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Reservoir/River System Reliability Considering Water Rights and Water Quality

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

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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:

1. develop a generalized simulation model for analyzing river/reservoir system reliability which integrates consideration of water rights and salinity,
2. 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,
3. evaluate the impacts of natural salt pollution on water supply capabilities, and
4. perform a comprehensive reliability study for the major reservoir system in the Brazos River Basin operated by

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.

Texas Water Resources Institute

1500 Research Parkway A110
2260 TAMU
College Station, TX 77843-2260

Phone:
979.845.1851
Fax: 979.845.0662
Email:
twri@tamu.edu

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