WATER AVAILABILITY MODELING TO SUPPORT WATER MANAGEMENT IN THE LOWER RIO GRANDE VALLEY OF TEXAS

REPORT

Written by

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ABSTRACT

The Rio Grande River is considered as an over-appropriated river basin in Texas, where the number of permits to use surface waters exceed the amount of available water. Agricultural and municipal water supply and use in the Lower Rio Grande Valley (LRGV) are essentially dependent upon storage of the International Amistad and Falcon Reservoirs, which are owned and operated by the International Boundary and Water Commission (IBCW) based on provisions of the 1944 treaty between Mexico and the United States. The Texas share of the waters of the Rio Grande is allocated among numerous farmers, irrigation districts, and cities by a unique water rights permit system administered by the Rio Grande watermaster of the Texas Commission on Environmental Quality (TCEQ). The Rio Grande Water Availability Model (WAM) obtained from the TCEQ WAM System has a hydrologic period-of-analysis of 1940-2000. However, hydrology since 2000 includes the severe 2008-2014 drought and is important to the simulation study. The hydrologic period of analysis for the Rio Grande WAM was extended from 2001 to 2015 using Water Rights Analyses Package (WRAP) programs and methodologies. Extending the hydrologic period-of-analysis of the Rio Grande WAM to cover 1940-2015 was an initial major task in the research.

A WRAP/WAM simulation combines natural hydrology represented by sequences of monthly naturalized streamflows and reservoir evaporation-precipitation rates for a specified hydrologic period-of-analysis, 1940-2015 in this study, with specified scenarios of water resources development, allocation, management, and use. Water availability is assessed based on supply reliability metrics and storage and flow frequency metrics computed from simulation results.

This research consisted of the following tasks:

1. The Rio Grande WAM original 1940-2000 hydrologic period of analysis is extended to cover 1940-2015.
2. Long-term simulations with the updated Rio Grande WAM were performed to develop supply reliability and storage frequency metrics for major water right groups, reallocation of municipal water rights in the Amistad-Falcon Reservoir system, and water planning scenarios including drought management.
3. Conditional Reliability Modeling (CRM) methods were applied to assess short-term water planning and management strategies for the LRGV.
4. Drought management scenarios were simulated to predict the likelihood of extended drought conditions based on beginning storage in the Amistad-Falcon Reservoir system. The reliability and exceedance frequencies of maximum end-of-month storage at Amistad and Falcon reservoirs were developed using CRM.

INTRODUCTION

The proposed research applies the Texas Water Availability Modeling (WAM) System to formulate and assess strategies for improving capabilities for water management during a drought in the Lower Rio Grande Valley. The WAM System maintained by the Texas Commission on Environmental Quality (TCEQ) consists of the Water Rights Analysis Package (WRAP) Modeling system developed at Texas A&M University and WRAP input datasets for all of the river basins of Texas. WRAP is generalized for application to river/reservoir systems located anywhere. WRAP combined with variations of one of the basin-specific datasets from the TCEQ WAM System is called a water availability model (WAM).

The Rio Grande WAM is applied in the dissertation research to develop an enhanced understanding of water management in the Lower Rio Grande and modeling thereof, with a particular focus on the following issues:

- Assessing impacts on water availability for all affected water rights, resulting from transfers of water rights from agricultural irrigation to municipal use.
- Assessing impacts on water availability for all affected water rights resulting from modifications of storage allocations and operating rules of Amistad and Falcon Reservoirs.
- Application of short-term conditional reliability modeling to forecast water availability for future periods ranging from several months to several years for given initial storage levels in Amistad and Falcon Reservoirs.

The Rio Grande WAM obtained from the TCEQ WAM System has a hydrologic period-of-analysis of 1940–2000. However, hydrology since 2000 includes the severe 2012–2014 drought and is important to the simulation study. Extending the hydrologic period-of-analysis of the Rio Grande WAM to cover 1940–2015 is an initial major task in the research.
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WAMs from the TCEQ WAM System for many of the other river basins of Texas have been applied extensively over the past decade to support water right permit applications and planning studies. However, similar applications of the Rio Grande WAM have been limited. The Rio Grande is over-appropriated, and the TCEQ approves no applications for additional water right appropriations. Water right permit applications in the Rio Grande have been limited essentially to market transfers, typically municipalities purchasing water rights from agricultural irrigators.

Hydrology and water resources allocation and management in the Lower Rio Grande Valley are very different than throughout the rest of Texas. The Rio Grande WAM is more complex

than other WAMs in many respects. Several major differences in both water management and modeling thereof are noted in the following paragraphs.
The Rio Grande Basin is much larger and more arid than the other river basins of Texas. Developing and updating hydrology datasets for the Rio Grande WAM are significantly more difficult than for the other WAMs.

The water resources of the Rio Grande are shared by Mexico and the United States. The Rio Grande flows above and below Fort Quitman are allocated between the two countries by 1906 and 1944 treaties, respectively. Fort Quitman is located several kilometers downstream of the City of El Paso. All of the WAMs including the Rio Grande WAM are designed for assessing water availability in Texas, but the effects of water use in Mexico and neighboring states are considered. The Rio Grande WAM incorporates the provisions of the 1906 and 1944 international treaties as well as the Pecos River and Rio Grande interstate compacts between Texas and New Mexico.

The water rights system administered by the TCEQ in allocating the Texas share of the waters of the Rio Grande below Fort Quitman is very different from the water rights system applied for the remainder of Texas. Water rights for the Rio Grande below Fort Quitman were adjudicated by court action during the 1950s–1970 in conjunction with a massive lawsuit motivated by the 1950–1957 drought. Water rights for the remainder of Texas have administratively adjudicated pursuant the Water Rights Adjudication Act of 1967. Unlike the conventional prior appropriation system implemented throughout the rest of Texas, water rights in the Lower Rio Grande Valley are categorized as being either municipal or falling within two categories of agricultural rights. A detailed accounting of both diversions from the river system and storage in Amistad and Falcon Reservoirs is maintained for each water right permit.

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Texas Water Availability Modeling (WAM) System

The 1997 Senate Bill 1 authorized the Water Availability Modeling (WAM) system and directed the TCEQ to develop a consistent set of databases and modeling tools for use both in conducting planning studies and in preparing and evaluating water rights permit applications (Sokulsky 1998). The WAM system consists of the WRAP model along with 20 sets of input files covering the 23 river basins of the state, geographic information system (GIS), and other supporting data (Wurbs, 2005). The TCEQ, in contract with several engineering firms, universities, and research institutes, developed complete WAM datasets for each river basin of Texas, including the Rio Grande (TCEQ, 2015). The WAM system facilitates the assessment of hydrologic and institutional water availability and reliability through the use of a WRAP model.

Water Rights Analysis Package (WRAP) Modeling System

WRAP, developed at Texas A&M University, was sponsored by the Texas Water Resources Institute (TWRI), Texas Commission on Environmental Quality (TCEQ), USACE

Fort Worth District, and other agencies in Texas and greatly expanded during 1997–2002. Water rights in WRAP are defined as a set of water use requirements, reservoir storage, and conveyance facilities' operating rules and institutional arrangements for managing water resources (Wurbs, 2005). WRAP is comprised of *SIM*, *HYD* and *TABLE S* programs that simulate river and reservoir water allocations using monthly time-step, converting gauged flows to naturalized flows by removing used water diversions and return flows and net evaporation rates for reservoirs, and organizing simulation results by developing frequency relationships, reliability indices, and summary statistics, respectively.

WRAP input files covering 23 river basins of Texas, a GIS, and another supporting system to the WRAP model were developed by TCEQ under the 1997 Senate Bill1 as the WAM system. It is available to users in monthly or sub-monthly time-steps in order to simulate river basin hydrology that is represented by sequences of naturalized streamflows.
WRAP is a generalized model designed to simulate a river basin under a priority-based water allocation system (Wurbs, 2005). WRAP evaluates the ability of the river/reservoir system to meet demand during hypothetical repetitions of historical hydrology. The spatial connectivity of the system is modeled as a set of control points. The computational algorithms are based on the location of each control point related to others as defined in the input data. Simulation results include regulated flows (physical flows at a location), reservoir storage contents, diversions, water rights shortages, unappropriated flows (flows left in the stream after all diversions are met), reliability indices, and other variables (Wurbs, 2003).

WAM datasets include FLO, EVA, DIS, and DAT files for simulations of water allocations. The monthly naturalized flow volumes and net evaporation less precipitation depth at pertinent control points are stored in FLO and EVA files, respectively. Naturalized flows are distributed from primary (gaged) control points to secondary (ungaged) control points by using watershed parameters that are stored in DIS files. Water use requirements, water right permits, and river/reservoir system operating rules and practices are stored in DAT files (Wurbs, 2009a). Also, the spring flows are also naturalized and included in WAM datasets as FAD files for some river basins, including the Rio Grande.

WRAP is divided into three main modeling programs: (1) WRAP-*SIM*—the river/reservoir water allocation/management program for input sequences of monthly naturalized flows and net evaporation rates; (2) WRAP-*HYD*—the program that assists in developing monthly naturalized streamflow and reservoir net evaporation less precipitation depth data for the WRAP-*SIM* hydrology input files; and (3) WRAP-*TABLES*—the program that is used to develop frequency relationships, reliability indices, and various user-specified tables for organizing, summarizing, and displaying simulation results (Wurbs and Kim 2011). Naturalized flows represent natural conditions without water resources development and use. Permit application and planning processes with WRAP include two water-use scenarios: (1) authorized use (Run 3), which includes full use of authorized water targets while excluding return flows, sediment accumulations in reservoirs, and term permits; and (2) current use (Run 8), which includes best estimates of return flows, sediment accumulation reflecting the year 2000 conditions, and water use targets and settings for each water right based on the maximum annual amount actually used in any year during a recent 10-year period (Wurbs, 2005). The authorized use (RG3) of the Rio Grande WAM datasets was used for this research.

Rio Grande Water Availability Model

The Rio Grande WAM datasets covering the 1940–2000 hydrologic period of record were developed by the R.J. Brandes Company in 2004 in contractual agreement with TCEQ in order to meet the requirements of Senate Bill 1 of the 76th Texas Legislature regarding the development of a new Rio Grande Basin water-availability simulation modeling. It consists of 963 control points with 55 primary (gaged) control points for which monthly naturalized flows were developed and distributed to the rest of the 908 secondary (ungaged) control points. This model is capable of determining water availability in the basin under a range of policy and planning scenarios by the prior appropriation doctrine and the TCEQ Rio Grande operating rules (Brandes, 2004). A 2014 version of the program with fully authorized Rio Grande WAM input datasets was used in this research.

Objectives and Scope of the Research

This dissertation research included simultaneous investigations of both water management strategies and modeling capabilities for evaluating water management strategies. A comprehensive review of the literature has been performed. Published and unpublished studies of the Rio Grande have been explored. River/reservoir system modeling capabilities that have been developed throughout the world and reported in the literature have also been reviewed. The objectives of the research were to accomplish the following:

- Test, evaluate, and improve WRAP/WAM modeling capabilities.
- Develop a better understanding of the effects on water supply capabilities of transfers of diversion and storage rights between agricultural irrigation and municipal use and associated modifications of reservoir storage allocations and operating rules.
- Investigate the potential for short-term (several months to several years) forecasts of future storage levels and water availability based on WRAP conditional reliability modeling (CRM) in order to improve water management capabilities in the Lower Rio Grande Valley.

The simulation study of the Rio Grande Basin consisted of the following major tasks:

- Updating the 1940–2000 hydrologic period-of-analyses to cover 1940–2014.
- Performing a water availability modeling study in WRAP long-term simulation mode to investigate the effects on reliabilities of all water rights when (1) transferring water rights between agricultural and municipal use, and (2) increasing or decreasing the municipal pool or changing other operating rules for Amistad and Falcon Reservoirs.
- Developing supply reliability and storage frequency metrics from future short-term forecasts based on using WRAP conditional reliability modeling (CRM) capabilities.

SUMMARY AND CONCLUSIONS

Research Summary

The Rio Grande Basin WAM consists of complex modeling parameters that incorporate two inter-state compacts and two international agreements on allocations of water between three states and two countries. Amistad and Falcon Reservoirs, owned and operated as a system by IBWC, are the main impoundments that store and allocate water diversions between Mexico and the United States to meet municipal and irrigation demands of the LRGV in accordance with the 1944 treaty provisions. The Conchos River basin in Mexico and the Pecos River Basin in Texas are the main contributors of storage to Amistad Reservoir. Falcon Reservoir is primarily used to supply water demands of the LRGV, and because of that, most of the time it has lower storage volumes than Amistad Reservoir. However, both of these reservoirs are operated as a system; therefore, lower storage volumes in Falcon do not translate to water shortages in the LRGV unless reservoir storage dries up in Amistad simultaneously. The Texas WAM system is routinely used to evaluate permit applications and determine unappropriated and regulated flows. In this study, the Rio Grande WAM was extended using WRAP WAM extension methodologies from 2001 to 2015 and the final 1940–2015 hydrologic period of analyses were used to simulate different water allocation scenarios.

Unlike any other river basin in Texas, water in the Rio Grande is allocated based on special prior appropriation doctrine in which municipal and industrial rights have seniority over Class A and Class B irrigation and mining rights. Water rights in the Rio Grande are grouped into three major groups by the following priority: (a) domestic-industrial-municipal (DMI); (b) Class A irrigation and mining; and (c) Class B irrigation and mining. Total Class A and Class B mining rights are about 1% of the total water use; therefore, they were not considered in this research. Combined Class A and Class B rights in the Rio Grande WAM are about 86% of the total diversions. Class A rights have 1.7 times more allocation than Class B rights. The storage volume in the Amistad-Falcon Reservoir system should not exceed 1.4 total allocations for Class A and Class B irrigation rights. When Class A or Class B rights are acquired by the cities and converted to municipal rights, it leaves the rest of the users with less reliability. Future water allocations are handled by the IBWC accounting system.

Priority among irrigation rights does not exist, and water shortages accrued during the drought periods is shared equally. Irrigation rights can be sold or leased between irrigation and municipal or industrial rights. When sold to municipal use, Class A and Class B irrigation rights can only be converted by 50% and 40% per ac-ft of their market values, respectively. However, the municipal right holder acquires full volume of the irrigation rights. This special water marketing system is created to protect municipal water demands in the LRGV from future water shortages. Several research findings show that the DMI pool in the Amistad-Falcon system acquired more water rights from irrigation districts, which led to conservative protection of these rights. The modeling analyses in this dissertation research showed that the firm yield for municipal rights is about 456,893 ac-ft while the annual combined demand for the Lower and Middle parts of the Rio Grande WAM is 351,922 ac-ft/year. This volume does not account for the 225,000 ac-ft/month protection in the Amistad-Falcon Reservoir system that is left in the DMI pool.

Long-term simulations were performed and volume reliabilities for each water right group in the Middle and Lower Rio Grande were determined in order to guide regional water planning groups and irrigation districts. Conditional reliability modeling (CRM) with equal weight and storage flow frequency (SFF) options were applied to the Amistad-Falcon Reservoir system to determine the probability of exceeding maximum storage contents subject to initial reservoir volumes. CRM with SFF option was applied to simulate drought conditions for the Rio Grande.

Major Research Findings and Conclusions

Original Rio Grande WAM datasets were developed by Brandes (2004) in contractual agreement with TCEQ as part of Senate Bill 1 provisions. The Rio Grande is modeled as essentially two parallel rivers; one represents Mexico, and the other represents the United States' parts of the basin. Amistad and Falcon Reservoirs, the main water storage impoundments, were built with the sole purpose of meeting water demands from each country. Hydrology files of Rio Grande WAM consisted of monthly naturalized flow volumes and reservoir net evaporation minus precipitation depths covering the 1940–2000 hydrologic period of analysis. The monthly naturalized flow volumes were developed for 23 primary control points on the U.S. parts of the watershed and 32 primary control points on the Mexico parts of the watershed. Net evaporation minus precipitation depths were developed for seven control points on the U.S. portion of the Basin and 18 control points on the Mexico portions of the Basin.

Although the hydrologic extension methodologies have not been officially accepted by TCEQ, they have been applied to several river basins in Texas. TCEQ still uses original WAM datasets for permit evaluation applications. The updated 2014 Rio Grande WAM original files along with TWDB's monthly evaporation and precipitation depths covering 1940–2015 were used to extend the hydrology input datasets from 2001–2015. This was done by several calibration steps in order to compute monthly naturalized flow volumes and net evaporation minus precipitation depth based on known naturalized flow volumes. Monthly computed versus known naturalized flow volumes were compared after calibration, and plots show that flows had higher and lower peaks in some periods. Higher flow volumes in some periods will essentially be balanced with the low flow volumes. The objective of the flow extension process is to replicate known naturalized flows as closely as possible.

However, monthly naturalized flow statistics are the most important part of the extension process. There were several quadrangles with missing evaporation and precipitation data prior to 1954. Also, the monthly evaporation depth from reservoir surface areas were measured using different methodology prior to 1954. Hence, the calibration and computing flows for the Rio Grande were based on known naturalized flow volumes covering 1954–2000. The known naturalized flow volumes covering 1940-1953 hydrologic period was added back to the newly extended naturalized flow data. Known monthly naturalized flow

data are a critical part of the flow extension process, along with TWDB's monthly evaporation minus precipitation depths.
One of the biggest challenges of the flow extension process was to calculate contributing drainage areas based on sub-watersheds—created for the entire basin using ArcGIS mapping tools and methodologies—because each sub-watershed within each specific quadrangle had to be determined to incorporate evaporation and precipitation data for each drainage area. Four different flow zones in FP and FZ records were assigned specific percentages of zero flows for each period to improve the accuracy of the computed flows. The initial calibration process required significant computer simulation time. For the future period of extension, TWDB quadrangle data can be added to existing EVA file of the Rio Grande WAM, and it should allow water users to have the most up-to-date datasets. The necessity of updated Rio Grande WAM datasets is mentioned several times in the Rio Grande Water Planning Group's reports.

2011 and 2012 are the years for the drought of record for the Rio Grande; Falcon Reservoir had only 38,453 ac-ft of water, while Amistad storage was at 45,873 ac-ft. In 2013, the reservoir system began regaining storage volume due to rainfall following the drought. The extended Rio Grande WAM captured that period, which is important for water planning activities. The EVA file can be used to remove reservoir surface areas from the naturalized flow process in order to determine streamflows. Spring flow adjustments for a single control point were extended using monthly averages for 1940–2000 because there were no stream gaging data that could have been used to extend this file.

Long-Term Simulation Results

Texas WAM datasets are used to evaluate permit applications for Texas rivers by TCEQ and for long-term water planning by TWDB. The updated Rio Grande WAM, with 76-year sequences of hydrologic period analysis covering 1940–2015, was used to simulate long-term reliability and end-of-reservoir storage frequency analysis for the Amistad-Falcon Reservoir system. The purpose of the long-term simulation option was to investigate water allocation reliabilities for irrigation and municipal water right groups. TCEQ applications of WRAP assume that the reservoirs are full at the beginning of the simulation. The rationale behind this assumption is that the results for a long period of analysis are not significantly affected by the initial conditions. However, having full reservoirs at the beginning of the simulation may not be a realistic assumption for arid areas like the Rio Grande Basin (Santos, 2005). The BES feature is based on setting the beginning and ending storage equal, which reflects the concept of a cycling hydrologic simulation period. Volume reliability and exceedance frequency analysis were performed for both middle and lower segments of the Rio Grande.

The Middle Rio Grande includes all water rights between Amistad and Falcon Reservoirs, and the Lower Rio Grande includes all water rights below Falcon Reservoir.
In evaluating permit applications, TCEQ applies a general rule that municipal supplies should have a volume and period reliability of 100%, and for agricultural supplies, 75% of the permitted demand should be met at least 75% of the time. The simulation results show that municipal rights had maintained 100% reliability while irrigation Class A had 67.14% and 68.29% reliability and Class B had 43.23% and 44.32% reliability for the Middle and

Lower Rio Grande, respectively. DMI reserves were lowered from 100% to 0%, but volume reliabilities for irrigation rights were only increased to about 2% while 100% of municipal reliabilities were maintained. However, when Operation Reserve (OR) at the Amistad-Falcon Reservoir system was lowered to 0% storage, the volume reliabilities for Lower Rio Grande were at 99.85%, which is not acceptable by TCEQ. The simulation results showed that the volume reliabilities for municipal water rights with 0% DMI storage can still be maintained at 100%, but if combined with 0% OR storage, a reliability of less than 100% is achieved. Curtailing all Class B irrigation rights significantly improves volume reliabilities for Class B rights. The DMI and OR storage reserves were used in combination to reallocate waters to Class A irrigation diversions while curtailing Class B rights during drought periods. The results show a 6.8% increase in volume reliabilities for Class A irrigation rights and 100% reliability for municipal rights. The DMI pool of the Amistad-Falcon Reservoir system is extremely protected, with excess volume of storage due to conversion of irrigation rights to municipal rights based on the water marketing in the LRGV. This protection was evidenced by 100% volume reliability for municipal water rights in all simulation scenarios with various initial storages. Although prohibited, some of the water in the DMI pool can be temporarily released to irrigation purposes during severe drought to prevent water conveyance infrastructure from deteriorations.

The 2016 Rio Grande Regional Water Planning Group's projected water demands from 2020 to 2070 were also incorporated and simulated to evaluate potential curtailment or water transfer options. The results show that based on the current water rights in the Rio Grande WAM, the incorporated projected municipal demands for 2020 would have less than 100% municipal volume reliability. Curtailment of Class B irrigation rights would meet 2020 municipal demand and maintain a volume reliability of 53% for Class A water rights. Additionally, Class A irrigation rights should be reduced by 20% each decade in order to meet future municipal demands in the LRGV. These reductions will be achieved by purchasing and converting irrigation rights to municipal rights based on a water marketing system in the region. In addition, the 2016 regional water-planning group report projects a decrease in current agricultural land due to population growth and water shortages.

Conditional Reliability Modeling (CRM)

CRM is used to predict the likelihood of meeting water supply demands in the near future, which is highly dependent on current reservoir storage levels. In CRM, naturalized flows and net evaporation rates are divided into short sequences that begin with the same initial reservoir storage. CRM can be used to support operational planning, drought management plans, and many other applications.

Equal weight and probability array options of CRM were applied to the Amistad-Falcon Reservoir system, and the probability of exceeding maximum storage contents based on initial storage at the beginning of April were developed. Then, the probability of exceedance for the next six months for Amistad and Falcon Reservoirs was developed. The equal weight option, as expected, produced higher exceedance frequencies for Amistad and Falcon Reservoirs since it assigns probabilities of meeting or exceeding specific diversions on an equally likely basis. This method can be used for long-term water planning purposes, but the

CRM method would be a better option for short-term drought management or reservoir operations.

CRM with the SFF option using storage changes was also demonstrated in this research. The linear and Spearman correlation coefficients were developed for each scenario. However, the combined Amistad and Falcon Reservoir with full storage option in SFF appears to be a better option to apply for the Rio Grande. Power and exponential regression analysis were used because they demonstrated a better fit in relating storage to naturalized flows in simulations.

Drought Management

CRM methods were applied to simulate different drought conditions based on the storage trigger percentages developed by the Texas State Drought Preparedness Council and Rio Grande Municipal Use. The probability of exceeding maximum end-of-storage for the next three months into the future for three months beginning with May, June, and July based on initial reservoir triggers were presented. The simulation results show that drought at the beginning of month continues to be persistent in the next three months with the initial reservoir storages. CRM methods were applied with different initial reservoir storage contents to the Amistad-Falcon Reservoir system.

The beginning of May, June, and July were selected to determine likelihood of water allocations for the next three months. Peak irrigation season for the LRGV begins in May and ends by September. The end-of-month probability of exceeding maximum storage volumes from May to September were developed for the LRGV. Volume reliabilities for irrigation rights appeared to be lower with the low initial storage contents of the Amistad-Falcon Reservoir system at the beginning of each period. The probability of severe drought occurring at the beginning of May appeared to continue through the end of July. If irrigation districts and farmers anticipate lower storage levels in the Amistad-Falcon system at the beginning of May, the water shortage will continue into the next three months and curtailment of some of the irrigation rights will be enforced by IBWC.

Future Research

Irrigation district operations are somewhat unknown. For instance, it is not clear which Class A or Class B water right holders should get their allocations first since priorities among the same group does not exist. Detailed account holders are maintained by the irrigation district's database, and the watermaster office only maintains municipal, Class A, and Class B rights along with annual authorized diversions for each irrigation district. When developing reliability analysis for drought conditions, the IBWC uses the Amistad-Falcon system storage before issuing any drought condition triggers. However, based on simulation results, it is evident that both Amistad and Falcon Reservoirs have significantly different storage volumes. This difference can also be seen from the historical data on the IBWC website. In addition, there is no release schedule from Amistad to Falcon to meet water demands in the LRGV. Also, the accounting systems of prior diversions are also unknown. There is very limited literature on specific operation policies of the Amistad-Falcon Reservoir system.

Future research should focus on examining and understanding these parameters in order to improve the understanding of reliability and exceedance frequency analysis for the LRGV. Since Amistad and Falcon Reservoirs operate as a system, it is difficult to identify specific minimum storage capacity at which certain reliabilities can be expected. The available storage in Amistad Reservoir is usually higher than it is in Falcon Reservoir. For example, when Falcon is at 34% capacity, Amistad might be at 71% capacity. In this case, it will be difficult for an irrigation district manager or a farmer to make any water plans because Falcon Reservoir can be filled by Amistad at any time in order to meet the water demands of the LRGV. IBWC makes the final decision on the amount of water to be diverted to the LRGV per request from the Rio Grande watermaster. Once finalized, the watermaster informs each irrigation district about the allocations for the next weeks. Water allocations within irrigation districts are governed by the board of directors comprised of farmers. The board makes a decision on who gets the appropriated water for the next week.

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