water Code is based upon the prior appropriation doctrine. Section 11.027 of the Texas Water Code states: "As between appropriators, the first in time is the first in right." However, there is an exception to the first in time, first in right rule. Section 11.028

provides: "Any appropriation made after May 17, 1931, for any purpose other than domestic or municipal use is subject to the right of any city or town to make further appropriation of the water without paying for the water." This provision was originally enacted by the Wagstaff Act in 1931, and is still commonly referred to as the Wagstaff Act. The implications of the Wagstaff Act have not yet been defined by court cases. The TNRCC has interpreted the statute as authorizing it to issue new rights to a municipality even if existing non-municipal rights are adversely impacted. In a water crisis, a city may take water from another appropriator and use it for domestic purposes even though the other appropriator used the water first. Major appropriations by cities under the provisions of the Wagstaff Act have not occurred to date. However, the statute is expected to become increasingly important as demands on limited water resources intensify.

The prior appropriation doctrine requires that water be used for a beneficial purpose. The Texas Water Code defines beneficial use as the use of such a quantity of water, when reasonable intelligence and diligence are exercised in its application for a lawful purpose, as is economically necessary for that purpose. Section 11.024 of the code lists beneficial uses in order of priority as follows: (1) domestic and municipal uses, (2) industrial uses, (3) irrigation, (4) mining, (5) hydroelectric power, (6) navigation, (7) recreation and pleasure, and (8) other beneficial uses. These priorities are followed when a conflict exists between water use applications. After permits have been issued and water rights perfected, priorities are based on dates, with the previously discussed exception of the Wagstaff Act.

Water Rights Administration

The legal right to use or sell the water from a reservoir is usually granted to the owner prior to construction of the project. Many reservoirs are owned and operated by cities to provide water to their citizens for domestic, public, and commercial use. The city holds the permit or water right and sells the water to its citizen customers. Another common case is a reservoir or system of several reservoirs owned and operated by a river authority which sales the water to a number of cities, water districts, industries, businesses, and/or irrigators. The river authority holds the permit or water right. The entities which purchase the water from the river authority are not required to hold a water right. The river authority operates the reservoirs to meet its contractual obligations to its customers. The nonfederal project sponsors which contract for the conservation storage in federal reservoirs are responsible for obtaining the appropriate water rights permits through the TNRCC.

Individual farmers, industries, and cities also hold water rights permits not associated with reservoirs. In several of the river basins, a number of reservoir operators, all holding appropriate water rights permits, operate reservoirs in the same basin. Reservoir operators are required to make releases, typically not exceeding inflows, to allow downstream users not associated with the reservoir access to the water for which they are legally entitled.

Although watermaster operations are common in other western states, the Rio Grande Watermaster and South Texas Watermaster are the only watermasters in Texas. The Rio Grande is the only river basin in Texas with a significant history of water master operations. The Rio Grande Watermaster Program has been in operation since the 1960s. The South Texas Watermaster was established in the late 1980s, with responsibilities for the Guadalupe, Nueces, and San Antonio River Basins. Its office is located in San Antonio. The Rio Grande Watermaster has offices in Weslaco and Eagle Pass.

The International Falcon and Amistad Reservoirs on the Rio Grande are owned and operated by the International Boundary and Water Commission, United States and Mexico. The TNRCC is responsible for utilizing the United States share of the conservation storage capacity in the two reservoirs and administering the allocation of the water to users. The watermaster discussed above, who is on the staff of the TNRCC, works directly with irrigation districts, individual farmers, and municipalities in Texas who hold permits for use of water from the Rio Grande. The watermaster administers the water allocation system and determines the required releases to be made from Falcon and Amistad Reservoirs. The International Boundary and Water Commission makes the releases as requested by the watermaster.

According to Rice and White (1987), ensuring that the water to which seniors are entitled is not taken by juniors is a task which is very simple to describe but quite difficult to carry out. Rice and White (1987) describe the system of calls followed in most western states, including Texas. The prior appropriation water rights on most of the streams of the western states are virtually self-administering. In some cases, long-time neighbors are familiar with one another's priorities and voluntarily restrict their water usage to maintain the priority system. On larger streams, as competition for water becomes intense during drought conditions, voluntary compliance with the priority system often breaks down. A system of "calls" is triggered. A senior water right owner will contact the water commissioner requesting action to stop diversions by junior users. The senior water right owner is said to be "putting a call" on the river. The water commissioner will contact junior water users directing appropriate curtailment of water use. Enforcement actions can be taken as necessary.

With the exception of water master operations in the Lower Rio Grande Valley, experience in administering water rights in Texas has been limited to date. Few situations have arisen in which junior rights holders had to curtail water use during low flow periods to protect senior water rights. Although severe reservoir drawdowns have occurred, particularly during 1984, the last 25 years have been characterized by relatively abundant precipitation and streamflow as compared to the droughts of the 1950s and earlier periods. The water rights system has not yet been tested by a major drought comparable to those of the 1950s, 1930s, and 1910s. The next severe drought will provide the opportunity to refine and polish the system.

Water Availability Modeling

Under the prior appropriation doctrine, an application for a water use permit can be approved only if water is available and its use does not impair vested water rights. Thus, the TNRCC must determine the amount of water available for appropriation at various locations in each river basin of the state. The Texas Water Rights Commission (TNRCC predecessor agency) began development of a water availability model in 1968 (Murthy, Liu, and Crow 1975). Several generations of the model were developed during the 1970s and 1980s reflecting various improvements and extensions. Most of the major river basins in Texas were modeled during the 1970s and 1980s, including the Brazos, Colorado, Guadalupe, Lavaca, Nueces, San Antonio, San Jacinto, and Trinity. Although data from past runs of the model continue to be used, the TNRCC is no longer making additional runs of the model. For pertinent river basins, unappropriated flows provided by past runs of the model are used along with other available information to evaluate permit applications. Replacement of the existing computer model is presently being considered.

The Texas Water Commission Water Availability Model consists of a set of computer programs and data files for analyzing the allocation of the surface waters of a river basin under the water rights system. The primary purpose of the model is to determine unappropriated streamflows. This information is used by the TNRCC in the evaluation of applications for permits to appropriate water. The water availability model simulations for the various river basins are based on monthly naturalized historical streamflow, historical reservoir evaporation rates, permitted water use and reservoir storage capacities, and historical return flow and monthly water use patterns. The model computes unappropriated water amounts for each pertinent location for each month of the simulation period. The simulation periods for the various river basins range from 1940-1972 to 1940-1981. For example, a 1940-1976 simulation period was adopted for the Brazos River Basin simulation.

The water availability modeling is based on historical gaged monthly streamflow data. The streamflows have been naturalized to remove nonhomogeneities caused by the activities of man in the basin. Missing data in gage records were filled in by regression analyses with records at other gages. The point of diversion for each water right is located on a map. Streamflow at the water right location is estimated by various techniques such as applying drainage area ratios to streamflow at gaged locations. Historical monthly reservoir evaporation rates are applied to computed water surface areas. All water rights holders are assumed to fully use their permitted amounts each year. Return flows and monthly water use distribution factors are estimated based on past records.

The computed monthly unappropriated water amounts represent the highly stochastic nature of streamflows. Since the model is based on historical streamflows, actual future streamflow will result in different amounts of unappropriated water than the model. Precise methods of quantifying the probability or likelihood of various water amounts being available for appropriation have not been developed as part of the modeling effort. The water availability model provides a quantitative basis for estimating unappropriated water. However, considerable judgement is exercised in using the model output to determine whether applications for permits for additional water use are approved.

Complexities of Administering and Modeling the Water Rights System

The implementation of a permit system and the adjudication of water rights have resulted in a manageable allocation of the streamflow resources of the state. However, allocating a highly variable water resource to numerous water managers and users, who use the water for a broad range of purposes, is necessarily complex. The complicating factors and considerations cited below are illustrative of the complexities of administering and also modeling a water rights system. Several key issues or complexities of the Texas system of surface water rights are discussed in this section as outlined below.

- limitations to regulatory authorities and capabilities
  - water master operations
  - ground water regulation
  - diffuse surface water regulation

- definition of various aspects of water rights
  - priorities by date versus type of use
  - reservoir storage
  - multiple-reservoir system operation
  - return flows
  - instream flow requirements
  - hydroelectric power

- evaluation of water availability
  - river/reservoir system simulation models
  - data representing the basin hydrology
  - data representing the water storage/use system
  - instream flow requirements
  - water quality constraints
  - reliability criteria

Limitations to Regulatory Authorities and Capabilities

As previously discussed, the Rio Grande Watermaster and recently established South Texas Watermaster are presently the only watermaster programs in Texas. Plans during the mid-1980s for establishing watermaster operations throughout the state have since been abandoned. For the majority of the state, there is no precise water use accounting system. Water diversions are not closely monitored and may not be accurately measured and recorded. The impacts of junior diversions at certain locations on senior rights at other locations in the basin may not be clearly evident. Monitoring of withdrawals is relatively unimportant as long as everyone has plenty of water but will become important during the next major drought when shortages begin to occur. The system has not yet been tested by a really severe drought such as those of the 1950s and 1930s.

Ground water regulation is a major issue which continues to be debated in Texas. Depletion of ground water reserves is a serious problem. Unlike other western states which have implemented ground water permit systems, there is little governmental control over the use of ground water in Texas. The various ground water conservation districts have only limited regulatory authority. A major exception is the water rights permitting system for the Edwards Aquifer which was recently authorized by the Texas Legislature with enactment of SB1477 in 1993. However, the system for regulating the Edwards Aquifer has not been designed and implemented. From the perspective of hydrology and water resources management, ground water and streamflow water are two interrelated phases of the hydrologic cycle. Use of one resource often has significant impacts on the other. However, water rights are viewed completely differently for subsurface and surface water. Consequently, conjunctive management of ground and surface water resources is extremely difficult.

Only water in a water course is subject to state ownership in Texas. Diffuse surface water does not become the property of the state until it reaches a navigable stream. A landowner may construct any number of dams on his own property to impound and use surface runoff, without a permit, as long as the volume of water impounded by any single dam does not exceed 200 acre-feet. Many thousands of these small impoundments have been constructed through the state. This provision of the law is pertinent to streamflow rights and management of major reservoirs because construction of numerous small dams in many watersheds has significantly reduced the amount of water which reaches the main rivers.

Complexities in Defining Various Aspects of Water Rights

Assigning priorities by appropriation date versus type of use is another issue. The Texas Water Code is based on the prior appropriation doctrine. However, a provision of the Texas Water Code, originally enacted as the Wagstaff Act, allows municipalities to appropriate water previously appropriated by other users under certain circumstances. The implications of the Wagstaff Act have not yet been clearly defined by court cases. The TNRCC (TWC) has interpreted the statute as authorizing it to issue new rights to a municipality even if existing non-municipal rights are adversely impacted. In a water crisis, a city may be given preference over senior non-municipal appropriators. Major appropriations by cities under the provisions of the Wagstaff Act have not occurred to date. However, the statute is expected to become increasingly important as demands on limited water resources intensify.

Assigning priorities to maintaining reservoir storage levels relative to diversion rights is an important issue. Reservoir operation in Texas is based on providing long-term storage as protection against infrequent but severe droughts. The right to store water is as important as the right to divert water. If junior appropriators located upstream of a reservoir diminish inflows to the reservoir when it is not spilling, reservoir dependable yield is adversely affected. Each drawdown could potentially be the beginning of a several-year critical drawdown which empties the reservoir. Thus, protecting reservoir inflows is critical to achieving the purpose of the reservoir, which is to provide a dependable water supply. On the other hand, forcing appropriators, with rights junior to the rights of the reservoir owner, to curtail diversions to maintain inflows to an almost full, or even an almost empty, reservoir is difficult and often is not the optimal use of the water resource. If junior diversions are not curtailed, the reservoir will likely later refill anyway, without any shortages occurring. Although water right permits often include reservoir storage, handling of the storage aspect of water rights is not yet precisely defined.

Water rights permits are for individual reservoirs. However, in some cases, multiple reservoirs are operated in combination to meet common demands. Significant complexities arise in attempts to relate individual reservoir water rights to multiple-reservoir system operations. Innovative strategies are needed for incorporating multiple-reservoir system operations into water rights permits.

Although some recent permits have addressed return flows, most permits do not specify the amount of the diversion to be returned to the streams. Return flows can significantly impact the availability of water to downstream users.

Defining instream flow requirements is a key aspect of the water rights system which is receiving increasingly more attention in recent years. Instream uses include maintenance of aquatic habitat and species, protecting or improving water quality, public recreation, preservation of wetlands, and providing freshwater inflows for bays and estuaries. The TNRCC is required to analyze the effects on instream flows in the evaluation of water right permit applications. Quantifying instream flow needs is difficult but necessary.

Hydroelectric power operations can have beneficial as well as adverse impacts on downstream water availability. Although some hydroelectric plants have water rights permits, others do not. Hydroelectric energy is generated by unappropriated or unused flows and water supply releases.

Complexities in Evaluating Water Availability

Evaluation of water availability is a key aspect of administering the water rights system. The study documented by this report focuses on improving capabilities for modeling and analysis of water availability. The TAMUWRAP water availability model presented in Chapter 3 simulates water use and river/reservoir system management under the water rights system described by the present chapter. The complexities, outlined above, in defining various aspects of water rights are pertinent to modeling as well as administration of the water rights system. Additional issues involved in evaluating water availability are noted below.

Although numerous reservoir/river system analysis models are reported in the literature, few if any are designed to simulate a water rights priority system involving numerous reservoirs and diversions (Wurbs 1993). The TAMUWRAP model was developed to fill the need for a generalized water rights analysis model. The basic water accounting computational capabilities of TAMUWRAP were already provided by the Texas Water Commission (TWC) Water Availability Model. However, the TWC model is designed strictly for use within the agency. TAMUWRAP is designed to be used by any water management professionals, including those employed by agencies, consulting firms, and universities. TAMUWRAP also provides greater flexibility for modeling multiple-reservoir system operations. The new version of TAMUWRAP developed and applied in the present study also includes capabilities for incorporating salinity considerations.

Water availability modeling requires voluminous input data. The most voluminous and perhaps most difficult to develop is the streamflow data. Complete sets of naturalized streamflow sequences covering the period of analysis at all pertinent locations are required. Improved methodologies and computer software are needed for filling in missing data and naturalizing the streamflows to remove the impacts of human activities in the basin. An even greater need exists for improved capabilities for developing streamflow data for remote sites located significant distances from available streamflow gages. The case study analyses presented in Chapters 5 & 6 were simplified by aggregating all the water rights in the basin to selected control point locations near streamflow gaging stations for which flow data were available. Thus, in the model, numerous smaller rights have access to the flow at the control points, which may be significantly higher than the flow at their actual upstream diversion location. Aggregation of the numerous rights to a few selected control points worked well for this study because the focus was on the USACE/BRA system which is composed of major reservoirs located near the gages. The numerous other water rights in the basin were also included in the model but were analyzed from the perspective of basinwide totals rather than a detailed analysis of each individual right. However, in general, the water availability model should provide capabilities for detailed analysis of any water right at any location, including locations which are far removed from any streamflow gage. Additional research is needed in this regard.

Reservoir storage volume versus water surface area data are also difficult to obtain for the numerous smaller reservoirs. Storage versus area relationships are required for the evaporation computations. In the present study, storage-area tables were obtained for 29 of the largest reservoirs in the basin. A generalized storage-area relationship, described in Chapter 5, was adopted for the over 500 other smaller reservoirs. Another complication is that actual storage capacities may be significantly less than permitted capacities due to sedimentation. The permitted storage capacities are usually based on initial storage volumes at the time of construction prior to sedimentation. Reservoir storage capacities are significantly reduced over a period of years as sediment accumulates. In the present study, storage capacities and storage-area relationships used for several of the larger reservoirs reflect sediment surveys made since construction. However, for most of the reservoirs, the permitted storages are used in the model without adjusting for sediment accumulation.

Instream flow needs and related environmental issues are important considerations in formulating and evaluating water rights permits. The Texas Water Code requires that the TNRCC consider existing instream uses and water quality issues in the water rights permitting process. In recent years, establishment of diversion restrictions to maintain instream flows is an integral part of evaluating water availability. Determining instream flow requirements and the impacts of water rights permits on instream flows are complex tasks.

Water quality considerations have typically focused on including restrictions on new water rights permits to maintain instream flows. The water availability modeling study presented in the present report views water quality from a different perspective. Salinity is treated as a constraint to the use of diverted water for off-stream uses. The availability of water *of adequate quality* as well as quantity is evaluated.

Another important consideration is the approach adopted to use the results of a simulation model to assess water availability. Since streamflows, evaporation rates, water use, and other factors are highly variable, and the future is unknown, water availability must be viewed from a reliability, likelihood, or percent-of-time perspective. The concept of firm (100% reliability based on modeling assumptions) yield has traditionally been used in water supply planning and management. Period and volume reliabilities, defined in Chapter 3, are used in the TAMUWRAP model and this study to concisely quantify water supply capabilities. However, water management decisions necessarily require qualitative judgement in determining acceptable levels of reliability for various situations. Tradeoffs occur between the amount of water to commit for beneficial use and level of reliability that can be achieved. Beneficial use of water is based on assuring a high level of reliability. However, limited resources may have to be allocated to many competing users. If water commitments are limited as required to assure an extremely high level of reliability, the amount of streamflow available for beneficial use is constrained, and most of the water flows to the ocean or is lost through reservoir evaporation much of the time.

CHAPTER 3
THE TAMUWRAP WATER RIGHTS ANALYSIS MODEL

The Texas A&M University Water Rights Analysis Package (TAMUWRAP) simulates the management and use of the streamflow and reservoir storage resources of a river basin, or multiple basins, under a prior appropriation water rights permit system. TAMUWRAP, excluding salinity features, is documented by Wurbs, Dunn, and Walls (1993). Capabilities recently added to the model for incorporating salinity considerations are documented by Sanchez-Torres (1994). The present chapter provides a general overview of the model.

TAMUWRAP is designed for use by water management agencies, consulting firms, and university researchers in performing reservoir/river system water availability and reliability studies. The generalized model can be used in various types of applications to evaluate alternative water use scenarios and management strategies. Model results can be used to analyze the capability of a river basin to supply existing water rights and the amount of unappropriated streamflow remaining for potential additional water rights applicants. Reservoir system simulation studies can be performed to evaluate alternative operating policies or the impacts of adding new reservoirs to a system.

Computer Programs

The TAMUWRAP Water Rights Analysis Package presently includes the following computer programs:

WRAP2	Water Rights Analysis Program - Version 2
WRAP3	Water Rights Analysis Program - Version 3
WRAPNET	Water Rights Analysis Program - Network Flow Programming Version
WRAPSALT	Water Rights Analysis Program - Salinity Version
TABLES	Post-processor Program to Create Tables

The TAMUWRAP package has been expanded, in conjunction with the study reported here, to incorporate salinity considerations. Wurbs, Dunn, and Walls (1993) document WRAP2 and WRAP3, which include no salinity modeling capabilities, and TABLES excluding the salinity related tables which have been recently added. Yerramreddy (1993) documents WRAPNET. WRAPSALT and the salinity-related features of TABLES are documented by Sanchez-Torres (1994).

WRAP2 and WRAP3

A stream/reservoir/rights system simulation can be performed with either WRAP2 or WRAP3. WRAP3 provides expanded capabilities, not incorporated in WRAP2, related primarily to providing flexibility in modeling a comprehensive range of reservoir system operating strategies and associated system water rights. WRAP2 is limited to simple single-reservoir or run-of-river water rights. Any input data file developed for WRAP2 can also be run with WRAP3. However, a WRAP3 input data file may specify optional capabilities which are not available with WRAP2. The only advantage of WRAP2 over WRAP3 is the relative simplicity of the computer code. The additional capabilities incorporated in WRAP3 result in a significantly different and much more complex computer program. Neither of the two alternative simulation models includes salinity features.

WRAPNET

WRAPNET reads an input file and writes an output file which are essentially identical to those of WRAP2. WRAPNET and WRAP2 provide the same simulation results. However, the computational algorithms incorporated in the two alternative versions of the model are totally different. Unlike WRAP2, WRAPNET is based on network flow programming, which is a special form of the widely applied linear programming optimization technique. WRAPNET was developed in conjunction with a comparative evaluation of network flow programming versus conventional simulation models (Yerramreddy 1993). Although each approach has advantages over the other for various other applications, the study concluded that either approach could be used for the water rights analysis program. The decision was made to continue with the conventional simulation approach in further development of TAMUWRAP.

WRAPSALT

WRAPSALT was developed by adding salinity modeling capabilities to WRAP3. In WRAP3, a diversion shortage is declared whenever available streamflow and storage is insufficient to meet the permitted diversion target. In WRAPSALT, diversion shortages are based upon water quality as well as quantity availability. Shortages are declared if specified maximum allowable salt concentration limits can not be met. WRAPSALT also includes an option which allows salinity considerations to be incorporated in multiple-reservoir release decisions. The basic WRAP3 computational algorithms are preserved in WRAPSALT. The salinity computations are performed by several added subroutines with some changes to the main program. WRAPSALT provides all the modeling capabilities of WRAP3, reads a WRAP3 input file, and writes an output file which is identical to the WRAP3 output file. However, unlike WRAP3, WRAPSALT also reads a unregulated salt load input file and writes an additional output file with salinity related simulation results.

TABLES

The computer program TABLES is used with either WRAP2, WRAP3, WRAPNET, or WRAPSALT. TABLES reads WRAP input and/or output data files and writes various user-selected data listings and tables. The simulation input and output data is extremely voluminous. TABLES provides flexible options for organizing and presenting the simulation results.

Modeling Capabilities

The Water Rights Analysis Programs (WRAP2, WRAP3, or WRAPSALT) basically provide an accounting system for tracking inputted streamflow sequences, subject to specified reservoir storage capacities and diversion requirements. WRAPSALT also tracks inputted salt load sequences. Water and salt load balance computations are performed for each monthly time interval of the overall simulation period. The generalized computer model provides the capability to simulate a stream/reservoir/use system involving essentially any stream tributary configuration. Interbasin transfers of water can be included in the simulation. Closed loops such as conveying water by pipeline from a downstream location to an upstream location on the same stream or from one tributary to another tributary can be modeled.

The WRAP3 and WRAPSALT versions of the model allow specification of a comprehensive range of reservoir system operating rules and also inclusion of hydroelectric power generation. WRAPSALT allows specification of maximum allowable salt concentrations for diversions and also includes an option for incorporating salinity considerations in the reservoir system operating rules. Active and inactive storage capacities are inputted for each reservoir. User-defined operating rules specify that diversion requirements be met from streamflow and/or releases from storage in single or multiple reservoirs. Multiple-reservoir release rules are based on balancing the percent depletion (or percent full) of the storage capacity in user-specified zones of the alternative reservoirs from which releases can be made. The user defines multiple-reservoir operating rules by identifying which reservoirs can release for a particular diversion and specifying zones in the active conservation pool of each reservoir. In each month of the simulation, the model selects the reservoir from which to release based on balancing the storage levels, expressed as a percentage of the storage capacities of the specified zones, in each reservoir. The model provides flexibility in allowing the user to define operating rules involving uneven as well as even balancing of storage in the multiple reservoirs. The user also specifies whether or not the diversion must deplete available streamflow before releases are made from upstream reservoirs. WRAPSALT also includes an option to balance storage to the extent possible while minimizing shortages for the month.

The spatial configuration of the reservoir/river/use sytem is represented in the model by a set of control points. Reservoirs, diversions, return flows, streamflows, salt loads, and other basin features are located at control points. The simulation is performed sequentially for each month of the simulation period. Input data includes:

- naturalized monthly streamflows and salt loads (for each salt constituent) at each control point covering the simulation period,
- monthly reservoir evaporation rates for each month of the simulation period at each control point,
- control point location, annual diversion amount (or hydroelectric energy demand), storage capacity, priority date, type of water use, and return flow specifications for each right,
- storage versus area relationship for each reservoir provided as either a table or set of coefficients,
- elevation versus storage table and tailwater elevation for each reservoir with hydroelectric power,
- set of 12 monthly water use distribution factors for each type of water use,
- maximum allowable concentrations for each salinity constituent for each type of water use, and

- multiple-reservoir release rules for each diversion and/or reservoir refilling right which can be met by releases from more than one reservoir.

For each month of the simulation, the WRAP programs perform the water accounting computations for each water right, in turn, on a priority basis. The computations proceed by month and, within each month, by water right with the most senior water right in the basin being considered first. The model computes diversions and diversion shortages associated with each water right. Diversion shortages are declared whenever (1) insufficient streamflow and/or reservoir storage is available to meet the diversion target or (2) the salt concentrations of the streamflow or reservoir storage exceed maximum allowable concentrations. Hydroelectric energy shortages are declared whenever streamflow and storage are not adequate to meet the energy demand. Permitted reservoir capacity is filled to the extent allowed by available streamflow. Reservoir evaporation is computed and incorporated in the water balance. Reservoir evaporation is determined by multiplying inputted net evaporation rates and water surface areas obtained from inputted storage versus area relationships. Since evaporation is computed based on storage at both the beginning and end of the month, and end-of-month storage depends upon evaporation, an iterative computational algorithm is incorporated in the model. Return flows are computed as a fraction of diversions and re-enter the stream at user-specified control points in either the next month or same month as the diversion. An accounting is maintained of storage levels in each reservoir and streamflow still available at each control point.

WRAPSALT performs the salinity accounting computations upon completion of the water quantity aspects of the simulation each month. The salts are assumed to be conservative with no chemical or other transformations. Thus, the salinity accounting computations are based on simple mass balances. The results of the quantity simulation, for the month, provide input for salt balances. Salt loads entering and leaving each control point are determined. Salt loads stored at each control point are updated for the month. Concentrations of reservoir storage and streamflows are computed. Mean monthly streamflow or end-of-month storage concentrations are compared with maximum allowable concentrations to determine limits on diversions during the following month.

The output from a WRAP simulation includes, for each month:

- diversions and diversion shortages for each diversion right and the corresponding summations for each control point,
- hydroelectric energy generated and energy shortages for each hydropower right,
- reservoir storage levels and reservoir evaporation volumes for each right and summations for each reservoir and each control point,
- return flows for each control point,
- amount of water available to each right,
- streamflow depletions for each right and summations for each control point,

- unappropriated streamflows for each control point,
- regulated streamflows for each control point, and
- concentrations and loads for each salt constituent for each control point.

WRAP output is quite voluminous. Simulation results can be organized, tabulated, and summarized in various optional formats, using the TABLES program. TABLES reads WRAP input and output files and builds user-specified tables. Some of the tables are direct tabulations of WRAP input and/or output data in convenient formats. TABLES also performs various data manipulations including sorting, computing means and totals, developing frequency tables for various variables, and determining period and volume reliabilities.

Volume and Period Reliability

Concise measures of system reliability are useful in analyzing and displaying simulation results. Various expressions of reliability can be formulated. Program TABLES incorporates the concepts of period and volume reliability. These reliability measures can be applied to either diversion or hydroelectric energy demands for individual rights, the aggregation of all rights associated with individual reservoirs or control points, groups of selected rights, or the entire river basin. Period reliability is based on counting the number of months of the simulation during which the specified demand target is, and is not, completely met without regard to shortage magnitude. Volume reliability reflects the shortage magnitude as well as frequency.

Period reliability is the percentage of months during the simulation during which a specified demand target is met without shortage. Period reliability (R) is computed from the results of a WRAP simulation as:

$$R_{period} = (n/N)\ 100\%$$

where n denotes the number of months during the simulation for which the demand is fully met and N is the total number of months in the simulation. Thus, reliability is an expression of the percentage of time that the demand can be met. Equivalently, the reliability represents the likelihood or probability of the demand being met in any randomly selected month. Reliability (R) is the complement (R=1-F) of the risk of failure (F) that the target will not be met.

Volume reliability is the percentage of the total demand volume which can be actually supplied. The total volume supplied is the demand volume totalled for the entire simulation period minus the sum of the shortages in each month. Volume reliability (R) is the ratio of total volume supplied (v) to volume demanded (V):

$$R_{volume} = (v/V)\ 100\%$$

or, equivalently, the ratio of the mean actual diversion rate to mean target diversion rate.

CHAPTER 4
THE BRAZOS RIVER BASIN

Basin Description

As indicated by Figure 4.1, the Brazos River Basin extends from eastern New Mexico southeasterly across the state of Texas to the Gulf of Mexico. The basin has an overall length of approximately 640 miles, with a width varying from about 70 miles in the High Plains in the upper basin to a maximum of 110 miles in the vicinity of the city of Waco to about 10 miles near the city of Richmond in the lower basin. The basin drainage area is 45,600 square miles, with about 43,000 square miles in Texas and the remainder in New Mexico. The basin encompasses about 16 percent of the land area of Texas. Approximately 9,570 square miles in the northwest portion of the basin, including all the area in New Mexico and a portion of the area in Texas, are non-contributing to downstream streamflows. Mean annual precipitation varies from about 16 inches/year in the western (upstream) end of the basin to over 50 inches/year in the lower basin near the Gulf.

From its inception at the Salt Fork and Double Mountain Fork, the Brazos River flows in a meandering path some 920 miles 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, cotton fields, and hardwood bottoms. Upon its descent from the high plains and Caprock Escarpment, the Brazos River flows through a semiarid region of gypsum and salt encrusted hills and valleys containing numerous salt springs and seeps. This area of the upper basin is the primary source of the salt contamination.

The 1980 and 1990 population of the Brazos River Basin was 1.53 million and 1.73 million, respectively (Texas Water Development Board 1990). The population is expected to increase to between 3.1 and 3.8 million people by 2040. Lubbock is the largest city in the basin. The 1987 population of the Lubbock Metropolitan Area was 225,000. The cities of Waco, Abilene, Bryan-College Station, Killeen, and Temple, each have populations exceeding 25,000. The area economy is based on agriculture, agribusiness, manufacturing, mineral production, trades, and services.

A significant portion of the water diverted from the Brazos River is actually used in the adjoining San Jacinto-Brazos Coastal Basin. The San Jacinto-Brazos Coastal Basin has a drainage area of 1,440 square miles bordered by the Brazos River Basin, Gulf, Galveston Bay, and Houston. There are no major reservoirs with conservation storage capacity to capture runoff in the coastal basin. However, the Galveston County Water Authority operates a 12,500 acre-foot capacity off-channel reservoir which stores and regulates water diverted from the Brazos river through a canal system. Water supply sources include saline water from the Gulf, groundwater pumped within the coastal basin, and surface water diversions primarily from the Brazos Basin but also from the Trinity River and San Jacinto River Basins.

The 1980 and 1990 population of the San Jacinto-Brazos Coastal Basin was 536,800 and 647,100, respectively (TWDB 1990). The basin population is projected to increase to between 1.1 and 1.3 million by 2040. Major cities located wholly or partially within the coastal basin include Houston, Pasadena, Galveston, Texas City, Missouri City, League City, and Deer Park.

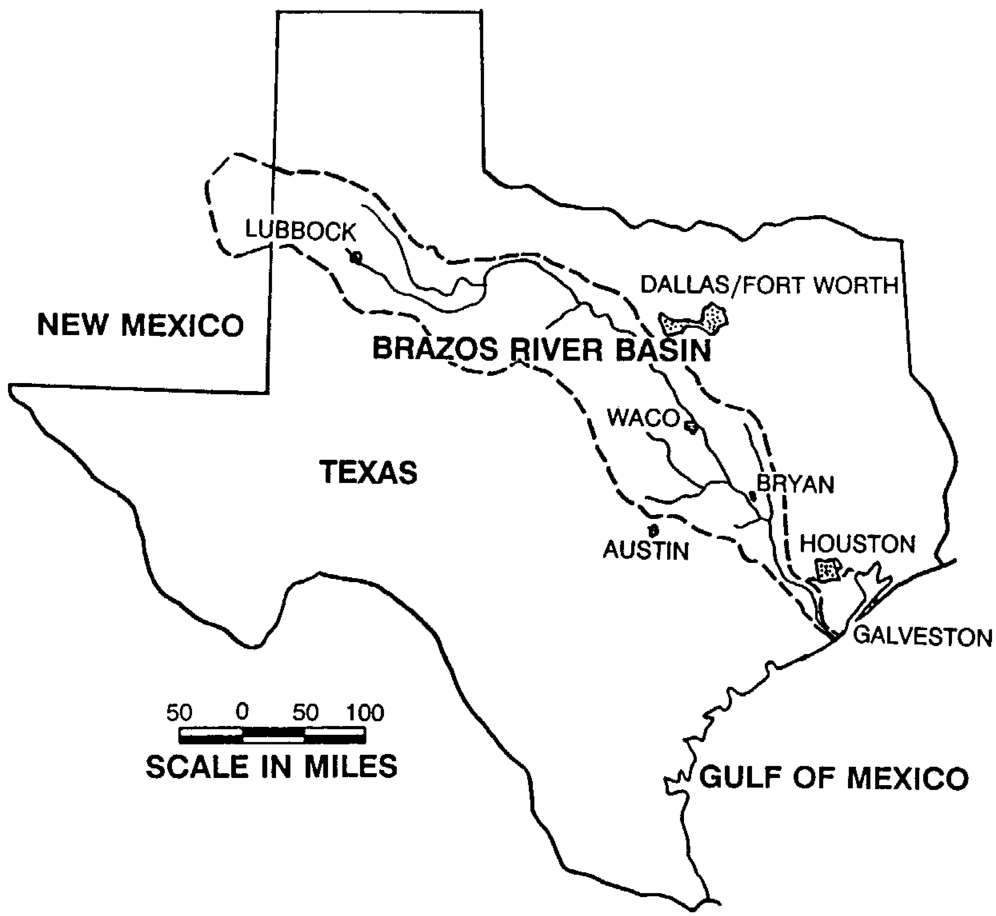

Figure 4.1 Brazos River Basin

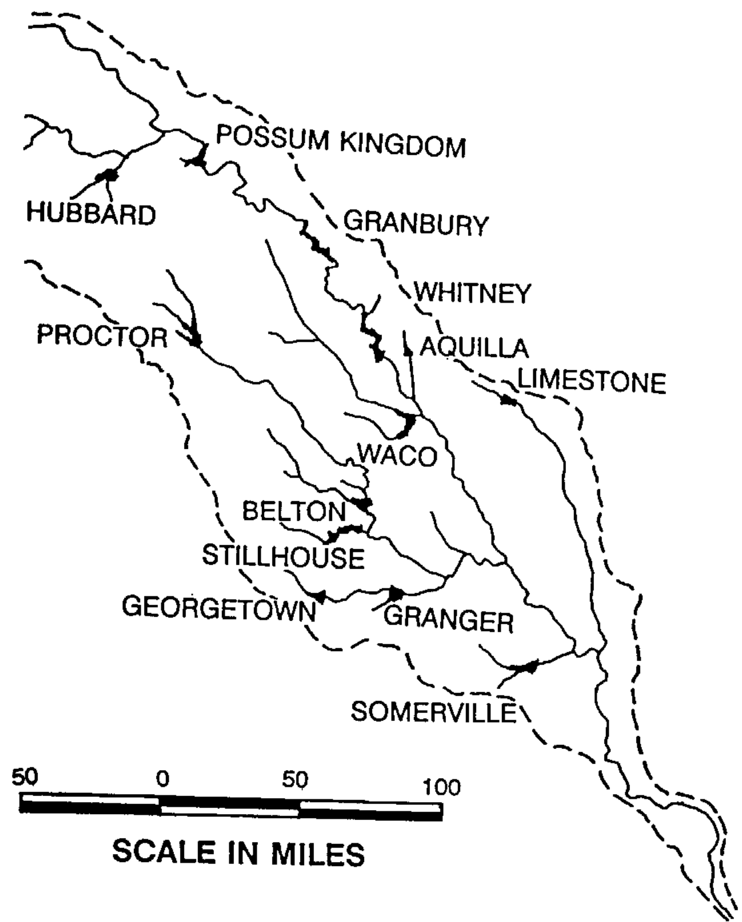

Figure 4.2 12-Reservoir USACE/BRA System and Hubbard Creek Reservoir

Reservoirs

A total of about 1,200 reservoirs included in the Texas Natural Resource Conservation Commission dam inventory are located in the Brazos River Basin. Almost 600 of the reservoirs in the basin are included in the water rights permits discussed later in this chapter. Forty existing reservoirs in the Brazos River Basin have storage capacities exceeding 5,000 acre-feet. Other major reservoirs included in the water rights are either presently under construction or proposed for the future. The 40 existing major reservoirs account for about 94 percent of the total conservation storage capacity of the 1,200 reservoirs. Thus, although the basin has numerous reservoirs, most of the storage capacity is contained in a relatively few large reservoirs. The 13 major reservoirs shown in Figure 4.2 include the system of 12 reservoirs owned by the U.S. Army Corps of Engineers (USACE) and Brazos River Authority (BRA) and also Hubbard Creek Reservoir owned by the West Central Texas Municipal Water District. The 12 USACE/BRA reservoirs contain all of the controlled (gated) flood control storage capacity and about 70 percent of the conservation storage in the basin. Hubbard Creek Reservoir has the fourth largest conservation storage capacity in the basin and accounts for an additional eight percent of the total conservation storage.

Major Reservoirs

The forty reservoirs in the Brazos River Basin with controlled storage capacities of 5,000 acre-feet or greater are listed in Table 4.1. The major reservoirs in the basin include 28 reservoirs in addition to the 12-reservoir USACE/BRA system. Eleven reservoirs with storage capacities totalling about seven percent of the total conservation storage of all the major reservoirs are owned and operated by cities for municipal and industrial water supply and recreation. The City of Abilene owns and operates Kirby, Abilene, and Fort Phantom Hill Reservoirs for municipal, industrial, and recreational use. Likewise, Mineral Wells, Cisco, Daniel, Sweetwater, Pat Cleburne, and Graham Reservoirs are owned and operated by the Cities of Mineral Wells, Cisco, Breckenridge, Sweetwater, Cleburne, and Stamford, respectively. Lake Stamford, owned by the City of Stamford, was constructed primarily for supplying cooling water for a steam-electric power plant but also serves municipal uses. Bryan Utilities Lake, owned by the City of Bryan, is used for steam-electric power plant cooling and recreation.

Six reservoirs with storage capacities totalling about 11 percent of the conservation storage in the major reservoirs of the basin are owned and operated by municipal water districts which supply water to member cities and other users. These reservoirs are Mexia, Millers Creek, Leon, White River, Palo Pinto and Hubbard Creek. The corresponding water districts are Bristone Municipal Water Supply District, North Central Texas Municipal Water Supply District, Eastland County Water Supply District, White River Municipal Water District, Palo Pinto Municipal Water District No. 1, and West Central Texas Municipal Water District.

Six reservoirs with a storage capacity totalling about six percent of the total conservation storage of the major reservoirs in the basin are owned and operated by electric utility companies to provide cooling water for steam-electric power plants. Texas Power and Light Company owns and operates Lake Creek, Tradinghouse, and Twin Oaks Reservoirs for steam-electric power plant cooling. Smithers Reservoir is owned and operated by Houston Lighting and Power for the same purpose. Likewise, Gibbons Creek Reservoir is owned and operated by Texas

Table 4.1

MAJOR RESERVOIRS IN THE BRAZOS RIVER BASIN

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPCITY CONSERVATION INACTIVE	CONSERVATION ACTIVE	FLOOD CONTROL	TOTAL
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Brazos River Basin									
Davis	League Ranch	I	1959	32	580	-	5,400	-	5,400
Mineral Wells	City of Mineral Wells	M	1920	74	650	-	6,760	-	6,760
Kirby	City of Abilene	M	1928	50	740	-	7,620	-	7,620
Abilene	City of Abilene	M,R	1921	51	590	-	7,900	-	7,900
Lake Creek	Texas Power & Light	P	1952	50	550	-	8,400	-	8,400
Camp Creek	Camp Creek Water Company	M,R	1948	49	750	-	8,550	-	8,550
Cisco	City of Cisco	M	1923	96	440	-	8,800	-	8,800
Daniel	City of Breckenridge	M	1948	60	920	-	9,520	-	9,520
Mexia	Bristone MWSD	M	1961	50	1,200	-	10,000	-	10,000
Sweetwater	City of Sweetwater	M	1930	50	630	-	11,900	-	11,900
William Harris	Dow Chemical Company	I	1947	12	1,660	-	12,000	-	12,000
Alcoa	Aluminum Company of America	I,R	1953	50	880	-	14,750	-	14,750
Bryan Utilities	City of Bryan	P,R	1975	62	830	-	15,230	-	15,230
Smithers	Houston Lighting & Power	P	1957	18	2,480	-	18,700	-	18,700
Brazoria	Dow Chemical Company	I	1954	16	1,860	-	21,970	-	21,970
Pat Cleburne	City of Cleburne	M	1964	78	1,550	-	25,300	-	25,300
Millers Creek	North Central Texas MWA	M	1974	75	1,900	-	25,520	-	25,520
Leon	Eastland County WSD	M,I	1954	90	1,590	-	26,420	-	26,420
Gibbons Creek	Texas Municipal Power Agency	P	1981	50	2,490	-	26,820	-	26,820
Twin Oaks	Texas Power & Light	P	1982	56	1,460	-	30,320	-	30,320
Tradinghouse	Texas Power & Light	P	1968	60	2,010	-	35,120	-	35,120
White River	White River MWD	M,Mi	1963	84	1,810	-	37,950	-	37,950
Palo Pinto	Palo Pinto MWD 1	M	1964	96	2,660	-	42,200	-	42,200
Stamford	City of Stamford	M	1953	78	4,690	-	52,700	-	52,700
Graham	City of Graham	M	1929;1958	57;82	2,550	-	53,680	-	53,680
Fort Phantom Hill	City of Abilene	M,R	1938	84	4,250	-	74,310	-	74,310
Georgetown	Corps of Engineers	F,M,R	1980	162	1,310-3,220	14,000	29,200	87,600	130,800
Aquilla	Corps of Engineers	F,M,R	1983	104	3,280-7,000	25,700	33,600	86,700	146,000
Squaw Creek	Texas Utilities Services	P	1977	159	3,230	-	151,050	-	151,050
Granbury	Brazos River Authority	M,A,P	1969	84	1,300	-	153,500	-	153,500
Limestone	Brazos River Authority	M,A	1978	65	14,200	-	225,400	-	225,400
Granger	Corps of Engineers	F,M,R	1980	115	4,400-11,040	44,100	37,900	162,200	244,200
Hubbard	West Central MWD	M,I,Mi	1962	112	16,250	-	314,280	-	314,280
Proctor	Corps of Engineers	F,M,A,R	1963	86	4,610-14,010	32,700	31,400	310,100	374,200
Somerville	Corps of Engineers	F,M,A,R	1967	80	11,460-24,400	25,900	143,900	337,700	507,500
Possum Kingdom	Brazos River Authority	M,A,R,H,Mi	1941	189	14,440	-	569,380	-	569,380
Stillhouse Hollow	Corps of Engineers	F,M,A,R	1968	200	6,430-11,830	34,900	204,900	390,600	630,400
Waco	Corps of Engineers	F,M,R	1965	140	7,270-19,440	65,100	104,100	553,300	722,500
Belton	Corps of Engineers	F,M,A,R	1954	192	12,300-23,600	76,500	365,500	640,000	1,082,000
Whitney	Corps of Engineers	F,H	1951	159	23,560-49,820	245,200	381,900	1,372,400	1,999,500

Source: Wurbs (1985)

Municipal Power Agency. Supplemental water is delivered to Gibbons Creek Reservoir from Lake Limestone through contractual arrangements with the Brazos River Authority. Squaw Creek Reservoir, owned and operated by Texas Utilities Generating Company, provides cooling water for the Comanche Peak Nuclear Power Plant. Lake Granbury supplies water as needed to Squaw Creek Reservoir.

Dow Chemical Company owns and operates Brazoria and William Harris Reservoirs to provide off-channel storage and regulation of water diverted from the Brazos River for manufacturing use at the industrial complex in southern Brazoria County. The Aluminum Company of America owns and operates Alcoa Lake for manufacturing use and steam-electric power plant cooling. Davis Lake, owned by the League Ranch, is used for irrigation. Camp Creek Lake, owned by the Camp Creek Water Company, is used primarily for recreation.

USACE/BRA Reservoir System

The twelve reservoirs operated by the U.S. Army Corps of Engineers (USACE) and Brazos River Authority (BRA) are listed in Tables 4.2. 4.3, and 4.4 and shown in Figure 4.2. Hubbard Creek Reservoir is also included in the tables and figures because of its size, location, and significance in the simulation study. Hubbard Creek Reservoir is a municipal water supply project owned by the West Central Texas Municipal Water District, whose member cities include Abilene, Breckenridge, Anson, and Albany.

As indicated by Table 4.2, nine of the reservoirs were constructed by the USACE as components of a comprehensive basin-wide plan of development. The USACE projects contain about half of the conservation capacity and all of the flood control capacity of the 40 major reservoirs in the basin. Georgetown, Aquilla, Granger, Proctor, Somerville, Stillhouse Hollow, Waco, Belton and Whitney Reservoirs are each operated by the Fort Worth District for flood control, water supply, and recreation. Whitney Reservoir serves the additional purpose of hydroelectric power generation. Fort Worth District personnel operate and maintain the nine federal multiple-purpose projects. The USACE is responsible for flood control operations. Conservation releases are made as directed by the local project sponsor, which for most of the conservation capacity, is the Brazos River Authority (BRA). The BRA has contracted for the water supply capacity in each of the USACE projects, except Fort Hood military base has 3.2 percent of the conservation storage in Belton Lake and the City of Waco has 12.5 percent of the conservation storage capacity in Lake Waco. The City of Waco is also the primary customer for the 87.5 percent of the Lake Waco conservation capacity controlled by the BRA. The Southwestern Power Administration is responsible for marketing hydroelectric power from Whitney Reservoir, which it sells to the Brazos Electric Power Cooperative.

In addition to controlling the conservation storage in the nine USACE projects, the BRA constructed, owns, and operates Granbury, Limestone, and Possum Kingdom Reservoirs. The 12 reservoirs are operated as a system to supply downstream municipal, industrial, and agricultural water users as well as users located in the vicinities of the reservoirs.

Possum Kingdom Reservoir, completed in 1941, provides water supply and hydroelectric power. BRA sells the power to the Brazos Electric Power Cooperative. Lake Granbury, completed in 1969, provides cooling water for a gas-fired plant near the lake and to Squaw

Table 4.2
PRINCIPAL RESERVOIRS

Fort Worth District (FWD) of U.S. Army Corps of Engineers (USACE) and Brazos River Authority (BRA)

Whitney Lake and Whitney Dam; Brazos River; flood control, water supply, hydroelectric power, and recreation.

Aquilla Lake and Aquilla Dam; Aquilla Creek; flood control, water supply, and recreation.

Waco Lake and Waco Dam; Bosque River; flood control, water supply, and recreation.

Proctor Lake and Proctor Dam; Leon River; flood control, water supply, and recreation.

Belton Lake and Belton Dam; Leon River; flood control, water supply, and recreation.

Stillhouse Hollow Lake and Stillhouse Hollow Dam; Lampasas River; flood control, water supply, and recreation.

Georgetown Lake and Georgetown Dam; formerly North Fork Lake and North Fork Dam; North Fork San Gabriel River; flood control, water supply, and recreation.

Granger Lake and Granger Dam; formerly Laneport Lake and Laneport Dam; San Gabriel River; flood control, water supply, and recreation.

Somerville Lake and Somerville Dam; Yequa Creek; flood control, water supply, and recreation.

Brazos River Authority

Possum Kingdom Lake and Morris Sheppard Dam; Brazos River; hydroelectric power, water supply, and recreation.

Lake Granbury and DeCordova Bend Dam; Brazos River; water supply and recreation.

Limestone Lake and Sterling C. Robertson Dam; Navasota River; water supply and recreation.

West Central Texas Municipal Water District

Hubbard Creek Reservoir and Hubbard Creek Dam; Hubbard Creek; water supply and recreation.

Table 4.3
RESERVOIR DATA

Reservoir	Hubbard	Possum Kingdom	Granbury	Whitney	Aquilla	Waco
Storage Capacity (ac-ft)						
Flood Control	-	-	-	1,372,400	86,700	553,300
Water Supply	297,910	551,860	104,790	50,000	33,600	104,100
Hydroelectric Power	-	-	-	198,000	-	-
Sediment Reserve (ac-ft)						
Flood Control Pool	-	-	-	8,155	6,900	20,600
Conservation Pool	19,840	118,380	48,700	51,645	18,800	48,400
Accumulative Storage (ac-ft)						
Flood Control Pool	-	-	-	1,999,500	146,000	726,400
Conservation Pool	317,750	570,240	153,490	627,100	52,400	152,500
Inactive Pool	-	221,050	52,500	379,100	-	-
Lowest Outlet Invert	3,470	0	2,500	4,250	0	580
Elevation (feet msl)						
Top of Dam	1,208	1,024	706.5	584	582.5	510
Flood Control Pool	-	-	-	571	556	500
Conservation Pool	1,183	1,000	693	533	537.5	455
Inactive Pool	-	970	675	520	-	-
Lowest Outlet Invert	1,136	875	640	449	503	400
Stream	Hubbard	Brazos	Brazos	Brazos	Aquilla	Bosque
Drainage Area (sq mi)	1,085	23,596	25,679	27,189	252	1,652
Gage Station Number	367	376	381	387	389	400
Gage Drainage Area (sq mi)	1,089	23,811	25,818	27,244	308	1,656
Drainage Area Ratio	1.0	1.0	1.0	1.0	0.818	1.0
Date of:						
Initial Impoundment	1962	1941	1969	1951	1983	1965
Accumulative Capacity Data	1962	1974	1969	1959	1983	1965

Reservoir	Proctor	Belton	Stillhouse	Georgetown	Granger	Limestone	Somerville
Storage Capacity (ac-ft)							
Flood Control	310,100	640,000	390,660	87,600	162,200	-	337,700
Water Supply	31,400	372,700	204,900	29,200	37,900	210,990	143,900
Sediment Reserve (ac-ft)							
Flood Control Pool	4,700	15,600	4,100	6,100	16,500	-	9,700
Conservation Pool	28,000	69,300	30,800	7,900	27,600	14,450	16,200
Accumulative Storage (ac-ft)							
Flood Control Pool	374,200	1,091,320	630,400	130,800	244,200	-	507,500
Conservation Pool	59,400	447,490	235,700	37,100	65,500	225,440	160,100
Lowest Outlet Invert	70	11	780	238	222	0	220
Elevation (feet msl)							
Top of Dam	1,205	662	698	861	555	380	280
Flood Control Pool	1,197	631	666	834	528	-	258
Conservation Pool	1,162	594	622	791	504	363	238
Lowest Outlet Invert	1,128	483	515	720	457	325.5	206
Stream	Leon	Leon	Lampasas	San Gabriel	San Gabriel	Navasota	Yequa
Drainage Area (sq mi)	1,259	3,531	1,313	247	709	675	1,007
Gage Station Number	412	418	424	426	431	448	443
Gage Drainage Area (sq mi)	1,261	3,542	1,321	248	738	968	1,009
Drainage Area Ratio	1.0	1.0	1.0	1.0	1.0	0.697	1.0
Date of:							
Initial Impoundment	1963	1954	1968	1980	1980	1978	1967
Accumulative Capacity Data	1963	1975	1968	1980	1980	1978	1967

Table 4.4

STORAGE CAPACITY BELOW TOP OF CONSERVATION POOL

	Storage Capacity (acre-feet)					Date	
Reservoir	Water Rights	Initial or Resurveyed	1984	2010	Ultimate	Initial or Resurveyed	Ultimate
Hubbard Creek	317,750	317,750	308,070	300,730	297,910	1962	2020
Possum Kingdom	724,739	570,240	544,510	477,600	451,860	1941/74	2020
Granbury	155,000	153,490	137,410	113,850	104,790	1969	2020
Whitney	627,092	627,100	599,160	574,520	574,520	1951/59	2010
Aquilla	52,400	52,400	52,210	47,340	33,600	1983	2083
Waco	104,100	152,500	133,750	108,880	104,100	1965	2015
Proctor	59,400	59,400	46,850	31,400	31,400	1963	2010
Belton	457,600	447,490	428,250	372,700	372,700	1954/75	2010
Stillhouse	235,700	235,700	225,310	209,700	204,900	1968	2018
Georgetown	37,100	37,100	36,540	34,540	29,200	1980	2080
Granger	65,500	65,500	64,190	57,070	37,900	1980	2080
Limestone	225,400	225,440	218,050	214,060	210,990	1978	2030
Somerville	160,110	160,100	154,450	146,140	143,900	1967	2017
	3,221,891	3,104,210	2,948,750	2,688,530	2,598,711		

Creek Reservoir for the Comanche Peak Nuclear Power Plant. Granbury and Possum Kingdom Reservoirs provide makeup water, as needed, to maintain constant operating levels in Tradinghouse Creek and Lake Creek Reservoirs which are owned and operated by utility companies for stream-electric power plant cooling. A recently constructed desalting water treatment plant provides the capability to treat water from Lake Granbury to supplement the water supply for the City of Granbury. Lake Limestone, completed in 1978, supplies water to off-channel cooling lakes owned by the Texas Power and Light Company.

BRA uses Lake Belton to supply water under contracts with the Cities of Temple and McGregor, and through Bell County Water Control and Improvement District No. 1 and two water supply corporations, to several other cities and communities. Water from Lake Whitney is contracted for use by the Cities of Cleburne, Whitney, and Rio Vista. Lake Waco supplies the City of Waco. A reallocation of 8.6 percent of the flood control capacity of Lake Waco to conservation is planned to meet the increasing water needs of the City of Waco and its suburbs. Water from Proctor Reservoir is provided to several cities under a contract between BRA and the Upper Leon River Municipal Water District. Proctor also provides water for agricultural use to individual farmers around the lake and to a corporation of farmers along the Leon River downstream of the dam. Stillhouse Hollow Reservoir supplies water to a number of communities and rural water supply corporations. Somerville Reservoir and the recently completed Georgetown, Granger, and Aquilla Reservoirs are also committed for municipal and industrial water supply.

In addition to the uses cited above, BRA operates the upstream reservoir system to regulate flows for municipal, industrial, and irrigation uses in the lower Brazos Basin and the neighboring San Jacinto-Brazos Coastal Basin. Downstream water customers include a large chemical plant at the mouth of the Brazos River, several thermal-electric generating plants, municipalities and industries in the coastal area south of Houston, and rice farmers in the lower basin and adjoining coastal basin. Water is diverted to users through extensive canal systems.

Reservoir Storage Capacities

Pertinent basic data describing the physical characteristics of the reservoirs are cited in Table 4.3. Reservoir operations are based on the top of conservation and flood control pool elevations tabulated. Flood control operations are in effect whenever the water surface rises or is predicted to rise above the top of conservation pool elevation. The inactive pool elevation at Possum Kingdom Reservoir is contractually set to accommodate hydroelectric power operations. Likewise, the inactive pool elevation at Granbury Reservoir is contractually set to accommodate withdrawals of cooling water for a stream-electric plant near the reservoir. The inactive pool at Whitney Reservoir is also dead storage for hydroelectric power. Withdrawals from the inactive pools can physically be made at these three reservoirs. Drawdown limits are set by contractual operating policies, not outlet structures. The other 10 projects can be emptied to the invert of the lowest outlet structure.

The accumulated storage capacities cited in Table 4.3 are total capacity, including sediment reserves and inactive storage, below the indicated elevation for the topography existing at the indicated year. A portion of this capacity can be expected to have since been lost due to deposition of sediment. The streams have heavy sediment loads, and the reservoirs are efficient sediment traps. The incremental flood control and water supply storage capacities listed in Table 4.3 are exclusive of sediment reserve storage. Sediment reserves in the flood control and conservation pools are also tabulated. Thus, more capacity is actually available than indicated by the incremental data prior to depletion of the sediment reserve.

Elevation versus capacity and area relationships for Possum Kingdom, Whitney, and Belton Reservoirs have been updated based on surveys at the dates indicated in Tables 4.3 and 4.4. The area and capacity data for the other projects have not been updated by field surveys since project design and construction. The USACE and BRA provided elevation/storage/area tables for initial or resurveyed topographic data as well as for the projected future condition of sedimentation (termed ultimate) upon which designated sediment reserves are based. Ultimate refers to the condition in which the designated (typically 50 or 100 year) sediment reserve has been depleted. Linear interpolation was applied to the initial (or resurveyed) and ultimate storage data to develop estimates for the years 1984 and 2010 conditions of sedimentation shown in Table 4.4.

Water Use

Total in-basin annual water use in the Brazos River Basin is projected by the Texas Water Development Board (1990) to increase from 2,035,000 acre-feet in 1990 to 2,474,000 and 2,877,000 acre-feet in years 2000 and 2040, respectively. Much of the water diverted from the Brazos River is used in the adjoining San Jacinto-Brazos Coastal Basin. Total in-basin annual water use in the San Jacinto-Brazos Coastal Basin is projected by the TWDB to increase from 403,000 acre-feet in 1990 to 480,000 and 755,000 acre-feet in 2000 and 2040, respectively.

Year 1984 Water Use

Table 4.5 is a tabulation of year 1984 water use summarized by Wurbs et al. (1988) from a TWDB data base. In Table 4.5 and the following discussion, water use is viewed from the perspective of three geographical areas: the Brazos River Basin above and below Possum Kingdom Reservoir and the San Jacinto-Brazos Coastal Basin. The first and last sets of data in Table 4.5 are total in-basin water use in the Brazos River Basin and Jacinto-Brazos Coastal Basin, respectively. The middle set of data shows in-basin water use in the Brazos River Basin excluding water use in all counties located above Possum Kingdom Reservoir. This represents in-basin water use at locations adjacent to and below the 12 USACE/BRA reservoirs. All data are for water withdrawals, except stream electric use which reflects consumptive use only.

A majority of the water use in the Brazos Basin consists of irrigation in the High Plains from the Ogallala Aquifer. The groundwater irrigation in the extreme upper basin has little impact on operation of the USACE/BRA reservoir system. There are few reservoirs and relatively little surface water use in the upper basin. Surface water from the Brazos River and several of its tributaries upstream of Possum Kingdom Reservoir is too saline for most beneficial uses. The city of Lubbock and several other smaller cities in the upper basin obtain water via pipeline from Lake Meredith in the Canadian River Basin. About 9,570 square miles of drainage area located in the upper extreme of the basin are noncontributing to downstream streamflows. Consequently, the upper third of the basin accounts for a large portion of the total basin water use but does not play a significant role, from the perspective of water use, in the operation of the USACE/BRA reservoir system or the simulation modeling study presented by this report. The primary sources of salinity, which greatly impacts downstream water quality, are located in the upper basin.

Table 4.5
1984 WATER USE

Source	Municipal	Manufacturing	Steam Electric	Mining	Irrigation	Livestock	Total
1984 Water Use in the Brazos River Basin (acre-feet/year)							
Surface	173,900	169,200	75,900	600	106,000	38,200	563,800
Ground	131,400	12,200	11,300	13,600	2,394,100	26,100	2,588,700
Total	305,300	181,400	87,200	14,200	2,500,100	64,200	3,152,500
1984 Water Use in the Brazos River Basin Excluding the Subbasin Above Possum Kingdom Reservoir (acre-feet/year)							
Surface	97,200	164,800	68,700	600	85,000	26,200	442,500
Ground	103,500	7,600	3,300	12,000	99,700	9,900	236,000
Total	200,700	172,400	72,000	12,600	184,700	36,100	678,500
1984 Water Use in the San Jacinto-Brazos Coastal Basin (acre-feet/year)							
Surface	26,580	102,970	1,940	2,440	176,420	470	310,820
Ground	72,480	3,220	530	190	11,000	700	88,120
Total	99,060	106,190	2,480	2,630	187,420	1,170	398,940

As indicated by Table 4.5, municipal, manufacturing, steam electric, mining, irrigation, and livestock are all significant water uses in the basin below Possum Kingdom Reservoir. Hydroelectric power and recreation are also important uses but are not included in the data because they involve no water diversions or withdrawals. Surface water use exceeds groundwater use. Groundwater is important to reservoir operations both as an alternative water supply source and as a source of return flows to the stream system. Groundwater also provides base flow directly to the streams.

Brazoria and Fort Bend Counties, at the lower end of the Basin, have the largest surface water use of any area in the basin. Most of this water use is for manufacturing, primarily by chemicals and petroleum refining industries, and irrigation. In addition to the fresh water use shown in the tables, 1,275,000 acre-feet of saline water from the Gulf was used in Brazoria County in 1984 for manufacturing purposes.

Significant quantities of water are also diverted from the Brazos River in Brazoria and Fort Bend Counties for transport to the adjoining San Jacinto-Brazos Coastal Basin. Water use in the San Jacinto-Brazos Coastal Basin is also tabulated in Table 4.5. A majority of the surface water use represents diversions from the Brazos River Basin through Brazos River Authority, Gulf Coast Water Authority, Chocolate Bayou Company, and Dow Chemical Company conveyance facilities. Texas Department of Water Resources (1984) data indicate that 87 percent of the surface water used in the San Jacinto-Brazos Coastal Basin in 1980 had been transported from the Brazos River Basin.

Water Amount Comparison

Various water amounts for 1984 are tabulated in Table 4.6 for comparative purposes in developing a basin overview (Wurbs, Bergman, Carriere, Walls 1988). The 1984 annual streamflow at the Richmond gage was about five percent of the volume of the precipitation falling on the watershed above the gage. The total surface water withdrawn for beneficial uses in 1984 throughout the basin was about 23 percent of the 1984 streamflow at the Richmond gage or eleven percent of the 1940-1984 mean annual streamflow at the Richmond gage. The total 1984 within basin surface water use, excluding the upper basin above Possum Kingdom Reservoir, was 443,000 acre-feet. An additional 270,000 acre-feet was diverted from the Brazos River for use in the San Jacinto - Brazos Coastal Basin. About 60 percent of the 794,000 acre-feet total 1984 water use from the Brazos River and its tributaries occurred in the lowermost two counties in the basin (26%) and in the adjoining coastal basin (34%). The total annual surface water use represents a volume equivalent to about 20 percent of the 3,910,000 ac-ft conservation storage capacity of the 40 major reservoirs.

A total of 329,000 acre-feet was released from the 12 BRA reservoirs during 1984 under water rights permits associated with the reservoirs, excluding water released through hydroelectric power turbines. A portion of the 186,000 acre-feet and 79,000 acre-feet of water released through the hydroelectric plants at Whitney and Possum Kingdom Reservoirs, respectively, was diverted at downstream locations for other beneficial uses. The reservoir releases shown were made under water rights permits associated with the reservoirs. The BRA Canal A and Canal B systems diverted an additional 130,000 acre-feet under separate water rights permits for use in the San Jacinto - Brazos Basin and in the Brazoria and Fort Bend Counties portion of the Brazos Basin.

Reservoir evaporation withdraws more surface water than all the beneficial uses in the basin combined. Total 1984 withdrawals of surface water for beneficial use in the basin and annual gross reservoir evaporation are equivalent to 20 and 23 percent, respectively, of the conservation storage capacity of the 40 major reservoirs. The evaporation amounts were estimated using water surface area and evaporation rate data (Wurbs, Bergman, Carriere, Walls 1988).

Water Rights

The water rights summary presented in this section is based upon a listing of active water rights in the Brazos River Basin, as of May 1993, provided by the Texas Water Commission. Additional information regarding the Brazos River Authority's water rights comes from a review of their individual permits. The Texas Water Commission (TWC) list includes about 1,240 water rights entries with diversions totalling 2,323,000 acre-feet/year and storage capacities in 592 reservoirs totalling 4,150,000 acre-feet. About 1,100 individual citizens, private companies, cities, and public agencies hold the water rights. Many of the water rights owners have just one right, while other owners have several rights included in the list. Rights held by a single entity for different types of use include a separate citation for each use. A majority of the water rights are held by private citizens and involve relatively small amounts of water. Cities and other public agencies hold most of the rights with larger diversion and storage amounts. The Brazos River Authority is, by far, the largest water rights holder in the basin. Most of the water rights

Table 4.6
1984 WATER AMOUNT COMPARISON

Annual Precipitation (acre-feet)

Watershed (excluding 9,566 square mile non-contributing area)	1984	1940-1984 Mean
Above Richmond Gage	50,000,000	52,080,000
Above Waco Gage	26,160,000	26,630,000
Above Cameron Gage	10,250,000	11,320,000

Annual Streamflow (acre-feet)

Gage	1984	1940-1984 Mean
Richmond	2,413,000	5,188,000
Waco	303,000	1,558,000
Cameron	309,000	1,172,000

1984 Basin Water Use (acre-feet)

Subbasin	Surface Water	Ground Water	Total
Above Possum Kingdom	121,000	2,353,000	2,474,000
Brazoria and Fort Bend Counties	207,000	33,000	240,000
Remainder of Basin	236,000	203,000	439,000
Total	564,000	2,589,000	3,153,000

1984 Interbasin Diversions (acre-feet)

From Canadian (Lake Meredith) to Brazos Basin	38,000
From Colorado (Oak Creek Reservoir) to Brazos Basin	2,000
From Brazos to San Jacinto-Brazos Coastal Basin	270,000

1984 Conservation Releases from 12-Reservoir System (acre-feet)

Whitney Hydropower Releases	186,000
Possum Kingdom Hydropower Releases	79,000
All Other Water Supply Releases	329,000

1984 Reservoir Evaporation (acre-feet)

Reservoirs	Gross	Net
12 BRA Reservoirs	557,000	382,000
1,166 Other Reservoirs	337,000	248,000
Total	894,000	630,000

were granted in the form of certificates of adjudication issued during the adjudication process. Others are permit applications approved since completion of the adjudication process. In addition to the 1,240 water rights entries cited above, the TWC list also includes 150 entries for contractual agreements between water suppliers and users. The contractual agreements are for sell or use of water for which other actual water rights have been issued.

The basic data provided in the TWC list of active water rights includes for each right: the identifying water right number and/or permit number; type of right; date issued; location by county and stream; owner; type of water use; permitted annual diversion amount; irrigation acreage; maximum rate of diversion; reservoir storage capacity; priority date; and remarks. Specified provisions associated with the Brazos River Authority water rights are discussed later in this chapter.

Water Rights Diversions

The diversion rights above the locations shown in Figure 4.3 are tabulated in Table 4.7. The water rights are aggregated by the reservoir and non-reservoir control points used in the simulation model discussed in later chapters. The total permitted diversion amounts associated with each control point location represents all the water rights with diversion locations between the control point and the next upstream control point(s). For example, diversions totalling 105,544 ac-ft/yr assigned to the Hempstead gage include all rights with diversion locations upstream of the Hempstead gage but downstream of the Bryan gage, Somerville Reservoir, and Limestone Reservoir. The 105,544 ac-ft/yr includes all permitted diversions from the Brazos River, Navasota River, and Yequa Creek between the indicated locations and on tributaries that confluence with these stream reaches. The reservoir control points in Table 4.7 include the water rights associated with the reservoir as well as upstream rights. Water rights diversions downstream of the Richmond gage are denoted in the table as being above the coast.

The permitted water right diversion amounts, as cited in the TWC list, are summarized in Table 4.7 by type of use. Municipal and industrial diversion totals are 1,277,889 and 530,258 ac-ft/yr, respectively, or 55% and 23% of the total basin permitted diversion of 2,322,916 ac-ft/yr. However, the distribution between types of water use is not strictly represented in the TWC list and Table 4.7 because some permits allow a degree of flexibility in how the water is used as long as the total permitted diversion amount is not exceeded. In particular, the permitted diversions associated with the Brazos River Authority rights can be used for different types of use within specified limits. The distribution between types of use in the Brazos River Authority permits is discussed later in this chapter.

Table 4.8 compares the accumulative diversion rights above a location with the 1940-1976 Texas Water Commission naturalized streamflows at the location. As discussed in Chapter 5, the naturalized streamflow is gaged streamflow adjusted to remove the effects of reservoir regulation and water use. Throughout the basin, water rights greatly exceed the lowest annual flow occurring during the 1940-1976 period. The last column of the table shows water rights in the watershed above a location as a percentage of the mean annual naturalized flow at the location. At the coast, the total basin water rights are divided by the mean annual streamflow at the Richmond gage. Total annual diversion rights are 40 percent of mean annual streamflow.

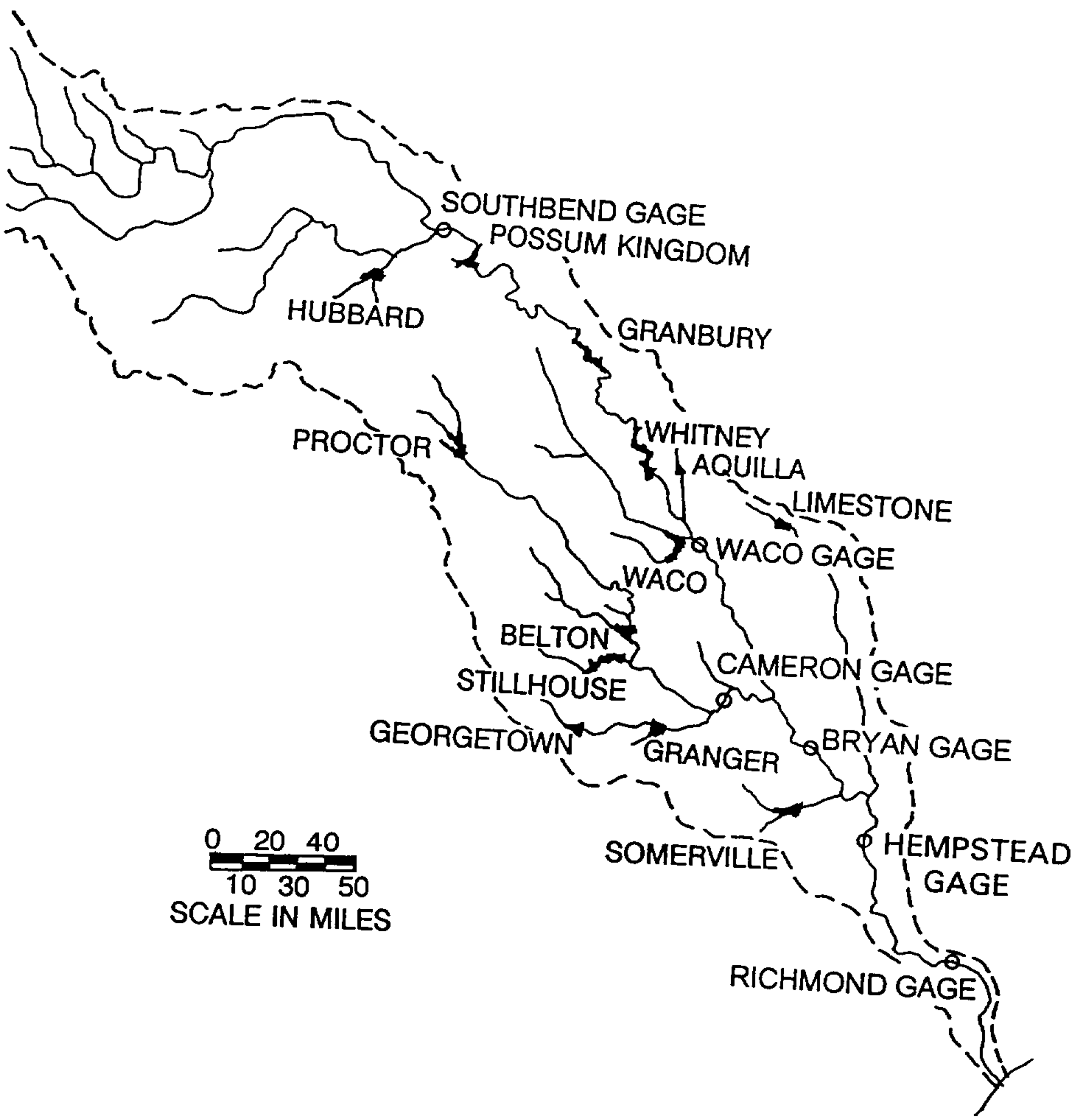

Figure 4.3 Reservoir and Stream Gage Locations at Which Water Rights Are Aggregated

Table 4.7
DIVERSION RIGHTS SUMMARY BY LOCATION AND TYPE OF USE

Location	Water Rights (acre-feet per year)						
	Municipal	Industrial	Irrigation	Mining	Recreation	Other	Total
1. Hubbard Reservoir	51,011	1,403	3,119	6,063	-	-	61,596
2. South Bend Gage	101,413	14,846	62,075	18,416	50	-	196,800
3. Possum Kingdom	241,840	8,858	414	600	-	-	251,712
4. Granbury Reservoir	80,557	6,157	9,921	71	-	-	96,706
5. Whitney Reservoir	41,516	23,180	4,009	125	-	25	68,855
6. Aquilla Reservoir	13,896	-	41	-	-	-	13,937
7. Waco Reservoir	97,532	-	10,477	-	-	-	108,009
8. Waco Gage	-	-	12,299	-	-	-	12,299
9. Proctor Reservoir	25,558	400	12,331	1,607	-	-	39,896
10. Belton Reservoir	148,875	38,894	12,005	-	45	-	199,819
11. Stillhouse Reservoir	71,528	48	4,573	-	-	-	76,149
12. Georgetown Reservoir	13,610	-	95	70	-	-	13,775
13. Granger Reservoir	19,840	203	1,028	270	-	270	21,611
14. Cameron Gage	3,102	18,212	11,254	138	-	-	32,706
15. Bryan Gage	25,424	39,000	34,459	-	-	-	98,883
16. Somerville Reservoir	48,000	20	99	-	-	-	48,119
17. Limestone Reservoir	71,095	65	13	50	-	-	71,223
18. Hempstead Gage	-	85,616	19,609	-	-	119	105,544
19. Richmond Gage	174,932	50,721	224,187	200	310	-	450,150
20. Coast	48,160	242,635	7,509	52,000	4,823	-	355,127
Total	1,277,889	530,258	429,517	79,610	5,228	414	2,322,916

Table 4.8
COMPARISON OF DIVERSION RIGHTS AND NATURALIZED STREAMFLOWS

Location	Water Rights		Streamflow		Water Rights
	Incremental (ac-ft/yr)	Accumulation (ac-ft/yr)	Mean (ac-ft/yr)	Low (ac-ft/yr)	(%)
Hubbard Res	61,596	61,596	98,310	698	62.7
South Bend Gage	196,800	258,396	738,077	57,149	35.0
Possum Kingdom	251,712	510,108	861,520	69,200	59.2
Granbury Res	96,706	606,814	1,166,340	134,000	52.0
Whitney Res	68,855	675,669	1,755,920	370,320	38.5
Aquilla Res	13,937	13,937	86,620	4,140	16.1
Waco Res	108,009	108,009	343,140	29,620	31.5
Waco Gage	12,299	809,914	1,933,700	434,410	41.9
Proctor Res	39,896	398,796	114,800	22,540	34.8
Belton Res	199,819	239,715	518,150	21,810	46.3
Stillhouse Res	76,149	76,149	251,240	17,710	30.3
Georgetown Res	13,775	13,775	65,470	0	21.0
Granger Res	21,611	35,386	174,980	2,000	20.2
Cameron Gage	32,706	383,956	1,328,640	98,450	28.9
Bryan Gage	98,883	1,292,753	4,006,580	787,590	32.3
Limestone Res	71,223	71,223	319,440	8,790	22.3
Somerville Res	48,119	48,119	223,060	10,010	21.6
Hempstead Gage	105,544	1,517,639	5,232,674	926,813	29.0
Richmond Gage	450,150	1,967,789	5,804,560	898,580	33.9
Coast	355,127	2,322,916			40.0

Note: The last column is the total (accumulative) water rights diversions above the location expressed as a percentage of the TWC 1940-1976 mean naturalized streamflow.

As previously discussed, Section 11.028 of the Texas Water Code states: "Any appropriation made after May 17, 1931 for any purpose other than domestic or municipal use is subject to the right of any city or town to make further appropriation of the water without paying for the water." Ramifications of the Wagstaff Act during drought conditions have not been precisely defined. However, municipal water rights with priority dates after May 1931 could conceivably have their priority dates changed to May 1931 or otherwise be given priority over non-municipal water rights. In Table 4.9, municipal water rights are categorized based on whether their priority dates are after May 17, 1931. Municipal diversions totalling 1,069,675 ac-ft/yr, or 84% of the total municipal rights of 1,277,899 ac-ft/yr, have priority dates later than May 1931 and thus are subject to being changed to May 1931. Thus, the priorities of 46% of the total water rights diversion amount (1,069,675 ac-ft/yr of 2,322,916 ac-ft/yr) could be increased by implementation of the Wagstaff Act. As noted above, some major rights include flexibility for using water for either municipal or other purposes. Thus, in some cases, the municipal rights cited here from the TWC list are not strictly fixed as being for municipal use only.

Table 4.9
MUNICIPAL WATER RIGHTS

	Location	Number of Rights		Diversions (ac-ft/yr)	
		Total	After May 1931	Total	After May 1931
1.	Hubbard Reservoir	8	5	51,011	48,950
2.	South Bend Gage	28	18	101,413	90,792
3.	Possum Kingdom Res	6	5	241,840	237,840
4.	Granbury Reservoir	14	13	80,557	78,877
5.	Whitney Reservoir	4	4	41,516	41,516
6.	Aquilla Reservoir	1	1	13,896	13,896
7.	Waco Reservoir	8	7	97,532	39,332
8.	Waco Gage	0	0	0	0
9.	Proctor Reservoir	3	2	25,558	25,108
10.	Belton Reservoir	7	4	148,875	132,257
11.	Stillhouse Reservoir	2	1	71,528	67,768
12.	Georgetown Reservoir	1	1	13,610	13,610
13.	Granger Reservoir	2	2	19,840	19,840
14.	Cameron Gage	5	4	3,102	310
15.	Bryan Gage	9	8	25,424	19,824
16.	Somerville Reservoir	1	1	48,000	48,000
17.	Limestone Reservoir	5	4	71,095	68,595
18.	Hempstead Gage	1	1	0	0
19.	Richmond Gage	2	1	174,932	75,000
20.	Coast	4	4	48,160	48,160
	Total	111	86	1,277,889	1,069,675

Reservoir Storage Capacity

Over a third of the water rights permits include reservoir storage capacity as well as diversion rates. As indicated by Tables 4.10 and 4.11, the water rights include storage capacities totalling 4,149,829 acre-feet in 592 reservoirs. Forty-eight of the reservoirs have

Table 4.10
PERMITTED STORAGE CAPACITY IN THE BRAZOS RIVER BASIN

Category of Reservoirs	Number of Rights	Capacity (acre-feet)
USACE/BRA reservoirs	12	2,339,049
Hubbard Creek Reservoir	1	317,750
other major reservoirs	35	1,318,814
small reservoirs (less than 5,000 ac-ft)	544	174,216
Total	592	4,149,829

Table 4.11
PERMITTED STORAGE CAPACITY BY LOCATION

Location (reservoirs are at or above)	Number of Reservoirs		Capacity (acre-feet)	
	Small	Major	Incremental	Accumulative
Hubbard Reservoir	11	2	371,022	371,022
South Bend Gage	107	10	473,381	844,403
Possum Kingdom Res	5	3	778,319	1,622,772
Granbury Reservoir	40	3	216,221	1,838,943
Whitney Reservoir	17	4	332,121	2,171,064
Aquilla Reservoir	1	1	52,450	52,450
Waco Reservoir	55	3	318,309	318,309
Waco Gage	4	0	320	2,542,143
Proctor Reservoir	118	2	104,443	104,443
Belton Reservoir	42	1	478,115	582,558
Stillhouse Reservoir	14	1	236,678	236,678
Georgetown Reservoir	4	1	37,250	37,250
Granger Reservoir	3	1	65,534	102,784
Cameron Gage	30	0	3,585	925,605
Bryan Gage	27	3	74,304	3,542,052
Limestone Reservoir	10	2	242,483	242,483
Somerville Reservoir	8	2	176,146	176,146
Hempstead Gage	35	4	97,930	4,058,611
Richmond Gage	7	2	30,624	4,089,235
Coast	6	3	60,594	4,149,829
Total	544	48	4,149,829	

permitted storage capacities of 5,000 acre-feet or greater. Several of these major reservoirs are proposed but not yet constructed. The 12 USACE/BRA reservoirs have permitted capacities of 2,339,049 acre-feet or 56% of the basin total. Hubbard Creek Reservoir contains 7.7% of the total permitted storage capacity. The 554 reservoirs with individual storage capacities less than 5,000 acre-feet have a total permitted capacity of 174,216 acre-feet or 4.2% of the basin total. Table 4.11 tabulates the storage capacity totals for reservoirs located between model control points and the total accumulative capacity above each control point. Data for reservoir control points include the capacity of the reservoir as well as upstream reservoirs. For example, 42 small reservoirs (permitted capacities less than 5,000 ac-ft) and 1 major reservoir (Belton), with a total permitted capacity of 478,115 acre-feet, are located on the Leon River and tributaries that flow into the Leon River between Belton Dam and Proctor Dam. Including Belton Reservoir, 163 reservoirs with a combined permitted capacity of 582,558 acre-feet are located above Belton Dam.

For several reasons, the storage capacities specified in the water rights permits are not necessarily the same as the physical capacities that actually exist. The nine U.S. Army Corps of Engineers (USACE) reservoirs contain 3,940,000 acre-feet of designated flood control storage capacity which is not included in the water rights. Numerous smaller reservoirs in the basin, typically with capacities of less than 200 acre-feet, are not included in the permits. Water rights permits have been issued for several proposed major reservoir projects which have not yet been constructed.

Whitney Reservoir is an unusual case. With a conservation storage capacity of 627,100 acre-feet, Whitney is the largest reservoir in the basin. However, the conservation storage capacity has been used since 1951 for hydroelectric power and recreation without a water rights permit. In 1982, a permit was issued for municipal water supply use of 50,000 acre-feet of the 248,000 acre-feet active pool portion of the total active and inactive pool conservation storage of 627,100 acre-feet. The storage capacities cited in Tables 4.10 and 4.11 include only 50,000 acre-feet for Whitney Reservoir.

Storage capacities significantly change over time due to sedimentation. Most of the water rights permits are based on the reservoir storage available at the time of construction prior to any loss due to sediment deposition. Thus, the actual physical storage capacity is less than the permitted amount due to sedimentation. Waco Reservoir is an example of an exception to this general rule. The permit for Waco Reservoir does not include the storage capacity reserved for sedimentation. Thus until the sediment reserve is depleted, the actual capacity in Waco Reservoir is greater than the permitted amount.

Water Rights for the 12-Reservoir USACE/BRA System and Hubbard Creek Reservoir

As noted above, rights to divert water from the Brazos River and its tributaries total 2,322,916 ac-ft/yr. Water rights for withdrawals or releases from the 12 USACE/BRA reservoirs are 977,933 ac-ft annually, or 42% of the total. The 12-USACE/BRA reservoirs have permitted storage capacities totalling 2,339,049 acre-feet or 56% of the basin total. The 12-USACE/BRA reservoirs account for 62% of the total basin storage if the Whitney Reservoir actual conservation storage capacity of 627,100 acre-feet is considered instead of the 50,000 acre-feet included in the water rights. Permitted diversions from Hubbard Creek Reservoir are

56,000 ac-ft/yr. Hubbard Creek Reservoir has a permitted storage capacity of 317,750 acre-feet. The water rights associated with these 13 reservoirs are tabulated in Table 4.12.

Table 4.12
WATER RIGHTS ASSOCIATED WITH THE 13 RESERVOIRS

Water Right Number	Reservoir	Diversion Amount (ac-ft/yr)	Storage Capacity (ac-ft/)	Type Use	Priority Date
		Brazos River Authority			
5155	Possum Kindom Reservoir	230,750	724,739	multiple	Apr 1938
5156	Granbury Reservoir	64,712	155,000	multiple	Feb 1964
5157	Whitney Reservoir	18,336	50,000	municipal	Aug 1982
5158	Aquilla Reservoir	13,896	52,400	multiple	Oct 1976
5159	Proctor Reservoir	19,658	59,400	multiple	Dec 1963
5160	Belton Reservoir	100,257	457,600	multiple	Dec 1963
5161	Stillhouse Reservoir	67,768	235,700	multiple	Dec 1963
5162	Georgetown Reservoir	13,610	37,100	multiple	Feb 1968
5163	Granger Reservoir	19,840	65,500	multiple	Feb 1968
5165	Limestone Reservoir	65,074	225,400	multiple	May 1974
5164	Somerville Reservoir	48,000	160,110	multiple	Dec 1963
		City of Waco			
2315	Waco Reservoir	58,200	104,100	municipal	Jan 1929
2315	Waco Reservoir	900		irrigation	Jan 1929
		U.S. Department of the Army			
2936A	Belton Reservoir	10,000	12,000	municipal	Aug 1953
2936	Belton Reservoir	2,000	-	municipal	Aug 1954
		City of Temple			
2938	Belton Reservoir	20,000	-	municipal	Jan 1957
		West Central Texas Municipal Water District			
4213	Hubbard Reservoir	44,800	317,750	municipal	May 1957
4213	Hubbard Reservoir	6,000	-	mining	May 1957
4213	Hubbard Reservoir	2,000	-	irrigation	May 1957
4213	Hubbard Reservoir	2,000	-	municipal	Aug 1972
4213	Hubbard Reservoir	1,200	-	industrial	Aug 1972

The Brazos River Authority rights listed in Table 4.12 include total withdrawals or releases of 661,901 ac-ft/yr and storage capacity of 2,222,949 acre-feet associated with eleven reservoirs. For many years, the BRA owned two canal systems with associated diversion rights of 224,932 ac-ft/yr. BRA recently transferred these canal systems to the Gulf Coast Water Authority. These systems include canals and pumping stations which supply water diverted from the lower Brazos River to water users in the industrial area south of Houston. The water rights associated with the canal systems are cited in the TWC water rights data as now belonging to the Gulf Coast Water Authority. The canal system rights are not included in Table 4.12.

The rights associated with Waco Reservoir are held by the City of Waco. Waco Reservoir is one of the nine reservoirs owned and operated by the Fort Worth District of the U.S. Army Corps of Engineers. As previously noted, the Brazos River Authority and City of Waco have contracted with the USACE for 87.5% and 12.5% of the conservation storage capacity. The BRA, in turn, sells water from Waco Reservoir to the City of Waco.

The permitted diversion of 59,100 ac-ft/yr and storage capacity of 104,100 acre-feet cited in Table 4.11 are for the existing Waco Reservoir. A reallocation to water supply of a portion of the flood control pool of Waco Reservoir has been proposed. The storage reallocation involves raising the designated top of conservation pool elevation by seven feet. In 1991, the BRA was issued a water right permit for the proposed storage reallocation which includes a diversion of 20,770 ac-ft/yr and storage capacity of 87,962 acre-feet. At the same time, the BRA was also issued a permit for construction of the proposed Bosque Reservoir project on the Bosque River upstream of Waco Reservoir. The BRA also holds a permit for the John Montford Dam and Alan Henry Reservoir project which is presently under construction. Alan Henry Lake is located in the upper Brazos Basin and will supply water for the City of Lubbock.

As indicated by Table 4.11, the City of Temple and the Fort Hood Army Base hold rights to portions of the water from Belton Reservoir. West Central Texas Municipal Water District owns the water rights associated with Hubbard Creek Reservoir.

Brazos River Authority System Operation

The BRA rights include special provisions which provide certain flexibility for multiple-reservoir multiple-use reservoir/river system operations. Water rights are normally for a specified type of water use. However, the BRA permits provide significant flexibility in regard to the annual amounts of water which can be withdrawn or released from each reservoir for the various types of use. The permits specify the total annual water right diversion for each reservoir, as tabulated in Table 4.12 and 4.13. As indicated in Table 4.13, maximum limits are also specified for diversions for each type of use. However, the sum of the diversion limits for the various types of use exceed the maximum allowable total diversion. Thus, flexibility is provided in allocation of the total diversion between types of use. However, the TWC water availability model as well as the model studies conducted in the present study require specified diversions for each type of use which sum to the total for the reservoir. As indicated in the bottom half of Table 4.13, the Texas Water Commission water rights list cites all the BRA water rights as being for municipal use.

The BRA also has a system order in effect since July 1964 which allows the reservoirs to be operated as a system such that releases from tributary and main stem reservoirs can be coordinated. Diversions from individual reservoirs can exceed the amounts specified in the individual permits as long as the sum of the diversions in a year for each use type from all the reservoirs does not exceed the sum of the amounts specified in the individual reservoir permits. Thus, the system order does not change the total annual amount of water which can be withdrawn from the BRA system, but does add operational flexibility in selecting the reservoirs from which to make releases.

Table 4.13
BRAZOS RIVER AUTHORITY DIVERSION RIGHTS BY TYPE OF USE

Reservoir	Water Rights Diversions (acre-feet/year) Total	Municipal	Industrial	Irrigation	Mining
		BRA Permitted Diversions			
Possum Kingdom	230,750	175,000	250,000	250,000	49,800
Granbury	64,712	10,000	70,000	19,500	500
Whitney	18,336	25,000	25,000	-0-	-0-
Aquilla	13,896	17,000	18,200	-0-	200
Proctor	19,658	18,000	17,800	18,000	200
Belton	100,257	95,000	150,000	149,500	500
Stillhouse	67,768	74,000	74,000	73,700	300
Georgetown	13,610	16,500	16,400	4,100	100
Granger	19,840	30,000	29,800	5,500	200
Limestone	65,074	69,500	77,500	70,000	500
Somerville	48,000	49,500	50,000	50,000	500
	BRA Diversions Included in TWC Water Rights List				
Possum Kingdom	230,750	230,750	-0-	-0-	-0-
Granbury	64,712	64,712	-0-	-0-	-0-
Whitney	18,336	18,336	-0-	-0-	-0-
Aquilla	13,896	13,896	-0-	-0-	-0-
Proctor	19,658	19,658	-0-	-0-	-0-
Belton	100,257	100,257	-0-	-0-	-0-
Stillhouse	67,768	67,768	-0-	-0-	-0-
Georgetown	13,610	13,610	-0-	-0-	-0-
Granger	19,840	19,840	-0-	-0-	-0-
Limestone	65,074	65,074	-0-	-0-	-0-
Somerville	48,000	48,000	-0-	-0-	-0-

The BRA also holds an excess flows permit, granted in June 1974, which allows utilization of unregulated flows in the lower reaches of the Brazos River in lieu of reservoir releases, subject to the provisions of the permit, if other water rights are not adversely affected. The excess flows permit allows the BRA to divert, without priority and as limited by several special provisions, not to exceed 100,000 ac-ft/yr for municipal purposes, 450,000 ac-ft/yr for industrial purposes, and 100,000 ac-ft/yr for irrigation purposes. Irrigation diversions can be used to irrigate not more than 119,078 acres of land. However, these diversions from excess unregulated streamflows in the lower Brazos River are charged against the permitted diversions of the BRA rights cited in Table 4.12. Thus, the excess flows permit does not change the total amount of water which can be diverted in a particular year but does allow more water to remain in storage.

Interbasin Transfers

The BRA permits have been amended to allow an interbasin transfer of 200,000 ac-ft/yr to the San Jacinto-Brazos Coastal Basin. This is not a right to more water in addition to that included in the permits tabulated in Table 4.12. However, it allows the already permitted diversions to be transported to the San Jacinto-Brazos Coastal Basin as well as be used within the Brazos River Basin.

The Possum Kingdom Reservoir permit was amended in January 1987 to allow diversion of 5,240 ac-ft/yr for municipal use in the Trinity River Basin. Again, this allows previously permitted diversions to be transported out of the basin but does not increase the total permitted amount of water which can be diverted from the reservoir.

Hydroelectric Power

Possum Kingdom and Whitney Reservoirs have hydroelectric power plants. However, no water rights exist specifically for hydroelectric power. Hydropower is generated by unappropriated flows and water supply releases. Hydroelectric power was aggregated with municipal, industrial, and agricultural water supply in the original Possum Kingdom Reservoir water rights permit which included a diversion of 1,500,000 ac-ft/yr. However, hydropower was treated as incidental to water supply at Possum Kingdom in the adjudication process which resulted in the present permitted diversion of 230,750 ac-ft/yr. Whitney Reservoir has never had a water right for hydroelectric power. Prior to the BRA obtaining a right for water supply from a relatively small portion of the storage capacity in 1982, no water right permit had ever been granted for Whitney Reservoir.

Senior Rights

Total water rights senior to the rights associated with each of the 12 BRA reservoirs are tabulated in Table 4.14. The senior rights include all rights with priority dates earlier than the rights associated with the reservoir, which are located upstream of the reservoir, such that the diversion affects reservoir inflows, or located at downstream locations at which flows are affected by the reservoir storage and releases. For example, the Brazos River Authority right to use water from Possum Kingdom Reservoir has a priority date of April 1938. There are 46 water rights with diversions totalling 53,337 ac-ft/yr located upstream of Possum Kingdom Reservoir which have priority dates earlier than April 1938. Another 23 rights with diversions of 409,633 ac-ft/yr located downstream of Possum Kingdom Reservoir have priorities senior to April 1938.

Contractual Commitments

As previously noted, water supply contracts have been executed by the USACE and BRA for the water supply storage capacity in each of the nine USACE reservoirs, except the City of Waco has contracted with the USACE for 12.5 percent of the conservation storage capacity of Waco Reservoir and the Fort Hood Army Base has 3.2 percent of the conservation storage capacity in Belton Lake. The BRA has contracted with the USACE for the other 87.5% of the conservation capacity in Waco Reservoir. The City of Waco, in turn, has contracted with the BRA for this capacity. Waco Reservoir is the only reservoir in the BRA system for which the conservation storage capacity is committed to a single user.

The BRA has water supply contracts with a number of cities, water districts, water supply corporations, electric utilities, businesses, companies, and irrigators. The annual amounts of water committed from the various reservoirs, as of June 1993, are listed in Table 4.15. The contractual commitments include supplying diversions totalling 576,700 ac-ft/yr. Of this amount 427,236 ac-ft/yr, or 74%, is associated with individual reservoirs. The remaining 149,464 ac-

Table 4.14
SENIOR WATER RIGHTS

Reservoir	Priority Date	Senior Water Rights Diversions					
		Upstream		Downstream		Total	
		Number	Amount (ac-ft/yr)	Number	Amount (ac-ft/yr)	Number	Amount (ac-ft/yr)
Possum Kingdom	Apr 1938	46	53,337	23	409,633	69	462,970
Granbury	Feb 1964	187	419,309	80	805,822	267	1,225,131
Whitney	Aug 1982	390	607,295	127	961,578	517	1,568,873
Aquilla	Oct 1976	2	41	109	890,364	111	890,405
Waco	Jan 1929	4	453	11	165,693	15	166,146
Proctor	Dec 1963	18	8,335	174	911,313	192	919,648
Belton	Dec 1963	110	103,177	82	816,471	192	919,648
Stillhouse	Dec 1963	41	5,909	82	816,471	123	822,380
Georgetown	Feb 1968	3	95	112	833,333	115	833,428
Granger	Feb 1968	15	1,108	100	832,320	115	833,428
Limestone	May 1974	10	6,070	38	807,663	48	813,733
Somerville	Dec 1963	3	20	28	749,058	31	749,078

ft/yr, or 26% of the total, can be met by releases from multiple reservoirs and/or by streamflow under the excess flows permit.

Table 4.15
BRAZOS RIVER AUTHORITY WATER SUPPLY COMMITMENTS
(as of June 1993)

Reservoir	: Diversion (ac-ft/yr)
Possum Kingdom	124,039
Granbury	54,936
Whitney	12,939
Aquilla	5,953
Proctor	18,075
Belton	100,277
Stillhouse Hollow	39,530
Georgetown	13,440
Granger	6,721
Limestone	46,837
Somerville	4,489
System	149,464
Total	576,700

All the reservoirs are operated for water supply. Possum Kingdom and Whitney Reservoirs also have hydroelectric power plants. The BRA owns and operates Possum Kingdom Reservoir. Hydroelectric power is produced under a contract between the BRA and the Brazos Electric Power Cooperative. In the past, under a recently expired contract, Possum Kingdom Reservoir was operated primarily for hydroelectric power with water supply being an incidental purpose. With the current operating policy, Possum Kingdom is operated primarily for water supply with water supply releases through the turbines also generating power.

The Corps of Engineers operates Whitney Reservoir. The Southwestern Power Administration is responsible for marketing the power from the federal project. The Whitney active conservation pool, which is between elevations 520 feet and 533 feet, provides releases for both water supply and hydroelectric power generation. The water supply contract between the USACE and BRA commits 22.017 percent of the water provided by the active conservation pool to BRA for water supply. A hydroelectric power contract between the Southwestern Power Administration and the Brazos Electric Power Cooperative provides for 30,000 kilowatts of peaking power and 1,200 kilowatt-hours of annual energy per kilowatt of peaking power, with the energy not to exceed 200 kilowatt-hours per kilowatt in any one month or 600 kilowatt-hours per kilowatt during four consecutive months.

Natural Salt Pollution

Management and utilization of the water resources of the Brazos River Basin is seriously constrained by salinity. Water quality is degraded by natural contamination by salts consisting largely of sodium chloride with moderate amounts of calcium sulfate and other dissolved solids. The primary source of the salinity is geologic formations and associated groundwater emissions in an area of the upper basin consisting of the Salt Fork of the Brazos River watershed and portions of the adjacent Double Mountain Fork Brazos River and North Croton Creek watersheds. This semiarid region of about 1,500 square miles consists of gypsum and salt encrusted hills and valleys studded with salt springs and seeps. The groundwater emissions and runoff from salt flats in these areas contribute large salt loads to the tributary streams and the Brazos River. Salt concentrations in the three reservoirs located on the main stream of the Brazos River are too high for municipal and most other uses without costly desalinization treatment processes or significant dilution. The quality of the river improves significantly in the lower basin with dilution from good quality tributaries.

Salinity Data

U.S. Geological Survey water quality monitoring activities in the Brazos River Basin date back to the early 1900s. The USGS conducted a particularly extensive water quality sampling program during the period 1964-1986 in support of the natural salt pollution control studies performed by the Corps of Engineers. Wurbs, Karama, Saleh, and Ganze (1993) present a summary and analysis of salinity data collected at the 26 gaging stations shown in Figure 4.4. Salinity is quantified in terms of monthly loads and concentrations of total dissolved solids (TDS), chloride (Cl), and sulfate (SO_4). Chloride and sulfate are major constituents of total dissolved solids in the Brazos River Basin. Streamflow rates, salt loads, and concentrations vary greatly with location and over time.

Discharges, loads, and concentrations averaged over the period of record at each of the 26 stations are shown in Table 4.16. Since the periods-of-record vary between the stations, the means are not strictly comparable. Adding or deleting a few years of data can significantly change the averages. Table 4.17 shows the discharges, loads, and concentrations at selected stations averaged over the period 1964-1986 or as close thereto as available data allows. The means shown for stations 1, 3, 7, 13, 15, 20, and 25 are averaged over the period 1964-1986. The means for the other stations in Table 4.17 are for somewhat shorter periods. These data indicate a tremendous difference between the extremely high concentrations at certain locations in the upper basin and the much lower concentrations in the lower reaches of the Brazos River and the better quality tributaries. The highest mean concentrations in Table 4.17 are 56,900 mg/l, 32,900 mg/l, and 2,270 mg/l for TDS, Cl, and SO_4, respectively, at station 4 on Salt Croton Creek near Aspermont. Mean TDS, Cl, and SO_4 concentrations at the Richmond gage in the lower Brazos River are 339, 79, and 56 mg/l, respectively. For purposes of relative comparison, maximum total dissolved solids (TDS), chloride (Cl), and sulfate (SO_4) concentration limits of 500, 250, and 250 mg/l, respectively, are specified in the Environmental Protection Agency drinking water standards.

The TDS concentration versus duration relationships of Table 4.18 demonstrate temporal variability. The percent of months during the period 1964-1986 for which indicated

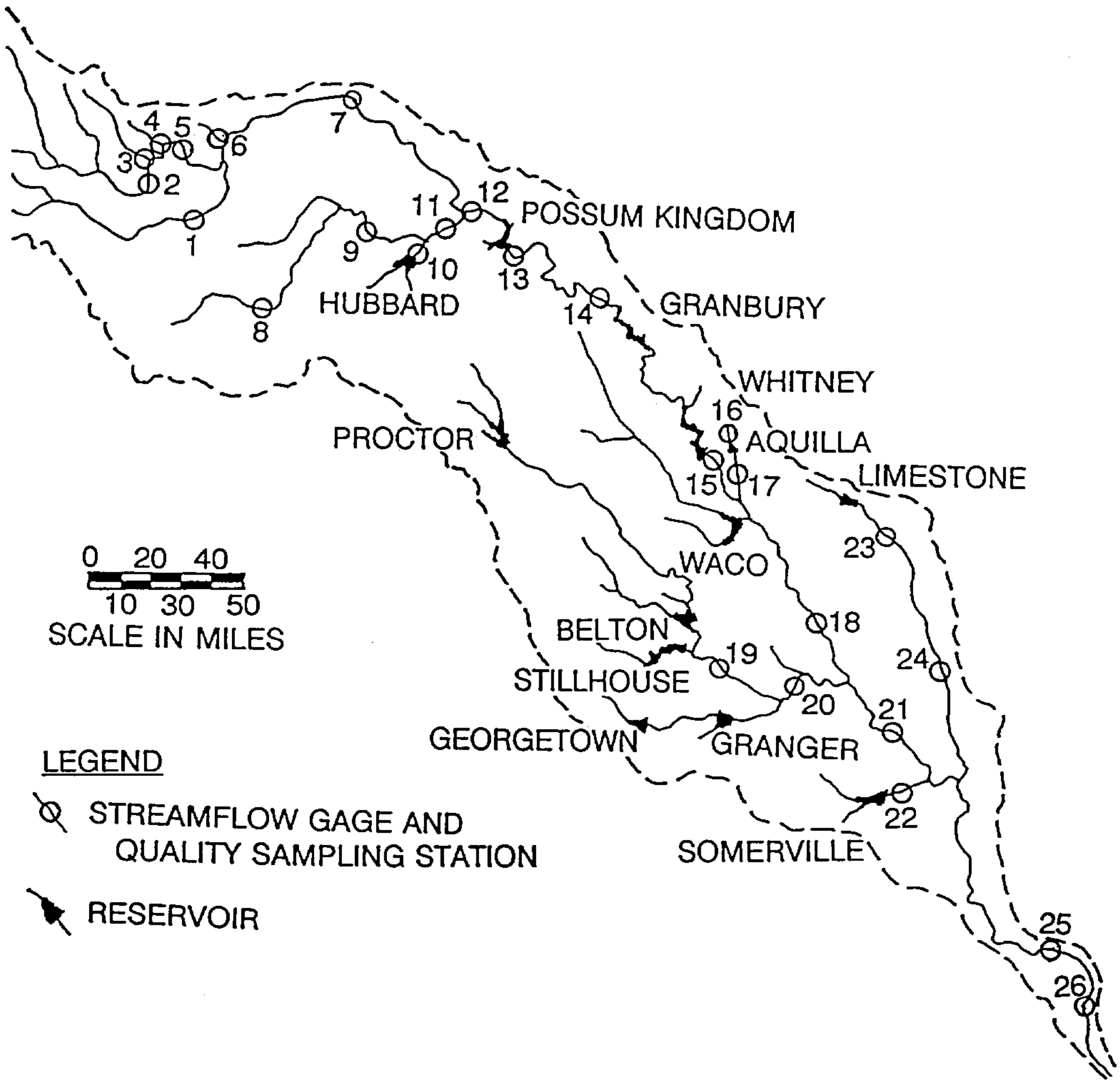

Figure 4.4 Water Quality Sampling Stations

Table 4.16
MEAN DISCHARGES, LOADS, AND CONCENTRATIONS FOR PERIOD-OF-RECORD

Study Station Number	Abbreviated Station Name	Tributary	Years of Record	Mean Discharge (cfs)	Load (tons/day) TDS	Load (tons/day) Cl	Load (tons/day) SO4	Concentration (mg/l) TDS	Concentration (mg/l) Cl	Concentration (mg/l) SO4
1	Aspermont	Double Mountain Fork	33	147	562	136	218	1,353	324	510
2	Peacock	Salt Fork	24	43	680	334	83	5,317	2,585	657
3	Jayton	Croton Creek	24	13	237	96	58	6,321	2,487	1,617
4	Aspermont	Salt Croton Creek	9	4	673	388	27	56,923	32,856	2,273
5	Aspermont	Salt Fork	29	81	1,887	942	217	8,606	4,153	989
6	Knox City	North Croton Creek	21	17	216	82	60	4,723	1,786	1,323
7	Seymour	Main Stem	27	292	2,638	1,018	447	3,356	1,295	569
8	Hawley	Clear Fork	15	46	235	51	94	1,893	411	759
9	Fort Griffin	Clear Fork	15	151	391	105	116	961	258	286
10	Breckenridge	Hubbard Creek	19	93	73	25	4	268	91	20
11	Eliasville	Clear Fork	21	319	614	201	148	715	234	172
12	South Bend	Main Stem	11	760	2,601	996	561	1,261	486	274
13	Possum Kingdom	Main Stem	45	836	2,959	1,127	636	1,299	493	279
14	Dennis	Main Stem	19	892	3,103	1,205	622	1,291	501	259
15	Whitney	Main Stem	38	1,376	3,174	1,120	633	856	302	171
16	Aquilla	Aquilla Creek	3	55	35	2	10	236	14	69
17	Aquilla	Aquilla Creek	14	147	102	6	29	257	14	73
18	Highbank	Main Stem	18	2,530	4,154	1,287	772	609	189	113
19	Little River	Little River	16	912	768	79	61	313	32	25
20	Cameron	Little River	26	1,544	1,094	129	126	263	31	30
21	College Station	Main Stem	22	4,364	5,315	1,379	944	452	117	80
22	Somerville	Yegua Creek	5	252	114	20	33	167	30	48
23	Groesbeck	Navasota River	19	161	56	9	6	131	22	13
24	Bryan	Navasota River	23	600	232	61	38	144	38	23
25	Richmond	Main Stem	41	6,545	6,140	1,431	1,020	351	81	58
26	Rosharon	Main Stem	12	7,305	6,462	1,491	1,004	328	76	51

Table 4.17
MEAN DISCHARGES, LOADS, AND CONCENTRATIONS FOR COMPARABLE TIME PERIODS

Study Station Number	Abbreviated Station Name	Tributary	Years of Record	Mean Discharge (cfs)	Load (tons/day)			Concentration (mg/l)		
					TDS	Cl	SO4	TDS	Cl	SO4
1	Aspermont	Double Mountain Fork	1964-86	126	580	153	209	1,540	416	548
2	Peacock	Salt Fork	1965-86	40	684	339	81	5,782	2,830	698
3	Jayton	Croton Creek	1964-86	13	225	93	53	6,391	2,541	1,591
4	Aspermont	Salt Croton Creek	1969-77	4	676	425	33	56,923	32,856	2,273
5	Aspermont	Salt Fork	1964-82	60	1,660	1,094	219	12,407	6,066	1,235
6	Knox City	North Croton Creek	1966-86	17	211	80	58	4,723	1,786	1,323
7	Seymour	Main Stem	1964-86	269	2,601	1,074	504	3,591	1,482	696
13	Possum Kingdom	Main Stem	1964-86	686	2,795	111	571	1,512	601	309
15	Whitney	Main Stem	1964-86	1,230	3,075	1,134	591	928	342	178
20	Cameron	Little River	1964-86	1,481	1,024	123	119	256	31	30
21	College Station	Main Stem	1964-83	4,529	5,348	1,368	938	438	112	77
25	Richmond	Main Stem	1964-86	6,868	6,267	1,466	1,030	339	79	56

Table 4.18
TDS CONCENTRATION VERSUS EXCEEDENCE FREQUENCY

Percent Equalled or Exceeded	Seymour Gage (mg/l)	Possum Kingdom Gage (mg/l)	Whitney Gage (mg/l)	College Station Gage (mg/l)	Richmond Gage (mg/l)
0.01	15,400	2,810	2,050	1,360	978
0.05	15,400	2,810	2,050	1,360	978
0.1	15,400	2,810	2,050	1,360	978
0.2	15,400	2,810	2,050	1,360	978
0.5	15,000	2,800	1,580	1,260	910
1	14,500	2,710	1,560	1,040	902
2	13,700	2,540	1,520	1,010	845
5	12,700	2,420	1,400	870	701
10	11,900	2,290	1,250	763	635
15	11,000	2,190	1,210	704	601
20	10,500	2,090	1,170	659	566
30	8,530	1,890	1,070	596	498
40	7,320	1,780	1,000	557	426
50	6,220	1,620	945	505	382
60	5,270	1,510	864	448	346
70	4,320	1,420	750	412	317
80	3,320	1,350	723	370	264
85	2,800	1,300	699	339	250
90	2,420	1,130	666	313	235
95	1,870	948	639	270	218
98	1,400	739	567	238	198
99	1,290	583	552	231	169
99.5	1,190	508	487	228	164
99.8	817	500	476	225	161
99.9	774	495	472	223	160
99.95	742	492	469	221	159
99.99	692	486	464	218	157
100	618	475	456	212	153

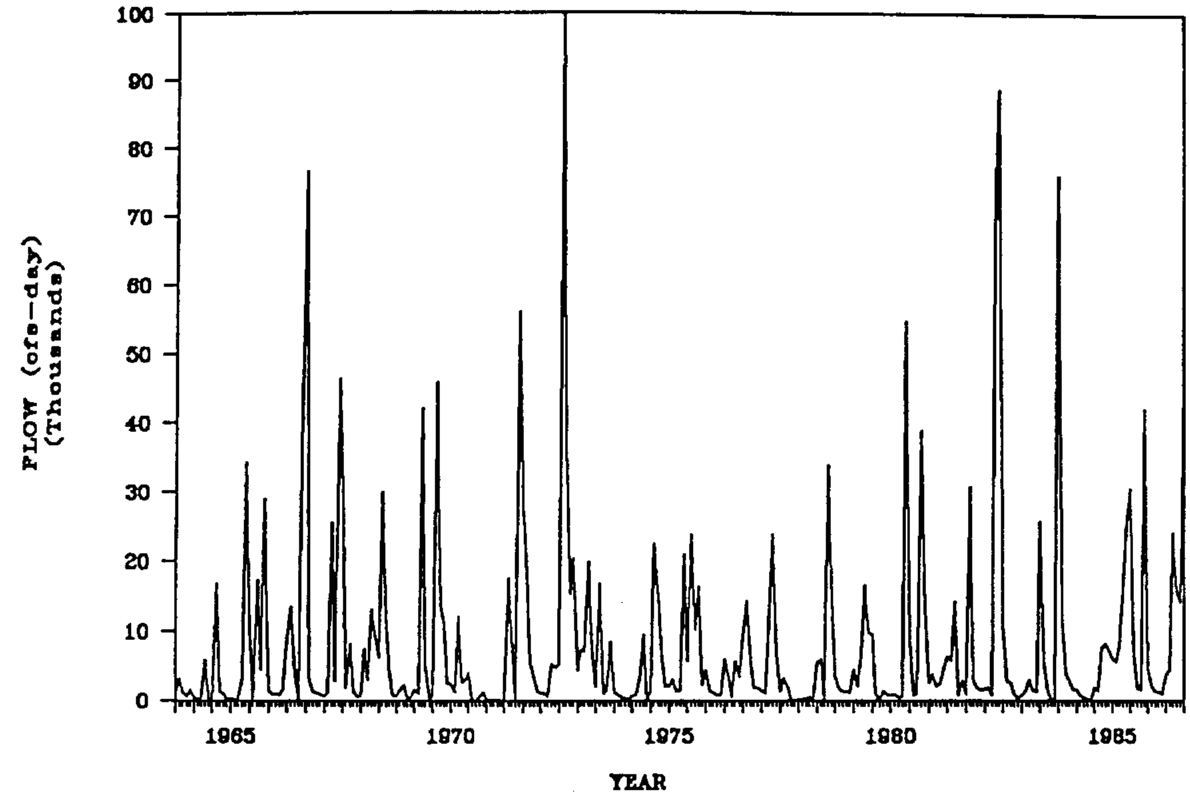

Figure 4.5 Discharge Hydrograph, Seymour Gage (Station 7)

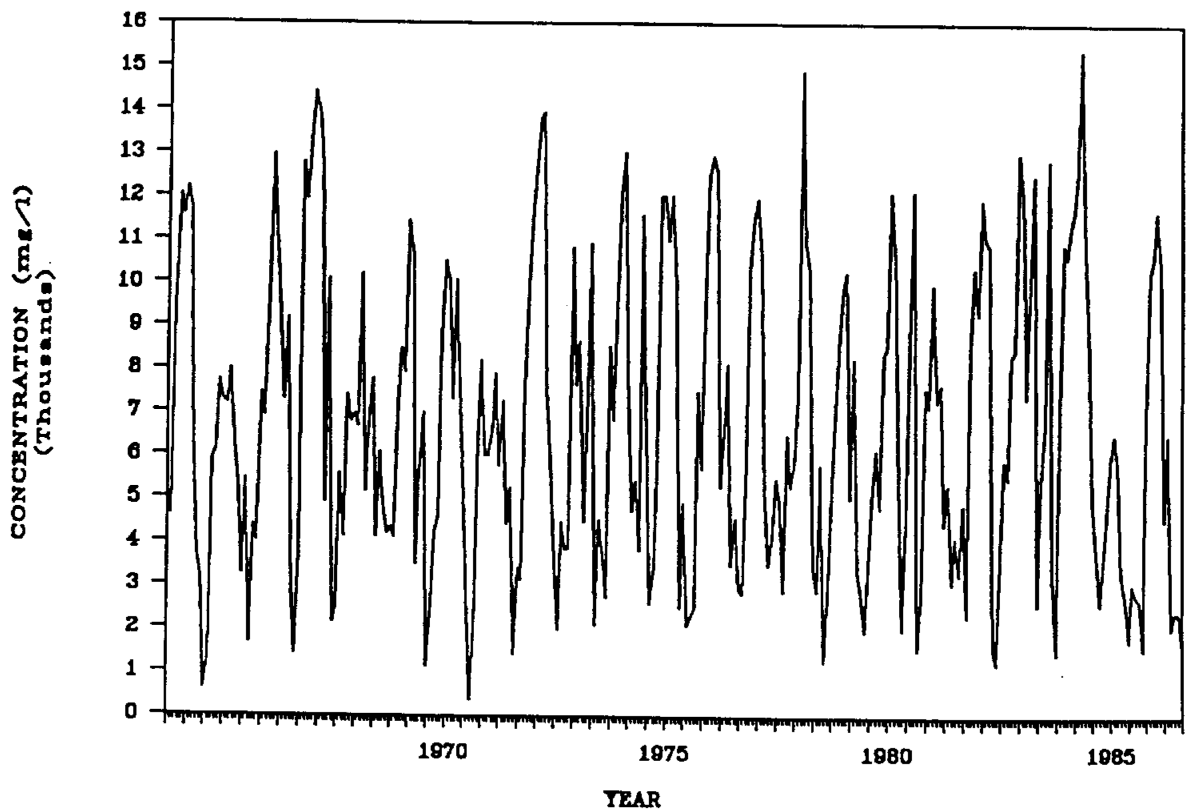

Figure 4.6 TDS Concentration Versus Time, Seymour Gage (Station 7)

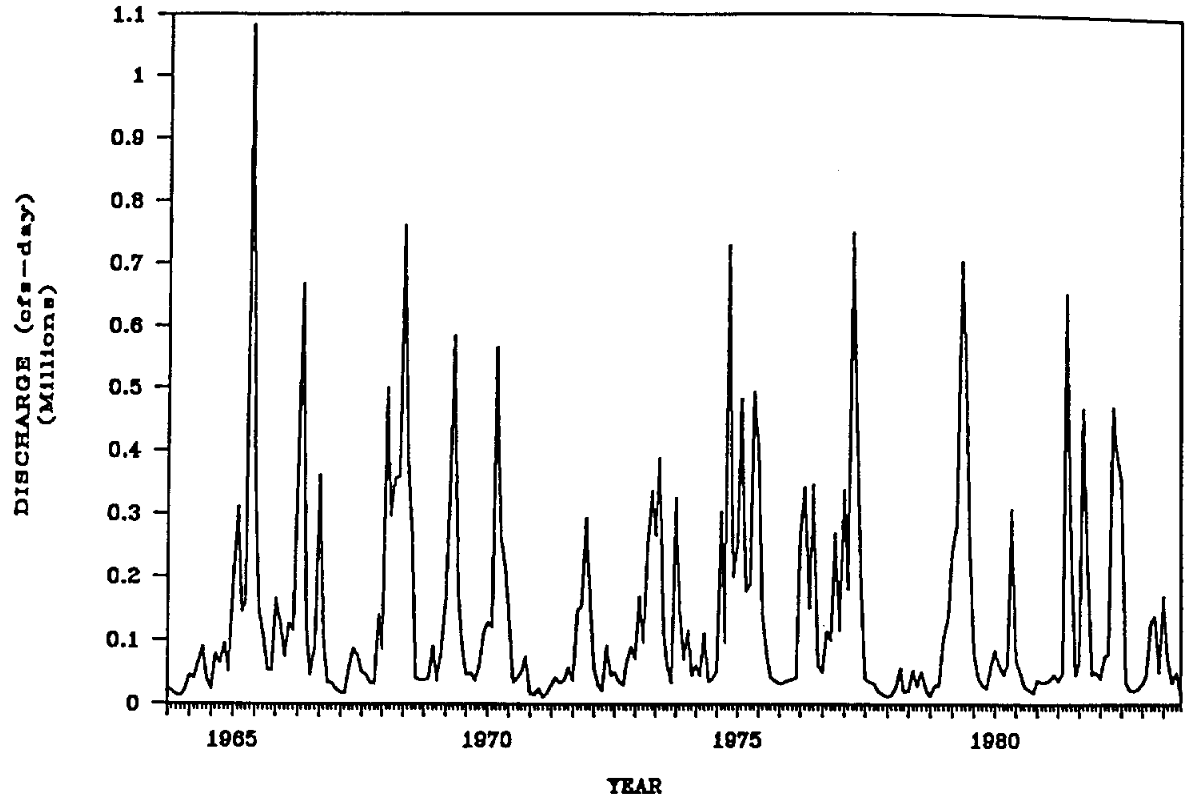

Figure 4.7 Discharge Hydrograph, College Station Gage (Station 21)

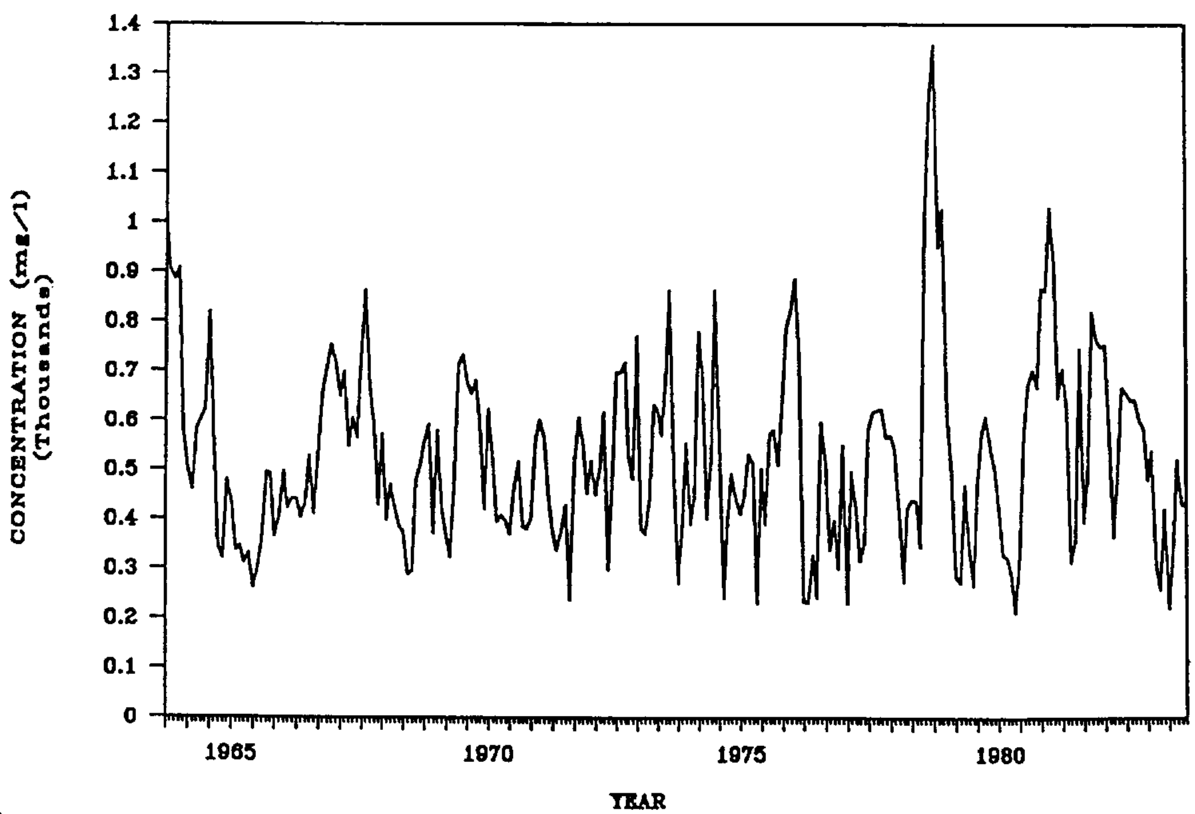

Figure 4.8 TDS Concentration Versus Time, College Station Gage (Station 21)

concentrations were equalled or exceeded are tabulated for selected sampling stations on the main stem Brazos River. The EPA drinking water standard of 500 mg/l TDS is exceeded 99.8% of the time at the Possum Kingdom gage and 50% of the time at the College Station gage. A TDS concentration of 500 mg/l is exceeded 30% of the time at the Richmond gage. Hydrographs of mean monthly flows and TDS concentrations for 1964-1986 at the Seymour and College Station gages (stations 7 and 21) are plotted in Figures 4.5-4.8.

Much of the salt load in the Brazos River originates from a small area in the upper basin. For example, the watersheds above stations 3, 4, and 6 are particularly significant salinity sources. These stations have very small watersheds and flows but extremely high salt concentrations and loads. As indicated by Figure 4.9, these stations are located on Croton Creek, Salt Croton Creek, and North Croton Creek, respectively. Croton and Salt Croton Creeks are tributaries of the Salt Fork of the Brazos River. North Croton Creek flows into the Brazos River downstream of the Salt Fork confluence. As indicated by Table 4.17 the TDS concentration at stations 3, 4, and 6 are 6,390 mg/l, 56,900 mg/l, and 4,720 mg/l, as compared to 339 mg/l at the Richmond gage. In Table 4.19, the sum of the mean salt loads at stations 3, 4, and 6 is expressed as a percentage of the mean salt loads at the selected stations shown in Figure 4.9. The sum of the mean TDS loads at stations 3, 4, and 6 is 34.17% of the mean TDS load at the Possum Kingdom gage (station 13). The sum of the mean chloride load at the three upstream stations is 48.74% of the chloride load at Possum Kingdom gage. However, the sum of the mean flow rates at stations 3, 4, and 6 is only 11.16% of the mean flow at the Possum Kingdom gage. The sums of the mean discharge, TDS load, and chloride load at the stations 3, 4, and 6 are 0.36%, 14.41%, and 32.05% of the corresponding values at the Richmond gage (station 25).

Table 4.19
MEAN DISCHARGES AND LOADS
FOR SUM OF STATIONS 3, 4, AND 6
AS A PERCENTAGE OF DOWNSTREAM STATIONS (1967-1977)

Downstream Station	Sta 3, 4 & 6 Discharge	Stations 3,4 & 6 Loads TDS	Cl	SO4
7	11.16%	38.43%	48.74%	24.81%
13	4.61%	34.17%	43.08%	20.64%
15	2.18%	31.00%	42.38%	20.25%
21	0.59%	18.38%	37.01%	13.34%
25	0.36%	14.41%	32.05%	11.42%

Proposed Salt Control Impoundments

The simulation modeling study presented in Chapters 5-8 includes an evaluation of the impacts on water supply reliabilities of impounding the runoff from selected salt source areas. As discussed below, impoundment plans have been proposed and studied by the Corps of Engineers. Other studies continue to address proposals for preventing flows from the primary source area from entering the stream system. James and Masciangliolі (1992) suggest the use of a shallow-well recovery system combined with disposal of brine by deep-well injection. Chapter 8 of the present report includes an assessment of the impacts of salt control on water supply reliabilities, from the perspective of assuming that salt loads at specified locations are somehow prevented from entering the Brazos River regardless of the particular mechanism of salt control.

Brazos River Basin natural salt pollution control studies conducted by the U.S. Army Corps of Engineers (USACE) are documented by a survey report (USACE 1973), environmental impact statement (USACE 1976), and draft general design memorandum (USACE 1983). McCrory (1984) provides an overview summary. The studies involved formulation and evaluation of a comprehensive array of strategies for dealing with the salt pollution problem. A number of the alternative plans consist of systems of salt control dams located in the primary salt source areas of the upper basin. The survey report (USACE 1973) recommended construction of a system of three salt control dams to contain the runoff from the primary salt source areas. In the restudy documented by the draft general design memorandum (USACE 1983), the previously recommended salt control impoundment plan and alternative plans were found not to be economically feasible based on current evaluation methods and conditions.

The plan recommended in the original survey report consists of three impoundments: Croton Lake on Croton Creek, Dove Lake on Salt Croton Creek, and Kiowa Peak Lake on North Croton Creek. The locations of the three proposed impoundments are shown in Figure 4.9. The dam sites are near gaging stations 3, 4, and 6 discussed above. The proposed salt control dams would impound the runoff from their upstream watersheds. A connecting pipeline would be provided for transferring excess water from Croton and Dove Lakes to Kiowa Peak Lake. The impounded water will be partially lost over time due to evaporation, with the remaining brine being permanently stored in Kiowa Peak Lake. Each of the three dams would consist of an earth-fill embankment and outlet structures for emergency releases only. No releases are planned during the project life.

In the simulation modeling studies presented in the following chapters, the salt control impoundment plan is represented as removal of all flows and salt loads at stations 3, 4, and 6 of Figure 4.9. The improvements in water supply reliabilities of removing these flows and loads are determined.

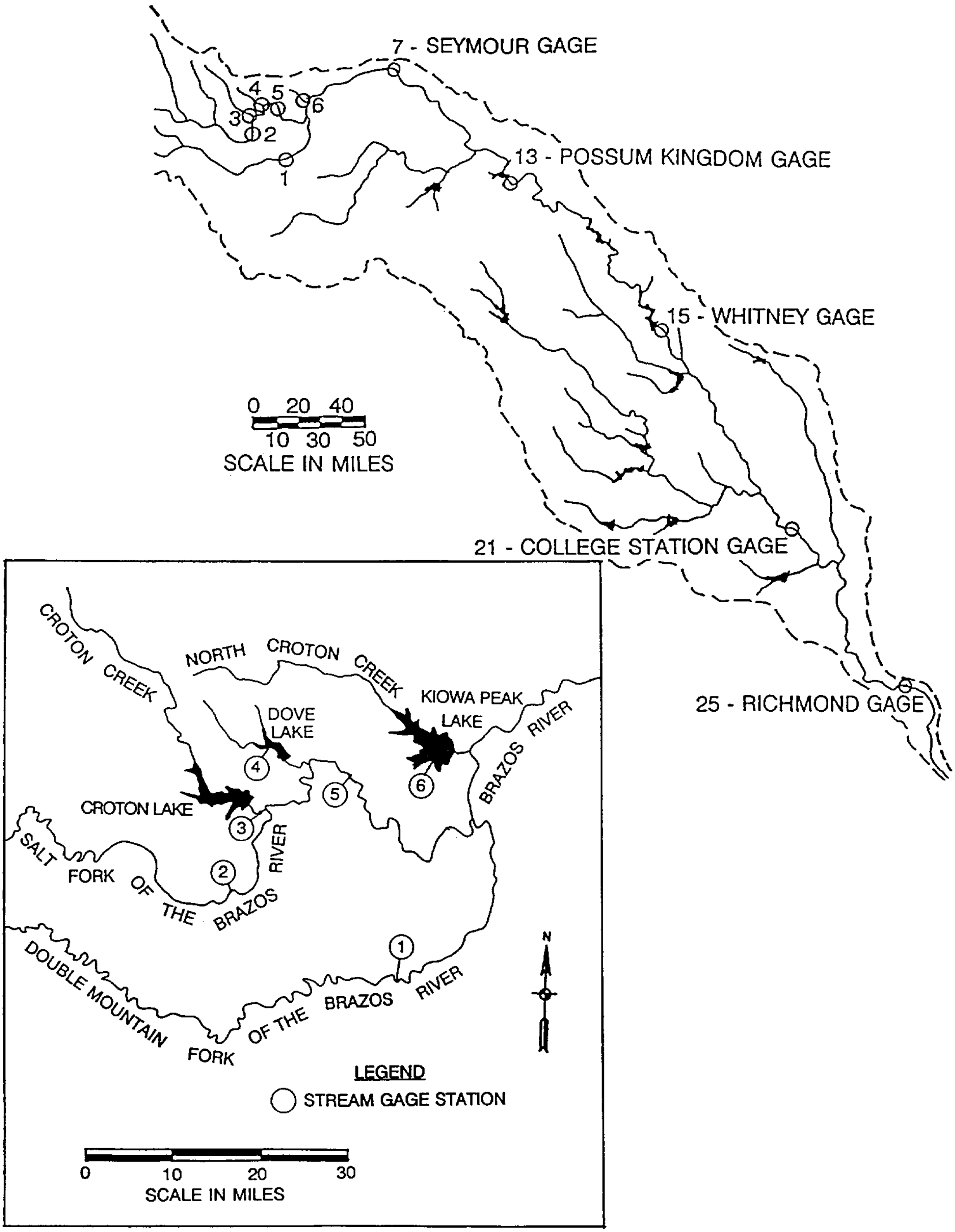

Figure 4.9 Selected Gaging Stations and Salt Control Impoundment Sites

CHAPTER 5
SIMULATION MODEL INPUT DATA

The TAMUWRAP simulation modeling study for the Brazos River Basin is presented in Chapters 5-8. The scope and organization of the simulation study is outlined in Chapter 6. Results are presented in Chapters 7 & 8. The present Chapter 5 describes the basic input data developed for the model. The Water Rights Analysis Program (WRAP) input files include the following types of data:

- water rights, including diversion, storage, priority, and related information,
- monthly water use distribution factors,
- reservoir storage versus area relationships,
- reservoir evaporation rates,
- streamflows, and
- salt loads.

The spatial or locational configuration of the river/reservoir/water-use system is represented in the model by the set of selected control points shown on the map of Figure 5.1 and schematic of Figure 5.2. A control point is specified at each of the 12 BRA/USACE reservoirs and at Hubbard Creek Reservoir. Five other control points are located at key stream gaging stations. Each water right diversion, return flow, and reservoir is assigned a control point location. Each control point is assigned sets of streamflows, salt loads, and reservoir evaporation rates.

Input data were developed for an additional control point, the Waco gage (CP-8), which is also included in Figures 5.1-5.2 and several of the tables in this chapter. There are 19 control points with and 18 without the Waco gage being included. The Waco gage control point was removed from the model because significant negative incremental streamflows and salt loads were found to unnecessarily and unrealistically complicate the model. The few relatively small water rights at the Waco gage were aggregated with the Bryan gage control point.

The simulation is based on a monthly computational time interval. The simulation period is from January 1900 through December 1984. Monthly streamflows, salt loads, and evaporation rates for each of the control points are provided for each of the 1,020 months of the 1900-1984 simulation period.

Water Rights

For purposes of the WRAP model, a water right is represented by the following input data: (1) a control point location, (2) annual diversion amount (or hydroelectric energy requirement), (3) reservoir storage capacity, (4) priority number, (5) type of use, and (6) return flow factor and location. A water right may also include multiple-reservoir system operating rules. Many of the water rights have values of zero for the diversion amount, storage capacity, and/or return flow factor. The priority number represents dates. For example, a priority date of August 17, 1949 is inputted as 19490817. A model option allows diversion return flows to reenter the river at a user-specified location during either the same month as the diversion or the following month.

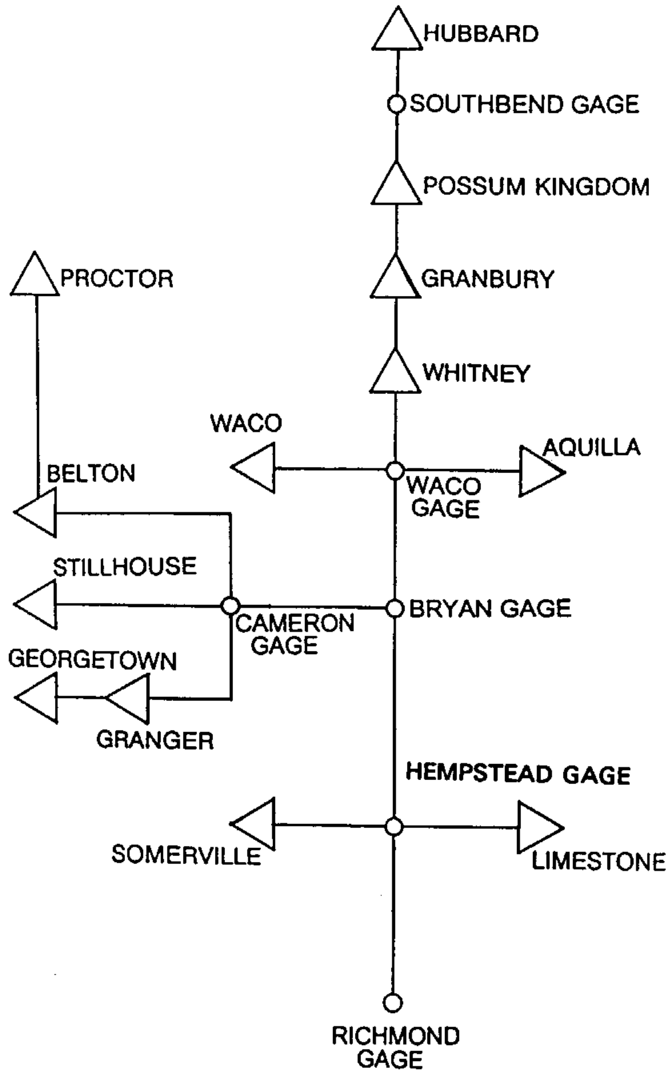

Figure 5.2 System Schematic

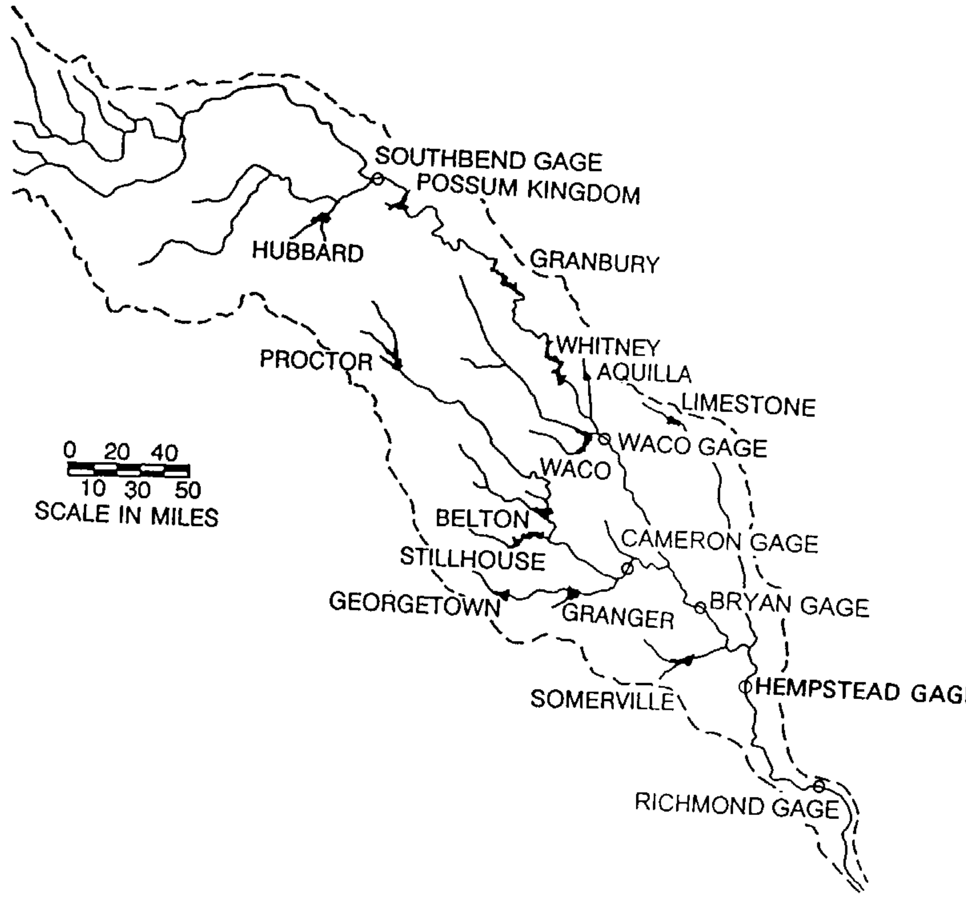

Figure 5.1 Location of Model Control Points

The water rights input file was developed from the previously discussed list of active water rights in the Brazos River Basin, as of May 1993, furnished by the Texas Water Commission (recently renamed the Texas Natural Resource Conservation Commission). The water rights data from this list are summarized in Tables 4.7-4.14. Additional information for the Brazos River Authority (BRA) water rights were obtained from the actual permits.

A water right is represented in the model by a single value of each of the variables cited above. Therefore, a water right which includes three different uses, such as municipal, industrial, and irrigation, is treated as three separate water rights. A single reservoir may have several water rights with different priority dates. Likewise, the diversion amount and storage capacity can be assigned different priorities by treating the right as two separate rights, one with zero storage capacity and the other with a zero diversion. Thus, the model provides considerable flexibility in describing water rights. However, the total number of rights in the model, or in the Texas Natural Resource Conservation Commission (TNRCC) water rights list, may be somewhat misleading since a single appropriator owning a single reservoir may have several rights listed representing different water uses or other variables with multiple values.

Return Flow Factors

A significant portion of the water diverted for beneficial use typically re-enters the river as wastewater treatment plant effluent, irrigation return flows, or other types of return flows. The WRAP model allows a portion of diversions, computed based on inputted return flow factors, to contribute to available streamflow at specified control point locations. A return flow factor is the fraction of a diversion which is returned to the stream. The actual water rights permits for the Brazos River Basin do not include return flow specifications. However, estimates were included in the WRAP model. Return flow factors developed by the Texas Water Commission (TWC) and incorporated in an earlier TWC water availability model were also adopted in the study documented by Wurbs, Bergman, Carriere, and Walls (1988) and used again in the present study. The TWC developed the return flow factors from reported measured return flows and diversions. The factors vary with location in the basin (TWC subwatershed) and type of water use. Measured data were not available for many of the subwatersheds and, thus, return flow factors were not assigned. In the present study, zero return flows were assumed for rights located in any subwatershed for which the TWC did not determine return flow factors. In the present study, diverted flows are returned at the next downstream control point during the following month.

Aggregation of Water Rights to Selected Control Points

Water rights diversions and reservoir storage actually occur at numerous locations throughout the basin. To simplify the modeling study, the basin representation was limited to 19 selected control points, which were later reduced to 18 control points. Each of the over 1,200 water rights was assigned to one of the 19 control point locations. (Several of the BRA diversion rights were divided between more than one control point.) The water rights associated with a control point includes all rights located between the control point and the next upstream control point(s). The most upstream control points on the Brazos River and each tributary include all water rights above the control point. As previously discussed, the water rights initially assigned to the Waco gage control point (CP-8) were later reassigned to the Bryan gage control point (CP-15), and CP-8 was omitted from the model.

The total permitted diversion and storage for the water rights at each control point are tabulated in Table 5.1. The return flows from the diversions at each control point, assuming no diversion shortages, are also included in the table. The return flows are listed with the control points at which the diversion occurs rather than the location where the return flow reenters the stream. Since the Richmond gage is the most downstream control point in the model, the return flows from diversions at the Richmond gage do not affect available streamflows downstream and thus have no impact on the simulation. Note that the diversions assigned to the control points at each of the 13 selected major reservoirs include upstream diversions as well as diversions from the reservoir. Likewise, the tabulated storage capacity includes upstream reservoirs.

Special Considerations in Modeling Reservoir Storage Rights

As discussed in Chapter 2, the handling of priorities associated with refilling reservoir storage is not clearly defined in the present Texas water rights system. In the model, 17 selected major reservoirs were allowed to refill to 80% of capacity with the priorities associated with the water rights. The remaining 20% of the storage capacity was allowed to refill with a priority junior to all diversions in the basin. Thus, a junior diversion right may be shorted if necessary to refill a senior reservoir up to 80% of capacity. The junior diversion is not shorted to refill the senior reservoir above 80% capacity. The 17 reservoirs for which this rule was adopted in the model are Hubbard Creek, Fort Phantom Hill, Graham, Stamford, Palo Pinto, and White River Reservoirs, and all the BRA/USACE reservoirs except Whitney. As discussed later in this chapter, 22% of the active conservation capacity of Whitney Reservoir is filled with the priority associated with a water supply right, and the remaining storage capacity is refilled with a hydropower right which is junior to all diversion rights. These 17 reservoirs are the largest water supply reservoirs in the basin and, combined with Whitney, account for most of the total basin storage capacity. All other reservoirs are refilled totally with the priorities associated with the water rights.

The water rights data incorporated in the model input are based on the TNRCC list discussed in the preceding Chapter 4 but reflect some changes. The TNRCC water rights data were modified in several cases to more realistically model the reservoirs. The differences between the TNRCC water rights data and the model input data are as follows.

- Table 4.4 includes a comparison of the initial or resurveyed storage capacity for 13 principal reservoirs and the corresponding storage in the water rights. The initial or resurveyed storage capacities are included in the model. These are the same as the water rights except for two reservoirs. The storage capacities of Possum Kingdom and Belton Reservoirs have been updated by sediment surveys performed since the water rights were granted. Thus, the capacities in the model are less than in the water rights permit by the amount of the measured sediment accumulation.

- Unlike the other rights, the Waco Reservoir right permit does not include the sediment reserve, but the model does.

Table 5.1
DIVERSIONS, RETURN FLOWS, AND STORAGE BY CONTROL POINT

Control Point	Diversion (ac-ft/yr)	Return Flow (ac-ft/yr)	Storage (ac-ft)
1. Hubbard Creek Reservoir	61,596	16,354	371,022
2. South Bend Gage	196,800	24,150	473,762
3. Possum Kingdom Reservoir	174,162	14,029	623,820
4. Granbury Reservoir	86,930	44,216	214,713
5. Whitney Reservoir	68,855	56,114	910,551
6. Aquilla Reservoir	6,811	3,588	52,450
7. Waco Reservoir	69,339	31,197	166,309
9. Proctor Reservoir	39,896	4,129	102,648
10. Belton Reservoir	199,819	118,021	455,942
11. Stillhouse Hollow Reservoir	47,911	17,583	236,678
12. Georgetown Reservoir	13,775	5,444	37,250
13. Granger Reservoir	12,733	4,568	65,534
14. Cameron Gage	32,706	5,223	3,585
15. Bryan Gage	111,182	41,555	78,050
16. Somerville Reservoir	26,376	13,926	176,136
17. Limestone Reservoir	52,989	44,852	242,722
18. Hempstead Gage	105,544	61,644	97,623
19. Richmond Gage	976,822	603,060	91,177
Total	2,284,246	1,109,653	4,399,972

Notes:

1. Diversions assigned to a control point include all diversions located between that control point and the next upstream control point(s). Thus, diversions assigned to a reservoir control point include diversions located upstream as well as diversions from the reservoir.

2. Return flows are from the diversions assigned to the indicated control points assuming no shortages. Return flows are cited at the control points of the diversions rather than at the control point at which diverted flows reenter the stream.

3. The return flows from diversions at the Richmond gage, totalling 585,155 ac-ft/yr, are not available for further diversion.

- The rights associated with the proposed Bosque Reservoir project, which has not yet been constructed, and the associated proposed storage reallocation in Waco Reservoir were omitted from the model.

- The Department of Army right for use of Belton Reservoir to supply water for Fort Hood is treated in the model as a diversion of 12,000 ac-ft/yr with the 12,000 acre-feet storage capacity considered to be part of the overall BRA storage capacity.

- The model includes the entire 627,100 acre-feet conservation capacity of Whitney Reservoir rather than the 50,000 acre-feet of capacity which has actually been permitted.

- Several of the BRA reservoirs are modeled with inactive as well as active conservation pools.

Whitney Water Supply and Hydroelectric Energy Generation

In TAMUWRAP, water rights include hydroelectric energy generation as well as diverting and/or storing water. However, in reality, the hydroelectric power plants at Possum Kingdom and Whitney Reservoirs are actually operated without priority water rights. Hydroelectric power generation at Possum Kingdom Reservoir is largely incidental to water supply, with flows through the turbines being limited primarily to downstream water supply releases. Therefore, power generation at Possum Kingdom was not included in the WRAP model. The only hydroelectric power right included in the WRAP model is at Whitney Reservoir.

The active conservation pool in Whitney Reservoir is shared by municipal water supply and hydroelectric energy generation. The rules incorporated in the model to represent the Whitney rights are illustrated in Figure 5.3. No releases are made from the 379,100 ac-ft inactive pool. The Brazos River Authority holds a right to divert 18,336 ac-ft/yr from Whitney for municipal water supply, with a relatively junior priority date of 1982. This water right includes a storage capacity of 50,000 ac-ft. The BRA has contracted with the USACE for 22.017% of the active conservation pool to supply the diversion. A right is included in the model, with a 1982 priority, to divert 18,336 ac-ft/yr and replenish storage to a cumulative capacity of 429,100 ac-ft. The hydroelectric power right refills the total storage capacity of 627,100 ac-ft. The Whitney hydropower right is treated, in the model, as being junior to all diversion rights in the basin. It is treated as being senior to refilling the upper 20% of the storage capacity of the major reservoirs discussed above. The releases through the turbines contribute to available streamflow at downstream control points during the next month.

The model limits the water available to the hydropower right. Hydroelectric energy is generated only with releases from the Whitney active conservation pool and unappropriated flows. Streamflows passed through Whitney Reservoir and diverted at other downstream locations are not allowed, in the model, to contribute to hydroelectric power generation.

The Whitney hydroelectric power right incorporated in the model is based upon the contract between the Southwestern Power Administration and Brazos Electric Power Cooperative. The contract provides for annual energy of 1,200 kilowatt-hours per kilowatt of

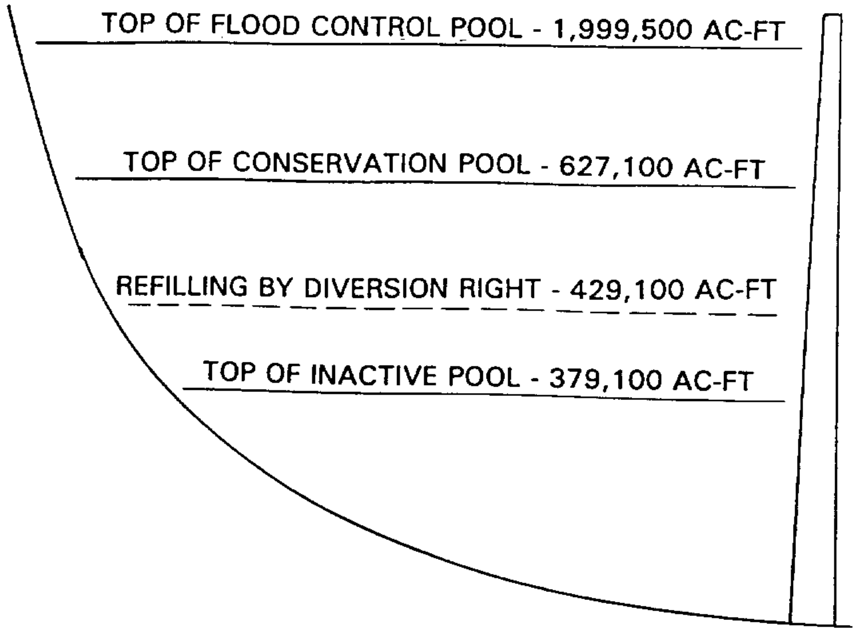

Figure 5.3 Whitney Reservoir Storage Allocation

Figure 5.4 Seven Reservoirs Which Release for the System Diversions at the Richmond Gage Control Point

peaking power, with the energy not to exceed 200 kilowatt-hours per kilowatt in any one month or 600 kilowatt-hours per kilowatt during four consecutive months. Whitney provides 30,000 kilowatts of peaking power. The monthly energy demands incorporated in the model are 6,000,000 kilowatt-hours in July and August, 2,000,000 kilowatt-hours in June and September, and 2,225,000 kilowatt-hours in each of the eight other months. This totals to 36 gigawatt-hours/year. The hydropower input data also includes: an efficiency factor of 0.86; constant tailwater elevation of 440 feet; and a storage versus reservoir surface elevation table.

Brazos River Authority System Rights

As discussed in Chapter 4, the Brazos River Authority water rights have been amended to allow flexibility in operating multiple reservoirs for multiple uses. The BRA rights are associated with individual reservoirs. The total amount of water diverted in any year can not exceed the summation of the individual reservoir diversion rights. However, flexibility is provided for shifting between types of water use and between reservoirs. An excess flows permit also allows diversion of unregulated flows in the lower reach of the Brazos River in lieu of reservoir releases as long as other water rights are not adversely affected. These provisions of the BRA water rights are reflected in the model input data.

The permitted diversions and storage capacities associated with the 12 BRA reservoirs are shown in Tables 4.12, 4.13, and 5.2. The City of Waco holds the water rights for Waco Reservoir. Waco Reservoir is committed totally to supplying water for the City of Waco and adjoining communities. The BRA holds almost all of the water rights associated with the other eleven reservoirs. The BRA diversion rights associated with the eleven reservoirs total to 661,901 ac-ft/yr. The water may be withdrawn from the reservoirs as lake-side diversions or may be released to the rivers for diversion at downstream locations. As indicated by Table 4.13, the permits provide significant flexibility in regard to types of water use.

The BRA has executed contractual commitments to supply water to various entities under these rights. As indicated by Table 4.15, the BRA water supply commitments, as of June 1993, are 576,700 ac-ft/yr. Thus, 87% of the BRA total diversion rights of 661,901 ac-ft/yr is committed to various water users. The remaining 13% allows the BRA to sell water to additional customers in the future. The diversion targets incorporated in the model represent water rights rather than contractual commitments or actual water use in any particular year.

In developing the water rights input data for the model, diversion locations and types of water use for the BRA diversion rights were assigned in proportion to the existing commitments. The annual diversion targets incorporated in the model are tabulated in Table 5.2. The diversion of 171,545 ac-ft/yr at the Richmond gage is 25.92% of the total BRA diversion rights of 661,901 ac-ft/yr. This approximate and somewhat judgmental division of diversions between locations is based on the system commitments in Table 4.15 being 25.92% of the total BRA commitments. Based on existing commitments, the following seven reservoirs were selected for operation as a multiple-reservoir system in the model to release for the Richmond gage diversion: Possum Kingdom, Granbury, Aquilla, Stillhouse Hollow, Granger, Somerville, and Limestone. In order to simulate the BRA excess flows permit, the Richmond gage diversion is treated as being junior to all other diversion rights in the basin and is supplied by yet unappropriated flows, if available, supplemented by releases from the seven reservoirs as

Table 5.2
STORAGE CAPACITIES AND DIVERSIONS FOR BRAZOS RIVER AUTHORITY RESERVOIRS

Reservoir	Cumulative Storage		Diversion	Diversion Target in Model				
	Inactive (ac-ft)	Conservation (ac-ft)	Right (ac-ft/yr)	Total (ac-ft/yr)	Municipal (ac-ft/yr)	Industrial (ac-ft/yr)	Irrigation (ac-ft/yr)	Mining (ac-ft/yr)
Possum Kingdom	0	570,240	230,750	153,200	6,480	146,673	-	47
Granbury	52,500	153,490	64,712	54,936	3,466	51,470	-	-
Whitney	379,100	627,100	18,336	18,336	17,769	567	-	-
Aquilla	0	52,400	13,896	6,770	6,770	-	-	-
Waco	580	152,500	59,100	59,100	58,200	-	900	-
Proctor	70	59,400	19,658	19,658	5,259	-	14,399	-
Belton	11	447,490	100,257	100,257	42,760	57,497	-	-
Stillhouse	780	235,700	67,768	39,530	39,028	502	-	-
Georgetown	238	37,100	13,610	13,610	13,610	-	-	-
Granger	222	65,500	19,840	10,962	10,962	-	-	-
Somerville	220	160,100	48,000	26,257	26,231	26	-	-
Limestone	0	225,440	65,074	46,840	234	46,606	-	-
Richmond Gage	-	-	-	171,545	34,309	137,236	-	-
Total	433,721	2,786,460	721,001	721,001	265,078	440,577	15,299	47

Note: In the model, the diversions at the Richmond gage control point are met by unappropriated flows, if available, supplemented as necessary by releases from the following seven reservoirs: Possum Kingdom, Granbury, Aquilla, Stillhouse Hollow, Granger, Somerville, and Limestone.

needed. The diversions at the seven reservoir control points were determined by reducing the diversion rights in amounts which total to the 171,545 ac-ft/yr assigned to the Richmond gage. The 171,545 ac-ft/yr reduction in diversions was apportioned to the seven reservoirs in proportion to active conservation storage capacity, subject to having at least the present (Table 4.15) water supply commitment diverted at each reservoir.

The reservoirs which release for the BRA system diversions at the Richmond gage control point are shown in Figure 5.4. Multiple-reservoir release decisions in each month of the simulation are based on balancing the percent full (or percent depleted) of the active conservation storage capacity in each reservoir. In inputting the multiple-reservoir release specifications, the active conservation pool in each reservoir is treated as a single zone, and all seven reservoirs are weighted equally.

As indicated in Table 4.13, the BRA permits allow considerable flexibility in regard to type of water use. In the model, the diversions associated with each water use type must sum to the total permitted diversion amount. Judgement had to be applied in dividing the diversion rights between types of water use. Based on a review of the BRA contractual commitments, the committed water amounts were somewhat judgmentally divided between use type. The water rights diversions were then divided by type of use in the same proportions as the water supply commitments. The model diversion targets are shown in Table 5.2 by use type. The model uses the designated type of water use to assign the appropriate set of 12 monthly distribution factors and also to assign the appropriate set of inputted maximum allowable concentrations for each salt constituent.

Monthly Water Use Distribution Factors

A water right includes an annual diversion rate which is distributed by the model to the 12 months of the year using inputted monthly factors for each type of water use. Monthly water use distribution factors have been developed by the former Texas Department of Water Resources for the upper, middle, and lower Brazos River Basin for municipal, industrial, irrigation, and mining uses. Wurbs, Bergman, Carriere, and Walls (1988) averaged the TDWR factors for the upper, middle, and lower basin to obtain the basinwide factors tabulated in Table 5.3, which were also adopted for the present study.

Reservoir Storage Versus Area Relationships

A storage volume versus water surface area relationship is required for each reservoir, since evaporation volumes are computed as a function of area. An elevation versus storage relationship is required for determining head in the hydroelectric power computations. Data compiled by Wurbs, Bergman, Carriere, and Walls (1988) were used again in the present study. Elevation versus storage and area tables for the 12 USACE/BRA reservoirs were provided from the files of the USACE Fort Worth District and Brazos River Authority. Storage versus area tables for 23 other major reservoirs were developed from curves included in Texas Water Development Board (1973) Report 126. A single generalized storage versus area relationship was developed for all the other smaller reservoirs by averaging storage versus area curves for nine of the smallest reservoirs in the Brazos River Basin included in Texas Water Development Board (1973) Report 126.

Table 5.3
MONTHLY WATER USE DISTRIBUTION FACTORS

Month	Type of Use			
	Municipal	Industrial	Irrigation	Mining
Jan	0.070	0.070	0.000	0.080
Feb	0.060	0.070	0.010	0.080
Mar	0.070	0.070	0.060	0.080
Apr	0.070	0.080	0.060	0.080
May	0.080	0.090	0.130	0.080
Jun	0.100	0.100	0.220	0.090
Jul	0.130	0.100	0.230	0.090
Aug	0.120	0.100	0.150	0.090
Sep	0.090	0.080	0.060	0.090
Oct	0.080	0.080	0.080	0.080
Nov	0.060	0.080	0.000	0.080
Dec	0.070	0.080	0.000	0.080
Total	1.000	1.000	1.000	1.000

Reservoir Evaporation Rates

The reservoir evaporation rate input data previously compiled by Wurbs, Bergman, Carriere, and Walls (1988) were used again in the present study. The net reservoir evaporation rates are from a data base maintained by the Texas Water Development Board and described by Kane (1967). The data base includes both gross and net reservoir surface evaporation rates. Net evaporation is the gross evaporation loss rate minus the effective rainfall rate, which is rainfall over the reservoir site less the amount of runoff under pre-project conditions. The monthly data extends back to January 1940 and were used directly for the 1940-1984 portion of the WRAP simulation period. For the 1900-1939 portion of the simulation period, 1940-84 averages for each of the 12 months of the year were used. The data is available on a one-degree quadrangle basis. For reservoirs extending across quadrangle boundaries, the evaporation rates for adjacent quadrangles were averaged. The 1940-1984 means of the net reservoir evaporation at each control point are tabulated in Table 5.4.

Naturalized Monthly Streamflows

Homogeneous time series of natural streamflow data are a fundamental requirement for a reservoir/river system simulation study. The streamflow input data should reflect the stochastic characteristics of the natural hydrologic cycle. However, the streamflow data should represent constant conditions of watershed development. Significant nonhomogeneities may be caused by human activities such as constructing reservoirs and using water. Consequently, gaged streamflow data is adjusted to remove significant man-induced effects. Naturalized or unregulated streamflows representing undeveloped watershed conditions are inputted to WRAP.

Table 5.4
MEAN NET RESERVOIR EVAPORATION RATES

Control Point	Mean Net Reservoir Evaporation Rates (Inches/Month) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual (In/Yr)
1. Hubbard Creek	1.38	1.68	3.18	3.00	2.88	5.88	8.46	8.82	6.06	4.26	3.30	2.16	51.06
2. South Bend Gage	1.38	1.68	3.18	3.00	2.88	5.88	8.46	8.82	6.06	4.26	3.30	2.16	51.06
3. P.K. Reservoir	1.20	1.32	2.88	2.64	2.64	5.88	8.52	8.88	6.00	4.20	3.12	2.04	49.32
4. Granbury Res.	0.72	0.72	2.16	1.32	1.80	4.92	7.92	8.16	5.64	3.84	2.28	1.32	40.80
5. Whitney Res.	0.78	0.72	2.04	1.26	1.74	4.68	7.68	7.98	5.40	3.72	2.22	1.26	39.48
6. Aquilla Reservoir	0.78	0.72	2.04	1.26	1.74	4.68	7.68	7.98	5.40	3.72	2.22	1.26	39.48
7. Waco Reservior	0.84	0.72	1.92	1.20	1.68	4.44	7.44	7.80	5.16	3.60	2.16	1.20	38.16
8. Waco Gage	0.84	0.72	1.92	1.20	1.68	4.44	7.44	7.80	5.16	3.60	2.16	1.20	38.16
9. Proctor Reservoir	1.26	1.32	2.82	2.46	2.58	5.52	8.34	8.58	5.76	4.14	2.88	1.98	47.64
10. Belton Reservoir	0.84	0.72	1.92	1.20	1.68	4.44	7.44	7.80	5.16	3.60	2.16	1.20	38.16
11. Stillhouse H. Res.	0.66	0.54	1.86	1.20	1.80	4.20	7.08	7.32	4.44	3.24	1.80	0.90	35.04
12. Georgetown Res.	0.48	0.36	1.80	1.20	1.92	3.96	6.72	6.84	3.72	2.88	1.44	0.60	31.92
13. Granger Res.	0.48	0.36	1.80	1.20	1.92	3.96	6.72	6.84	3.72	2.88	1.44	0.60	31.92
14. Cameron Gage	0.48	0.36	1.80	1.20	1.92	3.96	6.72	6.84	3.72	2.88	1.44	0.60	31.92
15. Bryan Gage	0.12	0.00	1.08	0.60	1.32	3.36	5.52	5.52	3.12	2.52	0.96	0.24	24.36
16. Somerville Res.	0.12	0.00	1.08	0.60	1.32	3.36	5.52	5.52	3.12	2.52	0.96	0.24	24.36
17. Limestone Res.	0.36	0.36	1.44	0.72	1.08	3.60	6.24	6.36	4.20	3.24	1.68	0.72	30.00
18. Hempstead Gage	0.12	0.00	1.08	0.60	1.32	3.36	5.52	5.52	3.12	2.52	0.96	0.24	24.36
19. Richmond Gage	0.12	0.00	1.08	0.60	1.32	3.36	5.52	5.52	3.12	2.52	0.96	0.24	24.36

The naturalized (unregulated) monthly streamflows documented by Wurbs, Bergman, Carriere, and Walls (1988) were also used in the present study. This naturalized streamflow data set includes streamflows for 1940-1976 developed by the Texas Water Commission and data covering 1900-1939 and 1977-1984 developed at Texas A&M University by Wurbs, Bergman, Carriere, and Walls (1988). The naturalized monthly streamflows were developed by adjusting gaged flows to remove nonhomogeneities caused by the activities of man in the basin. The Texas Water Commission 1940-76 naturalized streamflows include adjustments for water use diversions, return flows, and Soil Conservation Service flood retarding structures, as well as for the numerous major reservoirs. The Texas A&M University data for 1900-39 and 1977-84 include adjustments for 21 major reservoirs and limited diversions. Most of the gaging stations do not have records extending back to January 1900. Records were extended and gaps filled by regression analyses using the MOSS-IV Monthly Streamflow Simulation computer program available from the Texas Water Development Board. Streamflows measured at the gages listed in Table 5.5 were used to develop the naturalized streamflow input data set. Several gaging stations listed in Table 5.5 were not adopted as model control points but were used in the MOSS-IV regression analyses to fill in missing data at other gages.

In most cases, the control points used to represent the reservoir/river system coincide with the stream gaging stations. The exceptions are the Limestone and Aquilla control points for which the flows at the gage are multiplied by a drainage area ratio (control point area / gage area) to obtain flows at the control point. At the Limestone Reservoir control point, a drainage area ratio of 0.697 is used to transfer the data from the downstream gage to the dam site. A drainage area ratio of 0.818 is used for the Aquilla Reservoir control point.

The 1940-1976 naturalized streamflow data developed by the Texas Water Commission is summarized in Table 5.6. Mean annual flow is tabulated both in acre-feet/year and as an equivalent depth in inches over the watershed above the gage, as estimated by Wurbs, Bergman, Carriere, and Walls (1988). The extreme low and high annual flows are also shown. The gage number refers to the map numbers assigned in Texas Department of Water Resources Report 244 (Dougherty 1980). Table 5.7 illustrates the seasonality of the naturalized flows with a tabulation of monthly means at three stations expressed as a percentage of annual means.

The 1900-1984 means of the naturalized monthly streamflows incorporated in the WRAP input file are included in Table 5.10. The mean of the 1,020 monthly naturalized streamflows in the WRAP input file for the Richmond gage control point is 472,287 ac-ft/month.

Unregulated Monthly Salt Loads

The WRAPSALT input file includes total dissolved solids (TDS), chloride (Cl), and sulfate (SO_4) loads for each month of the 1900-1984 simulation period for each of the control points. Wurbs, Karama, Saleh, and Ganze (1993) document development of the unregulated salt loads.

Although U.S. Geological Survey (USGS) water quality monitoring activities in the Brazos River Basin date back to the early 1900s, the sampling program was significantly expanded from 1964 through 1986 in support of the U.S. Army Corps of Engineers (USACE) natural salt pollution control studies. Ganze and Wurbs (1989) document a compilation and

Table 5.5
STREAMFLOW GAGES

Gage	Gage Number	Report 244 Map Number	Stream	Near City	Drainage Area (sq mile)	Record Began
1	08086500	367	Hubbard	Breckenridge	1,089	May 55
2	08088000	369	Brazos	South Bend	22,673	Oct 38
3	08089000	376	Brazos	Palo Pinto	23,811	Jan 24
4	08090800	379	Brazos	Dennis	25,237	May 68
5	08091000	381	Brazos	Glen Rose	25,818	Oct 23
6	08093100	387	Brazos	Aquilla	27,244	Oct 38
7	08093500	389	Aquilla	Aquilla	308	Jan 39
8	08095000	394	Bosque	Clifton	968	Oct 23
9	08095600	400	Bosque	Waco	1,656	Sep 59*
10	08096500	401	Brazos	Waco	29,573	Oct 98
11	08099500	412	Leon	Hasse	1,261	Jan 39
12	08102500	418	Leon	Belton	3,542	Oct 23
13	08104000	422	Lampasas	Youngsport	1,240	Nov 24
14	08104100	424	Lampasas	Belton	1,321	Feb 63
15	08104700	426	Gabriel	Georgetown	248	Jul 68
16	08105700	431	Gabriel	Laneport	738	Aug 65
17	08106500	434	Little	Cameron	7,065	Nov 16
18	08109000	439	Brazos	Bryan	39,515	Aug 99*
19	08110000	443	Yequa	Somerville	1,009	Jun 24
20	08110500	448	Navasota	Easterly	968	Apr 24
21	08111000	449	Navasota	Bryan	1,454	Jan 51
22	08111500	452	Brazos	Hempstead	43,880	Oct 38
23	08114000	456	Brazos	Richmond	45,007	Jan 03*

*Note: Gages 9, 18, and 23 have missing records during the periods Oct 81-Feb 82 (gage 9); Jan 03-Feb 18 and Jan 26-June 26 (gage 18); and Jul 06-Sep 22 (gage 23).

Table 5.6
NATURALIZED ANNUAL STREAMFLOW DATA
TWC Naturalized Streamflow (1940-1976)

Reservoir (R) or Gage (G)	Gage Number	Mean Annual Flow: inches	Mean Annual Flow: acre-feet	Annual Extremes (ac-ft): Low	Annual Extremes (ac-ft): High	Year: Low	Year: High
Hubbard R	367	1.69	98,310	698	385,340	1952	1941
South Bend G	369	0.59	711,940	55,080	3,267,090	1952	1941
Possum Kingdom R	376	0.68	861,520	69,200	3,686,376	1952	1957
Granbury R	381	0.85	1,166,340	134,000	4,783,570	1952	1957
Whitney R	387	1.21	1,755,920	370,320	6,475,600	1952	1957
Aquilla R	389	5.27	86,620	4,140	213,110	1963	1968
Clifton G	394	2.87	148,200	11,540	503,240	1954	1941
Waco R	400	3.89	343,140	29,620	1,130,140	1963	1941
Waco G	401	1.23	1,933,700	434,410	6,726,270	1952	1957
Proctor R	412	1.71	114,800	22,540	400,140	1948	1941
Belton R	418	2.74	518,150	21,810	1,531,590	1954	1941
Stillhouse R	424	3.57	251,240	17,710	672,770	1951	1968
Georgetown R	426	4.95	65,470	-0-	134,310	1956	1941
Granger R	431	4.44	174,980	2,000	446,820	1956	1957
Cameron G	434	3.53	1,328,640	98,450	3,384,820	1954	1957
Bryan G	439	1.90	4,006,580	787,590	11,779,920	1956	1957
Somerville R	443	4.15	223,060	10,010	549,420	1951	1968
Limestone R	448	6.19	319,440	8,790	677,230	1963	1976
Hempstead G	452	2.28	5,343,580	929,800	13,942,180	1956	1957
Richmond G	456	2.67	6,400,580	898,580	14,984,780	1956	1957

Table 5.7
MEAN MONTHLY STREAMFLOW AS A PERCENT OF ANNUAL MEAN
TWC Naturalized Streamflow (1940-1976)

Average Monthly Streamflow as a Percentage of Mean Annual Streamflow

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Brazos River at Waco (gage 401)											
4.5	5.8	6.2	12.3	24.5	11.8	6.6	3.7	6.8	9.1	4.9	3.9
Little River at Cameron (gage 434)											
8.2	9.3	9.0	12.5	20.0	9.4	5.2	2.1	4.2	7.4	5.9	6.7
Brazos River at Richmond (gage 456)											
7.6	8.2	8.2	10.9	20.3	10.8	5.8	2.8	4.8	6.8	6.3	7.5

analysis of available salinity data conducted for the USACE. These data were used in the investigation documented by Wurbs, Karama, Saleh, and Ganze (1993) to develop unregulated salt concentrations which were also used in the present simulation study. The unregulated concentrations were combined with the naturalized streamflows described above to compute salt loads.

Monthly salt (TDS, Cl, SO_4) concentrations from measurements at selected sampling stations, collected from 1964 through 1986, were used to develop the unregulated salt loads for each of the control points for each month of the 1900-1984 simulation period. Computational tasks involved in developing the salinity data set for stations on the main stream Brazos River included: (1) regression analysis to fill in gaps in the measured records; (2) adjustments to remove the effects of storage and evaporation in Hubbard Creek, Possum Kingdom, Granbury, and Whitney Reservoirs; and (3) development of discharge versus salt load regression equations to be used in synthesizing monthly salt loads for the period 1900-1963 (Wurbs, Karama, Saleh, Ganze 1993). For the better quality (lesser salinity) tributaries, long-term mean salt concentrations, adjusted to remove the effects of evaporation at selected major reservoirs, were used to compute salt loads. Many of the model control points are at streamflow gage locations which also served as water quality sampling stations, but measured salinity data were not available at some of the control points. Salt loads were developed, as necessary, by adjusting data at nearby locations.

The 1964-1984 mean regulated discharges, loads, and concentrations shown in Table 5.8 are based on field measurements and have not been adjusted to remove the effects of reservoirs. The corresponding 1964-84 means in Table 5.9 have been adjusted to remove the storage and evaporation effects of Hubbard Creek, Possum Kingdom, Granbury, and Whitney Reservoirs. The 1900-1984 means of the unregulated discharges, loads, and concentrations incorporated in the model are shown in Table 5.10.

The salinity data set adopted for the simulation study reported here represents the expected value of salt loads for given discharges. The salt loads represent the expected or most likely loads for each month for the given discharges. Since the unregulated discharges and salt loads are highly correlated, the corresponding unregulated concentrations are relatively constant. The variance of the unregulated concentrations are unrealistically low even though the corresponding loads and flows are realistic. In addition to this data set, Wurbs, Karama, and Saleh (1993) developed an alternative set of unregulated salt loads, which incorporates a random component which reflects those variations in loads and concentrations which are independent of discharge. The objective of this alternative data set is to more realistically represent the variation in concentrations. The addition of a random component to the salt loads still maintains the same 1900-1984 mean loads and concentrations but greatly increases the variance of the concentrations. Wurbs, Karama, and Saleh (1993) present the results of simulations using the two alternative sets of unregulated salt loads. The alternative input data sets yield very similar simulation results, at least from the perspective of summary statistics such as reliabilities, long-term mean concentrations, and water and load balances. Thus, only the "expected value" set of unregulated salt loads is used in the present simulation study.

Another alternative set of unregulated salt loads was used by Wurbs, Karama, and Saleh (1993) and again in the present simulation study to evaluate the impacts of the salt control

Table 5.8
MEAN REGULATED DISCHARGES, LOADS AND CONCENTRATIONS (1964-1984)

TR-160 Station	Discharge (ac-ft/month)	Load (tons/month) TDS	Cl	SO_4	Concentration (mg/l) TDS	Cl	SO_4
10	2,640	1,590	604	211	442	168	59
11	17,700	18,300	6,030	4,260	759	250	177
12	38,500	100,500	41,500	20,900	1,921	793	399
13	41,400	82,900	34,300	16,900	1,472	610	301
14	56,600	94,400	38,000	18,800	1,226	493	245
15	75,500	92,900	34,000	17,800	904	332	173
18	137,000	113,000	33,900	21,500	606	182	115
21	265,000	157,000	40,000	27,500	436	111	76
25	417,000	191,000	44,400	31,200	337	78	55

Table 5.9
MEAN UNREGULATED DISCHARGES, LOADS AND CONCENTRATIONS (1964-1984)

TR-160 Station	Discharge (ac-ft/month)	Load (tons/month) TDS	Cl	SO_4	Concentration (mg/l) TDS	Cl	SO_4
10	7,770	1,590	604	211	151	57	20
11	22,900	18,300	6,030	4,260	589	194	137
12	43,600	100,500	41,500	20,900	1,695	700	352
13	52,900	82,800	34,300	16,900	1,151	477	235
14	68,200	94,400	38,000	18,900	1,018	410	203
15	94,900	92,900	34,000	17,900	720	264	138
18	156,000	116,000	34,700	22,100	531	159	101
21	285,000	157,000	40,000	27,500	406	104	71
25	436,000	191,000	44,400	31,200	322	75	53

Stations

10 Hubbard Creek below Hubbard Creek Dam
11 Clear Fork near Eliasville
12 Brazos River near Southbend
13 Brazos River below Possum Kingdom Dam
14 Brazos River near Dennis
15 Brazos River below Whitney Dam
18 Brazos River near Highbank
21 Brazos River near College Station
25 Brazos River near Richmond

Source: Wurbs, Karama, Saleh, Ganze (1993)

Table 5.10

MEANS OF THE UNREGULATED DISCHARGES, LOADS, AND CONCENTRATIONS INCORPORATED IN THE MODEL (1900-1984)

Control Point	Discharge	Load (Tons/Month)			Concentration (mg/l)		
	(ac-ft/month)	TDS	CL	SO4	TDS	CL	SO4
1. Hubbard Creek Res.	9,498	1,943	739	258	150	57	20
2. South Bend Gage	61,506	119,538	48,091	24,764	1,429	575	296
3. Possum Kingdom	74,472	121,764	50,498	25,047	1,202	499	247
4. Granbury Reserv.	97,050	138,239	55,974	27,516	1,047	424	209
5. Whitney Reser.	138,290	131,640	49,384	25,817	700	262	137
6. Aquilla Reservoir	6,094	2,047	116	587	247	14	71
7. Waco Reservoir	27,227	5,220	626	603	141	17	16
8. Waco Gage	156,529	108,570	30,934	21,386	510	145	100
9. Proctor Reservoir	9,597	1,664	218	162	127	17	12
10. Belton Reservoir	38,976	6,758	886	658	127	17	12
11. Stillhouse Hollow	18,374	3,186	418	310	127	17	12
12. Georgetown Res.	5,403	1,037	124	120	141	17	16
13. Granger Res.	14,920	2,862	342	332	141	17	16
14. Cameron Gage	107,225	20,570	2,459	2,384	141	17	16
15. Bryan Gage	324,453	170,263	41,110	29,860	386	93	68
16. Somerville Res.	19,518	2,598	647	448	98	24	17
17. Limestone Res.	18,411	3,280	550	325	131	22	13
18. Hempstead Gage	436,057	184,112	42,096	30,972	311	71	52.2
19. Richmond Gage	472,287	197,965	43,082	32,083	308	67	50

impoundments previously proposed by the Corps of Engineers. This input data set reflects removal of all salt loads and discharges at the sites of the proposed salt control dams, which are shown as stations 3, 4, and 6 in Figure 4.9. The flows and loads for the main-stem Brazos River control points were adjusted using the 1964-1984 means at the salt control dam sites. Discharges and loads, reflecting the upstream salt impoundments, were developed by multiplying the unregulated flows and loads of the basic (without salt dams) data set by the factors tabulated in Table 5.11, which were determined as follows:

$$\text{multiplier factor} = 1\ (M_{scds} \ / \ M_{cp})$$

where M_{scds} denotes the sum of the 1964-84 mean loads or discharges at the three salt control dam sites (scds) and M_{cp} denotes the mean at the downstream control point (cp). The mean total dissolved solids (TDS) concentrations with and without the salt control impoundments are shown in Table 5.12.

Table 5.11
DISCHARGE AND LOAD MULTIPLIERS REPRESENTING
THE EFFECTS OF THE SALT CONTROL IMPOUNDMENTS

Control Point	Station Number	Discharge Multiplier	Load Multipliers		
			TDS	Chloride	Sulfate
salt dams	3,4,6	0.000	0.000	0.000	0.000
2 Southbend gage	12	0.960	0.767	0.704	0.852
3 Possum Kingdom	13	0.967	0.664	0.563	0.788
4 Granbury Res	14	0.975	0.720	0.624	0.818
5 Whitney Res	15	0.982	0.723	0.593	0.813
8 Waco Gage	18	0.985	0.649	0.335	0.766
15 Bryan Gage	21	0.993	0.796	0.575	0.850
18 Hempstead Gage	--	0.994	0.811	0.590	0.857
19 Richmond Gage	25	0.995	0.825	0.604	0.863

Table 5.12
MEAN UNREGULATED TDS CONCENTRATIONS
WITH AND WITHOUT THE SALT CONTROL IMPOUNDMENTS

Control Point	Station Number	Concentration (mg/l)			
		Without Dams		With Dams	
		1900-84	1964-84	1900-84	1964-84
2 Southbend Gage	12	1,429	2,087	1,149	1,695
3 Possum Kingdom	13	1,203	1,178	838	832
4 Granbury Res	14	1,048	1,075	778	812
5 Whitney Res	15	700	767	518	577
8 Waco Gage	18	510	517	339	352
15 Bryan Gage	21	386	425	311	346
19 Richmond Gage	25	308	332	257	279

CHAPTER 6
SCOPE OF THE BRAZOS RIVER BASIN SIMULATION STUDY

Water availability in the Brazos River Basin is investigated using the TAMUWRAP model. Development of the model input data is discussed in the preceding Chapter 5. The scope of the simulation modeling study is outlined in the present Chapter 6. Results are presented in Chapters 7 and 8.

Objectives

The objectives of the simulation modeling study of the Brazos River Basin are to:

- develop, test, and demonstrate the generalized modeling capabilities of the TAMUWRAP Water Rights Analysis Package,
- investigate basic river basin management strategies and associated modeling approaches, and
- perform a comprehensive water availability study for the Brazos River Basin.

Thus, the research objective is to expand water management and associated modeling capabilities in general as well as to develop a better understanding of the particular case study river basin. The computer programs, modeling and analysis approaches, and reservoir/river system management plans addressed are applicable to other river basins as well as the Brazos.

The water availability assessment of the Brazos River Basin includes evaluation of the:

- water supply capabilities of both the overall river basin and, in particular, the BRA/USACE reservoir system,
- impacts of salinity on water supply capabilities,
- effectiveness of alternative reservoir/river system management strategies in improving water supply capabilities, and
- sensitivity of reliability estimates to modeling assumptions and premises.

The Simulation Model

The spatial configuration of the river/reservoir/rights system is represented by the 18 control points shown by the map of Figure 6.1 and schematic of Figure 6.2. The simulation modeling exercises are based on combining a specified water use scenario and operating plan with historical natural hydrology. The model quantifies reservoir/river system capabilities for meeting the specified annual water demands during inputted sequences of naturalized streamflows and salt loads. The water use scenario is based on the premise that all water users divert and/or store the full amounts authorized by their water rights permits as long as sufficient quantities of

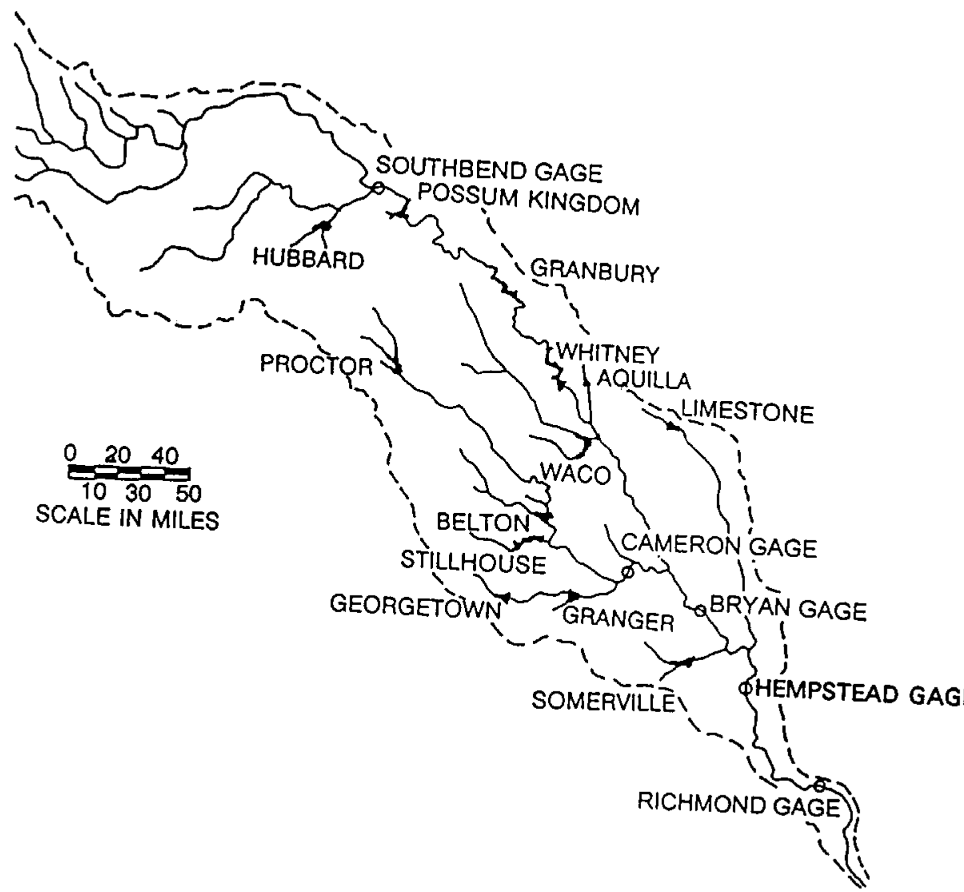

Figure 6.1 Control Points Adopted for the Model

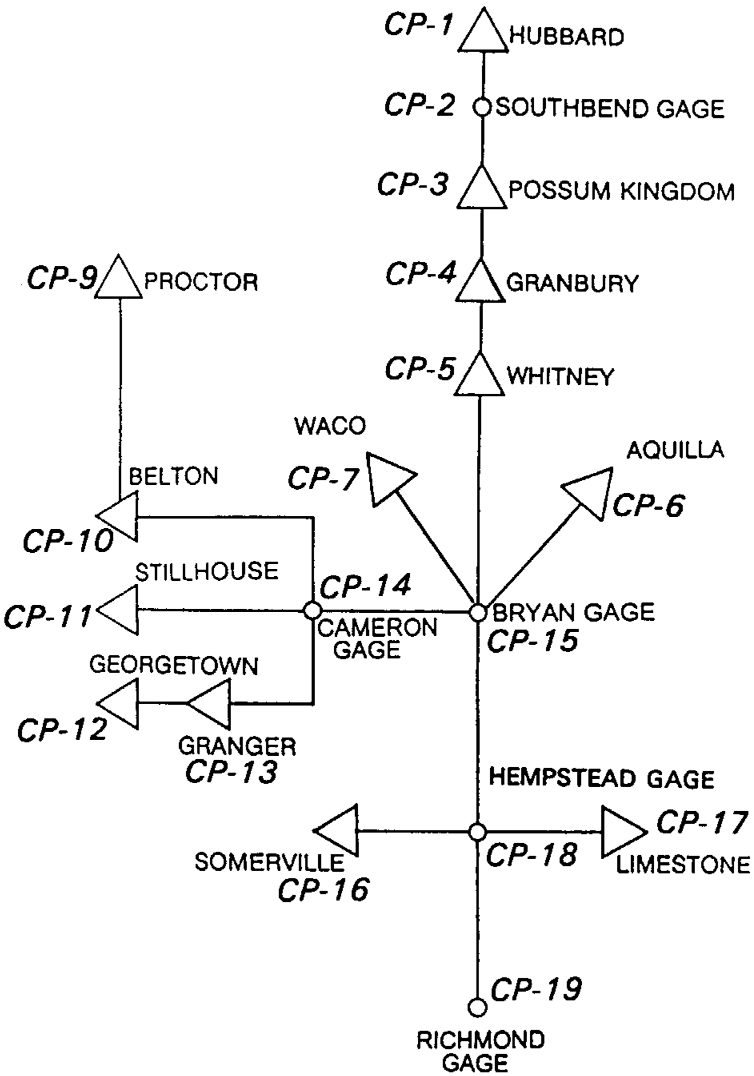

Figure 6.2 System Schematic

suitable quality water are available. The annual water use demands vary over the 12 months of the year but are constant from year to year in the simulation. These currently permitted water demands are repeated continuously for each year of a 1900-1984 hydrologic simulation period using a monthly computational time interval.

WRAP2, WRAP3, WRAPSALT, and TABLES were all run in the study. The results obtained with the common features of the alternative models were compared as a check of model validity. However, WRAPSALT and TABLES provide comprehensive capabilities to perform all of the simulations presented in this report. Much of the computer work was performed on the Texas A&M University Academic Computing Services (ACS) VAXcluster which runs under the VMS operating system. MicroSoft Disk Operating System (MS-DOS) based microcomputers were also used in the study.

Modeling Assumptions and Premises

A simulation model is a simplified representation of a real-world system. Simulation is the process of experimenting with a simulation model to investigate the response of the system to alternative conditions. All models incorporate assumptions and simplifications and are never perfect reproductions of the real world. Several of the fundamental assumptions or premises incorporated into the Water Rights Analysis Program (WRAP) model of the Brazos River Basin are summarized below.

- A specified set of water demands and system operating rules is combined with a set of time sequences of hydrologic variables (streamflows, net reservoir evaporation rates, and salt loads). The annual water demands (diversion and hydroelectric energy targets) are assumed constant from year to year but vary during the 12 months of the year. The demand targets are the same in both wet years and dry years. Diversion shortages in the model represent emergency water reductions to be achieved by demand management as well as failures to meet water needs.

- The water demands in the model are based on water rights. All water rights holders are assumed to use the full amounts of water to which they are legally entitled by their permits. However, in reality, water users have used only a portion of the amounts specified in their permits. Of course, some unknown illegal water use may also occur. Actual water use has historically been much less than the water rights. Therefore, the water demands in the model are conservatively high from the perspective of actual present water use.

- Multiple-reservoir release decisions and other day-to-day operating decisions are complex involving many factors, are flexible, are based largely on judgement, and will vary over time. The operating rules incorporated in the model represent long-term averages based on reasonable criteria such as balancing storage in multiple reservoirs.

- The numerous water rights are aggregated to 18 selected control point locations at which unregulated streamflows and salt loads are provided as input data. Each water right has access to the yet unappropriated streamflows at its assigned control point.

- Capabilities for meeting water demands in the future, not the past, is of concern. However, future streamflows and other hydrologic variables are unknown. Historical hydrology is used as a representation of general characteristics expected to continue in the future. Since streamflows, evaporation rates, and salt loads are highly variable and random, the sequences used in the model will never actually be repeated in the future.

- The streamflows, evaporation rates, and salt loads are estimates of historical hydrology unaffected by river regulation and water use. The model input is based on historical measurements, with inherent gaging inaccuracies, but required significant computational manipulations, with associated approximations, to remove nonhomogeneities and to extend record lengths and reconstitute missing data.

- Salinity computations are based on the assumptions that the salts are conservative and that the salts are instantaneously and uniformly mixed in reservoirs and river reaches. The conservative salt constituents undergo no chemical, biological, or physical transformations. Mass is conserved. Reservoir evapoaration removes water but not salt. Diversions remove both water and salt.

- Acceptable levels of salinity for various types of water use depend on many factors and are difficult to precisely define. No attempt is made in this study to establish appropriate maximum allowable salt concentrations for various types of water use. Rather the study simply tests the sensitivity of simulation results to an assumed range of hypothetical allowable concentrations.

Organization of the Simulation Study and this Report

The results of the simulation modeling study are presented in Chapters 7 and 8. The study involved numerous executions of the TAMUWRAP model. The results of a single base scenario simulation are presented in Chapter 7. The results of over 75 simulation runs are presented in Chapter 8. The alternative simulation runs reflect selected changes made to the base scenario model input file to investigate particular modeling assumptions and river basin management approaches. Thus, Chapter 7 provides a detailed analysis of a base scenario represented by a single run of the model. Chapter 8 is a comparative evaluation of alternative reservoir/river system management strategies and modeling assumptions, which is based on numerous runs of the model.

The base scenario simulation of Chapter 7 represents the existing water rights and reservoir system operating policies, without explicitly incorporating salinity constraints in the model. In this base run, the water rights are modeled as described in Chapter 5. Chapter 8 addresses several key issues or aspects of reservoir/river system management and associated water availability modeling as noted below.

- Maximum allowable salt concentration limits for various types of water use are difficult to precisely define. A range of maximum allowable salt concentrations are specified in the alternative model runs of Chapter 8 to demonstrate the sensitivity of reliabilities and other system characteristics to salinity constraints.

- The Brazos River Authority operates multiple reservoirs as an integrated system and also holds an excess flows permit. The advantages of system operations involving multiple-reservoirs and unregulated flows are analyzed.

- The simulation study deals primarily with existing water rights. However, the impacts on reliabilities of adding a hypothetical additional major new diversion right at the Richmond gage control point is also examined.

- The priority of reservoir storage rights, relative to diversion rights, is not necessarily precisely defined in the water rights permitting system. The simulation study also demonstrates the importance of storage rights.

- The impacts of return flows on water availability and system reliabilities are evaluated.

- The salt pollution control studies previously conducted by the Corps of Engineers involved a proposed plan for constructing salt control dams. The impacts of the salt control impoundments on water supply reliabilities are evaluated.

- Yield versus reliability relationships, including firm yields, for a multiple reservoir system diversion from the lower Brazos River are also presented in Chapter 8.

Glossary

Definitions of selected terms used in discussing the simulation modeling study are provided in Table 6.1. The terms are defined in the glossary from the perspective of their usage in this report.

Table 6.1

GLOSSARY

Water Rights Analysis Package (TAMUWRAP) Computer Programs

TAMUWRAP - The generalized simulation modeling package is presently composed of six computer programs: WRAP2, WRAP3, WRAPNET, WRAPSALT, and TABLES. WRAPSALT and TABLES provide comprehensive capabilities to perform all of the analyses documented in this report.

WRAP - The alternative versions of the Water Rights Analysis Program (WRAPSALT, WRAP2, WRAP3, and WRAPNET) simulate a river basin stream/reservoir/use system. WRAP3 is an expanded version of WRAP2. WRAPSALT is an expanded version of WRAP3 with salinity features added.

TABLES - This computer program develops tables and data listings from WRAP input and output files which organize and summarize the simulation results.

Streamflow and Salinity Data

control point - a modeling mechanism for representing the location of streamflows, salt loads, reservoirs, diversions, return flows, and other system features.

hydrologic simulation period - unregulated sequences of monthly flows and loads are provided in the WRAP input file, and the simulation computations performed for the 1,020-month 1900-1984 period-of-analysis.

salt - Salinity is expressed in terms of monthly loads (tons/month) and mean concentrations (mg/l) of total dissolved solids (TDS), chlorides (Cl), and sulfates (SO_4). Chloride and sulfate are two constituents of the total dissolved solids.

salt constraint - Diversion shortages occur if the concentration of available streamflow or storage exceed the maximum allowable concentration specified for that type of water use.

naturalized or unregulated streamflows - Historical gaged monthly flows adjusted to remove the impacts of reservoir construction, water use, and other activities of man in the river basin are provided as WRAP input data.

unregulated salt loads - Historical monthly salt loads adjusted to remove the impact of reservoir regulation are provided as WRAP input data.

regulated flows and loads - Computed regulated streamflows and salt loads reflect the effects of all the reservoirs, diversions, and other water management activities represented in the simulation model.

incremental flows and loads - An incremental streamflow or salt load is the difference between total flows or loads at adjacent control points and represent the flow or load entering the river between the control points.

streamflow depletions - WRAP computed streamflow depletions are the streamflow amounts appropriated to meet water rights diversions and/or refill reservoir storage capacity. Streamflow depletions are associated with a particular water right.

unappropriated streamflows - WRAP computed unappropriated flows, associated with a particular control point, are the portions of the naturalized streamflows still remaining after the streamflow depletions are made for all the water rights in the simulation.

Table 6.1 Continued

GLOSSARY

Water Rights

water right - A water right consists of a permitted annual water diversion amount (or permitted annual hydroelectric energy amount), a permitted storage capacity which can be refilled in a reservoir, control point location, and priority number, along with associated data such as type of water use (which identifies the monthly use factors and allowable salt concentrations), return flow specifications, and various data (including operating rules) for multiple reservoirs which can make releases to satisfy the permitted diversion, hydropower, and reservoir storage targets.

permitted diversion - the target amount of water to be appropriated from streamflow at a control point location and reservoir storage at the same or other locations. Monthly permitted diversion amounts are inputted as an annual diversion amount and water use type, which has an associated set of 12 monthly distribution factors.

actual diversion - permitted diversion target limited by water availability.

shortage - permitted diversion minus actual diversion.

return flow - An amount of water computed as the actual diversion multiplied by an inputted return flow factor is returned to the stream system at a user-specified control point in either the same month as the diversion or the next month.

priority - a numerical value included in the input data for a water right indicating the relative seniority of the right. The inputted priority numbers will typically represent prior appropriation dates but could represent any other type of priority indicator. In each period of the simulation, water rights are considered in turn and available water appropriated in order of the priorities.

senior or junior rights - A water right is senior or junior relative to another water right depending on the priority number included in the input data for each right. A senior right has the highest priority, which is represented by the smallest priority number (earliest date or other priority indicator), and is considered first in the computations.

active and inactive conservation storage - WRAP includes both inactive and active conservation pools but does not model flood control storage. Releases are made from the active conservation storage to meet diversion and hydroelectric energy requirements. The inactive pool can be drawn down only by evaporation.

storage zones - The active conservation pool can be divided into two zones for purposes of defining release rules for multiple reservoirs supplying a common diversion. Release decisions are based on balancing the storage, as a percentage of zone capacity, in each reservoir. Releases are not made from zone 2 of any system reservoir until zone 1 of each of the other reservoirs is empty.

Reliability

period reliability - the percentage of the 1,020 months (periods) in the overall 1900-1984 simulation period-of-analysis during which a specified permitted diversion target (or hydroelectric energy target) is met without shortage.

volume reliability - the total volume of actual diversions (or total firm hydroelectric energy generated) during the simulation period-of-analysis expressed as a percentage of the corresponding total permitted diversion or hydroelectric energy targets.

CHAPTER 7
SIMULATION RESULTS FOR THE BASE SCENARIO

The base scenario represents existing water rights and operating policies, without explicitly incorporating salinity considerations in operating decisions. The simulation results for the base scenario model run are summarized in the set of tables provided at the end of this chapter. These tables were developed by the program TABLES from WRAPSALT input and output data files.

Reservoir/River System Operating Policy for the Base Run

The following operating rules are reflected in the base scenario simulation of the Brazos River Basin. These reservoir/river system operating policies are also discussed in Chapter 5.

- The permitted water rights diversions summarized in Table 5.1 are met as long as sufficient streamflow and/or storage are available.

- The Brazos River Authority system diversions at the Richmond gage control point are met by unappropriated streamflows supplemented as necessary by releases from Possum Kingdom, Granbury, Aquilla, Stillhouse Hollow, Granger, Somerville, and Limestone Reservoirs. Multiple-reservoir release decisions are based on balancing the percent depletion of active conservation pools of the seven system reservoirs. As a representation of the excess flows permit, the BRA system diversion is treated as being junior to all other diversions in the basin and is met by yet unappropriated flows supplemented by reservoir releases as needed. The final 100% capacity refilling of the reservoirs, noted below, has a priority which is junior to the BRA system diversion.

- The BRA/USACE reservoirs (except for Whitney) and six other major reservoirs are refilled to 80% of their conservation storage capacity with the priorities associated with the water rights, and then to 100% capacity with priorities junior to all diversion rights in the basin. As illustrated by Figure 5.3, storage in Whitney Reservoir is partially refilled by a water supply right and then refilled to capacity by a hydropower right.

- Hydroelectric power releases, and storage refilling, at Whitney Reservoir are junior to all diversions. The sources supplying hydropower releases are limited to unappropriated flows and storage in the Whitney active power pool. Neither hydropower releases nor water supply diversions are allowed from Whitney Reservoir any time the storage falls below the top of inactive pool (bottom of active power pool). Releases through the turbines contribute to available streamflow at downstream control point locations during the next month following the release.

- Water supply diversions are not constrained by specification of maximum allowable salt concentrations.

Basin Water Balance

An annual summary of water quantities for the entire river basin is tabulated in Table 7.1. An annual summary for the Richmond gage control point (CP-19) is provided in Table 7.2. A water balance for the river basin for a particular month, year, or the entire 1900-84 simulation period can be expressed as follows.

storage change = naturalized streamflows + return flows - evaporation
- diversions - unappropriated streamflows

where the naturalized and unappropriated flows are cumulative totals at the Richmond gage (CP-19) and all other terms represent summations for all of the control point locations. Tables 7.1-7.2 are tabulations of annual quantities in acre-feet/year. The storage change during the year is the difference in the end-of-period (EOP) storage for that year and the preceding year. In addition to the terms in the above water balance equation, Tables 7.1-7.2 include streamflow depletions, which are the amounts of streamflow appropriated to refill reservoir storage, meet evaporation requirements, supply diversions, and generate hydroelectric power. Basin-total streamflow depletions are related to naturalized and unappropriated streamflows as follows.

unappropriated flows = naturalized flows + return flows + hydropower
releases - streamflow depletions

Diversions and shortages are also tabulated and are related as follows.

shortage = permitted diversion - actual diversion

Permitted diversions are included in the input data, and the model computes actual diversions and shortages each month for each diversion right. Permitted and actual energy and associated energy shortages for hydroelectric power rights are handled similarly. The water balance equations for the entire basin noted above are not valid for the Richmond gage quantities in Table 7.2 because the naturalized streamflows supply streamflow depletions at upstream control points as well as at this particular location.

The Richmond gage (CP-19) is the most downstream control point in the model. Thus, naturalized flows at the Richmond gage represent flows to the Gulf of Mexico assuming no reservoirs, diversions, or other human activities in the basin. The unappropriated flows at the Richmond gage represent flows to the Gulf of Mexico assuming all the water use and regulation activities reflected in the model. Flows at the Richmond gage are cumulative basin totals. The annual naturalized and unappropriated streamflows in Table 7.1 are the summation of the maximum monthly flows occurring at any control point. In some months, the maximum naturalized flows do not necessarily occur at the Richmond gage. Thus, the naturalized streamflows in Tables 7.1 and 7.2 are not the same in some years. However, the unappropriated flows are always maximum at the Richmond gage, and the fifth columns of Tables 7.1 and 7.2 are identical. The other quantities in Table 7.1 are the sums of the values for all the control points in the model. The corresponding values in Table 7.2 are associated with only the Richmond gage control point (CP-19).

The basinwide water balance for the entire 1900-1984 simulation period involves the 1900-84 means which are cited below in units of acre-feet/year. Annual values for the years 1956 and 1957 are also listed below and discussed in subsequent paragraphs. The tabulation below illustrates the relative magnitude of the various quantities involved in the simulation.

	1900-84 mean	1956	1957
naturalized streamflow	5,667,400	929,200	14,983,300
return flow	472,900	412,200	437,800
storage change	-18,100	-1,027,000	2,955,000
evaporation	593,700	631,300	409,825
diversion	2,131,600	1,733,200	2,177,600
unappropriated flow	3,433,100	3,900	9,852,500

The 1900-1984 means, in ac-ft/yr, are related by the previously discussed water balance equation.

storage change = naturalized streamflows + return flows - evaporation - diversions - unappropriated streamflows

-18,100 = 5,667,400 + 472,900 - 593,700 - 2,131,100 - 3,433,100

The most severe drought during the 1900-84 simulation period occurred during the period 1950-1957 and ended with one of the largest floods of record in April-May 1957. As indicated by Table 7.1, during the 1900-1984 hydrologic simulation period, 1956 is the driest year with the smallest naturalized streamflows and greatest diversion shortages. Interestingly, the following year, 1957, has the highest naturalized streamflow of the 85 years. The annual water balances for 1956 and 1957 involve the quantities from Table 7.1 which are also reproduced in the tabulation above. The naturalized streamflows for 1956 provided in the WRAPSALT input data total 929,191 acre-feet at the Richmond gage (Table 7.2). The 1956 unappropriated streamflows remaining after simulating all the water rights are 3,860 acre-feet, all of which, as indicated in Table 7.6, occur in February. The monthly distributions of the annual naturalized and unappropriated flows are shown in Tables 7.3 and 7.6, respectively. In the model, from the end of December 1955 to the end of December 1956, the total amount of water in storage in the 592 reservoirs in the basin had a net decrease of 1,026,973 ac-ft, from 2,394,324 ac-ft to 1,367,351 ac-ft. For comparison, the total inactive storage capacity is 433,721 ac-ft, and the total cumulative inactive plus active conservation storage capacity is 4,399,972 ac-ft in the 592 reservoirs. Thus, the 1,367,351 ac-ft in storage at the end of December 1956 represents 31% of the active conservation storage capacity of the basin. The evaporation from the 592 reservoirs during 1956 is 631,255 ac-ft. Actual diversions of 1,733,223 ac-ft are 76% of the permitted diversions of 2,284,246 ac-ft. Return flows totalling 412,174 ac-ft contribute to available streamflow.

The quantities shown in Table 7.1 vary greatly from month to month and from year to year throughout the simulation period. The years 1956 and 1957 represent extreme drought and flood conditions, rather than more normal or average hydrologic conditions, and thus are illustrative of particularly extreme variations. For example, the 1957 naturalized streamflows of 14,983,300 ac-ft are 16 times the 1956 flows of 929,200 ac-ft. The 1957 unappropriated flows of 9,852,500 ac-ft are 2,552 times the 1956 unappropriated flows of 3,860 ac-ft. The

1956 and 1957 diversions are 187% and 15%, respectively, of the naturalized streamflows. Reservoir storage is greatly drawn down in 1956 and largely refilled in 1957.

Naturalized and Unappropriated Streamflows

Naturalized or unregulated streamflows are included in the WRAPSALT input data for each of the 1,020 months of the 1900-84 simulation period for each of the 18 control points. As discussed in Chapter 5, the naturalized flows are based on historical measured flows adjusted to remove the effects of reservoir regulation and other human activities. The unappropriated flows computed by WRAPSALT for each control point are the portions of the naturalized flows still remaining after appropriations are made for all the water rights. Streamflow depletions are the portions of the naturalized flows used to meet diversion and hydroelectric energy generation requirements and refill reservoir storage. Available streamflow at a control point is decreased by streamflow depletions and increased by return flows and instream flows from hydropower releases. The unappropriated flow for a given month is the available streamflow still remaining after all the water rights have been simulated. At the Richmond gage, the most downstream control point in the model, the naturalized and unappropriated flows represent total basin flows before and after the simulation computations. Also, since the Richmond gage is the basin outlet, regulated and unappropriated flows are the same and represent instream flows to the Gulf of Mexico. In general, the regulated or actual flows computed at a control point may include flows appropriated for downstream diverters as well as unappropriated flows. Thus, unappropriated and regulated flows are not necessarily the same at locations other than the most downstream control point (basin outlet).

Naturalized and unappropriated flows at three selected control points are reproduced in Tables 7.3-7.8. Naturalized flows at the Richmond gage and Granbury Reservoir on the Brazos River and at the Cameron gage on the Little River are tabulated in Tables 7.3-7.5, respectively. The corresponding unappropriated flows at these locations are provided in Tables 7.6-7.8. As noted above, the annual totals of the monthly naturalized and unappropriated flows at the Richmond gage are also included in Table 7.2.

Shortages and Reliabilities

Diversion shortages occur in the model for any right in any month for which insufficient streamflow and/or storage is available to meet the permitted diversion target in full. A shortage is the permitted minus actual diversion amount. Total shortages for each month associated with all the water rights diversions assigned to the Richmond gage control point are shown in Table 7.9. Table 7.10 presents a concise summary of the frequency and magnitude of shortages at each control point. The sum of the inputted permitted annual diversion amounts and computed mean annual shortages for all the diversion rights assigned to each control point are tabulated. For example, the permitted diversions and corresponding mean shortages at the Richmond gage control point (CP-19) are 976,822 and 24,125 acre-feet/year, respectively. The period and volume reliabilities and shortage frequency tables are also shown.

As discussed in Chapter 3, volume reliability is the percentage of the permitted diversion volume that is actually diverted in the simulation. For diversions at the Richmond gage (CP-19), the volume reliability (R_v) is:

R_v = ((976,822-24,125)/976,822)*100% = 97.53%

The basin totals can be obtained by summing the control point totals from Table 7.10. The volume reliability for the sum of all the permitted diversions for the entire river basin is:

R_v = ((2,284,246-152,653)/2,284,246)*100% = 93.32%

for total permitted diversion targets of 2,284,246 ac-ft/yr and mean annual shortages of 152,653 ac-ft/yr.

As discussed in Chapter 3, period reliability is computed as:

$$R_p = (n/N)*100\%$$

where n denotes the number of months during the simulation for which the demand is fully met and N is the 1,020 months in the 1900-84 simulation. The period reliabilities shown in Table 7.10 are for control points and are based on counting the number of months in the WRAP simulation during which at least one diversion at the control point is partially or fully shorted. For example, for the numerous diversions assigned to the Richmond gage control point (CP-19), Table 7.10 indicates that at least one permitted diversion target was not fully met for 248 months of the simulation. Thus, all diversions were fully supplied during 772 months. The period reliability for the aggregated Richmond gage diversions is as follows.

R_p = ((1,020-248)/1,020)*100% = 75.69%

The number of months (periods) during the 1,020-month simulation for which the shortage volume equalled or exceeded specified percentages of the sum of the permitted diversion targets for the month at the control point are tabulated in Table 7.10. For example, at the Richmond gage (CP-19), at least some shortage occurred in 248 months; shortages equalling or exceeding 5% of the total monthly diversion targets occurred in 147 months; and in 12 of these months the total shortages equalled or exceeded 25% of the permitted diversion targets for the month. Similarly, Table 7.10 shows the number of years during the 85 year simulation for which the annual shortages totalled to amounts equalling or exceeding specified percentages of the annual permitted diversions. Again using the Richmond gage (CP-19) as an example, the permitted annual diversions for the numerous diversion rights assigned to the control point total 976,822 ac-ft/yr. During 7 years of the 85-year simulation, the shortages totalled to at least 97,682 ac-ft (10% of the 976,822 ac-ft/yr permitted diversions).

Table 7.11 has the same format as Table 7.10 but provides information for diversions associated with specified reservoirs. All Brazos River Authority and City of Waco diversion rights associated with the 12 USACE/BRA reservoirs, as tabulated in Table 5.2, are included in Table 7.11. This includes the BRA system diversions at the Richmond gage. Hubbard Creek Reservoir, owned by the West Central Texas Municipal Water District, is also included in Table 7.11. The BRA multiple-reservoir/excess-flows system diversions totalling 171,545 ac-ft/yr at the Richmond gage have period and volume reliabilities of 100.00%. Likewise, the individual-reservoir diversion rights at Possum Kingdom, Waco, Stillhouse Hollow, Georgetown, and Granger Reservoirs have reliabilities of 100.00%. Period and volume reliabilities for diversion rights associated with Granbury, Aquilla, Belton, Somerville, and Limestone Reservoirs range from 96.67% to 99.96%. Diversion rights at Proctor Reservoir have relatively low period and volume reliabilities of 83.33% and 83.71%. The permitted water supply diversions of 18,336 ac-ft/yr from the Whitney Reservoir hydroelectric power pool have low period and volume reliabilities of 69.31% and 70.45%, respectively, because of the hydropower releases.

Period and volume (energy) reliabilities and energy shortage frequency relationships for the hydroelectric power generation at Whitney Reservoir are presented in Table 7.12. The energy target is 36,000 megawatt-hours/year. Mean energy shortages are 12,586 megawatt-hours/year. Thus, the volume (energy) reliability is:

$$R_v = ((36{,}000-12{,}586)/36{,}000)*100\% = 65.04\%$$

The energy reliability computed by the model is conservatively low. As discussed in Chapters 4-5, there actually is no water right for hydroelectric power generation. In the model, water for generating energy is limited to unappropriated flows and releases from the active power pool of Whitney Reservoir. No water appropriated for diversions at downstream locations was allowed, in the model, to generate power even though some of this water can, in reality, be passed through the turbines. The inactive and active conservation pools in Whitney Reservoir have cumulative storage capacities of 379,100 ac-ft and 627,100 ac-ft, respectively. In the model, the BRA municipal and industrial water supply right (Table 5.2), with a very junior 1982 priority, refills 50,000 ac-ft of the active conservation (power) pool to a cumulative storage of 429,100 ac-ft. The priority for refilling to the 627,100 ac-ft capacity is junior to all diversions in the basin. Thus, maintaining storage in Whitney Reservoir and generating hydropower is treated as extremely junior in priority to all the other rights in the basin.

As indicated in Tables 5.2 and 7.10, the diversion rights associated with the 12 BRA/USACE reservoirs total 721,001 ac-ft/yr. Based on the assumptions, premises, and data incorporated in the base scenario simulation, the volume reliability for these diversions is:

$$R_v = ((721{,}001-12{,}836)/721{,}001)*100\% = 98.22\%$$

where the mean shortages from Table 7.11 sum to 12,836 ac-ft/yr for the 12 reservoirs and BRA system diversions. Diversions at Whitney, Proctor, and Belton Reservoirs account for 87% of the diversion shortages associated with the 12-reservoir system. Omitting the permitted diversions and corresponding shortages for these three reservoirs, the aggregate reliability for the nine other BRA/USACE reservoirs is as follows.

$$R_v = ((582{,}750-1{,}608)/582{,}750)*100\% = 99.72\%$$

As discussed above, the volume reliability for the total of all diversions in the basin is 93.32%. The total permitted diversions of 2,284,246 ac-ft/yr include the 721,001 ac-ft/yr associated with the 12 BRA/USACE reservoirs and the remaining 1,563,246 ac-ft/yr total for all the other rights. The volume reliability for the 1,563,246 ac-ft/yr diversion rights not associated with the 12 BRA/USACE reservoirs is:

$$R_v = ((1{,}563{,}246-139{,}817)/1{,}563{,}246)*100\% = 91.06\%$$

Thus, volume reliabilities are 93.32%, 98.22%, and 91.06%, respectively, for the diversion rights associated with the entire river basin, the 12 BRA/USACE reservoirs, and all other basin rights.

Streamflow records are, of course, available only at gaging sites. As discussed in Chapter 5, the numerous water rights in the basin were aggregated to 18 control points located near streamflow gages. Water rights were assigned to the nearest downstream control point. The 12 BRA/USACE reservoirs are located near the gages used to compile the streamflow data. However, many of the other smaller rights are actually located significant distances upstream of the control points adopted for the model. Therefore, the model may allow water rights at remote tributary locations to have access to significantly more water in the model than in reality. The model allows diversion rights which are actually (in reality) located at remote upstream tributary locations to incorrectly take water (in the model) which is actually physically not accessible to them and would otherwise flow into the major reservoirs. This particular modeling simplification should tend to make reliability estimates for the rights not associated with the BRA/USACE reservoirs higher than they would otherwise be. Conversely, this simplification results in the reliability estimates for the diversion rights associated with the 12 BRA/USACE reservoirs being conservatively low.

Flows, Loads, and Concentrations

Unregulated streamflows and salt loads are provided as WRAPSALT input data for each month of the 1,020-month 1900-84 simulation period for each of the 18 control points. These unregulated flows and loads represent natural conditions without reservoirs, diversions, and other human activities. WRAPSALT computes regulated streamflows and loads which reflects the reservoirs, diversions, and related water management activities incorporated in the model. Salt concentrations are loads divided by flows. The salt constituents included in the simulation are total dissolved solids (TDS), chlorides, and sulfates. Chloride and sulfate comprise a large portion of the total dissolved solids in the Brazos River. In the base scenario simulation, maximum allowable concentrations were not specified for limiting diversions. However, salt load balances are maintained, and the concentrations of streamflows and reservoir storage at each control point for each month are determined.

The 1900-1984 means of the unregulated and regulated, respectively, streamflow discharges, loads, and concentrations are tabulated in Tables 7.13 and 7.14 by control point. Table 7.14, for regulated conditions, also includes the mean amount of salt in storage in the 592 reservoirs by control point. Unregulated conditions have no reservoirs. Due to diversions and reservoir evaporation, the regulated flows shown in Table 7.14 are significantly lower than the unregulated flows of Table 7.13. For example, the unregulated and regulated flows at the Richmond gage (CP-19) have means of 472,287 and 286,094 acre-feet/month, respectively. Thus, the regulated flow is 61% of the unregulated flow. Reservoir evaporation increases the concentration of stored water and the corresponding concentrations and loads of the diversions from the reservoirs. Reservoir evaporation removes water but not salt.

As indicated in Tables 7.13 and 7.14, the unregulated and regulated 1900-84 mean TDS loads at the Richmond gage are 197,965 and 86,830 tons/month, respectively. The 1900-1984 mean salt load stored in the 592 reservoirs is 3,370,000 tons, which over the 1,020 months of the simulation is equivalent to a mean monthly load of 3,300 tons/month. The mean unregulated TDS load of 197,965 tons/month, at the Richmond gage control point, represents the salt inflow to the overall river system. The Richmond gage mean regulated TDS load of 86,830 tons/month represents the Brazos River salt load flowing into the Gulf of Mexico. Net diversions account for the difference between the regulated and unregulated salt loads. The change in the salt load stored in the reservoirs between the beginning and end of the 85-year simulation period is negligible compared to the streamflow salt loads over this period. Thus, the salt load inflows to the river system are accounted for as either net water right diversions or flows to the Gulf. Net diversions are diversions minus return flows. The return flows at a control point are assumed to have the same concentrations as the streamflow or reservoir. The net TDS load diversions are distributed among locations as follows. Of the total net diverted TDS load, approximately 68% is at the three upstream Brazos River control points (South Bend, Possum Kingdom, and Granbury); 24% is at the Richmond gage; and the remaining 8% is at the 14 other control points.

Concentrations vary greatly with location. For example, mean regulated TDS concentrations of the Brazos River vary from 1,918 mg/l at the South Bend gage (CP-2) to 223 mg/l at the Richmond gage (CP-19), as compared to 152 mg/l at the Cameron gage (CP-14) on the Little River.

The streamflows vary greatly from month to month. Unregulated and regulated flow-duration relationships for each control point are provided in Tables 7.15 and 7.16. These tables were developed by the program TABLES by counting the number of months during the 1,020-month 1900-84 hydrologic simulation period for which the flow equalled or exceeded specified amounts. The computations were repeated at each control point for both the unregulated flows found in the WRAPSALT input file and the regulated flows found in the WRAPSALT output file. Tables 7.15 and 7.16 show the percentage of time that streamflows at the specified locations equal or exceed various levels. For example, unregulated or naturalized flows at the Richmond gage are tabulated in Table 7.3. The flow-duration relationship of Table 7.15 indicates that these Richmond gage flows are greater than or equal to 18,108 ac-ft/month for 99% of the 1,020 months. The unregulated flow is zero for at least one month and equals or exceeds 258,866 ac-ft/month during 50% of the time. Unappropriated, or regulated, flows at the Richmond gage are tabulated in Table 7.6. Since the Richmond gage represents the basin outlet, unappropriated and regulated streamflows are the same and represent flows to the Gulf of Mexico. However, at the other control points, unappropriated flows are typically less than regulated (actual) flows because a portion of the regulated flow is committed to (appropriated by) downstream water rights. At the Richmond gage, regulated flows are at least 67,473 ac-ft/month during 50% of the time. The regulated flows are generally lower than the unregulated flows since streamflow is loss to diversions and reservoir evaporation. However, in some cases, toward the lower end of the flow range, reservoir releases maintain streamflows at levels higher than the unregulated conditions.

Tables 7.17, 7.18, and 7.19 provide unregulated concentration-duration relationships, for each control point, for total dissolved solids, chloride, and sulfate, respectively. The corresponding concentration-duration curves for regulated conditions are tabulated in Tables 7.20-2.22.

Reservoir Storage

The end-of-month storages, in acre-feet, computed in the WRAPSALT simulation are tabulated in Tables 7.23-7.28 for six selected reservoirs: Possum Kingdom, Whitney, Waco, Proctor, Belton, and Stillhouse Hollow. The tables show, for each reservoir, the storages for each month of the 1,020-month simulation and also the annual means of the monthly storages.

The end-of-month storages of each of the 12 BRA/USACE reservoirs during the period 1950-1957 are shown in Table 7.29, expressed as a percentage of the active conservation storage capacity. The active, inactive, and total conservation capacities, in acre-feet, for the 12 reservoirs are included in Table 7.30. As previously discussed, the most severe drought during the 1900-1984 hydrologic simulation period occurred in 1950-1957. The storages in Table 7.29 are in units of percent of active conservation capacity. In some cases, the percentages are negative, indicating that the active pool is empty and evaporation has encroached into the inactive pool. For example, from Table 7.30, the Proctor Reservoir conservation storage capacity of 59,400 acre-feet, includes active and inactive pools of 59,330 ac-ft and 70 ac-ft, respectively. The inactive pool is 0.12% the size of the active pool. Thus, a Proctor storage of -0.12% in Table 7.29 indicates that the inactive as well as active conservation storage capacity is completely empty. Granbury and Whitney Reservoirs have large inactive pools in the model which are partially depleted in some months by evaporation continuing after the active pools are emptied by diversions and evaporation.

Remember that Table 7.29 summarizes the results of a particular simulation of current water rights and reservoir development, with all the assumptions and premises inherent in the model, during an assumed hypothetical repetition of historical hydrology. These are not actual historical storages. The drought has a very definite ending in April-May 1957 but does not have a clearly defined starting month. As indicated in Table 7.29, in May and June 1950 of the simulation, four of the 12 reservoirs are 100% full. However, Proctor, the most severely depleted reservoir, has already been drawn down to 21.83% in June 1950. Likewise, Whitney Reservoir is at 28.33% capacity at the end of June 1950. Likewise, in June 1950, Possum Kingdom, Granbury, Aquilla, Belton, Stillhouse Hollow, and Limestone have end-of-month storages of 80.00%, 71.59%, 86.51%, 55.67%, 71.70%, and 99.03%, respectively, of their active conservation storage capacity. The other four reservoirs are 100% full. June 1950 is the last time any of the 12 reservoirs are full until May 1957. All 12 reservoirs are 100% full at the end of May 1957. Proctor Reservoir is empty from January 1951 through April 1957. The active power pool in Whitney Reservoir is empty from January 1951 through March 1957. The active conservation storage in Granbury is also empty during several intervals of time during this drought. Aquilla and Belton Reservoirs are also completely depleted for several months at different times. Somerville and Limestone are empty during the one month of January 1957. The other reservoirs were never completely emptied during this drought. Possum Kingdom dropped to a minimum of 1.94% of capacity in June 1953. Georgetown dropped to 2.91% of capacity in February 1957 for this particular simulation. Waco Reservoir was affected least of the 12 reservoirs by the drought. The most severe draw-down in Waco resulted in a storage of 27.78% in March 1955.

Storage-duration relationships for each of the 12 BRA/USACE reservoirs are provided in Table 7.30. The table shows the percentage of the 1,020 months of the simulation for which the end-of-month storage is equal or less than specified levels. Storage levels are expressed as a percentage of the active conservation storage capacity. The active storage capacity in acre-feet is provided at the top of the table. For example, Possum Kingdom has an active capacity of 570,240 ac-ft. The WRAPSALT computed storage was equal or less than 90% capacity for 80% of the 1,020 months. The Possum Kingdom storage is at or below 75% of capacity during 29% of the time. Table 7.30 indicates a sharp drop in duration between 90% and 75% of the storage capacity. This is because, in the model, with the exception of Whitney, the reservoirs are refilled to 80% capacity with the priority associated with the water right and then to 100% capacity with a priority junior to all diversions.

Table Building Capabilities Provided by TABLES

The tables presented in this chapter are developed by program TABLES from WRAPSALT input and output files. The tables illustrate various types of simulation data. WRAP2, WRAP3, or WRAPSALT create a particular output file which contains basic monthly output except for salinity-related data. WRAPSALT creates an additional output file for salt loads. TABLES reads these output files as well as input files and outputs user specified tables. TABLES is simply a collection of subroutines, and each subroutine builds a particular type of tables with various user-specified optional formats. Several of the types of tables are illustrated by Tables 7.1-7.30. Variations to these tables and a number of other types of tables are described in the model users manual (Wurbs, Dunn, Walls 1993). Sanchez-Torres (1994) describes the salinity related tables added to TABLES in conjunction with development of WRAPSALT.

The tables developed by TABLES organizes, tabulates, manipulates, and summarizes the monthly data from WRAP input and output files. TABLES performs simple computations such as sorting data, computing means or annual totals, computing basin totals, developing various frequency tables, and determining volume and period reliabilities. The basic WRAP output file includes the following data for each month, one record per month, for user specified control points, water rights, or reservoirs. Water rights records include diversion target and shortage, evaporation, storage, releases, streamflow depletion, and available streamflow. Control point records include diversion target and shortage, evaporation, storage, streamflow depletion, unappropriated streamflow, return flow, and naturalized streamflow. Reservoir/hydropower output records include storage, evaporation, hydroelectric energy generated and shortages or secondary energy, inflows from streamflow depletions, inflows from releases from other reservoirs, releases accessible to turbines, and releases not accessible to turbines. The WRAPSALT salinity output file includes regulated flows and loads in the streamflow and loads in reservoir storage, for each control point, for each month of the simulation. Salt loads include loads for each constituent. With 1,020 months, 18 control points, 592 reservoirs, and well over 1,000 water rights, the monthly output data records can be extremely voluminous. The WRAP input file includes specification of the control points, reservoirs, and/or water rights for which records are to be included in the output file. TABLES provides the capability to organize and summarize the data in a variety of understandable formats.

Table 7.1
ANNUAL SUMMARY FOR THE RIVER BASIN

YEAR	NATURALIZED STREAMFLOW (ACRE-FEET)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (ACRE-FEET)	UNAPPROPRIATED FLOW (ACRE-FEET)	EOP STORAGE (AC-FT)	EVAPORATION (ACRE-FEET)	PERMITTED DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
1900	12611783.0	437995.8	3338272.8	9182923.0	4311790.0	741873.8	2284246.3	2257650.8	26595.4
1901	1791948.0	493939.7	1951109.8	618400.8	3187547.5	665987.9	2284246.3	2125742.8	158503.6
1902	5073739.0	467142.4	3724609.3	1906799.5	3812318.0	622992.0	2284246.3	2201508.0	82738.2
1903	6296636.0	498986.7	2944054.8	4177859.5	3435759.3	662187.9	2284246.3	2218667.5	65578.8
1904	2565395.0	499200.1	2573498.0	589461.1	3057432.0	579231.2	2284246.3	2169903.3	114343.1
1905	8684288.0	469289.3	3722955.8	5218594.0	3544957.8	645695.1	2284246.3	2185695.0	98551.2
1906	3933204.0	502045.1	3108829.3	1371702.9	3418343.0	635885.1	2284246.3	2219669.8	64576.4
1907	4430559.0	500743.6	3399238.0	1870688.1	3579605.0	604631.5	2284246.3	2232731.0	51515.2
1908	10212888.0	503100.0	3200405.8	7933610.0	3454543.5	666662.6	2284246.3	2230692.0	53554.2
1909	1233724.0	459933.8	1608080.6	5932.7	2501480.5	523351.8	2284246.3	2037181.8	247064.5
1910	1328976.0	426206.4	1593135.8	85687.0	1905995.4	434222.2	2284246.3	1746399.5	537846.8
1911	2239987.0	412388.4	2151463.3	223713.3	1749995.1	372686.3	2284246.3	1934777.9	349468.4
1912	2569606.0	364211.6	1923440.9	910247.4	1555749.6	339834.6	2284246.3	1777851.6	506394.6
1913	7499763.0	377732.7	4261049.0	2783772.0	3478549.5	384796.5	2284246.3	1895897.0	388349.2
1914	13655375.0	492044.3	3611273.5	9307831.0	3812224.3	643084.9	2284246.3	2202171.3	82075.1
1915	11909867.0	501087.3	3680142.8	8518051.0	4070959.3	721203.1	2284246.3	2268156.8	16089.6
1916	5605340.0	499495.7	2566829.3	3822949.0	3366643.0	669278.3	2284246.3	2199092.0	85154.2
1917	1045653.0	450947.8	1417774.5	40056.5	2251765.5	520741.5	2284246.3	2002292.9	281953.4
1918	4112238.0	425776.7	3631928.3	846115.1	3466952.3	439488.3	2284246.3	1921256.4	362989.8
1919	13092624.0	500024.8	4230256.5	8280196.5	4295523.5	703635.0	2284246.3	2275980.5	8265.8
1920	8566448.0	499632.9	3383226.5	5555576.0	4253084.0	732598.9	2284246.3	2268273.5	15972.7
1921	5832389.0	498472.8	2538982.5	3409460.8	3511752.0	681594.5	2284246.3	2223871.8	60374.4
1922	12161224.0	469420.9	2902343.3	10031250.0	3246088.8	641384.7	2284246.3	2212086.0	72160.3
1923	6415546.0	474124.8	3763752.0	3345756.8	3836503.3	604165.4	2284246.3	2197712.8	86533.6
1924	5856225.0	494084.1	2407447.0	4161877.0	3087226.8	620520.9	2284246.3	2180791.8	103454.6
1925	3594955.0	441518.9	2415302.8	1300325.4	3070572.5	516066.4	2284246.3	1915891.3	368355.0
1926	7905227.0	466391.3	4042875.0	4593770.5	3899030.0	632686.0	2284246.3	2228240.5	56005.8
1927	5063423.0	496201.3	2841607.0	3106473.0	3448435.5	643442.6	2284246.3	2205097.5	79148.7
1928	3016934.0	494948.9	2797334.0	822147.2	3213202.3	616685.2	2284246.3	2156243.8	128002.5
1929	6573829.0	471108.0	3227942.8	4052226.5	3225648.0	608702.7	2284246.3	2199404.8	84841.6
1930	6664061.0	498626.3	3950455.3	3413304.8	4015646.8	630525.7	2284246.3	2181667.3	102579.0
1931	4365713.0	496608.9	2512824.8	2417663.0	3352735.3	638113.5	2284246.3	2187212.3	97034.1
1932	8233949.0	472585.1	3961066.5	4858798.0	3934609.8	696096.1	2284246.3	2255814.0	28432.2
1933	2610025.0	498498.3	2516721.5	777550.8	3240958.0	659223.9	2284246.3	2171440.8	112805.4
1934	3741574.0	448122.0	2288886.3	2077706.5	2738755.5	549017.9	2284246.3	2022975.6	261270.6
1935	8941629.0	464327.3	4532720.0	4994392.0	4064594.5	661897.1	2284246.3	2224616.0	59630.2
1936	7387410.0	499231.4	3317216.8	4512551.5	4044746.8	666920.9	2284246.3	2237058.5	47187.8
1937	3640327.0	492696.7	2491366.0	1891074.4	3384146.8	622283.7	2284246.3	2159039.8	125206.5
1938	6557723.0	501504.8	3369584.0	3874637.0	3399409.5	667123.4	2284246.3	2249926.3	34319.9
1939	2163808.0	486871.2	2359647.3	345234.9	2868763.0	589349.3	2284246.3	2138925.5	145320.7
1940	8140994.0	459076.4	3828582.3	4576352.0	3960611.5	473775.8	2284246.3	2141375.8	142870.4
1941	13872917.0	500064.1	3534264.5	11167962.0	4312166.5	481949.0	2284246.3	2279336.8	4909.5
1942	8562348.0	499633.1	3268424.8	6150652.0	4347241.0	548441.9	2284246.3	2257023.3	27222.9
1943	2011881.0	497266.4	2250470.0	569710.9	3225492.5	829488.0	2284246.3	2204602.8	79643.6
1944	8960604.0	470719.3	3193586.5	6537362.5	3321497.5	522337.3	2284246.3	2188514.3	95732.0
1945	10186189.0	500149.9	3459278.8	7521770.5	3586034.0	558398.0	2284246.3	2202029.3	82217.1
1946	8409121.0	493946.0	3433155.0	5882590.5	3880664.3	537752.1	2284246.3	2158568.3	125678.1
1947	4876952.0	482916.3	2463531.8	3228002.3	3172158.3	699183.8	2284246.3	2124740.5	159505.7
1948	1877437.0	470784.3	2300122.5	305682.6	2444826.8	697451.8	2284246.3	2068188.9	216057.4
1949	4434028.0	459044.4	3599906.3	1505559.3	3104321.8	458482.8	2284246.3	2157449.3	126797.1
1950	4068190.0	471679.7	3021897.8	1756278.1	2938681.3	651750.9	2284246.3	2189676.8	94569.5
1951	1015932.0	438277.8	1435127.5	0.0	1870257.0	615603.9	2284246.3	1887947.6	396298.6
1952	1648437.0	414479.3	1930506.4	130956.0	1494446.5	460861.5	2284246.3	1821718.4	462527.9
1953	4649544.0	389916.8	3094783.0	1902443.1	2372503.5	375130.7	2284246.3	1841595.3	442651.0
1954	1388204.0	358833.2	1644575.8	76597.4	1645255.5	691968.0	2284246.3	1679856.6	604389.6
1955	3314829.0	411836.0	3191800.3	206984.3	2394323.8	517516.9	2284246.3	1925215.9	359030.4
1956	977187.0	412173.9	1337504.6	3860.4	1367350.6	631255.0	2284246.3	1733223.1	551023.2
1957	15583308.0	437781.0	5897766.5	9852517.0	4322348.5	409824.8	2284246.3	2177556.3	106690.1
1958	6033499.0	499366.6	2685890.8	4149681.8	3748852.0	589772.4	2284246.3	2236237.0	48009.3
1959	6005065.0	501178.7	3450038.3	3210273.8	4171972.8	492564.2	2284246.3	2225092.3	59153.9
1960	7196225.0	499377.6	3000729.8	5064400.0	3933416.5	576422.9	2284246.3	2228408.0	55838.2
1961	10018476.0	500315.3	3369321.0	7549063.5	4072698.3	549303.8	2284246.3	2254950.8	29295.6
1962	3459118.0	499172.7	3144796.0	1136053.5	3921821.5	625737.6	2284246.3	2243454.8	40791.6
1963	1755858.0	495024.3	2063459.9	415481.6	2795304.3	734898.3	2284246.3	2169436.5	114809.8
1964	2246424.0	449122.8	2587342.8	162170.7	2789205.0	475067.1	2284246.3	2011771.6	272474.6
1965	8703662.0	482132.1	3761625.0	5768747.0	3438951.0	467807.8	2284246.3	2199567.8	84678.5
1966	6572299.0	500239.3	3630365.3	3664418.8	3810436.8	623205.6	2284246.3	2226113.0	58133.3
1967	1969067.0	493859.2	2351020.3	307693.2	3116971.5	663760.8	2284246.3	2170328.3	113918.0
1968	11236039.0	481218.5	3798334.0	8162689.0	3661349.0	561832.1	2284246.3	2258251.8	25994.6
1969	6414811.0	501362.3	3464005.3	3864676.3	3884917.3	568002.1	2284246.3	2222378.3	61867.9
1970	5062296.0	500043.0	2638028.3	3294645.3	3301614.5	607700.1	2284246.3	2201007.3	83239.0
1971	3426376.0	464821.8	3268865.0	623476.5	3716115.8	605134.3	2284246.3	2138387.8	145858.5
1972	3042947.0	488993.1	2784105.0	1087560.1	3318487.0	615456.6	2284246.3	2156488.5	127757.7
1973	9130501.0	490374.4	3368476.0	6640474.5	3562139.3	500448.0	2284246.3	2190519.8	93726.5
1974	7845426.0	485419.9	3567937.8	4995090.5	4185045.5	552027.4	2284246.3	2111540.3	172705.9
1975	7279962.0	499534.3	2649860.8	5513551.0	3567682.8	641985.5	2284246.3	2241321.3	42925.0
1976	6400484.0	469618.2	3327234.0	3876406.3	3803498.0	515805.3	2284246.3	2214772.5	69473.7
1977	6454303.0	494509.2	2545112.0	4671312.5	3074281.3	773702.9	2284246.3	2175014.5	109231.7
1978	2390580.0	447719.9	2219087.5	496513.8	2715983.3	590461.4	2284246.3	1986925.1	297321.1
1979	8902648.0	468497.8	3554724.8	6126174.5	3254658.0	503942.0	2284246.3	2154068.5	130177.7
1980	4027323.0	465063.9	2496674.8	1956048.6	3027852.5	709788.4	2284246.3	1966499.4	317746.9
1981	6431066.0	462014.4	3965961.8	2984477.0	4102048.3	552432.8	2284246.3	2162030.8	122215.4
1982	4363023.0	495171.3	2725794.8	2537471.8	3500698.3	673122.8	2284246.3	2215617.3	68628.9
1983	4445743.0	496524.0	2895759.0	2217995.0	3270884.5	649451.3	2284246.3	2142915.5	141330.8
1984	3194156.0	452551.8	2150424.0	1412595.4	2863778.5	633373.8	2284246.3	1924156.4	360089.8

Table 7.2
ANNUAL SUMMARY FOR RICHMOND GAGE CONTROL POINT

YEAR	NATURALIZED STREAMFLOW (ACRE-FEET)	RETURN FLOW (AC-FT)	STREAMFLOW DEPLETION (ACRE-FEET)	UNAPPROPRIATED FLOW (ACRE-FEET)	EOP STORAGE (AC-FT)	EVAPORATION (ACRE-FEET)	PERMITTED DIVERSION (AC-FT)	ACTUAL DIVERSION (AC-FT)	SHORTAGE (AC-FT)
1900	11682666.0	56712.1	975086.6	9182923.0	91177.0	16463.7	976821.9	976776.1	45.9
1901	1791948.0	60056.5	875800.3	618400.8	89806.0	16260.8	976821.9	937092.6	39729.4
1902	4915118.0	60990.4	939783.8	1906799.5	91177.0	16489.2	976821.9	976101.8	720.2
1903	6212631.0	61643.6	993345.8	4177859.5	91177.0	16493.5	976821.9	976821.9	0.0
1904	2461067.0	61019.2	923055.2	589461.1	91177.0	16408.6	976821.9	968372.4	8449.5
1905	8098545.0	61222.5	963988.9	5218594.0	91177.0	16438.7	976821.9	965737.3	11084.6
1906	3628073.0	61222.5	928817.4	1371702.9	91177.0	16448.7	976821.9	972052.8	4769.2
1907	4398889.0	61643.6	993345.8	1870688.1	91177.0	16493.5	976821.9	976821.9	0.0
1908	10209155.0	61643.6	975789.6	7933610.0	91177.0	16493.5	976821.9	976821.9	0.0
1909	1153469.0	54097.3	777207.4	5932.7	87230.6	15784.3	976821.9	915685.3	61136.6
1910	1244616.0	47256.7	682066.1	85687.0	86351.1	12875.4	976821.9	801564.3	175257.6
1911	1962789.0	56291.0	892282.6	223713.3	91177.0	16413.0	976821.9	954540.3	22281.6
1912	2469477.0	59274.8	834207.4	910247.4	90616.2	15060.0	976821.9	911351.6	65470.4
1913	6637021.0	60544.3	941632.8	2783772.0	91177.0	16369.9	976821.9	956570.4	20251.5
1914	12022316.0	61643.6	975453.4	9307831.0	91177.0	16472.7	976821.9	976790.9	31.0
1915	11292281.0	61643.6	993345.8	8518051.0	91177.0	16493.5	976821.9	976821.9	0.0
1916	5487508.0	61222.5	952880.4	3822949.0	91177.0	16460.4	976821.9	972413.9	4408.0
1917	997265.0	51807.8	781820.1	40056.5	87762.2	15524.0	976821.9	896052.8	80769.1
1918	4022818.0	55659.4	820213.0	846115.1	91177.0	15723.1	976821.9	919134.3	57687.6
1919	11614557.0	61643.6	993345.8	8280196.5	91177.0	16493.5	976821.9	976821.9	0.0
1920	8040568.0	61643.6	993345.8	5555576.0	91177.0	16493.5	976821.9	976821.9	0.0
1921	5075127.0	61643.6	975492.6	3409460.8	91177.0	16484.1	976821.9	976818.8	3.1
1922	12151902.0	61643.6	993345.8	10031250.0	91177.0	16493.5	976821.9	976821.9	0.0
1923	6290273.0	61222.5	938789.7	3345756.8	91177.0	16443.1	976821.9	972064.3	4757.7
1924	5719830.0	60888.4	923758.9	4161877.0	90616.2	16452.9	976821.9	974345.6	2476.3
1925	3274109.0	54451.1	737754.1	1300325.4	91177.0	13514.9.	976821.9	853919.9	122902.0
1926	7843222.0	61643.6	993345.8	4593770.5	91177.0	16493.5	976821.9	976821.9	0.0
1927	5038272.0	61643.6	993345.8	3106473.0	91177.0	16493.5	976821.9	976821.9	0.0
1928	2864894.0	60166.0	912181.9	822147.2	91177.0	16427.4	976821.9	963114.1	13707.9
1929	6429473.0	61643.6	986248.2	4052226.5	91177.0	16493.5	976821.9	976821.9	0.0
1930	6543061.0	61643.6	962707.6	3413304.8	91177.0	16463.7	976821.9	976776.1	45.9
1931	4083469.0	60888.5	934105.1	2417663.0	91177.0	16426.3	976821.9	967396.3	9425.6
1932	7947029.0	61643.6	993345.8	4858798.0	91177.0	16493.5	976821.9	976821.9	0.0
1933	2416065.0	61192.3	929637.9	777550.8	90665.0	16324.6	976821.9	959116.4	17705.5
1934	3699377.0	47709.0	834811.4	2077706.5	91177.0	15726.7	976821.9	912660.4	64161.5
1935	8768609.0	61643.6	993345.8	4994392.0	91177.0	16493.5	976821.9	976821.9	0.0
1936	6923648.0	61643.6	993345.8	4512551.5	91177.0	16493.5	976821.9	976821.9	0.0
1937	3549565.0	60790.5	928249.2	1891074.4	91177.0	16374.7	976821.9	961616.6	15205.3
1938	6334270.0	61643.6	991166.6	3874637.0	91177.0	16493.5	976821.9	976821.9	0.0
1939	2055990.0	60475.5	888883.3	345234.9	89143.1	16397.9	976821.9	959930.8	16891.1
1940	7850608.0	60623.2	876242.8	4576352.0	91177.0	6284.8	976821.9	968094.6	8727.3
1941	13806996.0	61643.6	983740.9	11167962.0	91177.0	6906.2	976821.9	976821.9	0.0
1942	8517753.0	61643.6	972245.9	6150652.0	91177.0	13242.4	976821.9	976819.8	2.1
1943	1984786.0	61643.6	993182.9	569710.9	91177.0	16331.0	976821.9	976821.9	0.0
1944	8901734.0	61643.6	941582.8	6537362.5	91177.0	4769.5	976821.9	976776.1	45.9
1945	10074292.0	61643.6	984799.1	7521770.5	91177.0	7962.3	976821.9	976821.9	0.0
1946	8406420.0	61643.6	963366.6	5882590.5	91177.0	4380.3	976821.9	976818.8	3.1
1947	4876952.0	60888.0	947560.7	3228002.3	91177.0	11740.6	976821.9	967721.1	9100.9
1948	1873208.0	59337.3	857525.4	305682.6	87638.9	22695.1	976821.9	945731.6	31090.4
1949	4321941.0	57737.4	954085.0	1505559.3	91177.0	7742.8	976821.9	972638.8	4183.1
1950	3960386.0	61643.6	975735.5	1756278.1	91177.0	17111.5	976821.9	976776.1	45.9
1951	996849.0	50421.9	686260.1	0.0	77153.4	23492.9	976821.9	848400.8	128421.1
1952	1623246.0	44827.5	749932.5	130956.0	91177.0	17862.0	976821.9	844093.1	132728.8
1953	4607306.0	58137.7	862223.1	1902443.1	91177.0	16169.1	976821.9	926704.6	50117.4
1954	1362340.0	46557.0	673409.3	76597.4	65002.9	27686.9	976821.9	821534.6	155287.4
1955	2986948.0	51662.3	823349.1	206984.3	90456.6	24970.2	976821.9	919449.4	57372.5
1956	929191.0	45837.7	627438.0	3860.4	83891.4	23396.4	976821.9	770564.9	206257.1
1957	14983308.0	51773.6	946840.0	9852517.0	91177.0	6950.7	976821.9	964885.1	11936.9
1958	5932074.0	61643.6	985124.7	4149681.8	91177.0	8287.4	976821.9	976821.9	0.0
1959	5876065.0	61643.6	972745.1	3210273.8	91177.0	9985.3	976821.9	976807.9	14.0
1960	7158198.0	61643.6	981054.5	5064400.0	91177.0	4224.8	976821.9	976821.9	0.0
1961	10018476.0	61643.6	985694.3	7549063.5	91177.0	8856.2	976821.9	976821.9	0.0
1962	3381713.0	61643.6	993020.3	1136053.5	91177.0	16168.6	976821.9	976821.9	0.0
1963	1698274.0	60408.7	893806.8	415481.6	91177.0	24825.5	976821.9	964798.4	12023.5
1964	2209915.0	57972.9	834274.5	162170.7	91177.0	17321.5	976821.9	915917.3	60904.6
1965	8631581.0	61643.6	972388.7	5768747.0	91177.0	13727.3	976821.9	976819.8	2.1
1966	6411800.0	61221.9	978720.9	3664418.8	91177.0	21084.6	976821.9	975781.3	1040.7
1967	1963572.0	60871.8	911169.4	307693.2	91177.0	23509.0	976821.9	964616.4	12205.5
1968	11074828.0	61643.6	987810.8	8162689.0	91177.0	10968.7	976821.9	976821.9	0.0
1969	6405519.0	61222.0	967528.9	3864676.3	91177.0	13605.5	976821.9	972082.1	4739.9
1970	5020008.0	60789.9	949576.2	3294645.3	91177.0	18703.6	976821.9	966862.3	9959.6
1971	3342968.0	60617.9	855351.0	623476.5	91177.0	24477.0	976821.9	962264.1	14557.8
1972	3001679.0	61222.9	956719.3	1087560.1	91177.0	17359.3	976821.9	972082.1	4739.9
1973	9112670.0	61643.6	989601.6	6640474.5	91177.0	12756.1	976821.9	976821.9	0.0
1974	7822334.0	60760.2	924377.9	4995090.5	91177.0	17238.6	976821.9	960320.1	16501.8
1975	7279962.0	61643.6	993345.9	5513551.0	91177.0	16493.5	976821.9	976821.9	0.0
1976	6400484.0	61643.6	990741.3	3876406.3	91177.0	13893.5	976821.9	976821.9	0.0
1977	6396303.0	60887.5	928403.7	4671312.5	91177.0	24059.8	976821.9	967718.9	9103.0
1978	2267881.0	58076.7	829617.7	496513.8	91177.0	19867.1	976821.9	905191.6	71630.3
1979	8864448.0	61643.6	988868.9	6126174.5	91177.0	12024.9	976821.9	976821.9	0.0
1980	3940466.0	58583.8	824685.0	1956048.6	87274.5	23670.9	976821.9	895179.4	81642.6
1981	6337486.0	60946.2	962063.1	2984477.0	91177.0	16554.2	976821.9	972649.4	4172.5
1982	4359863.0	61643.6	997904.1	2537471.8	91177.0	21043.3	976821.9	976821.9	0.0
1983	4298145.0	60911.4	942015.7	2217995.0	91177.0	15816.0	976821.9	956369.3	20452.6
1984	3110466.0	47527.0	788124.8	1412595.4	91177.0	19369.7	976821.9	864570.4	112251.5

Table 7.3
NATURALIZED STREAMFLOWS AT RICHMOND GAGE

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	563104.	293242.	526759.	2493000.	4250000.	850751.	278379.	260077.	997696.	645893.	301272.	222493.	11682666.
1901	154940.	86087.	105469.	194555.	365099.	537395.	38577.	72725.	124230.	28031.	46201.	38639.	1791948.
1902	40535.	34444.	182346.	116407.	826999.	278613.	1193000.	848246.	169242.	148713.	673457.	403116.	4915118.
1903	451521.	994702.	2194000.	415000.	268400.	228099.	296088.	718200.	77834.	397536.	82711.	88540.	6212631.
1904	62537.	110100.	62967.	142800.	924804.	300901.	249083.	162600.	112492.	118792.	144201.	69790.	2461067.
1905	159506.	374400.	822759.	1052000.	3424000.	1016000.	148994.	325302.	188584.	163898.	148600.	274502.	8098545.
1906	231989.	229000.	120010.	134000.	296000.	649000.	181816.	182094.	409334.	107436.	211167.	876227.	3628073.
1907	302595.	179971.	263659.	89980.	534924.	391254.	437457.	274646.	73375.	854220.	437173.	559635.	4398889.
1908	486531.	381635.	595986.	3594000.	2892000.	1101000.	183103.	95862.	195678.	374831.	116457.	192072.	10209155.
1909	45137.	19370.	43491.	60789.	177845.	267037.	108448.	63829.	19417.	86768.	71697.	189641.	1153469.
1910	84308.	163813.	14403.	278443.	418457.	68823.	16737.	0.	51321.	66550.	26993.	54768.	1244616.
1911	42804.	281703.	139067.	257339.	194704.	212449.	214758.	232263.	168502.	39552.	61212.	118436.	1962789.
1912	167914.	303873.	349263.	586694.	178999.	272091.	61777.	124169.	44958.	306012.	40550.	33177.	2469477.
1913	23929.	102122.	151891.	191575.	924321.	514784.	259640.	49996.	344048.	582821.	983894.	2508000.	6637021.
1914	239598.	299825.	303234.	820334.	5291000.	2842000.	474478.	196136.	254455.	311151.	433732.	556373.	12022316.
1915	364565.	329877.	455656.	2066000.	3335000.	1836000.	1274000.	297568.	152664.	730442.	186635.	263874.	11292281.
1916	529132.	911642.	512171.	969370.	1161000.	577509.	156082.	53198.	140818.	300651.	116155.	59780.	5487508.
1917	59362.	20139.	77768.	64042.	223268.	232751.	60513.	25332.	156860.	24872.	25513.	26845.	997265.
1918	44852.	60047.	24130.	638718.	309505.	293781.	54150.	65234.	171070.	425882.	869449.	1066000.	4022818.
1919	842635.	960761.	739365.	630317.	1469000.	970336.	1016000.	339230.	745913.	1417000.	1294000.	1190000.	11614557.
1920	1498000.	804309.	381188.	134134.	1925000.	525964.	265914.	755479.	704325.	332805.	340019.	373431.	8040568.
1921	277810.	277343.	540520.	843805.	351962.	1103000.	378890.	44363.	861015.	174876.	117951.	103592.	5075127.
1922	82959.	146592.	387834.	2573000.	7354000.	903061.	190258.	236121.	45977.	54601.	113999.	63500.	12151902.
1923	79608.	221001.	435079.	1400000.	615998.	405999.	99099.	45500.	189999.	296002.	631988.	1870000.	6290273.
1924	727024.	893998.	1380000.	765000.	632002.	909001.	88794.	46100.	108012.	83798.	41000.	45101.	5719830.
1925	44094.	34400.	30894.	27000.	514001.	52700.	31903.	42400.	289993.	990923.	1120000.	95801.	3274109.
1926	539003.	186000.	955161.	2190000.	1240000.	462001.	372041.	272000.	340027.	382974.	203006.	701009.	7843222.
1927	292003.	544001.	678773.	961001.	421001.	838002.	378040.	103999.	58589.	598964.	81499.	82400.	5038272.
1928	85505.	318000.	298026.	214000.	295000.	814999.	160988.	264000.	104978.	37601.	40800.	230997.	2864894.
1929	327997.	96100.	296001.	708001.	1130000.	2360000.	321963.	57500.	393010.	86100.	555002.	97799.	6429473.
1930	213977.	408000.	238020.	134000.	2600000.	582001.	128003.	58000.	117980.	916048.	212005.	935027.	6543061.
1931	713016.	782995.	867016.	378000.	416000.	218000.	96495.	59500.	44995.	175453.	152001.	179998.	4083469.
1932	1750000.	1470000.	971892.	165000.	938027.	447200.	575062.	139451.	1153000.	162996.	68400.	106001.	7947029.
1933	282002.	270000.	434088.	220000.	390680.	346541.	51695.	165610.	115752.	57197.	48400.	34100.	2416065.
1934	329998.	513998.	787098.	1330000.	189400.	47500.	26130.	19650.	33220.	37481.	155002.	229900.	3699377.
1935	207578.	443501.	197279.	210250.	3310000.	1420000.	425448.	163750.	563707.	328996.	285100.	1213000.	8768609.
1936	201487.	144447.	118424.	81216.	1199000.	839344.	1091000.	96394.	458420.	1443000.	466254.	784662.	6923648.
1937	850138.	380693.	583095.	237926.	118970.	278637.	131333.	65289.	125478.	169899.	177502.	430605.	3549565.
1938	1140000.	1047000.	510080.	1191000.	1170000.	327504.	368193.	374854.	79643.	47868.	38356.	39772.	6334270.
1939	165143.	155105.	169399.	83678.	561454.	471581.	216692.	56261.	51533.	32584.	34721.	57839.	2055990.
1940	43979.	150997.	44992.	209548.	318992.	657363.	1320000.	258866.	112492.	70379.	1408000.	3255000.	7850608.
1941	1190000.	1358000.	1592000.	1267000.	2856000.	2117000.	1172000.	387614.	320748.	741702.	633588.	171344.	13806996.
1942	138638.	106386.	100126.	2164000.	1977000.	1316000.	349097.	114780.	870712.	724501.	410817.	245696.	8517753.
1943	328207.	115141.	227960.	313063.	225381.	274433.	131333.	80376.	56740.	89277.	54390.	88485.	1984786.
1944	675042.	972134.	1164000.	380079.	2871000.	1088000.	176990.	71858.	270816.	122419.	326728.	782668.	8901734.
1945	1314000.	918403.	1373000.	2577000.	776313.	592044.	564668.	433917.	356551.	562681.	129235.	476480.	10074292.
1946	656289.	881762.	1317000.	511211.	1626000.	884195.	213733.	89761.	324182.	267781.	1041000.	593506.	8406420.
1947	980444.	302441.	817827.	435877.	1033000.	348401.	92886.	343523.	125315.	78052.	88987.	230199.	4876952.
1948	97102.	243493.	355764.	157975.	319772.	246314.	282757.	9911.	53819.	46964.	33019.	26318.	1873208.
1949	64998.	242636.	496760.	799105.	1119000.	510608.	207981.	33181.	106806.	280256.	197295.	263315.	4321941.
1950	281880.	754916.	172102.	541217.	598158.	662994.	259943.	198180.	297477.	123188.	38680.	31651.	3960386.
1951	18108.	47982.	61780.	69729.	196927.	394752.	28535.	25522.	71144.	32521.	24250.	25599.	996849.
1952	24714.	51635.	79561.	391629.	471905.	207097.	40459.	0.	27167.	12751.	65308.	251020.	1623246.
1953	287208.	125812.	267688.	109659.	1821000.	101092.	338688.	137851.	124609.	508462.	227623.	557614.	4607306.
1954	139885.	55161.	28821.	160228.	550554.	153442.	24653.	56238.	26729.	43290.	89671.	33668.	1362340.
1955	38260.	262026.	84993.	321477.	636244.	432484.	145987.	94662.	238191.	627421.	68963.	36240.	2986948.
1956	38656.	100277.	43017.	48741.	414158.	48623.	0.	19805.	23589.	30548.	58511.	103266.	929191.
1957	11777.	280831.	234267.	2085000.	6287000.	1832000.	554147.	179194.	117929.	1855000.	1073000.	473163.	14983308.
1958	559535.	893880.	793155.	440331.	1573000.	320604.	435964.	115714.	366755.	232978.	112818.	87340.	5932074.
1959	63800.	311416.	119466.	857250.	565529.	558960.	314704.	158669.	70545.	1728000.	461634.	666092.	5876065.
1960	1050000.	677207.	389115.	252205.	482585.	441130.	476968.	119427.	52089.	635472.	1009000.	1573000.	7158198.
1961	2332000.	2018000.	723573.	310738.	213198.	1144000.	1038000.	255302.	801071.	373209.	401258.	408127.	10018476.
1962	232648.	198177.	137268.	131537.	195089.	576561.	357269.	155117.	579394.	301362.	158027.	359264.	3381713.
1963	184632.	203508.	103665.	296241.	264913.	222024.	90160.	38831.	44612.	58331.	128496.	62861.	1698274.
1964	70536.	192851.	254859.	168276.	178775.	212896.	42593.	73437.	353894.	123100.	412282.	126416.	2209915.
1965	489035.	1108000.	376972.	488675.	3613000.	976683.	165813.	156363.	176174.	209693.	406421.	464752.	8631581.
1966	202290.	424726.	375885.	1228000.	2161000.	346608.	107398.	360909.	785812.	283637.	75531.	60004.	6411800.
1967	73917.	53112.	67004.	182236.	258725.	358963.	218510.	63638.	178666.	88150.	259615.	161036.	1963572.
1968	1787000.	624444.	1122000.	952189.	2414000.	1837000.	1009000.	184476.	267185.	133812.	214080.	529642.	11074828.
1969	151085.	595612.	984624.	1470000.	1663000.	298873.	114798.	131166.	232169.	175059.	182773.	406360.	6405519.
1970	302562.	405029.	1636000.	687273.	741264.	340320.	81091.	47522.	219227.	401994.	96629.	61097.	5020008.
1971	56173.	61461.	70758.	98688.	241782.	164659.	285791.	497591.	243188.	463719.	282445.	876713.	3342968.
1972	429845.	257742.	153073.	114888.	591796.	181531.	100822.	209017.	185217.	189235.	408592.	179921.	3001679.
1973	562283.	585691.	987296.	1406000.	934610.	1468000.	396278.	167280.	188005.	1452000.	530484.	434743.	9112670.
1974	802234.	412032.	204717.	167651.	355111.	149466.	81376.	258746.	1715000.	960423.	1848000.	767578.	7822334.
1975	516296.	1409000.	478596.	684386.	1779000.	1137000.	536875.	286318.	173072.	102865.	90438.	86116.	7279962.
1976	71537.	110470.	148328.	882118.	1272000.	681466.	785435.	174679.	239827.	523722.	378902.	1132000.	6400484.
1977	374568.	1183000.	759509.	2169000.	992080.	381910.	119887.	65603.	125418.	62080.	69980.	93268.	6396303.
1978	171997.	264606.	238327.	135384.	90549.	154499.	36617.	707237.	176166.	37916.	145645.	108938.	2267881.
1979	679376.	584734.	1109000.	1202000.	1856000.	2002000.	465023.	377501.	254720.	104566.	61355.	168173.	8864448.
1980	425642.	402314.	211558.	346073.	1287000.	438864.	48736.	59689.	244857.	311579.	66900.	97254.	3940466.
1981	63555.	93462.	226716.	209686.	310975.	2289000.	470141.	131382.	269175.	1365000.	771387.	137007.	6337486.
1982	70351.	104902.	175402.	322726.	1507000.	1076000.	563466.	88406.	38573.	53286.	83678.	276073.	4359863.
1983	187916.	702475.	1203.	1033000.	1054000.	383738.	109106.	238867.	174207.	201085.	100927.	111621.	4298145.
1984	102555.	100778.	258449.	69426.	90741.	100349.	23876.	34307.	27400.	1007000.	558179.	737406.	3110466.

Note: Units are acre-feet in Tables 7.3-7.9.

Table 7.4
NATURALIZED STREAMFLOWS AT GRANBURY RESERVOIR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	29313.	5971.	15063.	661497.	152613.	158543.	200185.	63523.	546014.	173006.	32530.	41641.	2079899.
1901	5991.	14499.	6550.	80610.	129249.	34074.	18365.	37363.	24402.	5338.	8373.	2025.	366839.
1902	1879.	1398.	18973.	32576.	204685.	58783.	559390.	70377.	90272.	56407.	125036.	27005.	1246781.
1903	45288.	164597.	209976.	233913.	23716.	27002.	50713.	19090.	19408.	96523.	8137.	7979.	906342.
1904	4857.	21277.	11853.	4057.	97347.	153892.	65329.	37097.	46728.	59884.	34209.	10313.	546843.
1905	3679.	20045.	59799.	125138.	621080.	221551.	248469.	159691.	99554.	51573.	15570.	21822.	1647971.
1906	8349.	10862.	3861.	18911.	268785.	307646.	123664.	132116.	188368.	239055.	12760.	16160.	1330537.
1907	10497.	4390.	14128.	46608.	207070.	208838.	215660.	37315.	15602.	157451.	70007.	38521.	1026087.
1908	25678.	31220.	31846.	339078.	1160000.	106820.	22825.	16917.	31112.	46922.	2912.	28936.	1844266.
1909	980.	3197.	1701.	0.	18447.	118584.	758.	33867.	2188.	12028.	26100.	72474.	290324.
1910	5237.	6626.	947.	118654.	178825.	49557.	8074.	672.	27505.	16176.	1710.	1695.	415678.
1911	2626.	64908.	4689.	32425.	2809.	2407.	63448.	50131.	274844.	0.	2128.	19264.	519679.
1912	11482.	7421.	21168.	14525.	27970.	25974.	1734.	133082.	16510.	19659.	5287.	2354.	287166.
1913	5849.	4506.	2262.	10372.	170983.	30017.	34545.	6739.	135827.	312170.	195753.	233146.	1142169.
1914	19058.	3690.	9850.	281523.	566118.	223593.	40350.	380154.	294041.	45851.	64676.	25452.	1954356.
1915	31841.	61586.	62833.	316608.	486541.	653784.	217760.	141929.	93245.	222316.	10125.	7911.	2306479.
1916	16963.	41777.	8412.	96438.	149867.	91689.	39151.	15467.	16245.	140212.	12218.	3864.	632303.
1917	13659.	2937.	1807.	328.	34756.	48873.	9398.	22030.	69447.	370.	95.	785.	204485.
1918	9308.	1643.	1270.	100228.	210896.	88859.	7071.	57.	71840.	216003.	441782.	257657.	1406614.
1919	105262.	99221.	105688.	215091.	407748.	382353.	253511.	147813.	205051.	1279000.	130557.	91899.	3423194.
1920	89574.	102571.	93586.	2882.	164872.	189480.	77157.	252464.	577978.	248892.	108506.	40072.	1948034.
1921	38334.	63209.	41409.	25186.	10695.	217153.	28773.	4724.	22311.	0.	1537.	788.	454119.
1922	3427.	715.	1051.	172382.	634447.	189569.	14612.	9617.	0.	2772.	7495.	2065.	1038152.
1923	4922.	41751.	5806.	141686.	131540.	193594.	6624.	3420.	43363.	366988.	292998.	217002.	1449694.
1924	22401.	12800.	133998.	86001.	154002.	86300.	1668.	1110.	121999.	12400.	3040.	1440.	637159.
1925	1680.	1220.	368.	127000.	412001.	16802.	7790.	46300.	356997.	119005.	26500.	4130.	1119793.
1926	19200.	2680.	24100.	168000.	113000.	313968.	136955.	239002.	217992.	353972.	40101.	143001.	1771971.
1927	24901.	32801.	71300.	175001.	30000.	102012.	72412.	24699.	19000.	87909.	3360.	10200.	653595.
1928	3710.	11800.	3440.	33600.	338000.	230954.	197273.	201009.	52501.	1790.	14400.	41601.	1130078.
1929	36600.	16400.	20800.	44300.	235997.	113990.	44116.	4699.	327001.	63305.	13200.	7070.	927478.
1930	2530.	2340.	2550.	558.	627003.	359130.	38286.	6890.	68999.	477038.	31500.	238001.	1854825.
1931	15900.	104007.	45200.	23200.	50100.	64885.	18889.	5199.	209.	294026.	76202.	70100.	767917.
1932	174002.	144001.	43999.	15800.	235997.	223981.	480675.	32501.	660017.	42402.	16500.	108000.	2177875.
1933	58698.	15300.	67000.	24000.	314995.	63090.	10802.	61498.	84502.	20800.	7500.	7690.	735875.
1934	24999.	10400.	70700.	73200.	13500.	3682.	0.	0.	12400.	4980.	57119.	14310.	285290.
1935	30558.	13910.	21560.	42040.	813606.	509132.	258610.	33399.	204599.	24979.	32930.	25720.	2011043.
1936	7086.	4507.	3100.	2506.	184849.	68859.	53376.	508.	757687.	272607.	41140.	22830.	1419055.
1937	13853.	8135.	43453.	8649.	11130.	95362.	8456.	86348.	28167.	60131.	6374.	29024.	399082.
1938	112993.	165353.	211424.	127643.	198835.	148333.	200500.	56604.	7932.	681.	1196.	1302.	1232796.
1939	36284.	7405.	3510.	13858.	175726.	227808.	42831.	36774.	4462.	404.	17971.	2249.	569282.
1940	1149.	7524.	3261.	39739.	121801.	333459.	70614.	285258.	75023.	9742.	193672.	144293.	1285535.
1941	33347.	195107.	71415.	247559.	1312000.	791136.	181261.	214683.	106957.	723210.	193636.	49769.	4120080.
1942	32993.	16201.	18205.	871989.	398654.	287843.	23923.	29291.	218787.	443114.	63635.	30331.	2434966.
1943	17425.	17502.	60833.	72865.	34503.	92853.	10766.	1117.	8309.	5876.	975.	2682.	325706.
1944	10316.	57332.	63690.	43455.	185026.	62536.	46414.	28585.	56278.	58334.	19502.	20283.	651751.
1945	30519.	92136.	264232.	220931.	59683.	57428.	255318.	13593.	12694.	157174.	9953.	6273.	1179934.
1946	36516.	74955.	24932.	17667.	73110.	67025.	21132.	58432.	255193.	130707.	165681.	182320.	1107670.
1947	29191.	18996.	57663.	29893.	444906.	65359.	9581.	2853.	15705.	47033.	13381.	74196.	808757.
1948	21145.	59874.	41160.	4784.	64800.	141572.	120574.	13170.	14027.	17520.	10659.	1687.	510972.
1949	1308.	37260.	58612.	39341.	625326.	262607.	27986.	9035.	97431.	102407.	17719.	6415.	1285447.
1950	14705.	31846.	7260.	97207.	248049.	55913.	279221.	104747.	190696.	37949.	5251.	3256.	1076100.
1951	0.	10502.	5846.	0.	141176.	203475.	22286.	21426.	27704.	2277.	3640.	617.	438949.
1952	1263.	2876.	1446.	15281.	69109.	1.	13408.	7450.	4347.	213.	15401.	4995.	135790.
1953	3499.	727.	8704.	8496.	119258.	1.	281906.	89733.	6500.	311398.	37546.	8835.	876603.
1954	6747.	4537.	5043.	119153.	420198.	74139.	9958.	27439.	4508.	7391.	28736.	2706.	710555.
1955	2767.	10510.	20652.	18021.	344166.	246492.	73720.	38261.	356378.	534845.	23655.	10665.	1680132.
1956	7576.	5282.	4248.	8776.	129525.	19224.	0.	5051.	5845.	14552.	23364.	50255.	273698.
1957	839.	259562.	19907.	648393.	2724000.	547447.	75049.	17782.	37516.	226102.	192317.	34052.	4782966.
1958	31232.	22566.	82932.	92266.	455997.	52652.	281906.	33378.	89350.	7988.	9638.	7464.	1167369.
1959	3005.	6285.	4281.	3455.	47296.	195961.	126814.	29375.	7809.	593116.	16232.	33745.	1067374.
1960	100772.	58656.	28518.	32057.	19167.	21238.	220935.	27635.	5857.	263185.	47260.	12961.	838241.
1961	93433.	60773.	51755.	12635.	33989.	320440.	254502.	35513.	73417.	49705.	51060.	21203.	1058425.
1962	5181.	4648.	8868.	22212.	7927.	335972.	292892.	86938.	533092.	95617.	62963.	46927.	1503237.
1963	11968.	8249.	19366.	147644.	157638.	224392.	16615.	5654.	19282.	22546.	59824.	4839.	698017.
1964	10266.	68986.	16328.	14633.	24983.	36340.	0.	33176.	90774.	20794.	143374.	7317.	466971.
1965	21026.	42586.	10356.	64449.	613185.	46998.	8521.	44968.	73449.	87461.	12607.	9966.	1035572.
1966	0.	18053.	16914.	278147.	475941.	87868.	5083.	98738.	664742.	53931.	11584.	4610.	1715611.
1967	8951.	7444.	11359.	52377.	47929.	177598.	194094.	31593.	79812.	17970.	2984.	11902.	644013.
1968	383521.	83206.	311192.	168629.	226375.	157693.	107810.	32600.	6167.	5000.	16087.	14956.	1513236.
1969	9209.	28940.	173423.	164500.	707695.	81988.	5943.	29485.	176272.	68051.	54422.	111971.	1611899.
1970	47315.	56582.	247518.	103018.	139558.	19753.	0.	0.	15643.	1522.	0.	3488.	634397.
1971	4840.	7406.	3508.	6823.	77197.	97157.	44901.	327649.	190348.	165652.	42603.	102386.	1070470.
1972	18466.	19840.	10556.	25956.	95763.	28823.	12090.	171299.	176422.	74693.	174617.	28341.	836866.
1973	62492.	67312.	101875.	176659.	60197.	122012.	83458.	42076.	41251.	0.	10670.	5828.	773830.
1974	12788.	9012.	9657.	43156.	24630.	78835.	32293.	47399.	315929.	318512.	364849.	38723.	1295783.
1975	50651.	182218.	45728.	101110.	128292.	246716.	72933.	76958.	57015.	8286.	15297.	9415.	994619.
1976	9174.	12343.	6696.	54794.	106241.	25612.	47049.	30617.	95163.	164792.	79351.	26488.	658320.
1977	19578.	43647.	260993.	100090.	113127.	66847.	34371.	24888.	54024.	26166.	16611.	34574.	794916.
1978	4630.	573.	38669.	82789.	55530.	68588.	48636.	778021.	28073.	22674.	4177.	2735.	1135095.
1979	7984.	4228.	113711.	93372.	282602.	126659.	23413.	25719.	0.	10114.	0.	14165.	701967.
1980	3609.	16617.	4798.	14396.	181968.	53210.	36970.	46154.	192452.	323053.	37538.	56931.	967696.
1981	23212.	21329.	77698.	108356.	71593.	200195.	39961.	51902.	39650.	1264000.	113208.	23836.	2034940.
1982	9202.	21148.	29829.	13655.	795194.	870201.	279030.	24519.	13029.	12967.	0.	63685.	2132459.
1983	0.	28782.	0.	799124.	176345.	68137.	44682.	33808.	43987.	14352.	49980.	24497.	1283694.
1984	35687.	24299.	34213.	36037.	43614.	42370.	14268.	14243.	678.	130473.	82226.	50932.	509040.

Table 7.5
NATURALIZED STREAMFLOWS AT THE CAMERON GAGE

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	44761.	26135.	84947.	371334.	1009000.	179298.	129199.	97148.	88021.	489064.	115882.	115410.	2750199.
1901	6709.	64009.	35808.	26156.	236076.	35519.	5907.	11261.	13573.	237.	12601.	6192.	454048.
1902	8454.	3043.	69009.	14688.	932527.	59363.	165111.	29239.	30718.	24453.	41866.	36887.	1415358.
1903	176223.	375920.	503529.	134286.	39650.	45523.	35566.	17305.	3737.	99146.	105157.	20946.	1556988.
1904	23638.	22515.	34025.	53361.	100788.	135863.	84615.	33562.	28210.	26035.	36013.	40579.	619204.
1905	26010.	40418.	47742.	566403.	1443000.	120869.	77125.	29769.	10989.	16097.	78591.	165265.	2622278.
1906	64457.	73669.	53693.	13628.	313500.	109630.	11896.	6422.	195471.	6471.	58136.	189730.	1096703.
1907	42043.	43783.	69712.	13484.	108559.	117398.	74813.	59139.	14785.	337198.	39846.	54632.	975392.
1908	44934.	77181.	132848.	873944.	706608.	71629.	43705.	9139.	64062.	74642.	49117.	33471.	2181280.
1909	2816.	2158.	11903.	8158.	35211.	45988.	20195.	14525.	487.	15371.	19971.	56171.	232954.
1910	9729.	29382.	726.	77509.	28906.	29839.	0.	0.	6524.	21775.	5234.	2935.	212559.
1911	6324.	15831.	23359.	35508.	35527.	20545.	9675.	17265.	26296.	2549.	20732.	19471.	233082.
1912	10280.	32560.	41671.	92270.	58030.	0.	3488.	7534.	1905.	57588.	6777.	574.	312677.
1913	2730.	12135.	18496.	47566.	345200.	178851.	29981.	3583.	71090.	196963.	167468.	770067.	1844130.
1914	13059.	36121.	58046.	369294.	1672000.	372485.	105880.	37674.	27216.	129989.	105057.	94696.	3021517.
1915	89886.	37523.	120116.	862941.	728985.	589506.	302793.	43755.	8035.	288804.	62907.	82345.	3217596.
1916	147447.	219405.	104663.	163718.	123994.	110451.	64746.	15416.	28591.	64641.	7200.	5790.	1056062.
1917	5850.	5030.	5110.	13787.	26600.	13200.	4830.	867.	35196.	1210.	3480.	1880.	117040.
1918	2340.	4651.	2290.	163972.	29000.	47999.	2550.	512.	5140.	46199.	178000.	186018.	668671.
1919	219997.	189028.	141002.	124064.	257005.	317005.	246996.	101996.	134996.	433997.	335992.	234023.	2736101.
1920	499994.	203963.	122001.	75023.	228003.	120001.	68899.	194989.	167981.	60200.	101999.	84192.	1927245.
1921	69500.	53499.	87300.	183993.	105998.	146001.	79902.	10699.	1565000.	36099.	20200.	23299.	2381490.
1922	20200.	29802.	108000.	825975.	1000000.	126001.	31201.	10600.	9520.	7780.	12100.	9200.	2190379.
1923	7760.	19998.	39901.	244971.	98595.	53001.	17800.	2670.	62795.	29601.	72801.	316994.	966887.
1924	98398.	178992.	217002.	179879.	172004.	130999.	22301.	10899.	27500.	8460.	6310.	7790.	1060534.
1925	8350.	6280.	5330.	3656.	53702.	4870.	1810.	2510.	20100.	141994.	182997.	16701.	448300.
1926	123000.	38297.	218999.	571392.	273999.	96103.	105000.	21500.	13100.	30300.	15400.	28301.	1535391.
1927	33700.	173027.	164000.	182956.	91298.	222003.	39398.	10899.	5860.	180004.	26600.	21799.	1151544.
1928	18200.	85719.	41100.	27611.	42099.	98203.	12900.	21500.	8390.	3060.	2430.	11901.	373113.
1929	17600.	12099.	33799.	141901.	535006.	140003.	26300.	8241.	53897.	8480.	29300.	7810.	1014436.
1930	15500.	25401.	25601.	10087.	559013.	37400.	11600.	10899.	17000.	207004.	30300.	134988.	1084793.
1931	152000.	222006.	198998.	97660.	121003.	73801.	35701.	9590.	10199.	23600.	6370.	13301.	964229.
1932	140001.	197958.	161997.	61290.	303003.	134005.	35198.	28999.	179021.	13200.	8330.	14401.	1277403.
1933	67601.	34304.	68202.	49681.	114002.	48401.	14700.	27199.	12099.	4480.	6250.	3820.	450739.
1934	71300.	78288.	121000.	293237.	39701.	10500.	3060	1490.	6840.	968.	68330.	9601.	704315.
1935	11380.	73862.	15420.	27978.	656502.	470104.	63002.	21340.	290722.	100402.	65989.	246790.	2043491.
1936	64560.	37261.	36400.	46184.	682917.	203488.	184110.	19630.	352692.	359407.	176906.	352868.	2516423.
1937	292102.	157507.	216699.	85543.	37601.	114000.	86805.	12740.	17999.	29480.	47500.	186309.	1284285.
1938	459591.	323908.	144702.	334890.	268699.	134505.	278700.	106003.	22439.	12400.	10030.	11250.	2107117.
1939	28010.	19930.	27171.	25106.	118105.	63620.	18640.	14449.	3720.	11990.	3020.	4100.	337861.
1940	4388.	21760.	5401.	106861.	118957.	246881.	402090.	19386.	8181.	4586.	506143.	610190.	2054824.
1941	315147.	455434.	480003.	373946.	726572.	362917.	284317.	63612.	64538.	91270.	32561.	31879.	3282196.
1942	23845.	21361.	19307.	427484.	430921.	399940.	50157.	37507.	364395.	195109.	105261.	79751.	2155038.
1943	57606.	36043.	63878.	80976.	60671.	21726.	13368.	5490.	17994.	14575.	7584.	11928.	391839.
1944	135390.	250840.	293809.	105411.	1070000.	348393.	61591.	25529.	56160.	22821.	52075.	168108.	2590127.
1945	297647.	273501.	364957.	727567.	203116.	199216.	78375.	36743.	27723.	109166.	39130.	91502.	2448643.
1946	139822.	208036.	286227.	149400.	297142.	130627.	28713.	14321.	69133.	32109.	196052.	142494.	1694076.
1947	291225.	104170.	195152.	143262.	154319.	50547.	16168.	10461.	7379.	4937.	9113.	16015.	1002748.
1948	11129.	31184.	29098.	35695.	76565.	22878.	35322.	7104.	10312.	2578.	1925.	2991.	266781.
1949	15008.	24936.	79492.	329385.	131026.	80173.	19307.	6838.	3426.	9248.	8275.	14088.	721202.
1950	7108.	57257.	10895.	63479.	68326.	53878.	33000.	3715.	62214.	3689.	1959.	2454.	367974.
1951	3050.	5575.	18061.	5769.	34420.	55117.	1790.	615.	9706.	1439.	1184.	1613.	138339.
1952	1802.	2566.	4934.	66821.	149145.	40929.	6460.	869.	502.	366.	9991.	49069.	333454.
1953	36987.	21598.	31562.	42988.	310825.	20737.	14403.	8410.	23365.	180946.	29690.	139696.	861207.
1954	12701.	7658.	4756.	9195.	34445.	1128.	143.	447.	1220.	3309.	21849.	1601.	98452.
1955	4164.	37798.	15764.	51565.	177684.	106826.	21201.	26523.	31355.	11883.	1927.	2315.	489005.
1956	4092.	11168.	2139.	3215.	159297.	7162.	1059.	4949.	1382.	2323.	17122.	18282.	232190.
1957	4039.	5407.	52102.	944328.	925442.	430489.	66307.	40894.	21260.	563173.	218610.	112758.	3384809.
1958	88856.	459028.	268831.	136313.	378536.	122406.	41798.	15972.	70028.	26415.	20837.	16738.	1645758.
1959	14459.	30564.	17437.	52336.	41107.	78972.	53287.	29137.	27448.	761412.	154417.	240562.	1501138.
1960	342365.	232170.	123203.	80089.	52230.	27090.	21415.	13747.	10840.	324453.	127844.	422887.	1778333.
1961	558789.	606125.	230299.	99401.	62069.	226202.	220059.	50635.	119075.	117797.	58033.	74815.	2423299.
1962	41782.	38678.	30500.	61863.	38339.	88157.	35473.	13352.	77922.	63141.	55630.	60797.	605634.
1963	20599.	45826.	21615.	26594.	76883.	26840.	17267.	5780.	9874.	15434.	26844.	6159.	299715.
1964	13559.	33176.	50978.	69110.	47805.	125682.	17912.	31908.	177347.	38856.	116272.	34983.	757588.
1965	235011.	371591.	144708.	116626.	1376000.	185892.	66696.	43259.	62367.	61897.	178659.	130824.	2973530.
1966	71353.	125948.	98675.	383679.	299458.	87770.	26375.	83121.	153046.	39693.	21201.	19073.	1409392.
1967	16627.	13239.	15629.	29977.	97662.	55168.	22307.	9472.	35642.	32377.	85747.	49265.	463112.
1968	743213.	179940.	418548.	230801.	479555.	239570.	202421.	39772.	33632.	14990.	31389.	59999.	2673830.
1969	26100.	77695.	127473.	334890.	263755.	58126.	27961.	37193.	21083.	47719.	32542.	101569.	1156106.
1970	83836.	167603.	514249.	172891.	240229.	130808.	29983.	18812.	80377.	46477.	13505.	14566.	1513336.
1971	13626.	13560.	27305.	35132.	65309.	35661.	166001.	58748.	18515.	90487.	54781.	154441.	733566.
1972	75480.	47452.	28560.	24828.	86492.	48581.	20984.	12524.	8518.	68807.	47473.	32950.	502649.
1973	109339.	101115.	146977.	199854.	159654.	92219.	70963.	17947.	37126.	293137.	112371.	47974.	1388676.
1974	78361.	44101.	34647.	22712.	118618.	27081.	21845.	136342.	286668.	245977.	397201.	121332.	1534885.
1975	126048.	408974.	128674.	146580.	590059.	265954.	134061.	69102.	32023.	25301.	16988.	18895.	1962659.
1976	9078.	16394.	26734.	277405.	240459.	96780.	247839.	46315.	45207.	78001.	67030.	172816.	1324058.
1977	82412.	253647.	180840.	656722.	239908.	76890.	24722.	8577.	6097.	4710.	2980.	4489.	1541994.
1978	6358.	22287.	21565.	15115.	11311.	12527.	542.	5748.	3739.	0.	16813.	9430.	125435.
1979	85138.	131130.	283014.	220070.	442319.	319514.	234641.	61827.	16397.	9467.	8032.	22886.	1834435.
1980	25732.	39815.	52534.	46783.	346596.	39787.	4507.	621.	9545.	2346.	6484.	13246.	587996.
1981	8916.	18971.	61314.	39572.	61546.	811252.	84689.	22871.	86049.	148354.	48753.	22992.	1415279.
1982	18940.	18956.	34168.	70021.	238907.	118842.	25012.	5588.	0.	2186.	11567.	8564.	552751.
1983	15321.	85147.	148801.	43687.	200324.	87974.	11666.	24489.	718.	10238.	1897.	508.	630770.
1984	7623.	5075.	29475.	3621.	0.	29551.	830.	0.	0.	161116.	40477.	98587.	376355.

Table 7.6
UNAPPROPRIATED STREAMFLOWS AT THE RICHMOND GAGE

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	420770.	218775.	399765.	2230151.	4032665.	527773.	0.	0.	620033.	412011.	170768.	150213.	9182923.
1901	105618.	25710.	39879.	100525.	40009.	286007.	0.	0.	20653.	0.	0.	0.	618401.
1902	0.	0.	37953.	0.	327115.	0.	280485.	654822.	66483.	13872.	286394.	239676.	1906800.
1903	262916.	774613.	1924310.	188336.	123880.	0.	34079.	600365.	62530.	132419.	23562.	50850.	4177860.
1904	30175.	66988.	0.	607.	454391.	0.	0.	0.	802.	0.	36498.	0.	589461.
1905	56560.	212490.	613228.	482395.	2736184.	643183.	0.	145265.	93799.	11425.	62632.	161433.	5218594.
1906	152264.	122748.	31814.	18522.	0.	0.	0.	0.	166627.	0.	153838.	725890.	1371703.
1907	173969.	121557.	154325.	8429.	225015.	0.	0.	142419.	39169.	455378.	255489.	294940.	1870688.
1908	361942.	259085.	386807.	3091009.	2470549.	797383.	0.	500.	103996.	251868.	72580.	137890.	7933610.
1909	5933.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	5933.
1910	0.	66748.	0.	2412.	16527.	0.	0.	0.	0.	0.	0.	0.	85687.
1911	0.	70193.	31382.	54296.	39906.	25342.	0.	2595.	0.	0.	0.	0.	223713.
1912	71714.	181244.	181747.	374398.	0.	68421.	0.	0.	0.	32724.	0.	0.	910247.
1913	0.	1140.	56578.	40333.	220287.	156367.	0.	0.	75340.	28688.	497252.	1707788.	2783772.
1914	161867.	249048.	200228.	403848.	4785734.	2442264.	190298.	0.	26469.	168655.	278727.	400693.	9307831.
1915	253390.	227295.	274897.	1645370.	2958069.	1403325.	877134.	56344.	64911.	461406.	122304.	173607.	8518051.
1916	408110.	763819.	417421.	715574.	929734.	292556.	0.	0.	109248.	107445.	72508.	6536.	3822949.
1917	6932.	0.	0.	0.	12214.	20911.	0.	0.	0.	0.	0.	0.	40057.
1918	0.	0.	0.	242352.	0.	0.	0.	0.	0.	49051.	45886.	508826.	846115.
1919	525676.	714630.	523102.	398521.	1073602.	633816.	592640.	52045.	513420.	1027071.	1158376.	1067296.	8280197.
1920	1383724.	677086.	220297.	42540.	1673341.	161734.	12648.	336402.	505352.	95175.	206057.	241223.	5555576.
1921	171550.	189491.	393861.	710086.	199388.	675181.	150966.	0.	703511.	103550.	71538.	40340.	3409461.
1922	27624.	88764.	263984.	1921144.	6878175.	558474.	0.	160887.	42074.	7511.	78790.	3823.	10031250.
1923	4689.	102956.	307116.	825232.	322561.	0.	0.	0.	101395.	0.	166119.	1515689.	3345757.
1924	644281.	803257.	1142831.	560521.	360616.	632198.	0.	0.	0.	18174.	0.	0.	4161877.
1925	0.	0.	0.	0.	0.	0.	0.	0.	0.	452413.	816426.	31486.	1300325.
1926	408643.	108893.	688793.	1567626.	975125.	0.	0.	94857.	44242.	44058.	111424.	550110.	4593771.
1927	217760.	414124.	507825.	686459.	223360.	488461.	131592.	11310.	41306.	302347.	47667.	34262.	3106473.
1928	53984.	184297.	226964.	0.	0.	249186.	0.	44450.	0.	0.	0.	63266.	822147.
1929	216785.	26264.	184571.	383881.	540749.	2012563.	144599.	3714.	10668.	0.	468743.	59688.	4052227.
1930	177184.	335607.	153110.	30452.	1441832.	297393.	0.	0.	45807.	130757.	103012.	698152.	3413305.
1931	581012.	599596.	685841.	247401.	236177.	0.	0.	0.	31603.	0.	7089.	28944.	2417663.
1932	1093909.	1189208.	828482.	40493.	574590.	117537.	201051.	27695.	707772.	48183.	29878.	0.	4858798.
1933	109050.	203168.	212464.	82185.	7280.	118168.	0.	19141.	17672.	0.	8424.	0.	777551.
1934	118156.	404744.	503574.	952027.	35794.	0.	0.	0.	0.	0.	0.	63412.	2077707.
1935	113433.	211270.	71470.	11288.	1965189.	991008.	31894.	44864.	148434.	142590.	163210.	1099743.	4994392.
1936	135776.	92267.	47729.	0.	757912.	567199.	815704.	31215.	0.	1052945.	354064.	657741.	4512552.
1937	747901.	299823.	436992.	128436.	0.	0.	0.	0.	33938.	0.	81683.	162302.	1891074.
1938	734511.	792230.	220911.	1006257.	851969.	0.	0.	181864.	60716.	0.	15979.	10202.	3874637.
1939	80833.	47428.	76558.	0.	98964.	0.	41452.	0.	0.	0.	0.	0.	345235.
1940	0.	86086.	0.	0.	3476.	0.	901175.	0.	0.	0.	527654.	3057962.	4576352.
1941	1091648.	1226135.	1462170.	1021287.	2451077.	1768847.	792738.	102565.	144920.	565084.	480993.	60499.	11167962.
1942	50407.	41735.	9174.	1801677.	1759313.	1005333.	95485.	0.	427619.	573717.	265803.	120391.	6150652.
1943	217086.	23849.	50938.	116876.	47735.	22378.	1961.	35097.	22615.	6932.	1535.	22710.	569711.
1944	437527.	660373.	972964.	215911.	2486043.	803982.	0.	0.	169551.	0.	217886.	573127.	6537363.
1945	1089716.	612077.	1147229.	2380972.	558318.	312376.	115779.	329123.	300982.	242674.	52194.	380329.	7521771.
1946	549642.	664309.	1202324.	376825.	1454793.	590515.	53469.	0.	0.	60899.	667456.	262359.	5882591.
1947	844943.	192105.	684612.	311068.	640587.	115097.	0.	272750.	112832.	0.	4963.	49044.	3228002.
1948	20431.	11817.	200235.	66879.	6322.	0.	0.	0.	0.	0.	0.	0.	305683.
1949	0.	42481.	186004.	424942.	307283.	66456.	38939.	0.	15690.	86650.	143992.	193123.	1505559.
1950	183310.	490032.	93407.	320248.	198609.	422612.	0.	4043.	0.	35807.	6434.	1776.	1756278.
1951	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1952	0.	0.	0.	77333.	0.	53623.	0.	0.	0.	0.	0.	0.	130956.
1953	172839.	59185.	84554.	0.	1031458.	0.	0.	0.	0.	16061.	117384.	420963.	1902443.
1954	76597.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	76597.
1955	0.	57627.	0.	149358.	0.	0.	0.	0.	0.	0.	0.	0.	206984.
1956	0.	3860.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3860.
1957	0.	0.	0.	0.	5386660.	1508872.	265136.	76473.	47573.	1372493.	843167.	352143.	9852517.
1958	466962.	819574.	651648.	290270.	1343991.	72324.	0.	0.	245875.	153080.	67448.	38510.	4149682.
1959	29937.	248783.	49959.	758364.	393121.	60109.	0.	64540.	0.	724130.	333358.	547973.	3210274.
1960	926700.	566197.	258143.	102615.	301970.	280817.	106765.	42871.	41083.	209774.	906191.	1321273.	5064400.
1961	2167900.	1909287.	581076.	172836.	33640.	605785.	664821.	110942.	665898.	81432.	265944.	289503.	7549064.
1962	155244.	130591.	44355.	22169.	52256.	42954.	0.	4677.	252360.	103987.	59042.	268419.	1136054.
1963	135984.	161124.	23783.	94591.	0.	0.	0.	0.	0.	0.	0.	0.	415482.
1964	0.	32536.	55986.	0.	17848.	0.	0.	0.	0.	0.	0.	55801.	162171.
1965	286495.	671992.	240105.	269221.	2847484.	701851.	0.	19797.	63727.	46520.	224114.	397442.	5768747.
1966	160012.	319911.	247981.	654911.	1599495.	66189.	0.	98264.	346506.	138758.	18576.	13817.	3664419.
1967	32545.	16591.	0.	40910.	60421.	0.	0.	0.	0.	0.	132426.	24799.	307693.
1968	730632.	472059.	917162.	766494.	2222690.	1530449.	628445.	46366.	238110.	45249.	150484.	414548.	8162689.
1969	105357.	490548.	687015.	1063943.	1245017.	41319.	0.	14874.	53319.	12361.	45435.	105487.	3864676.
1970	151454.	189188.	1362226.	521231.	527150.	75306.	0.	0.	95064.	292002.	66203.	14820.	3294645.
1971	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	113138.	510339.	623477.
1972	284791.	139690.	47099.	1083.	315660.	0.	0.	0.	7141.	0.	194018.	98079.	1087560.
1973	305465.	350702.	695774.	1113613.	713865.	1169596.	88348.	45515.	107265.	1251374.	436150.	362808.	6640475.
1974	746329.	337723.	111431.	42450.	180732.	0.	0.	0.	947479.	480284.	1490598.	658065.	4995091.
1975	402441.	1249879.	331629.	528175.	1564398.	823695.	271953.	127522.	109657.	37059.	53251.	13892.	5513551.
1976	1239.	22336.	33153.	594375.	923836.	395487.	320816.	47013.	102181.	226304.	229841.	979827.	3876406.
1977	300715.	1056472.	414795.	1969789.	717011.	132788.	0.	0.	79743.	0.	0.	0.	4671313.
1978	111656.	168724.	83099.	0.	0.	0.	0.	0.	58949.	0.	35527.	38559.	496514.
1979	510120.	428741.	605736.	929371.	1156849.	1565691.	259543.	258327.	246755.	36348.	44470.	84222.	6126175.
1980	324075.	308011.	114767.	209338.	769903.	229955.	0.	0.	0.	0.	0.	0.	1956049.
1981	0.	0.	14034.	0.	71658.	1400635.	250958.	0.	133519.	358557.	680298.	74817.	2984477.
1982	32914.	26877.	30445.	210489.	1006476.	730755.	232990.	10770.	29056.	2518.	64196.	159985.	2537472.
1983	147372.	519088.	0.	212538.	772483.	181141.	0.	129811.	140270.	0.	33693.	81600.	2217995.
1984	32611.	20134.	86019.	0.	0.	0.	0.	0.	0.	420479.	372946.	480405.	1412595.

Table 7.7
UNAPPROPRIATED STREAMFLOWS AT GRANBURY RESERVOIR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	18206.	0.	0.	481520.	88847.	67512.	0.	0.	303202.	87333.	12990.	0.	1059609.
1901	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1902	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1903	9857.	144550.	88612.	0.	0.	0.	0.	0.	0.	0.	0.	0.	243019.
1904	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1905	0.	0.	0.	0.	158103.	0.	0.	0.	0.	0.	0.	0.	158103.
1906	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1907	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1908	0.	0.	0.	122866.	911937.	27509.	0.	0.	0.	0.	0.	0.	1062312.
1909	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1910	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1911	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1912	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1913	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	114504.	114504.
1914	7391.	0.	0.	5515.	226637.	64190.	0.	0.	0.	0.	0.	0.	303733.
1915	0.	0.	0.	89264.	262646.	461437.	0.	0.	0.	0.	0.	0.	813347.
1916	0.	0.	0.	28849.	71740.	2847.	0.	0.	0.	0.	0.	0.	103436.
1917	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1918	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1919	43835.	82656.	58809.	108810.	279555.	286163.	58024.	0.	117173.	1027071.	82914.	54728.	2199737.
1920	49716.	45301.	42222.	0.	84528.	56501.	0.	0.	326687.	69303.	58420.	9772.	742449.
1921	7615.	48092.	7369.	0.	0.	43350.	0.	0.	0.	0.	0.	0.	106427.
1922	0.	0.	0.	0.	310172.	78951.	0.	0.	0.	0.	0.	0.	389123.
1923	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	8528.	8528.
1924	7983.	2940.	69303.	20996.	64824.	0.	0.	0.	0.	0.	0.	0.	166046.
1925	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1926	0.	0.	0.	0.	0.	0.	0.	0.	0.	33257.	0.	0.	33257.
1927	0.	0.	0.	54276.	10822.	4705.	0.	0.	0.	0.	0.	0.	69802.
1928	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1929	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1930	0.	0.	0.	0.	0.	139608.	0.	0.	0.	9316.	5414.	106206.	260543.
1931	102.	55304.	9903.	2995.	6188.	0.	0.	0.	0.	0.	0.	0.	74491.
1932	0.	48230.	20102.	0.	28385.	109993.	201051.	0.	240833.	0.	0.	0.	648594.
1933	0.	0.	15236.	0.	7280.	0.	0.	0.	0.	0.	0.	0.	22516.
1934	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1935	0.	0.	0.	0.	242892.	318396.	31894.	0.	24171.	0.	0.	3177.	620529.
1936	0.	0.	0.	0.	12885.	0.	0.	0.	0.	72187.	18415.	6048.	109534.
1937	2912.	0.	9969.	0.	0.	0.	0.	0.	0.	0.	0.	0.	12882.
1938	0.	0.	34195.	54406.	3319.	0.	0.	0.	0.	0.	0.	0.	91919.
1939	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1940	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	47943.	47943.
1941	15781.	115166.	34342.	93346.	1054309.	638554.	76469.	102565.	5423.	565084.	134896.	0.	2835935.
1942	0.	0.	0.	740206.	335443.	195779.	0.	0.	0.	394394.	17413.	5867.	1689102.
1943	0.	0.	0.	0.	7615.	0.	0.	0.	0.	0.	0.	0.	7615.
1944	0.	0.	0.	0.	81505.	0.	0.	0.	0.	0.	0.	0.	81505.
1945	0.	1645.	129992.	111834.	17850.	0.	80328.	0.	0.	0.	0.	0.	341649.
1946	0.	0.	0.	0.	26496.	6613.	0.	0.	0.	0.	0.	0.	33109.
1947	2618.	0.	34352.	13815.	196626.	0.	0.	0.	0.	0.	0.	0.	247412.
1948	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1949	0.	0.	0.	0.	178087.	15469.	0.	0.	0.	0.	0.	0.	193555.
1950	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1951	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1952	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1953	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1954	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1955	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1956	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1957	0.	0.	0.	0.	2335987.	450784.	0.	0.	0.	0.	66065.	6296.	2859132.
1958	14288.	8095.	41926.	34905.	383357.	0.	0.	0.	0.	0.	0.	0.	482571.
1959	0.	0.	0.	0.	0.	0.	0.	0.	0.	263311.	957.	5812.	270080.
1960	47640.	18030.	7504.	0.	0.	0.	0.	0.	0.	0.	0.	0.	73175.
1961	0.	18800.	19898.	0.	0.	25035.	151566.	0.	0.	0.	0.	0.	215299.
1962	0.	0.	0.	0.	0.	0.	0.	0.	252360.	48124.	0.	0.	300484.
1963	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1964	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1965	0.	0.	0.	0.	125280.	0.	0.	0.	0.	0.	0.	0.	125280.
1966	0.	0.	0.	0.	193991.	11358.	0.	0.	278729.	0.	0.	0.	484077.
1967	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1968	0.	0.	208979.	90087.	169735.	74411.	16544.	0.	0.	0.	0.	0.	559756.
1969	0.	0.	0.	36904.	441071.	0.	0.	0.	0.	0.	0.	0.	477976.
1970	0.	0.	123239.	33741.	76818.	0.	0.	0.	0.	0.	0.	0.	233797.
1971	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	25197.	25197.
1972	7752.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	7752.
1973	0.	0.	0.	50648.	22391.	47368.	0.	0.	0.	0.	0.	0.	120407.
1974	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	134170.	10946.	145116.
1975	10660.	102591.	8516.	60307.	52510.	161392.	0.	0.	0.	0.	0.	0.	395977.
1976	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1977	0.	0.	124334.	15983.	7438.	0.	0.	0.	0.	0.	0.	0.	147755.
1978	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1979	0.	0.	0.	0.	35419.	10301.	0.	0.	0.	0.	0.	0.	45720.
1980	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1981	0.	0.	0.	0.	0.	0.	0.	0.	0.	352103.	87597.	0.	439700.
1982	0.	0.	0.	0.	530225.	730755.	120870.	0.	0.	0.	0.	0.	1381851.
1983	0.	0.	0.	110830.	76096.	0.	0.	0.	0.	0.	0.	0.	186925.
1984	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Table 7.8
UNAPPROPRIATED STREAMFLOWS AT THE CAMERON GAGE

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	21738.	17234.	66835.	347777.	982207.	144712.	0.	0.	45926.	355488.	101514.	60763.	2144194.
1901	9893.	25710.	30938.	22390.	40009.	28319.	0.	0.	14940.	0.	0.	0.	172199.
1902	0.	0.	0.	0.	0.	0.	0.	26651.	3700.	13872.	14244.	9056.	67522.
1903	102795.	251432.	447040.	116656.	29558.	0.	12579.	22041.	10924.	48309.	23562.	21417.	1086313.
1904	22280.	22293.	0.	607.	7960.	0.	0.	0.	802.	0.	25806.	0.	79748.
1905	16637.	34807.	12308.	407069.	1390508.	85102.	0.	20985.	17920.	11425.	62632.	138636.	2198028.
1906	50186.	44509.	31814.	6894.	0.	0.	0.	0.	161512.	0.	55482.	139155.	489552.
1907	15115.	31938.	57797.	8429.	86578.	0.	0.	40580.	12731.	181199.	34720.	23328.	492416.
1908	28880.	66900.	79945.	824157.	658981.	44684.	0.	500.	49795.	61762.	45758.	32213.	1893574.
1909	5933.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	5933.
1910	0.	1584.	0.	2412.	0.	0.	0.	0.	0.	0.	0.	0.	3996.
1911	0.	15567.	12626.	8213.	27156.	12506.	0.	2595.	0.	0.	0.	0.	78661.
1912	5805.	4852.	15064.	25200.	0.	885.	0.	0.	0.	539.	0.	0.	52345.
1913	0.	1140.	9099.	23187.	76067.	57804.	0.	0.	45883.	28688.	63557.	483757.	789183.
1914	7112.	28510.	37972.	313454.	1632708.	329516.	66816.	0.	0.	108785.	87212.	57479.	2669564.
1915	78019.	26710.	96804.	843103.	702192.	546536.	247710.	24614.	15681.	222709.	51612.	68298.	2923989.
1916	131620.	194106.	87647.	141111.	97201.	75553.	0.	0.	31318.	56113.	12887.	6536.	834091.
1917	6932.	0.	0.	0.	12214.	11883.	0.	0.	0.	0.	0.	0.	31028.
1918	0.	0.	0.	77649.	0.	0.	0.	0.	0.	0.	45886.	127939.	251474.
1919	89055.	21052.	63459.	88106.	116640.	274036.	196773.	51578.	111733.	405441.	321525.	219623.	1959020.
1920	486992.	192819.	101215.	42540.	191274.	77032.	12648.	149054.	129584.	46928.	87180.	59684.	1576950.
1921	55375.	42353.	66508.	167306.	78473.	101771.	52733.	0.	703511.	29620.	18734.	23371.	1339754.
1922	23214.	32309.	85795.	720128.	973159.	83032.	0.	6077.	16332.	7511.	15927.	3823.	1967304.
1923	4689.	16352.	26892.	166564.	66431.	0.	0.	0.	44865.	0.	27683.	219103.	572579.
1924	91333.	159700.	136366.	132316.	116519.	95179.	0.	0.	0.	15439.	0.	0.	746852.
1925	0.	0.	0.	0.	0.	0.	0.	0.	0.	23982.	85375.	16768.	126125.
1926	106701.	32925.	145095.	373091.	242762.	0.	0.	26802.	20025.	21784.	19674.	23204.	1012060.
1927	21303.	132234.	138366.	128189.	51114.	169173.	25623.	11310.	14985.	100455.	24602.	14674.	832026.
1928	18916.	68305.	30664.	0.	0.	24041.	0.	15583.	0.	0.	0.	9506.	167015.
1929	11366.	13271.	19700.	62105.	437749.	105359.	25076.	3714.	0.	0.	27741.	11594.	717674.
1930	12275.	27866.	25874.	0.	377049.	31075.	0.	0.	20492.	44587.	20918.	78134.	638270.
1931	106031.	148900.	144960.	79110.	96935.	0.	0.	0.	13781.	0.	7089.	1866.	598671.
1932	57823.	73761.	135654.	40493.	276210.	96996.	11476.	18053.	134361.	16703.	12925.	0.	874454.
1933	47916.	27349.	41608.	22561.	7280.	24442.	0.	19141.	17672.	0.	8424.	0.	216393.
1934	46756.	56855.	77076.	163065.	14769.	0.	0.	0.	0.	0.	0.	10266.	368787.
1935	12631.	37660.	13396.	11288.	314739.	427135.	31894.	20881.	148434.	74737.	51520.	231922.	1376238.
1936	53966.	29809.	28817.	0.	633688.	160501.	150605.	18685.	0.	294099.	158684.	338413.	1867268.
1937	272708.	146361.	195907.	66418.	0.	0.	0.	0.	17255.	0.	34916.	88263.	821828.
1938	391046.	312764.	123916.	315771.	241906.	0.	0.	52730.	18577.	0.	13111.	8982.	1478803.
1939	14813.	9759.	14684.	0.	29037.	0.	8627.	0.	0.	0.	0.	0.	76920.
1940	0.	19478.	0.	0.	3476.	0.	315189.	0.	0.	0.	258746.	579810.	1176699.
1941	301170.	450782.	465021.	360984.	704533.	331701.	244411.	19239.	35029.	64188.	16711.	19014.	3012783.
1942	17229.	13939.	9174.	387212.	409800.	362587.	0.	0.	308993.	179052.	87470.	64591.	1840046.
1943	42136.	22667.	42597.	52024.	38361.	13810.	1961.	14866.	14236.	6932.	1535.	11149.	262274.
1944	58280.	141112.	271202.	84708.	1034773.	310970.	0.	0.	40914.	0.	43282.	108983.	2094223.
1945	232551.	253347.	333003.	716681.	167835.	162684.	35766.	29310.	22681.	63913.	25248.	57201.	2100220.
1946	127464.	186097.	269534.	131575.	271843.	91340.	18725.	0.	0.	23709.	156901.	110785.	1387973.
1947	231582.	80940.	166115.	126548.	130486.	32818.	0.	16102.	15971.	0.	4963.	6432.	811957.
1948	12766.	0.	16245.	21664.	6322.	0.	0.	0.	0.	0.	0.	0.	56996.
1949	0.	0.	0.	162236.	46718.	15208.	12772.	0.	14333.	10565.	11657.	14422.	287912.
1950	11570.	36343.	10932.	45975.	22403.	26935.	0.	4043.	0.	11001.	6434.	1776.	177411.
1951	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1952	0.	0.	0.	13051.	0.	23410.	0.	0.	0.	0.	0.	0.	36461.
1953	27014.	17150.	5891.	0.	51725.	0.	0.	0.	0.	16061.	26320.	132219.	276380.
1954	15657.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	15657.
1955	0.	12414.	0.	16576.	0.	0.	0.	0.	0.	0.	0.	0.	28990.
1956	0.	3860.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3860.
1957	0.	0.	0.	0.	631951.	390819.	32759.	30709.	23475.	471587.	206097.	94772.	1882167.
1958	76741.	453010.	251620.	121492.	350683.	72324.	0.	0.	70436.	28251.	23581.	17898.	1466034.
1959	16737.	30583.	15995.	50584.	37276.	6487.	0.	18189.	0.	505376.	135228.	227863.	1044317.
1960	331564.	220736.	104490.	58536.	31397.	18456.	15373.	17118.	15902.	209774.	121827.	366107.	1511278.
1961	527649.	584153.	209309.	75608.	33640.	181846.	178079.	30404.	107537.	74448.	47066.	59828.	2109565.
1962	30383.	29403.	19200.	22169.	23843.	42954.	0.	4677.	18606.	24868.	48477.	51031.	315612.
1963	17982.	43424.	14707.	21686.	0.	0.	0.	0.	0.	0.	0.	0.	97799.
1964	0.	10257.	13395.	0.	17848.	0.	0.	0.	0.	0.	0.	18958.	60458.
1965	155816.	261302.	104181.	84103.	1368072.	149367.	0.	19797.	33816.	39551.	138500.	120674.	2475179.
1966	63006.	117109.	81007.	353867.	258392.	44137.	0.	26496.	117683.	24834.	16631.	13817.	1116979.
1967	14138.	13225.	0.	15373.	53419.	0.	0.	0.	0.	0.	60881.	24799.	181835.
1968	488118.	169892.	402048.	213029.	458865.	200338.	157473.	20605.	29632.	14505.	25956.	54529.	2234990.
1969	23982.	75979.	104276.	222207.	234228.	34620.	0.	14874.	23156.	12361.	14423.	56471.	816576.
1970	58427.	120337.	471901.	158881.	212044.	75306.	0.	0.	22229.	27125.	12261.	10198.	1168710.
1971	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	30473.	41883.	72356.
1972	22835.	25185.	13414.	1083.	45282.	0.	0.	0.	7141.	0.	35862.	23604.	174405.
1973	85172.	67182.	97418.	119545.	118070.	47593.	32848.	19107.	33374.	225756.	100773.	42263.	989101.
1974	74623.	36960.	25114.	16277.	106831.	0.	0.	0.	145623.	160018.	372860.	106705.	1045012.
1975	115196.	386815.	109077.	125931.	567369.	233545.	100429.	48083.	33032.	22632.	16781.	13892.	1772780.
1976	1239.	12223.	19777.	240463.	208194.	64675.	133358.	31109.	32689.	53303.	59384.	138135.	994549.
1977	74065.	242720.	116440.	634088.	210989.	42938.	0.	0.	16724.	0.	0.	0.	1337964.
1978	12272.	16701.	18242.	0.	0.	0.	0.	0.	11245.	0.	14111.	6788.	79360.
1979	56089.	76484.	166421.	154523.	289834.	189818.	210450.	52132.	27255.	15453.	14986.	21849.	1275295.
1980	27991.	35542.	47427.	36416.	172583.	20164.	0.	0.	0.	0.	0.	0.	340123.
1981	0.	0.	14034.	0.	29444.	581803.	66605.	0.	80626.	89099.	48838.	25432.	935882.
1982	23330.	18356.	14546.	53958.	165697.	47331.	18134.	10770.	12029.	2518.	16352.	12447.	395468.
1983	17355.	60938.	0.	30186.	144682.	78031.	0.	30542.	11259.	0.	9370.	6283.	388645.
1984	12092.	10751.	14844.	0.	0.	0.	0.	0.	0.	84023.	35303.	65079.	222092.

Table 7.9
SHORTAGES AT THE RICHMOND GAGE CONTROL POINT

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1900	0.0	0.0	0.0	0.0	0.0	0.0	45.9	0.0	0.0	0.0	0.0	0.0	45.9
1901	0.0	0.0	0.0	0.0	0.0	0.0	20260.4	3160.1	0.0	7961.0	4173.9	4174.0	39729.4
1902	701.3	2.8	0.0	14.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	720.2
1903	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1904	0.0	0.0	4183.7	0.0	0.0	0.0	45.9	31.0	0.0	4188.9	0.0	0.0	8449.5
1905	0.0	0.0	0.0	0.0	0.0	0.0	11084.6	0.0	0.0	0.0	0.0	0.0	11084.6
1906	0.0	0.0	0.0	0.0	27.2	0.0	4739.9	2.1	0.0	0.0	0.0	0.0	4769.2
1907	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1908	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1909	0.0	4174.3	4183.7	4185.1	0.0	44.0	5234.6	18121.7	12484.3	4361.0	4173.9	4174.0	61136.6
1910	2.1	0.0	10462.7	0.0	0.0	23997.5	55308.0	53394.1	12484.3	8561.0	6873.9	4174.0	175257.6
1911	4172.5	0.0	0.0	0.0	0.0	0.0	4739.9	0.0	4834.3	4361.0	4173.9	0.0	22281.6
1912	0.0	0.0	0.0	0.0	27.2	0.0	22758.7	27697.6	12484.3	0.0	3.1	2499.5	65470.4
1913	7322.5	0.0	0.0	0.0	0.0	0.0	0.0	12929.0	0.0	0.0	0.0	0.0	20251.5
1914	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.0	0.0	0.0	0.0	0.0	31.0
1915	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1916	0.0	0.0	0.0	0.0	0.0	0.0	4404.9	3.1	0.0	0.0	0.0	0.0	4408.0
1917	0.0	4195.8	0.0	2715.4	0.0	0.0	22758.7	27697.6	4834.3	10219.4	4173.9	4174.0	80769.1
1918	4172.5	4174.3	7462.7	0.0	3922.6	44.0	22758.7	10447.6	4705.2	0.0	0.0	0.0	57687.6
1919	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1920	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1921	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1
1922	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1923	0.0	0.0	0.0	0.0	0.0	0.0	4739.9	0.0	0.0	17.8	0.0	0.0	4757.7
1924	0.0	0.0	0.0	0.0	0.0	0.0	1365.5	0.0	1105.0	0.0	2.9	2.9	2476.3
1925	0.0	4.6	5549.5	15716.8	27.2	25622.2	39399.8	27697.6	8884.3	0.0	0.0	0.0	122902.0
1926	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1927	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1928	0.0	0.0	0.0	0.0	4479.3	0.0	4739.9	0.0	0.0	4188.9	299.8	0.0	13707.9
1929	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1930	0.0	0.0	0.0	0.0	0.0	0.0	45.9	0.0	0.0	0.0	0.0	0.0	45.9
1931	0.0	0.0	0.0	0.0	0.0	0.0	5234.6	2.1	0.0	4188.9	0.0	0.0	9425.6
1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1933	0.0	0.0	0.0	0.0	0.0	0.0	13513.7	0.0	0.0	17.8	0.0	4174.0	17705.5
1934	0.0	0.0	0.0	0.0	0.0	10739.8	21954.9	10447.6	8884.3	7961.0	4173.9	0.0	64161.5
1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1936	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1937	0.0	0.0	0.0	0.0	0.0	0.0	4739.9	10447.6	0.0	17.8	0.0	0.0	15205.3
1938	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1939	0.0	0.0	0.0	14.3	0.0	0.0	0.0	4725.0	14.0	7961.0	4173.9	2.9	16891.1
1940	2.1	0.0	4183.7	14.0	0.0	44.0	0.0	31.0	263.6	4188.9	0.0	0.0	8727.3
1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1942	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	2.1
1943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1944	0.0	0.0	0.0	0.0	0.0	0.0	45.9	0.0	0.0	0.0	0.0	0.0	45.9
1945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0	3.1
1947	0.0	0.0	0.0	0.0	0.0	0.0	4739.9	0.0	0.0	4361.0	0.0	0.0	9100.9
1948	0.0	0.0	0.0	0.0	0.0	4737.9	2.1	4725.0	4705.2	8572.3	4173.9	4174.0	31090.4
1949	4172.5	0.0	0.0	0.0	0.0	0.0	0.0	10.6	0.0	0.0	0.0	0.0	4183.1
1950	0.0	0.0	0.0	0.0	0.0	0.0	45.9	0.0	0.0	0.0	0.0	0.0	45.9
1951	4172.5	3966.2	4183.7	2.1	8079.3	4737.9	33914.7	30121.5	12484.3	12561.0	6873.9	7324.0	128421.1
1952	6126.0	4174.3	4266.9	0.0	0.0	0.0	32510.2	47132.2	12484.3	18561.0	7473.9	0.0	132728.8
1953	0.0	0.0	0.0	14.3	0.0	5211.1	22759.7	18697.6	3434.7	0.0	0.0	0.0	50117.4
1954	0.0	0.0	7462.7	7464.2	4199.6	5211.1	51452.8	27697.6	19234.3	16367.6	7473.9	8723.6	155287.4
1955	7470.7	0.0	4183.7	0.0	4199.6	4737.9	17304.8	10447.6	4834.3	17.8	2.1	4174.0	57372.5
1956	4172.5	0.0	4312.7	4314.2	4199.6	28389.4	66255.6	42250.9	19234.3	19183.1	9770.8	4174.0	206257.1
1957	7491.2	4445.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11936.9
1958	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1959	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.0	14.0
1960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	0.0	0.0	0.0	0.0	0.0	4739.9	2402.1	14.0	4864.6	2.9	0.0	12023.5
1964	0.0	0.0	0.0	14.0	0.0	5211.1	28087.8	18697.6	4705.2	4188.9	0.0	0.0	60904.6
1965	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	2.1
1966	0.0	0.0	0.0	0.0	0.0	0.0	1040.7	0.0	0.0	0.0	0.0	0.0	1040.7
1967	0.0	0.0	0.0	0.0	0.0	0.0	45.9	7967.8	2.9	4188.9	0.0	0.0	12205.5
1968	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	0.0	0.0	0.0	0.0	0.0	0.0	4739.9	0.0	0.0	0.0	0.0	0.0	4739.9
1970	0.0	0.0	0.0	0.0	0.0	0.0	5234.6	4725.0	0.0	0.0	0.0	0.0	9959.6
1971	2.1	4.6	13.9	14.0	27.2	9711.1	4739.9	31.0	14.0	0.0	0.0	0.0	14557.8
1972	0.0	0.0	0.0	0.0	0.0	0.0	4739.9	0.0	0.0	0.0	0.0	0.0	4739.9
1973	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1974	0.0	0.0	0.0	0.0	0.0	5211.1	11259.7	31.0	0.0	0.0	0.0	0.0	16501.8
1975	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1976	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1977	0.0	0.0	0.0	0.0	0.0	0.0	4739.9	0.0	0.0	4361.0	2.1	0.0	9103.0
1978	0.0	0.0	0.0	4185.1	8511.7	9711.1	32515.5	4725.0	0.0	11981.9	0.0	0.0	71630.3
1979	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1980	0.0	0.0	0.0	0.0	0.0	0.0	32523.9	27697.6	8884.3	4188.9	4173.9	4174.0	81642.6
1981	4172.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4172.5
1982	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1983	0.0	0.0	15712.7	0.0	0.0	0.0	4739.9	0.0	0.0	0.0	0.0	0.0	20452.6
1984	0.0	0.0	0.0	7464.2	8079.3	15486.8	41039.3	27697.6	12484.3	0.0	0.0	0.0	112251.5

Table 7.10
RELIABILITIES AND SHORTAGES BY CONTROL POINT

NAME	PERMITTED DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	NUMBER OF PERIODS WITH SHORTAGES EQUALLING OR EXCEEDING PERCENT OF PERMITTED DIVERSION AMOUNT: 0%	5%	10%	25%	50%	75%	100%	NUMBER OF YEARS: 0%	2%	5%	10%	25%	50%	100%
CP1	61596.0	13458.0	7.55	78.15	943	245	234	228	224	213	0	85	68	36	36	25	15	0
CP2	196800.0	46344.2	17.06	76.45	846	840	815	359	100	8	0	85	84	82	76	25	8	0
CP3	174162.0	1480.8	17.94	99.15	837	67	5	0	0	0	0	85	8	4	0	0	0	0
CP4	86930.0	3608.2	41.86	95.85	593	165	102	32	27	1	0	83	40	19	10	2	0	0
CP5	68855.0	6365.0	50.10	90.76	509	318	312	309	0	0	0	81	55	41	25	16	0	0
CP6	6811.0	57.6	84.41	99.15	159	9	9	8	7	7	4	60	2	2	2	1	0	0
CP7	69339.0	3176.4	44.41	95.42	567	355	109	0	0	0	0	83	66	28	8	0	0	0
CP9	39896.0	9899.3	13.63	75.19	881	680	536	317	126	94	0	85	85	77	54	30	15	0
CP10	199819.0	20118.2	29.02	89.93	724	419	299	125	27	21	0	85	71	53	31	4	2	0
CP11	47911.0	1585.2	58.04	96.69	428	196	71	0	0	0	0	82	47	21	2	0	0	0
CP12	13774.8	22.5	76.47	99.84	240	0	0	0	0	0	0	51	0	0	0	0	0	0
CP13	12733.0	453.2	57.25	96.44	436	279	87	0	0	0	0	78	53	21	5	0	0	0
CP14	32706.0	3568.0	77.16	89.09	233	198	191	105	66	63	0	57	52	41	22	17	3	0
CP15	111182.1	10693.4	77.94	90.38	225	222	213	151	22	0	0	56	52	48	30	13	0	0
CP16	26376.0	29.5	57.75	99.89	431	1	1	1	1	0	0	76	1	0	0	0	0	0
CP17	52988.9	285.6	33.53	99.46	678	21	1	1	1	0	0	85	2	1	0	0	0	0
CP18	105544.0	7382.3	75.39	93.01	251	226	191	102	33	2	0	58	48	34	19	8	0	0
CP19	976821.6	24125.1	75.69	97.53	248	147	76	12	0	0	0	58	22	17	7	0	0	0

Table 7.11
RELIABILITIES AND SHORTAGES FOR BRA/USACE RESERVOIRS

NAME	PERMITTED DIVERSION (AC-FT/YR)	MEAN SHORTAGE (AC-FT/YR)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	NUMBER OF PERIODS WITH SHORTAGES EQUALLING OR EXCEEDING PERCENT OF PERMITTED DIVERSION AMOUNT: 0%	5%	10%	25%	50%	75%	100%	NUMBER OF YEARS: 0%	2%	5%	10%	25%	50%	100%
HUBBAR	56000.0	11940.4	76.86	78.68	236	234	233	228	225	217	209	36	36	36	36	25	16	5
POSSUM	153200.0	0.0	100.00	100.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GRANBU	54936.0	1521.8	96.67	97.23	34	34	34	32	29	27	22	12	11	10	7	3	1	0
WHITNE	18336.0	5417.8	69.31	70.45	313	313	313	312	311	310	307	57	56	55	47	31	21	10
AQUILL	6770.0	48.6	99.12	99.28	9	9	9	8	7	7	7	2	2	2	2	1	0	0
WACO	59100.0	0.0	100.00	100.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PROCTO	19657.8	3201.4	83.33	83.71	170	170	170	168	168	163	160	21	19	18	17	15	15	7
BELTON	100257.1	2608.4	96.76	97.40	33	32	31	30	29	25	22	9	8	8	7	3	2	0
STILLH	39530.2	0.0	100.00	100.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GEORGE	13610.0	0.0	100.00	100.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GRANGE	10961.9	0.0	100.00	100.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOMERV	26257.2	9.5	99.90	99.96	1	1	1	1	1	0	0	1	1	0	0	0	0	0
LIMEST	46840.0	28.4	99.90	99.94	1	1	1	1	1	0	0	1	1	1	0	0	0	0
SYSTEM	171544.9	0.0	100.00	100.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 7.12
RELIABILITIES AND SHORTAGES FOR WHITNEY HYDROELECTRIC ENERGY

NAME	FIRM POWER (MW/GW-hr)	MEAN SHORTAGE (MW/GW-hr)	*RELIABILITY* PERIOD (%)	*RELIABILITY* VOLUME (%)	NUMBER OF PERIODS WITH SHORTAGES EQUALLING OR EXCEEDING PERCENT OF FIRM POWER: 0%	5%	10%	25%	50%	75%	100%	NUMBER OF YEARS: 0%	2%	5%	10%	25%	50%	100%
WHTNEY	36000.0	12585.8	59.02	65.04	418	415	408	398	375	340	307	64	63	61	57	37	25	10

Table 7.13
MEAN UNREGULATED FLOWS, LOADS, AND CONCENTRATIONS

CONTROL POINT	DISCHARGE (Ac-ft/Month)	CONCENTRATIONS (mg/l)			LOADS (Tons/Month)			EOP LOAD IN STORAGE (Tons)		
		1	2	3	1	2	3	1	2	3
CP1	9498.	150.5	57.2	20.0	1943.	739.	258.			
CP2	61506.	1429.4	575.1	296.1	119538.	48091.	24764.			
CP3	74472.	1202.5	498.7	247.4	121764.	50498.	25047.			
CP4	97050.	1047.6	424.2	208.5	138239.	55974.	27516.			
CP5	138290.	700.1	262.6	137.3	131640.	49384.	25817.			
CP6	6094.	247.0	14.0	70.9	2047.	116.	587.			
CP7	27227.	141.0	16.9	16.3	5220.	626.	603.			
CP9	9597.	127.5	16.7	12.4	1664.	218.	162.			
CP10	38976.	127.5	16.7	12.4	6758.	886.	658.			
CP11	18374.	127.5	16.7	12.4	3186.	418.	310.			
CP12	5403.	141.1	16.9	16.3	1037.	124.	120.			
CP13	14920.	141.1	16.9	16.4	2862.	342.	332.			
CP14	107225.	141.1	16.9	16.3	20570.	2459.	2384.			
CP15	324453.	386.0	93.2	67.7	170263.	41110.	29860.			
CP16	19518.	97.9	24.4	16.9	2598.	647.	448.			
CP17	18411.	131.0	22.0	13.0	3280.	550.	325.			
CP18	436057.	310.5	71.0	52.2	184112.	42096.	30972.			
CP19	472287.	308.3	67.1	50.0	197965.	43082.	32083.			

Table 7.14
MEAN REGULATED FLOWS, LOADS, AND CONCENTRATIONS

CONTROL POINT	DISCHARGE (Ac-ft/Month)	CONCENTRATIONS (mg/l)			LOADS (Tons/Month)			EOP LOAD IN STORAGE (Tons)		
		1	2	3	1	2	3	1	2	3
CP1	2688.	200.2	76.2	26.6	732.	278.	97.	36157.	13753.	4808.
CP2	32821.	1917.5	771.9	398.8	85566.	34444.	17796.	1000800.	402816.	207988.
CP3	27795.	1539.2	645.8	317.1	58167.	24406.	11983.	1101231.	462787.	226693.
CP4	41323.	1155.0	462.3	223.9	64891.	25975.	12582.	286723.	113586.	55100.
CP5	50236.	564.1	191.8	106.7	38533.	13098.	7288.	596407.	191204.	107742.
CP6	4804.	275.0	15.5	78.9	1796.	102.	516.	17318.	978.	4970.
CP7	19445.	150.0	18.0	17.3	3965.	475.	458.	31617.	3787.	3647.
CP9	5360.	148.3	19.4	14.4	1081.	142.	105.	14905.	1954.	1451.
CP10	17621.	135.2	17.7	13.2	3238.	424.	315.	67519.	8851.	6573.
CP11	13184.	134.6	17.6	13.1	2412.	316.	235.	38620.	5062.	3760.
CP12	3997.	145.9	17.4	16.9	793.	95.	92.	6839.	817.	792.
CP13	12097.	150.8	18.0	17.5	2481.	297.	287.	12400.	1482.	1437.
CP14	86637.	152.2	17.6	18.6	17933.	2076.	2185.	818.	88.	110.
CP15	226377.	270.8	36.3	43.0	83364.	11176.	13225.	32105.	4047.	5133.
CP16	15456.	105.8	26.3	18.2	2224.	554.	383.	23296.	5799.	4013.
CP17	11180.	147.1	24.7	14.6	2236.	375.	222.	43182.	7245.	4280.
CP18	325645.	216.8	28.4	32.5	95976.	12558.	14391.	30803.	3948.	4644.
CP19	286094.	223.2	29.0	32.0	86830.	11288.	12434.	29214.	3836.	4158.

Table 7.15
UNREGULATED FLOW-DURATION RELATIONSHIPS

CONTROL POINT	DISCHARGES (Acre-feet/Month) PERCENT OF MONTHS EQUALLED OR EXCEEDED 0	5	10	25	50	75	90	95	99	100
CP1	281243.0	39976.0	27527.0	8043.0	1521.0	10.0	0.0	0.0	0.0	0.0
CP2	1508093.4	265923.3	167101.0	62191.1	18828.9	5312.2	1002.6	73.5	0.0	0.0
CP3	1826000.0	321980.0	202326.0	75301.0	22798.0	6432.0	1214.0	89.0	0.0	0.0
CP4	2724000.0	359130.0	248469.0	107810.0	35513.0	10497.0	3100.0	1196.0	0.0	0.0
CP5	3363000.0	511727.0	355266.0	163971.0	62121.0	21531.0	8358.0	4508.0	224.0	0.0
CP6	149625.3	28905.7	17268.0	4867.1	966.1	96.5	0.0	0.0	0.0	0.0
CP7	588483.0	124919.0	79510.0	28379.0	7718.0	2662.0	1510.0	1127.0	529.0	0.0
CP9	355787.0	43419.0	20178.0	7644.0	2222.0	519.0	49.0	0.0	0.0	0.0
CP10	718653.0	160160.0	107292.0	42000.0	12936.0	3437.0	550.0	0.0	0.0	0.0
CP11	312711.0	80352.0	46597.0	19728.0	6650.0	2112.0	637.0	132.0	0.0	0.0
CP12	75024.0	21086.0	14621.0	6837.0	2172.0	562.0	118.0	0.0	0.0	0.0
CP13	214404.0	60278.0	39482.0	18575.0	5663.0	1720.0	338.0	42.0	0.0	0.0
CP14	1672000.0	418548.0	283014.0	124064.0	40929.0	14575.0	4949.0	2323.0	237.0	0.0
CP15	4773000.0	1196000.0	784250.0	388488.0	159199.0	57692.0	24720.0	15182.0	4646.0	0.0
CP16	360985.0	95399.0	62675.0	18707.0	3850.0	477.0	0.0	0.0	0.0	0.0
CP17	288364.9	85362.3	54102.5	19585.0	3791.0	533.9	94.8	16.0	0.0	0.0
CP18	6113000.0	1560000.0	1055000.0	521919.0	231003.0	88269.0	39762.0	27631.0	11867.0	0.0
CP19	7354000.0	1592000.0	1122000.0	565529.0	258866.0	105469.0	48736.0	34307.0	18108.0	0.0

Table 7.16
REGULATED FLOW-DURATION RELATIONSHIPS

CONTROL POINT	DISCHARGES (Acre-feet/Month) PERCENT OF MONTHS EQUALLED OR EXCEEDED 0	5	10	25	50	75	90	95	99	100
CP1	161262.3	18407.1	6293.6	3.4	0.0	0.0	0.0	0.0	0.0	0.0
CP2	1283582.6	149233.2	81944.1	22895.2	6254.5	17.0	6.0	0.0	0.0	0.0
CP3	1477773.4	145834.1	64780.7	9720.2	19.7	4.7	0.0	0.0	0.0	0.0
CP4	2335965.3	182409.9	107511.7	28384.3	4498.0	14.1	3.6	0.0	0.0	0.0
CP5	2955736.0	261175.2	139312.9	31635.7	361.8	78.7	12.4	3.7	0.0	0.0
CP6	148597.6	24809.8	15008.8	2439.3	0.0	0.0	0.0	0.0	0.0	0.0
CP7	581014.0	113607.7	66648.0	12895.9	0.0	0.0	0.0	0.0	0.0	0.0
CP9	349138.2	23721.6	9978.7	1826.5	8.4	0.0	0.0	0.0	0.0	0.0
CP10	692871.3	109798.5	51637.3	341.3	0.0	0.0	0.0	0.0	0.0	0.0
CP11	311320.8	70846.7	36703.2	14378.4	0.0	0.0	0.0	0.0	0.0	0.0
CP12	73663.1	19224.0	11991.2	4803.5	283.1	0.0	0.0	0.0	0.0	0.0
CP13	205672.9	54828.4	34799.1	14856.1	2218.4	0.0	0.0	0.0	0.0	0.0
CP14	1633277.4	362631.4	222724.3	84109.7	30664.3	16438.5	11680.8	9756.8	3569.8	0.0
CP15	4060800.0	869331.1	546862.5	224034.9	98527.3	50883.4	28930.9	19278.6	1605.4	18.7
CP16	358516.0	85742.4	55552.1	12008.2	0.0	0.0	0.0	0.0	0.0	0.0
CP17	282229.7	69812.2	35581.3	4528.9	0.0	0.0	0.0	0.0	0.0	0.0
CP18	5697810.0	1215776.1	790486.8	351268.6	130256.0	81977.0	48691.5	40629.1	27270.3	138.6
CP19	6878234.5	1202424.8	774663.6	322802.7	67473.3	263.6	29.7	10.5	0.0	0.0

Table 7.17
UNREGULATED TDS CONCENTRATION-DURATION RELATIONSHIPS

CONTROL POINT	CONCENTRATIONS (mg/l) PERCENT OF MONTHS EQUALLED OR EXCEEDED									
	0	1	2	5	10	25	50	75	90	100
CP1	245.2	154.8	152.2	151.0	150.6	150.5	150.5	144.2	0.0	0.0
CP2	1674.8	1517.0	1515.9	1514.3	1487.5	1437.9	1437.9	1437.7	1172.1	0.0
CP3	1409.0	1276.2	1275.3	1274.0	1251.5	1209.7	1209.7	1209.6	986.1	0.0
CP4	12938.3	1457.6	1365.3	1234.1	1087.2	1039.3	1039.3	1039.3	950.9	0.0
CP5	4440.8	1115.7	1046.6	893.9	842.6	787.1	732.4	696.4	661.3	0.0
CP6	252.6	247.8	247.4	247.1	247.1	247.0	246.8	244.3	0.0	0.0
CP7	141.0	141.0	141.0	141.0	141.0	141.0	140.9	140.8	140.5	0.0
CP9	245.2	131.3	129.8	128.4	127.8	127.6	127.5	127.4	124.7	0.0
CP10	245.2	128.6	127.9	127.6	127.6	127.5	127.5	127.5	127.4	0.0
CP11	137.9	128.6	128.1	127.7	127.6	127.5	127.5	127.5	127.4	0.0
CP12	183.9	144.9	143.4	142.0	141.6	141.2	141.1	141.0	140.3	0.0
CP13	145.0	142.2	141.7	141.3	141.2	141.1	141.1	141.1	140.8	0.0
CP14	141.5	141.2	141.2	141.1	141.1	141.1	141.1	141.1	141.1	0.0
CP15	2824.7	854.2	791.5	695.1	638.8	545.0	454.5	394.6	341.7	0.0
CP16	147.1	102.6	100.3	98.4	98.1	97.9	97.9	97.8	0.0	0.0
CP17	132.6	131.2	131.1	131.1	131.1	131.1	131.0	130.6	126.4	0.0
CP18	1838.7	803.8	726.0	612.2	537.1	442.4	359.0	297.7	261.0	0.0
CP19	1268.0	659.8	598.4	526.5	479.1	415.8	353.4	306.2	269.5	0.0

Table 7.18
UNREGULATED CHLORIDE CONCENTRATION-DURATION RELATIONSHIPS

CONTROL POINT	CONCENTRATIONS (mg/l) PERCENT OF MONTHS EQUALLED OR EXCEEDED									
	0	1	2	5	10	25	50	75	90	100
CP1	81.7	59.0	58.2	57.7	57.4	57.3	57.2	47.5	0.0	0.0
CP2	675.6	609.8	609.3	608.6	597.7	578.5	578.5	578.4	467.8	0.0
CP3	585.9	528.9	528.4	527.8	518.4	501.7	501.7	501.7	407.2	0.0
CP4	5356.5	703.8	550.2	494.1	436.8	421.3	421.3	421.3	373.3	0.0
CP5	2250.6	444.6	400.3	331.2	281.4	257.1	257.1	257.1	257.0	0.0
CP6	15.1	14.4	14.2	14.0	14.0	14.0	13.7	10.2	0.0	0.0
CP7	16.9	16.9	16.9	16.9	16.9	16.9	16.8	16.6	16.4	0.0
CP9	29.4	20.2	18.5	17.4	17.0	16.8	16.7	16.6	14.7	0.0
CP10	30.6	17.2	16.9	16.8	16.8	16.7	16.7	16.7	16.6	0.0
CP11	23.0	17.4	17.1	16.9	16.8	16.7	16.7	16.7	16.6	0.0
CP12	25.4	19.0	18.4	17.5	17.1	16.9	16.9	16.8	15.8	0.0
CP13	20.7	17.9	17.5	17.1	17.0	16.9	16.9	16.8	16.6	0.0
CP14	17.6	17.0	16.9	16.9	16.9	16.9	16.9	16.9	16.8	0.0
CP15	537.6	270.8	211.8	160.7	137.1	117.8	103.5	91.6	80.8	0.0
CP16	43.3	28.8	26.6	24.9	24.5	24.4	24.4	24.3	0.0	0.0
CP17	22.9	22.2	22.0	22.0	22.0	22.0	21.9	21.4	17.4	0.0
CP18	518.6	226.2	189.7	146.1	118.9	93.6	77.4	65.1	55.8	0.0
CP19	522.7	202.7	184.1	132.3	99.9	85.9	73.9	64.3	55.5	0.0

Table 7.19
UNREGULATED SULFATE CONCENTRATION-DURATION RELATIONSHIPS

CONTROL POINT	CONCENTRATIONS (mg/l) PERCENT OF MONTHS EQUALLED OR EXCEEDED									
	0	1	2	5	10	25	50	75	90	100
CP1	38.7	23.0	21.2	20.5	20.2	20.0	20.0	0.0	0.0	0.0
CP2	351.2	312.8	312.4	312.0	306.2	298.1	298.1	297.9	237.3	0.0
CP3	293.4	261.3	261.0	260.7	255.8	249.0	249.0	249.0	199.0	0.0
CP4	2635.1	307.6	273.8	247.7	215.0	206.8	206.8	206.8	183.1	0.0
CP5	802.7	221.7	206.8	174.1	144.8	134.5	134.5	134.5	134.4	0.0
CP6	76.6	71.9	71.2	71.0	71.0	70.9	70.7	68.2	0.0	0.0
CP7	16.3	16.3	16.3	16.3	16.3	16.3	16.2	16.0	15.7	0.0
CP9	24.5	16.0	15.0	13.3	12.7	12.5	12.4	12.3	11.0	0.0
CP10	19.9	13.1	12.7	12.5	12.5	12.4	12.4	12.4	12.3	0.0
CP11	23.0	13.1	12.9	12.6	12.5	12.4	12.4	12.4	12.3	0.0
CP12	25.4	18.6	17.8	17.0	16.6	16.4	16.3	16.3	15.5	0.0
CP13	20.7	17.8	17.3	16.6	16.5	16.4	16.3	16.3	16.1	0.0
CP14	16.7	16.5	16.4	16.4	16.4	16.4	16.3	16.3	16.3	0.0
CP15	386.0	156.0	133.3	113.5	104.1	91.2	77.3	68.0	59.5	0.0
CP16	33.4	22.3	18.7	17.4	17.0	16.9	16.9	16.8	0.0	0.0
CP17	14.9	13.1	13.1	13.0	13.0	13.0	12.9	12.4	8.7	0.0
CP18	222.3	138.8	116.9	98.5	86.8	71.2	58.6	49.2	43.0	0.0
CP19	219.5	118.3	104.7	84.4	73.9	64.8	55.9	49.0	43.5	0.0

Table 7.20
REGULATED TDS CONCENTRATION-DURATION RELATIONSHIPS

CONTROL POINT	CONCENTRATIONS (mg/l) PERCENT OF MONTHS EQUALLED OR EXCEEDED 0	1	2	5	10	25	50	75	90	100
CP1	434.5	314.9	294.2	272.6	236.1	173.5	0.0	0.0	0.0	0.0
CP2	4537.6	2905.6	2752.2	2629.5	2486.9	2239.5	2028.7	1825.1	1663.6	0.0
CP3	2726.9	2183.1	2138.0	1992.2	1912.3	1759.2	1637.4	1460.8	0.0	0.0
CP4	3677.4	2991.7	2123.6	1791.5	1514.7	1320.0	1148.3	972.5	598.6	0.0
CP5	1354.8	1165.5	1108.5	903.9	776.8	689.5	578.5	479.6	313.1	0.0
CP6	459.7	408.1	394.7	340.2	318.9	280.1	0.0	0.0	0.0	0.0
CP7	195.3	182.0	175.4	167.3	159.7	148.6	0.0	0.0	0.0	0.0
CP9	305.2	243.5	228.9	204.6	189.2	169.2	129.0	0.0	0.0	0.0
CP10	245.2	163.1	156.9	151.3	144.9	134.7	0.0	0.0	0.0	0.0
CP11	184.0	169.3	162.1	152.5	145.5	137.5	0.0	0.0	0.0	0.0
CP12	235.8	182.4	172.5	164.3	157.2	149.6	143.1	0.0	0.0	0.0
CP13	305.1	237.4	217.7	190.3	175.5	159.6	147.2	0.0	0.0	0.0
CP14	515.1	264.3	240.4	214.7	193.9	170.9	157.0	150.5	147.0	0.0
CP15	1745.1	711.2	642.4	547.2	492.3	411.7	313.2	210.4	4.9	0.0
CP16	182.8	141.2	131.3	123.6	115.5	105.0	0.0	0.0	0.0	0.0
CP17	296.4	218.7	210.1	190.8	173.1	151.3	0.0	0.0	0.0	0.0
CP18	1088.1	563.8	499.3	442.0	388.4	307.3	235.2	168.4	73.8	0.0
CP19	735.5	559.2	483.9	402.0	362.3	300.1	238.1	166.4	61.4	0.0

Table 7.21
REGULATED CHLORIDE CONCENTRATION-DURATION RELATIONSHIPS

CONTROL POINT	CONCENTRATIONS (mg/l) PERCENT OF MONTHS EQUALLED OR EXCEEDED 0	1	2	5	10	25	50	75	90	100
CP1	169.7	119.5	113.2	103.4	89.8	65.7	0.0	0.0	0.0	0.0
CP2	1826.3	1169.7	1107.2	1057.7	1000.5	901.2	815.6	735.5	671.8	0.0
CP3	1156.2	917.2	894.1	840.6	805.4	739.1	689.0	613.2	0.0	0.0
CP4	1471.0	1260.2	873.0	734.8	616.2	525.9	455.2	378.5	179.3	0.0
CP5	493.6	404.5	394.1	303.8	271.5	230.9	187.5	132.7	57.3	0.0
CP6	29.4	23.5	22.1	19.1	17.9	15.8	0.0	0.0	0.0	0.0
CP7	23.3	21.8	21.0	20.0	19.1	17.8	0.0	0.0	0.0	0.0
CP9	40.0	32.0	30.2	26.8	24.9	22.1	16.1	0.0	0.0	0.0
CP10	40.9	22.3	21.4	19.8	18.9	17.6	0.0	0.0	0.0	0.0
CP11	24.1	22.2	21.3	20.0	19.1	18.0	0.0	0.0	0.0	0.0
CP12	29.4	22.0	20.7	19.7	18.8	17.9	17.1	0.0	0.0	0.0
CP13	36.5	28.4	26.0	22.8	21.1	19.1	17.6	0.0	0.0	0.0
CP14	30.4	25.7	24.0	22.3	20.6	18.7	17.8	17.4	17.2	0.0
CP15	242.1	157.4	130.5	110.8	88.2	61.1	29.7	0.0	0.0	-36.8
CP16	45.5	35.5	33.0	30.8	28.8	26.2	0.0	0.0	0.0	0.0
CP17	52.5	42.8	34.8	32.1	28.9	25.2	0.0	0.0	0.0	0.0
CP18	187.0	119.5	102.7	77.9	65.3	44.6	27.2	7.2	0.0	-10.5
CP19	163.1	115.4	96.2	71.3	58.7	45.8	28.1	8.0	0.0	-3.5

Table 7.22
REGULATED SULFATE CONCENTRATION-DURATION RELATIONSHIPS

CONTROL POINT	CONCENTRATIONS (mg/l) PERCENT OF MONTHS EQUALLED OR EXCEEDED 0	1	2	5	10	25	50	75	90	100
CP1	57.8	49.0	49.0	37.0	31.2	22.9	0.0	0.0	0.0	0.0
CP2	944.3	609.7	574.5	547.6	518.0	466.4	421.4	378.8	345.6	0.0
CP3	735.5	449.9	441.3	412.6	394.3	363.4	337.9	298.9	0.0	0.0
CP4	735.5	533.0	438.7	355.0	302.2	256.8	221.7	181.0	76.4	0.0
CP5	214.0	199.9	184.0	166.2	146.1	126.0	107.1	81.7	42.3	0.0
CP6	126.0	117.5	112.6	97.5	91.5	80.4	0.0	0.0	0.0	0.0
CP7	22.5	21.0	20.2	19.3	18.4	17.2	0.0	0.0	0.0	0.0
CP9	29.7	23.7	22.3	19.9	18.5	16.5	2.2	0.0	0.0	0.0
CP10	26.3	16.4	15.7	14.7	14.0	13.0	0.0	0.0	0.0	0.0
CP11	17.9	16.5	15.8	14.8	14.2	13.4	0.0	0.0	0.0	0.0
CP12	29.4	21.8	20.4	19.1	18.2	17.3	16.6	0.0	0.0	0.0
CP13	35.4	27.6	25.2	22.0	20.4	18.5	17.1	0.0	0.0	0.0
CP14	111.1	46.6	40.3	31.8	26.9	22.4	19.5	18.0	17.2	0.0
CP15	239.1	127.6	110.0	92.7	82.6	66.7	49.4	28.0	0.0	0.0
CP16	36.8	24.5	22.6	21.3	19.9	18.1	0.0	0.0	0.0	0.0
CP17	30.6	22.6	20.5	18.8	17.1	14.8	0.0	0.0	0.0	0.0
CP18	148.4	99.5	81.7	72.0	61.5	47.2	35.6	21.9	4.6	0.0
CP19	129.1	86.5	75.6	61.6	55.1	44.8	34.2	18.7	1.3	0.0

Table 7.23
END-OF-MONTH STORAGE IN POSSUM KINGDOM RESERVOIR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1900	558174.4	547476.7	537844.6	570240.0	570240.0	570240.0	563001.4	549775.1	570240.0	570240.0	561118.8	560493.1	560757.1
1901	549999.6	544583.3	531141.3	530595.6	530054.6	522741.2	499406.2	487476.2	477923.3	462073.2	449258.0	435798.8	501754.3
1902	425257.5	402886.8	391734.8	389024.3	456192.0	452781.5	456192.0	456192.0	456192.0	456192.0	456192.0	451106.7	437495.3
1903	451779.6	449968.0	466435.0	527987.2	527469.1	517536.6	516173.9	492596.2	476614.6	476441.0	462819.9	449529.6	484612.6
1904	439445.6	439963.3	433121.1	419587.5	437751.3	456192.0	451770.1	430267.8	416412.1	449374.0	448926.4	435876.3	438224.0
1905	425196.5	425690.9	424254.1	456192.0	497691.9	529936.0	523827.9	522224.8	521168.2	510195.3	496655.1	483576.8	484717.5
1906	472877.6	462042.8	449042.7	436149.9	453454.7	456192.0	451770.1	452111.7	456192.0	447634.1	434184.8	421087.3	449395.0
1907	411574.8	401810.3	396764.6	395060.7	456192.0	456192.0	456192.0	435045.0	420261.6	456192.0	456192.0	456192.0	433139.1
1908	456192.0	455424.9	456192.0	493813.3	570240.0	568270.8	542954.9	518380.9	512719.3	512109.9	497462.0	485246.4	505750.6
1909	474360.4	463922.4	450694.7	436603.1	423771.7	435200.9	410589.5	396641.3	380516.5	362926.0	338840.9	346645.1	410059.4
1910	338470.4	328275.4	315923.3	362239.4	456192.0	451945.4	409020.0	366919.3	338064.4	311247.3	284920.7	272038.6	352938.0
1911	262014.7	252773.2	240934.7	231533.2	216097.8	198176.3	182181.9	161934.9	245744.8	220807.0	207905.2	196281.8	218032.1
1912	186826.8	176688.4	166692.0	155702.9	144984.8	130028.1	111733.6	146187.3	137616.2	130084.0	118230.2	105552.7	142527.3
1913	94364.6	84079.6	72810.1	61218.9	99082.6	83809.4	75817.8	59367.2	119086.1	319243.3	380511.8	432489.0	156823.4
1914	422305.5	410947.3	398932.0	456192.0	487000.7	488056.2	471804.9	467445.3	467308.9	467214.4	467144.8	456298.9	455054.3
1915	454751.8	456192.0	456192.0	570240.0	570240.0	570240.0	567399.0	564522.8	562627.1	561322.6	546566.6	533113.6	534450.6
1916	527704.7	521218.7	507967.4	507625.0	507285.7	506540.5	488274.5	465971.7	453336.8	456192.0	443254.9	429727.6	484591.6
1917	419509.4	408852.6	396061.9	381764.7	377324.4	383306.3	361717.1	338199.8	353101.4	327435.9	313952.3	300942.2	363514.0
1918	281907.3	271599.8	259542.7	306039.7	441136.4	452781.5	424529.0	383406.8	358376.8	422703.6	456192.0	489298.4	378959.5
1919	501007.2	497807.8	497531.7	513524.9	570240.0	570240.0	570240.0	567280.8	570240.0	570240.0	570240.0	569552.4	547345.4
1920	569150.1	570240.0	569616.6	555283.2	554525.6	570240.0	567399.0	564522.8	570240.0	570240.0	570240.0	569552.4	566770.8
1921	569150.1	563713.4	562806.6	561982.9	546098.7	570240.0	548394.1	522610.9	506207.5	490066.0	475500.1	461784.6	531546.3
1922	451103.9	440117.9	427029.1	456192.0	503847.8	518300.7	494266.1	470600.2	453228.8	437588.6	424099.0	410597.8	457247.7
1923	400271.1	392501.7	379839.4	444119.1	456192.0	456192.0	431213.8	408505.4	400931.2	442526.8	456192.0	456192.0	427056.4
1924	450573.7	440408.1	456192.0	456192.0	472695.8	472499.8	448599.4	425157.6	453122.9	438513.8	424324.1	410833.2	445759.4
1925	400083.0	389292.8	376519.5	361818.0	441136.4	410196.4	368023.6	344384.3	442210.5	456192.0	447907.7	434577.5	406028.5
1926	424568.0	413855.5	404466.3	456192.0	456192.0	456192.0	456192.0	456192.0	456192.0	570240.0	569190.3	568509.9	473998.5
1927	568111.8	567675.7	566730.9	570240.0	557873.3	556144.6	553698.9	530142.7	514884.6	514245.0	499766.0	486043.5	540463.1
1928	475305.2	464398.3	451295.9	437732.5	453454.7	456192.0	451770.1	456192.0	448887.4	433419.4	419333.4	406386.0	446197.3
1929	397584.4	386918.9	375376.1	366199.6	456192.0	456192.0	456192.0	432820.9	456192.0	449124.5	436819.7	423868.9	424456.8
1930	413188.9	402554.1	389836.8	375058.3	570240.0	570240.0	530535.4	506444.1	505700.4	570240.0	567626.4	570240.0	497658.7
1931	565598.3	570240.0	569270.7	560926.0	557418.8	541962.9	520563.9	495955.9	478253.4	464400.6	464348.7	464315.0	521104.5
1932	464295.2	499910.5	496114.3	490627.2	570240.0	570240.0	570240.0	555377.3	570240.0	568829.5	559029.9	558418.4	539463.6
1933	558060.6	553533.7	552724.3	551989.1	570240.0	557079.9	532393.9	530540.4	529318.9	517268.9	503540.9	490464.3	537263.0
1934	489105.2	482435.2	482282.0	482142.4	468072.6	447245.3	423491.4	400493.4	385872.2	371285.9	378518.1	366236.5	431431.7
1935	355835.0	346416.6	345776.3	359641.1	497409.6	570240.0	570240.0	546480.1	570240.0	568829.5	564476.1	560593.6	488014.8
1936	550003.6	539143.0	525592.3	510340.5	509977.3	509179.8	508051.6	483551.5	483219.9	564536.3	559332.0	549366.8	524357.9
1937	539849.4	529156.4	528580.3	515037.8	500091.7	499486.3	476186.2	471748.3	462610.8	448891.0	434986.4	422090.8	485726.3
1938	420313.0	456192.0	461530.6	473826.1	558640.4	563417.9	560768.3	548188.6	529571.0	513104.2	498354.0	484531.3	505703.2
1939	484462.3	473772.1	460858.4	447759.1	456192.0	456192.0	439385.3	437447.0	420598.0	403950.3	389809.1	376589.5	437251.3
1940	365034.5	354084.8	339089.7	329119.5	397214.2	452766.5	454220.4	452106.3	453132.9	439123.9	456192.0	456192.0	412356.4
1941	449230.7	465591.9	465546.2	570240.0	570240.0	570240.0	570240.0	570240.0	570240.0	570240.0	570240.0	569512.1	542650.1
1942	568470.0	559993.6	548681.5	570240.0	570240.0	570240.0	544769.7	533128.3	570240.0	570240.0	568549.8	568270.8	561922.1
1943	565345.9	553024.1	552486.8	550797.2	542170.1	540660.4	513807.9	484428.5	466011.8	448394.8	432047.5	420727.2	505825.3
1944	411878.3	407285.1	415066.6	418610.6	456192.0	456192.0	451666.1	429930.4	422795.0	451589.7	447641.5	447130.5	434664.8
1945	443492.8	447127.1	456192.0	456192.0	453593.7	456192.0	456192.0	432932.8	414253.2	456192.0	439992.5	425010.9	444780.3
1946	421802.4	428529.8	416469.5	401016.3	405264.4	413320.9	389559.7	400791.7	456192.0	456192.0	456192.0	460128.2	425454.9
1947	457704.3	445464.7	443694.5	431128.9	570240.0	567517.4	536727.4	510765.5	488710.9	463146.7	449966.0	456192.0	485104.9
1948	445801.6	441411.5	439589.0	421543.4	420036.3	452781.5	438155.6	414614.0	395292.0	380398.7	365614.0	348237.0	413622.9
1949	340770.0	333047.4	323603.0	317329.1	456192.0	458828.1	436681.0	414532.5	456192.0	456192.0	439972.4	427542.5	405073.5
1950	417218.2	407307.8	391082.5	418215.8	456192.0	456192.0	451750.3	456192.0	456192.0	443461.4	424238.4	408494.1	432211.4
1951	394703.0	384854.0	371416.8	355397.9	410928.5	452768.6	409441.8	366389.7	338083.7	308157.8	281596.3	254385.9	360677.0
1952	233336.9	219607.9	205274.6	194437.3	183721.7	162864.6	141844.3	119597.8	105600.9	89610.9	79310.8	67943.8	150262.6
1953	57397.9	47311.8	38031.5	26063.2	27848.2	11076.5	215989.9	270501.4	251242.5	456192.0	456192.0	442843.7	191724.2
1954	435317.9	422098.9	407745.1	442827.8	453451.7	439201.2	394748.5	348266.0	322133.4	293064.7	271506.1	254842.2	373767.0
1955	241330.9	232236.8	222753.7	212244.0	427740.3	439091.7	438188.3	408811.4	442213.9	442591.2	423210.4	399365.6	360814.9
1956	382963.9	376097.6	350394.3	323779.5	342157.8	301750.0	275778.8	231943.0	209296.4	181763.3	158024.5	149693.7	273636.9
1957	127001.0	304005.6	286863.0	456192.0	570240.0	570240.0	563754.4	529696.3	525776.1	525594.2	570240.0	567848.1	466454.3
1958	566591.7	561705.4	561816.9	570240.0	570240.0	567952.9	565756.2	541763.2	540404.9	523722.2	508182.6	493876.2	547687.7
1959	482159.7	471429.5	456530.9	441124.6	454590.9	456192.0	456192.0	436143.8	415285.7	509511.3	494705.8	494633.7	464041.7
1960	505762.1	516620.7	511798.5	511456.6	495669.9	475379.4	475091.5	456170.0	436577.6	456192.0	456192.0	456192.0	479425.2
1961	456192.0	457207.4	457202.3	442757.2	445574.1	570240.0	570240.0	557109.8	555361.2	549496.9	549078.4	544561.7	512918.4
1962	533219.2	520664.7	509687.1	501844.0	480741.1	534096.1	559461.9	538124.6	570240.0	568909.6	568072.1	567478.1	537711.6
1963	557160.4	547678.2	535367.8	535022.8	534969.8	525701.8	495200.4	470111.6	452447.2	423457.9	443165.7	419402.8	494973.9
1964	410875.2	446567.1	436277.6	423606.8	413294.9	399104.8	370817.5	335276.2	362049.4	347567.7	401394.3	387360.1	394516.0
1965	378379.3	370601.9	358810.7	387790.3	456192.0	456192.0	431070.2	420769.8	441764.0	456192.0	449007.1	437437.4	420350.6
1966	426081.7	416635.8	404656.6	456192.0	570240.0	568669.6	542042.9	540794.4	570240.0	566271.0	549957.6	534708.4	512207.5
1967	521882.8	509726.9	496037.4	495724.6	495457.8	486999.1	482137.5	456976.3	453891.8	440340.4	427998.0	415359.6	473544.3
1968	512655.9	532952.7	570240.0	570240.0	570240.0	570240.0	567913.2	543883.3	524273.2	504791.3	494260.2	482774.7	537038.7
1969	470810.3	470778.3	470785.4	470746.3	570240.0	568270.8	541634.4	522423.1	521742.0	521257.8	520695.0	520612.1	514166.3
1970	520384.9	520385.0	558943.8	570240.0	570240.0	553053.3	524345.3	500714.5	487203.0	471878.3	455072.7	438811.5	514272.7
1971	425790.6	413866.6	399056.1	385047.6	376733.6	424216.4	414870.5	438399.1	442186.8	456192.0	452250.3	456192.0	423733.5
1972	445930.5	441794.1	427444.0	419874.2	456192.0	447654.4	427934.8	445423.6	456192.0	456192.0	456192.0	454210.8	444586.3
1973	456192.0	456192.0	456192.0	471376.0	469057.0	468953.8	464496.5	444038.8	456192.0	443980.4	430392.5	414802.3	452655.5
1974	404555.7	393239.3	380218.0	380964.2	367610.8	387114.3	365147.9	357134.9	456192.0	456192.0	544424.7	544153.1	419745.6
1975	544827.8	570240.0	569391.3	568549.8	570240.0	570240.0	568151.4	565523.7	563798.1	545136.3	537499.3	526439.6	558336.4
1976	514873.8	501303.7	486819.0	486714.7	486536.5	466114.3	465459.1	457497.4	457488.2	457484.7	457479.3	450891.0	474055.1
1977	456192.0	456192.0	456192.0	468884.3	506456.5	505609.7	493114.4	467030.7	466831.7	453067.8	437242.0	444449.4	467605.3
1978	435475.3	426610.7	444029.6	453800.3	441162.0	452786.8	408301.2	438459.5	439249.5	419241.3	410444.8	395474.5	430419.7
1979	388133.9	379923.5	442298.5	447606.5	456192.0	456192.0	444426.7	437823.9	418428.5	400514.0	386271.0	375773.8	419465.4
1980	365531.9	356230.0	343612.6	330031.4	456192.0	456192.0	427657.2	423787.1	453118.8	442538.3	442066.3	442824.5	411648.5
1981	438748.4	443899.4	456192.0	455368.7	456192.0	456192.0	455104.2	456159.8	456192.0	570240.0	568161.3	557680.7	480844.3
1982	548534.8	545014.1	540902.6	526098.9	570240.0	570240.0	570240.0	546759.1	527745.8	515144.8	501956.3	501798.0	538722.9
1983	491432.0	491324.2	479593.9	570240.0	570240.0	568709.5	561475.9	554892.9	552717.1	543287.7	542487.9	537787.2	538682.3
1984	537484.4	536937.5	536421.9	521883.6	505745.2	475649.5	431905.7	393324.1	370747.6	456192.0	456192.0	456192.0	473223.0

Note: Units are acre-feet in Tables 7.23-7.28.

Table 7.24

END-OF-MONTH STORAGE IN WHITNEY RESERVOIR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1900	627100.0	626344.9	627100.0	627100.0	627100.0	627100.0	551516.9	538308.1	627100.0	627100.0	627100.0	596992.5	610830.2
1901	578921.4	552200.8	524627.4	493367.6	499529.1	515567.5	423815.1	379100.0	372070.7	367297.5	364475.6	362882.8	452821.3
1902	361899.9	360994.8	358441.4	356872.5	366566.6	379100.0	627100.0	593985.3	546558.9	536162.8	627100.0	627100.0	478490.2
1903	627100.0	627100.0	627100.0	627100.0	614356.7	599084.4	555180.0	488882.8	440638.6	477113.6	447880.9	415315.3	545571.1
1904	384936.4	379100.0	376430.5	379100.0	410360.9	404844.9	379100.0	379100.0	379100.0	374244.8	371374.5	369754.3	382287.2
1905	377260.4	379100.0	379100.0	579362.4	627100.0	627100.0	538032.7	446450.6	397534.8	419104.5	396855.1	390073.9	463089.5
1906	379100.0	379100.0	379100.0	379100.0	376822.0	627100.0	538032.7	460315.9	490435.1	461672.7	435656.9	426347.3	444398.6
1907	437433.8	419161.8	408204.6	379100.0	376822.0	399822.1	473723.3	404752.8	379100.0	374244.8	379100.0	407767.6	403269.4
1908	413875.3	446023.3	480238.1	627100.0	627100.0	627100.0	551516.9	483284.1	458789.5	422801.0	388412.8	379100.0	492111.8
1909	378077.3	377135.4	374478.5	372846.0	370602.2	379100.0	369138.3	359039.9	352349.4	347806.3	345120.3	343604.3	364108.2
1910	342668.8	341807.3	339376.9	337883.6	379100.0	373001.1	363185.3	353234.9	346642.4	342165.8	339519.3	338025.4	349717.6
1911	337103.6	336254.7	333860.0	332388.5	330366.2	324981.3	316314.8	307529.5	301708.9	297756.5	295419.8	295821.7	317458.8
1912	301643.8	314270.2	331301.5	350498.5	352895.8	362988.7	353412.6	343705.1	337273.5	332906.3	330324.3	328866.9	336673.9
1913	327967.6	327139.4	324803.2	323367.7	321394.7	332741.2	368095.9	358023.4	351350.1	370524.0	456808.9	627100.0	374109.7
1914	627100.0	605220.0	586107.6	627100.0	627100.0	627100.0	592062.3	501860.4	538960.0	516969.0	522933.2	536007.3	575710.0
1915	552855.6	522866.0	550449.4	627100.0	627100.0	627100.0	600212.1	566106.3	529919.8	583494.0	563761.1	545464.9	574702.4
1916	551849.0	584102.0	565117.1	627100.0	627100.0	627100.0	538032.7	446450.6	397534.8	392456.1	379100.0	377449.2	509449.3
1917	376430.5	375492.4	372846.0	371219.9	379100.0	379100.0	369138.3	359039.9	352349.4	347806.3	345120.3	343604.3	364270.6
1918	342668.8	341807.3	339376.9	337883.6	335831.1	330366.2	321570.9	312654.8	306747.7	334260.7	575442.0	627100.0	375475.9
1919	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	601173.6	627100.0	627100.0	627100.0	627100.0	624939.4
1920	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	538032.7	622952.1	627100.0	627100.0	627100.0	627100.0	619332.1
1921	627100.0	627100.0	627100.0	627100.0	614622.1	627100.0	545437.3	455124.9	406352.5	379100.0	376195.7	374556.4	523907.4
1922	375332.3	378319.3	379100.0	627100.0	627100.0	627100.0	557466.8	466412.4	418064.3	383749.8	379100.0	379100.0	466495.5
1923	379100.0	379100.0	379100.0	580070.9	596692.9	603347.3	513872.8	421601.9	379592.8	379100.0	604416.3	627100.0	486924.6
1924	627100.0	627100.0	627100.0	627100.0	627100.0	608181.4	518791.6	426664.0	379100.0	374244.8	371391.1	374146.1	515668.3
1925	377452.6	376512.2	373859.3	372229.2	369988.8	364023.3	354422.5	344689.9	338241.7	333863.1	331274.5	329813.3	355530.9
1926	339935.6	352546.4	378485.5	536518.8	579320.9	591563.5	574513.4	509813.6	627100.0	627100.0	612495.9	602952.3	527695.6
1927	575547.4	573077.0	570130.2	627100.0	627100.0	627100.0	552694.6	473350.9	426670.6	453095.6	421141.9	389290.1	526358.2
1928	379100.0	379100.0	379100.0	455967.4	422848.2	483780.5	390933.2	379100.0	379100.0	374244.8	371374.5	376379.1	397585.7
1929	379100.0	379100.0	379100.0	442528.7	550411.8	588913.8	499180.6	406472.6	467590.6	431712.9	402480.3	379100.0	442140.9
1930	379100.0	379100.0	379100.0	379100.0	627100.0	627100.0	538032.7	448450.6	414364.0	627100.0	627100.0	627100.0	504395.6
1931	627100.0	627100.0	627100.0	627100.0	627100.0	602867.8	513384.9	421099.7	379100.0	374244.8	371374.5	372540.8	514176.0
1932	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	541394.8	627100.0	611650.0	579571.8	555577.3	608749.6
1933	592885.0	573258.1	627100.0	622466.7	627100.0	616253.3	527002.9	435110.9	394603.3	379100.0	378661.3	377012.1	512546.2
1934	379100.0	379100.0	400369.1	487710.3	485039.7	437833.9	379100.0	368754.0	361899.4	357244.9	354493.1	352939.9	395298.8
1935	351981.4	351098.8	348608.9	378434.2	627100.0	627100.0	627100.0	558817.8	627100.0	627100.0	627100.0	627100.0	531553.4
1936	615006.3	596023.3	570473.1	544108.5	627100.0	611086.9	542271.1	451764.2	627100.0	627100.0	627100.0	627100.0	588852.8
1937	627100.0	627100.0	627100.0	617673.3	593365.1	574788.6	484701.5	391446.0	379100.0	379100.0	379100.0	395581.7	506346.4
1938	608479.2	627100.0	627100.0	627100.0	627100.0	627100.0	603574.8	528447.7	480640.8	444923.2	410914.8	379100.0	549298.4
1939	378077.3	379100.0	376985.7	375343.3	380455.6	494873.9	402467.5	379100.0	372070.7	367297.5	364475.6	362882.8	386094.2
1940	361371.7	360768.8	354938.5	354493.6	358706.6	379100.0	379100.0	379100.0	367986.5	360843.5	606680.4	627100.0	407515.8
1941	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	617046.3	626262.2
1942	598489.1	573313.7	544188.5	627100.0	627100.0	627100.0	596433.5	520842.6	627100.0	627100.0	627100.0	627100.0	601913.9
1943	627100.0	613411.5	627100.0	619013.6	627100.0	591832.5	501942.0	405573.3	379100.0	372303.1	367374.1	367910.3	508313.4
1944	379100.0	411465.4	461179.4	467483.6	627100.0	604388.6	512896.8	420037.7	379178.3	379100.0	379100.0	379100.0	450010.8
1945	434942.7	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	548047.6	495546.9	557692.5	533609.1	510012.3	570204.3
1946	529426.4	627100.0	627100.0	627100.0	627100.0	627100.0	533932.8	440788.2	426024.5	406706.3	536040.1	627100.0	552959.9
1947	627100.0	626677.0	627100.0	627100.0	627100.0	589245.4	496586.4	404792.3	379100.0	370293.3	366532.8	379100.0	510060.7
1948	379100.0	486429.7	501458.2	472657.3	528697.6	481285.2	402023.9	379100.0	369292.1	361069.6	354418.9	350878.3	422201.0
1949	353456.8	354270.7	379100.0	429821.6	627100.0	627100.0	540893.6	450760.5	399161.2	379100.0	374777.5	376441.8	440998.7
1950	379100.0	452386.6	426368.0	460375.3	467906.5	449357.9	379100.0	379100.0	454589.3	422164.2	382462.8	377181.2	419174.3
1951	373979.0	373979.0	369414.3	365433.2	363988.3	362019.6	350774.3	337569.3	330823.3	324335.5	320525.1	316888.7	349144.1
1952	314152.5	312296.1	310317.9	312031.7	379100.0	369522.9	358515.3	343242.4	332596.1	321975.8	323952.0	325595.7	333608.2
1953	322179.7	320348.5	319537.6	317585.6	364047.3	352966.3	345146.4	337341.5	329557.2	328241.1	325691.7	323569.4	332184.4
1954	322751.2	318553.3	314670.7	312679.0	310238.2	301219.4	289949.0	277144.3	267136.2	261997.8	259349.0	255447.4	290928.0
1955	254452.5	254673.3	252253.6	250071.3	250833.3	248769.9	241820.1	236482.1	232619.7	353983.6	347087.5	343757.3	272233.7
1956	343037.2	344294.5	338847.8	334814.0	331171.8	321270.1	307761.3	294761.5	283160.0	276502.0	272257.5	270331.4	309850.8
1957	268880.3	269169.9	269227.9	625451.6	627100.0	627100.0	583256.3	493366.5	458302.2	583812.1	627100.0	627100.0	504988.9
1958	627100.0	627100.0	627100.0	627100.0	627100.0	595359.1	627100.0	536811.1	510000.6	483152.3	454404.7	428682.1	564250.8
1959	397850.3	381713.5	379100.0	379100.0	379100.0	416453.4	392374.9	379100.0	370833.5	627100.0	627100.0	627100.0	446410.5
1960	627100.0	627100.0	627100.0	627100.0	627100.0	588766.9	579116.1	490286.0	438300.6	545188.0	525534.6	627100.0	577482.7
1961	627100.0	627100.0	627100.0	619698.7	602407.3	627100.0	627100.0	552313.2	516899.3	627100.0	627100.0	627100.0	609009.9
1962	620447.5	603347.3	579923.3	573224.2	543755.4	627100.0	627100.0	573420.1	627100.0	627100.0	611175.5	596084.9	600814.9
1963	570073.2	542303.4	508126.6	549700.1	563011.8	525186.2	430580.3	379100.0	370062.1	361371.2	359415.3	357618.3	459712.4
1964	358291.2	364733.2	379100.0	379100.0	379100.0	373467.0	360918.6	351024.5	349485.0	343747.9	387318.9	379100.0	367115.5
1965	387324.4	550632.7	532647.9	509979.6	627100.0	622283.5	530624.8	443747.9	400957.8	379100.0	386858.4	379100.0	479196.5
1966	379100.0	379100.0	379100.0	508727.9	627100.0	627100.0	539813.6	462315.4	627100.0	626323.3	596805.4	567943.4	526710.8
1967	536272.2	506062.6	474420.8	447165.9	423049.8	389471.8	379100.0	368677.2	364779.4	362958.2	365866.5	379100.0	416410.4
1968	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	546422.3	506989.5	485299.3	461610.5	454473.7	570374.6
1969	427840.8	421585.1	508994.6	627100.0	627100.0	620254.7	526796.7	444526.7	471277.7	460766.5	458494.4	525709.1	510037.2
1970	546198.0	603376.4	627100.0	627100.0	627100.0	627100.0	537921.6	444102.6	418656.9	410330.1	379100.0	379100.0	518932.1
1971	379100.0	379100.0	374285.9	379100.0	379100.0	369522.9	360994.3	356871.9	379100.0	582198.4	612907.1	627100.0	431615.0
1972	627100.0	627100.0	610189.9	588366.4	578275.9	534948.4	446288.3	379100.0	379100.0	381881.1	476276.0	449353.2	506498.3
1973	485428.2	557362.3	627100.0	627100.0	627100.0	627100.0	622470.9	554129.3	525821.3	523676.5	517176.2	495768.8	565852.8
1974	482454.0	463682.9	441900.8	415831.1	402826.1	379100.0	366837.9	368862.6	421149.7	483213.2	627100.0	627100.0	456671.5
1975	627100.0	627100.0	627100.0	627100.0	627100.0	627100.0	552338.1	469323.8	424534.4	386427.9	379100.0	377292.3	529301.4
1976	373778.0	369266.3	376044.2	401995.2	514077.8	538524.6	619603.4	544899.3	515728.8	529008.2	531170.0	566493.1	490049.1
1977	558266.3	574163.8	627100.0	627100.0	627100.0	581697.7	488151.0	395568.3	379100.0	372070.7	369523.2	364703.7	497045.4
1978	363792.2	364399.6	360919.4	357394.7	353235.7	344687.1	331619.5	322794.2	317251.9	310608.4	310674.2	308508.9	337157.2
1979	308901.6	320636.6	379100.0	411179.5	627100.0	627100.0	549760.3	476433.6	435933.2	407040.4	379100.0	379100.0	441782.1
1980	379100.0	379100.0	378630.9	379100.0	389543.2	378497.4	363741.1	350314.7	344132.1	337835.3	335148.5	334163.5	362442.2
1981	332271.2	331224.1	330319.0	338116.6	339842.1	433766.2	379100.0	375836.6	376076.9	627100.0	627100.0	602274.3	424419.0
1982	578212.6	578661.3	575400.1	555316.1	627100.0	627100.0	627100.0	536034.9	484050.8	447823.1	416215.9	383609.0	536385.3
1983	379100.0	378706.3	376978.7	627100.0	627100.0	581967.8	493425.9	403951.4	379100.0	430996.6	396751.0	379100.0	454523.2
1984	377292.3	374400.6	378453.3	371899.2	364991.5	356632.3	345901.2	335110.0	326889.4	325995.0	324349.5	335088.7	351416.9

Table 7.25
END-OF-MONTH STORAGE IN WACO RESERVOIR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1900	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152014.5	151513.8	152500.0	152500.0	152500.0	152500.0	152377.4
1901	149980.6	152500.0	148479.4	148411.0	152500.0	149001.3	138572.3	129085.8	129007.4	125264.0	122691.8	121674.5	138930.7
1902	119126.0	115845.9	116269.3	115071.1	122000.0	122000.0	122000.0	122000.0	130499.6	127740.8	130068.6	135380.8	123166.8
1903	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	147639.2	142704.9	137272.1	137084.7	134982.3	134948.8	145802.7
1904	131869.7	129518.0	128865.6	129772.1	152500.0	152209.3	151728.5	146190.5	139972.2	139061.7	136490.2	134109.0	139357.3
1905	134047.7	131605.7	141148.1	152500.0	152500.0	149252.1	148818.3	148370.9	145216.4	141758.0	146295.3	147303.1	144901.3
1906	151380.4	152500.0	152374.0	152500.0	152389.7	152100.1	150388.5	145734.5	145471.9	144070.5	140713.5	145930.6	148796.1
1907	152297.4	152500.0	152500.0	150433.8	150331.0	150061.0	149614.3	142381.1	137023.5	144858.2	150498.4	152500.0	148749.9
1908	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	147073.8	136803.8	131034.6	128439.0	128092.8	127976.4	142868.4
1909	125287.5	121514.2	117501.9	116018.7	119445.6	122000.0	113363.0	104376.1	97879.5	105502.8	103474.9	118954.1	113776.5
1910	122000.0	122000.0	117055.7	122000.0	122000.0	122000.0	112629.3	103053.7	96506.8	93849.5	90715.8	86962.4	109231.1
1911	83249.0	83533.9	84231.8	92608.9	96009.3	91588.1	92628.9	91033.9	86910.3	81616.2	78985.9	82233.6	87052.5
1912	83597.0	93571.8	96702.8	96998.1	117614.7	112867.5	103984.7	99313.2	92759.3	95091.4	91857.7	88028.1	97698.9
1913	84179.5	80880.1	78340.3	86860.6	142566.6	152500.0	148518.2	138898.5	133073.2	142995.5	150972.0	152500.0	124357.0
1914	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	145298.0	141318.1	152500.0	152500.0	150250.2	152500.0	150780.5
1915	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152421.2	152493.4
1916	152500.0	152500.0	150607.0	152500.0	152500.0	152209.3	148329.3	138382.6	132221.0	129685.9	127664.8	125676.9	142898.1
1917	122465.7	119801.9	115564.4	112342.9	116416.5	115156.8	105770.4	96622.9	92149.5	87149.2	83691.2	79664.7	103899.7
1918	76187.9	72577.7	68243.7	90471.6	92196.4	91835.2	82223.3	72980.6	68687.7	72166.8	84654.1	131904.2	83677.4
1919	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	151073.4	152500.0	152500.0	152500.0	152500.0	152381.1
1920	152500.0	152500.0	152500.0	149207.4	152500.0	152500.0	152500.0	151067.5	152500.0	152264.1	152500.0	152500.0	152086.6
1921	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	144174.5	140709.4	139478.3	137984.4	134788.4	147052.9
1922	131619.7	128644.8	128617.4	152500.0	152500.0	152500.0	143259.3	135698.8	130397.2	125813.3	122654.9	121728.6	135494.5
1923	119331.8	119551.6	122000.0	148030.7	152500.0	152209.3	142441.6	132502.8	129474.2	126358.7	152500.0	152500.0	137450.1
1924	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	142292.1	132077.2	125747.6	121106.0	118621.9	115832.7	139223.1
1925	112867.5	110727.7	106718.2	103691.6	122000.0	116252.6	107575.6	99002.9	95656.9	122000.0	137000.0	133332.2	113902.1
1926	135078.1	133877.5	152500.0	152500.0	152500.0	152209.3	151728.5	142458.8	138308.6	136621.0	136553.1	136515.5	143404.2
1927	134850.2	134714.2	137630.8	138714.3	152500.0	152500.0	146327.7	136938.0	130676.0	130608.9	128748.1	128276.5	137707.1
1928	126596.2	127707.9	125588.0	125578.7	125565.8	141868.9	137436.2	132595.8	127404.1	121839.2	118333.1	122000.0	127709.5
1929	122000.0	122000.0	122000.0	128282.1	152500.0	152500.0	142300.0	131956.1	131845.9	126114.1	122572.2	119101.5	131097.7
1930	115943.2	113576.6	109344.1	115692.5	152500.0	150149.8	139917.8	129996.3	125730.5	152500.0	152500.0	152500.0	134195.9
1931	152500.0	152500.0	152500.0	152500.0	152500.0	152209.3	145089.3	136770.4	135304.6	130196.5	128081.3	128065.6	143184.8
1932	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	146645.2	137579.4	152500.0	146907.3	143670.9	143614.9	148826.5
1933	147603.0	150583.6	152500.0	152500.0	152500.0	152209.3	142675.7	133867.5	129690.0	125333.7	122859.9	122857.7	140431.7
1934	141173.3	152500.0	152500.0	152500.0	152500.0	151003.7	141665.8	132167.4	127206.2	121629.9	120283.8	118687.5	138651.5
1935	117292.4	128839.6	130659.0	133063.9	152500.0	152500.0	152500.0	143886.9	147239.0	152500.0	152500.0	152500.0	142998.4
1936	152500.0	152500.0	150434.4	152500.0	152500.0	152500.0	147794.0	138074.3	137896.4	152500.0	152500.0	152500.0	149516.6
1937	152500.0	152500.0	152500.0	152500.0	152389.7	152100.1	151621.0	143580.8	141551.3	141400.1	140124.7	152500.0	148772.3
1938	152500.0	152500.0	152500.0	152500.0	152500.0	152209.3	151728.5	152500.0	146889.2	145415.1	142502.8	139128.3	149406.1
1939	136709.1	137375.8	135029.4	134995.7	148528.7	148275.9	139862.4	135282.9	128556.9	123150.4	120192.0	117263.7	133768.6
1940	113055.1	109877.8	104134.9	115637.6	113892.5	122000.0	122000.0	113324.6	104960.8	98448.2	152500.0	152500.0	118527.6
1941	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0
1942	152453.9	152500.0	152500.0	152500.0	152500.0	152500.0	152014.5	151651.6	152500.0	152500.0	152500.0	152500.0	152385.0
1943	152500.0	152500.0	152500.0	152500.0	152500.0	151566.9	142976.2	131531.2	131440.4	126900.4	123105.8	121640.9	140971.8
1944	124893.0	152500.0	152500.0	152500.0	152500.0	152500.0	145245.9	135152.3	129542.3	129217.0	127734.6	131732.1	140501.4
1945	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	148680.0	145023.8	152500.0	152500.0	152500.0	151558.6
1946	152500.0	152500.C	152500.0	152500.0	152500.0	152500.0	143142.5	132329.6	132292.2	130363.1	152500.0	152500.0	146510.6
1947	152500.0	152500.0	152500.0	152500.0	152500.0	145514.5	134329.3	124960.8	116775.9	121953.8	119571.4	122000.0	137300.5
1948	122000.0	136601.9	142609.5	142395.5	152500.0	152115.7	151736.2	141278.4	137495.8	133267.4	128651.6	125837.8	138874.1
1949	125850.7	133788.8	148100.8	152500.0	152500.0	152500.0	143078.9	133644.2	125845.6	125828.7	121090.8	119200.4	136160.8
1950	120231.0	140391.0	140840.3	150752.2	152500.0	152500.0	152092.3	141457.8	141322.3	135265.4	132865.2	128308.2	140710.5
1951	124523.0	123467.1	119968.1	118693.8	122000.0	122000.0	110929.3	99035.6	92887.2	86749.8	82717.0	78019.0	106749.2
1952	73892.1	71322.1	67691.9	98567.5	122000.0	122000.0	112037.8	100525.7	92177.7	84030.2	89672.9	92935.9	93904.5
1953	92556.4	90920.5	93425.6	95447.1	122000.0	115289.2	107610.6	101891.8	97302.6	98339.4	98562.6	95444.6	100732.5
1954	92646.7	88339.1	83925.5	84390.1	85149.7	81634.9	70608.8	60697.0	53306.2	52522.7	55566.0	51058.3	71653.8
1955	47582.7	45610.4	42781.0	44133.3	102009.5	112031.4	106446.5	101582.3	122000.0	116526.4	111910.1	107209.7	88318.6
1956	103916.0	101357.1	95998.7	93483.5	122000.0	115567.4	103786.0	93256.2	84716.5	78808.4	75774.0	75663.8	95360.6
1957	72514.2	70436.3	71446.0	122000.0	152500.0	152500.0	151975.7	142183.5	136562.3	152500.0	152500.0	152500.0	127468.2
1958	152500.0	152500.0	152500.0	152500.0	152500.0	152076.7	151468.0	143750.9	141982.6	141838.4	140772.3	139118.8	147792.3
1959	136379.6	136390.8	132634.1	131779.3	131756.5	152500.0	152240.6	146724.5	144829.2	152500.0	152500.0	152500.0	143561.2
1960	152500.0	152500.0	152500.0	152500.0	152500.0	147072.1	145950.9	137361.7	129814.9	135483.8	134243.8	152500.0	145410.6
1961	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	148887.2	148520.9	152500.0	152500.0	152500.0	151867.3
1962	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	144048.6	132623.1	132516.5	135008.0	131844.8	130021.1	143421.8
1963	127454.3	124250.8	120496.4	117370.5	115678.9	112186.0	102909.3	94327.5	87663.6	81991.8	79376.5	76154.8	103321.7
1964	75373.5	79997.7	95988.0	122000.0	122000.0	122000.0	113655.2	105233.1	122000.0	117985.9	152500.0	152500.0	115102.8
1965	152500.0	152500.0	148952.1	145496.9	152500.0	152500.0	147395.1	142141.0	138943.9	134004.6	152500.0	152500.0	147661.1
1966	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	144967.7	142031.8	152500.0	152209.3	149714.7	146519.1	150245.2
1967	142433.0	139419.7	135092.3	132132.6	128808.1	128711.9	120327.5	112758.7	108180.5	104771.9	101643.4	110496.0	122064.6
1968	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	146431.7	141023.7	141790.8	138732.7	152500.0	148998.3
1969	149499.2	152500.0	152500.0	152500.0	152500.0	148701.1	140515.6	135471.6	130904.9	125793.1	126679.3	152500.0	143338.7
1970	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	144633.0	136346.1	139303.7	136677.5	133630.9	130595.6	144682.2
1971	126452.5	123294.1	118818.0	115656.6	112068.9	106324.5	102359.0	122000.0	122000.0	122000.0	133138.1	152500.0	121384.3
1972	152500.0	152500.0	152193.7	148783.5	152500.0	148584.5	145298.8	138073.6	133073.5	131435.1	131418.0	130930.6	143107.6
1973	141631.0	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	144019.8	139662.7	152500.0	152500.0	152351.4	149805.4
1974	150131.7	149181.6	146274.2	145206.1	150145.8	143353.3	134088.9	128152.8	152500.0	152500.0	152500.0	152500.0	146377.9
1975	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	149928.3	142529.8	137470.0	132955.0	129152.2	126078.6	144426.2
1976	122609.0	119083.5	115910.6	119998.7	138648.1	152500.0	152500.0	146478.4	146358.3	152500.0	152500.0	152500.0	139298.9
1977	152500.0	152500.0	152500.0	152500.0	152500.0	152500.0	139904.5	128909.2	119232.4	112828.8	110495.7	105565.3	135994.7
1978	102661.7	104620.0	106728.4	106017.3	110043.9	103746.7	91077.0	81382.8	74278.6	68156.2	68551.6	65879.9	90262.0
1979	82674.4	101606.6	152500.0	152500.0	152500.0	152500.0	152500.0	152232.8	146754.9	141672.1	137480.6	137540.9	138538.5
1980	143654.2	152500.0	152500.0	152500.0	152500.0	149124.8	135618.1	122980.2	119481.4	112710.4	109766.9	109049.1	134365.4
1981	105581.3	104896.7	113799.7	116365.3	117359.0	152500.0	152061.2	143809.8	139343.2	140663.3	142074.9	139868.2	130693.6
1982	139796.8	140336.9	152500.0	152500.0	152500.0	152500.0	147943.8	135864.2	126076.6	120011.7	119525.5	118486.5	138170.2
1983	118267.1	128781.9	128766.1	125427.2	125024.3	121956.6	111947.9	102913.2	95227.2	90500.8	88302.1	84093.6	110100.7
1984	81539.8	79431.3	87899.4	83580.0	78940.3	72156.2	62410.1	54283.1	47858.5	76114.9	82669.3	117124.3	77000.6

Table 7.26
END-OF-MONTH STORAGE IN PROCTOR RESERVOIR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1900	59400.0	59328.8	58516.1	59400.0	59400.0	55024.0	48825.2	48775.2	49215.9	59400.0	59299.8	58177.2	56230.2
1901	57334.7	56775.5	54508.8	52398.7	59400.0	53658.8	46808.9	41334.3	38319.6	35602.2	34520.3	33637.4	47024.9
1902	32947.9	32157.8	30243.3	28444.5	25865.5	24541.6	22233.0	17984.5	15789.6	13653.3	12969.5	12355.6	22432.2
1903	14962.4	32165.5	56032.3	55903.4	52680.1	47106.0	40513.8	35310.2	32482.1	29907.8	28927.4	28113.3	37842.0
1904	27467.1	26722.0	24902.4	23186.2	34976.0	31981.5	32733.0	27912.8	25346.2	23570.9	22847.7	22111.0	26979.7
1905	21514.2	20820.9	19112.8	45822.3	59400.0	56190.3	49246.1	43672.8	40590.6	37825.3	36708.6	35799.8	38892.0
1906	35093.4	34285.6	32334.0	30503.3	47520.0	47520.0	40911.5	35689.1	32847.6	30263.9	29277.2	28458.7	35392.0
1907	27809.8	27061.9	25236.4	23514.8	20748.2	16174.5	11095.2	7407.1	5560.6	24588.3	23703.6	37398.0	20858.2
1908	39624.2	43758.9	44176.3	47520.0	59400.0	59105.0	52052.1	46365.2	43205.1	40385.3	39231.3	38297.3	46093.4
1909	37574.3	36748.3	34755.2	32887.5	29966.9	25064.6	19528.6	15424.7	13315.1	11237.6	10593.2	10005.9	23091.8
1910	9502.3	8904.9	7395.6	5943.1	3460.9	70.0	57.4	46.7	40.7	36.9	34.5	32.9	2960.5
1911	31.9	30.9	28.9	27.3	25.6	22.5	18.4	15.0	13.1	11.9	11.1	10.6	20.6
1912	10.2	9.9	9.3	8.8	8.2	7.2	5.9	4.8	4.2	3.8	3.6	3.4	6.6
1913	3.3	3.2	3.0	2.8	2.6	2.3	1.9	1.5	1.3	1.2	1.1	29248.8	2439.4
1914	28596.5	27968.7	26164.3	47520.0	59400.0	59400.0	53343.8	53120.5	52975.4	52552.6	52487.0	56533.7	47505.2
1915	56482.1	56428.4	58678.1	59400.0	59400.0	59400.0	59400.0	53430.9	50082.3	50034.4	48744.3	47716.5	54933.1
1916	47715.4	59400.0	57099.8	59400.0	59400.0	55520.8	48601.5	43054.3	39989.9	37237.2	36129.0	35226.7	48231.2
1917	34524.8	33721.7	31779.9	29957.6	27083.9	22283.3	16896.3	12927.5	10899.8	8878.6	8272.8	7711.9	20411.5
1918	7225.0	6645.1	5175.5	3766.5	1346.9	70.0	57.4	46.7	40.7	36.9	34.5	32.9	2039.8
1919	31.9	2536.5	22012.8	29617.3	59400.0	59400.0	58957.1	59400.0	58303.5	59400.0	59400.0	58916.1	43947.9
1920	59400.0	59400.0	59400.0	57235.4	59400.0	59400.0	52336.1	52151.4	59400.0	57239.3	57112.6	57313.7	57482.4
1921	59400.0	59400.0	59400.0	58289.9	58164.1	59400.0	52336.1	46637.8	43469.9	40644.6	39486.8	38550.2	51265.0
1922	37825.6	36997.9	35000.8	59351.6	59400.0	59400.0	52336.1	46637.8	43469.9	40644.6	39486.8	38550.2	45758.4
1923	37825.6	36997.9	35000.8	44910.1	46749.6	46911.8	40327.3	35132.5	32310.7	29740.7	28763.3	27951.2	36885.1
1924	27306.3	32669.7	47520.0	49159.6	50098.5	44591.2	38102.4	33013.0	30266.1	27748.4	26806.5	26018.5	36108.4
1925	25388.7	24660.7	22878.7	21196.2	18470.5	13975.8	9000.2	5416.7	3661.3	1862.2	1429.6	1001.4	12411.8
1926	608.0	136.3	70.0	23761.6	29845.4	32039.4	28492.8	23896.0	21478.4	19196.4	18417.7	17740.7	17973.6
1927	17180.7	16524.9	14892.6	13334.4	26212.4	25299.3	19750.8	15635.1	13518.5	17330.1	16584.6	15929.0	17682.7
1928	15382.4	14848.1	13243.3	12241.7	23920.3	47520.0	40911.5	35689.1	32847.6	30263.9	29277.2	28458.7	27050.3
1929	27809.8	27061.9	25236.4	23514.8	20748.2	16174.5	11095.2	7407.1	5560.6	3683.9	3191.2	2711.1	14516.2
1930	2277.4	1756.1	446.5	70.0	65.8	57.7	47.3	38.5	33.6	70.0	65.4	8299.8	1102.3
1931	17873.6	28694.7	50170.1	50140.6	49678.9	44182.6	37710.8	32640.0	29906.3	32211.4	31189.9	33203.3	36466.9
1932	47520.0	59400.0	59400.0	59400.0	59400.0	57416.9	52790.6	47074.9	47520.0	44611.2	43395.7	42419.9	51695.8
1933	42897.6	42035.9	43668.5	44773.9	59400.0	53658.8	46808.9	41334.3	38319.6	35602.2	34520.3	33637.4	43054.8
1934	32947.9	32157.8	30243.3	35922.7	35262.3	30180.4	24371.9	20001.3	17734.2	15551.1	14835.4	14200.1	25284.0
1935	13666.3	13037.6	11462.2	9952.1	59400.0	59400.0	52336.1	46637.8	59400.0	59400.0	59400.0	59293.3	41948.8
1936	58444.4	57486.6	55210.8	53092.9	59400.0	59400.0	52961.0	47238.8	47520.0	49014.8	52878.8	52506.2	53762.9
1937	59400.0	59400.0	59400.0	59400.0	56135.8	55921.9	48987.6	43424.9	40349.7	37589.5	36476.2	39148.2	49636.2
1938	59400.0	59400.0	59400.0	59400.0	59400.0	59105.0	53416.0	53280.6	49935.8	46979.8	45730.1	44730.9	54181.5
1939	43966.8	43097.9	41012.6	39061.5	47520.0	47520.0	40911.5	35689.1	32847.6	30263.9	29277.2	28458.7	38302.2
1940	27637.1	26955.6	24661.2	23030.3	20026.6	41462.5	35097.8	30374.7	26974.4	24381.3	47520.0	59400.0	32293.5
1941	59400.0	59400.0	59400.0	59400.0	59400.0	59400.0	55698.2	59400.0	59013.5	59400.0	59400.0	59277.2	59049.1
1942	58919.3	58244.3	55183.1	59400.0	59400.0	59400.0	52586.9	47602.8	59400.0	59400.0	59400.0	59400.0	57361.4
1943	59268.8	58236.6	58548.6	57616.3	57473.8	51459.0	44636.9	38339.7	35690.2	32494.8	31088.4	30705.9	46296.6
1944	33941.4	43967.5	47520.0	47520.0	59400.0	52567.1	45542.3	39869.9	36446.1	33364.4	33068.8	33973.9	42265.1
1945	36242.3	47520.0	59400.0	59400.0	59038.7	58752.6	58479.6	52137.3	48093.6	46537.3	44436.0	43059.6	51091.4
1946	47282.2	47520.0	47301.4	45228.0	47520.0	46485.5	39072.3	33224.4	41049.7	38137.1	47520.0	47520.0	43988.4
1947	47520.0	47084.8	52536.3	52476.3	51975.5	45506.7	38024.6	32782.9	28997.1	25903.3	24835.4	24359.0	39333.5
1948	23719.1	23317.6	21418.2	19422.8	16614.9	12029.4	7233.6	3626.8	1848.6	103.2	70.0	64.2	10789.0
1949	66.4	66.2	63.4	64.8	15397.8	43510.9	36791.7	32070.2	29034.0	27114.4	25554.7	24928.6	19555.3
1950	24403.6	23790.2	21446.8	20026.7	17473.7	13019.7	8407.4	4658.1	3025.8	1111.1	636.1	221.4	11518.4
1951	70.0	68.5	62.5	56.9	55.4	53.2	42.5	32.5	27.2	23.8	21.8	20.1	44.5
1952	18.7	17.2	16.2	15.8	15.4	12.6	9.9	7.1	5.8	4.5	4.4	4.4	11.0
1953	4.0	3.8	3.6	3.4	3.3	2.6	2.2	1.8	1.5	1.4	1.3	1.2	2.5
1954	1.2	1.1	1.0	0.9	0.9	0.7	0.5	0.4	0.3	0.3	0.3	0.2	0.7
1955	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2
1956	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957	0.0	0.0	0.0	0.0	59400.0	59111.3	51177.9	44208.6	41074.7	52690.6	59400.0	59260.5	35527.0
1958	59400.0	59400.0	59400.0	59400.0	59400.0	53910.6	47051.3	41236.1	38586.4	35929.0	34634.7	33657.2	48500.4
1959	32678.8	31965.3	29570.3	27607.1	24783.5	20976.5	16344.6	12536.4	10334.6	59400.0	59400.0	59400.0	32083.1
1960	59400.0	59400.0	59267.6	59105.0	58897.9	52494.7	45948.0	40745.7	37120.8	34687.6	33932.9	33875.4	47906.3
1961	47520.0	59400.0	59400.0	57004.7	53553.1	59400.0	59400.0	53365.5	50039.3	47320.3	46455.5	45564.6	53201.9
1962	44415.4	43078.3	40831.3	39231.0	35043.1	30894.0	25623.9	20739.8	47520.0	47520.0	46321.3	46841.0	39004.9
1963	45811.4	44606.3	42131.0	40148.2	47520.0	42437.0	35101.9	29865.9	27071.2	24145.4	23653.5	22894.5	35448.9
1964	22492.6	21867.4	20317.5	18776.9	15847.3	11275.6	6160.5	2836.9	47520.0	47520.0	59400.0	59258.0	27772.7
1965	59400.0	59400.0	59267.6	58051.6	59400.0	56815.9	49977.0	44760.2	41301.0	40420.2	41049.8	40486.3	50860.8
1966	40097.9	40834.6	38539.3	47520.0	59400.0	59400.0	52618.2	48061.7	48057.7	44868.5	43258.0	42046.4	47058.5
1967	40851.7	39757.9	37347.0	35182.2	43984.8	47520.0	41243.7	35889.5	33947.7	31261.7	30571.4	29765.1	37276.9
1968	59400.0	59400.0	59400.0	59400.0	59400.0	59400.0	57316.9	51194.3	48124.9	44665.1	43654.1	42363.7	53643.3
1969	41128.7	40784.8	47520.0	59400.0	59400.0	53417.3	46296.5	41964.9	39667.8	42248.3	41892.6	47520.0	46770.1
1970	47520.0	59400.0	59400.0	59400.0	59400.0	59089.1	51713.7	46257.9	45376.0	43320.0	41741.8	40268.0	51073.9
1971	38925.3	37615.9	34976.3	32781.8	41777.6	35919.9	32332.9	42980.5	40469.8	47520.0	46627.6	47520.0	39954.0
1972	47520.0	47413.6	44518.7	43065.7	44259.2	38784.4	33136.5	29142.4	26741.3	24583.8	23805.1	22929.4	35491.7
1973	22640.3	22180.8	21782.1	47520.0	45560.9	43854.8	44569.8	39155.0	36987.9	47520.0	46379.9	44761.9	38576.1
1974	43866.2	42445.2	39925.1	37223.3	33488.2	27916.9	21934.6	18580.0	30990.2	44611.9	47520.0	48506.6	36417.3
1975	50214.4	59400.0	59251.6	59400.0	59400.0	55132.4	52185.1	46831.7	43828.3	40473.7	39075.8	38092.3	50273.8
1976	36902.9	35252.7	32974.7	34672.4	35609.9	30396.7	26239.8	21892.3	21502.0	24424.9	23719.1	23110.9	28891.5
1977	22742.8	22085.3	54243.7	59400.0	59400.0	53329.7	46133.0	40996.5	37040.8	34066.8	33073.3	31717.3	41185.8
1978	31028.4	30655.1	28573.7	26357.6	23206.9	18239.5	12765.7	9292.6	7553.9	5472.1	5127.6	4541.8	16901.2
1979	4178.0	3694.5	2372.8	1064.2	16515.9	12274.2	7531.6	4314.9	2539.4	717.8	358.1	70.0	4636.0
1980	69.0	66.4	61.3	54.9	6156.1	1951.4	70.0	54.6	49.1	43.5	40.9	39.9	721.4
1981	38.4	36.9	35.8	33.2	30.3	27.7	22.4	18.7	16.7	29951.7	29011.8	28008.7	7269.4
1982	27468.7	26918.0	25244.9	23452.2	34070.4	47520.0	41317.8	36010.5	32741.8	29945.1	29143.1	28461.7	31857.8
1983	27959.6	27197.3	25735.8	23623.7	20789.4	16431.9	11363.7	7743.4	5736.6	3858.3	3360.6	2877.1	14723.1
1984	2447.8	1874.5	574.0	70.0	59.5	49.7	40.7	33.1	28.1	27.6	26.5	26.4	438.2

Table 7.27
END-OF-MONTH STORAGE IN BELTON RESERVOIR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1900	447490.0	445850.6	445592.5	447490.0	447490.0	447490.0	446475.9	445424.9	447490.0	447490.0	447490.0	439554.4	446277.4
1901	429444.0	425771.8	415857.8	406625.9	447490.0	429731.3	406894.4	384976.3	370256.0	356415.3	345415.7	334539.8	396118.2
1902	324565.3	315451.6	325998.4	316144.8	357992.0	348965.8	357992.0	336403.7	333061.1	328282.4	331865.8	334315.1	334253.2
1903	350978.6	447490.0	447490.0	447490.0	437912.3	443701.3	428903.7	406465.3	390183.6	405516.1	399853.8	388876.1	416238.4
1904	379385.5	370496.3	359565.1	359276.0	410428.5	410069.1	409472.3	389376.2	373834.8	365747.9	358568.6	347668.0	377824.0
1905	337676.4	329097.8	334870.6	447490.0	447490.0	447490.0	435230.4	412718.1	396387.1	382400.1	384078.1	384976.8	394992.1
1906	377937.9	382151.2	385759.2	378121.4	378068.7	377930.2	355683.7	334946.5	335719.1	322071.8	311187.7	332605.0	356015.2
1907	330873.9	333260.9	329081.3	318235.8	318597.6	331334.3	314776.3	299828.2	284771.6	395532.3	388619.3	390692.5	336300.3
1908	393174.7	388710.0	422111.1	447490.0	447490.0	438191.8	418295.4	395981.7	383767.5	371297.7	362449.8	351542.0	401708.5
1909	341545.3	332412.4	321524.6	316226.6	307354.3	292196.0	270984.5	250573.6	235667.1	222692.3	212450.3	213845.6	276456.0
1910	204063.9	199567.3	189173.4	198272.6	194836.6	179057.0	159599.0	141017.4	127298.6	115131.0	105135.0	94817.2	158997.4
1911	85238.6	76473.1	66592.2	63779.4	55729.6	48501.4	33190.8	17221.2	5471.3	11.0	9.0	8.1	37685.5
1912	7.5	11.0	571.5	8978.2	7651.6	11.0	5.4	2.6	1.6	10634.8	1450.5	11.0	2444.7
1913	10.2	9.5	8.0	11.0	142285.2	224225.4	204040.0	184704.4	175804.5	238810.1	302260.0	447490.0	159971.5
1914	445543.9	440471.3	443411.9	447490.0	447490.0	447490.0	443639.5	439530.1	438887.2	430442.8	432982.9	447490.0	442072.5
1915	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	433181.9	416692.0	447490.0	447490.0	447490.0	443731.2
1916	447490.0	447490.0	447490.0	447490.0	447490.0	447299.4	428625.6	406190.5	389910.9	375960.1	364894.8	353982.4	417026.2
1917	343982.5	334846.9	323951.8	313116.0	305583.0	288800.6	267640.2	247282.0	235173.7	222202.5	211734.3	201159.7	274622.8
1918	191401.2	182476.7	172155.2	184285.5	172196.0	166651.6	147396.0	129001.0	115389.4	116085.5	145670.4	160967.1	156973.0
1919	270674.7	351405.3	366262.6	375755.8	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	412001.5
1920	447490.0	447490.0	447490.0	441080.2	447490.0	447490.0	447490.0	447490.0	447490.0	439734.8	439464.4	447490.0	445640.8
1921	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	433511.8	411019.5	447490.0	434682.6	423925.8	412904.2	437372.8
1922	402827.5	393626.0	397988.5	447490.0	447490.0	447490.0	424455.2	402068.8	385821.7	371893.8	360842.1	349937.3	402660.9
1923	339942.7	330811.7	326218.4	350406.2	357121.7	357992.0	335975.6	314653.6	308870.8	301226.0	318724.9	357853.5	333316.4
1924	352043.3	351405.3	387518.1	411756.1	439678.7	442379.7	419401.8	397075.0	380867.6	366967.5	355932.4	345036.8	387505.2
1925	335048.6	325923.0	315054.6	304235.4	301819.2	285066.7	263962.5	243662.4	228828.1	233702.0	268124.0	257410.8	280236.5
1926	262332.0	255665.2	293892.5	446528.6	447490.0	446883.4	445876.1	423239.4	406826.4	392781.6	381659.7	370716.0	381157.6
1927	360694.2	385406.2	393100.4	431394.5	431755.2	447490.0	425865.3	403462.3	387204.3	411725.4	404832.9	397443.6	406697.8
1928	387386.8	391194.6	385570.0	377932.6	369296.1	369218.1	347072.2	330467.1	314793.7	301263.5	290451.5	279683.7	345360.8
1929	276122.0	267070.5	265739.7	282356.8	335816.4	339820.2	318013.4	296908.6	301828.3	288375.9	277617.1	266880.7	293045.8
1930	257007.9	247984.4	237396.6	226758.5	328807.3	311858.6	290381.7	269664.8	254558.5	349993.9	343557.6	370512.5	290706.9
1931	395602.3	447490.0	447227.2	447490.0	447490.0	446883.4	428708.5	406272.4	389992.2	381814.9	370729.8	363120.2	414401.8
1932	387806.8	447490.0	447490.0	447490.0	447490.0	447490.0	435230.4	415362.1	422418.6	408288.7	397115.1	386142.5	424151.2
1933	386771.1	382636.3	383175.8	393705.4	431035.6	426870.6	404065.7	381921.1	365835.2	352019.3	341034.4	330166.7	381603.1
1934	322429.6	315968.0	335526.6	415068.2	416944.3	399389.3	376895.3	355078.4	339207.7	325540.8	322988.9	312154.9	353099.4
1935	303382.4	308691.6	298476.4	294661.6	447490.0	447490.0	432386.4	409907.3	447490.0	447490.0	447490.0	447490.0	394370.5
1936	447490.0	445242.8	438534.4	437478.0	447490.0	447490.0	438499.3	415948.8	415488.6	447490.0	447490.0	447490.0	439677.7
1937	447490.0	447490.0	447490.0	447490.0	441237.0	440672.2	439734.1	417169.2	400803.2	392680.5	381558.9	432232.7	428004.0
1938	447490.0	447490.0	447490.0	447490.0	447490.0	446883.4	445876.1	447490.0	433339.5	419150.6	407941.6	396949.0	436256.7
1939	395192.0	392774.9	387451.3	382260.0	431332.5	430833.7	410106.1	388347.5	372210.1	358358.4	347352.3	336472.7	386057.6
1940	325982.7	317069.0	304352.2	310945.4	295891.5	347964.4	363062.8	340883.7	322261.9	307797.8	445865.8	447490.0	344130.6
1941	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447186.6	444479.4	447213.8
1942	437111.0	430568.7	419775.9	447490.0	447490.0	447490.0	435540.9	434789.1	447490.0	447490.0	447490.0	447490.0	440851.3
1943	447490.0	443433.9	443182.9	447490.0	445709.7	427058.5	405783.4	381913.3	367364.3	352570.1	340319.5	330447.3	402730.3
1944	357790.4	447490.0	447490.0	447490.0	447490.0	447490.0	433980.2	412432.7	396140.1	382866.3	376357.7	393996.8	415917.9
1945	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	446769.1	425274.2	411491.1	429387.0	427674.5	447490.0	439418.8
1946	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	424219.8	399263.0	391929.5	378755.7	378701.4	385653.5	420288.6
1947	434680.5	442931.5	447490.0	447490.0	447490.0	431806.7	407762.3	386716.8	367489.9	350867.3	339150.9	329421.2	402774.8
1948	319554.8	325382.1	320314.0	310858.8	317693.6	302139.7	290221.2	267954.9	253354.9	238161.8	225936.6	214473.7	282170.5
1949	206193.0	197974.8	240168.8	312189.7	349422.1	347984.1	328737.3	307801.7	290009.2	277844.2	264704.1	254173.5	281433.5
1950	244746.0	242341.2	229904.4	223022.5	247732.9	249114.2	244630.1	223269.2	234628.4	220000.8	207267.9	195105.3	230146.9
1951	184312.6	175735.0	164475.9	153165.5	145759.2	146232.3	126443.8	106377.1	93208.2	80747.2	70487.2	59670.0	125551.2
1952	49665.6	40780.5	31194.0	39987.6	79517.3	67526.4	49915.2	32493.7	19685.4	8153.7	11.0	3482.5	35201.1
1953	11.0	9.5	4014.4	11.0	134902.9	118327.6	100287.6	82948.5	69663.5	69069.7	59559.7	49306.0	57342.6
1954	39762.4	30330.3	20495.4	10455.9	11.0	5.0	1.5	0.5	0.2	0.1	0.1	0.1	8421.9
1955	0.1	11.0	8.9	11.0	67489.8	85315.2	67520.5	51666.2	52422.8	43966.4	33642.3	23291.5	35445.5
1956	13911.4	5316.0	11.0	7.6	112901.7	96264.7	76588.5	58464.7	44329.0	32360.9	22684.6	12618.9	39621.6
1957	3267.5	11.0	6458.0	310477.6	447490.0	447490.0	447490.0	426668.4	411694.3	447490.0	447490.0	447490.0	320293.1
1958	447490.0	447490.0	447490.0	447490.0	447490.0	444435.0	419383.6	396824.4	382882.6	369192.7	357282.3	345320.9	412731.0
1959	334082.2	326438.4	314362.6	304135.4	292112.3	317146.2	320704.8	309160.9	297022.2	447490.0	447490.0	447490.0	346469.6
1960	447490.0	447490.0	447490.0	447490.0	439740.5	423483.6	401184.8	380771.9	362828.3	400188.1	396157.4	447490.0	420150.4
1961	447490.0	447490.0	447490.0	447490.0	441735.6	447490.0	447490.0	435766.5	427140.6	447490.0	447490.0	447490.0	444337.7
1962	445488.2	442284.0	434587.4	432672.7	422178.4	413017.6	393106.4	369777.9	369692.2	369628.8	361361.3	356436.3	400852.6
1963	346569.3	336813.4	326737.1	316774.6	351674.2	346000.4	324946.0	302374.5	285038.2	269421.7	263945.6	252895.2	310265.9
1964	245970.7	245304.5	250483.3	285908.8	286980.2	355044.3	332539.8	311259.3	350198.7	351331.0	371066.9	366629.7	312726.5
1965	390299.9	447490.0	447490.0	447490.0	447490.0	447490.0	440499.4	432569.3	432048.6	425300.7	447490.0	447490.0	437762.3
1966	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	424819.3	444671.5	447490.0	438889.6	427852.0	416106.9	440397.5
1967	404266.6	393910.7	381030.6	375599.7	372770.1	372618.7	356269.3	334492.5	327999.3	316509.9	307203.6	296884.6	353296.3
1968	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	433193.7	418581.1	403651.4	393183.2	383090.2	430344.1
1969	373132.8	367089.5	367074.1	445811.8	447490.0	434817.8	413153.3	396750.3	382808.8	374644.7	374053.6	383488.9	396693.0
1970	392172.8	419971.1	447490.0	447490.0	447490.0	447490.0	424212.5	400073.3	415819.7	408323.6	396918.3	385832.2	419440.3
1971	373445.9	362853.6	349196.2	348292.5	349427.7	333960.8	357992.0	350316.8	342002.1	357992.0	363054.0	422451.2	359248.7
1972	447490.0	447490.0	440351.6	432282.5	431611.8	413620.4	392927.3	372255.7	356464.1	350568.2	343252.5	332908.7	396768.6
1973	337890.1	347634.8	372089.3	402037.6	416059.1	429391.4	425266.3	402049.2	388645.6	415188.8	412228.3	400486.8	395747.3
1974	395057.8	387473.4	377637.0	365673.0	353402.4	333982.0	310636.0	321727.8	393154.7	447490.0	447490.0	447490.0	381767.9
1975	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	445114.6	430735.1	415098.6	400541.8	387794.4	376727.0	428412.6
1976	365266.9	353626.2	344594.0	358018.2	365029.6	366237.2	447490.0	428261.8	423030.3	428131.5	424904.1	447490.0	396006.7
1977	447490.0	447490.0	447490.0	447490.0	447490.0	447490.0	422032.4	399791.1	380617.6	365286.7	354688.7	341680.7	412419.7
1978	331593.3	323184.8	312313.2	300226.4	286306.6	268591.7	245757.4	226067.7	211725.1	197900.2	188885.6	178235.1	255898.9
1979	180386.0	187231.1	233105.2	260034.9	349403.7	447490.0	439380.3	421250.3	405205.2	389907.2	377896.3	368284.3	338297.9
1980	358700.2	352570.0	344161.4	339078.2	447490.0	432436.0	406136.7	381807.3	366163.2	351055.6	340494.8	329938.0	370836.0
1981	319462.7	310553.8	304132.7	298251.2	285976.9	403797.6	386649.8	365708.6	350503.5	349978.9	339001.0	327107.9	336760.4
1982	317244.1	308138.6	309937.1	311523.0	349407.7	357992.0	336080.6	313748.6	295873.3	282083.3	272906.3	262537.9	309789.4
1983	252932.8	251589.2	241574.6	230488.4	237718.6	221535.9	201916.7	184228.5	169516.4	157116.1	147014.7	136380.3	202667.7
1984	126407.1	116784.1	111786.3	99767.1	86562.4	71248.3	53338.4	36465.0	23907.5	35164.9	28317.5	44093.9	69486.9

Table 7.28
END-OF-MONTH STORAGE IN STILLHOUSE HOLLOW RESERVOIR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
1900	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235137.8	234563.1	235700.0	235700.0	235700.0	235700.0	235558.4
1901	234920.0	235700.0	234441.8	234408.1	235700.0	235700.0	208752.9	188073.6	185169.0	180564.4	178059.1	175515.1	210583.7
1902	172485.4	170531.1	174301.4	171018.0	188560.0	188560.0	188560.0	187518.5	200343.9	198666.0	201257.1	207459.6	187438.4
1903	235700.0	235700.0	235700.0	235700.0	235700.0	233946.7	230729.0	223728.7	219240.5	226645.0	233512.1	233491.2	231649.4
1904	234231.5	234420.0	233893.5	235700.0	235700.0	235365.7	232189.0	226769.4	225161.4	211269.7	210819.6	214064.0	227465.3
1905	221082.4	221079.4	233754.8	235700.0	235700.0	235700.0	213188.0	209721.4	206398.7	203022.7	203371.3	216102.8	219568.5
1906	226860.1	235700.0	235700.0	235604.3	235461.0	235128.3	226269.0	204132.1	207106.4	203013.8	203701.5	219382.4	222338.3
1907	235700.0	235700.0	235700.0	235700.0	235700.0	235365.7	234807.3	235700.0	234930.9	235700.0	235700.0	235700.0	235533.7
1908	235541.7	235700.0	235700.0	235700.0	235700.0	235365.7	234807.3	228606.8	228303.7	235700.0	235700.0	234781.0	234300.5
1909	231728.3	229321.1	226018.9	222625.9	222520.0	221568.6	196980.1	171131.3	151720.6	139894.4	144162.0	155428.7	192758.3
1910	142520.2	144999.5	141551.4	140607.0	141263.1	135813.5	128262.5	121130.0	116175.3	112017.9	109095.4	106430.6	128322.2
1911	104326.0	103180.3	101214.2	106225.2	106916.6	102066.5	96945.0	96459.4	91712.1	87705.1	88953.8	89293.6	97916.5
1912	88920.4	94439.2	96125.5	108097.2	109726.6	104539.4	97417.9	90715.2	72010.6	76720.2	74405.6	58137.6	89271.3
1913	55242.2	53674.9	51945.9	56564.6	91580.5	101762.9	96313.7	89626.2	92730.4	111150.1	140224.1	235700.0	98043.0
1914	233568.8	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	231303.5	230981.3	235700.0	235700.0	235700.0	234762.8
1915	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	230619.2	235700.0	235700.0	235700.0	235276.6
1916	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	232346.5	225697.3	223346.5	222314.7	219660.1	218218.6	229648.6
1917	215118.1	201306.2	198132.7	184070.5	184359.2	178547.8	170383.6	144912.9	141073.9	136754.5	122844.2	120137.6	166470.1
1918	117372.1	115199.6	111863.3	121085.9	117348.1	112104.1	104881.5	98075.6	95154.0	105952.3	112707.0	125807.0	111462.5
1919	136565.0	209722.1	234068.9	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	225138.0
1920	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0
1921	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	228154.0	235700.0	235032.4	235700.0	235700.0	235015.5
1922	235564.7	235083.4	235700.0	235700.0	235700.0	235700.0	233653.1	229916.5	227482.0	224779.1	222418.9	222366.2	231172.0
1923	222327.6	222232.6	221535.6	235700.0	235700.0	230762.4	226697.6	200466.2	205700.2	203258.5	205206.3	235700.0	220440.6
1924	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	227750.6	212157.5	201033.3	196688.3	180858.7	178387.0	217589.6
1925	176610.9	172725.9	166774.8	161110.2	168130.5	162447.9	154508.0	129274.5	124248.4	158432.2	209511.5	209497.2	166106.0
1926	209559.1	212460.8	232067.5	235700.0	235700.0	235365.7	234807.3	227215.0	222190.4	228456.0	227435.2	229157.5	227509.6
1927	235179.6	235700.0	235700.0	235700.0	235700.0	235700.0	233140.0	225321.3	220791.0	235700.0	233508.0	234376.2	233043.0
1928	233388.7	235700.0	235700.0	235236.6	222760.9	227793.7	206216.5	197962.9	192927.6	174632.1	173280.9	171745.2	208945.4
1929	170332.1	168833.7	169438.5	183203.8	205142.7	205869.7	200047.0	191876.1	191848.7	187523.2	186584.8	184130.5	187069.3
1930	189007.4	187623.1	185769.0	182460.0	233476.9	228190.5	219409.4	211751.9	208963.8	235700.0	235234.5	235700.0	212773.9
1931	235700.0	235700.0	235700.0	235700.0	235700.0	235365.7	213626.3	189251.0	187570.6	185153.1	182743.3	180993.8	212767.0
1932	195860.8	230141.5	235700.0	235700.0	235700.0	235700.0	228140.4	227647.3	235700.0	232899.9	230916.6	229790.7	229491.4
1933	228927.0	230333.6	235700.0	233825.0	235700.0	234259.7	207328.8	202825.6	199137.9	183089.0	180816.0	178445.3	212532.3
1934	176995.9	180162.5	187968.4	213816.8	213736.2	190612.6	164227.7	156553.5	151276.9	146889.0	157848.4	155703.1	174649.3
1935	152679.3	161027.8	160019.0	159602.3	235700.0	235700.0	232838.7	226582.4	235700.0	235700.0	235700.0	235700.0	208912.5
1936	235700.0	235700.0	233980.5	234138.5	235700.0	235700.0	235700.0	230993.3	230673.3	235700.0	235700.0	235700.0	234615.5
1937	235700.0	235700.0	235700.0	235700.0	235556.5	235223.1	216585.0	194570.3	194208.0	193227.0	199741.7	223756.8	219639.0
1938	235700.0	235700.0	235700.0	235700.0	235700.0	235365.7	234807.3	235700.0	235700.0	231990.0	231462.3	231346.8	234572.7
1939	232579.5	235353.4	234763.2	231353.4	235700.0	235365.7	234003.8	227781.5	208178.6	189754.3	174246.8	161349.7	216702.5
1940	158871.3	159614.8	156448.9	164270.6	168824.8	188560.0	221296.9	201282.1	195066.5	178891.4	235700.0	235700.0	188710.6
1941	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	232371.6	235700.0	235700.0	235700.0	235422.6
1942	235700.0	234688.4	232628.3	235700.0	235700.0	235700.0	235284.9	232028.8	235700.0	235700.0	235700.0	235700.0	235019.2
1943	235700.0	235700.0	235700.0	235700.0	235700.0	230389.7	223335.5	213996.3	215271.7	211947.7	209658.7	208857.3	224329.8
1944	231310.6	235700.0	235700.0	235700.0	235700.0	235700.0	216967.5	205756.8	208483.6	197393.2	204273.5	235700.0	223198.8
1945	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0
1946	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	228927.8	222947.5	222901.1	221309.1	229658.7	235700.0	231303.7
1947	235700.0	235700.0	235700.0	235700.0	235700.0	234709.5	208955.4	203496.8	196993.0	190729.3	188614.4	187627.8	215802.2
1948	186298.9	188560.0	187810.0	190097.0	196330.6	190314.2	187378.3	177285.2	171309.4	162985.0	145976.8	142662.3	177250.6
1949	141903.6	141165.3	160370.8	201616.0	204913.5	211200.5	203934.0	179512.0	173128.6	169552.0	165793.6	164604.4	176474.5
1950	162571.9	166534.9	163462.9	167007.6	169797.0	169206.9	161821.1	153334.6	155630.1	150509.9	146526.5	142874.9	159106.5
1951	139494.1	137910.5	135031.8	131494.3	127860.6	126413.2	118284.6	110012.0	105309.4	100722.6	97504.9	93965.3	118666.9
1952	90513.1	88068.3	76185.6	92522.2	126882.7	126614.9	119118.6	93284.7	73874.8	57951.8	55850.6	69566.0	89202.8
1953	70653.7	70733.0	73092.1	78495.5	156282.5	152996.6	145014.5	137867.7	136154.0	142383.5	140989.2	144886.9	120796.6
1954	143167.1	140213.0	136187.0	132663.7	133925.8	127261.1	118788.9	110761.7	104520.2	99855.9	96659.7	92914.2	119743.2
1955	89957.0	94465.3	93297.6	94154.7	144597.2	163280.1	155399.4	149141.8	143933.3	138178.1	134193.9	130997.5	127633.0
1956	128336.3	126780.0	122526.4	118413.5	134925.2	128244.0	101579.4	93881.9	76868.9	72332.9	69199.2	52693.9	102148.5
1957	49536.2	47148.9	56364.0	188560.0	235700.0	235700.0	229174.6	221091.9	218541.4	235700.0	235700.0	235700.0	182409.8
1958	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	231812.1	225956.2	225879.2	224295.4	223136.4	221639.8	230576.6
1959	219633.7	219758.6	217035.9	218005.4	216198.1	234460.3	230472.0	231403.7	217074.9	235700.0	235700.0	235700.0	225928.6
1960	235700.0	235700.0	235700.0	235700.0	235700.0	234062.7	230497.5	226399.0	223780.0	235700.0	235700.0	235700.0	233361.6
1961	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	234273.1	235700.0	235700.0	235700.0	235700.0	235581.1
1962	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	228762.7	219349.1	223619.7	235700.0	235700.0	235700.0	232752.6
1963	235488.0	235700.0	233915.6	232225.3	231967.5	226862.2	200768.8	174113.3	168518.6	162634.6	162252.2	159934.4	202031.7
1964	158476.2	161289.8	167863.5	174158.7	177977.1	169309.5	142775.8	135361.6	149179.7	133556.3	140071.5	140997.6	154251.5
1965	153102.6	199658.1	221081.6	235700.0	235700.0	235700.0	217044.8	212858.4	219430.8	226198.1	235700.0	235700.0	218989.5
1966	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	229463.8	235700.0	235700.0	235700.0	235700.0	235700.0	235180.3
1967	235410.7	234906.7	232403.2	232264.7	232184.4	224776.5	215623.5	193188.4	190568.9	174814.7	176207.9	176559.4	209909.1
1968	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	235047.8	235700.0	233802.0	235700.0	235700.0	235487.5
1969	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	211248.0	209812.2	208044.9	223137.9	228766.8	235700.0	227575.8
1970	235700.0	235700.0	235700.0	232224.5	235700.0	235700.0	216240.1	192965.5	214280.0	222133.5	223691.0	225460.2	225457.9
1971	213274.8	213169.5	208212.5	190693.2	190248.5	166234.6	170503.7	177867.7	175423.5	188560.0	187767.9	208522.4	190873.2
1972	220289.6	224821.0	225070.7	228242.8	235700.0	231586.3	211922.1	208433.4	204016.4	203947.3	203915.9	206094.5	217003.3
1973	212237.2	228136.5	235700.0	235700.0	235700.0	235700.0	235700.0	229096.2	228257.2	235700.0	235700.0	235700.0	231943.9
1974	235700.0	235700.0	235700.0	235446.7	235700.0	235166.2	207430.1	207324.4	235700.0	235700.0	235700.0	235700.0	230914.0
1975	232389.3	235700.0	235700.0	235700.0	235700.0	235700.0	231184.7	235700.0	234159.2	233964.7	233967.9	235478.1	234612.0
1976	235204.0	235685.4	235650.7	235700.0	235700.0	235700.0	235700.0	234917.6	235700.0	235700.0	235700.0	235700.0	235588.1
1977	235700.0	235700.0	235700.0	235700.0	235700.0	235700.0	225669.6	216754.6	209754.1	204124.8	200933.5	196566.0	222333.6
1978	193575.1	194252.4	191438.5	187458.8	182889.1	176695.3	167592.6	160087.1	155227.5	150213.3	150121.9	147547.4	171424.9
1979	151653.9	162858.2	191579.3	211454.5	235700.0	235700.0	235700.0	235700.0	229821.9	223843.8	220044.5	219873.3	212827.5
1980	218477.9	218165.1	216221.0	215620.3	235700.0	233798.0	205321.2	178588.4	173375.9	168387.3	165938.5	163469.4	199421.9
1981	160276.3	159416.9	162417.8	165531.9	170598.4	235700.0	235700.0	228615.8	230550.1	235700.0	235700.0	233761.0	204497.4
1982	232282.6	231754.6	234830.5	235700.0	235700.0	235700.0	226870.5	217817.4	210924.9	206167.9	204983.9	202228.5	222913.4
1983	200809.5	209257.3	206136.8	207726.2	235700.0	235700.0	227560.3	220469.6	214364.9	209619.9	206324.4	202794.9	214705.3
1984	199780.9	196267.9	193894.5	188661.5	183167.8	176840.1	168495.1	160342.6	143368.8	147480.0	145414.1	147592.9	170942.2

Table 7.29
STORAGE IN BRA/USACE RESERVOIRS DURING 1950-1957 DROUGHT
AS A PERCENTAGE (%) OF ACTIVE CONSERVATION STORAGE CAPACITY

YEAR	MONTH	AVE	POSSKI	GRBURY	WHTNEY	AQUILK	WACRES	PRCTOR	BELRES	STHLOW	GEOTWN	GRNGER	SMVLLE	LMTONE
1950	1	66.20	73.17	75.27	0.00	60.12	78.76	41.01	54.69	68.87	79.30	90.11	100.00	73.08
50	2	74.71	71.43	75.28	29.55	74.37	92.03	39.98	54.15	70.56	89.17	100.00	100.00	100.00
50	3	72.10	68.58	71.64	19.06	72.70	92.33	36.03	51.38	69.25	88.18	99.16	99.30	97.55
50	4	76.41	73.34	71.63	32.77	86.68	98.85	33.64	49.84	70.76	99.43	100.00	100.00	100.00
50	5	77.72	80.00	71.62	35.81	88.95	100.00	29.33	55.36	71.95	100.00	100.00	100.00	99.68
50	6	76.22	80.00	71.59	28.33	86.51	100.00	21.83	55.67	71.70	100.00	100.00	100.00	99.03
50	7	69.07	79.22	71.56	0.00	58.23	99.73	14.05	54.67	68.55	95.52	96.76	95.90	94.63
50	8	65.01	80.00	71.50	0.00	53.67	92.73	7.73	49.89	64.94	89.19	91.35	89.89	89.27
50	9	67.47	80.00	71.47	30.44	55.57	92.64	4.98	52.43	65.92	89.14	91.20	89.82	86.09
50	10	63.70	77.77	71.42	17.36	52.41	88.66	1.75	49.16	63.74	85.76	88.61	85.66	82.08
50	11	59.77	74.40	66.11	1.36	49.72	87.08	0.95	46.32	62.04	82.77	86.20	82.15	78.19
50	12	57.11	71.64	59.43	-0.77	47.60	84.08	0.26	43.60	60.49	79.95	84.28	79.62	75.13
1951	1	53.37	69.22	54.40	-2.06	45.95	81.58	0.00	41.19	59.05	77.27	64.18	77.42	72.26
51	2	52.33	67.49	57.05	-2.06	45.37	80.89	0.00	39.27	58.37	76.59	65.10	69.31	70.61
51	3	50.65	65.13	54.29	-3.91	43.42	78.59	-0.01	36.75	57.15	78.14	68.07	62.85	67.36
51	4	48.06	62.32	48.25	-5.51	44.62	77.75	-0.02	34.23	55.64	75.60	62.95	61.92	58.99
51	5	47.29	72.06	42.92	-6.09	43.25	79.92	-0.02	32.57	54.10	72.32	61.07	59.62	55.74
51	6	50.88	79.40	69.60	-6.89	53.88	79.92	-0.03	32.68	53.48	74.00	64.84	57.30	52.37
51	7	45.30	71.80	59.01	-11.42	49.30	72.64	-0.05	28.25	50.02	67.10	59.19	51.40	46.37
51	8	39.67	64.25	48.47	-16.75	44.41	64.81	-0.06	23.77	46.50	60.43	53.50	46.64	40.08
51	9	36.44	59.29	40.73	-19.47	41.58	60.76	-0.07	20.83	44.50	56.46	50.94	44.38	37.38
51	10	33.13	54.04	33.59	-22.08	39.00	56.72	-0.08	18.04	42.54	52.56	48.08	40.89	34.19
51	11	30.71	49.38	27.97	-23.62	37.34	54.07	-0.08	15.75	41.17	49.88	46.33	38.71	31.62
51	12	28.23	44.61	22.41	-25.09	35.61	50.97	-0.08	13.33	39.67	46.86	44.47	36.69	29.27
1952	1	25.81	40.92	17.84	-26.19	34.11	48.26	-0.09	11.10	38.20	43.85	38.98	35.22	27.56
52	2	23.10	38.51	13.46	-26.94	32.94	46.57	-0.09	9.11	37.16	42.09	24.09	34.19	26.16
52	3	21.19	36.00	9.01	-27.73	31.63	44.18	-0.09	6.97	32.10	40.18	23.84	32.54	25.61
52	4	27.52	34.10	5.20	-27.04	66.60	64.50	-0.09	8.93	39.05	43.47	29.05	34.79	31.66
52	5	39.74	32.22	40.92	0.00	71.26	79.92	-0.09	17.77	53.68	53.05	40.80	44.50	42.80
52	6	37.80	28.56	31.51	-3.86	67.67	79.92	-0.10	15.09	53.57	55.69	45.39	41.40	38.81
52	7	30.45	24.87	22.12	-8.30	28.72	73.37	-0.10	11.15	50.37	49.56	41.27	37.19	35.23
52	8	24.87	20.97	12.12	-14.46	24.73	65.79	-0.11	7.26	39.38	43.28	36.66	32.05	30.73
52	9	20.91	18.52	4.94	-18.75	21.99	60.29	-0.11	4.40	31.11	39.04	33.89	28.54	27.07
52	10	16.99	15.71	0.00	-23.03	19.47	54.93	-0.11	1.82	24.34	35.00	26.87	25.11	23.72
52	11	15.73	13.91	0.00	-22.24	18.96	58.64	-0.11	0.00	23.44	33.00	22.98	17.62	22.48
52	12	19.43	11.91	0.00	-21.57	37.24	60.79	-0.11	0.78	29.28	35.02	26.97	27.11	25.79
1953	1	21.11	10.07	-0.75	-22.95	37.88	60.54	-0.11	0.00	29.74	39.35	33.29	35.22	31.03
53	2	21.41	8.30	-1.20	-23.69	37.52	59.47	-0.11	0.00	29.78	41.82	37.72	36.99	30.28
53	3	23.79	6.67	-1.45	-24.02	43.89	61.11	-0.11	0.89	30.78	41.08	38.82	36.38	51.43
53	4	23.70	4.57	-1.80	-24.80	31.35	62.45	-0.11	0.00	33.08	44.71	44.60	38.80	51.54
53	5	46.36	4.88	6.15	-6.07	68.10	79.92	-0.11	30.14	66.19	61.36	63.80	81.90	100.00
53	6	41.70	1.94	0.00	-10.54	63.48	75.51	-0.11	26.44	64.80	56.05	59.16	76.36	87.28
53	7	40.47	37.88	-1.80	-13.69	59.51	70.45	-0.11	22.41	61.40	49.55	53.88	71.43	74.68
53	8	37.58	47.44	-3.42	-16.84	55.72	66.69	-0.11	18.53	58.36	43.97	49.78	68.25	62.61
53	9	35.29	44.06	-5.31	-19.98	55.26	63.67	-0.12	15.57	57.63	43.92	51.90	57.59	59.29
53	10	47.12	80.00	5.54	-20.51	54.78	64.35	-0.12	15.43	60.28	84.14	97.07	67.11	57.36
53	11	47.75	80.00	9.82	-21.54	53.89	64.50	-0.12	13.31	59.69	88.14	100.00	69.49	55.66
53	12	50.33	77.66	4.95	-22.39	52.68	62.44	-0.12	11.02	61.34	100.00	100.00	76.73	79.65
1954	1	49.59	76.34	1.08	-22.72	51.78	60.60	-0.12	8.88	60.61	100.00	100.00	76.68	81.93
54	2	47.72	74.02	0.00	-24.41	49.92	57.77	-0.12	6.78	59.35	98.84	96.45	74.87	79.20
54	3	44.04	71.50	-0.94	-25.98	47.94	54.86	-0.12	4.58	57.64	95.21	75.12	72.21	76.44
54	4	43.27	77.66	-1.39	-26.78	46.48	55.17	-0.12	2.33	56.14	91.96	72.93	70.61	74.21
54	5	49.59	79.52	69.60	-27.77	44.79	55.67	-0.12	0.00	56.68	91.84	78.16	72.26	74.39
54	6	46.31	77.02	66.54	-31.40	41.09	53.35	-0.12	0.00	53.84	86.05	73.09	67.14	69.14
54	7	41.08	69.22	55.67	-35.95	36.54	46.10	-0.12	0.00	50.23	79.03	67.33	61.68	63.28
54	8	35.76	61.07	43.25	-41.11	31.96	39.57	-0.12	0.00	46.82	72.30	61.60	56.12	57.67
54	9	30.32	56.49	33.81	-45.15	28.59	34.71	-0.12	0.00	44.16	67.00	40.50	51.28	52.58
54	10	27.78	51.39	27.19	-47.22	26.47	34.19	-0.12	0.00	42.17	62.93	37.84	48.47	50.07
54	11	26.13	47.61	21.91	-48.29	25.16	36.19	-0.12	0.00	40.81	60.12	36.15	46.49	47.55
54	12	23.50	44.69	16.08	-49.86	23.50	33.23	-0.12	0.00	39.22	56.91	34.26	43.92	40.13
1955	1	21.46	42.32	11.95	-50.26	22.41	30.94	-0.12	0.00	37.96	54.28	33.03	36.42	38.57
55	2	22.85	40.73	8.11	-50.17	23.66	29.64	-0.12	0.00	39.88	58.61	39.28	45.40	39.19
55	3	21.26	39.06	3.41	-51.15	22.30	27.78	-0.12	0.00	39.38	58.36	40.74	35.92	39.37
55	4	22.21	37.22	0.00	-52.03	22.29	28.67	-0.12	0.00	39.75	62.22	46.53	36.58	45.39
55	5	37.74	75.01	63.59	-51.72	21.39	66.77	-0.12	15.08	61.22	68.61	55.26	34.38	43.41
55	6	40.98	77.00	69.60	-52.55	19.74	73.36	-0.12	19.06	69.17	76.49	65.72	33.54	40.71
55	7	37.13	76.84	59.08	-55.35	16.90	69.69	-0.12	15.09	65.82	70.08	60.91	29.29	37.36
55	8	33.43	71.69	49.21	-57.51	14.50	66.48	-0.12	11.54	63.15	64.79	57.48	26.02	33.95
55	9	32.88	77.55	42.08	-59.06	12.76	79.92	-0.12	11.71	60.94	60.32	54.09	23.14	31.29
55	10	37.30	77.61	69.60	-10.13	10.89	76.32	-0.12	9.82	58.49	56.07	51.10	19.96	27.96
55	11	34.78	74.22	63.48	-12.91	9.46	73.28	-0.12	7.52	56.79	53.17	49.45	17.96	25.02
55	12	32.58	70.03	57.70	-14.25	8.24	70.19	-0.12	5.20	55.43	50.59	48.42	16.62	22.85
1956	1	30.94	67.16	53.77	-14.54	7.28	68.02	-0.12	3.11	54.30	48.19	47.82	15.04	21.28
56	2	30.62	65.95	50.18	-14.03	6.63	66.34	-0.12	1.19	53.64	47.48	48.80	21.39	20.01
56	3	28.34	61.45	44.35	-16.23	5.27	62.81	-0.12	0.00	51.82	44.20	46.41	21.82	18.34
56	4	26.26	56.78	38.74	-17.86	4.06	61.15	-0.12	0.00	50.07	40.89	44.00	21.10	16.25
56	5	31.57	60.00	54.76	-19.33	2.81	79.92	-0.12	25.23	57.10	37.35	41.69	19.67	19.70
56	6	27.57	52.92	44.77	-23.32	1.18	75.69	-0.12	21.51	54.26	32.51	38.06	16.50	16.85
56	7	22.18	48.36	33.33	-28.77	0.00	67.93	-0.12	17.11	42.91	26.31	33.48	12.30	13.31
56	8	17.62	40.67	22.48	-34.01	0.00	61.00	-0.12	13.06	39.63	20.63	29.20	8.76	10.07
56	9	13.78	36.70	14.01	-38.69	0.00	55.38	-0.12	9.90	32.39	16.41	25.91	5.91	7.55
56	10	11.08	31.87	7.46	-41.37	0.00	51.49	-0.12	7.23	30.46	12.99	23.52	4.06	5.34
56	11	9.06	27.71	1.65	-43.08	0.00	49.50	-0.12	5.07	29.12	10.52	21.90	2.91	3.57
56	12	7.37	26.25	0.00	-43.86	0.00	49.42	-0.12	2.82	22.10	7.84	20.45	1.69	1.85
1957	1	5.91	22.27	-0.39	-44.44	0.00	47.35	-0.12	0.73	20.75	5.13	18.80	0.48	0.38
57	2	7.93	53.31	-0.20	-44.33	0.00	45.98	-0.12	0.00	19.74	2.91	17.80	0.00	0.00
57	3	10.05	50.31	3.58	-44.30	0.00	46.65	-0.12	1.44	23.66	5.40	22.40	5.76	5.78
57	4	73.15	80.00	69.60	99.34	80.00	79.92	-0.12	69.38	79.93	79.87	79.93	79.97	79.99
57	5	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
57	6	99.96	100.00	100.00	100.00	100.00	100.00	99.51	100.00	100.00	100.00	100.00	100.00	100.00
57	7	94.86	98.86	98.70	82.32	93.97	99.65	86.14	100.00	97.22	95.78	96.83	94.62	94.17
57	8	86.80	92.89	84.67	46.08	87.08	93.21	74.40	95.35	93.78	96.45	98.36	89.12	90.24
57	9	84.57	92.20	84.35	31.94	83.88	89.51	69.11	92.00	92.70	97.38	100.00	94.75	87.00
57	10	95.64	92.17	84.32	82.55	100.00	100.00	88.69	100.00	100.00	100.00	100.00	100.00	100.00
57	11	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
57	12	99.81	99.58	100.00	100.00	100.00	100.00	99.76	100.00	100.00	100.00	100.00	100.00	98.32

Table 7.30
STORAGE-DURATION RELATIONSHIPS

Reservoir	Possum K	Granbury	Whitney	Aquilla	Waco	Proctor
Capacity (ac-ft)	570,240	153,490	627,100	524,000	152,500	59,400
Active (ac-ft)	570,240	100,990	248,000	524,000	151,920	59,330
Inactive (ac-ft)	0	52,500	379,100	0	580	70
Mean (ac-ft)	449,473	124,564	469,797	42,323	132,298	31,258

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	86	75	77	70	62	86
95%	80	73	76	64	56	84
90%	72	68	74	55	46	82
75%	29	52	68	30	19	67
50%	7	19	59	11	3	43
25%	3	9	51	3	0	27
10%	1	5	45	2	0	21
0%	0	3	41	1	0	17

Reservoir	Belton	Stillhouse	Georgetown	Granger	Somerville	Limestone
Capacity (ac-ft)	447,490	235,700	37,100	65,500	160,100	225,440
Active (ac-ft)	447,479	234,920	36,862	65,278	159,880	225,440
Inactive (ac-ft)	11	780	238	222	220	0
Mean (ac-ft)	334,254	201,444	32,999	56,720	135,479	181,779

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	75	55	50	46	61	69
95%	69	49	44	41	54	64
90%	62	41	35	35	43	55
75%	36	25	16	23	23	30
50%	17	8	5	8	9	11
25%	10	1	1	1	2	3
10%	7	0	0.4	0	1	1
0%	3	0	0	0	0.1	0.1

CHAPTER 8
EVALUATION OF WATER MANAGEMENT STRATEGIES AND MODELING ASSUMPTIONS

Several key aspects of river basin management and associated water availability modeling are investigated in this chapter. Alternative reservoir/river system operating policies, an additional diversion right, a salt impoundment plan, and various modeling premises are examined from the perspective of their impacts on simulation results, particularly water supply reliability estimates. Yield versus reliability relationships, including firm yields, are also developed for a hypothetical diversion from the lower Brazos River. The evaluation of water management strategies and modeling assumptions is supported by over 75 alternative runs of the WRAP3 or WRAPSALT simulation model of the Brazos River Basin. A base run is discussed in the previous Chapter 7. The other simulation runs demonstrate the sensitivity of model results to particular plans or premises represented by modifications to the base run model input data file. Most of the basic concepts examined are pertinent to other river basins as well as the Brazos. The intent of this report, including the present chapter, is to identify and examine fundamental ideas of importance in reservoir/river system management and modeling in general as well as to evaluate the water supply capabilities of the Brazos River Basin in particular.

Prior Brazos River Basin Simulation Studies

The present study builds upon and expands earlier work. Wurbs, Bergman, Carriere, and Walls (1988) and Wurbs and Bergman (1990) document a simulation modeling study of the Brazos River Basin which included an evaluation of factors affecting reservoir system reliability, particularly firm yield estimates. The factors affecting reservoir yield are outlined within the categories of (1) basin hydrology, (2) basinwide water management, and (3) reservoir system simulation. The original TAMUWRAP was developed in conjunction with this study and applied along with HEC-3 and HEC-5 (Hydrologic Engineering Center 1981, 1982). The original TAMUWRAP did not include capabilities for considering multiple-reservoir system operations, hydroelectric energy, or salinity. Thus, the present study is based on significantly more comprehensive analysis capabilities in this regard.

Wurbs and Carriere (1988) evaluated storage reallocations and related strategies for improving reservoir yields. Permanent or seasonal reallocation of flood control storage capacity to water supply was a major focus of the study.

Dunn (1993) tested WRAP2, WRAP3, and TABLES using the basic Brazos River Basin data developed by Wurbs, Bergman, Carriere, and Walls (1988). Numerous model runs were made in the development and testing of various modeling capabilities involving multiple-reservoir system operations, hydroelectric power, negative incremental streamflows, and data management.

Wurbs, Karama, Saleh, and Ganze (1993) document a reliability study for the 12 BRA/USACE reservoirs and Hubbard Creek Reservoir performed using the RESSALT model. This investigation focused on salinity and included evaluations of the impacts of alternative reservoir system operating policies and the proposed salt control impoundments. Water rights and the numerous other reservoirs in the basin were not incorporated in the simulation study.

The unregulated salt load input data sets used in the present simulation study were developed in the investigation reported by Wurbs, Karama, Saleh, and Ganze (1993) as noted above. The sensitivity of simulation results to various factors, related primarily to salinity, were analyzed based on alternative runs of the RESSALT model. Since the same unregulated salt loads are used in the present study, prior analyses related to these data are particularly pertinent to the present discussion. The alternative hydrologic simulation periods of 1900-1984 and 1964-1984 were compared and found to yield reasonably similar simulation results. This is significant because the measured salt data upon which the unregulated loads are based were collected during the period 1964-86. The salt loads for 1900-1963 are synthesized.

Another significant issue addressed by Wurbs, Karama, Saleh, and Ganze (1993) involves the use of salt load versus flow relationships combined with flow data to synthesis loads. Thus, the unregulated salt loads represent expected values of loads for given discharges. Although the variation of loads with discharge is appropriate, the variations of concentrations is not. An alternative salt load data set was developed which included a random component to more realistically reflect random variations in concentrations. RESSALT simulations with the two alternative salt load input data sets resulted in similar simulation results, at least from the perspective of summary statistics such as reliabilities and means and frequency-duration relationships for various variables. Thus, the basic expected value salt load data set was adopted for the present study.

Firm yield has traditionally been used as the primary measure of reservoir/river system reliability in Texas and elsewhere. Wurbs, Bergman, Carriere, and Walls (1988) and Wurbs and Carriere (1988) focus on firm yield estimates. Yield versus reliability relationships, including firm yields, are investigated in the last section of the present chapter. The discussion includes a comparison of the results of the present simulation study with firm yields estimated in the previous studies.

Organization of the Simulation Runs and this Chapter

The sensitivity of simulation results, including reliability estimates, to various factors is analyzed in this chapter. The following aspects of river basin management and associated water availability modeling are addressed:

- salinity constraints,
- multiple-reservoir system operations,
- additional diversion rights imposed upon existing rights,
- water supply use of hydroelectric power storage,
- reservoir storage rights,
- return flows,
- proposed salt control impoundments, and
- hypothetical yield versus reliability relationships.

An examination of each of these topics is supported by the 75 alternative WRAPSALT simulation runs listed in Table 8.1 plus several additional related runs. The results of the base scenario simulation, labeled run 1, is presented in the preceding Chapter 7 and discussed further in the present Chapter 8. Each of the other runs represent a specific modification to the WRAP input file of the base run 1. Alternative model runs are grouped in Table 8.1 under the headings for the sections of this chapter in which each group of simulation runs is addressed. For example, runs 2-12 demonstrate the impacts of alternative salinity constraints, and runs 13-25 examine the effects of multiple-reservoir system operating policies.

Features characterizing each run are briefly noted in Table 8.1. The salinity constraints refer to the maximum allowable salt concentrations specified in the model. Shortages are declared in the simulation computations for any diversion right in any month for which the streamflow or storage concentration exceeds the maximum allowable. The concentration limits are cited in Table 8.1 in the following format.

TDS/chloride/sulfate type of use

For example, run 2 includes specification of maximum allowable concentration limits of 500 mg/l, 250 mg/l, and 250 mg/l, respectively, for total dissolved solids (TDS), chloride, and sulfate for municipal and irrigation uses and no limits for the other types of water use. Run 10 includes specification of a limit of 1,000 mg/l for TDS for all diversion rights and no chloride and sulfate limits. Table 8.1 also includes comments regarding other model features from the perspective of differences from the base run.

The results of the simulation runs are summarized in the tables found at the end of this chapter. Volume reliabilities for each run are cited in Table 8.2 for: (1) the total of all diversion rights in the basin; (2) the total diversion rights associated with the 12 BRA/USACE reservoirs; and (3) all of the other diversion rights in the basin which are not associated with the BRA/USACE reservoirs. Volume reliabilities for each simulation run are presented in Tables 8.3-8.24 by control point and also separately for each of the 12 reservoirs owned and operated by the Brazos River Authority (BRA) and the Fort Worth District of the U.S. Army Corps of Engineers (USACE). The locations of the control points and reservoirs are shown in Figures 8.2 and 8.3. The control point tabulations reflect the aggregated reliability for all diversion rights assigned to a particular control point. The reliabilities for the BRA/USACE reservoirs include the diversion rights held by the City of Waco (for Waco Reservoir) as well as all of the BRA diversion rights. The City of Waco contracts with the BRA for water from the BRA storage capacity in Waco Reservoir. However, the Belton Reservoir rights held by the U.S. Army and City of Temple, as listed in Table 4.12, are not grouped with the BRA rights in the summary tabulations of this chapter. For runs 1-24, 31-32, and 37-45, the aggregated water rights groups, for which reliabilities are cited in Table 8.2 and elsewhere, have the following annual permitted diversion amounts.

Brazos River Authority diversion rights	721,001 ac-ft/yr
All other diversion rights in basin	1,563,245 ac-ft/yr
Total basin diversion rights	2,284,246 ac-ft/yr

Runs 26-30 and 46-75 include hypothetical diversions at the Richmond gage either in addition to or in lieu of the rights cited above.

Mean regulated streamflow discharges and salt concentrations at three selected control points (CP-4, CP-14, and CP-19) are reproduced for many of the runs in Tables 8.31-8.42. The regulated flows and concentrations are computed by the model and vary between runs. The corresponding summary data for the unregulated flows and concentrations are provided in Tables 8.29-8.30. Two alternative sets of unregulated flows and loads, representing existing conditions without salt control impoundments (runs 1-41 and 46-69) and an alternative scenario with the proposed salt control impoundments (runs 42-45 and 70-75), are included in the WRAP input files and reflected in Tables 8.29-8.30. Tables 8.43-8.46 provide reservoir storage data for simulation runs 17 & 37-39. System yield versus reliability relationships, resulting from runs 46-63, are presented in Table 8.47. Firm yields developed in a previous study are reproduced in Table 8.48 for purposes of comparison.

Salinity Constraints

Salinity, or concentration of dissolved solids, is widely recognized as being an important consideration in managing river basins throughout the world. Salinity can severely limit the use of water for municipal, agricultural, industrial, and other beneficial uses. However, information is lacking in regard to precisely defining concentration limits for various types of water use. The U.S. Environmental Protection Agency secondary drinking water standards suggest limits for total dissolved solids (TDS), chloride, and sulfate of 500 mg/l, 250 mg/l, and 250 mg/l, respectively. These recommended limits are set on the basis of health effects and taste preferences of humans and because conventional water treatment processes do not remove salinity. Acceptable salt concentration limits for irrigation vary greatly depending on the type of crop and relative amounts of rainfall versus supplemental irrigation. Reasonable TDS concentration limits for irrigation might be in the range of 1,000 mg/l to 10,000 mg/l depending on the particular circumstances. Salinity tolerance for industrial water use also varies tremendously for different types of use. For municipal, industrial, and agricultural uses, the tolerance to infrequent short periods of high salinity is significantly different than constant long-term high salinity levels.

Water managers can be expected to apply for water rights permits and to use water in a manner consistent with the salinity problem at various locations in the basin. Thus, existing water rights, to a certain degree, should implicitly reflect salinity constraints. The WRAPSALT model allows explicit specification of maximum salt concentrations above which diversions are not made for specified types of water use. Shortages are declared whenever concentrations of the streamflow or storage, from which water is diverted, exceed the specified limits. In the present study, no attempt is made to adopt particular limits for allowable salt concentrations. Rather, alternative model runs are made to demonstrate the sensitivity of simulation results to a range of assumed maximum allowable concentrations.

Concentration limits for various types of water use are difficult to precisely define. Also, as discussed in Chapter 4, some water rights provide significant flexibility for shifting between types of use. Thus, water use types also are not necessarily precisely specified for the various diversion rights. The simulation study simply investigates the sensitivity of water supply reliabilities to alternative assumed concentration limits. The maximum allowable salt concentrations specified in the different simulation runs are noted in Table 8.1. Some runs, including base run 1, have no salt concentration limits placed on diversions. For some runs, the salinity constraints are applied only to municipal and irrigation diversions. For other runs, the concentration limits are applied to all diversions, regardless of water use type. For most runs, the allowable concentrations for TDS, chloride, and sulfate are 500 mg/l, 250 mg/l, and 250 m/l, respectively, or an integer (0, 1, 2 or 3) multiple thereof. The exception is runs 9-12 for which limits are specified for TDS only. The allowable TDS, chloride, and sulfate concentrations of 500 mg/l, 250 mg/l, and 250 mg/l, respectively, are viewed as extremely stringent limits. Specifying no salt constraint limits at all represents the opposite extreme.

Although the specified maximum allowable concentrations are specified at all control points, salinity significantly limits reliabilities only at the main-stem Brazos River control points. The streamflow salt concentrations on the tributaries are too low to have a significant effect. About 70% of the total diversion rights are on the main-stem Brazos River. The diversion rights on the main-stem Brazos River are distributed among use types as follows: municipal (44%), industrial (29%), irrigation (23%), and others (4%).

Simulation Results *(Salinity Constraints)*

The effects of specifying maximum allowable salt concentrations for municipal and irrigation diversions is demonstrated by a comparison of runs 1-4. As indicated in Tables 8.2, 8.3, and 8.4, the volume reliabilities for the entire basin, BRA/USACE reservoirs, and the other diversion rights are as follows.

		Basin	*BRA*	*Other*
• *Run 1 - no salinity limits*	-	*93.32%*	*98.22%*	*91.06%*
• *Run 2 - 500/250/250 mg/l*	-	*83.35%*	*95.15%*	*77.91%*
• *Run 3 - 1,000/500/500 mg/l*	-	*86.06%*	*97.02%*	*81.01%*
• *Run 4 - 2,000/1,000/1,000*	-	*89.90%*	*98.09%*	*86.12%*

As noted in Table 8.1, runs 1-4 differ only in the salinity limits. Run 1 has no salt concentration limits placed on the diversions. In run 2, diversion shortages are declared for any municipal or irrigation right any time the TDS, chloride, or sulfate concentrations, respectively, exceed 500 mg/l, 250 mg/l, or 250 mg/l. Run 3 reflects maximum allowable concentrations of 1,000 mg/l, 500 mg/l, and 500 mg/l for TDS, chloride, and sulfate. Likewise, run 4 is identical to runs 1-3 except the salinity constraints are 2,000/1,000/1,000 mg/l. The total basin permitted diversions of 2,284,246 ac-ft/yr have an aggregated volume reliability of 93.32%, 83.35%, 86.06%, and 89.90% for runs 1-4. Thus, specifying salinity limits of 500 mg/l, 250 mg/l, and 250 mg/l, for the diversions classified in the model as being for municipal or irrigation uses, reduces the total basin reliability from 93.32% to 83.35%. Less stringent salinity constraints result in correspondingly less severe reductions in reliabilities. The volume reliabilities for the diversion rights associated with the BRA/USACE reservoirs are 98.22%, 95.15%, 97.02%, and 98.09%, respectively, for runs 1-4. The corresponding reliabilities for the aggregation of all diversion rights other than those associated with the BRA/USACE reservoirs are 91.06%, 77.91%, 81.01%, and 86.12%.

As discussed in Chapter 4, salinity varies greatly with location, with the South Bend gage (CP-2) having the highest concentrations of the 18 control points. The South Bend gage (CP-2) is the most upstream control point on the main-stem Brazos River. Reliabilities of 76.45%, 11.37%, 11.35%, and 36.99%, respectively, for runs 1-4 are shown in Table 8.3 for the water rights aggregated at this control point. Numerous water rights are aggregated to each of the 18 control points for modeling purposes. Many of the rights assigned to CP-2 in the model are actually, in reality, located on tributaries with much lower salt concentrations. Thus, the CP-2 reliability estimates are conservatively low in this regard.

As previously noted, types of water use are not precisely specified for many of the rights, and determining reasonable concentration limits for the different use types is difficult. For runs 5-8, salinity limits are applied uniformly to all diversion rights regardless of their assigned water use types. Thus, whereas concentration limits are specified only for municipal and irrigation diversions in runs 2-4, the limits are applied to all diversions in runs 5-8. The maximum allowable TDS, chloride, and sulfate concentrations and the reliabilities for the entire basin, BRA diversion rights, and all other diversion rights for runs 5-8 are as follows.

		Basin	BRA	Other
• Run 5 - 500/250/250 mg/l	-	66.69%	64.90%	67.52%
• Run 6 - 1,000/500/500 mg/l	-	74.82%	69.10%	77.46%
• Run 7 - 2,000/1,000/1,000	-	87.25%	91.64%	85.23%
• Run 8 - 3,000/2,000/2,000	-	93.22%	98.12%	90.96%

Runs 5-8 are identical to the base run 1 except for specification of the above concentration limits on diversions. The basin total reliability of 93.32% for base run 1 is reduced to 66.69% for run 5. As indicated by Tables 8.3 & 8.4, the run 5 salt concentration limits of 500/250/250 mg/l eliminates almost all diversions at control points CP-2, CP-3, CP-4, and CP-5 on the Brazos River between and including South Bend and Whitney. The reliability of the BRA system diversion at the Richmond gage (CP-19) is reduced from 100.00% (run 1) to 86.58% (run 5). The impacts of the salt constraints of runs 6 & 7 vary at these locations. Simulation results for runs 1 and 8 are essentially the same.

Chloride and sulfate are major constituents of total dissolved solids (TDS) in the Brazos River. As indicated in Table 5.10, at the South Bend gage (CP-2), the mean unregulated chloride concentration of 575 mg/l is 40% of the TDS mean of 1,429 mg/l. The mean sulfate concentration is 21% of the mean TDS concentration. At the Richmond gage (CP-19), the mean unregulated chloride and sulfate concentrations are 22% and 16%, respectively, of the mean unregulated TDS concentration of 308 mg/l.

In runs 2-8, the maximum allowable diversion limits for chloride and sulfate concentrations are each set at 50% of the limit for TDS concentrations. Runs 9-12 are identical to runs 5-8, except diversions are constrained only by specified TDS limits.

		Basin	BRA	Other
• Run 9 - 500 mg/l TDS	-	66.69%	64.90%	67.52%
• Run 10 - 1,000 mg/l TDS	-	74.82%	69.10%	77.46%
• Run 11 - 2,000 mg/l TDS	-	87.25%	91.64%	85.23%
• Run 12 - 3,000 mg/l TDS	-	93.22%	98.12%	90.96%

The simulation results for runs 9-12 are identical to the corresponding runs 5-8. Thus, TDS is the controlling constraint in determining water quality related diversion shortages in these runs. For the allowable concentrations specified in runs 5-8, any time the chloride or sulfate limit is exceeded, the TDS limit is also exceeded. This is the case for all the runs cited in this report.

The 1900-1984 mean concentrations of the regulated streamflows at the Granbury Reservoir (CP-4), Cameron gage (CP-14), and Richmond gage (CP-19) control points for runs 1-12 are presented in Tables 8.31 & 8.33. The mean TDS concentration at Granbury Reservoir varies from 1,155 mg/l for run 1 to 1,487 mg/l for run 5. The mean TDS concentration at the Richmond gage varies from 223 mg/l for run 1 to 318 mg/l for run 5. The concentrations at Granbury and Richmond increase with increases in diversion shortages and corresponding decreases in the diversion of salt loads at the upper main-stem Brazos River control points. The mean TDS concentrations at the Cameron gage on the Little River are an essentially constant 152-154 mg/l for runs 1-12.

Regulated flow-duration relationships at control points CP-4, CP-14, and CP-19 for runs 1-12 are tabulated in Tables 8.32 & 8.34. Runs 1 and 5 again represent the two extremes for this set of 12 runs. Actual diversions are a maximum for run 1 and minimum for run 5, which has the most severe salinity constraints. The greater diversion shortages in run 5 result in greater storage, evaporation, and regulated and unappropriated flows. At the Richmond gage, regulated and unappropriated streamflows are the same and represent flows to the Gulf of Mexico. At the other control points, unappropriated flows are typically less than regulated flows since a portion of the regulated flows have been appropriated by downstream water rights. Tables 8.32 and 8.34 show the percentage of the 1,020 months during which streamflows at the specified locations exceed the indicated levels. For example, below Granbury Reservoir (CP-4), flows are at least 4,498 ac-ft/month (for run 1) and 17,133 ac-ft/month (for run 5) during 50% of the time. Likewise at CP-4, flows are at least 3.6 ac-ft/month (for run 1) and 16.7 ac-ft/month for 90% of the time. A flow of zero is associated with the 99% exceedence frequency for all of the runs. At the Richmond gage (CP-19), streamflows are at levels of at least 10.5 ac-ft/month (for run 1) and 53.8 ac-ft/month (for run 5) during 95% of the time. Conversely, monthly flows fall below these levels during 5% of the 1,020 months of the simulation. The flows at the main-stem Brazos River control points are significantly affected by diversions which, in turn, are significantly affected by the specified maximum allowable salt concentrations. As indicated by Tables 8.32 & 8.34, the flows at the Cameron gage (CP-14) differ relatively little between runs 1-12.

Summary and Conclusions Regarding Salinity Constraints

Reliabilities, streamflows, and other variables are very sensitive to salinity constraints. Diversion shortages are highly dependent on location and maximum acceptable levels of salinity. The simulation study provides an evaluation of the sensitivity of reliabilities and other variables to salinity constraints. However, no attempt is made to evaluate the salinity levels which can be tolerated for various types of water use or the economic losses associated with salinity.

The TDS limit of 500 mg/l recommended in the Environmental Protection Agency Drinking Water Standards can not be met at all at Whitney Reservoir and upstream locations on the main-stem Brazos River. A TDS limit of 500 mg/l also significantly constrains diversions at the Richmond gage on the lower Brazos River. The impacts on water supply reliability estimates summarized below result from specifying a TDS limit of 500 mg/l for either (1) all the diversions assigned municipal or irrigation use types in the model or (2) all diversions regardless of assigned type of use. Volume reliabilities for runs 1, 2, and 5 are cited for the total basin diversions and separately for the diversions associated with the BRA/USACE reservoirs.

	Basin	BRA
no salinity constraints (run 1)	93.32%	98.22%
municipal and irrigation only (run 2)	83.25%	95.15%
constraints on all diversions (run 5)	66.69%	64.90%

Specifying a maximum allowable TDS concentration of 3,000 mg/l has only minimal impacts on simulation results as compared to incorporating no salinity constraints. The effects vary greatly at different locations as the specified TDS limit varies between 500 mg/l and 3,000 mg/l.

Multiple-Reservoir System Operations

Multiple-reservoir system operation involves coordinated releases from two or more reservoirs to supply common diversions at downstream locations. Multiple-reservoir system operation is beneficial for improving reliability because critical draw-downs for individually operated reservoirs do not perfectly coincide. Operated individually, one reservoir may be completely empty and unable to supply its users while significant storage still remains in other reservoirs. At other times, the other reservoirs may be empty. System operation balances storage depletions and shares the risk of emptying and not meeting demands. Utilization of the excess streamflows consisting of spills and unregulated flows entering the river below the dams is an even more important aspect of system operation. Diversion demands at downstream locations can be largely met by excess flows much of the time, supplemented by reservoir releases as necessary. Various publications have noted the benefits of multiple-reservoir operations in improving yields and reliabilities in a variety of river basins including the Brazos (Wurbs and Carriere 1988).

BRA System Diversions from the Lower Brazos River

As discussed in previous chapters, the Brazos River Authority water rights permits provide flexibility for multiple-reservoir system operations including use of excess flows. Diversion rights of 721,001 ac-ft/yr are associated with the 12 BRA/USACE reservoirs, including rights held by the City of Waco as well as the BRA. As indicated in Table 5.2, in the model, diversions of 171,545 ac-ft/yr, or 24% of the total, are assigned to the Richmond gage and the remainder located at the reservoirs. In the base run, the BRA system diversions totalling 171,545 ac-ft/yr at the Richmond gage control point are met by otherwise unappropriated flows, if available, supplemented as necessary by releases from the following seven reservoirs: Possum Kingdom, Granbury, Aquilla, Stillhouse Hollow, Granger, Somerville, and Limestone. In the base run, the system diversions are treated as type 2 rights, as defined in the TAMUWRAP users manual (Wurbs, Dunn, and Walls 1993), with priorities junior to all other diversions in the basin.

Simulation runs 13-15, listed below, were performed to examine the effects of the BRA system operations in meeting diversions from the lower Brazos River. These runs include no salinity constraints.

		Basin	BRA	Other
•	*Run 1 - base run -*	*93.32%*	*98.22%*	*91.06%*
•	*Run 13 - no excess flows permit -*	*93.12%*	*98.15%*	*90.80%*
•	*Run 14 - no multiple-reservoir operation*	*92.94%*	*97.73%*	*90.73%*
•	*Run 15 - no single-reservoir operation -*	*93.42%*	*100.00%*	*90.39%*

The BRA excess flows permit allows diversion of unregulated streamflows in the lower basin as long as other water rights in the basin are not adversely affected. Tables 7.6 and 8.32 show the significant unappropriated flows at the Richmond gage still available much of the time after all the water rights are met. The system diversions at the Richmond gage can be supplied most of the time without releasing water from the reservoirs.

Simulation run 13 was performed to test the effects of the BRA excess flows permit. Run 13 is identical to the base run 1, except the BRA system diversions at the Richmond gage are met only by releases from the seven system reservoirs, without being allowed access to unappropriated or excess streamflow. The diversion rights are treated as a type 3 right as defined in the TAMUWRAP users manual. The computed reliabilities are similar for run 13 and the base run 1. As shown in Tables 8.4 and 8.8, the BRA system diversions are fully met 100% of the time in both runs. The reliabilities for diversions at the seven system reservoirs decrease slightly in run 13. The aggregated volume reliabilities for the total 721,001 ac-ft/yr BRA diversions are 98.22% and 98.15%, respectively, for runs 1 and 13. The BRA diversion rights at the Richmond gage and at the seven system reservoirs are met with relatively high reliabilities either with or without utilizing the unregulated flows at the Richmond gage. Some shortages occur at several of the system reservoirs in both runs 1 and 13, but the shortages are less in run 1. Most of the BRA shortages, in the model, are at locations which are only minimally affected by the use of excess flows at the Richmond gage. The excess flows permit is important in maintaining reservoir storage for recreation and other purposes. As demonstrated in the later section on yield-reliability relationships, the excess flows permit will be very important in providing water supply reliabilities if greater demands (increases in diversion rights) are placed on the system in the future.

Simulation runs 14 and 15 were performed to examine the effects of coordinated multiple-reservoir releases. The base run 1 has 171,545 ac-ft/yr or 24% of the total 721,001 ac-ft/yr BRA diversion rights assigned to the Richmond gage. Runs 14 and 15 represent extremes in dividing the 721,001 ac-ft/yr between diversion locations at the Richmond gage and at the reservoirs. In run 14, the 171,545 ac-ft/yr BRA system diversion rights are distributed back to the seven reservoir control points, with no diversions made at the Richmond gage. The diversion rights tabulated in Table 5.2 are all diverted at the reservoirs. In run 15, the total 721,001 ac-ft/yr is assigned to the Richmond gage with no diversions being located at the reservoirs. The 721,001 ac-ft/yr system diversion in run 15 is met by excess flows at the Richmond gage supplemented by releases from eleven reservoirs. All of the BRA reservoirs, except Whitney, are included in the run 15 multiple-reservoir releases. Whitney Reservoir is operated solely for hydroelectric power. The 721,001 ac-ft/yr system diversion right has a priority date junior to all other diversions in the basin, but the BRA reservoirs are refilled with the same priorities as in the base run.

The volume reliabilities for the 721,001 ac-ft/yr BRA diversion rights and the 1,563,245 ac-ft/yr other diversion rights in the basin are compared as follows for runs 1, 14, 15, and two other related simulation runs described below.

		BRA	Other
Run 14	individual reservoir	97.73%	90.73%
Run 1	base run	98.22%	91.06%
Run 15	multiple-reservoir	100.00%	90.39%
Run 15(a)	no excess flows	99.55%	89.21%
Run 15(b)	no storage priority	97.93%	92.73%

Of the over 75 runs discussed in this chapter, run 15 is the only run in which all of the BRA diversion rights have a reliability of 100.00%. Two other variations of the run 15 multiple-reservoir operating scenario were simulated without including the results in the tables at the end of the chapter. The first variation is identical to run 15 except the BRA rights are not allowed to use excess flows. The type 2 rights are changed to type 3 rights, as defined in the TAMUWRAP users manual. The period and volume reliabilities of the BRA rights are reduced to 99.22% and 99.55%, respectively, if the excess flows at the Richmond gage are not used. The last run listed above is identical to run 15 except that refilling of reservoir storage is junior to all diversion rights. The priority refilling of storage to 80% capacity was removed from the model. This reduces the period and volume reliabilities of the BRA rights to 97.35% and 97.93%.

BRA Diversions at Proctor Reservoir

Most of the base run diversion shortages associated with the 12 BRA/USACE reservoirs occur at Proctor, Whitney, and Belton Reservoirs. With the exception of Whitney at which water supply reliability is dominated by hydropower, Proctor is the only BRA reservoir with a reliability of less than 97%. In the base run, the reliability for the BRA diversion rights at Proctor Reservoir is a very low 83.71%. Strategies for improving this reliability are examined.

The Proctor Reservoir diversion rights have a reliability of 100.00% if they are hypothetically treated in the model as having priorities senior to all other diversion rights in the basin. However, as indicated in Table 4.12 the Proctor water rights have a relatively junior priority date of December 1963. Senior water rights result in the Proctor reliability being reduced to 83.71% in the base run.

Runs 16 and 39 cited below incorporate changes in the base run reservoir operating policies that improve the reliabilities for the Proctor Reservoir diversion rights.

		Basin	*BRA*	*Other*	*Proctor*
• *Run 1*	*- base run -*	*93.32%*	*98.22%*	*91.06%*	*83.71%*
• *Run 16*	*- multiple-reservoir -*	*93.34%*	*98.31%*	*91.04%*	*96.33%*
• *Run 39*	*- storage priority -*	*93.31%*	*98.24%*	*91.04%*	*93.87%*

Runs 16 and 39 are considered to more realistically represent the actual operation of the reservoir system than the base run 1. In both runs 16 and 39, the priority for refilling storage capacity at Belton Reservoir is made junior to the Proctor water rights. In run 16, but not run

39, multiple-reservoir system operations are used to improve the reliabilities of the Proctor diversion rights. Run 39 is included in the later discussion of relative priorities for reservoir storage rights but is also very pertinent to the present topic of adopting multiple-reservoir operating strategies to improve the reliabilities for the Proctor diversion rights.

In the model, the reservoirs are refilled to 80% capacity with priorities associated with the water rights and then to 100% capacity with priorities junior to all diversion rights in the basin. If more than one right have the same priority data, the right listed first in the input data file gets priority. The rights are listed in the input file in order from upstream to downstream. Thus, with the same priority dates, Proctor has access to streamflow before Belton.

The Proctor diversion rights of 19,658 ac-ft/yr have a priority date of December 1963. Several other rights, including those associated with Belton Reservoir, have the same December 1963 priority. These rights are held by the Brazos River Authority. However, as indicated in Table 4.12, the U.S. Army and City of Temple also hold water rights associated with Belton Reservoir with more senior priority dates of August 1953 and January 1957, respectively. In the base run, Belton Reservoir is refilled, perhaps inappropriately, to 80% capacity (357,992 ac-ft) with the August 1953 priority of its most senior right. Inflows are passed through Proctor Reservoir as necessary to meet more senior rights at Belton Reservoir. Run 39 is identical to base run 1, with the exception of one very simple change. In run 39, Belton Reservoir is refilled to a capacity of 12,000 ac-ft with the August 1953 priority of its more senior right and then to a capacity of 357,992 ac-ft with its December 1963 right. Remember that, in the base run, Belton Reservoir is refilled to the full 357,992 ac-ft (80% of capacity) with the August 1953 priority. In both runs 1 and 39, the major reservoirs continue to be refilled to 100% capacity with a hypothetical priority of January 2000 which is junior to all diversion rights.

Runs 1 and 39 result in almost identical reliabilities of 98.22% and 98.24%, respectively, for the total BRA diversion rights. However, as indicated in table 8.15 the reliabilities for the Proctor and Belton Reservoir diversion rights do change. Run 1 results in reliabilities of 83.71% and 97.40%, respectively, for Proctor and Belton. Run 39 results in reliabilities of 93.87% and 95.68%, respectively, for Proctor and Belton. The primary effect of the change is to move shortages from Proctor to Belton.

Run 16 is identical to run 39 except that multiple-reservoir system operation is used to reduce shortages at Proctor Reservoir. Stillhouse Hollow, Granger, and Georgetown Reservoirs are operated along with Proctor Reservoir to meet the diversion rights at Proctor Reservoir. Multiple-reservoir releases are transported by gravity in the river channels. Thus, Stillhouse, Granger, and Georgetown Reservoir releases can not be used directly to meet the Proctor diversions which are not located downstream of the reservoirs. However, the reservoirs can help satisfy senior rights located downstream. For example, instead of passing inflows through Proctor Reservoir to meet some senior diversion right at the Cameron gage (CP-14), the senior right can be met by releases from the other reservoirs. WRAP includes capabilities for simulating this type of release decisions.

Run 16 increases the reliability of the Proctor Reservoir diversion rights to 96.33% with almost no adverse impact on the other rights. The overall reliability for the BRA rights increase slightly to 98.31%.

Balancing Local Versus System Diversion Reliabilities

Releases for diversions at the Richmond gage increase the risk of shortages for the lakeside or local diversions at the system reservoirs. Reliabilities provided for local diversions at the reservoirs can be partially protected from the adverse effects of releases for downstream diversions by setting storage levels below which downstream releases are curtailed. Releases are not made for the downstream diversions if the reservoir storage falls below a specified level. The Brazos River Authority system permits specify that a reservoir is to be excluded from system operation any time its storage falls below 30% of capacity.

Run 17 is identical to run 16 except that each of the seven reservoirs is curtailed from releasing for the Richmond gage system diversion any time the storage level in the reservoir falls below 30% of the active storage capacity. The local diversions at the reservoirs continue until the active storage capacity is completely empty.

		Basin	BRA	Other
• *Run 17 - 30% storage for local use*	-	*93.29%*	*98.31%*	*90.98%*

The period and volume reliabilities for the BRA diversions at the reservoirs and the BRA system diversion at the Richmond gage are compared for runs 16 and 17 in the following tabulation.

	Run 16		Run 17	
Diversion Location	Period	Volume	Period	Volume
Possum Kingdom	100.00%	100.00%	100.00%	100.00%
Granbury	96.47%	97.05%	96.47%	97.05%
Whitney	69.31%	70.45%	69.31%	70.45%
Aquilla	99.31%	99.58%	99.41%	99.61%
Waco	100.00%	100.00%	100.00%	100.00%
Proctor	95.98%	96.33%	95.98%	96.33%
Belton	94.90%	95.69%	94.90%	95.69%
Stillhouse Hollow	100.00%	100.00%	100.00%	100.00%
Georgetown	99.90%	99.97%	99.90%	99.97%
Granger	100.00%	100.00%	100.00%	100.00%
Somerville	99.90%	99.97%	99.90%	99.97%
Limestone	99.80%	99.86%	99.80%	99.86%
System at Richmond	100.00%	100.00%	99.31%	99.41%
Total	-	98.310%	-	98.307%

The reliability for the total of all the BRA diversions are essentially the same in both runs. The reliabilities for the local diversions at the reservoirs are the same except for a small difference at Aquilla. The reliability of the system diversions at Richmond decreases in run 17.

Comprehensive Multiple-Reservoir System Operation *(Refined Base Run)*

If salinity is not considered, run 17 is probably the most realistic of the runs cited in this report. It is not clear which run represents the most realistic handling of salinity constraints. Run 17 includes no salt concentration limits on diversions.

			Basin	BRA	Other
•	*Run 1 - base run*	-	*93.32%*	*98.22%*	*91.06%*
•	*Run 17 - refined base run*	-	*93.29%*	*98.31%*	*90.98%*

Run 17 represents a refinement of the base run 1 multiple-reservoir operating policy. These refinements more realistically represent the way the reservoir system would likely actually be operated during drought conditions. Run 17 incorporates the features included in runs 16 and 39 discussed above. Thus, run 17 reflects the following refinements which are not included in base run 1.

- Belton reservoir is refilled to 80% capacity with a 1963 priority instead of the 1953 priority adopted in base run 1. Run 17 is like run 39 in this regard. This conserves storage in Proctor Reservoir.

- Proctor, Stillhouse Hollow, Granger, and Georgetown Reservoirs operate as a system to meet the Proctor diversion rights. This minimizes the adverse impacts of senior rights on Proctor storage levels and diversion reliabilities.

- Releases from the seven reservoirs for the system diversion at the Richmond gage are curtailed any time storage falls below 30% of capacity. This is intended to reduce the adverse impacts of draw-downs for the Richmond system diversions on the reliabilities of the local diversion rights at the reservoirs.

Run 17 is identical to base run 1 in all other respects. Reliabilities for run 17 are presented in Tables 8.7-8.8. The 1900-1984 mean storage in the 12 BRA/USACE reservoirs and storage-duration relationships for run 17 are provided in Table 8.39.

Balancing Multiple-Reservoir Releases

During each month of the simulation, if available flows at the Richmond gage are insufficient to supply the 171,545 ac-ft/yr BRA system diversion rights, the model releases from one of the seven system reservoirs. Are the simulation results sensitive to the choice of which of the reservoirs makes the release in various months? The relative effectiveness of alternative release policies is examined. In particular, tradeoffs between giving preference to tributary reservoirs versus Possum Kingdom and Granbury Reservoirs on the main-stem Brazos River are compared. From the perspective of water quality, preference would logically be given to releases from the tributary reservoirs which have much lower salt concentrations. However, the main-stem reservoirs have the quantity availability advantage of large inflows and storage capacity.

As noted in Chapter 3 and discussed in detail in the users manual (Wurbs, Dunn, and Walls 1993), the user defines multiple reservoir release rules by specifying storage zones in the pertinent reservoirs. The active conservation pool in each reservoir is divided into two zones. No releases are made from zone 2 of any system reservoir for a system diversion unless zone 1 is empty in all other system reservoirs. Within zone 1 or 2, storage is balanced between the reservoirs by releasing from the reservoir which is currently most full in terms of percentage of zone capacity.

In runs 1-16 discussed above and most of the other runs, the active conservation pool of each reservoir is treated as a single zone which is balanced evenly with the other system reservoirs. The reservoir which is most full, in terms of percentage of active conservation capacity, is selected to make the necessary release in any given month. Alternatively, runs 18-25 reflect release policies in which preference is given to either main-stem or tributary reservoirs as follows.

				Basin	BRA	Other
• *Run 18*	*none*		*tributary*	*93.43%*	*98.10%*	*91.28%*
• *Run 19*	*none*		*main-stem*	*93.15%*	*98.14%*	*90.85%*
• *Run 20*	*500 mg/l*	*mun&irrig*	*tributary*	*83.59%*	*95.14%*	*78.26%*
• *Run 21*	*500 mg/l*	*all uses*	*tributary*	*68.46%*	*65.78%*	*69.70%*
• *Run 22*	*1,000*	*all uses*	*tributary*	*75.07%*	*69.18%*	*77.79%*
• *Run 23*	*500 mg/l*	*mun&irrig*	*main-stem*	*82.86%*	*95.03%*	*77.25%*
• *Run 24*	*500 mg/l*	*all uses*	*main-stem*	*66.28%*	*64.75%*	*66.99%*
• *Run 25*	*1,000*	*all uses*	*main-stem*	*74.70%*	*69.06%*	*77.30%*

In runs 18 and 20-22, the active conservation pools of the tributary reservoirs (Aquilla, Stillhouse, Granger, Somerville, and Limestone) are divided into two zones with each containing 50% of the storage capacity. The active conservation pools in Possum Kingdom and Granbury Reservoirs are treated as a single zone 2. Thus, in meeting the system diversion right at the Richmond gage, no releases are made from Possum Kingdom and Granbury Reservoirs unless all of the tributary reservoirs are at least half empty. The lower zone of the tributary reservoirs are then balanced with the total active pools of the main-stem reservoirs. Similarly, in run 19 and 23-25, preference is given to the main-stem reservoirs. The active conservation pools of Possum Kingdom and Granbury are divided into two zones of 50% capacity each, and the tributary reservoirs are treated as 100% zone 2 storage capacity. Thus, releases are not made from the tributary reservoirs as long as the main-stem reservoirs are at least half full.

Runs 18 and 19 include no salinity constraints. Runs 20 and 23 impose TDS, chloride, and sulfate concentration limits of 500 mg/l, 250 mg/l, and 250 mg/l, respectively, on all municipal and irrigation diversion rights. Runs 21 and 24 apply these limits to all diversions regardless of water use type. Runs 22 and 25 increase the salinity limits to 1,000, 500, and 500 mg/l on diversions for all water use types.

A comparison of runs 18 and 19, runs 20 and 23, runs 21 and 24, and runs 22 and 25 indicate that the alternative release policies have relatively little effect on reliabilities if salinity is not a factor. Without salinity limits (runs 18-19), the system diversion has 100% reliability with either operating plan. The difference in reliability is the largest for runs 21 and 24 which have the most stringent salt concentration limits. Runs 21 and 24 reflect the same allowable salt concentration criteria as run 5. As indicated by Tables 8.7-8.10, reliabilities for diversions from the lower Brazos River are significantly reduced in these runs by the salinity constraints. In run 5, with all system reservoirs balanced evenly, the reliability for the BRA system diversions at the Richmond gage is 86.58%. For run 21, with preference given to releases from tributary reservoirs, the Richmond system diversion reliability is increased to 90.28%. The system diversion reliability for run 23 is 85.94%. The basin total reliabilities for runs 5, 21, and 24 are 66.69%, 68.46%, and 66.28%

Mean regulated salt concentrations are summarized in Tables 8.27 and 8.31. The mean TDS concentrations at the Richmond gage for comparable runs, with and without salinity constraints, are as follows:

	no salinity constraints	500 mg/l TDS constraint
tributary priority	run 18 - 223 mg/l	run 21 - 316 mg/l
same priority	run 1 - 224 mg/l	run 5 - 318 mg/l
main-stem priority	run 19 - 224 mg/l	run 24 - 319 mg/l

Thus, the concentrations at the Richmond gage are significantly affected by the amount of salt diverted upstream. The high diversions shortages in run 5, compared to run 1, are reflected in the increase in TDS concentration from 224 mg/l to 318 mg/l when salinity constraints are applied. However, the multiple-reservoir release policies for supplying the BRA system diversion have little impact on 1900-1984 mean concentrations. Runs 18 and 19 have about the same mean TDS concentrations at the Richmond gage. Of course, these are discharge weighted 1900-1984 mean regulated salt concentrations. Runs 18 and 19 (or runs 21 and 24) may result in significantly different concentrations at the Richmond gage during particular months of relatively low streamflow in which the reservoir releases constitute a greater portion of the total streamflow.

Summary and Conclusions Regarding the Effects of Multiple-Reservoir System Operations

Multiple-reservoir system operations, particularly use of excess flows in combination with reservoir releases, are very beneficial in maximizing water supply capabilities. If all of the BRA diversions are placed at the Richmond gage (run 15), they are supplied with 100% reliability by multiple-reservoir operation. Achieving the 100% reliability does require the use of excess flows as well as reservoir releases. This is the only scenario reflected in any of the simulation runs for which all of the BRA diversions are met with 100% reliability.

In the base run and most of the variations thereof, the BRA system diversions at the Richmond gage totalling 171,545 ac-ft/yr are met by otherwise unappropriated flows supplemented as necessary by releases from seven reservoirs. The system diversions represent 24% of the total diversions associated with the 12 BRA/USACE reservoirs and 7.5% of the total basin diversions.

Without salinity constraints, the total of the BRA system diversions and the local diversions at the seven system reservoirs are met with almost 100.00% reliability with any of the alternative operating plans investigated. The alternative operating policies slightly shift the relatively small shortages between the control points. Limiting diversions to a TDS concentration of 500 mg/l greatly reduces the reliability of the system diversion. The adverse impact of the salinity constraint can be minimized somewhat by a release policy that gives preference to releases from the better quality tributary reservoirs.

Hypothetical Diversion Right at the Richmond Gage

The discussion, so far, has dealt with existing water rights. However, water availability modeling is most often applied in evaluating capabilities for supplying additional future water demands. Applications for water rights permits continue to be submitted and approved as water demands grow and change. Tables 7.6-7.8 show the unappropriated flows still available for additional water rights applicants. The unappropriated flows computed with the WRAP model can be used as input for various yield analyses to evaluate permit applications. For example, the unappropriated flows may provide the inflows used to compute the firm yield of a proposed reservoir project. The unappropriated flows can also be viewed as a representation of a yield versus reliability relationship for a proposed run-of-river diversion right at the location. However, changing existing rights or incorporating new rights into an existing system can be quite complex. Any new right involving storage in existing or proposed reservoirs will have some effect on existing rights. The effects of the new right may or may not be significant. The WRAP model provides an useful tool for evaluating proposed new water rights. The additional rights are incorporated into the input file, the model executed, and the simulation results analyzed.

A simulation exercise is included in the present study to investigate BRA system capabilities for meeting additional demands in the lower basin and adjoining Houston-Galveston area. A hypothetically assumed municipal diversion right at the Richmond gage is added to the model. Several alternative scenarios for supplying the assumed additional diversion target are simulated.

Simulation Results *(Hypothetical Diversion Right)*

Simulation runs 26-30 listed below were performed to examine system capabilities for meeting additional diversion demands at the Richmond gage (CP-19).

				Basin	BRA	Diver
• *Run 26a*	- *none*	- *200,000*	*run-of-river*	- *90.87%*	*90.56%*	*62.94%*
• *Run 26b*	- *none*	- *200,000*	*run-of-river*	- *91.14%*	*91.34%*	*66.64%*
• *Run 27*	- *none*	- *200,000*	*system*	- *93.33%*	*97.89%*	*99.35%*
• *Run 28*	- *none*	- *400,000*	*system*	- *92.89%*	*96.78%*	*98.02%*
• *Run 29*	- *500 mg/l*	- *200,000*	*system*	- *83.73%*	*94.60%*	*93.46%*
• *Run 30*	- *500 mg/l*	- *400,000*	*system*	- *83.45%*	*92.93%*	*90.60%*

A hypothetical municipal diversion right at the Richmond gage is assumed to have a priority date junior to all the existing diversion rights. Alternative permitted annual diversion amounts of 200,000 ac-ft/year and 400,000 ac-ft/year are arbitrarily assumed. The diversion target is 200,000 ac-ft/year in runs 26-27&29 and 400,000 ac-ft/yr in runs 28 & 30. Runs 26-28 place no salinity limits on diversions. Runs 29-30 incorporate TDS, chloride, and sulfate limits of 500 mg/l, 250 mg/l, and 250 mg/l on all municipal and irrigation rights. The diversion right is run-of-river with no storage in runs 26a & 26b. In runs 27-30, the new municipal water demand is treated as another BRA system diversion right. The new diversion is met by yet unappropriated flows supplemented by releases from the seven system reservoirs just like the existing system diversion right. Runs 26-28 are identical to base run 1 except for the new hypothetical diversion right. Runs 29-30 are identical to run 5 except for the new diversion right.

In runs 26a & 26b, the 200,000 ac-ft/yr diversion right is met strictly by available otherwise unappropriated streamflow without releases from the reservoirs. In run 26a, the new diversion right is absolutely junior to all existing water rights including refilling of storage to 100% capacity. In run 26b, the new diversion right has a priority junior to all existing diversion rights but senior to the final refilling of the reservoirs. Remember that the major reservoirs are refilled to 80% capacity with the priorities associated with their diversion rights and the remaining storage capacity is refilled with a priority junior to all diversion rights, including the new diversion right in run 26b. As indicated in Table 8.12, the hypothetical new diversion right has a volume reliability of 62.94% and 66.64% in runs 26a and 26b. The corresponding period reliabilities are 64.41% and 68.04%.

Capabilities for meeting the 200,000 ac-ft/year permitted diversion target can also be visualized by inspection of the monthly unappropriated flows at the Richmond gage for run 1, which are tabulated in Table 7.6. These monthly data are summarized in the regulated or unappropriated flow-duration relationship at the Richmond gage provided in Tables 7.16 and 8.28. These tables show that flow rates of 264 ac-ft/month and 67,473 ac-ft/month, respectively, are exceeded 75% and 50% of the time. Thus, period reliability for the 200,000 ac-ft/year run-of-river diversion right should fall between 50% and 75%, which it does. In the model, the 200,000 ac-ft/year is distributed among the 12 months of the year using the municipal water use distribution factors. The diversion target varies from 14,000 ac-ft/month in January and February to 20,000 ac-ft/month during June-August of each year.

In runs 27-30 the new diversion right is treated exactly like the existing 171,545 ac-ft/yr BRA system diversion right, except the new right is junior to the existing system right. Both the new and existing BRA system rights are met by excess flows supplemented by releases from the seven reservoirs. Runs 27 & 28 have no salinity limits and thus are comparable to base run 1. Runs 29 & 30, like run 4, constrain all municipal and irrigation diversions to TDS, chloride, and sulfate concentrations of 500 mg/l, 250 mg/l, and 250 mg/l.

The run 27 hypothetical system diversion of 200,000 ac-ft/yr has period and volume reliabilities of 99.02% and 99.35%. Thus, a relatively large additional diversion right of 200,000 ac-ft/yr, or 28% of the existing BRA diversion rights of 721,001 ac-ft/yr, can be supplied with a very high reliability.

Impacts on existing water rights are now examined. Pertinent diversions, shortages, and volume reliabilities are tabulated on the next page for comparison. By adding the new 200,000 ac-ft/yr diversion right, the 1900-84 mean annual amount of water diverted from the basin increases by 187,219 ac-ft/yr from 2,131,593 ac-ft/yr (run 1) to 2,318,812 ac-ft/yr (run 27). The reliability increases slightly from 93.32% to 93.34% for the total basin diversions. The new diversion right causes the reliability of the existing BRA rights to decrease 0.74% from 98.22% to 97.48%. The reliability for the other non-BRA diversion rights decrease by 0.40% from 91.06% to 90.66%. In order to divert an additional mean annual 198,709 ac-ft/yr as part of the BRA system right, the other BRA and non-BRA rights suffer additional mean shortages of 5,300 and 6,190 ac-ft/yr, respectively. Thus, the hypothetical right has a relatively small but yet somewhat significant adverse impact on the reliabilities of the other rights.

		Run 1	Run 27	Difference
New right:	permitted	-	200,000	200,000 ac-ft/yr
	actual	-	198,709	198,709 ac-ft/yr
	shortage	-	1,291	1,291 ac-ft/yr
	reliability	-	99.35%	-
BRA diversions:	permitted	721,001	721,001	-
(other than	actual	708,165	702,865	-5,300 ac-ft/yr
new right)	shortage	12,836	18,136	5,300 ac-ft/yr
	reliability	98.22%	97.48%	-0.74%
Other rights:	permitted	1,563,245	1,563,245	-0- ac-ft/yr
	actual	1,423,428	1,417,238	-6,190 ac-ft/yr
	shortage	139,817	146,007	6,190 ac-ft/yr
	reliability	91.06%	90.66%	-0.40%
Basin total:	permitted	2,284,246	2,484,246	200,000 ac-ft/yr
	actual	2,131,593	2,318,812	187,219 ac-ft/yr
	shortage	152,653	165,435	12,782 ac-ft/yr
	reliability	93.32%	93.34%	0.02%

Run 28 is identical to run 27 except the hypothetical diversion right is doubled from 200,000 ac-ft/yr to 400,000 ac-ft/yr. A very large additional diversion right of 400,000 ac-ft/yr is met with a relatively high reliability of 98.02%. The permitted diversion of 400,000 ac-ft/yr has shortage and actual diversion means of 7,934 ac-ft/yr and 392,066 ac-ft/yr. The total shortages for all the other existing rights in the basin are 30,334 ac-ft/yr higher in run 28 than the base run 1.

Runs 29 & 30 are identical to runs 27 & 28 except that all municipal and irrigation diversions are limited to maximum TDS, chloride, and sulfate concentrations of 500 mg/l, 250 mg/l, and 250 mg/l. The volume reliability for the hypothetical 200,000 ac-ft/yr diversion right is reduced by 5.89% from 99.35% (run 27) to 93.46% (run 29) by the salinity constraint. The corresponding run 27 and run 29 period reliabilities are 99.02% and 92.84%, respectively, or a difference of 6.18%. The alternative hypothetical 400,000 ac-ft/yr diversion right has volume reliabilities of 98.02% (run 28) and 90.60% (run 30) without and with the 500/250/250 mg/l salinity constraint applied to all municipal and irrigation diversions in the basin.

Summary and Conclusions Regarding Capabilities for Supplying Additional Diversion Rights

A large additional diversion from the lower Brazos River can be supplied by the BRA multiple-reservoir system with a relatively high reliability and a relatively small impact on the reliabilities of the existing diversion rights. Any additional use of existing water supply storage capacity in the BRA reservoir system results in some impact on both BRA and non-BRA diversion rights. An additional municipal diversion right of 200,000 ac-ft/yr can be supplied by the existing BRA reservoir system, which includes use of excess flows, with a reliability of

99.35% (run 27). This new diversion right reduces the reliability of the existing BRA rights from 98.22% (run 1) to 97.24% (run 27). The reliability of all the other non-BRA rights is reduced from 91.06% to 90.66%.

Salinity constraints significantly reduce the reliability of new diversion rights as well as existing rights. A 500 mg/l TDS limit reduces the reliability of the hypothetical 200,000 ac-ft/yr diversion from 99.35% (run 27) to 93.46% (run 29).

Whitney Hydroelectric Power Storage

Whitney Reservoir is the largest reservoir in the basin. Its conservation storage capacity of 627,100 ac-ft includes inactive and active pool capacities of 379,100 ac-ft and 248,000 ac-ft, respectively. Whitney Reservoir is operated in the model to meet a hydroelectric energy generation target of 36 gigawatt-hours/year. Hydroelectric power generation is treated as being junior to all diversion rights. As indicated in Table 4.12, the BRA holds a permit to divert 18,336 ac-ft/yr and store 50,000 ac-ft in the active conservation pool, with a priority date of August 1982. As illustrated in Figure 5.4, in the model, storage in Whitney is filled to 429,100 ac-ft with the 1982 priority water supply right and then to 100% capacity with the hydropower right which is junior to all diversion rights.

Effects of Hydroelectric Power Operations on Water Supply Reliabilities

Run 31 is identical to the base run 1 except the hydroelectric energy target is changed to zero. No releases are made for hydroelectric power.

	Basin	BRA	Other
• *Run 31 - no hydropower releases -*	*92.83%*	*98.90%*	*90.03%*

The reliability for the 18,336 ac-ft/yr water supply diversion at Whitney Reservoir is increased from 70.45% (run 1) to 97.62% (run 31). This results in the total BRA reliability increasing from 98.22% (run 1) to 98.90% (run 31). The basin total reliability for run 31 is 92.83% as compared to 93.32% for the base run. This difference is due to the hydropower releases in the base run contributing to meeting diversion rights at the Bryan, Hempstead, and Richmond gage control points.

Hydroelectric Power Reliability

Tables 8.3-8.28 include the hydroelectric energy reliabilities for the 75 alternative simulation runs. The hydroelectric power reliability is computed by program TABLES as:

((mean energy target - mean shortage) / mean energy target) * 100%.

The reliability varies from 61.60% to 82.50% for the alternative runs. The base run 1 reliability is 65.04%. In the model, only unappropriated flows and releases from the Whitney active conservation pool are used to generate power. In reality, flows appropriated for water supply diversions at locations downstream of Whitney may be passed through the turbines. Thus, the estimated hydroelectric energy reliabilities are conservatively low.

Run 32 is identical to the base run 1 except that the hydroelectric power right is made the most senior right in the basin.

	Basin	BRA	Other
• *Run 32 - senior priority for hydropower -*	*91.84%*	*97.26%*	*89.34%*

As indicated by Table 8.14, the hydroelectric energy reliability is 99.32% for run 32.

Use of Whitney Storage Capacity for System Water Supply

Storage reallocations and related operating strategies for increasing reservoir system yields and reliabilities have received increasing attention nationwide in recent years (Wurbs and Carriere 1988). The large hydroelectric power storage capacity, including both the inactive and active pools, in Whitney Reservoir is a potential resource to consider in investigating strategies for improving water supply capabilities in the Brazos River Basin.

	Basin	BRA	Diver
• *Run 33 - none - 200,000 active pool -*	*92.83%*	*98.51%*	*99.55%*
• *Run 34 - none - 200,000 total pool -*	*93.45%*	*98.18%*	*100.00%*
• *Run 35 - 500 - 200,000 total pool -*	*83.73%*	*94.61%*	*93.53%*
• *Run 36 - 500 - 400,000 total pool -*	*83.50%*	*93.24%*	*90.91%*

In runs 33-36, Whitney Reservoir is included with the other seven system reservoirs in meeting the existing and hypothetical system diversions at the Richmond gage. No releases are made for hydropower. Although hydropower releases are not included in model runs 33-36, in actuality the releases for downstream diversions could also be used to generate energy. Runs 33 & 34 are identical to run 27 except Whitney Reservoir is included with the other seven reservoirs in releasing for the system diversions at the Richmond gage. In run 33, only the active pool of Whitney is used for water supply releases. In run 34, the inactive pool is also used for water supply. Releases are made from the Whitney conservation pool for the Richmond gage diversion only if storage in the other system reservoirs falls below 50% of their active conservation storage capacity. Multiple-reservoir release decisions are based on balancing the percent full of the bottom half of the other reservoirs with Whitney. Runs 35 & 36 are identical to runs 29 & 30 except for inclusion of Whitney Reservoir, including the inactive as well as active pools, in the multiple-reservoir system operations. Runs 27, 33, and 34 include no salinity constraints. Runs 29, 30, 35, and 36 limit municipal and irrigation diversions to TDS, chloride, and sulfate concentrations of 500 mg/l, 250 mg/l, and 250 mg/l.

Inclusion of Whitney Reservoir in the multiple-reservoir system releases for the diversions at the Richmond gage slightly improves the reliabilities for these diversions. However, since these diversions are met with reliabilities of near 100% even without benefit of releases from Whitney, this modeling exercise really does not address the actual potential for increasing water supply capabilities by modifying Whitney operating policies.

Summary and Conclusions Regarding the Effects of Whitney Hydroelectric Power Storage

The hydroelectric energy reliabilities computed by the model are conservatively low because releases through the turbines are limited, in the model, to unappropriated flows and releases from the Whitney active conservation pool. In reality, streamflows appropriated for downstream water supply diversions can also be passed through the turbines. The energy demands included in the model are met with 99.32% reliability if the hydroelectric power is treated as the most senior right in the basin. However, hydropower actually has no priority and is treated in the model as being junior to all diversion rights. The diversion rights greatly reduce the hydroelectric energy reliability.

The hydropower releases contribute to excess flows available in the lower Brazos River. The hydropower releases improve diversion reliabilities at the downstream Brazos River control points significantly but not drastically.

With the assumptions incorporated in the model, the hydropower releases greatly draw-down the storage in Whitney Reservoir which results in very low reliabilities for the water supply diversions from the reservoir. The sharing of the conservation pool between water supply and hydroelectric power is not necessarily clearly defined.

Whitney has the largest conservation storage capacity of any reservoir in the basin. A reallocation or sharing of hydroelectric power storage could significantly increase water supply capabilities in the basin. However, the water supply potential of Whitney Reservoir is significantly constrained if salinity limits are imposed on diversions.

Reservoir Storage Rights

Water rights permits grant the right to store water as well as to divert water. Water rights have a single priority date. Priorities are not specified separately for diversions and storage. As discussed in previous chapters, the handling of priorities associated with refilling reservoir storage is not clearly defined in the Texas water rights system. The priority date associated with a water right may not necessarily be applicable to the permitted diversion and storage in the same manner. The following scheme was adopted in the simulation study for refilling previously drawn-down reservoir capacity whenever streamflows become available. Seventeen major water supply reservoirs are refilled to 80% of active conservation storage capacity with the priorities specified in the water rights. Whitney Reservoir is filled to 20% of its active conservation capacity with the priority of its water supply right. The 18 reservoirs are then filled to 100% capacity with a hypothetical priority of January 2000 which is junior to all diversion rights in the basin. The reservoirs have the same junior priority for filling to 100% capacity. When different rights have the same priorities, the rights are met in upstream to downstream order. The 18 largest reservoirs account for most of the storage capacity in the basin. The numerous other smaller reservoirs are refilled with the priority dates of their water rights permits.

Simulation Results *(Reservoir Storage Rights)*

Runs 37 and 38 were performed to test the sensitivity of simulation results to assumptions in handling reservoir storage priorities. Base run 1 represents a compromise falling between runs 37 and 38.

	Basin	BRA	Other
• *Run 37 - no priority for storage* -	*94.27%*	*97.21%*	*92.91%*

- *Run 1 - base run - 93.32% 98.22% 91.06%*
- *Run 38 - same priority as diversions - 92.26% 97.92% 89.65%*

Run 37 is identical to the base run except that the refilling to 80% capacity, with the priorities of the rights, is reduced to 8% of capacity. In run 37, the storage in the 18 largest reservoirs is refilled to 8% of capacity with the water right priority and then to 100% capacity with a priority junior to all diversion rights in the basin. For run 38, reservoir storage for all reservoirs is refilled to 100% capacity with the priorities assigned in the permits. Storage and diversions have the same priorities in run 38. Runs 37-38, like run 1, include no salinity constraints.

If storage is treated as being junior to all diversions in the basin, the basin total reliability increases from 93.32% (run 1) to 94.27% (run 37), and the reliability for the total BRA diversion rights decreases from 98.22% (run 1) to 97.21% (run 37). As indicated by Table 8.16, the reliabilities of most BRA rights decrease with run 37, but the Whitney and Proctor reliabilities increase. In Table 8.15, some control point totals increase while others decrease. If the priorities of the diversion rights are also applied to storage, the total basin reliability decreases from 93.32% (run 1) to 92.26% (run 38). The total BRA reliability also decreases slightly due to significant decreases in the Whitney and Proctor diversion reliabilities.

Storage data for the 12 BRA reservoirs for runs 1, 37, and 38, respectively, are presented in Tables 7.30, 8.40, and 8.41. The storage-duration relationships vary significantly between the three alternative simulation runs. The tables show, for each reservoir, the percentage of time that the storage is at or below specified storage levels expressed as a percentage of active conservation storage capacity. The tables also show the 1900-1984 mean storage for each of the 12 reservoirs.

The 1900-1984 means of the total storage in the active conservation pools of the 12 reservoirs are shown below for the three alternative simulation runs. The minimum storage in the active pools are also shown. Minimum storages occur at different times in the simulation for the different reservoirs. However, the minimum of the summation of the simultaneous storage in all 12 reservoirs, shown below, occurs in January 1957 in all three runs. The storages are expressed both in ac-ft and as a percentage of the total active conservation storage capacity of the 12 reservoirs.

Run	Minimum Storage		Mean Storage	
	(ac-ft)	(%)	(ac-ft)	(%)
37	-0-	0	1,643,800	70
1	266,700	11	1,758,700	75
38	450,700	19	1,834,100	78

The priorities for refilling storage do significantly affect the storage levels in the reservoirs.

Storage Priorities for Belton Reservoir

Run 39 is identical to the base run 1 except for the priority for refilling storage in Belton Reservoir. Run 39 is more realistic than the base run 1 in this regard. Simulation results are almost identical for runs 1 and 39 except for storages, reliabilities, and related variables at Belton and Proctor Reservoirs. Summary reliabilities are as follows.

		Basin	BRA	Other
•	*Run 39 - storage priority for Belton -*	*93.31%*	*98.24%*	*91.04%*
•	*Run 1 - base run -*	*93.32%*	*98.22%*	*91.06%*

The Belton Reservoir water right held by the Brazos River Authority has a December 1963 priority. As indicated in Table 4.12, the U.S. Army and City of Temple also hold water rights associated with Belton Reservoir with more senior priority dates of August 1953 and January 1957, respectively. As previously discussed, in the model, the reservoirs are refilled to 80% capacity with priorities associated with the water rights and then to 100% capacity with priorities junior to all diversion rights in the basin. In the base run, Belton Reservoir is refilled, perhaps inappropriately, to 80% capacity (357,992 ac-ft) with the August 1953 priority of its most senior right. Run 39 is identical to base run 1, with the exception of one very simple change. In run 39, Belton Reservoir is refilled to a capacity of 12,000 ac-ft with the August 1953 priority of its more senior right and then to a capacity of 357,992 with its December 1963 right. In both runs 1 and 39, all the major reservoirs continue to be refilled to 100% capacity with a hypothetical priority of January 2000 which is junior to all diversion rights.

Reliabilities for run 39 are tabulated in Tables 8.15 and 8.16. Storage data are presented in Table 8.41. From a basinwide perspective, the change in storage priority has relatively little impact. However, the rights at Belton and Proctor Reservoirs are significantly affected. The priority change results in a tradeoff between storage and diversion shortages at these two reservoirs. The BRA rights at Proctor and Belton Reservoirs have the same priority date of December 1963. However, since Proctor is located upstream, it has first access to streamflows. Setting the Belton Reservoir priority at August 1953 in base run 1 causes streamflows to be passed through Proctor Reservoir to refill Belton. The reliabilities for the 19,658 ac-ft/yr Proctor Reservoir diversion rights are 83.71% and 93.87%, respectively, in runs 1 and 39. The reliabilities for the 100,257 ac-ft/yr Belton diversion rights are 97.40% and 95.68%, respectively, in runs 1 and 39. Proctor has a 1900-1984 mean storage of 31,258 ac-ft and 35,760 ac-ft, respectively, in runs 1 and 39. Proctor Reservoir is empty during 17% of the 1,020 months in run 1 and during 6% of the 1,020 months in run 39. Belton has a mean storage of 334,254 ac-ft and 327,893 ac-ft, respectively, in runs 1 and 39. Belton Reservoir is empty about 5% of the time in both simulation runs.

Summary and Conclusions Regarding the Effects of Reservoir Storage Rights

Reservoir storage priorities have a very significant effect on reliabilities, storages, and other variables. The effects are primarily reflected in tradeoffs between individual water rights rather than in changes in basin totals. Basin total reliability is maximized by assigning reservoir storage priorities junior to all diversion rights. However, reliabilities for most of the BRA diversion rights are significantly reduced if a reasonably senior priority is not assigned to a significant portion of the storage capacity. The high reliabilities associated with the BRA diversion rights result from having a large amount of reservoir storage capacity.

Return Flows

A significant portion of the water diverted from the rivers and reservoirs for beneficial use is returned as wastewater treatment plant effluent, irrigation returns flows, and other types of return flows. Return flows to the stream system include water supplied from ground water as well as surface water sources. Gaged return flow data are lacking. However, return flows may actually be quite a large proportion of the diversions, depending on the type of water use.

The WRAP model includes specification of a return flow factor and location for each water right. The return flow factor is the fraction of the computed actual diversion which is returned to the river system at the specified control point location. An option allows specification of return flows in either the same or next month as the diversion. The return flow factors adopted for the model are based on data developed by the Texas Water Commission in the 1970s and early 1980s. The return flow factors vary with location and type of water use. In the model, the return flows are returned at the next downstream control point during the month following the diversion. No return flows reenter at the most upstream control point on each tributary. Since the Richmond gage (CP-19) is the most downstream control point, return flows from diversions at CP-19 do not contribute to water availability. In the model, there are no return flows from diversions at the Richmond gage. Diversions at the Richmond gage control point account for 43% of the basin total.

The return flows, assuming no diversion shortages, are tabulated in Table 5.1 at the control points of the originating diversions. Return flows are 22.2% of the total diversions in the model. Excluding diversions at the Richmond gage, the return flows are 38.7% of diversions. If the return flows from diversions at the Richmond gage were allowed to reenter the stream system, the return flows would be 48.6% of the diversions.

Runs 40 and 41 are identical to base run 1 except for the return flow factors. In run 40, all return flow factors are zero. In run 41, all return flow factors are 100%.

	Basin	BRA	Other
• *Run 40 - return flow factors of zero -*	*90.12%*	*97.40%*	*86.76%*
• *Run 1 - base run -*	*93.32%*	*98.22%*	*91.06%*
• *Run 41 - return flow factors of 100% -*	*96.60%*	*99.17%*	*95.41%*

The control point total reliabilities tabulated in Table 8.15 vary greatly between runs 1, 40, and 41. The basin total reliabilities are 90.12%, 93.32%, and 96.60%, respectively, for runs 40, 1, and 41.

Summary and Conclusions Regarding Effects of Return Flows

Simulation results are sensitive to return flows. The handling of return flows in the simulation study is based on limited data and is quite approximate. In the model, return flows available for further diversion downstream are a conservatively low 22.2% of the total diversions in the basin. If zero return flows are assumed, the basin total reliability is decreased from 93.32% (run 1) to 90.12% (run 40). Eliminating all return flows reduces the reliability of the BRA diversion rights from 98.22% (run 1) to 97.40% (run 40).

Salt Control Impoundments

As discussed in Chapter 4, much of the salt load in the Brazos River originates from isolated areas of the upper basin. The Corps of Engineers has investigated various natural salt pollution control plans, including construction of a system of three impoundments at the locations shown in Figure 4.9. The salt control dams would completely contain all runoff originating from their watersheds. As indicated in Table 4.19, the salt loads at the sites of the three proposed salt control dams represent a large proportion of the salt load in the Brazos River.

Runs 42-45 are identical to runs 2 & 5-7 except for the unregulated streamflows and salt loads provided as WRAP input. Runs 42-45 incorporate an alternative set of unregulated flows and loads which have been adjusted using the factors of Table 5.11 to reflect impoundment or removal of all flows and loads at the sites of the three salt control dams. The salt control impoundments significantly reduce the salt loads. As indicated in Table 5.11, the mean unregulated TDS load at the Possum Kingdom control point with the salt control impoundments is 66.4% of the mean TDS load without the inpoundments. Likewise, for unregulated conditions at the Richmond gage, the mean TDS load with the impoundments is 82.5% of the mean load without the impoundments. The simulated mean regulated concentrations are shown in Tables 8.31 and 8.41. Releases from Granbury Reservoir have mean TDS concentrations of 1,320 mg/l and 995 mg/l, respectively, without (run 2) and with (run 42) the salt control impoundments. The corresponding mean regulated TDS concentrations at the Richmond gage are 255 mg/l and 221 mg/l, respectively, without (run 2) and with (run 42) the salt control impoundments.

A comparison of runs 2 & 5-7 with the base run 1 demonstrates the drastic reduction in reliabilities which result from imposing maximum allowable salt concentration limits on diversions. Constraining all diversions to TDS, chloride, and sulfate limits of 500 mg/l, 250 mg/l, and 250 mg/l reduces the basin total reliability from 93.32% (run 1) to 66.69% (run 5) and the BRA total reliability from 98.22% (run 1) to 64.90% (run 5). A TDS limit of 500 mg/l essentially eliminates diversions at the South Bend, Possum Kingdom, and Whitney control points (CP-2, CP-3, and CP-4) and greatly reduces reliabilities at the Bryan, Hempstead, and Richmond control points (CP-15, CP-18, and CP-19). Impoundment or removal of salt loads at the proposed salt control dam sites (runs 41-45) somewhat reduces the adverse effects of the salinity constraints.

With Salt Impoundment		Basin	BRA	Other
• Run 42 - 500 mg/l mun&irrig	-	84.17%	95.61%	78.89%
• Run 43 - 500 mg/l all uses	-	69.57%	66.11%	71.17%
• Run 44 - 1,000 mg/l all uses	-	77.11%	72.30%	79.33%
• Run 45 - 2,000 mg/l all uses	-	92.60%	98.09%	90.07%
Without Salt Impoundment				
• Run 2 - 500 mg/l mun&irrig	-	83.35%	95.15%	77.91%
• Run 5 - 500 mg/l all uses	-	66.69%	64.90%	67.52%
• Run 6 - 1,000 mg/l all uses	-	74.82%	69.10%	77.46%
• Run 7 - 2,000 mg/l all uses	-	87.25%	91.64%	85.23%

As indicated in Tables 8.17-8.18, the effects of salt impoundment vary greatly with location and with the level of allowable concentrations adopted. For the aggregate of all diversions at the Richmond gage, with a 500 mg/l salinity constraint, the salt control impoundments increase the reliability from 86.48% (run 5) to 90.65% (run 43). With a TDS constraint of 1,000 mg/l, the Richmond gage reliability is increased from 97.37% (run 6) to 97.70% (run 44). At Granbury Reservoir, a TDS constraint of 500 mg/l prevents essentially all diversions either with or without the salt control impoundments (runs 5 and 43). At Granbury Reservoir, for a TDS constraint of 2,000 mg/l, the reliability is increased from 87.47% to 94.35% by the salt impoundments.

Summary and Conclusions Regarding Salt Control Impoundments

The salt control impoundments result in a significant reduction in concentrations at all locations on the main-stem Brazos River. The improvement in water supply reliabilities achieved by the salt impoundments is not as pronounced as the reduction in concentrations. For example, if a TDS concentration limit of 1,000 mg/l is imposed on all diversion rights regardless of water use type, the basin total reliability is increased from 74.82% (run 6) to 77.11% (run 44). The improvements in reliabilities achieved by the salt control impoundments vary greatly with location and the specified allowable salt concentration limits placed on diversions. Reliabilities, as defined here, provide useful but limited information in evaluating the effects of the salt control impoundments. In addition to all the approximations and simplifications incorporated into the computation of water supply reliabilities, there is no consideration of the physical, economic, environmental, and health effects of various level of salinity in water used for various purposes.

Yield Versus Reliability Relationships

The water supply capabilities of reservoir/river systems have traditionally been quantified in terms of yield versus reliability relationships, particularly firm yield. Yield is a hypothetically assumed demand target. The reliabilities for meeting various yield levels are estimated. Firm yield is the maximum yield level that results in 100% reliability. Yields greater than the firm yield have estimated period and volume reliabilities of less than 100%.

Firm yield is the estimated maximum release or withdrawal rate which can be maintained continuously during a repetition of the hydrologic period-of-record, based on specified assumptions regarding various factors such as the interactions between multiple reservoirs and multiple users. A precise textbook definition of firm yield (and yield versus reliability relationships) can be formulated for a simple river basin with one reservoir and one diversion location. However, for a complex multiple-reservoir, multiple-user system sharing the water resources of a river basin with numerous other water users, firm yield (and yield versus reliability relationships) must be defined in terms of the basic assumptions and approaches used in handling various complicating factors in the simulation. Yield and reliability estimates depend on the assumptions and data incorporated in the computations. It is always important to realize that reliabilities are estimates based on numerous modeling simplifications and assumptions combined with imperfect data. For example, reliability estimates are based on the assumption of a repetition of historical hydrology. However, a drought more severe than the worst drought of record will eventually occur at some unknown future time, sooner or later. Thus, firm or 100% reliability yield estimates do not represent a guarantee of future water availability.

Formulation of System Operations for Hypothetical
9-Reservoir System Yield Versus Reliability Analysis

Simulation runs 46-75 provide yield versus reliability relationships, including firm yields, for a hypothetical diversion supplied by releases from nine BRA reservoirs. A yield formulation is adopted to represent the capabilities of the Brazos River Authority reservoir system to supply demands concentrated largely in the lower basin. The yield is defined as a diversion right at the Richmond gage with a priority which is junior to all other diversion rights in the basin. Municipal monthly water use factors are used to distribute the annual diversion demand over the 12 months of the year. All the BRA/USACE reservoirs except Waco, Whitney, and Proctor are treated as a multiple-reservoir system. Multiple-reservoir release decisions are based on balancing storage levels just like in previous simulation runs.

Waco, Whitney, and Proctor Reservoirs are not included in the nine system reservoirs which release to meet the yield target at the Richmond gage. Waco, Whitney, and Proctor Reservoirs have unique characteristics that warrant their treatment in the simulation as separate individual, rather than system, reservoirs. Waco Reservoir is committed totally to supplying water for the City of Waco. The city holds the water rights. Whitney Reservoir conservation pool operations are dominated by hydroelectric power. Proctor Reservoir is isolated on the upper Leon River and would not be involved in releasing for diversions from the lower Brazos River.

Diversion, storage, and hydropower rights at Waco, Whitney, and Proctor Reservoirs are identical to base run 1. The other BRA diversion rights, totaling 623,907 ac-ft/yr, are removed from the model and replaced with the diversion at the Richmond gage representing the hypothetical yield. Runs 46-75 include the following diversions:

Non-BRA diversion rights	1,563,245 ac-ft/yr	(same as base run 1)
Waco Reservoir diversion right	59,100 ac-ft/yr	(same as base run 1)
Whitney Reservoir diversion right	18,336 ac-ft/yr	(same as base run 1)
Proctor Reservoir diversion right	19,658 ac-ft/yr	(same as base run 1)
Total of the above	1,660,339 ac-ft/yr	

Hypothetical yield diversion right with an amount which varies in each run.

The diversion rights in runs 46-75 differ from the base run in that BRA rights totaling 623,907 ac-ft/yr are removed and replaced with the hypothetical yield. Hydroelectric power operations at Whitney Reservoir are the same in all runs. Runs 46-63 incorporate no salinity constraints. Runs 64-75 constrain all municipal and irrigation diversions, including the hypothetical yield diversion, to TDS, chloride, and sulfate limits of 500 mg/l, 250 mg/l, and 250 mg/l, respectively. Runs 70-75, unlike runs 46-69, incorporated the salt control impoundments.

Alternative simulations are performed with and without using excess or otherwise unappropriated streamflows to meet the yield. In runs 46-54 and 64-75, the yield is a diversion right at the Richmond gage which is supplied by excess streamflows supplemented as necessary by releases from the nine reservoirs. In runs 55-63, the yield diversion is met only by releases from the nine reservoirs. Unappropriated or excess streamflows are not used. The yield for this second operating scenario can be viewed as a diversion at any location downstream of all nine reservoirs, which means either the Hempstead or Richmond gages (CP-18 and CP-19). Thus, the hypothetical yield diversion is treated as a type 2 and type 3 right in runs 46-54&64-75 and runs 55-63, respectively.

In all runs, the reservoirs are refilled to 80% capacity with the priorities of the existing water rights and 100% capacity with priorities junior to all diversion rights including the hypothetical yield. Refilling of reservoir storage in runs 46-75 is identical to base run 1.

Hypothetical 9-Reservoir System Yield Versus Reliability Relationships

Results for simulation runs 46-75 are presented in Tables 8.19-8.28 and Table 8.47. Volume reliabilities are tabulated by control point and by BRA reservoir in Tables 8.19-8.28 along with reliabilities for basin and BRA totals. Table 8.47 provides a summary of period and volume reliabilities for the hypothetical yield diversion for runs 46-63 and also volume reliabilities for the total of all other rights in the basin. Table 8.47 also shows the number of months during the 1,020-month simulation for which the yield target is not met and the 1900-84 mean shortages. The reliabilities for runs 46-63 from Table 8.47 are tabulated below and plotted in Figure 8.1. The period and volume reliabilities are shown for the hypothetical yield, and the volume reliability is shown for the aggregation of other diversion rights in the basin.

		Yield		Other
		Period	Volume	Volume
With Excess Flows				
• Run 46	623,907 ac-ft/yr	100.00%	100.00%	90.66%
• Run 47	700,000 ac-ft/yr	100.00%	100.00%	90.45%
• Run 48	710,000 ac-ft/yr	99.90%	99.99%	90.41%
• Run 49	730,000 ac-ft/yr	99.71%	99.89%	90.35%
• Run 50	750,000 ac-ft/yr	99.61%	99.80%	90.27%
• Run 51	800,000 ac-ft/yr	99.12%	99.45%	90.18%
• Run 52	1,000,000 ac-ft/yr	97.06%	97.76%	89.73%
• Run 53	1,200,000 ac-ft/yr	94.80%	96.23%	89.11%
• Run 54	1,400,000 ac-ft/yr	93.14%	94.66%	89.01%
Without Excess Flows				
• Run 55	530,000 ac-ft/yr	100.00%	100.00%	89.77%
• Run 56	540,000 ac-ft/yr	99.80%	99.96%	89.72%
• Run 57	560,000 ac-ft/yr	99.61%	99.83%	89.63%
• Run 58	600,000 ac-ft/yr	99.22%	99.62%	89.47%
• Run 59	623,907 ac-ft/yr	99.12%	99.50%	89.29%
• Run 60	700,000 ac-ft/yr	97.84%	98.81%	88.87%
• Run 61	800,000 ac-ft/yr	96.37%	97.68%	88.29%
• Run 62	1,000,000 ac-ft/yr	94.02%	95.66%	87.17%
• Run 63	1,200,000 ac-ft/yr	91.37%	93.17%	85.96%

Runs 46-54 are identical except for changing the annual diversion amount for the right representing the 9-reservoir system yield. The yield is a diversion target at the Richmond gage met by excess flows supplemented as necessary by releases from the nine reservoirs. The hypothetical yield diversion right replaces BRA diversion rights totaling 623,907 ac-ft/yr. As indicated above, a yield of 623,907 ac-ft/yr (run 46) has period and volume reliabilities of 100.00%. The firm yield is 700,000 ac-ft/yr (run 47). This is the maximum yield with a reliability of 100.00%. A yield of 710,000 ac-ft/yr (run 48) has period and volume reliabilities of 99.90% and 99.99%. Doubling the yield to 1,400,000 ac-ft/yr (run 54) decreases the period and volume reliabilities to 93.14% and 94.66%.

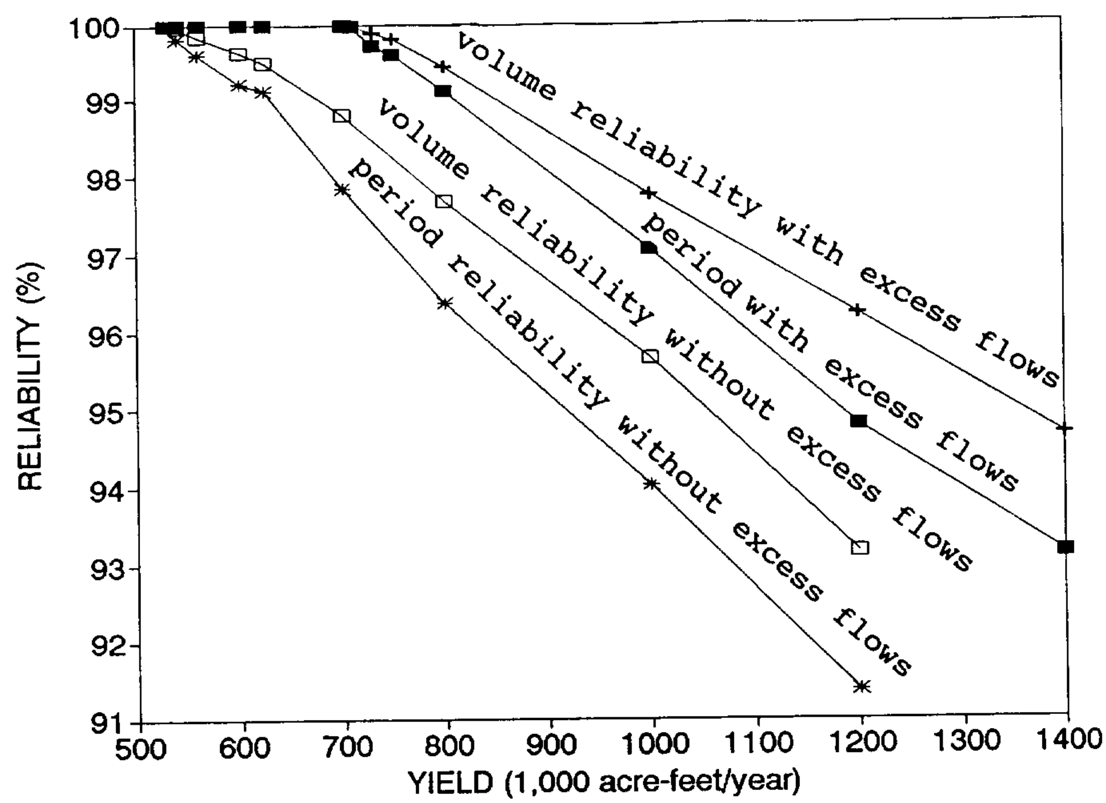

Figure 8.1 Yield Versus Reliability Relationships for the 9-Reservoir System Yield

There are diversion rights totalling 1,660,339 ac-ft/yr in the model in addition to the yields cited above. The volume reliabilities for the sum of these other rights are also cited above. The diversion right representing the hypothetical yield is junior to all other rights in the basin. However, the diversion is supplied by reservoirs which do have priorities for refilling to 80% of their storage capacity. Use of reservoir storage affects the other rights in the basin. With a yield of 623,907 ac-ft/yr (run 1) the mean shortages associated with the 1,660,339 ac-ft/yr of other diversion rights are 155,048 ac-ft/yr for a volume reliability of 90.66%. As indicated by Table 8.47, increasing the yield to the firm yield of 700,000 ac-ft/yr (run 47) slightly increases the other basinwide shortages to 158,618 ac-ft/yr. Doubling the yield, from the firm yield of 700,000 ac-ft/yr to the run 54 yield of 1,400,000 ac-ft/yr, increases the shortages associated with the yield and all other diversion rights, respectively, to 74,767 ac-ft/yr and 182,565 ac-ft/yr. The other diversions have a volume reliability of 89.01% in run 54.

In runs 55-63, the yields are limited to releases from the nine reservoirs. Excess flows are not used to meet the diversion right. With this operating scenario, the firm yield is 530,000 ac-ft/yr. A yield of 623,907 ac-ft/yr has period and volume reliabilities of 99.12% and 99.50%. A yield of 700,000 ac-ft/yr has period and volume reliabilities of 97.84% and 98.81%. Thus, the excess flows are very important to the multiple-reservoir system yield versus reliability relationship.

An alternative series of simulation runs, not included in the report, were performed to examine the sensitivity of the yield versus reliability relationship to reservoir storage priorities. In runs 46-63, like in the base run 1, the major reservoirs are filled to 80% capacity with priorities of the existing water rights and then to 100% capacity with priorities junior to all diversion rights in the basin. Alternative simulation runs setting refilling of the seven system reservoirs totally junior to all diversion rights (removal of the 80% capacity refilling rights) results in reliabilities significantly lower than those cited in the corresponding runs 46-63 cited above. Maintaining the storage priorities is important to the yield versus reliability relationships.

Runs 64-69 are identical to runs 46-47&51-54, except that runs 64-69 incorporate maximum allowable TDS, chloride, and sulfate concentrations of 500 mg/l, 250 mg/l, and 250 mg/l on all municipal and irrigation diversions. Runs 70-75 are identical to runs 64-69, except that runs 70-75 incorporate the salt control impoundments. The 9-reservoir yield versus volume reliability relationships for the hypothetical municipal diversion at the Richmond gage are presented below for three alternative scenarios: (1) salinity is not considered (runs 46-47&51-54); (2) salinity constraints without the salt control impoundments (runs 64-69); and (3) salinity constraints with the salt control impoundments (runs 70-75).

```
•  Runs 46, 64, 70 -   623,907 ac-ft/yr - 100.00%  84.78%  89.31%
•  Runs 47, 65, 71 -   700,000 ac-ft/yr - 100.00%  84.15%  90.40%
•  Runs 51, 66, 72 -   800,000 ac-ft/yr -  99.45%  83.00%  90.42%
•  Runs 52, 67, 73 - 1,000,000 ac-ft/yr -  97.76%  82.01%  89.95%
•  Runs 53, 68, 74 - 1,200,000 ac-ft/yr -  96.23%  80.60%  89.79%
•  Runs 54, 69, 75 - 1,400,000 ac-ft/yr -  94.66%  78.24%  86.94%
```

The 9-reservoir system firm yield (100% reliability) is 700,000 ac-ft/yr if salinity is not considered. The 500 mg/l TDS concentration limit on the 700,000 ac-ft/yr diversion target reduces its reliability to 84.15% and 90.40%, respectively, without and with the salt control impoundments. The 500 mg/l TDS concentration limit is a very stringent constraint. Ignoring salinity is the other extreme. The salt control impoundments significantly improve reliabilities for the Richmond gage diversion, but the 500 mg/l TDS constraint still significantly reduces reliabilities even with the salt impoundments. It is interesting to note that the reliabilities for a drastic increase in yield (such as from 623,907 to 1,200,000 ac-ft/yr) has a relatively small effect on reliabilities. The change in reliability with increasing yield is essentially insignificant in the case of the 500 mg/l TDS constraint with the salt control impoundments. The combined effects on concentrations of reservoir evaporation and diversions even result in slightly higher reliabilities for higher yields in some cases.

Comparison with Previous Studies

Firm yield estimates documented in Technical Report 144 (Wurbs, Bergman, Carriere, and Walls 1988) are reproduced in Table 8.48. These firm yields were computed using the same naturalized streamflows, reservoir evaporation rates, and storage/area relationships as the present study. Hydrologic firm yields are presented in Table 8.48 for alternative conditions of reservoir sedimentation. The hydrologic firm yields were computed using HEC-3 and HEC-5 (Hydrologic Engineering Center 1981 and 1982) considering the 12 BRA/USACE reservoirs and Hubbard Creek Reservoir. The other water users and reservoirs reflected in the water rights were not considered. An alternative set firm yields constrained by water rights are also included in Table 8.48. These firm yields were computed by using HEC-3 and HEC-5 in combination with the original version of TAMUWRAP. The original TAMUWRAP includes no capabilities for simulating multiple-reservoir system operations or hydroelectric power. HEC-3 and HEC-5 contain no capabilities for simulating a water rights priority system. However, a strategy was adopted for applying the models in combination to incorporate capabilities of each model in an approximate manner. Water rights as of June 1986 were incorporated in the study. This previous simulation study demonstrated that firm yield estimates are greatly reduced by incorporating the effects of senior water rights in the analysis. Multiple-reservoir system operation combined with use of excess flows was shown to significantly increase firm yields.

The previously estimated firm yields shown in Table 8.48 can be compared with the values computed in the present study. The TR-144 individual reservoir firm yields constrained by water rights total to 548,100 ac-ft/yr for the nine reservoirs associated with the system firm yield of 530,000 ac-ft/yr estimated in the present study. The TR-144 10-reservoir system firm yields are 844,900 ac-ft/yr and 648,700 ac-ft/yr, respectively, with and without excess flows. These values are significantly higher than the present firm yield estimates of 700,000 ac-ft/yr and 530,000 ac-ft/yr. Part of the difference is due to: (1) the 10-reservoir TR-144 firm yields include releases from Proctor Reservoir and the Granbury Reservoir inactive pool which do not contribute to the present 9-reservoir firm yields; (2) the prior studies allow storage refilling to 100% of capacity with the priority of the rights; (3) the present study incorporates an updated water rights data file; and (4) the simulation modeling approach is different. The current TAMUWRAP model contains significantly expanded modeling capabilities. The firm yields in the TR-144 study have reliabilities slightly greater than 99% in the present simulation model.

Wurbs, Karama, Saleh, and Ganze (1993) investigated yield-reliability relationships constrained by salinity. This previous study, as well as the present study, demonstrate that firm yields are zero for diversions at the Richmond gage and all other locations on the main -stem Brazos River if diversions are constrained to TDS concentrations of 500 mg/l, or even less stringently, regardless of the modeling assumptions or system operating strategies adopted. Yields are severely constrained by salinity.

Summary and Conclusions Regarding the Yield Versus Reliability Relationships

The 9-reservoir system has a firm yield of 700,000 ac-ft/yr and 530,000 ac-ft/yr, respectively, with and without allowing use of excess flows. Thus, multiple-reservoir system operation and the BRA excess flows permit are important. The 700,000 ac-ft/yr firm yield exceeds the water rights diversions associated with the nine reservoirs totaling 623,907 ac-ft/yr. However, the firm yield of 530,000 ac-ft/yr does not exceed the 623,907 ac-ft/yr diversion rights. These firm yield estimates reflect no salinity limits on diversions.

Specifying a maximum allowable TDS concentration of 500 mg/l will reduce the firm yield to zero. A TDS concentration limit of 500 mg/l reduces the reliability for the 700,000 ac-ft/yr diversion target to 84.15% and 90.40%, respectively, without and with the salt control impoundments. The 500 mg/l TDS concentration limit is a very stringent constraint. Ignoring salinity is the other extreme. The salt control impoundments significantly improve reliabilities for the Richmond gage diversion, but the 500 mg/l TDS constraint still significantly reduces reliabilities even with the salt control impoundments.

Reliabilities are not very sensitive to changes in yields. Conversely, yields change greatly with relatively small changes in reliability. For example, without considering salinity, a 15% increase in yield results in less than a 1% decrease in reliability. Conversely, a 1% decrease in reliability results in a greater than 15% increase in yield. Adding a relatively large 100,000 ac-ft/yr to the firm yield of 700,000 ac-ft/yr results in a yield of 800,000 ac-ft/yr which still has relatively high period and volume reliabilities of 99.12% and 99.45%. The exclusion of excess flows drastically reduces the firm yield from 700,000 to 530,000 ac-ft/yr. However, even without using excess flows, the 700,000 ac-ft/yr still has relatively high period and volume reliabilities of 97.84% and 98.81%. If diversions are constrained by specifying maximum allowable salt concentration limits, reliabilities are even less sensitive to changes in yield. If the Richmond gage yield is constrained to a TDS concentration of 500 mg/l, the salinity constraint controls the reliability with almost no variation of reliability for different yield magnitudes.

The amount of water supplied from the Brazos River Basin can be increased significantly by accepting somewhat higher risks of shortages or emergency demand reductions. Firm yield estimates are not highly precise and can vary significantly with incorporation of different but yet still reasonable assumptions in the model.

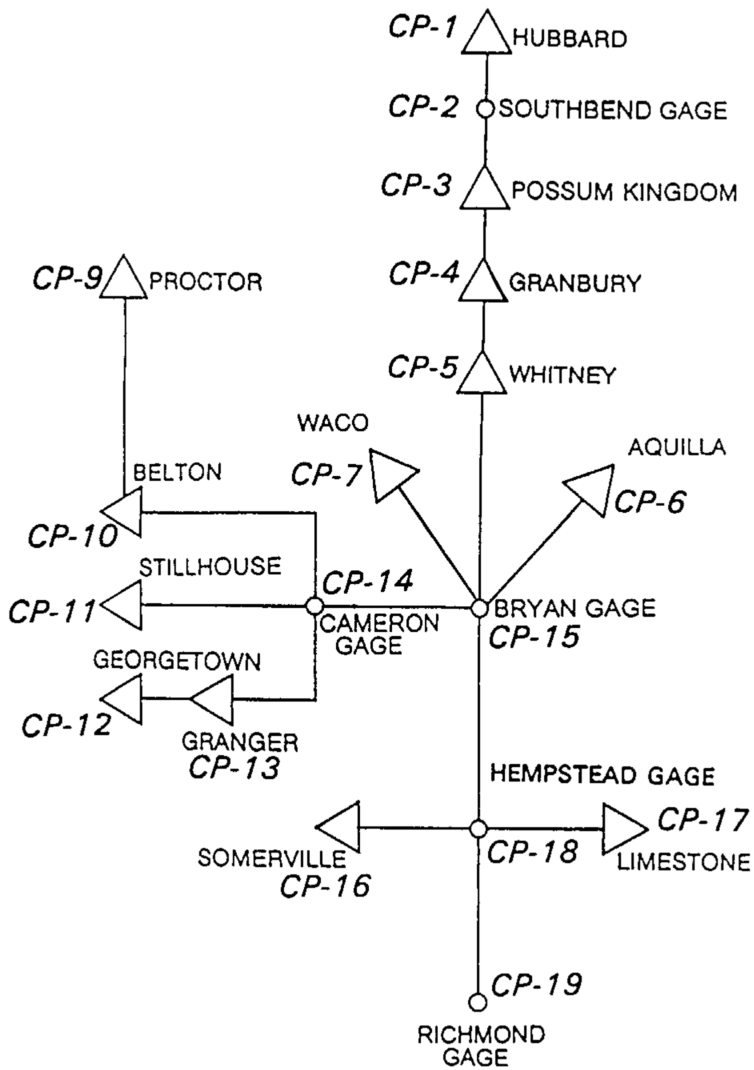

Figure 8.2 Model Control Points

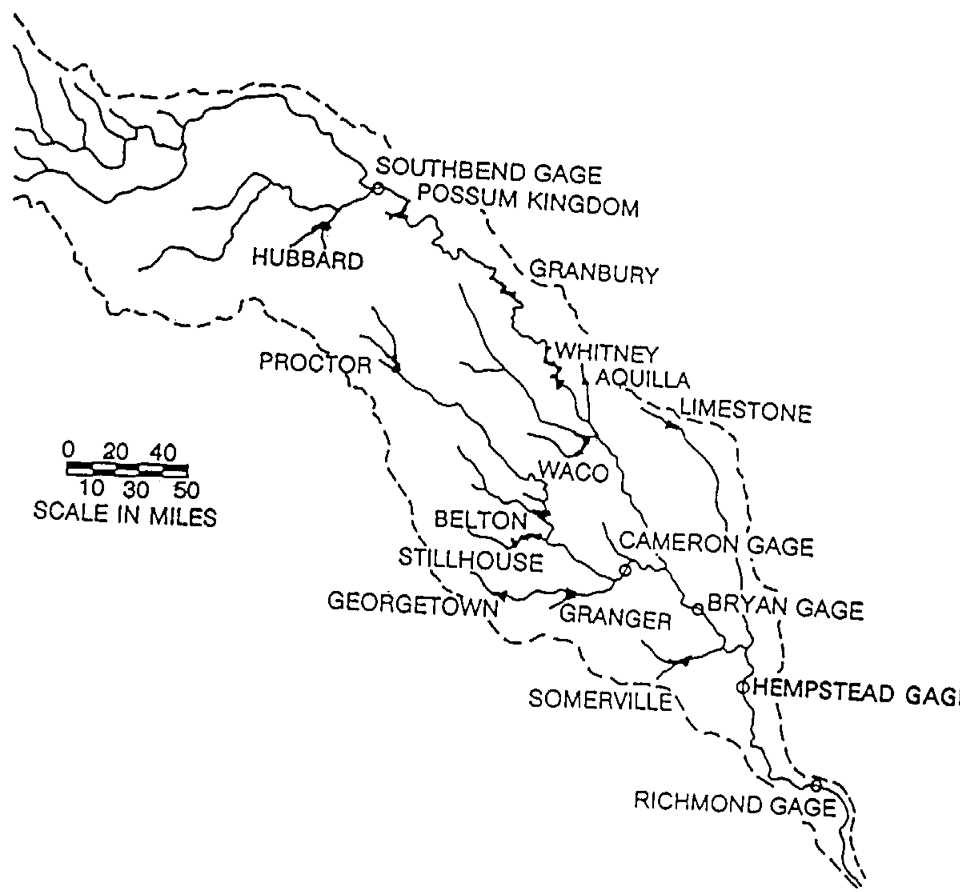

Figure 8.3 Brazos River Basin

Table 8.1
SIMULATION RUNS

Run	Salinity Constraints		Other Features
	Base Scenario		
1	none		base run
	Salinity Constraints		
2	500/250/250 mg/l	mun&irrig	same as base run
3	1,000/500/500	mun&irrig	same as base run
4	2,000/1,000/1,000	mun&irrig	same as base run
5	500/250/250 mg/l	all uses	same as base run
6	1,000/500/500	all uses	same as base run
7	2,000/1,000/1,000	all uses	same as base run
8	3,000/1,500/1,500	all uses	same as base run
9	500/-/- mg/l	all uses	same as base run
10	1,000/-/- mg/l	all uses	same as base run
11	2,000/-/- mg/l	all uses	same as base run
12	3,000/-/- mg/l	all uses	same as base run
	Multiple-Reservoir System Operations		
13	none		no excess flows permit
14	none		no multiple-reservoir operation
15	none		no single-reservoir operation
16	none		Proctor multiple reservoir operation
17	none		refined base run
18	none		tributary reservoirs have priority
19	none		main-stem reservoirs have priority
20	500/250/250 mg/l	mun&irrig	tributary reservoirs have priority
21	500/250/250 mg/l	all uses	tributary reservoirs have priority
22	1,000/500/500	all uses	tributary reservoirs have priority
23	500/250/250 mg/l	mun&irrig	main-stem reservoirs have priority
24	500/250/250 mg/l	all uses	main-stem reservoirs have priority
25	1,000/500/500	all uses	main-stem reservoirs have priority
	Hypothetical Diversion Right at Richmond Gage		
26(a)	none		200,000 ac-ft/yr run-of-river diversion
26(b)	none		200,000 ac-ft/yr run-of-river diversion
27	none		200,000 ac-ft/yr system diversion
28	none		400,000 ac-ft/yr system diversion
29	500/250/250 mg/l	mun&irrig	200,000 ac-ft/yr system diversion
30	500/250/250 mg/l	mun&irrig	400,000 ac-ft/yr system diversion

Table 8.1 Continued
SIMULATION RUNS

Run	Salinity Constraints	Other Features
	Whitney Hydroelectric Power Storage	
31	none	no hydropower releases
32	none	senior priority for hydropower
33	none	200,000 ac-ft/yr system diversion
34	none	200,000 ac-ft/yr system diversion
35	500/250/250 mg/l mun&irrig	200,000 ac-ft/yr system diversion
36	500/250/250 mg/l mun&irrig	400,000 ac-ft/yr system diversion
	Reservoir Storage Rights	
37	none	no priority for storage
38	none	same priority as diversions
39	none	change in Belton storage priority
	Return Flows	
40	none	no return flows
41	none	100% return flows
	Salt Control Impoundments	
42	500/250/250 mg/l mun&irrig	adjusted unregulated flows and loads
43	500/250/250 mg/l all uses	adjusted unregulated flows and loads
44	1,000/500/500 all uses	adjusted unregulated flows and loads
45	2,000/1,000/1,000 all uses	adjusted unregulated flows and loads
	Hypothetical Yields with Excess Flows	
46	none	623,907 ac-ft/yr for 9-reservoir system
47	none	700,000 ac-ft/yr for 9-reservoir system
48	none	710,000 ac-ft/yr for 9-reservoir system
49	none	730,000 ac-ft/yr for 9-reservoir system
50	none	750,000 ac-ft/yr for 9-reservoir system
51	none	800,000 ac-ft/yr for 9-reservoir system
52	none	1,000,000 ac-ft/yr for 9-reservoir system
53	none	1,200,000 ac-ft/yr for 9-reservoir system
54	none	1,400,000 ac-ft/yr for 9-reservoir system
	Hypothetical Yields without Excess Flows	
55	none	530,000 ac-ft/yr for 9-reservoir system
56	none	540,000 ac-ft/yr for 9-reservoir system
57	none	560,000 ac-ft/yr for 9-reservoir system
58	none	600,000 ac-ft/yr for 9-reservoir system
59	none	623,907 ac-ft/yr for 9-reservoir system
60	none	700,000 ac-ft/yr for 9-reservoir system
61	none	800,000 ac-ft/yr for 9-reservoir system
62	none	1,000,000 ac-ft/yr for 9-reservoir system
63	none	1,200,000 ac-ft/yr for 9-reservoir system

Table 8.1 Continued
SIMULATION RUNS

Run	Salinity Constraints	Other Features
	Hypothetical Yields with Salt Constraints	
64	500/250/250 mun&irrig	623,907 ac-ft/yr for 9-reservoir system
65	500/250/250 mun&irrig	700,000 ac-ft/yr for 9-reservoir system
66	500/250/250 mun&irrig	800,000 ac-ft/yr for 9-reservoir system
67	500/250/250 mun&irrig	1,000,000 ac-ft/yr for 9-reservoir system
68	500/250/250 mun&irrig	1,200,000 ac-ft/yr for 9-reservoir system
69	500/250/250 mun&irrig	1,400,000 ac-ft/yr for 9-reservoir system
	Hypothetical Yields with Salt Control Impoundments	
70	500/250/250 mun&irrig	623,907 ac-ft/yr for 9-reservoir system
71	500/250/250 mun&irrig	700,000 ac-ft/yr for 9-reservoir system
72	500/250/250 mun&irrig	800,000 ac-ft/yr for 9-reservoir system
73	500/250/250 mun&irrig	1,000,000 ac-ft/yr for 9-reservoir system
74	500/250/250 mun&irrig	1,200,000 ac-ft/yr for 9-reservoir system
75	500/250/250 mun&irrig	1,400,000 ac-ft/yr for 9-reservoir system

Table 8.2
RELIABILITY FOR ALTERNATIVE SIMULATION RUNS

Run	Volume Reliability (%)		
	Basin	BRA	Other
1	93.32	98.22	91.06
2	83.35	95.15	77.91
3	86.06	97.02	81.01
4	89.90	98.09	86.12
5	66.69	64.90	67.52
6	74.82	69.10	77.46
7	87.25	91.64	85.23
8	93.22	98.12	90.96
9	66.69	64.90	67.52
10	74.82	69.10	77.46
11	87.25	91.64	85.23
12	93.22	98.12	90.96
13	93.12	98.15	90.80
14	92.94	97.73	90.73
15	93.42	100.00	90.39
16	93.34	98.31	91.04
17	93.29	98.31	90.98
18	93.43	98.10	91.28
19	93.15	98.14	90.85
20	83.59	95.14	78.26
21	68.46	65.78	69.70
22	75.07	69.18	77.79
23	82.86	95.03	77.25
24	66.28	64.75	66.99
25	74.70	69.06	77.30
26a	90.87	90.56	91.01
26b	91.14	91.34	91.05
27	93.33	97.89	91.23
28	92.89	96.78	91.10
29	83.73	94.60	78.72
30	83.45	92.93	79.08
31	92.83	98.90	90.03
32	91.84	97.26	89.34
33	92.83	98.51	90.21
34	92.78	98.49	90.15
35	82.08	93.77	76.69
36	81.95	92.28	77.19
37	94.27	97.21	92.91
38	92.26	97.92	89.65
39	93.31	98.24	91.04
40	90.12	97.40	86.76
41	96.60	99.17	95.41
42	84.17	95.61	78.89
43	69.57	66.11	71.17
44	77.11	72.30	79.33
45	92.60	98.09	90.07
46	93.21	99.05	90.52
47	93.28	99.11	90.59
48	93.28	99.11	90.59
49	93.26	99.48	90.39
50	93.23	98.97	90.58
51	93.19	98.69	90.66
52	92.75	97.27	90.67
53	92.10	95.90	90.35
54	91.32	94.44	89.88

Table 8.2 Continued
RELIABILITY FOR ALTERNATIVE SIMULATION RUNS

Run	Volume Reliability (%)		
	Basin	BRA	Other
55	92.24	98.85	89.20
56	92.23	98.83	89.19
57	92.21	98.75	89.19
58	92.16	98.61	89.19
59	92.08	98.52	89.11
60	91.82	97.99	89.97
61	91.34	97.05	88.71
62	90.36	95.28	88.10
63	88.99	93.01	87.13
64	78.00	84.26	75.11
65	77.85	83.75	74.84
66	77.53	82.76	74.53
67	77.27	81.90	74.02
68	76.67	80.61	73.40
69	75.36	78.41	72.44
70	80.71	89.31	76.74
71	80.87	89.28	76.58
72	81.12	89.43	76.35
73	81.41	89.20	75.94
74	81.80	89.17	75.68
75	80.66	86.59	74.98

Note:

The annual permitted diversion amounts shown below are the summation of the existing diversion rights for the three groups for which reliability estimates are tabulated in Table 8.2:

diversion rights for entire basin	2,284,246 ac-ft/yr
Brazos River Authority diversion rights	721,001 ac-ft/yr
all other diversion rights in basin	1,563,245 ac-ft/yr

These existing diversion rights are associated with volume reliabilities shown in the table for runs 1-25, 31-32, and 37-45. The reliabilities for the other runs include hypothetical diversions either in addition to the existing rights (runs 26-30&33-36) or in lieu of some of the existing BRA rights (runs 46-75).

Table 8.3
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 1-6

Control Point	Volume Reliability (%) for Alternative Model Runs 1	2	3	4	5	6
1. Hubbard	78.15	81.45	81.03	79.69	87.21	86.76
2. South Bend	76.45	11.37	11.35	36.99	0.24	0.24
3. Possum K.	99.15	89.46	89.49	97.14	0.68	0.99
4. Granbury	95.85	66.52	68.14	94.45	1.31	2.28
5. Whitney	90.76	37.02	86.32	91.69	3.03	51.78
6. Aquilla	99.15	99.78	99.87	99.83	99.13	99.88
7. Waco	95.42	95.49	95.46	95.45	95.65	95.59
9. Proctor	75.19	75.29	75.21	75.19	75.33	75.27
10. Belton	89.93	90.03	89.94	89.94	90.07	90.06
11. Stillhouse	96.69	96.77	96.72	96.71	97.04	96.97
12. Georgetown	99.84	99.85	99.84	99.83	99.88	99.87
13. Granger	96.44	96.70	96.59	96.48	97.15	96.98
14. Cameron	89.09	90.53	89.89	89.47	92.43	92.02
15. Bryan	90.38	83.82	91.47	90.97	63.16	90.50
16. Somerville	99.89	99.93	99.93	99.93	99.93	99.93
17. Limestone	99.46	99.52	99.52	99.49	99.52	99.52
18. Hempstead	93.01	94.03	93.80	93.28	80.35	94.04
19. Richmond	97.53	95.79	97.74	97.69	86.48	97.37
Basin Total	93.32	83.35	86.06	89.90	66.69	74.82

Table 8.4
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 1-6

Reservoir	Volume Reliability (%) for Alternative Model Runs 1	2	3	4	5	6
Possum Kingdom	100.00	95.80	95.81	98.98	0.68	0.99
Granbury	97.23	93.21	93.52	97.16	1.33	2.28
Whitney	70.45	5.75	69.13	73.71	2.70	47.81
Aquilla	99.28	99.91	100.00	99.96	99.24	100.00
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	83.71	83.72	83.72	83.71	83.72	83.72
Belton	97.40	97.40	97.40	97.40	97.41	97.41
Stillhouse	100.00	100.00	100.00	100.00	100.00	100.00
Georgetown	100.00	100.00	100.00	100.00	100.00	100.00
Granger	100.00	100.00	100.00	100.00	100.00	100.00
Somerville	99.96	100.00	100.00	100.00	100.00	100.00
Limestone	99.94	100.00	100.00	99.97	100.00	100.00
System	100.00	99.01	99.98	100.00	86.58	98.79
Total	98.22	95.15	97.02	98.09	64.90	69.10
Whitney Hydropower	65.04	73.29	70.84	68.60	82.50	79.31

Table 8.5
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 7-12

Control Point	Volume Reliability (%) for Alternative Model Runs 7	8	9	10	11	12
1. Hubbard	82.57	78.17	87.21	86.76	82.57	78.17
2. South Bend	28.10	75.93	0.24	0.24	28.10	75.93
3. Possum K.	70.97	99.16	0.68	0.99	70.97	99.16
4. Granbury	87.47	94.58	1.31	2.28	87.47	94.58
5. Whitney	92.74	90.78	3.03	51.78	92.74	90.78
6. Aquilla	99.87	99.45	99.13	99.88	99.87	99.45
7. Waco	95.49	95.42	95.65	95.59	95.49	95.42
9. Proctor	75.21	75.19	75.33	75.27	75.21	75.19
10. Belton	89.99	89.93	90.07	90.06	89.99	89.93
11. Stillhouse	96.84	96.69	97.04	96.97	96.84	96.69
12. Georgetown	99.85	99.84	99.88	99.87	99.85	99.84
13. Granger	96.64	96.44	97.15	96.98	96.64	96.44
14. Cameron	90.56	89.10	92.43	92.02	90.56	89.10
15. Bryan	91.77	90.38	63.16	90.50	91.77	90.38
16. Somerville	99.93	99.89	99.93	99.93	99.93	99.89
17. Limestone	99.52	99.46	99.52	99.52	99.52	99.46
18. Hempstead	94.10	93.01	80.35	94.04	94.10	93.01
19. Richmond	98.06	97.52	86.48	97.37	98.06	97.52
Basin Total	87.25	93.22	66.69	74.82	87.25	93.22

Table 8.6
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED
WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 7-12

Reservoir	Volume Reliability (%) for Alternative Model Runs 7	8	9	10	11	12
Possum Kingdom	71.15	100.00	0.68	0.99	71.15	100.00
Granbury	88.88	95.82	1.33	2.28	88.88	95.82
Whitney	77.16	70.53	2.70	47.81	77.16	70.53
Aquilla	100.00	99.58	99.24	100.00	100.00	99.58
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	83.71	83.71	83.72	83.72	83.71	83.71
Belton	97.41	97.40	97.41	97.41	97.41	97.40
Stillhouse	100.00	100.00	100.00	100.00	100.00	100.00
Georgetown	100.00	100.00	100.00	100.00	100.00	100.00
Granger	100.00	100.00	100.00	100.00	100.00	100.00
Somerville	100.00	99.96	100.00	100.00	100.00	99.96
Limestone	100.00	99.94	100.00	100.00	100.00	99.94
System	100.00	100.00	86.58	98.79	100.00	100.00
Total	91.64	98.12	64.90	69.10	91.64	98.12
Whitney Hydropower	72.06	65.06	82.50	79.31	72.06	65.06

Table 8.7
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 13-19

Control Point	Volume Reliability (%) for Alternative Model Runs 13	14	15	16	17	18	19
1. Hubbard	76.57	73.45	79.90	78.06	78.06	78.77	76.78
2. South Bend	75.61	73.79	79.40	76.41	76.42	77.57	75.27
3. Possum K.	99.01	98.55	95.07	99.15	99.15	99.34	98.88
4. Granbury	95.67	95.34	93.71	95.73	95.73	96.17	95.46
5. Whitney	90.49	90.75	97.92	90.75	90.75	90.83	90.58
6. Aquilla	98.61	98.77	75.25	99.45	99.48	98.78	99.87
7. Waco	95.42	95.47	74.53	95.42	95.42	95.43	95.42
9. Proctor	75.04	75.02	73.44	81.81	81.81	75.19	75.19
10. Belton	89.92	89.92	83.48	89.19	89.19	89.93	89.93
11. Stillhouse	96.59	97.48	82.50	96.69	96.69	95.96	96.84
12. Georgetown	99.83	99.85	77.82	99.80	99.80	99.83	99.85
13. Granger	96.23	97.83	70.85	96.42	96.43	95.47	96.62
14. Cameron	88.92	90.01	85.17	89.05	89.05	89.26	89.08
15. Bryan	90.26	90.80	88.81	90.34	90.34	90.48	90.48
16. Somerville	99.80	99.04	84.91	99.90	99.90	98.88	99.94
17. Limestone	99.27	99.42	95.92	99.40	99.40	98.68	99.52
18. Hempstead	92.86	93.45	91.24	92.99	92.99	93.06	93.09
19. Richmond	97.47	97.29	97.38	97.50	97.39	97.55	97.52
Basin Total	93.12	92.94	93.42	93.34	93.29	93.43	93.15

Table 8.8
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 13-19

Reservoir	Volume Reliability (%) for Alternative Model Runs 13	14	15	16	17	18	19
Possum Kingdom	99.97	99.20	-	100.00	100.00	100.00	99.84
Granbury	97.02	96.35	-	97.05	97.05	97.69	96.68
Whitney	69.48	70.54	-	70.45	70.45	70.76	69.82
Aquilla	98.73	98.84	-	99.58	99.61	98.91	100.00
Waco	100.00	100.00	-	100.00	100.00	100.00	100.00
Proctor	83.69	83.69	-	96.33	96.33	83.71	83.71
Belton	97.40	97.40	-	95.69	95.69	97.40	97.40
Stillhouse	100.00	99.69	-	100.00	100.00	99.15	100.00
Georgetown	100.00	100.00	-	99.97	99.97	100.00	100.00
Granger	100.00	100.00	-	100.00	100.00	98.94	100.00
Somerville	99.88	99.09	-	99.97	99.97	98.95	100.00
Limestone	99.73	99.76	-	99.86	99.86	99.06	100.00
System	100.00	-	100.00	100.00	99.41	100.00	100.00
Total	98.15	97.73	100.00	98.31	98.31	98.10	98.14
Whitney Hydropower	64.57	64.16	64.08	64.92	64.92	65.40	64.42

Table 8.9
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 20-25

Control Point	Volume Reliability (%) for Alternative Model Runs 20	21	22	23	24	25
1. Hubbard	82.57	87.39	87.41	79.50	87.12	86.40
2. South Bend	11.43	0.24	0.24	11.34	0.24	0.24
3. Possum K.	89.48	0.68	0.99	89.36	0.68	0.99
4. Granbury	66.66	1.39	2.95	66.25	1.31	2.28
5. Whitney	37.17	2.88	54.01	37.04	3.03	51.81
6. Aquilla	98.90	99.23	99.89	99.78	99.03	99.88
7. Waco	95.51	95.64	95.58	95.55	95.65	95.57
9. Proctor	75.27	75.33	75.29	75.29	75.32	75.23
10. Belton	90.00	90.07	90.07	90.01	90.07	90.04
11. Stillhouse	96.64	96.85	96.79	96.94	97.08	97.01
12. Georgetown	99.85	99.86	99.86	99.86	99.88	99.87
13. Granger	96.42	96.91	96.80	96.91	97.26	97.10
14. Cameron	90.76	92.22	92.29	90.74	92.38	91.99
15. Bryan	85.15	69.37	91.72	80.94	61.03	90.27
16. Somerville	99.38	99.93	99.91	99.94	99.94	99.94
17. Limestone	99.12	99.52	99.52	99.52	99.52	99.52
18. Hempstead	94.19	84.78	94.58	93.85	79.49	93.70
19. Richmond	96.13	89.44	97.50	95.15	85.85	97.18
Basin Total	83.59	68.46	75.07	82.86	66.28	74.70

Table 8.10
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED
WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 20-25

Reservoir	Volume Reliability (%) for Alternative Model Runs 20	21	22	23	24	25
Possum Kingdom	95.80	.68	.99	95.80	0.68	0.99
Granbury	93.43	1.42	3.01	92.79	1.33	2.28
Whitney	5.81	2.52	47.57	5.82	2.70	47.99
Aquilla	99.02	99.34	100.00	99.91	99.14	100.00
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	83.72	83.72	83.72	83.72	83.72	83.72
Belton	97.40	97.41	97.41	97.40	97.41	97.40
Stillhouse	99.86	100.00	100.00	100.00	100.00	100.00
Georgetown	100.00	100.00	100.00	100.00	100.00	100.00
Granger	99.71	100.00	100.00	100.00	100.00	100.00
Somerville	99.45	100.00	99.99	100.00	100.00	100.00
Limestone	99.55	100.00	100.00	100.00	100.00	100.00
System	99.17	90.28	98.92	98.61	85.94	98.62
Total	95.14	65.78	69.18	95.03	64.75	69.06
Whitney Hydropower	73.88	82.61	79.75	72.79	82.25	79.06

Table 8.11
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 26-30

Control Point	Volume Reliability (%) for Alternative Model Runs 26a	26b	27	28	29	30
1. Hubbard	78.15	77.89	76.01	73.25	78.92	78.17
2. South Bend	76.45	76.43	75.09	73.23	11.28	11.18
3. Possum K.	99.15	99.13	97.74	95.53	89.23	88.39
4. Granbury	95.85	95.85	95.31	93.07	65.92	64.51
5. Whitney	90.76	90.52	90.22	89.86	37.03	37.12
6. Aquilla	99.15	99.15	96.07	92.87	98.47	97.16
7. Waco	95.42	95.42	95.41	93.35	95.45	95.44
9. Proctor	75.19	75.19	75.16	74.98	75.26	75.25
10. Belton	89.93	89.93	89.90	89.75	89.99	89.89
11. Stillhouse	96.69	96.69	95.92	94.83	96.63	96.29
12. Georgetown	99.84	99.83	99.82	99.80	99.83	99.82
13. Granger	96.44	96.43	95.48	93.46	96.49	95.30
14. Cameron	89.09	89.07	88.77	88.17	90.25	90.15
15. Bryan	90.38	90.36	90.13	89.79	82.68	81.30
16. Somerville	99.89	99.93	98.94	96.95	99.64	99.15
17. Limestone	99.41	99.48	98.12	96.21	99.15	98.42
18. Hempstead	93.01	92.97	92.73	92.34	93.68	93.43
19. Richmond	91.65	92.26	97.69	97.29	94.91	93.18
Basin Total	90.87	91.14	93.33	92.89	83.73	83.45

Table 8.12
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 26-30

Reservoir	Volume Reliability (%) for Alternative Model Runs 26a	26b	27	28	29	30
Possum Kingdom	100.00	99.98	98.55	96.05	96.65	94.70
Granbury	97.23	97.23	96.48	93.09	92.27	90.05
Whitney	70.45	69.59	68.55	67.39	5.63	5.72
Aquilla	99.28	99.28	96.18	92.96	98.59	97.27
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	83.71	83.71	83.71	83.69	83.72	83.72
Belton	97.40	97.40	97.40	97.25	97.40	97.27
Stillhouse	100.00	100.00	99.27	98.16	100.00	99.68
Georgetown	100.00	100.00	100.00	100.00	100.00	100.00
Granger	100.00	100.00	99.11	97.03	100.00	98.89
Somerville	99.96	100.00	99.02	97.04	99.73	99.24
Limestone	99.94	99.96	98.42	96.27	99.59	98.77
System	100.00	100.00	99.55	98.66	98.69	97.89
Hypothetical	62.94	66.64	99.35	98.02	93.46	90.60
Total	90.56	91.34	97.89	96.78	94.60	92.93
Whitney Hydropower	65.04	64.19	63.32	61.60	70.84	69.01

Table 8.13
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 31-36

Control Point	Volume Reliability (%) for Alternative Model Runs 31	32	33	34	35	36
1. Hubbard	78.19	63.30	75.23	76.00	78.98	77.85
2. South Bend	76.37	66.28	74.39	75.07	11.28	11.17
3. Possum K.	99.18	96.08	97.89	97.98	88.19	88.78
4. Granbury	95.61	82.03	95.03	95.28	65.96	65.16
5. Whitney	97.96	93.48	97.13	90.20	37.03	37.11
6. Aquilla	99.18	99.34	96.67	97.48	97.85	98.35
7. Waco	95.41	95.27	95.38	95.41	95.44	95.44
9. Proctor	74.93	74.15	74.76	75.16	75.26	75.25
10. Belton	89.81	89.69	89.77	89.90	89.99	89.90
11. Stillhouse	96.48	96.64	95.88	96.33	96.62	96.48
12. Georgetown	99.80	99.85	99.79	99.82	99.83	99.81
13. Granger	95.87	96.53	94.74	95.87	96.38	96.15
14. Cameron	85.22	90.71	84.85	88.78	90.10	90.10
15. Bryan	87.45	91.48	87.12	90.10	82.76	80.73
16. Somerville	99.93	99.93	98.80	99.03	99.76	99.13
17. Limestone	99.49	99.32	98.38	98.49	99.12	98.90
18. Hempstead	91.13	95.03	90.80	92.73	93.60	93.30
19. Richmond	96.62	98.33	96.96	97.84	94.91	93.23
Basin Total	92.83	91.84	92.83	93.45	83.73	83.50

Table 8.14
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 31-36

Reservoir	Volume Reliability (%) for Alternative Model Runs 31	32	33	34	35	36
Possum Kingdom	100.00	97.30	98.70	98.84	95.61	95.17
Granbury	97.10	83.45	96.32	96.43	92.34	91.07
Whitney	97.62	98.26	94.71	68.47	5.63	5.71
Aquilla	99.34	99.49	96.82	97.59	97.97	98.47
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	83.64	83.61	83.64	83.71	83.72	83.72
Belton	97.40	97.17	97.40	97.40	97.40	97.27
Stillhouse	100.00	100.00	99.52	99.76	100.00	99.91
Georgetown	100.00	100.00	100.00	100.00	100.00	100.00
Granger	100.00	100.00	98.98	99.56	99.87	99.87
Somerville	100.00	100.00	98.88	99.11	99.84	99.22
Limestone	99.98	99.78	98.72	99.84	99.55	99.30
System	100.00	100.00	99.64	99.78	98.71	98.12
Hypothetical	-	-	99.55	100.00	93.53	90.91
Total	98.90	97.26	98.51	98.18	94.61	93.24
Whitney Hydropower	-	99.32	-	-	-	-

Table 8.15
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 37-41

Control Point	Volume Reliability (%) for Alternative Model Runs 1	37	38	39	40	41
1. Hubbard	78.15	79.19	72.08	78.06	72.79	86.20
2. South Bend	76.45	82.44	72.08	76.41	72.95	84.42
3. Possum K.	99.15	96.91	99.00	99.15	98.04	99.66
4. Granbury	95.85	94.22	95.78	95.73	93.30	99.70
5. Whitney	90.76	93.59	89.26	90.75	87.58	97.48
6. Aquilla	99.15	97.30	99.43	99.45	98.22	99.91
7. Waco	95.42	96.26	94.67	95.42	95.15	95.71
9. Proctor	75.19	82.59	66.76	80.57	74.29	77.40
10. Belton	89.93	89.38	89.67	89.16	88.54	93.61
11. Stillhouse	96.69	95.88	96.31	96.70	96.31	97.17
12. Georgetown	99.84	99.79	99.80	99.84	99.21	99.91
13. Granger	96.44	96.83	95.82	96.44	94.65	97.67
14. Cameron	89.09	91.63	87.67	89.05	78.94	97.66
15. Bryan	90.38	92.88	88.73	90.34	85.14	96.95
16. Somerville	99.89	99.23	99.89	99.90	99.59	99.94
17. Limestone	99.46	99.04	99.50	99.39	99.12	99.52
18. Hempstead	93.01	94.63	91.72	92.99	87.33	98.35
19. Richmond	97.53	98.13	97.31	97.49	93.71	99.67
Basin Total	93.32	94.27	92.26	93.31	90.12	96.60

Table 8.16
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 37-41

Reservoir	Volume Reliability (%) for Alternative Model Runs 1	37	38	39	40	41
Possum Kingdom	100.00	97.49	100.00	100.00	98.95	100.00
Granbury	97.23	94.06	97.74	97.05	94.36	100.00
Whitney	70.45	79.63	66.85	70.45	60.69	92.46
Aquilla	99.28	97.40	99.57	99.58	98.40	100.00
Waco	100.00	99.70	100.00	100.00	100.00	100.00
Proctor	83.71	88.76	73.00	93.87	83.34	85.43
Belton	97.40	95.52	97.70	95.68	96.99	98.26
Stillhouse	100.00	98.22	100.00	100.00	100.00	100.00
Georgetown	100.00	99.88	100.00	100.00	99.45	100.00
Granger	100.00	99.04	100.00	100.00	99.48	100.00
Somerville	99.96	99.26	100.00	99.97	99.67	100.00
Limestone	99.94	99.44	100.00	99.86	99.56	100.00
System	100.00	99.43	100.00	100.00	100.00	100.00
Total	98.22	97.21	97.92	98.24	97.40	99.17
Whitney Hydropower	65.04	73.86	61.62	64.92	57.25	87.68

Table 8.17
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 42-45

Control Point	Volume Reliability (%) for Alternative Model Runs 42	43	44	45
1. Hubbard	80.51	87.10	86.55	77.71
2. South Bend	11.32	0.24	0.35	68.86
3. Possum K.	89.49	0.90	4.66	99.26
4. Granbury	66.71	1.60	24.16	94.35
5. Whitney	48.01	4.13	83.49	90.72
6. Aquilla	99.51	99.12	99.88	99.70
7. Waco	95.47	95.64	95.56	95.43
9. Proctor	75.25	75.33	75.26	75.19
10. Belton	90.02	90.09	90.06	89.93
11. Stillhouse	96.77	97.05	96.95	96.68
12. Georgetown	99.85	99.88	99.87	99.83
13. Granger	96.67	97.09	96.90	96.43
14. Cameron	90.37	92.13	91.61	89.15
15. Bryan	89.09	77.71	91.69	90.45
16. Somerville	99.93	99.93	99.93	99.92
17. Limestone	99.52	99.52	99.52	99.46
18. Hempstead	94.02	87.65	94.65	93.00
19. Richmond	96.40	90.65	97.70	97.50
Basin Total	84.17	69.57	77.11	92.60

Table 8.18
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 42-45

Reservoir	Volume Reliability (%) for Alternative Model Runs 42	43	44	45
Possum Kingdom	95.81	0.90	4.66	99.98
Granbury	93.27	1.62	24.02	95.59
Whitney	20.69	3.73	73.51	70.32
Aquilla	99.64	99.24	100.00	99.83
Waco	100.00	100.00	100.00	100.00
Proctor	83.72	83.72	83.72	83.71
Belton	97.40	97.41	97.41	97.40
Stillhouse	100.00	100.00	100.00	100.00
Georgetown	100.00	100.00	100.00	100.00
Granger	100.00	100.00	100.00	100.00
Somerville	100.00	100.00	100.00	100.00
Limestone	100.00	100.00	100.00	99.94
System	96.67	91.27	99.26	100.00
Total	95.61	66.11	72.30	98.09
Whitney Hydropower	72.21	81.76	76.77	64.85

Table 8.19
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 46-51

Control Point	Volume Reliability (%) for Alternative Model Runs 46	47	48	49	50	51
1. Hubbard	80.20	78.81	78.76	78.74	78.28	78.10
2. South Bend	79.20	78.65	78.49	78.26	77.98	77.76
3. Possum K.	94.87	94.38	93.65	93.21	92.71	92.47
4. Granbury	93.83	93.60	93.59	93.54	93.52	93.42
5. Whitney	90.14	89.77	89.76	89.67	89.62	89.36
6. Aquilla	75.84	75.43	75.43	75.43	75.49	75.43
7. Waco	95.39	95.38	95.38	95.37	95.37	95.36
9. Proctor	81.66	81.60	81.60	81.59	81.59	81.56
10. Belton	84.03	83.88	83.88	83.79	83.71	83.52
11. Stillhouse	82.33	81.98	81.91	82.13	82.12	81.75
12. Georgetown	81.51	81.09	81.03	80.83	80.73	80.48
13. Granger	71.20	70.91	70.90	70.76	70.74	70.19
14. Cameron	85.66	85.45	85.37	85.30	85.28	85.22
15. Bryan	88.97	88.84	88.82	88.30	88.75	88.70
16. Somerville	83.07	82.50	82.50	82.46	82.44	82.28
17. Limestone	95.93	95.92	95.91	95.91	95.90	95.90
18. Hempstead	91.44	91.24	91.23	91.23	91.22	91.15
19. Richmond	97.39	97.48	97.48	97.46	97.43	97.31
Basin Total	93.21	93.28	93.28	93.26	93.23	93.19

Table 8.20
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED
WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 46-51

Reservoir	Volume Reliability (%) for Alternative Model Runs 46	47	48	49	50	51
Possum Kingdom	-	-	-	-	-	-
Granbury	-	-	-	-	-	-
Whitney	68.73	67.54	67.48	67.15	66.97	66.02
Aquilla	-	-	-	-	-	-
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	94.22	94.22	94.22	94.22	94.22	94.22
Belton	-	-	-	-	-	-
Stillhouse	-	-	-	-	-	-
Georgetown	-	-	-	-	-	-
Granger	-	-	-	-	-	-
Somerville	-	-	-	-	-	-
Limestone	-	-	-	-	-	-
System	100.00	100.00	99.99	99.98	98.80	99.45
Total	99.05	99.11	99.11	99.48	98.97	98.69
Whitney Hydropower	64.04	63.16	63.06	62.94	62.72	62.02

Table 8.21
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 52-57

Control Point	Volume Reliability (%) for Alternative Model Runs 52	53	54	55	56	57
1. Hubbard	76.57	73.82	70.46	75.88	75.68	75.29
2. South Bend	76.20	73.83	72.30	75.21	75.18	74.99
3. Possum K.	92.31	90.97	90.50	93.79	93.55	92.94
4. Granbury	93.09	92.88	92.61	93.02	92.94	92.90
5. Whitney	88.99	88.60	88.01	89.54	89.50	89.47
6. Aquilla	74.25	73.62	73.29	74.06	74.06	74.06
7. Waco	95.33	95.28	95.25	95.36	95.35	95.35
9. Proctor	81.11	80.75	80.03	81.49	81.46	81.36
10. Belton	82.73	82.03	81.46	83.69	83.57	83.52
11. Stillhouse	80.99	79.78	78.14	81.54	81.46	81.31
12. Georgetown	79.33	78.95	77.32	78.66	78.52	78.59
13. Granger	69.17	67.39	66.04	68.91	68.71	68.53
14. Cameron	84.74	84.22	83.60	84.85	84.75	84.65
15. Bryan	88.47	88.18	87.82	88.50	88.44	88.36
16. Somerville	80.40	79.67	79.34	81.44	81.49	80.99
17. Limestone	95.89	95.86	95.82	95.87	95.87	95.87
18. Hempstead	90.82	90.43	89.97	91.09	91.06	90.96
19. Richmond	96.55	95.69	94.63	97.07	97.06	97.03
Basin Total	92.75	92.10	91.32	92.24	92.23	92.21

Table 8.22
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED
WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 52-57

Reservoir	Volume Reliability (%) for Alternative Model Runs 52	53	54	55	56	57
Possum Kingdom	-	-	-	-	-	-
Granbury	-	-	-	-	-	-
Whitney	64.87	63.56	61.57	66.77	66.64	66.64
Aquilla	-	-	-	-	-	-
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	93.94	93.46	93.12	94.22	94.22	94.22
Belton	-	-	-	-	-	-
Stillhouse	-	-	-	-	-	-
Georgetown	-	-	-	-	-	-
Granger	-	-	-	-	-	-
Somerville	-	-	-	-	-	-
Limestone	-	-	-	-	-	-
System	97.76	96.23	94.66	100.00	99.96	99.83
Total	98.42	95.90	94.44	98.85	98.83	98.75
Whitney Hydropower	60.56	59.27	57.46	62.76	62.61	62.24

Table 8.23
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 58-63

Control Point	Volume Reliability (%) for Alternative Model Runs 58	59	60	61	62	63
1. Hubbard	74.76	74.48	72.90	70.70	62.41	56.43
2. South Bend	74.49	73.64	72.01	69.18	65.31	61.22
3. Possum K.	91.87	92.23	91.35	90.81	88.35	80.90
4. Granbury	92.85	92.75	92.48	92.16	91.62	91.15
5. Whitney	89.20	88.94	88.69	88.43	87.93	87.52
6. Aquilla	74.06	73.97	73.36	73.26	71.90	70.77
7. Waco	95.33	95.32	95.30	95.27	95.20	95.17
9. Proctor	81.13	81.05	80.52	80.21	78.44	77.59
10. Belton	83.33	83.26	82.81	82.24	81.35	79.92
11. Stillhouse	80.76	80.57	79.48	78.75	77.45	76.09
12. Georgetown	78.10	78.22	77.65	77.36	76.15	73.26
13. Granger	68.16	67.72	66.41	65.15	63.62	61.09
14. Cameron	84.41	84.23	83.92	83.69	83.15	82.18
15. Bryan	88.23	88.08	87.87	87.56	87.24	86.83
16. Somerville	80.27	80.62	79.02	78.21	75.48	69.93
17. Limestone	95.84	95.84	95.81	95.80	95.72	95.65
18. Hempstead	90.87	90.69	90.23	89.97	89.44	88.83
19. Richmond	96.99	96.95	96.71	96.23	95.16	93.58
Basin Total	92.16	92.08	91.82	91.34	90.36	88.99

Table 8.24
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 58-63

Reservoir	Volume Reliability (%) for Alternative Model Runs 58	59	60	61	62	63
Possum Kingdom	-	-	-	-	-	-
Granbury	-	-	-	-	-	-
Whitney	65.71	64.85	64.15	63.32	61.63	60.38
Aquilla	-	-	-	-	-	-
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	94.22	94.22	94.21	94.18	93.00	92.08
Belton	-	-	-	-	-	-
Stillhouse	-	-	-	-	-	-
Georgetown	-	-	-	-	-	-
Granger	-	-	-	-	-	-
Somerville	-	-	-	-	-	-
Limestone	-	-	-	-	-	-
System	99.62	99.50	98.81	97.68	95.66	93.17
Total	98.61	98.52	97.99	97.05	95.28	93.01
Whitney Hydropower	61.72	61.20	60.14	59.53	57.51	55.60

Table 8.25
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 64-69

Control Point	Volume Reliability (%) for Alternative Model Runs 64	65	66	67	68	69
1. Hubbard	85.55	84.21	84.24	83.21	81.01	79.53
2. South Bend	12.22	12.16	12.11	11.97	11.78	11.63
3. Possum K.	43.59	43.57	43.56	43.51	43.24	43.21
4. Granbury	20.52	20.52	20.52	20.45	20.45	20.54
5. Whitney	36.59	36.45	36.25	36.05	35.97	36.13
6. Aquilla	77.85	77.63	77.66	76.90	76.16	77.06
7. Waco	95.52	95.61	95.52	95.59	95.49	95.47
9. Proctor	82.05	81.99	81.88	81.89	81.87	81.70
10. Belton	84.41	84.41	84.36	84.19	84.02	83.86
11. Stillhouse	83.84	83.58	83.35	82.42	82.04	81.27
12. Georgetown	85.21	85.12	84.77	83.39	83.03	81.46
13. Granger	75.02	74.76	73.58	72.30	71.99	70.71
14. Cameron	89.85	89.89	90.07	89.46	88.57	88.42
15. Bryan	75.19	74.58	74.57	73.75	73.75	72.41
16. Somerville	86.33	86.99	86.27	84.69	83.56	83.71
17. Limestone	95.98	95.98	95.98	95.94	95.91	95.87
18. Hempstead	92.59	92.60	92.52	92.07	91.36	91.08
19. Richmond	87.86	87.25	86.20	85.02	83.55	81.24
Basin Total	78.00	77.85	77.53	77.27	76.67	75.36

Table 8.26
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED
WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 64-69

Reservoir	Volume Reliability (%) for Alternative Model Runs 64	65	66	67	68	69
Possum Kingdom	-	-	-	-	-	-
Granbury	-	-	-	-	-	-
Whitney	5.24	4.96	4.59	4.38	4.33	4.56
Aquilla	-	-	-	-	-	-
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	94.23	94.22	94.23	94.22	94.32	94.23
Belton	-	-	-	-	-	-
Stillhouse	-	-	-	-	-	-
Georgetown	-	-	-	-	-	-
Granger	-	-	-	-	-	-
Somerville	-	-	-	-	-	-
Limestone	-	-	-	-	-	-
System	84.78	84.15	83.00	82.01	80.60	78.24
Total	84.26	83.75	82.76	81.90	80.61	78.41
Whitney Hydropower	74.54	73.54	73.25	70.97	68.63	67.41

Table 8.27
VOLUME RELIABILITY BY CONTROL POINT FOR SIMULATION RUNS 70-75

Control Point	Volume Reliability (%) for Alternative Model Runs 70	71	72	73	74	75
1. Hubbard	84.94	83.46	82.48	81.08	78.76	77.56
2. South Bend	12.18	12.10	12.00	11.85	11.64	11.51
3. Possum K.	43.71	43.69	43.59	43.02	42.30	42.27
4. Granbury	20.72	20.72	20.72	20.70	20.79	20.65
5. Whitney	37.49	37.76	37.77	38.56	38.82	39.22
6. Aquilla	77.98	77.29	76.49	76.52	75.44	74.84
7. Waco	95.52	95.52	95.51	95.50	95.39	95.35
9. Proctor	81.99	81.94	81.85	81.73	81.68	80.98
10. Belton	84.35	84.34	84.24	84.04	83.79	83.09
11. Stillhouse	83.43	83.14	82.95	81.83	80.75	80.33
12. Georgetown	83.96	83.93	83.09	81.94	80.89	79.80
13. Granger	74.55	73.53	72.48	71.02	69.51	68.26
14. Cameron	89.29	88.90	88.61	87.75	86.80	87.19
15. Bryan	81.90	81.76	80.79	80.55	80.71	79.88
16. Somerville	85.75	85.60	85.35	83.72	81.45	81.72
17. Limestone	95.97	95.96	95.93	95.91	95.88	95.86
18. Hempstead	93.00	92.75	92.34	91.78	91.35	91.17
19. Richmond	91.66	91.45	91.33	90.76	90.52	88.27
Basin Total	80.71	80.87	81.12	81.41	81.80	80.66

Table 8.28
VOLUME RELIABILITY FOR DIVERSION RIGHTS ASSOCIATED WITH BRA/USACE RESERVOIRS FOR SIMULATION RUNS 70-75

Reservoir	Volume Reliability (%) for Alternative Model Runs 70	71	72	73	74	75
Possum Kingdom	-	-	-	-	-	-
Granbury	-	-	-	-	-	-
Whitney	6.52	6.83	6.76	7.87	8.18	8.74
Aquilla	-	-	-	-	-	-
Waco	100.00	100.00	100.00	100.00	100.00	100.00
Proctor	94.23	94.23	94.22	94.23	94.18	92.83
Belton	-	-	-	-	-	-
Stillhouse	-	-	-	-	-	-
Georgetown	-	-	-	-	-	-
Granger	-	-	-	-	-	-
Somerville	-	-	-	-	-	-
Limestone	-	-	-	-	-	-
System	90.58	90.40	90.42	89.95	89.79	86.94
Total	89.31	89.28	89.43	89.20	89.17	86.59
Whitney Hydropower	72.96	71.94	70.88	68.78	65.73	64.27

Table 8.29
MEAN UNREGULATED FLOWS AND CONCENTRATIONS

	Mean Unregulated Flows (ac-ft/month) and Concentrations (mg/l) Runs 1-41 & 46-63	Runs 42-45
Below Granbury Reservoir (CP-4) on the Brazos River		
Flow	97,050	94,624
TDS	1,048	774
Chloride	424	272
Sulfate	209	175
Cameron Gage (CP-14) on the Little River		
Flow	107,225	107,225
TDS	141	141
Chloride	17	17
Sulfate	16	16
Richmond Gage (CP-19) on the Brazos River		
Flow	472,287	469,925
TDS	308	256
Chloride	67	41
Sulfate	50	43

Table 8.30
UNREGULATED FLOW-DURATION CURVES

Exceedence Frequency	Unregulated Flows (acre-feet/month) Runs 1-41 & 46-63	Runs 42-45
Below Granbury Reservoir (CP-4) on the Brazos River		
5%	359,130	350,150
25%	75,301	73,420
50%	22,798	22,230
75%	6,432	6,270
90%	1,214	1,180
95%	89	87
99%	0	0
100%	0	0
Cameron Gage (CP-14) on the Little River		
5%	418,550	418,550
25%	124,060	124,060
50%	40,930	40,930
75%	14,580	14,580
90%	4,950	4,950
95%	2,320	2,320
99%	237	237
100%	0	0
Richmond Gage (CP-19) on the Brazos River		
5%	1,592,000	1,584,000
25%	565,529	562,700
50%	258,866	257,570
75%	105,469	104,940
90%	48,736	48,490
95%	34,307	34,140
99%	18,108	18,020
100%	0	0

Table 8.31
MEAN REGULATED FLOWS AND CONCENTRATIONS FOR RUNS 1-6

	Mean Regulated Flows (ac-ft/month) and Concentrations (mg/l) for Runs					
	1	2	3	4	5	6
Below Granbury Reservoir (CP-4) on the Brazos River						
Flow	41,323	50,925	50,882	45,594	67,873	67,925
TDS	1,155	1,319	1,319	1,269	1,487	1,484
Chloride	462	530	530	509	602	601
Sulfate	224	260	260	249	297	297
Cameron Gage (CP-14) on the Little River						
Flow	86,637	86,519	86,572	86,596	86,327	86,363
TDS	152	153	153	152	154	154
Chloride	18	18	18	18	18	18
Sulfate	19	19	19	19	19	19
Richmond Gage (CP-19) on the Brazos River						
Flow	286,094	298,264	294,788	289,977	322,441	309,986
TDS	223	255	251	237	318	306
Chloride	29	40	39	34	63	60
Sulfate	32	39	38	35	51	49

Table 8.32
REGULATED FLOW-DURATION CURVES FOR RUNS 1-6

Exceedence	Regulated Flows (acre-feet/month) for Runs					
Frequency	1	2	3	4	5	6
Below Granbury Reservoir (CP-4) on the Brazos River						
5%	182,410	222,922	222,922	195,776	287,290	297,290
25%	28,384	42,628	40,927	33,765	71,274	69,948
50%	4,498	6,792	7,079	5,289	17,133	17,844
75%	14	17	17	15	1,568	2,457
90%	4	4	4	4	17	19
95%	0	2	2	0	9	12
99%	0	0	0	0	0	0
100%	0	0	0	0	0	0
Cameron Gage (CP-14) on the Little River						
5%	362,631	362,631	362,631	362,631	366,117	362,631
25%	84,110	85,105	85,105	87,105	87,179	86,980
50%	30,664	29,619	30,382	30,525	27,847	28,039
75%	16,439	15,995	16,141	16,332	14,988	15,318
90%	11,681	11,508	11,594	11,740	10,573	10,924
95%	9,756	9,370	9,370	9,619	8,627	8,935
99%	3,570	3,572	3,572	3,570	1,866	3,554
100%	0	0	0	0	0	0
Richmond Gage (CP-19) on the Brazos River						
5%	1,202,425	1,217,704	1,218,373	1,202,433	1,298,698	1,262,311
25%	322,803	335,667	327,356	324,083	374,199	362,886
50%	67,473	79,186	71,723	70,517	104,608	85,819
75%	264	370	304	289	20,078	503
90%	30	78	62	36	153	92
95%	11	16	15	13	54	24
99%	0	0	0	0	4	0
100%	0	0	0	0	0	0

Table 8.33
MEAN REGULATED FLOWS AND CONCENTRATIONS FOR RUNS 7-12

	Mean Regulated Flows (ac-ft/month) and Concentrations (mg/l) for Runs					
	7	8	9	10	11	12
Below Granbury Reservoir (CP-4) on the Brazos River						
Flow	50,228	41,404	67,8733	67,925	50,228	41,404
TDS	1,378	1,161	1,487	1,484	1,378	1,161
Chloride	555	465	602	601	555	465
Sulfate	273	225	297	297	273	225
Cameron Gage (CP-14) on the Little River						
Flow	86,500	86,630	86,327	86,363	86,500	86,630
TDS	153	153	154	154	153	152
Chloride	18	18	18	18	18	18
Sulfate	19	19	19	19	19	19
Richmond Gage (CP-19) on the Brazos River						
Flow	293,663	286,120	322,441	309,986	293,663	286,120
TDS	252	223	318	306	252	223
Chloride	40	29	63	60	40	29
Sulfate	38	32	51	49	38	32

Table 8.34
REGULATED FLOW-DURATION CURVES FOR RUNS 7-12

Exceedence	Regulated Flows (acre-feet/month) for Runs					
Frequency	7	8	9	10	11	12
Below Granbury Reservoir (CP-4) on the Brazos River						
5%	223,411	182,410	287,290	287,290	223,411	182,410
25%	41,549	28,385	71,274	69,948	41,549	28,384
50%	8,013	4,498	17,133	17,844	8,013	4,498
75%	17	14	1,568	2,456	17	14
90%	4	4	17	19	4	4
95%	0	0	9	11	0	0
99%	0	0	0	0	0	0
100%	0	0	0	0	0	0
Cameron Gage (CP-14) on the Little River						
5%	362,631	362,631	366,117	362,631	362,631	362,631
25%	85,135	84,110	87,179	86,980	85,135	84,110
50%	29,809	30,664	27,847	28,039	29,809	30,664
75%	15,681	16,439	14,988	15,318	15,681	16,439
90%	11,299	11,681	10,573	10,924	11,399	11,681
95%	8,997	9,757	8,627	8,935	8,997	9,757
99%	3,570	3,570	1,866	3,554	3,570	3,570
100%	0	0	0	0	0	0
Richmond Gage (CP-19) on the Brazos River						
5%	1,240,052	1,202,425	1,298,698	1,262,311	1,240,052	1,202,425
25%	327,356	322,803	374,199	362,886	327,356	322,803
50%	72,534	67,473	104,609	85,819	72,534	67,473
75%	355	264	20,078	503	355	264
90%	75	30	153	92	75	30
95%	16	11	54	24	16	11
99%	0	0	4	0	0	0
100%	0	0	0	0	0	0

Table 8.35
MEAN REGULATED FLOWS AND CONCENTRATIONS FOR RUNS 20-25

Mean Regulated Flows (ac-ft/month) and Concentrations (mg/l) for Runs	20	21	22	23	24	25
Below Granbury Reservoir (CP-4) on the Brazos River						
Flow	50,553	67,556	67,454	51,321	67,959	68,036
TDS	1,323	1,492	1,493	1,313	1,485	1,482
Chloride	532	604	604	528	601	600
Sulfate	261	298	298	259	297	296
Cameron Gage (CP-14) on the Little River						
Flow	86,647	86,502	86,549	86,399	86,284	86,324
TDS	152	153	153	153	154	154
Chloride	18	18	18	18	18	18
Sulfate	19	19	19	19	19	19
Richmond Gage (CP-19) on the Brazos River						
Flow	297,801	319,609	309,641	299,169	323,110	310,213
TDS	256	316	307	255	319	307
Chloride	41	63	60	40	63	60
Sulfate	39	51	49	39	51	49

Table 8.36
REGULATED FLOW-DURATION CURVES FOR RUNS 20-25

Exceedence Frequency	Regulated Flows (acre-feet/month) for Runs 20	21	22	23	24	25
Below Granbury Reservoir (CP-4) on the Brazos River						
5%	222,921	301,687	291,851	210,381	287,290	287,290
25%	40,677	71,372	71,274	42,134	70,696	69,037
50%	3,548	11,721	11,846	12,802	17,845	18,052
75%	16	208	208	23	2,305	3,978
90%	4	14	14	6	18	22
95%	1	4	4	0	11	12
99%	0	0	0	0	0	0
100%	0	0	0	0	0	0
Cameron Gage (CP-14) on the Little River						
5%	360,851	362,631	362,120	366,117	366,117	366,117
25%	84,719	83,108	84,011	87,235	87,179	87,179
50%	30,187	30,156	30,403	27,757	27,014	27,119
75%	16,352	15,995	16,352	15,115	14,707	14,854
90%	11,547	11,391	11,594	11,259	10,605	10,679
95%	9,515	9,370	9,547	9,099	8,451	8,891
99%	4,422	4,032	3,700	3,573	1,865	1,866
100%	0	0	0	0	0	0
Richmond Gage (CP-19) on the Brazos River						
5%	1,213,724	1,285,489	1,281,300	1,227,301	1,298,698	1,266,353
25%	335,725	374,199	362,448	335,663	374,199	362,886
50%	79,076	102,480	87,155	80,834	107,098	86,534
75%	375	12,043	928	468	20,339	928
90%	78	121	103	82	149	85
95%	18	31	27	20	44	21
99%	0	4	2	0	4	0
100%	0	0	0	0	0	0

Table 8.37
MEAN REGULATED FLOWS AND CONCENTRATIONS FOR RUNS 26-30

Mean Regulated Flows (ac-ft/month) and Concentrations (mg/l) for Runs	26a	26b	27	28	29	30
Below Granbury Reservoir (CP-4) on the Brazos River						
Flow	41,323	41,375	42,448	43,960	51,610	52,246
TDS	1,155	1,155	1,157	1,162	1,313	1,312
Chloride	462	462	463	466	528	527
Sulfate	224	224	225	226	259	259
Cameron Gage (CP-14) on the Little River						
Flow	86,637	86,641	86,867	87,165	86,714	86,923
TDS	152	152	152	152	152	152
Chloride	18	18	18	18	18	18
Sulfate	19	19	19	18	19	19
Richmond Gage (CP-19) on the Brazos River						
Flow	275,604	275,043	271,398	257,647	284,359	271,642
TDS	223	223	221	221	255	254
Chloride	29	29	29	28	40	39
Sulfate	32	32	32	31	38	38

Table 8.38
REGULATED FLOW-DURATION CURVES FOR RUNS 26-30

Exceedence Frequency	Regulated Flows (acre-feet/month) for Runs 26a	26b	27	28	29	30
Below Granbury Reservoir (CP-4) on the Brazos River						
5%	182,410	183,718	173,056	183,049	222,921	222,475
25%	28,384	28,384	34,653	47,096	45,259	51,111
50%	4,498	4,561	8,306	9,610	9,619	10,983
75%	14	14	15	16	19	20
90%	4	4	4	4	4	6
95%	0	0	0	0	0	0
99%	0	0	0	0	0	0
100%	0	0	0	0	0	0
Cameron Gage (CP-14) on the Little River						
5%	362,631	362,631	360,967	351,809	360,967	350,707
25%	84,110	85,105	83,340	86,077	83,340	86,256
50%	30,664	30,664	31,601	33,931	31,198	31,981
75%	16,439	16,701	17,982	17,982	16,745	16,723
90%	11,681	11,595	11,667	11,669	11,607	11,570
95%	9,757	9,518	9,370	9,619	9,193	9,011
99%	3,570	3,570	3,700	3,147	3,330	2,442
100%	0	0	0	0	0	0
Richmond Gage (CP-19) on the Brazos River						
5%	1,188,425	1,188,425	1,188,425	1,174,425	1,199,724	1,185,724
25%	306,802	306,803	753,543	280,413	321,663	300,257
50%	53,775	52,752	52,197	33,830	65,066	53,078
75%	204	197	193	138	260	223
90%	25	24	24	20	38	31
95%	11	11	10	6	13	13
99%	0	0	0	0	0	0
100%	0	0	0	0	0	0

Table 8.39
MEAN REGULATED FLOWS AND CONCENTRATIONS FOR RUNS 31-36

Mean Regulated Flows (ac-ft/month) and Concentrations (mg/l) for Runs	31	32	33	34	35	36
Below Granbury Reservoir (CP-4) on the Brazos River						
Flow	41,159	49,015	42,558	43,068	51,795	52,591
TDS	1,157	1,154	1,159	1,162	1,316	1,311
Chloride	464	464	465	467	529	527
Sulfate	224	225	225	226	260	259
Cameron Gage (CP-14) on the Little River						
Flow	86,824	86,867	87,104	87,068	86,923	87,029
TDS	152	152	152	152	152	152
Chloride	18	18	18	18	18	18
Sulfate	19	19	18	19	19	19
Richmond Gage (CP-19) on the Brazos River						
Flow	284,611	292,874	270,364	270,483	284,849	272,197
TDS	239	224	237	237	281	279
Chloride	34	30	34	34	50	49
Sulfate	35	32	35	35	43	43

Table 8.40
REGULATED FLOW-DURATION CURVES FOR RUNS 31-36

Exceedence Frequency	31	32	33	34	35	36
	Regulated Flows (acre-feet/month) for Runs					
Below Granbury Reservoir (CP-4) on the Brazos River						
5%	191,581	171,076	171,694	176,300	228,322	214,365
25%	27,547	48,695	37,052	37,396	44,056	53,547
50%	5,145	19,919	9,301	9,969	11,298	11,661
75%	14	7,239	15	16	20	22
90%	4	2,279	4	4	6	7
95%	0	5	0	0	0	0
99%	0	0	0	0	0	0
100%	0	0	0	0	0	0
Cameron Gage (CP-14) on the Little River						
5%	362,631	362,631	360,967	360,967	360,967	355,338
25%	82,221	85,375	80,698	80,698	79,953	87,113
50%	32,818	30,709	34,714	34,807	32,848	33,996
75%	17,920	15,966	18,958	18,263	17,150	16,782
90%	11,382	11,099	11,801	11,570	11,347	11,221
95%	9,131	9,105	9,494	9,278	9,008	8,766
99%	3,541	3,097	3,363	2,655	2,655	2,000
100%	0	0	0	0	0	0
Richmond Gage (CP-19) on the Brazos River						
5%	1,226,315	1,210,688	1,209,895	1,209,895	1,215,301	1,203,301
25%	331,558	331,544	306,469	306,469	332,823	313,530
50%	49,457	85,261	31,480	31,480	46,249	32,506
75%	135	8,007	112	112	149	126
90%	21	0	17	17	22	21
95%	4	0	4	4	11	10
99%	0	0	0	0	0	0
100%	0	0	0	0	0	0

Table 8.41
MEAN REGULATED FLOWS AND CONCENTRATIONS FOR RUNS 42-45

Mean Regulated Flows (ac-ft/month) and Concentrations (mg/l) for Runs	42	43	44	45
Below Granbury Reservoir (CP-4) on the Brazos River				
Flow	48,657	65,512	63,584	39,832
TDS	995	1,108	1,110	882
Chloride	348	389	390	305
Sulfate	221	252	253	192
Cameron Gage (CP-14) on the Little River				
Flow	86,534	86,332	86,389	86,629
TDS	153	154	153	152
Chloride	18	18	18	18
Sulfate	19	19	19	19
Richmond Gage (CP-19) on the Brazos River				
Flow	294,902	315,724	305,028	284,597
TDS	221	264	253	198
Chloride	24	37	34	17
Sulfate	34	44	42	29

Table 8.42
REGULATED FLOW-DURATION CURVES FOR RUNS 42-45

Exceedence Frequency	Regulated Flows (acre-feet/month) for Runs 42	43	44	45
Below Granbury Reservoir (CP-4) on the Brazos River				
5%	214,513	279,375	278,247	175,845
25%	40,232	68,469	62,482	27,758
50%	6,567	16,741	16,181	4,410
75%	17	1,760	1,225	14
90%	3.8	17	14	3.7
95%	0.2	9.2	7.7	0
99%	0	0	0	0
100%	0	0	0	0
Cameron Gage (CP-14) on the Little River				
5%	362,631	366,117	362,631	362,631
25%	85,105	87,179	87,179	84,719
50%	29,632	27,788	28,268	30,542
75%	16,173	15.065	15,331	16,503
90%	11,633	10,709	10,975	11,657
95%	9,349	8,765	9,058	9,464
99%	3,572	1,866	3,551	3,570
100%	0	0	0	0
Richmond Gage (CP-19) on the Brazos River				
5%	1,210,585	1,291,533	1,255,116	1,196,476
25%	330,361	366,825	343,230	320,060
50%	76,711	98,396	81,818	67,751
75%	363	13,572	438	260
90%	66	126	84	30
95%	16	31	21	11
99%	0	0	0	0
100%	0	0	0	0

Table 8.43
STORAGE-DURATION RELATIONSHIPS FOR RUN 17

Reservoir	Possum K	Granbury	Whitney	Aquilla	Waco	Proctor
Capacity (ac-ft)	570,240	153,490	627,100	524,000	152,500	59,400
Active (ac-ft)	570,240	100,990	248,000	524,000	151,920	59,330
Inactive (ac-ft)	0	52,500	379,100	0	580	70
Mean (ac-ft)	448,244	124,477	469,477	42,690	132,297	36,577

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	86	75	77	69	62	85
95%	81	73	76	63	56	83
90%	73	68	74	54	46	80
75%	30	52	68	28	20	61
50%	7	19	59	10	3.4	32
25%	2.6	9	51	2.8	0	14
10%	0.6	5.6	45	1.1	0	8.2
0%	0	3.5	41	0.6	0	4.0

Reservoir	Belton	Stillhouse	Georgetown	Granger	Somerville	Limestone
Capacity (ac-ft)	447,490	235,700	37,100	65,500	160,100	225,440
Active (ac-ft)	447,479	234,920	36,862	65,278	159,880	225,440
Inactive (ac-ft)	11	780	238	222	220	0
Mean (ac-ft)	328,061	202,547	32,657	56,899	135,764	181,890

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	75	55	51	46	61	69
95%	69	49	44	40	54	64
90%	62	40	36	34	44	54
75%	38	24	18	24	23	30
50%	18	8.1	5.8	9	9	11
25%	11	0.1	1.1	0.9	2	2.6
10%	8.5	0	0.6	0	0.8	0.8
0%	5.1	0	0.1	0	0.1	0.2

Table 8.44
STORAGE-DURATION RELATIONSHIPS FOR RUN 37

Reservoir	Possum K	Granbury	Whitney	Aquilla	Waco	Proctor
Capacity (ac-ft)	570,240	153,490	627,100	524,000	152,500	59,400
Active (ac-ft)	570,240	100,990	248,000	524,000	151,920	59,330
Inactive (ac-ft)	0	52,500	379,100	0	580	70
Mean (ac-ft)	357,297	115,480	490,876	41,149	128,049	31,186

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	90	80	73	68	63	86
95%	85	76	72	63	56	83
90%	79	71	70	53	47	79
75%	60	55	63	27	22	70
50%	20	31	53	14	9	43
25%	13	21	43	9	3	28
10%	11	13	36	8	1	19
0%	3	7	33	4	0.6	13

Reservoir	Belton	Stillhouse	Georgetown	Granger	Somerville	Limestone
Capacity (ac-ft)	447,490	235,700	37,100	65,500	160,100	225,440
Active (ac-ft)	447,479	234,920	36,862	65,278	159,880	225,440
Inactive (ac-ft)	11	780	238	222	220	0
Mean (ac-ft)	321,619	181,396	32,940	58,770	136,406	182,342

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	77	59	51	45	61	70
95%	71	53	44	36	53	64
90%	64	45	35	27	41	54
75%	42	31	17	14	20	28
50%	21	19	4	6	8	12
25%	12	12	1	3	4	3
10%	9	9	0.7	1	2	1
0%	5	3	0.2	1	0.8	0.7

Table 8.45
STORAGE-DURATION RELATIONSHIPS FOR RUN 38

Reservoir	Possum K	Granbury	Whitney	Aquilla	Waco	Proctor
Capacity (ac-ft)	570,240	153,490	627,100	524,000	152,500	59,400
Active (ac-ft)	570,240	100,990	248,000	524,000	151,920	59,330
Inactive (ac-ft)	0	52,500	379,100	0	580	70
Mean (ac-ft)	502,331	130,596	457,805	43,261	138,030	27,082

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	63	62	79	67	56	84
95%	50	58	78	61	48	83
90%	37	52	76	52	37	80
75%	15	33	71	26	11	71
50%	5	18	62	9	2	51
25%	2	9	54	3	0	40
10%	0	5	48	1	0	31
0%	0	3	45	1	0	28

Reservoir	Belton	Stillhouse	Georgetown	Granger	Somerville	Limestone
Capacity (ac-ft)	447,490	235,700	37,100	65,500	160,100	225,440
Active (ac-ft)	447,479	234,920	36,862	65,278	159,880	225,440
Inactive (ac-ft)	11	780	238	222	220	0
Mean (ac-ft)	347,671	207,733	33,254	58,075	137,862	184,136

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	71	53	50	46	60	69
95%	65	46	42	40	53	64
90%	56	36	33	33	42	55
75%	29	19	16	19	21	28
50%	16	6	4	5	7	9
25%	9	0.1	0.8	0.3	0.8	2
10%	6	0	0.4	0	0.3	0.5
0%	3	0	0	0	0	0

Table 8.46
STORAGE-DURATION RELATIONSHIP FOR RUN 39

Reservoir	Possum K	Granbury	Whitney	Aquilla	Waco	Proctor
Capacity (ac-ft)	570,240	153,490	627,100	524,000	152,500	59,400
Active (ac-ft)	570,240	100,990	248,000	524,000	151,920	59,330
Inactive (ac-ft)	0	52,500	379,100	0	580	70
Mean (ac-ft)	448,337	124,477	469,439	42,656	132,297	35,760

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	86	75	77	69	62	86
95%	81	73	76	63	56	84
90%	73	68	74	54	46	82
75%	30	52	68	28	19	67
50%	7	19	59	10	3	43
25%	3	9	51	3	0	27
10%	1	6	41	1	0	17
0%	0	3	41	1	0	17

Reservoir	Belton	Stillhouse	Georgetown	Granger	Somerville	Limestone
Capacity (ac-ft)	447,490	235,700	37,100	65,500	160,100	225,440
Active (ac-ft)	447,479	234,920	36,862	65,278	159,880	225,440
Inactive (ac-ft)	11	780	238	222	220	0
Mean (ac-ft)	327,893	202,534	32,997	56,872	135,769	181,880

Storage as % of Active Capacity	Percentage (%) of the 1,020 Months For Which Storage Equals or Falls Below Indicated Level					
100%	100	100	100	100	100	100
98%	75	55	50	46	61	69
95%	69	48	44	40	54	64
90%	62	40	35	34	43	55
75%	38	24	16	23	23	30
50%	18	8	5	9	9	11
25%	11	1	1	2	2	3
10%	9	0	0.4	0.1	1	1
0%	5	0	0	0	0.1	0.2

Table 8.47
YIELD VERSUS RELIABILITY RELATIONSHIPS

Run	Hypothetical Yield: Yield Target (ac-ft/yr)	Shortages: Periods	Shortages: Mean (ac-ft/yr)	Reliability: Period (%)	Reliability: Volume (%)	Other Rights: Mean Shortage (ac-ft/yr)	Other Rights: Volume Reliability (%)
			With Excess Flows				
46	623,907	0	0	100.00	100.00	155,048	90.66
47	700,000	0	0	100.00	100.00	158,618	90.45
48	710,000	1	83	99.90	99.99	159,309	90.41
49	730,000	3	777	99.71	99.89	160,284	90.35
50	750,000	4	1,534	99.61	99.80	161,622	90.27
51	800,000	9	4,425	99.12	99.45	163,055	90.18
52	1,000,000	30	22,361	97.06	97.76	170,582	89.73
53	1,200,000	53	45,252	94.80	96.23	180,742	89.11
54	1,400,000	70	74,767	93.14	94.66	182,465	89.01
			Without Excess Flows				
55	530,000	0	0	100.00	100.00	169.889	89.77
56	540,000	2	221	99.80	99.96	170.683	89.72
57	560,000	4	940	99.61	99.83	172,123	89.63
58	600,000	8	2,291	99.22	99.62	174,912	89.47
59	623,907	9	3,125	99.12	99.50	177,795	89.29
60	700,000	22	8,350	97.84	98.81	184,767	88.87
61	800,000	37	18,554	96.37	97.68	194,452	88.29
62	1,000,000	61	43,390	94.02	95.66	212,982	87.17
63	1,200,000	88	81,907	91.37	93.17	233,095	85.96

Table 8.48
FIRM YIELDS FROM TWRI TECHNICAL REPORT 144

Reservoir	Water Right Diversion (ac-ft/yr)	Model Permitted Diversion (ac-ft/yr)	TR-144 Firm Yields: Hydrologic Yields for Sediment Conditions: Base (ac-ft/yr)	1984 (ac-ft/yr)	2010 (ac-ft/yr)	Constrained by Water Rights (ac-ft/yr)
Possum Kingdom	230,750	153,200	296,104	291,760	278,004	207,100
Granbury	64,712	54,936	60,813	60,090	48,500	33,300
Whitney	18,336	18,336	138,278	132,487	131,763	6,500
Aquilla	13,896	6,770	18,099	18,099	17,375	8,000
Waco	59,100	59,100	87,600	83,981	76,741	67,300
Proctor	19,658	19,658	24,615	21,719	14,479	-0-
Belton	100,257	100,257	130,315	128,143	119,455	87,600
Stillhouse	67,768	39,530	79,637	78,189	76,017	70,900
Georgetown	13,610	13,610	16,651	16,651	15,927	14,500
Granger	19,840	10,962	25,339	24,615	22,443	26,800
Somerville	48,000	26,257	44,886	44,162	43,438	38,400
Limestone	65,074	46,840	76,017	72,397	70,949	61,500
System	-	171,545	-	-	-	-
Total	721,001	721,001	998,354	972,293	915,091	621,900
10-Reservoir System Firm Yield:						
With Unregulated Flows				1,639,800	1,579,700	844,900
Without Unregulated Flows				1,228,600	1,171,400	648,700

CHAPTER 9
SUMMARY AND CONCLUSIONS

How much water is available now and in the future to meet the needs of society? This question is pertinent to the Brazos River Basin, the state of Texas, and communities and regions throughout the world. The answer, in all cases, is that nobody knows for sure. However, conscientious water resources management requires our best estimates regarding water availability. This report presents an approach for evaluating the water supply capabilities of a river basin for various water management strategies. The simulation modeling approach is applied in a water supply reliability study of the Brazos River Basin.

Generalized Modeling Capabilities

The TAMUWRAP Water Rights Analysis Package simulates reservoir/river system management under a prior appropriation water rights system such as that of Texas. The model is designed for simulation studies involving a priority-based allocation of water resources among many different water users. Water use diversions and reservoir storage facilities may be numerous, and the allocation system may be quite complex. TAMUWRAP is generalized for application to essentially any river basin or multiple river basins. The model provides considerable flexibility for analyzing a broad range of reservoir/river system operating policies and water use scenarios. Salinity considerations also can be incorporated in a simulation study.

The generalized WRAP3 and WRAPSALT programs simulate a river basin-reservoir-water rights system. The computer program TABLES provides capabilities for organizing, summarizing, and presenting simulation results in a variety of formats. The modeling package is designed for application by water management practitioners in agencies, consulting firms, and universities for a broad range of types of studies and decision-support activities.

An operational model for a river basin consists of the generalized TAMUWRAP programs combined with input data files developed for the particular river basin. The input data files developed for the Brazos River Basin are readily available for continuing studies of the basin. Upon compilation of the basic data files, the model can be readily applied on an ongoing basis to analyze various questions that may arise in conjunction with applications for water rights permits, execution of water supply contracts, evaluation of reservoir system operating procedures, planning for construction of new facilities, and other water management activities.

Development of the basic data required for simulating a river basin represents a major area for further research. Considerable time and expertise is required to develop the necessary model input data. The TAMUWRAP input files include: (1) naturalized monthly streamflows for all pertinent locations for each month of the simulation period; (2) net monthly reservoir evaporation rates for all pertinent locations covering the simulation period; (3) storage versus area relationships for each reservoir; (4) water rights data; and (5) reservoir storage allocations and operating rules. If salinity is considered, monthly loads for each salt constituent of interest are required along with the streamflows. Systemization of methodologies and development of computer software are needed to facilitate compilation of basic data. Development of complete, homogeneous sequences of naturalized streamflows, for all pertinent gaged and ungaged locations, represents a particularly significant area for further research. Better data and methods are also needed for estimating reservoir evaporation rates, seepage, and river channel losses. Improved methods for developing reservoir storage data, reflecting appropriate conditions of sedimentation, are also important. Quantifying instream flow requirements and water quality considerations are also major areas warranting further research.

Water Availability in the Brazos River Basin

The Water Rights Analysis Program (WRAP) simulations are based on assuming that water users use the full amounts of their water rights, to the extent that sufficient streamflow and/or storage is available, during a repetition of historical hydrology. The following basinwide 1900-1984 means for the base model run illustrate the relative magnitude of the quantities involved in the simulation.

naturalized streamflows	5,667,400 ac-ft/yr
return flows	472,900 ac-ft/yr
storage change	-18,100 ac-ft/yr
reservoir evaporation	593,700 ac-ft/yr
diversions	2,131,600 ac-ft/yr
unappropriated flows	3,433,100 ac-ft/yr

These quantities are related by the following water balance expression.

storage change = naturalized streamflows + return flows - evaporation
- diversions - unappropriated streamflows

The 1900-1984 mean of the naturalized monthly streamflows, provided as input to the simulation model, is 5,667,400 acre-feet/year at the Richmond gage, which represents the basin outlet. The mean unappropriated flows remaining after streamflow depletions to meet the water rights requirements are 3,433,100 ac-ft/yr. The unappropriated streamflows represent flows to the Gulf of Mexico or water that is available for instream flows or for further appropriation.

The diversion rights in the basin total 2,284,200 ac-ft/yr. In the base run, which does not include specification of salinity limits on diversions, the actual diversions and shortages are 2,131,600 and 152,700 ac-ft/yr, respectively, resulting in a volume reliability of 93.3%. The water rights include storage capacities totalling 4,400,000 acre-feet in 590 reservoirs. Many of the more than a thousand diversion rights are run-of-the-river without storage.

The study focused on a system of 12 reservoirs operated by the U.S. Army Corps of Engineers (USACE) and Brazos River Authority (BRA). If salinity constraints are not considered, based on the assumptions and data incorporated in the model, the diversion rights totalling 721,000 ac-ft/yr associated with the 12 reservoirs have an estimated aggregate volume reliability of 98.2%. If the diversion rights are all hypothetically assigned to the Richmond gage control point, the resulting computed reliability is 100%. However, the diversion rights are distributed between local diversions at the individual reservoirs and system diversions from the lower reach of the Brazos River. The reliabilities for the system diversion rights assigned to the Richmond gage are 100%. Several of the local diversion rights experience shortages during some months of the 1900-1984 simulation period, resulting in reliabilities of less than 100%.

Waco Reservoir is essentially totally committed to supplying water for the City of Waco and adjoining communities. It was treated in the simulation study strictly as a local use reservoir. The diversion rights associated with Waco Reservoir have reliabilities of 100%. With Georgetown Reservoir limited strictly to local use, diversion rights are also met with 100% reliability.

The diversion rights for Proctor and Belton Reservoirs, on the Leon River, were also treated, in most of the model runs, as local use only with no rights allocated to the system diversion from the lower Brazos River. The BRA diversion rights at Proctor and Belton Reservoirs have volume reliabilities (run 17) of 96.3% and 95.7%, respectively. Reliabilities for these two reservoirs are closely interrelated. The BRA water rights for Belton and Proctor Reservoirs have the same priority date, but Proctor has first access to streamflow since it is located upstream. Significant tradeoffs in the reliabilities of diversion rights at the two reservoirs occur, in the model, if the relative priorities are switched. The Belton reliability noted above can be improved by passing streamflows through Proctor Reservoir to maintain storage in Belton Reservoir. The permitted diversions associated with either Proctor or Belton Reservoirs can be met, in the model, with 100% reliability if they are hypothetically assigned priorities senior to all other rights in the basin. However, the many other more senior rights in the basin result in significant reductions in the reliability estimates for the Proctor and Belton diversion rights.

The active conservation pool in Whitney Reservoir is used for both hydroelectric power and water supply. Rules for allocating storage and streamflow between water supply and hydroelectric power are not clearly defined. In the model, the active conservation pool is empty much of the time due largely to hydroelectric power releases. Thus, both the water supply diversion rights and hydropower have extremely low reliability estimates. Hydroelectric energy is generated without a priority water right. In the model, hydroelectric power generation is limited to releases from Whitney Reservoir and unappropriated flows, without passing flows appropriated for downstream diversions through the turbines. This simplified modeling scenario results in conservatively low estimates for the reliabilities of both hydroelectric energy generation and water supply diversions at Whitney Reservoir.

The other BRA/USACE reservoirs comprise a multiple-reservoir system which is operated to meet diversions from the lower Brazos River as well as local demands near the reservoirs. As noted above, if salinity constraints are not considered, and all of the diversion rights are assigned to the Richmond gage control point, the resulting reliability is 100%. However, with the diversion rights divided between local diversions at the reservoirs and system diversions at the Richmond gage, the aggregate reliability is less than 100%. The location of shortages vary slightly with alternative operating policies. Granbury Reservoir has significant shortages in the model which could be alleviated by use of the sizable inactive pool. Granbury and Whitney are the only reservoirs with storage allocated to large inactive pools in the model.

Again ignoring salinity, the BRA system has the capability to supply additional multiple-reservoir system diversions of relatively large magnitude with a reasonably high level of reliability and fairly small impact on existing rights. For example, an additional new 200,000 ac-ft/yr diversion right at the Richmond gage has an estimated reliability of 99.3%, and results in significant but yet relatively minimal reductions in reliabilities of existing rights. The amount of water supplied from the lower Brazos River from BRA multiple-reservoir system operations combined with excess flows can be increased significantly by accepting somewhat higher risks of shortages or temporary demand reductions during drought periods.

Total diversion rights of 623,907 ac-ft/yr are associated with Possum Kingdom, Granbury, Aquilla, Belton, Stillhouse Hollow, Georgetown, Granger, Somerville, and Limestone Reservoirs. A yield versus reliability analysis was performed with yield defined in terms of a hypothetical municipal diversion right at the Richmond gage supplied by releases from these nine reservoirs. The estimated nine-reservoir firm yield is 700,000 ac-ft/yr and 530,000 ac-ft/yr, respectively, with and without use of excess flows. Thus, with use of excess flows, the 700,000 ac-ft/yr firm (100% reliability) yield significantly exceeds the 623,907 ac-ft/yr water rights. Increasing the yield to 800,000 ac-ft/yr reduces the period and volume reliabilities to 99.1% and 99.4%, respectively, and decreases the volume reliability of all other diversion rights in the basin from 90.4% to 90.2%. Limiting municipal diversions to a maximum allowable TDS concentration of 500 mg/l reduces the reliability of the 700,000 ac-ft/yr yield to 84.1% and 90.4%, respectively, without and with the proposed salt control impoundments.

If salinity is not a concern, a large increase in the permitted diversions can be supplied, with a relatively high reliability and relatively minimal impact on existing rights, by excess flows combined with multiple-reservoir releases from the Brazos River Authority system.

At any location in the river basin, any additional water right will impact the reliabilities of other water rights. The impacts may or may not be significant. The WRAP model provides capabilities for quantitative estimates of the impacts. Judgement is required to evaluate the significance of the impacts and the tradeoffs involved.

Evaluation of Water Management Strategies and Modeling Assumptions

The study included identification and examination of several key aspects of river basin management and associated water availability modeling. The results of the simulation study support the following observations.

Salinity Constraints

Management and use of the waters of the main-stem Brazos River are seriously constrained by salinity. The primary source of the salinity is geologic formations and associated groundwater emissions in an area of the upper basin consisting of the Salt Fork of the Brazos River watershed and portions of the adjacent Double Mountain Fork Brazos River and North Croton Creek watersheds. The quality of the river improves greatly in the lower Basin with dilution from good quality tributaries.

The total dissolved solids (TDS) concentration versus duration relationships shown in Table 9.1 are based on 1964-1986 historical monthly data developed by the USGS water quality sampling program. TDS concentrations are shown for stream gages on the Brazos River below Possum Kingdom Reservoir, the most upstream main-stem reservoir, and near the city of Richmond located in the lower basin. Concentrations further upstream near the primary salt sources are much higher than at the Possum Kingdom gage. At the Possum Kingdom and Richmond gages, the mean monthly TDS concentrations were less than 2,290 mg/l and 635 mg/l, respectively, for 90% of the months during the 1964-1986 sampling period. The TDS concentrations were less than 1,620 mg/l and 382 mg/l during 50% of the time. The 1964-86 mean TDS concentrations are 1,510 and 339 mg/l at the Possum Kingdom and Richmond gages. A mean TDS concentration of 256 mg/l at the Cameron gage on the Little River is representative of concentrations on the tributaries which confluence with the Brazos River below Whitney Dam. If water quantities are more than sufficient such that quality rather than quantity controls water supply reliabilities, the TDS concentration-duration relationships of Table 9.1 can be viewed as an approximate representation of the relationship between water supply reliability versus maximum allowable TDS concentration.

Table 9.1
1964-86 MEASURED TDS
CONCENTRATION-DURATION RELATIONSHIPS

Percent of Time (%)	Possum Kingdom (mg/l)	Richmond Gage (mg/l)
100	2,810	978
99	2,710	902
95	2,420	701
90	2,290	635
80	2,090	566
50	1,620	382
0	475	153
mean	1,510	339

The 1900-1984 mean unregulated total dissolved solids (TDS) concentrations of the streamflows incorporated in the model for the main-stem Brazos River vary from 1,430 mg/l at the South Bend gage to 308 mg/l at the Richmond gage. The regulated salt concentrations at different locations, computed by the model, vary between simulation runs depending on the combined effects of reservoir evaporation, storage, diversions, and mixing of flows from the tributaries with the main-stem Brazos River. The regulated salt concentrations are significantly increased by evaporation. The diversion of high salinity water from the upper Brazos River tends to lower salt loads in the lower basin. Concentrations are influenced somewhat by multiple-reservoir system release decisions.

The WRAPSALT model allows specification of maximum allowable salt concentrations above which diversions are not made for specified types of water use. An alphanumeric water use identifier is included in the input data for each diversion right. Maximum allowable concentrations for each salt constituent of interest are inputted for each water use identifier. The model applies the appropriate inputted concentration limits to all diversion rights assigned the specified water use identifiers. In a given month, if the concentration of the streamflow or reservoir storage source for a particular salt constituent for a particular diversion right exceeds the allowable, a shortage is declared.

Salinity is widely recognized as being an important consideration in river basin management. However, tolerable or acceptable concentration limits for various types of water use are difficult to define. The tolerance to infrequent short periods of high salinity may be significantly different than to more constant long-term high salinity levels. Acceptable salt concentration limits for irrigation vary greatly depending on various factors such as the type of crop and relative amounts of rainfall versus supplemental irrigation. Salinity impacts and tolerance limits also vary greatly with different types of industrial water use. The U.S. Environmental Protection Agency secondary drinking water standards suggest a TDS limit of 500 mg/l. The state of Texas uses a 1,000 mg/l drinking water criterion. Incorporation of salinity limits in water supply reliability studies is further complicated because the water rights system allows significant flexibility for shifting between types of use each year.

In the present study, no attempt was made to adopt particular limits for salt concentrations. Rather alternative model runs were made to demonstrate the sensitivity of simulation results to a range of assumed maximum allowable concentrations. For example, the TDS concentration versus reliability relationships (from runs 1 & 9-12) shown in Table 9.2 are based on the hypothetical assumption that the indicated TDS concentration limits are applied to all the diversion rights in the basin. Reliabilities are shown for aggregated groups of diversion rights. Specified maximum allowable TDS concentration limits incorporated in the alternative simulation runs range from constraining all diversions to a very stringent TDS limit of 500 mg/l to the other extreme of specifying no limits at all. The reliability estimates for the total of all the diversion rights in the basin range from 66.69% for the 500 mg/l TDS limit to 93.32% if salinity is not considered. For the aggregated total of all the Brazos River Authority (BRA) diversion rights, the reliability ranges from 64.90% to 98.22%. For just the BRA diversions assigned to the Richmond gage control point in the model, the aggregated reliability is 86.58%, 98.79%, and 100.00%, respectively, for TDS constraints of 500 mg/l, 1,000 mg/l, and 2,000 mg/l. Reliabilities shown, for the total of all diversion rights other than the BRA rights, range from 67.52% to 91.06%.

Table 9.2
ALLOWABLE TDS CONCENTRATION VERSUS RELIABILITY
FOR SELECTED GROUPS OF DIVERSION RIGHTS

TDS Limit (mg/l)	Volume Reliability			
	Basin Total (%)	Non-BRA (%)	BRA Total (%)	BRA at Richmond (%)
500	66.69	67.52	64.90	86.58
1,000	74.82	77.46	69.10	98.79
2,000	87.25	85.23	91.64	100.00
3,000	93.22	90.96	98.12	100.00
none	93.32	91.06	98.22	100.00

Diversion shortages are highly dependent on location and maximum allowable levels of salinity. Specifying a maximum allowable TDS concentration of 500 mg/l in the model results in: (1) essentially no limit on diversions at locations on the good-quality tributary streams; (2) elimination of essentially all diversions at main-stem Brazos River control points at and above Whitney Reservoir; (3) and significant shortages at the lower main-stem Brazos River control points. Specifying a TDS constraint of 3,000 mg/l results in only very slight impacts on reliabilities. Table 9.2 and the information presented in Chapter 8 demonstrate the variation of reliabilities with salt constraints for various scenarios between the two extremes of constraining all diversions to a TDS concentration limit of 500 mg/l and not considering salinity at all.

Salt Control Impoundments

Much of the salt load in the Brazos River originates from relatively small subwatersheds located in the upper basin. The Corps of Engineers previously proposed a system of three impoundments to control runoff from primary salt source areas. An alternative set of streamflows and salt loads were developed for the simulation study which represent impoundment or removal of all flows and loads at the sites of the salt control dams. The unregulated flows and loads in the basic WRAPSALT input file represent unregulated or natural conditions. An alternative *unregulated* flows and loads data set reflects regulation by the proposed salt control impoundments. The mean unregulated TDS load at the Possum Kingdom control point, with the upper basin salt control impoundments, is 66.4% of the mean unregulated TDS load without the salt control impoundments. The mean TDS load at the Richmond gage with the salt impoundments is 82.5% of the mean unregulated load without the impoundments.

The effects of salt control impoundments vary with location and with the specified salinity limits placed on diversions. The salt control impoundments result in significant reductions in concentrations at all locations on the main-stem Brazos River. The improvement in water supply reliabilities achieved by the salt impoundments is not as pronounced as the reduction in concentrations. For example, the basin total reliabilities without the salt impoundments shown in Table 9.2 are compared with the corresponding values with the salt control impoundments as follows.

	without	with
500 mg/l	66.69%	69.57%
1,000 mg/l	74.82%	77.11%
2,000 mg/l	87.25%	92.60%

If all diversions are constrained to an assumed hypothetical TDS concentration limit of 1,000 mg/l, the salt control impoundments increase the basin total diversion volume reliability from 74.82% to 77.11%.

The estimated reductions in salt concentrations and increases in water supply reliabilities to be achieved by the salt control impoundments, under various modeling scenarios, provide meaningful and useful information . However, this information provides only a very limited basis for evaluating the impacts of the proposed impoundments or other plans for controlling the natural salt pollution. The present study does not address the actual physical and economic impacts of salinity in various types of water use.

Multiple-Reservoir System Operations

A large portion of the BRA diversion rights involve withdrawals from the lower Brazos River which are supplied by excess streamflows and releases from multiple reservoirs. The Brazos River Authority and Corps of Engineers operate their reservoirs as a system. The various aspects of multiple-reservoir system operation addressed in the report include: use of excess flows in combination with reservoir releases; balancing multiple-reservoir releases; effects of tributary versus main-stem reservoir releases on salinity in the lower Brazos River; and balancing local versus system diversion reliabilities.

The simulation study demonstrates that multiple-reservoir system operations, particularly use of excess flows in combination with reservoir releases, are very beneficial in maintaining water supply reliabilities. For example, as previously noted, 9-reservoir system firm yields are 530,000 ac-ft/yr and 700,000 ac-ft/yr, respectively, without and with use of excess flows. These firm yields represent hypothetical diversions at the Richmond gage control point in the model.

Whitney Reservoir Multiple-Purpose Operations

Whitney Reservoir is the largest reservoir in the Brazos River Basin. Flood control, hydroelectric power, and recreation influence operation of Whitney much more than water supply. Storage reallocations and/or otherwise improved coordination of multiple-purpose operations represent a potential strategy for increasing the water supply capabilities of the basin. Potential operational modifications of Whitney Reservoir to enhance water supply include: (1) refinements in coordination of the joint hydroelectric power and water supply use of the active conservation pool; (2) use of the large inactive pool as a contingency water supply source to be used during drought conditions whenever storage in the other reservoirs fall below pre-specified emergency levels; and (3) permanent or seasonal reallocation of storage capacity between the flood control and conservation pools. Salinity is an important consideration in increasing the water supply use of Whitney Reservoir.

Storage Priorities

Priorities for maintaining reservoir storage are not clearly defined in the Texas water rights system. In the simulation model, the major reservoirs are filled to 80% of capacity with priorities associated with the water rights and then to 100% capacity with priorities junior to all diversion rights. Reservoir storage priorities have a very significant effect on simulation results. The effects are primarily reflected in tradeoffs between individual water rights rather than basin totals.

Return Flows

Simulation results are also sensitive to return flows. In the model, return flows available for further diversion downstream are a conservatively low 22.2% of the total diversions in the basin. If zero return flows are assumed, the basin total reliability is decreased from 93.2% to 90.1%.

REFERENCES

Davenport, H., "Development of the Texas Law of Waters," feature in Vernon's Annotated Revised Civil Statutes of the State of Texas, Volume 21, Vernon Law Book Company, 1954.

Dougherty, J.P., "Streamflow and Reservoir Content Records in Texas, Compilation Report, January 1889 through December 1975," Report 244, Texas Department of Water Resources, April 1980.

Dunn, D.D., "Incorporation of System Operation Strategies in Water Rights Modeling and Analysis," Master of Science Thesis, Texas A&M University, December 1993.

Ganze, C.K., and Wurbs, R.A., "Compilation and Analysis of Monthly Salt Loads and Concentrations in the Brazos River Basin," Prepared for U.S. Army Corps of Engineers Fort Worth District under Contract DACW63-88-M-0793, January 1989.

Getches, D.H., Water Law, West Publishing Company, St. Paul, Minnesota, 1990.

Hydrologic Engineering Center, "HEC-3 Reservoir System Analysis for Conservation, Users Manual," U.S. Army Corps of Engineers, Davis, California, March 1981.

Hydrologic Engineering Center, "HEC-5 Simulation of Flood Control and Conservation Systems, Users Manual," U.S. Army Corps of Engineers, Davis, California, April 1982.

James, W.P., and P. Masciangliolі, "Control of Natural Salt Pollution in the Upper Brazos River Basin," Proceedings of the American Water Resources Association Texas Section Fall Meeting, December 1992.

Kaiser, R.A., "Handbook of Texas Water Law," Texas Water Resources Institute, 1987.

Kane, J.W., "Monthly Reservoir Evaporation Rates for Texas, 1940 through 1965," Texas Water Development Board,' Report 64, October 1967.

Karama, A.S., "Analysis of Reservoir System Reliability Constrained by Natural Salt Pollution," Ph.D. Dissertation, Texas A&M University, August 1993.

McCrory, J.A., "Natural Salt Pollution Control, Brazos River Basin, Texas," Salinity in Watercourses and Reservoirs (edited by R.H. French), Buttersworth Publishers, pp. 135-144, 1984.

McNeely, J.G., and R.D. Lacewell, "Surface Water Management in Texas," Texas Agricultural Experiment Station, Texas A&M University System, May 1977.

Murthy, K., Liu, and Crow, "Surface Water Allocation Simulation Model," Water for Human Needs: Proceedings of the Second World Congress on Water Resources, New Delhi, India, International Water Resources Association, 1975.

Rice, L. and M.D. White, Engineering Aspects of Water Law, John Wiley & Sons, 1987.

Saleh, I., "Synthesis of Streamflow and Salt Loads," Master of Science Thesis, Texas A&M University, August 1993.

Sanchez-Torres, G., "Reservoir System Reliability Considering Water Rights and Salinity," Ph.D. Degree Dissertation, Texas A&M University, May 1994.

Sayger, S.L., "Analysis of Surface and Subsurface Interactions of Streamflows and Salt Loads," Master of Science Thesis, Texas A&M University, August 1992.

Templer, O.T., "The Evolution of Texas Water Law and the Impact of Adjudication," Water Resources Bulletin, American Water Resources Association, Vol. 17, No. 5. October 1981.

Texas Department of Water Resources, "Water for Texas, A Comprehensive Plan for the Future," GP-4-1, November 1984.

Texas Water Development Board, "Engineering Data on Dams and Reservoirs in Texas," Report 126, Part II, November 1973.

Texas Water Development Board, "Water of Texas, Today and Tomorrow," GP-5-1, December 1990.

U.S. Army Corps of Engineers, Fort Worth District, "Natural Salt Pollution Control Study, Brazos River Basin, Texas," December 1973.

U.S. Army Corps of Engineers, Fort Worth District, "Final Environmental Impact Statement, Natural Salt Pollution Control Study, Brazos River Basin, Texas," January 1976.

U.S. Army Corps of Engineers, Fort Worth District, "Brazos Natural Salt Pollution Control, Brazos River Basin, Texas, Design Memorandum No. 1, General, Phase I - Plan Formulation," April 1983.

Wurbs, R.A., Bergman, C.E. Carriere, P.E., and Walls, W.B., "Hydrologic and Institutional Water Availability in the Brazos River Basin," TR-144, Texas Water Resources Institute, August 1988.

Wurbs, R.A., and Carriere, P.E., "Evaluation of Storage Reallocation and Related Strategies for Optimizing Reservoir System Operations," TR-145, Texas Water Resources Institute, August 1988.

Wurbs, R.A., D.D. Dunn, and W.B. Walls, "Water Rights Analysis Package (TAMUWRAP), Model Description and Users Manual," TR-146, Texas Water Resources Institute, March 1993.

Wurbs, R.A., A.S. Karama, I. Saleh, and C.K. Ganze, "Natural Salt Pollution and Water Supply Reliability in the Brazos River Basin," TR-160, Texas Water Resources Institute, August 1993.

Wurbs, R.A., "Reservoir Operation in Texas," TR-135, Texas Water Resources Institute, June 1985.

Wurbs, R.A., "Reservoir-System Simulation and Optimization Models," Journal of Water Resources Planning and Management, ASCE, Vol. 119, No. 4, July/August 1993.

Yerramreddy, A., "Comparative Evaluation of Network Flow Programming and Conventional Reservoir System Simulation Models," Master of Science Thesis, Texas A&M University, August 1993.