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Perspective Piece

Institutional Aspects of Assessing Surface Water Availability

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Water resources of river and reservoir systems are shared by many people for diverse, sometimes complimentary but often competing purposes. Effective water management requires a thorough understanding of water availability assessed from a reliability or frequency perspective. The great variability inherent in river system hydrology and the complexities of managing constructed facilities are important considerations in assessing capabilities for meeting water needs. The following two institutional dimensions highlighted in this article are also crucial in water availability modeling.

Infrastructure ownership, regulatory authorities, water rights, contracts, treaties, interstate compacts, and other institutional aspects of water development, management, allocation, and use must be modeled within computer-based quantitative assessments of water availability.

Effective implementation of a water availability modeling system requires collaboration of a water management community that includes government agencies, consulting firms, university researchers and educators, and diverse other entities.

The Texas experience in water management and associated water availability assessments illustrates these two institutional perspectives. Texas provides an informative study of river and reservoir system water management relevant nationwide and worldwide (Wurbs 2024a).

A 1984-1988 research project at Texas A&M University (TAMU), titled *Optimizing Reservoir Operations in Texas*, was sponsored by the cooperative federal/state research program of the Texas Water Resources Institute (TWRI) and U.S. Geological Survey authorized by the Water Resources Research Act of 1964 (Wurbs 2021; 2024b). The Brazos River Authority (BRA) served as nonfederal sponsor. This was the beginning of continuing endeavors to develop and apply the Water Rights Analysis Package (WRAP) discussed in this article. Extensive use of the modeling system over many years has greatly contributed to improving water management throughout Texas (Wurbs 2024a). The modeling system continues to be improved and expanded.

The TWRI, Texas Commission on Environmental Quality (TCEQ), Texas Water Development Board (TWDB), U.S. Army Corps of Engineers (USACE), National Institute for Global Environmental Change, and other agencies have sponsored research at TAMU since 1988 to either expand capabilities of WRAP or investigate specific water management issues employing the modeling system. TCEQ sponsored research at TAMU to expand and improve WRAP during 1997-2002 and continuously from 2005 through the present. With 2,800 employees, TCEQ is the largest state environmental regulatory agency in the United States.

WRAP and the Water Availability Models

WRAP is a set of generalized simulation models and auxiliary software for supply reliability, streamflow and storage frequency, and other analyses that can be applied anywhere in the world. Water resources development, management, regulation, and use in a river basin or region under a priority-based water allocation system are simulated and analyzed. Basin-wide impacts of water resources development projects and management practices are accessed. The modeling system facilitates assessments of hydrologic and institutional water availability and reliability in satisfying requirements for municipal, industrial, and agricultural water supply, hydroelectric energy generation, environmental instream flows, and reservoir storage. A routinely applied simulation component of WRAP is based on a monthly computational time step. A daily time step version of the simulation model currently being implemented provides additional capabilities for simulating environmental flow requirements and reservoir flood control operations. WRAP is documented by six manuals published as TWRI technical reports (Wurbs 2009; 2024b; 2024c; 2024d; 2024e; Wurbs and Hoffpauir 2024). Wurbs (2005b) presents an extensive literature review and compares WRAP with other models. A lengthy bibliography of TWRI technical reports, TCEQ reports, graduate student theses and dissertations, journal papers, and book chapters is provided as an appendix in the WRAP reference manual (Wurbs 2024b).

WRAP software, publications, and training courses are accessible at the TAMU WRAP website (https://wrap.engr.tamu.edu/). WRAP training courses presented at TCEQ, TWDB, and TWRI facilities and elsewhere in Texas and abroad have now essentially been replaced with online courses at the website. An introduction to WRAP employing the fundamentals manual (Wurbs 2024d), with student projects, is included in a TAMU graduate course in water resources systems engineering.

The WRAP website interlinks with the TCEQ water availability models (WAM) website. TCEQ maintains input datasets, called WAMs, for the WRAP simulation model at the WAM website along with an array of information regarding water right administrative procedures, environment flow standards (EFS), and water availability modeling. TWDB also maintains an extensive array of databases and information online.

Fifteen major river basins and eight coastal basins of Texas are modeled with twenty WAMs. These WRAP input datasets available at the TCEQ WAM website simulate naturalized stream flow at 14,800 sites and other aspects of river system hydrology combined with operation of 3,400 reservoirs and other constructed facilities in accordance with 6,235 water rights, two international treaties, five interstate river compacts, federal/state water supply contracts, water supply and hydroelectric energy agreements, and environmental flow standards.

TCEQ as lead agency, TWDB, and Texas Parks and Recreation Department (TPRD) with the assistance of university researchers and about ten consulting engineering firms created the water availability modeling system during 1997-2002 pursuant to Senate Bill 1 (SB1) enacted by the Texas Legislature in 1997 (Wurbs 2005a; TCEQ 2023). A committee representing the three agencies adopted the generalized WRAP modeling system developed at TAMU over the preceding several years along with compiling an extensive list of required additions and improvements to WRAP to be performed under contract with TAMU.

WRAP simulation input datasets (WAMs) were developed by consulting firms for each major river basin or combination of adjacent basins. The consultants applied WRAP with the WAMs to simulate specified alternative water management scenarios. Geographic information system capabilities were developed at the University of Texas to support data compilation.

TCEQ and its partner agencies and consultants have continued to update and improve the WAMs (TCEQ 2023). TCEQ has continued to sponsor WRAP research and development at TAMU. WRAP User Group conferences are conducted periodically by TCEQ or in collaboration with TCEQ hosted by river authorities or consulting firms. The WRAP Subcommittee of the Surface Water Committee of the Texas Water Conservation Association provides expert advice for improving WRAP capabilities for addressing various complexities and issues.

Development and continual improvement of the WRAP/WAM modeling system have been driven primarily by water allocation and statewide and regional planning endeavors administered by TCEQ and TWDB. River authorities, other water agencies, and their consultants also apply the modeling system in operational and project planning studies. Agency and university research studies have investigated a diverse array of water management issues employing the modeling system.

The WRAP/WAM modeling system combines simulation of river system hydrology, constructed facilities, and institutional practices. The following institutional perspectives are illustrated by the following synopsis of water management in Texas. (1) Modeling of complex institutional capabilities and practices is a necessary component of the simulation model. (2) The modeling system is implemented within a collaborative framework of decision-support needs, funding sources, and agency jurisdictions and responsibilities.

Water Management in Texas

Water management in Texas is driven by dramatic spatial and temporal hydrologic variability, rapid population growth, declining groundwater supplies, and intensifying demands on river and reservoir systems. Dams, reservoirs, conveyance systems, and other constructed facilities along with effective planning, water allocation, and resource management capabilities are essential for providing reliable water supplies, reducing flood damages, protecting ecosystems, and providing other water-related services. Numerous water development projects, most constructed during the 1940s-1980s era of large-scale water project construction nationwide, are operated throughout Texas to regulate extremely variable river flows for beneficial purposes. Other projects are in various stages of planning and development. Effective water management requires integration of improvements in both operation of constructed facilities and institutional capabilities for planning, allocation, and management of both water and other related resources.

The major rivers and largest cities in Texas are shown on the map of Figure 1. Mean annual precipitation ranges from less than 10 inches at El Paso in West Texas to over 55 inches along the border with Louisiana. The population of the state increased from three million people in 1900 to 9.6 million in 1960 to 20.9 million in 2000 and 29.7 million in 2020. TWDB projects a future statewide population of 33.9 million in 2030 and 40.2 million in 2050.

Conservation storage in about 3,400 reservoirs with capacities of 200 acre-feet or greater is authorized by water rights. These storage authorizations do not include flood control and surcharge storage capacity. About 97% of the licensed storage capacity is contained in 195 major reservoirs located wholly or partially in Texas with storage capacities of 5,000 acre-feet or greater. These 195 major reservoirs contain storage capacities, excluding surcharge storage, of 58,872,700 acre-feet with 40,129,600 acre-feet in 192 reservoirs allocated to conservation (water supply, hydropower, recreation) storage and 18,743,100 acre-feet in 36 reservoirs allocated to flood control (Wurbs 2024a).

River authorities, water districts, and cities are directly responsible for supplying water to the citizens of Texas. These local and regional agencies own and operate storage, conveyance, and treatment facilities and contract for water supply storage in federal reservoirs. Water management is a collaborative effort of many local, regional, state, and federal agencies and private sector entities.

The 1940s-1980s nationwide era of federally dominated basin-wide planning and construction of large-scale water projects has transitioned to a greater focus on operation, maintenance, and rehabilitation of a massive inventory of aging constructed facilities concurrently with dramatic growth in regulations to protect the environment. State water right systems and other water allocation mechanisms continue to grow in importance with intensifying demands on limited resources. A shift from federal and local community dominance to increased state-level responsibilities in water resources planning and allocation, funding, and environmental protection has occurred. Advances in computer-based decision support technologies are improving capabilities for managing hydrologic variability and future uncertainty. Institutional changes are driven by politics, economics,

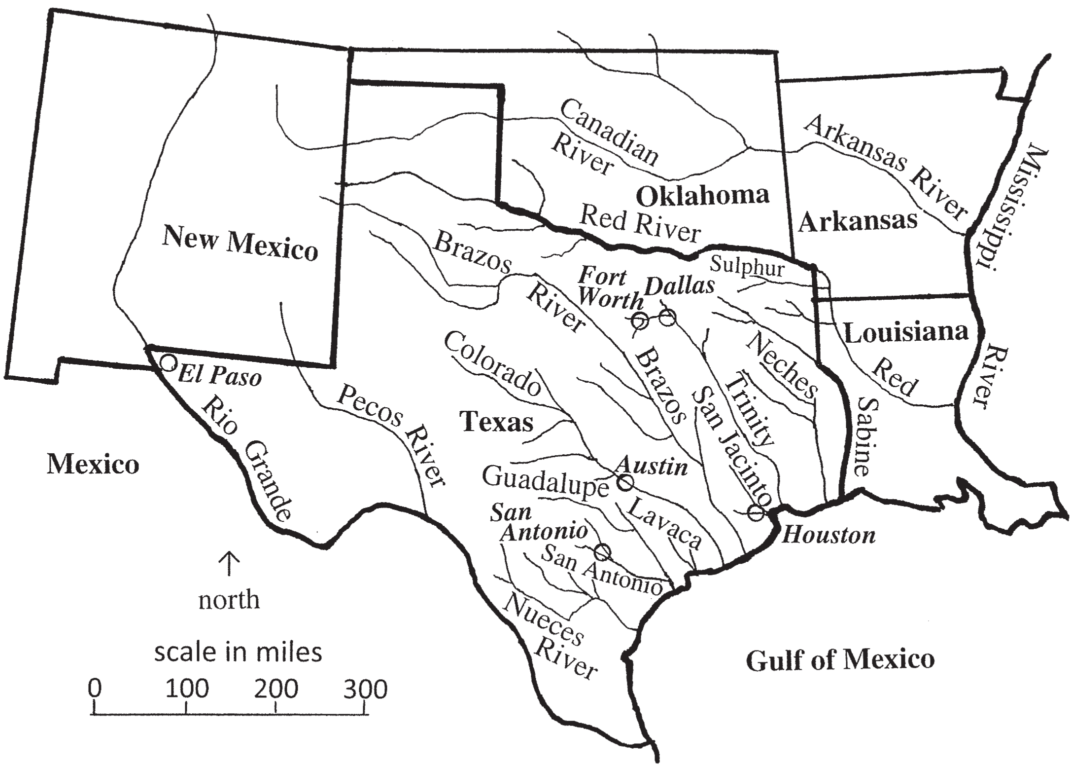

Figure 1. Major rivers and largest cities of Texas.

technology, resource availability, and often by floods or droughts (Wurbs 2020).

The waters of the Rio Grande above Fort Quitman, 90 miles south of El Paso, were allocated between the U.S. and Mexico in 1906. A 1944 treaty allocates Rio Grande waters from Fort Quitman to the Gulf of Mexico between the two nations. About 14.8% and 11.9% of the storage capacity in the 195 major Texas reservoirs are contained in International Amistad and Falcon Reservoirs operated by the International Boundary and Water Commission. The TCEQ Rio Grande Water Master Office administers distribution among Texas water right holders of the U.S. allocation of the water stored in the two reservoirs and flowing in the Rio Grande. Five interstate river compacts administered by compact commissioners with support from TCEQ allocate water between Texas and neighboring states (Wurbs 2024a).

About 27.7% and 78.3% of the conservation and flood control storage capacity of the 195 major reservoirs are contained in 30 reservoirs owned and operated by USACE. Impoundment of water at the oldest and newest USACE reservoirs in Texas began in 1943 and 1991. Costs allocated to flood control are borne by the federal government. Under provisions of the Water Supply Act of 1958, costs allocated to water supply are repaid by nonfederal sponsors. River authorities, water districts, and cities that have contracted for the water supply storage capacity of USACE reservoirs are paying for use of storage capacity, not delivery of water. These nonfederal sponsors sell water, not storage capacity, to cities, industries, and other customers under various agreements. The Bureau of Reclamation has constructed five reservoir projects in Texas, which are now owned and operated by two river authorities, a water district, and two cities.

State and Regional Water Planning

A devastating 1950-1957 drought ended by extreme flooding in April-May 1957 motivated creation of the TWDB by a legislative act in 1957. TWDB with about 400 employees is responsible for statewide planning and administering grant and loan programs for local communities. Agency staff completed the first state water plan in 1966 and plan updates in 1969 and 1984. Motivated by drought conditions during 1995-1996, the Legislature in 1997 enacted water management legislation known as SB1 which included adding local stakeholder-guided consensus-based regional planning to the TWDB statewide planning process and also authorized development of a water availability modeling system.

Pursuant to the 1997 SB1, the state was divided into 16 regions with planning groups representing diverse water interests guiding planning for each region. Sixteen regional plans and a consolidated statewide plan are updated in a five-year cycle with a 50-year future planning horizon. Reports documenting the 2002, 2007, 2012, 2017, and 2022 regional plans and consolidated state water plan are available at the TWDB website. Completion of the next regional and state water plans is scheduled for 2027. TWDB staff and consulting firms perform technical studies that include applying the WRAP/WAM modeling system to evaluate water supply capabilities and impacts of proposed strategies and projects under various scenarios.

SB1 planning focuses on water supply and environmental protection needs and capabilities. The Legislature in 2019 authorized TWDB creation of a similar planning process for flood mitigation. The new flood planning process has a five-year cycle and 15 regional planning groups. The first set of 15 regional flood plans was completed in March 2024. The first statewide flood plan was submitted to the Legislature in September 2024.

Water Rights

Water rights in Texas evolved over several centuries into an unmanageable assortment of poorly recorded and often conflicting riparian and prior appropriation strategies. The severe 1950-1957 drought motivated a massive lawsuit that resulted in establishing water rights for the Texas share of the Rio Grande below Fort Quitman. The Water Rights Adjudication Act of 1967 created a process to convert existing water rights into a prior appropriation permit system for the rest of Texas that was completed by 1990. TCEQ administers both the allocation system for the Texas share of water in International Amistad and Falcon Reservoirs and the different allocation system applicable for the remainder of Texas.

Surface water is owned by the state. A water right holder has no ownership of water but only a right to store water in reservoirs and withdraw the water for beneficial use. Water rights can be sold or leased subject to TCEQ approval. Any organization or person may apply to TCEQ for a new right or change in existing water right. TCEQ will approve the application if unappropriated water is available, the proposed beneficial need for water will be supplied at an acceptable level of reliability, existing water rights are not impaired, efficient water conservation will be practiced, and proposed actions are consistent with relevant SB1 statewide and regional water plans. During the 1968-1990 adjudication process, priority dates were established based on historical water use. Since then, priorities are based on the dates that applications are received by TCEQ.

Currently 6,235 water rights are defined by 4,892 certificates issued pursuant to the adjudication process and 1,343 water use permits issued later. Typically, over 100 applications for new permits or modifications to existing rights are under review by TCEQ at any time. Many are not approved. Water conservation plans are required for water rights. More complex rights also include periodically updated system water management plans.

TCEQ approved in 2016 a water use permit application and associated system operation plan prepared by the BRA and consultants that is more complicated than most water rights. Modifications to BRA water rights approved in 2016 significantly increase water supply capabilities. The system water use permit and management plan combine multiple-reservoir operations of a 12-reservoir USACE/BRA reservoir system with use of unregulated flows entering below the dams and return flows, coordination with groundwater sources, interbasin conveyance, water conservation, and environmental flow requirements. Combining firm and interruptible water commitments as facilitated by WRAP/WAM simulations is a major feature of the plan. BRA initiated further studies in 2024 for constructing an off-channel reservoir.

Permit applicants and their consultants apply relevant WAMs in preparation of permit applications and associated water management plans. TCEQ staff apply the modeling system in evaluations of the proposed new or amended water rights.

Environmental Flow Standards

The importance of protecting instream flows for fish, riverine ecosystems, wetlands, and freshwater inflows to bays and estuaries has been recognized in Texas since the 1980s. Efforts to formulate and implement EFS intensified pursuant to legislation enacted in 2001 as Senate Bill 2 (SB2) and in 2007 as Senate Bill 3 (SB3). SB2 created the Texas Instream Flow Program (TIFP) jointly administered by TWDB, TCEQ, and TPWD to improve capabilities for protecting aquatic ecosystems. SB3 created an accelerated process for establishing EFS for priority river systems using best available information and science. EFS for selected river systems are created by appointed science teams and stakeholder committees subject to public review and final approval by TCEQ.

The SB3 process results in EFS that are incorporated by TCEQ in the WAMs. EFS metrics and rules that vary with location, season, and hydrologic condition govern curtailment of diversion and/or storage of stream flows by junior water rights. EFS have subsistence, base, and high pulse flow components. The SB3 process includes periodically reevaluating and updating the EFS.

EFS are incorporated in the WAMs with a priority based on the date TCEQ receives recommendations from the science team. TCEQ may not issue a permit for a new appropriation or amendment to an existing water right if any EFS would be impaired. Holders of existing senior water right permits are not required to curtail appropriations of water to maintain junior EFS.

Conclusions

Water availability assessment capabilities are essential for effective water management. Institutional considerations are relevant to other types of computer modeling as well as to other regions of the nation and world. For example, the 1997 SB1 also created a groundwater modeling program within TWDB that reflects institutional perspectives that are very different but analogous to those associated with surface water discussed in this article.

With increasing demands on limited water resources, water allocation systems have become an essential component of water management. Water allocation and planning are integrally related. Shared modeling tools facilitate integration of planning and water allocation as well as connecting with other aspects of water management.

Modeling systems include computer programs, databases, organizations, people, and decision processes. Compilation and management of voluminous data may be necessary. A modeling system is constructed rather than just a model.

Model development is a dynamic evolutionary process. As long as a modeling system continues to be applied, its development is never completed. Model development is a process of continual expanding and improving to address evolving needs and objectives.

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Dr. Ralph A. Wurbs was employed in the USACE water development program for nine years prior to joining the TAMU faculty in 1980. His teaching, research, and administrative service at TAMU have been recognized by an endowed professorship, graduate student fellowship endowed by former students named in his honor, several teaching awards, and various other awards including the Outstanding Research and Innovation Award of the American Academy of Water Resources Engineers (AAWRE) and inaugural Texas Water Lifetime Achievement Award. He is a Founding and Honorary Diplomate of AAWRE and Fellow of ASCE. He was an associate director of TWRI in 2007-2012 and for many years a TAMU Delegate to UCOWR. He may be contacted at r-wurbs@tamu.edu or by mail at Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, Texas 77843.

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