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Reservoir evaporation in Texas, USA

Ralph A. Wurbs *, Rolando A. Ayala [1]

Department of Civil Engineering, Texas A&M University, College Station, TX 77843-3136, USA

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SUMMARY

The role of reservoir surface evaporation in river/reservoir water budgets and water management is explored using a modeling system that combines historical natural hydrology with current conditions of water resources development and management. The long-term mean evaporation from the 3415 reservoirs in the Texas water rights permit system is estimated to be 7.53 billion m^3/year, which is equivalent to 61% of total agricultural or 126% of total municipal water use in the state during the year 2010. Evaporation varies with the hydrologic conditions governing reservoir surface areas and evaporation rates. Annual statewide total evaporation volumes associated with exceedance probabilities of 75%, 50%, and 25% are 7.07, 7.47, and 7.95 billion m^3/year, respectively. Impacts of evaporation are greatest during extended severe droughts that govern water supply capabilities.

1. Introduction

Reservoir storage is essential for developing dependable water supplies and is a major component of the river system water budget. The storage contents of reservoirs fluctuate greatly over time with variations in water use and hydrologic conditions that range from severe multiple-year droughts to floods. Water surface evaporation typically represents a major component of the reservoir water budget. The impacts of reservoir evaporation on water management vary greatly with location with differences in climate, reservoir characteristics, and water management and use practices. An enhanced understanding of the relative magnitude of evaporation in reservoir/river system volume budgets is relevant to various aspects of water resources development, allocation, management, and use.

The research presented in this paper consists of simulating evaporation from the 3415 reservoirs in the Texas Water Availability Modeling (WAM) System and investigating the significance of reservoir evaporation in river system water budgets and water management. Climate, geography, and water management vary dramatically across Texas with reservoirs being managed under diverse conditions representative of many other regions of the world. The water management community of Texas invested much effort over many years to implement a statewide WAM System, maintained by the Texas Commission on Environmental Quality (TCEQ), to support administration of the water rights permit system, regional and statewide planning, and other water management endeavors. The modeling system made possible the research on reservoir evaporation presented in this paper.

Essentially all of the storage capacity in Texas is contained in man-made rather than natural lakes. Most of the dam and reservoir projects were constructed between 1945 and 1990, with the majority being completed after 1960. Thus, much of the present storage capacity did not exist during the 1950–1957 most hydrologically severe drought on record. The estimates of evaporation volumes presented here along with reservoir storage contents and stream flow and water use quantities are computed within the monthly computational time step TCEQ WAM System based on combining several decades of highly variable historical hydrology dating back to 1940 with present conditions of water resources development, management, and use. Simulation model hydrology includes naturalized stream flows developed based on adjusting observed flows to remove the effects of water development and a dataset maintained by the Texas Water Development Board (TWDB) of monthly evaporation rates extending from January 1940 to near the present derived from compiling and adjusting pan evaporation observations.

2. Other studies reported in the literature

Linsley et al. (1982) and Abtew and Melesse (2013) describe evaporation processes and measurement techniques. The use of evaporation pan measurements along with pan coefficients in the

* Corresponding author. Tel.: +1 979 845 3079; fax: +1 979 862 1542.
E-mail addresses: r-wurbs@tamu.edu (R.A. Wurbs), Rolando.Ayala@freese.com (R.A. Ayala).
[1] Present address: Freese and Nichols, Inc., Houston, TX 77024, USA.

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compilation of the TWDB statewide database of lake surface evaporation rates is consistent with conventional practices commonly adopted in hydrology and water management.

Lowe et al. (2009) assess the uncertainties associated with applying evaporation pan measurements to estimate evaporation volumes from water supply reservoirs. An uncertainty analysis strategy is applied to three reservoirs with the results indicating that 95% probability intervals are as large as ±40% of the best estimate. Spatial extrapolation of pan evaporation data and determining lake/pan coefficients are concluded to be by far the greatest contributors to the overall uncertainty. The greatest reductions in uncertainty can be achieved by installing evaporation pans near a reservoir rather than using measurements from pans located some distance away. Seasonally varying coefficients are more accurate than annual coefficients.

Reed et al. (1997) developed statewide atmospheric, soil–water, and surface water balances for Texas. Their surface water balance of precipitation, hydrologic losses, and runoff is based on 1961–1990 means that include reservoir evaporation from about 200 of the largest reservoirs in Texas estimated by applying the TWDB evaporation rates to the total reservoir water surface area in defined watersheds assuming the reservoirs are full to conservation storage capacity. Since the TCEQ WAM System is designed for detailed assessments of water supply reliabilities and stream flow and storage frequency metrics, reservoir evaporation is computed for each individual reservoir for each month of the simulation based on simulated water surface areas and historical observed evaporation rates from the TWDB database (Wurbs 2005).

Hydrologists and water managers have long recognized that reservoir evaporation represents significantly large quantities of water. Linsley et al. (1982) notes that the mean annual evaporation from Lake Mead on the Colorado River, the largest reservoir in the USA, is about 10% of reservoir inflow in a normal year. Martinez-Alvarez et al. (2008) estimate that the evaporation from numerous agricultural irrigation reservoirs in a river basin in a semiarid region of Spain is a quantity equivalent to about 8.3% of the irrigation use in the basin and equal to 27% of the domestic water use of the two million inhabitants of the region. Martinez-Granados et al. (2011) evaluate the significant economic impacts of evaporation from the numerous small irrigation reservoirs and other much larger reservoirs in this same river basin in Spain.

Measures have been implemented or proposed for reducing evaporation from reservoirs, including monomolecular films, floating devices, suspended shading covers, and wind retarding devices (Sinha et al., 2006; Martinez-Alvarez et al., 2006; Assouline et al., 2011). Pioneering work in demonstrating the potential effectiveness of monomolecular films in suppressing evaporation from reservoir water surfaces was performed during the 1950s in Australia and the USA (Magin and Randall, 1960). Barnes (1993, 2008) provides thorough literature reviews of the technology and issues associated with the use of monolayer films in reducing reservoir evaporation. Craig et al. (2005) conclude that annual evaporative losses in regions of Australia are up to 40% of reservoir storage capacity and that spreading monolayer films over water surfaces could significantly reduce these losses. Prime et al. (2012) investigate recent advances in monolayer technology that could contribute to water management in Australia. Sinha et al. (2006) highlight the importance of reservoir evaporation in India and investigate case studies of technologies that have been applied to retard reservoir evaporation in India and elsewhere.

Ayala (2013) performed simulations with the Texas WAM System to explore the effects of potential reductions in evaporation. Timing was found to be important. Evaporation suppression is particularly important during severe reservoir draw-downs. Evaporation suppression has little impact on supply reliabilities during periods when reservoir contents lower a little and then refill to capacity and spill, either with or without evaporation suppression.

3. River/reservoir systems and water management in Texas

Texas is a large state, with an area of 685,000 km^2, located in the south-central United States that is representative of both the drier western and wetter eastern regions of the country from the perspectives of climate and water management. Climate, hydrology, geography, and water management practices vary greatly across the state from the arid western desert to humid eastern forests, from sparsely populated rural regions in the western and eastern extremes of the state to the metropolitan areas of Dallas and Fort Worth, Austin, San Antonio, and Houston shown in Fig. 1. Mean annual precipitation varies from 20 cm at El Paso on the Rio Grande to 140 cm in the lower Sabine River Basin. Mean annual lake surface evaporation ranges from 125 cm in the Sabine River Basin to 200 cm along reaches of the Rio Grande.

The population of Texas increased from 20.9 million people in 2000 to 25.4 million in 2010 and is projected to increase to 46.3 million by 2060 (TWDB, 2012). Total withdrawals from surface and groundwater sources of 22.2 billion m^3/year in 2010 were divided among water use sectors as follows: agricultural irrigation (56.0%), municipal (26.9%), manufacturing (9.6%), steam-electric consumptive use (4.1%), livestock (1.8%), and mining (1.6%). Depleting aquifers have resulted in surface water use growing from less than 30% of total water use in 1970 to greater than 50% in 2010. Population growth and declining groundwater reserves are resulting in continually intensifying demands on surface water resources.

Eleven of the 15 major river basins of Texas discharge directly into the Gulf of Mexico, and the other four are tributaries of the Mississippi River as shown in Fig. 1. Coastal basins located between the lower reaches of the major river basins are drained by smaller streams flowing into the Gulf of Mexico.

The 3415 reservoirs in the water rights permit system include essentially all impoundments with storage capacities greater than 246,800 m^3 (200 acre-feet) used for water supply, hydropower, and/or recreation and many smaller impoundments. The 196 major reservoirs with conservation storage capacities exceeding 6.17×10^6 m^3 (5000 acre-feet) contain over 90% of the total storage capacity of the 3415 reservoirs. Conservation storage capacities of 115 reservoirs range between 6.17×10^6 m^3 and 6.17×10^7 m^3, and capacities of 81 reservoirs exceed 6.17×10^7 m^3. Toledo Bend Reservoir on the Sabine River is the largest conservation storage reservoir in Texas with a capacity of 5.52×10^9 m^3 and surface area

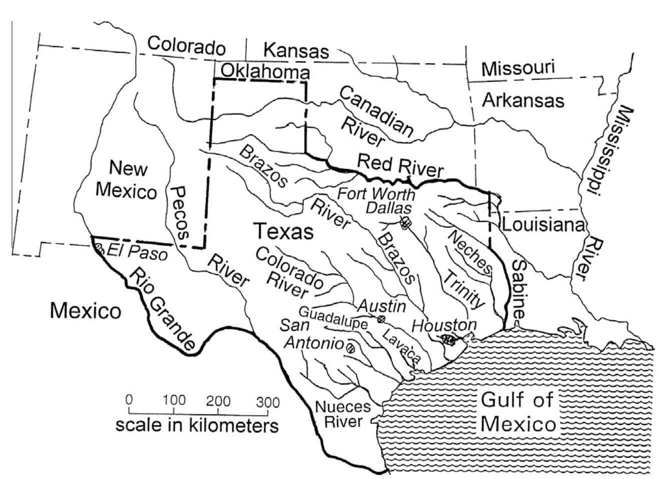

Fig. 1. Map of Texas with major rivers, largest cities, and neighboring states.