Evaluating Alternatives to Increase the Water Available to Water Rights in the Lower Republican River Basin Scenarios: Final Report

Kansas Water Office Contract #16-116

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Executive Summary

The Lower Republican River Basin (LRRB) OASIS model was modified to reflect resolutions passed on August 24, 2016, as documented in *Resolution Approving Long-Term Agreements Related to the Operation of Harlan County Lake for Compact Call Years*. These modifications include the addition of a Remaining Compact Compliance Volume (RCCV), in which water from Nebraska's augmentation activities is stored until called for by Kansas Bostwick Irrigation District (KBID) or by the water rights junior to minimum desirable streamflow (MDS) within the basin comprising the access district. The Kansas account in Harlan County Lake (HCL) was modified to receive water from the RCCV for KBID's exclusive use, and a supplemental account was developed in HCL to receive water from the RCCV for the access district's exclusive use. In addition, three proposed new reservoirs, West, East, and Beaver Creek, are included in the model. The objective of this work is to evaluate these new management options to meet the demands of Nebraska's irrigation districts within the basin, KBID, and the access district. Two climate scenarios are simulated, consistent with the original LRRB OASIS model simulations: a repeat of historic conditions and a hot and dry scenario. Under both climate scenarios, model simulations were performed with a variety of maximum yearly augmentation volumes ranging from 30,000 acre feet (AF) to 70,000 AF. Operation of each reservoir was simulated without a supplemental account and with a supplemental account that receives water from the RCCV with a 70,000 AF yearly augmentation limit. Results indicate the best way to reduce water shortages is not the same for the access district as for KBID. KBID's water shortages are the lowest when the access district does not operate a supplemental account in HCL, whereas the access district's shortages are lowest when they operate a supplemental account in HCL in addition to either East or West reservoir.

Water can be lost from the system and not put to Kansas' beneficial use by two mechanisms: (1) through item 10 of the resolution dated August 24, 2016, which indicates that in a non-compact call year the volume stored in the RCCV will be reduced by 20%, and (2) when water in the Kansas account is not used by the end of the calendar year and is transferred to the irrigation pool, where approximately 35% of the water is used by Nebraska. When these are considered together, it is clear that operating a supplemental account in HCL reduces system losses. When considering system losses and reductions in water shortages, the operation of the supplemental account provides a balance between optimizing both.

These results are subject to a great deal of uncertainty, including, but not limited to, reservoir inflows, augmentation volumes, frequency of compact call years and MDS administration, climate uncertainty, water right involvement in the access district, and reservoir management options. Therefore, the results of this work should not be considered representative of future conditions but rather indicators of trends in system behavior under the simulated management strategies. Future work should attempt to assess these uncertainties to provide a better understanding of how the system will respond to changes in the uncertain parameters.

Introduction

The Republican River Basin encompasses approximately 24,540 square miles of eastern Colorado, southern Nebraska, and northern Kansas that drain to the Republican River above the gaging station at Clay Center, Kansas (Figure 1). The study area contains more than 2.7 million acres of irrigated agriculture served by a combination of surface and groundwater supplies. Of these, 1.6 million acres are in Nebraska, 435,000 acres are in Kansas, and 550,000 acres are in Colorado. In addition to irrigated agriculture, the water resources serve municipalities, industry, recreation, and wildlife.

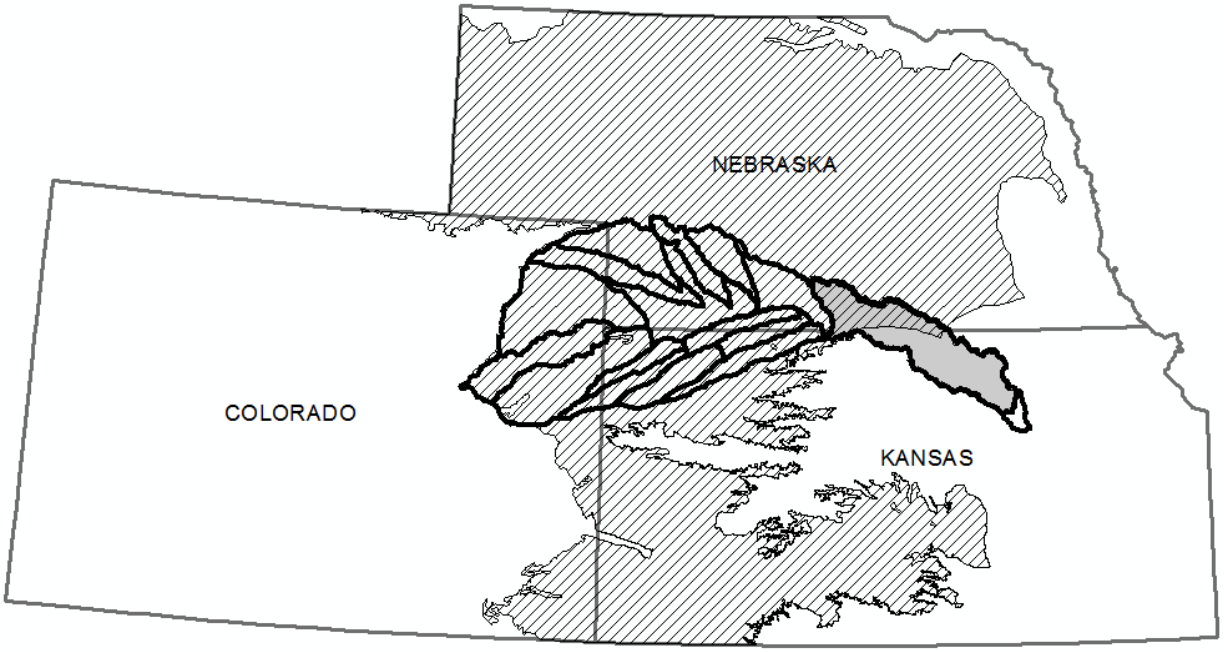

Figure 1 – Location of the Republican River Basin, including sub-basins. Study area, here referred to as the Lower Republican River Basin, is shaded gray. Hatched area denotes location underlain by the High Plains aquifer.

The entire basin includes seven U.S. Bureau of Reclamation (USBR) storage reservoirs, one U.S. Army Corps of Engineers reservoir (Harlan County Lake [HCL]) and several irrigation canal districts that supply water to agriculture. Much of the upper basin is underlain by the High Plains aquifer, which is used extensively for irrigation purposes. Alluvial aquifers are also present along the Republican River itself, and these aquifers are used for irrigation throughout the basin. Because of long-term imbalances between water supply and demand, Colorado, Nebraska, and Kansas ratified an interstate compact in 1943 to ensure equitable distribution of water within the basin. The compact also dictates that each state must efficiently manage its resources and should continuously try to improve efficiency measures to address current and future water supply issues. This study focuses on the Lower Republican River Basin (LRRB) region between Harlan Reservoir and the inlet to Milford Reservoir (Figure 2). This region covers approximately 4,000 mi^2 and contains two reservoirs (HCL and Lovewell) and several irrigation canal districts. The LRRB in Kansas is not underlain by the High Plains aquifer; subsurface resources are derived almost entirely from the alluvial aquifer along the Republican River channel.

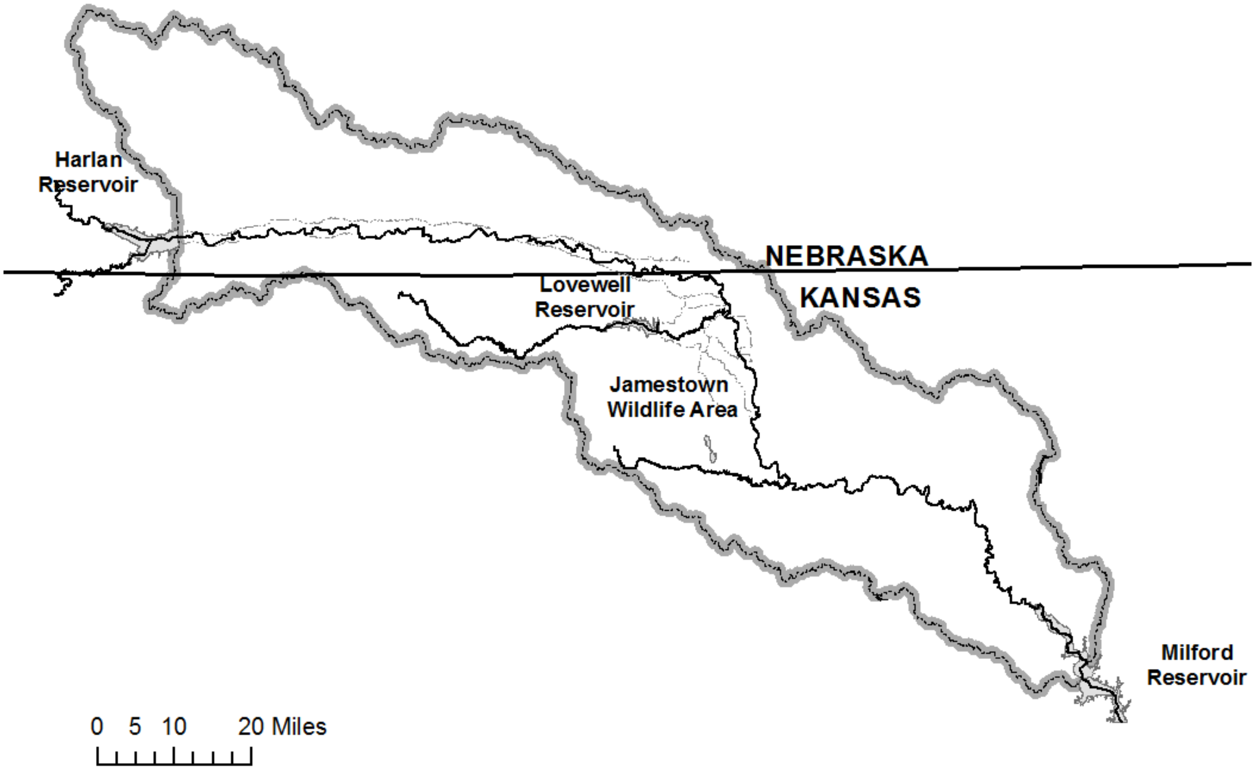

Figure 2 – Lower Republican River Basin study area. Republican River and main tributaries are represented by black lines and primary irrigation canals by gray lines.

Project Objectives

The Kansas Water Office (KWO) contracted with the Kansas Geological Survey (KGS) in the spring of 2016 to further advance the model developed for the United States Bureau of Reclamation (USBR) WaterSMART Basin Study. Modifications to the model reflect the resolutions passed on August 24, 2016, as documented in *Resolution Approving Long-Term Agreements Related to the Operation of Harlan County Lake for Compact Call Years*, and include management of three potential new reservoirs.

The objective of this work is to simulate the distribution of water resources in the LRRB under different management alternatives to optimize beneficial use by the Kansas Bostwick Irrigation District (KBID) and junior water rights in the basin using the existing model of the LRRB. The management alternatives are based upon optimizing the use of Nebraska's augmentation water between KBID and a newly developed access district in Harlan reservoir and the development of new reservoirs for use by the access district. The management alternatives will be evaluated under two different climate scenarios for 2011–2060 as developed for the WaterSMART basin study: the baseline climate representing a repeat of 1960–2010 climate and a hot and dry scenario from an archive of bias-corrected and spatially disaggregated CMIP3 projections. The effectiveness of each management scenario is quantified by simulated water shortages for KBID and the access district and the amount of water lost from the system through non-beneficial use or transfers back to Nebraska.

Model Development

The LRRB OASIS model, as developed for the USBR WaterSMART Basin Study (USBR et al., 2016), was modified to reflect the resolutions passed on August 24, 2016, as documented in *Resolution Approving Long-Term Agreements Related to the Operation of Harlan County Lake for Compact Call Years* (Kansas and Nebraska, 2016). These modifications are summarized as follows: 1) development of an access district within the LRRB; 2) development of the Remaining Compact Compliance Volume (RCCV); 3) development of a Kansas account in HCL; and 4) development of a Kansas supplemental account in HCL. In addition, three potential reservoirs were included in the model to assess their ability to meet access district demands, and slight modifications to HCL operations were included to better reflect current management. These modifications are described in the following sections, and Figure 3 shows the updated schematic of the OASIS LRRB model.

Access District

All surface water and groundwater rights junior to the minimum desirable streamflow (MDS) administered at either Concordia or Clay Center along the Republican River in Kansas are currently considered part of the access district. The water rights in the access district were divided into eight groups, depending on water source and location (Table 1).

Table 1—Access district groups in OASIS

Location Description	**Source**	**# in Figure 3 (yellow boxes)**
Upstream of all Kansas reservoirs	Surface	550
Upstream of all Kansas reservoirs	Groundwater	551
Between proposed upper reservoirs and Lovewell reservoir	Surface	450
Between proposed upper reservoirs and Lovewell reservoir	Groundwater	451
Between Lovewell reservoir and proposed Beaver Creek reservoir	Surface	351
Between Lovewell reservoir and proposed Beaver Creek reservoir	Groundwater	352
Downstream of reservoirs	Surface	250
Downstream of reservoirs	Groundwater	251

Access district demands can only be met by water transferred from the RCCV to the Kansas supplemental account in HCL or from water within one of the three new reservoirs (East, West, and Beaver Creek). In addition, water can only be released to meet access district demands during MDS administration. Water is released into the Republican River to offset the effect of continued withdrawals by access district members, allowing these junior water rights to continue to pump under MDS without affecting water levels at MDS administration points. Based on results of a study by the Kansas Department of Agriculture Division of Water Resources, it is estimated that groundwater users receive approximately 66% of their water from the river (D. Barfield, personal communication, May 1, 2017). Thus, each acre-foot (AF) of water pumped from groundwater users in these groups is replaced by 0.66 AF of water released to the river. The surface water groups get their water from the river, so each AF of water pumped by users in these groups is represented by 1 AF of water released to the river.

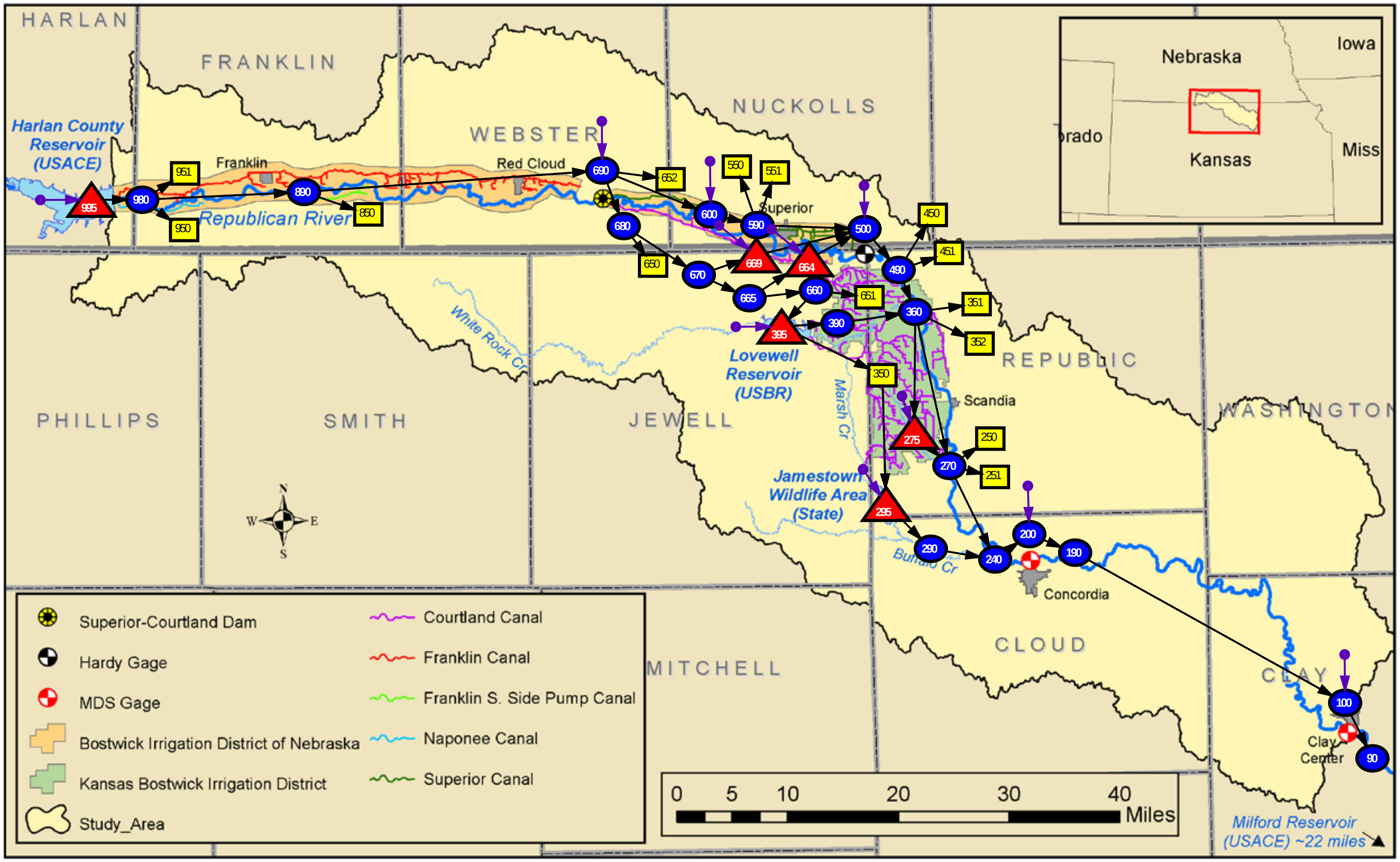

Figure 3 – Updated schematic of OASIS LRRB model.

Remaining Compact Compliance Volume

The Remaining Compact Compliance Volume (RCCV) is the portion of water Nebraska would need to contribute to the natural flows of the Republican River Basin through augmentation activities during a compact call year for Kansas' exclusive use that is retained for Kansas' use in a subsequent compact call year. This water is not held in HCL until transferred during a compact call year to either the Kansas account for KBID's use or to the Kansas supplemental account for the access district's use. The volume of each transfer is decided upon by KBID and the access district in October for use the following year and must be present in HCL by June 1 of the following year.

To simulate operation of the RCCV, OASIS calculates the transfer volume to the Kansas account for KBID's exclusive use by estimating KBID's shortage for the following year. This is the difference between the estimated quantity of project water that will be available to KBID on June 1 of the following year and KBID's estimated demands in the following year. If there is projected to be a shortage and water is available in the RCCV, water is transferred to the Kansas account. Although in reality this water would be transferred during the period between the transfer request and June 1, OASIS performs the transfer at the time of the request to simplify model accounting.

Any water remaining in the RCCV after meeting KBID's demands can be transferred to the supplemental account for the access district's use. Several management options have been developed within OASIS to control this transfer to optimize Kansas' beneficial use. A maximum volume can be set for the supplemental account to prevent it from taking up too much space within HCL. In addition, a reserve of water in the RCCV can be preserved for future use by KBID; water can only be transferred to the supplemental account if the volume of water in the RCCV is greater than the reserve volume after KBID's transfer for the year.

In an effort to be consistent with resolution 10, if the year following a compact call year is a normal year (not a compact call year) and the RCCV is greater than 0, the volume is reduced by 20%. This continues until the end of another compact call year when the RCCV is reset or is zero.

Kansas Account

The Kansas account was previously included in the LRRB OASIS model to represent Warren Act contracts in a compact call year and was a user-defined constant (default was 60,000 AF). In all simulations for this work, the Warren Act contracts were disabled but the functionality remains in the model. The Kansas account was altered to accept transfers from the RCCV, and water in the Kansas account remains for the exclusive use of KBID. At the end of every calendar year, water left in the Kansas Account remains in the HCL but is transferred to project water, where it is distributed between NBID and KBID as per the compact.

Supplemental Account

The supplemental account is used to provide water to the access district during MDS administration. As previously described, water can only be transferred to the supplemental account from the RCCV during a compact call year, when transfers to the Kansas account have been completed and the reserve volume is met, up to the maximum supplemental account volume. Water in the supplemental account can be used when MDS is administered regardless of whether it is a compact call year or not. If unused, this water can carry over to the following year, regardless of it being a normal or compact call year. This water is not depleted by any means other than use by the access district.

New Reservoirs

Three proposed new reservoirs were developed in the model to meet access district demands (Figure 4). Two of the three reservoirs are located close to the Nebraska-Kansas state line (West and East reservoirs), and the third is farther downstream at the confluence of Beaver Creek and the Republican River (Beaver Creek reservoir). Burns & McDonnell completed a hydrology and hydraulics study for each of the reservoirs, providing elevation and storage information (Table 2) in addition to watershed delineation, which provided inflow estimates.

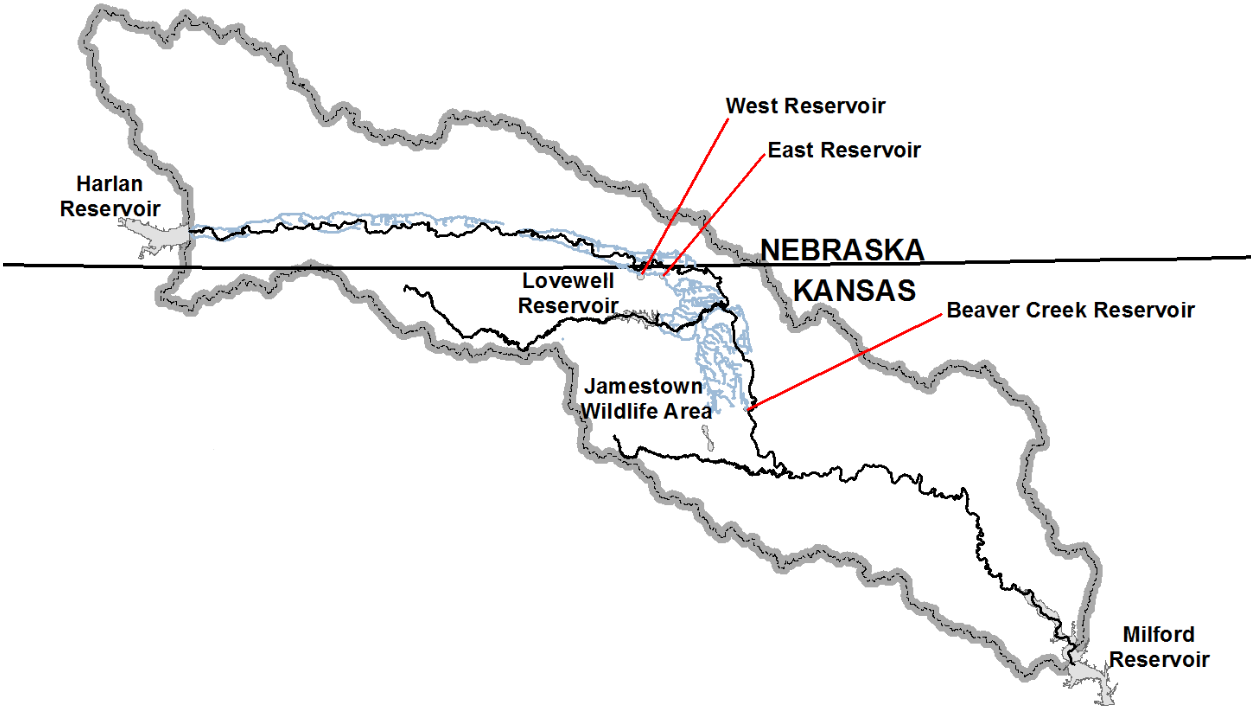

Figure 4 – Study area with existing and potential new reservoir locations indicated. Black lines indicate river locations, and blue lines indicate irrigation canals.

Table 2 - Reservoir capacity estimates from Burns & McDonnell

	West Reservoir	East Reservoir	Beaver Creek Reservoir
Max. Elevation (ft)	1,660	1,640	1,460
Max. Surface Area (ac)	344	246	1,740
Max. Embankment Length (ft)	3,366	2,647	3,404
Max. Storage Capacity (ac-ft)	8,506	6,078	19,371

In the simulations, all three reservoirs are operated solely for access district use. The closest upstream reservoir with available resources is used to meet access district demands. For example, demands from nodes 250 and 251 are first met by water in Beaver Creek reservoir, followed by East reservoir, West reservoir, and the supplemental account. Water can enter the reservoirs through natural inflow from the watershed and diversions from the river. Diversions only occur when MDS is not in administration and are limited by a pump capacity of 23.2 ft^3/s. All reservoirs are subject to MDS administration, whereby reservoir levels cannot increase during MDS administration. During MDS administration, therefore, all natural inflows are passed through the reservoir to the river system. Water also can be lost due to evaporation; the model uses evaporation rates calculated for Lovewell reservoir.

Harlan County Lake Operations

Two further modifications to HCL operations were completed to make them more consistent with current management. The first modification separated HCL inflow values, as provided by Nebraska, into natural and augmentation water. Nebraska did not provide a distinction between augmentation volumes and natural inflow. It provided total inflows to HCL, which included augmentation water. Without further information, augmentation was estimated to be any water in excess of the historic inflows to HCL for both the baseline and hot and dry scenarios. For example, January 2011 was compared to January 1961, February 2011 was compared to February 1961, etc. This is clearly flawed in many respects. While for the baseline climate the climate conditions from 2011–2060 are considered a repeat of 1961–2010, the hot and dry scenario uses modified precipitation and temperature values. In addition, the amount of groundwater and surface water extraction upstream of HCL drastically increased between 1961 and 2010; therefore, it is expected that augmentation may be underestimated for the early portion of the simulations. Monthly and yearly limits on augmentation volumes are incorporated in the model to reflect physical limitations of the system and management strategies. The maximum physical limits of augmentation are 6,000 AF per month and 70,000 AF per year.

The second modification changes how water is released at the end of a compact call year. Previously, in compact call years, if the water level in HCL was higher at the end of a compact call year than it was on January 1, the excess water was released downstream, often with no beneficial use. In the current operations, water is retained in HCL and reverts to project water for the following year, with the exception of water in the supplemental account, which remains in the supplemental account.

Modifications to HydroGeoSphere Link

Minor modifications were made to the link between OASIS and HydroGeoSphere (HGS). The volume of water delivered to each of the access district groups is now written to an output file by OASIS for use in HGS. Releases from the new reservoirs are also output for use in HGS.

Results and Discussion

Simulations were completed for scenarios that encompass a variety of management options in the basin under both the baseline and the hot and dry climates. These are summarized in Table 3.

Table 3 – Summary of model scenarios completed for both baseline and hot and dry climate. Gray area indicates simulation was completed.

		No additional reservoirs	West Reservoir		East Reservoir		Beaver Creek Reservoir	
			No SA*	SA*	No SA*	SA*	No SA*	SA*
Maximum Volume of Yearly Augmentation (AF)	70,000	▨	▨	▨	▨	▨	▨	▨
	60,000	▨						
	50,000	▨						
	40,000	▨						
	30,000	▨						

*SA = Supplemental Account

All simulations, unless otherwise noted, operated with a maximum supplemental account capacity of 20,000 AF and a monthly augmentation limit of 6,000 AF. The supplemental account could not receive water unless there was a reserve volume of 20,000 AF for KBID's future use. The maximum yearly augmentation limit was modified in several simulations, as demonstrated in Table 3, however the default value is the physical constraint of 70,000 AF. All simulations include the operation of the Kansas account for KBID's exclusive use.

Results from these simulations provide a wide variety of information about the storage, distribution, and use of water in the LRRB. It is not feasible to present every result from these simulations, so results presented here focus on assessing the effectiveness of the new management options in reducing water shortages.

OASIS-HGS Link

According to previous results (Brookfield et al., 2017), OASIS results can cause a noticeable change in groundwater/surface water interaction in the HGS simulation only when a change in irrigation delivery is much greater than 10%. Therefore, before we ran time-consuming linked HGS/OASIS simulations, we completed an initial analysis of OASIS-only results. We calculated the percent change in irrigation delivery to KBID and the water rights between some simulations with the access district and those without. A change in reservoir release does not significantly impact HGS results as the extra water released is quickly dissipated over the width of the stream, causing only a small change in head within the stream. As can be seen in Table 4, the total difference in irrigation deliveries exceeds 10% of the total deliveries in hot and dry scenarios (max of 18.6%) but in none of the baseline scenarios. Although the hot and dry results are not exceptionally higher than 10% (the only tested limit in Brookfield et al., 2017), and because the HGS simulations take considerably more computational effort and time to complete, previous HGS outputs from the original simulations were used to allow for expedited results. In addition, all scenarios result in an increase in deliveries to KBID, which would increase groundwater levels and thus increase groundwater discharge to the surface, increasing surface water levels. Therefore, by using the original results, we are evaluating a worse-case scenario. Future work will include linked simulations to confirm these assumptions.

Table 4 – Change in KBID deliveries in OASIS-only simulations

	% difference in total deliveries	
	Baseline climate	Hot and dry climate
RCCV with 30kAF max	3.1	13.9
RCCV with 40kAF max	2.9	14.8
RCCV with 50kAF max	4.0	16.8
RCCV with 60kAF max	4.1	17.2
RCCV with 70kAF max	4.2	17.2
West reservoir only	4.5	18.6
East reservoir only	4.5	18.5
Beaver Creek reservoir only	4.5	18.5
West reservoir and RCCV with 70kAF max	4.2	17.5
East reservoir and RCCV with 70kAF max	4.2	17.5
Beaver Creek reservoir and RCCV with 70kAF max	4.2	17.5

Irrigation Deliveries and Shortages

The objective of this work is to optimize water management in the basin to best meet irrigation demands. This includes reducing water shortages experienced by KBID and releasing water for access district use during MDS administration.

KBID Shortages

KBID's shortages drastically decrease under all scenarios compared to the original simulation results from the WaterSMART study. In the original simulations, KBID could purchase up to 60,000 AF of water through a Warren Act contract. The new simulations presented here do not have any Warren Act contracts.

Shortages are reduced by between 47% and 71% for the baseline scenario and by 29% to 58% for the hot and dry scenario compared to the original simulations (Figure 5). The greatest reduction under both climate scenarios is during the operation of any of the reservoirs with no supplemental account in HCL. This allows all of the augmentation water to be used by KBID, thus reducing KBID's shortages the most. When the supplemental account operates in addition to the Kansas account, KBID's shortage increases by just more than 7,000 AF under the baseline climate and more than 30,000 AF under the hot and dry climate over the 50-year simulation period. The highest shortages for KBID occur when the maximum yearly augmentation volume is reduced to 40,000 AF or lower.

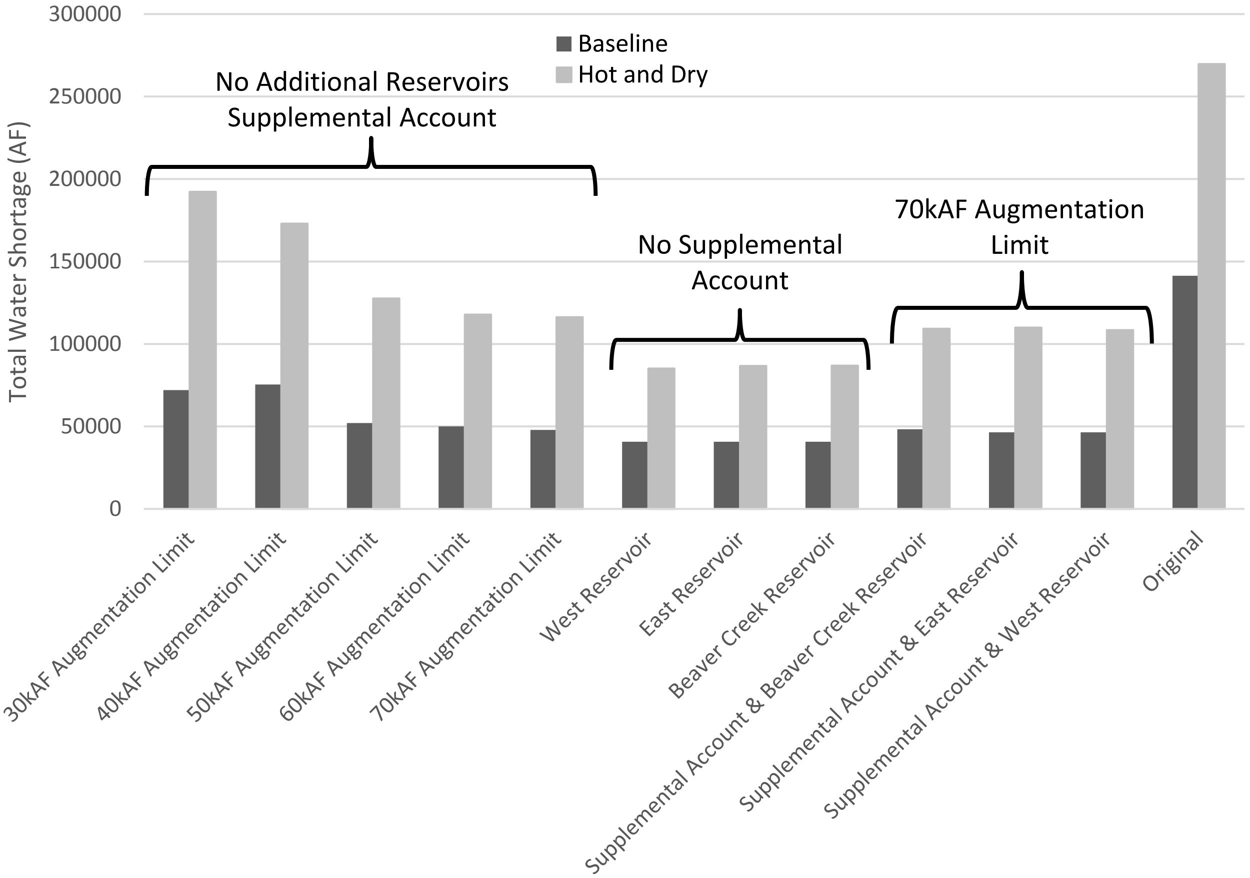

Figure 5 – Total water shortages for KBID over the 50-year simulation period under baseline and hot and dry climate scenarios.

Access District Shortages

The access district is a new addition to the LRRB simulations, and therefore we cannot compare results to previous shortage estimates. However, without an access district, the junior water rights can still pump 38% of their allocated amount during MDS administration under a consent agreement with the Kansas Department of Agriculture Division of Water Resources (DWR). Therefore, the utility of the access district can be assessed by comparing simulated shortages against 62% of the demand during MDS administration to estimate net benefit.

Shortages are reduced by between 23% and 100% for the baseline scenario and by 20% to 100% for the hot and dry scenario compared to 62% of the demand during MDS administration (Figure 6). The greatest reduction under both climate scenarios is during the operation of East and West reservoirs along with a supplemental account in HCL. This gives the district access to the most water the farthest upstream, thus reducing its shortages the most. The greatest water shortage for the access district occurs when augmentation water from Nebraska is limited to 30,000 AF per year for the baseline climate and when only water from the East reservoir is available under the hot and dry climate.

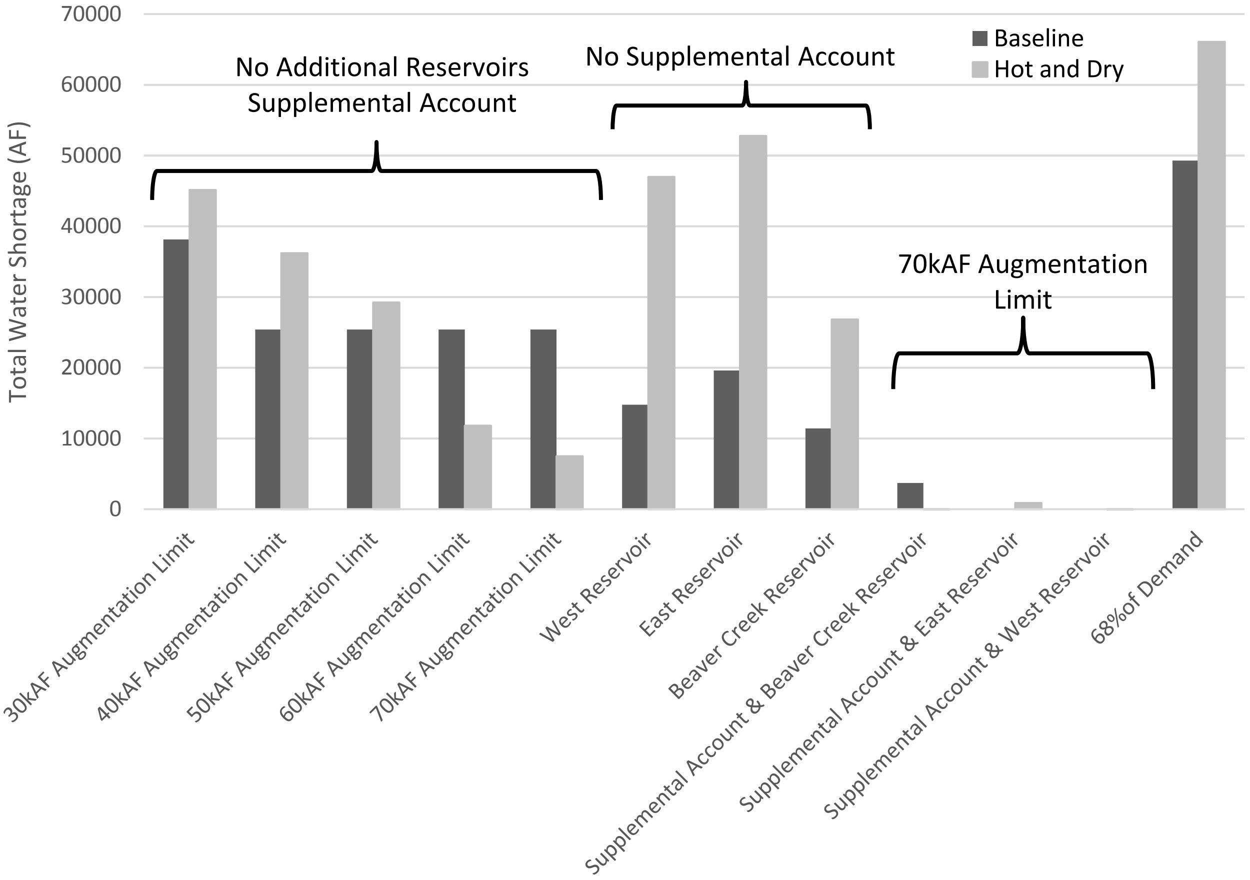

Figure 6 – Total water shortages for the access district over the 50-year simulation period under baseline and hot and dry climate scenarios.

MDS Administration

Access district water shortages are due to MDS administration; junior water rights can only use water during MDS administration through a consent agreement or as part of the access district. Therefore, the utility of the supplemental account in HCL and the new reservoirs is dependent upon either providing water to the access districts during MDS administration or shortening the duration of MDS administration. It should be noted that there are several model simplifications and uncertainties that make simulating MDS administration difficult. MDS is administered based on a 7- to 10-day window of water levels; however, the model's monthly timestep forces MDS to be assessed based upon monthly simulated streamflows. By definition, MDS is administered at a low level of streamflow, which is hard to accurately simulate due to model inaccuracies. Specifically, uncertainty in reservoir inflows and stream routing make estimates of low streamflow prone to high error. Therefore, the simulation of MDS administration and response to associated water shortages should be taken as an indication of trend and not a representation of future conditions. Results indicate that the new reservoirs and alternative HCL management simulated here do not significantly change the number of months MDS is administered (Figure 7).

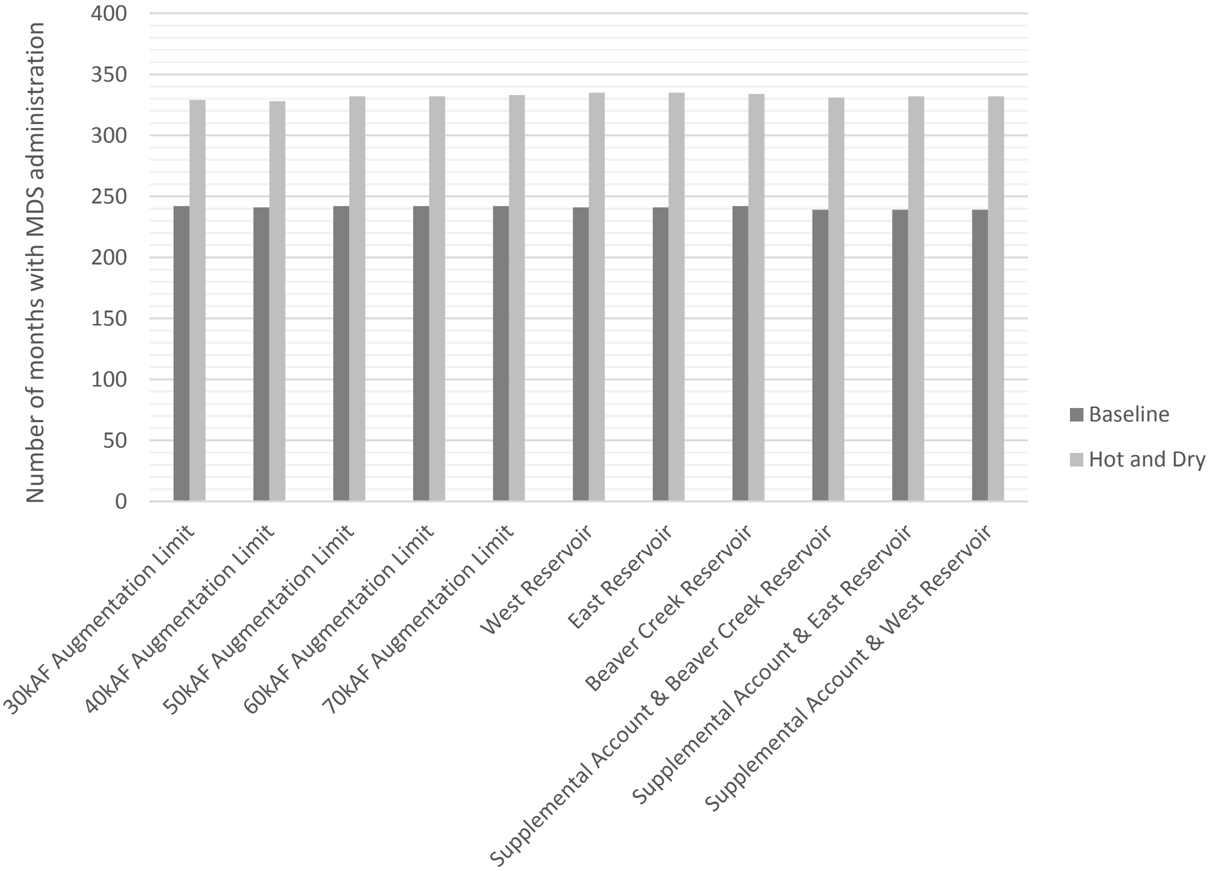

Figure 7 – Number of months with MDS administration for each scenario. New management options do not significantly change the number of months MDS is in administration.

Remaining Compact Compliance Volume

The volume of water in the RCCV dictates how much water is available to fill the Kansas account and the supplemental account. Augmentation water from Nebraska is the source of water in the RCCV; therefore, limitations on the maximum volume of augmentation water affect the volume stored in the RCCV (Figure 8). A lower limit on augmentation volume generally causes a lower volume of water stored in the RCCV.

When comparing the other management alternatives that include new reservoir operation (Figure 9), it is clear that when there is no supplemental account and the access district does not have access to the RCCV, the volume of the RCCV is highest (labeled “All reservoirs, no supplemental”). In addition, as compared to the simulations with no reservoirs and a supplemental account (labeled “70kAF,” indicating the maximum yearly augmentation limit), the inclusion of any reservoir also increases the water stored in the RCCV as the access district uses water in the reservoirs before transferring water from the RCCV to the supplemental account.

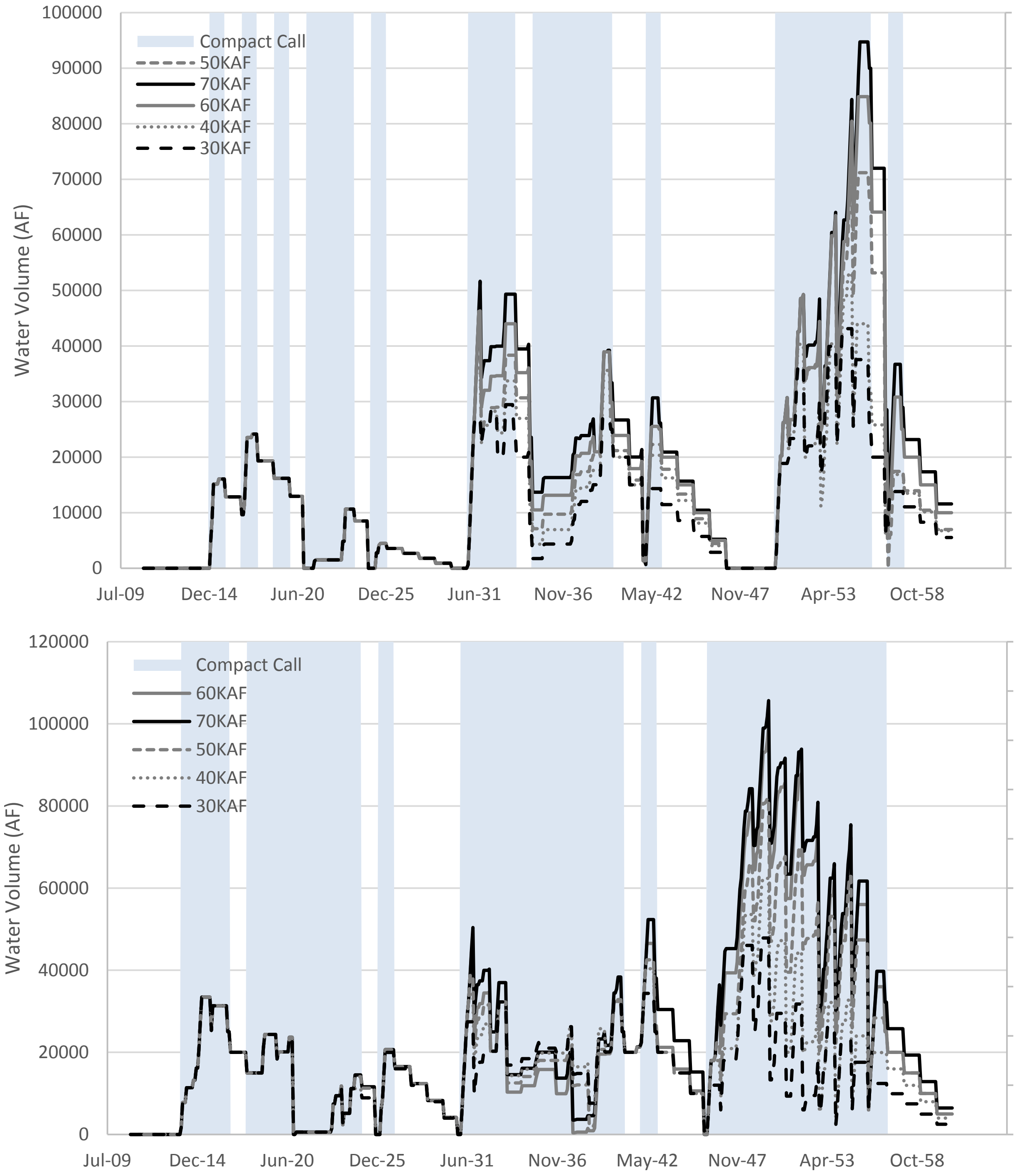

Figure 8 – Volume of water stored in the RCCV for a variety of maximum augmentation water volumes under the baseline (top) and hot and dry (bottom) climate scenarios. A higher maximum augmentation water volume generally results in higher volumes in the RCCV. The frequency of compact call years, which dictates when augmentation activities can occur, are indicated by the shaded regions.

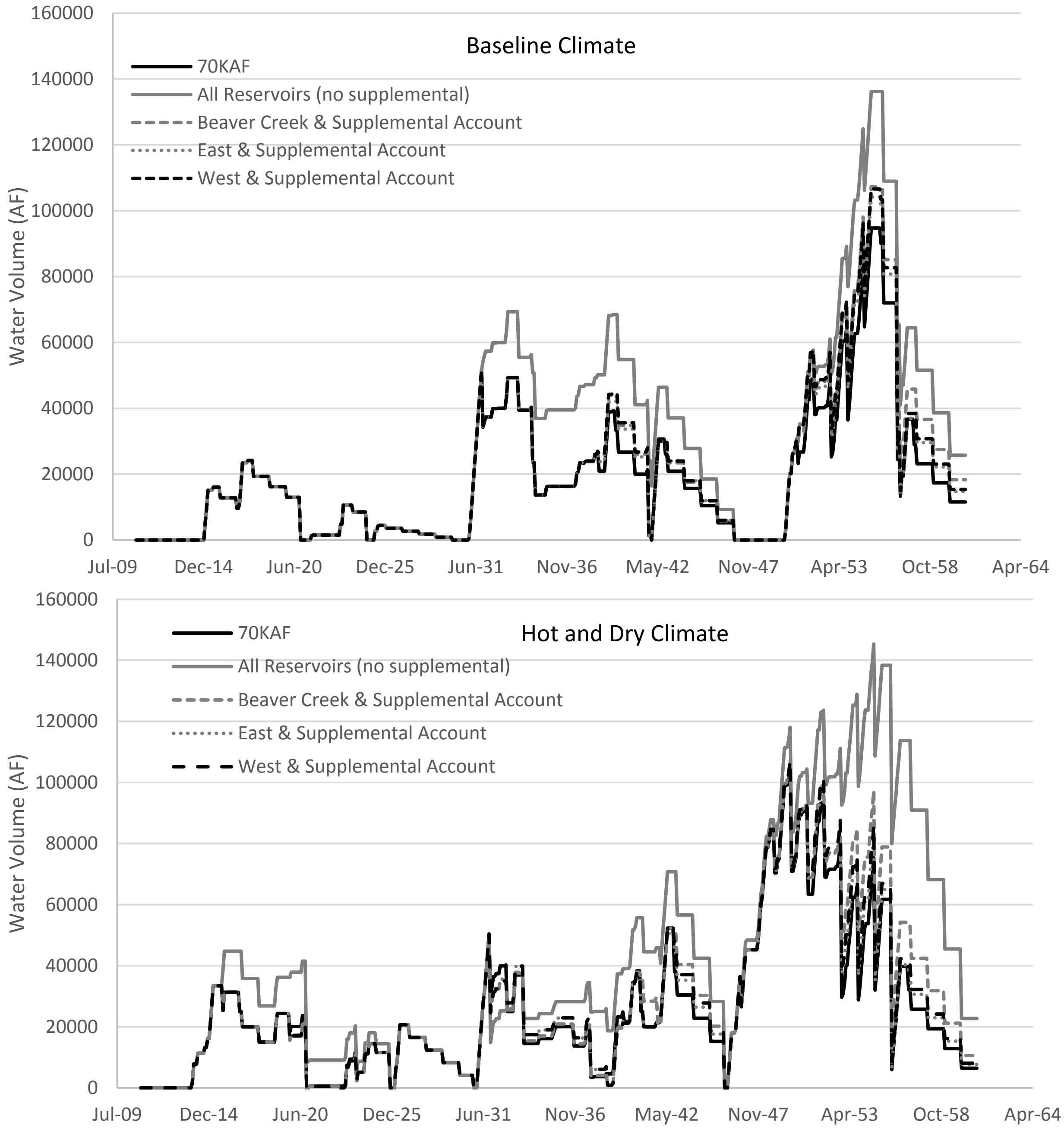

Figure 9 – Volume of water stored in the RCCV for the simulations with the new reservoirs, all with a maximum augmentation water volume of 70k AF under the baseline (top) and hot and dry (bottom) climate scenarios.

Having a higher volume of water in the RCCV is only beneficial to Kansas if it is used. Item 10 of the resolution dated August 24, 2016, indicates that in non-compact call years the volume stored in the RCCV will be reduced by 20% of the original volume (potentially eliminating all water in the RCCV over 5 years). To help determine what management options optimize Kansas' beneficial use of the RCCV, the model was designed to calculate how much water is lost through this mechanism (Figure 10). When the RCCV volume is highest in Figures 8 and 9, the water lost through this mechanism is also highest. Therefore, to optimize Kansas' use of the RCCV, this must be taken into consideration.

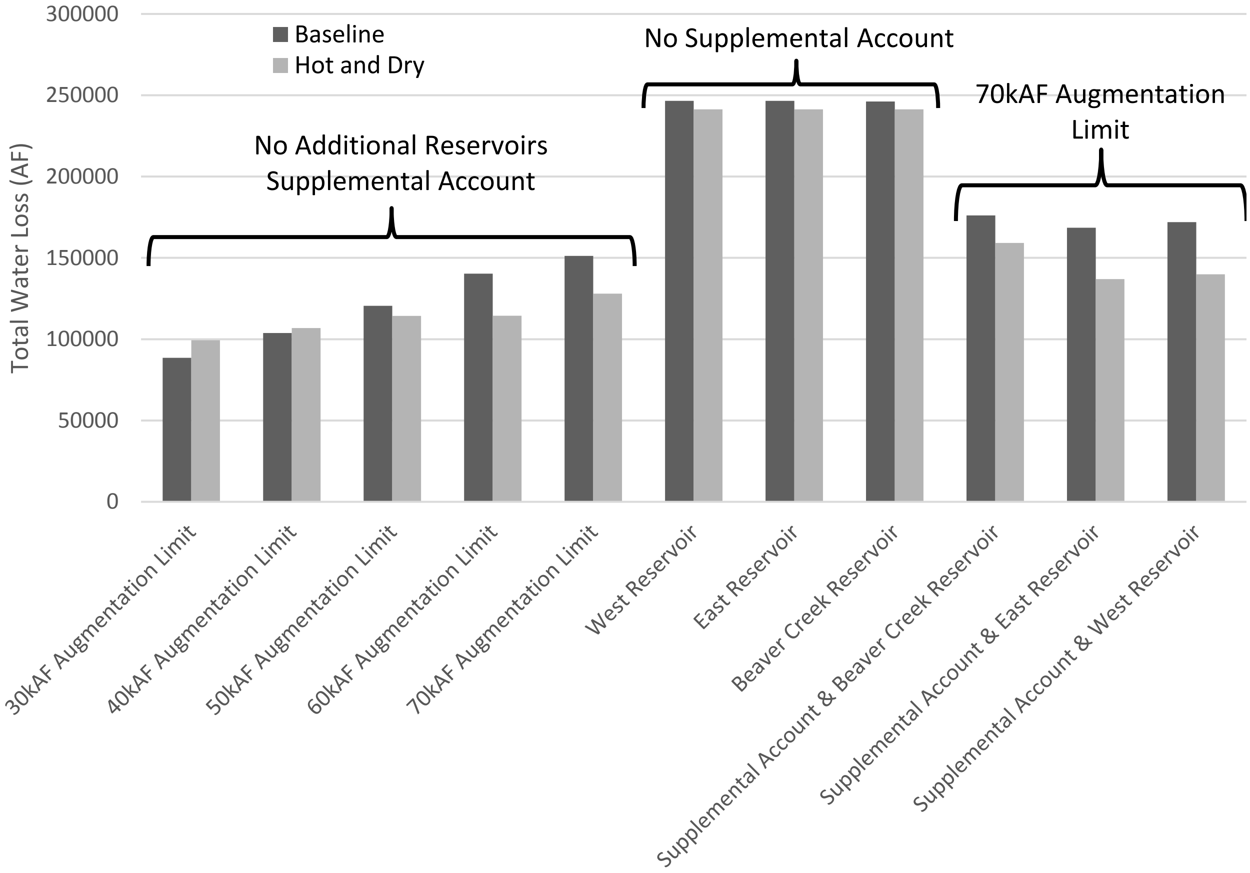

Figure 10 – Volume of water previously stored in the RCCV that is not put to Kansas' beneficial use under item 10 of the August 24, 2016, resolution.

Kansas Account

The Kansas account operations were modified from the simulations conducted as part of the WaterSMART study. During that study, the Kansas account was used to store water purchased by KBID under a Warren Act contract, was limited to 60,000 AF in each compact year, and was not retained in the following year if not used. As such, a comparison between storage in the Kansas account between the WaterSMART simulations and the current simulations cannot be made.

Consistent with the volumes of water stored in the RCCV, more water is available to transfer to the Kansas account when the maximum yearly augmentation volume is higher. However, differences in the volumes transferred to the Kansas account are only evident when KBID's demand is high enough to differentiate between the volumes stored in the RCCV (i.e., when all of the demand cannot be met by the RCCV at lower maximum yearly augmentation volumes, and can be better met by the higher limits, see 2056–57 in Figure 11). Also consistent with projected water storage in the RCCV, when there is no supplemental account and the access district does not have access to the RCCV or has access to storage in other reservoirs, the volume of the Kansas account is higher than the simulations in which the supplemental account is the only water available to the access district (Figure 12).

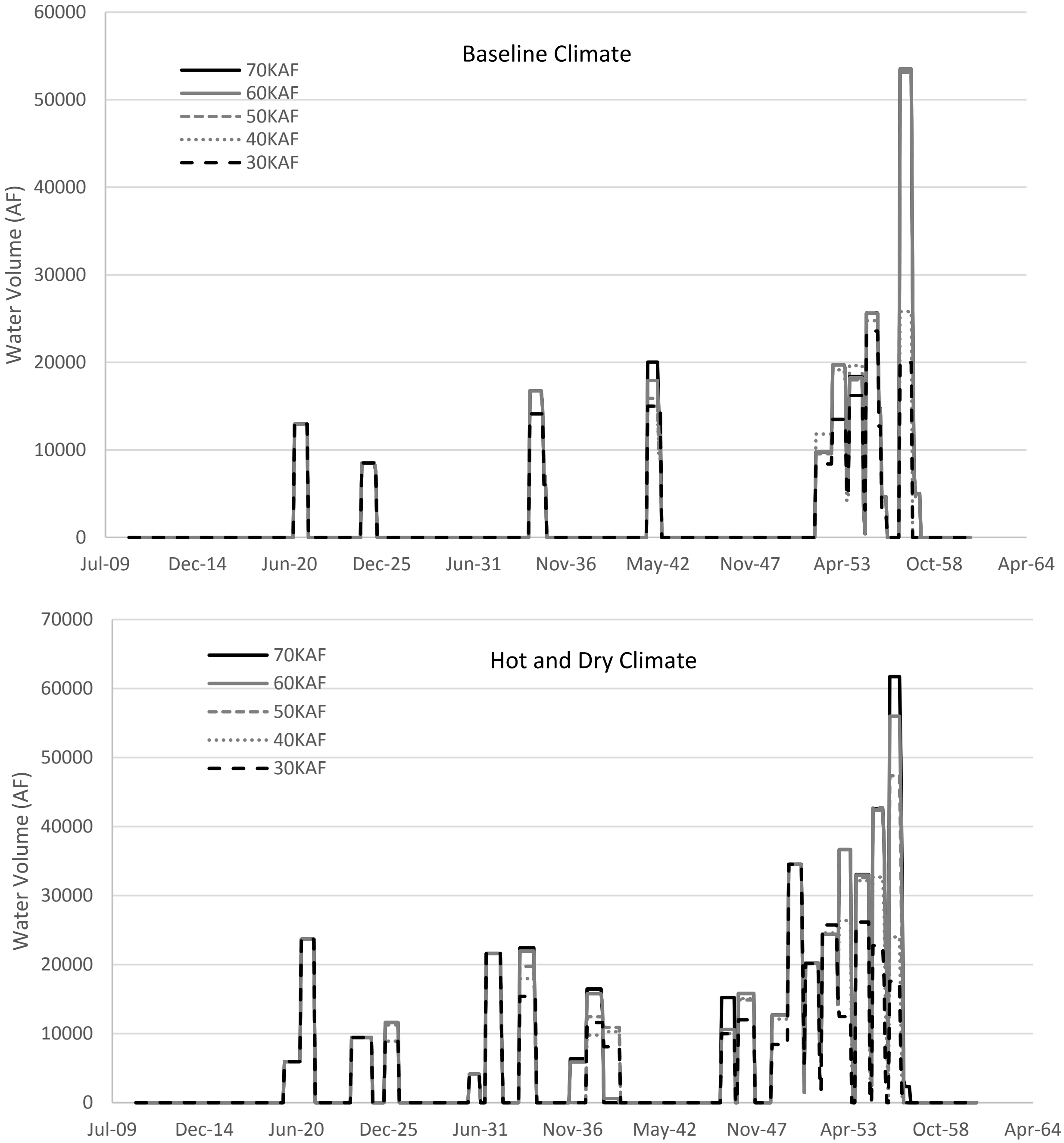

Figure 11 – Volume of water stored in the Kansas account for a variety of maximum augmentation water volumes under the baseline (top) and hot and dry (bottom) climate scenarios. A higher maximum augmentation water volume generally results in higher volumes in the Kansas account if KBID's demand requires it.

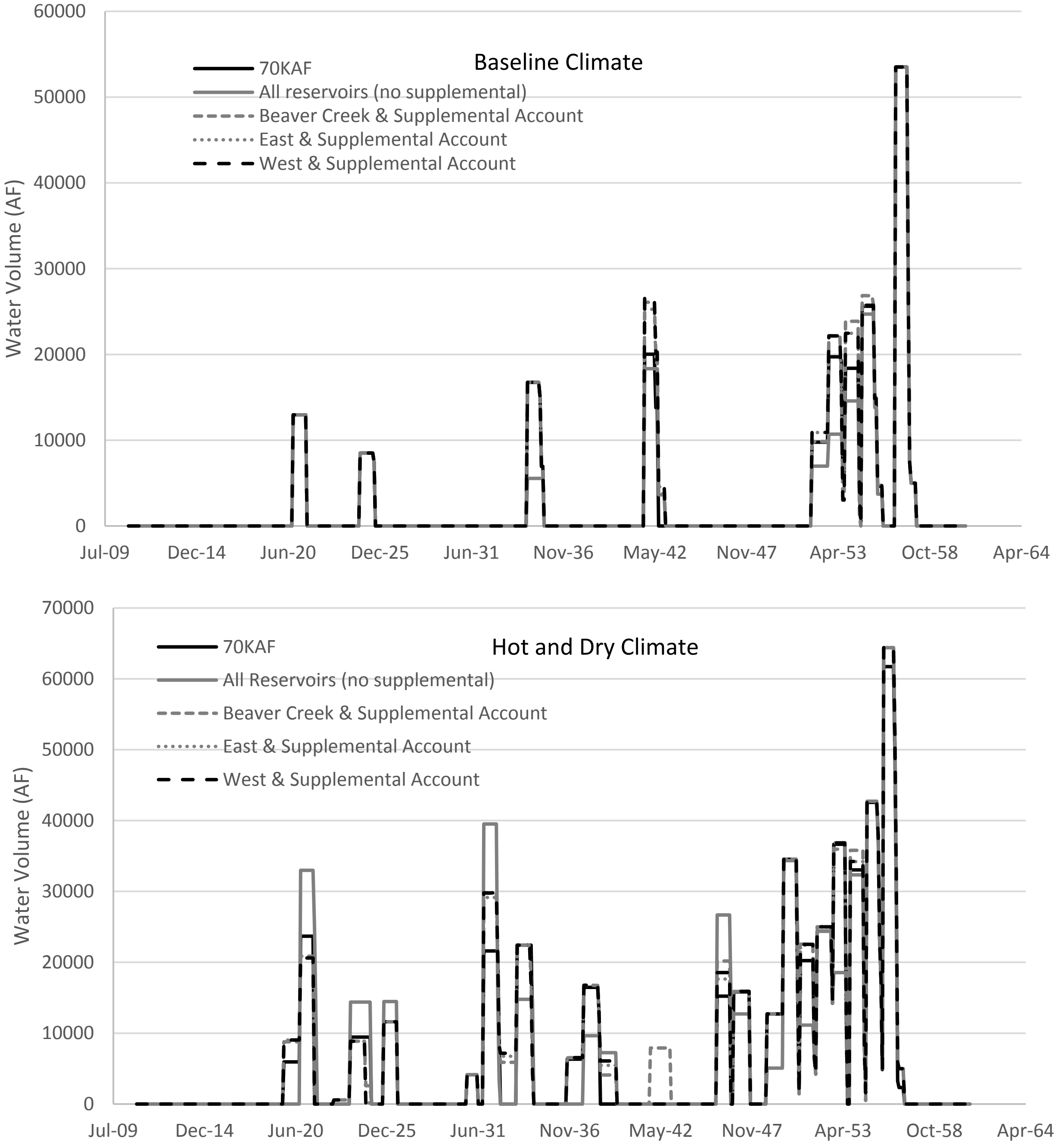

Figure 12 – Volume of water stored in the Kansas account for the simulations with the new reservoirs, all with a maximum augmentation water volume of 70k AF under the baseline (top) and hot and dry (bottom) climate scenarios.

Again, having a higher volume of water in the Kansas account is only beneficial to Kansas if it is used. In the current model simulations, any water remaining in the Kansas account at the end of the calendar year is transferred to the irrigation pool as project water, to be shared with the Nebraska Bostwick Irrigation District (NBID) as per the compact. Historically, this water is split by approximately 35% to NBID and 65% to KBID. To help determine what management options optimize Kansas' beneficial use of this water, the model was designed to calculate how much water is transferred to the irrigation pool from the Kansas account, assuming 35% of this water can no longer benefit Kansas (Figure 13). When the access district only has access to the new reservoirs, the water transferred to the Kansas account is highest and the water lost through this mechanism is also highest. Therefore, to optimize Kansas' use of water, this must be taken into consideration. The Kansas account water transferred back to the irrigation pool is also highest during the hot and dry simulations as there is error involved in estimating KBID's future water needs, and that error increases as demands increase under the hot and dry climate.

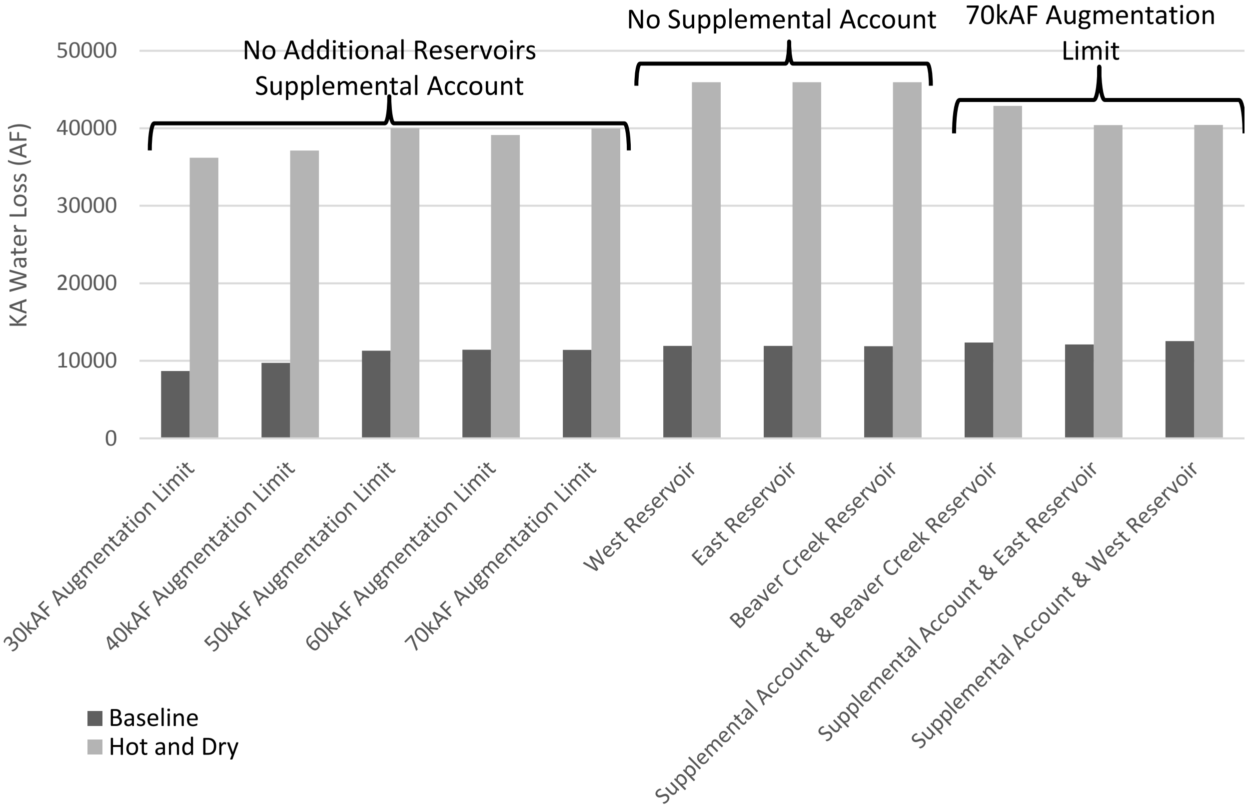

Figure 13 – Kansas' water loss represented by 35% of the Kansas account volume transferred to the irrigation pool. This represents water that is not put to Kansas' beneficial use as it is used by Nebraska's irrigation district.

Supplemental Account

The supplemental account provides water to the access district from HCL during MDS administration. It was not part of the original WaterSMART simulations; therefore, a comparison of storage in the supplemental account between WaterSMART simulations and current simulations cannot be made.

Consistent with the volumes of water stored in the RCCV, more water is available to transfer to the supplemental account, up to the 20,000 AF limit, when the maximum yearly augmentation volume is higher (Figure 14). Also consistent with water storage in the RCCV, when the access district has access to the RCCV and a reservoir, the volume of the supplemental account is higher than the simulations in which the supplemental account is the only water available to the access district (Figure 15). The increased benefit of having a reservoir for access district use is clearly visible when Figures 14 and 15 are compared; the access district relies less on the supplemental account, and therefore the supplemental account regularly has more water.

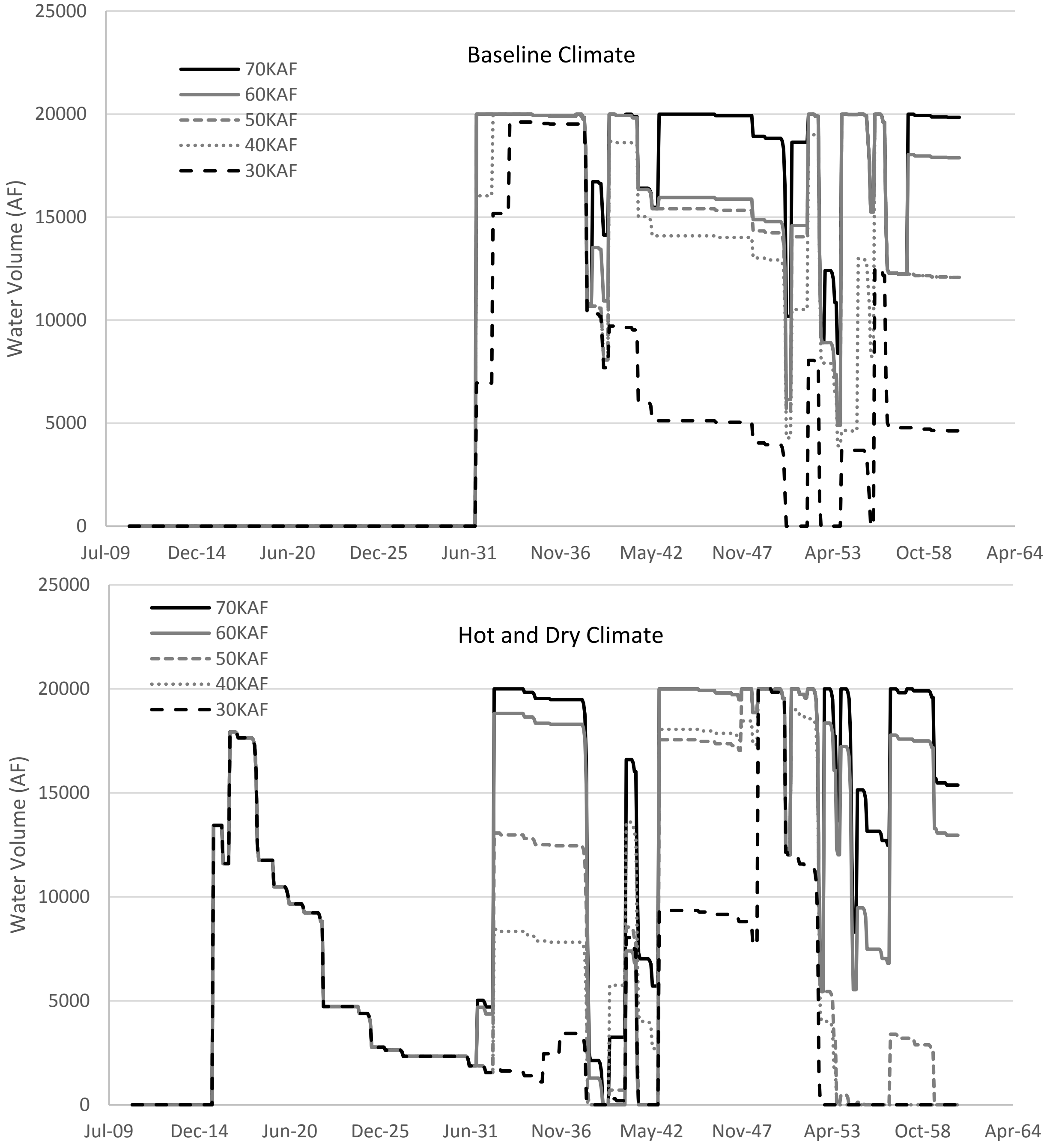

Figure 14 – Volume of water stored in the supplemental account for a variety of maximum augmentation water volumes under the baseline (top) and hot and dry (bottom) climate scenarios. A higher maximum augmentation water volume generally results in more water in the supplemental account, up to the 20,000 AF limit.

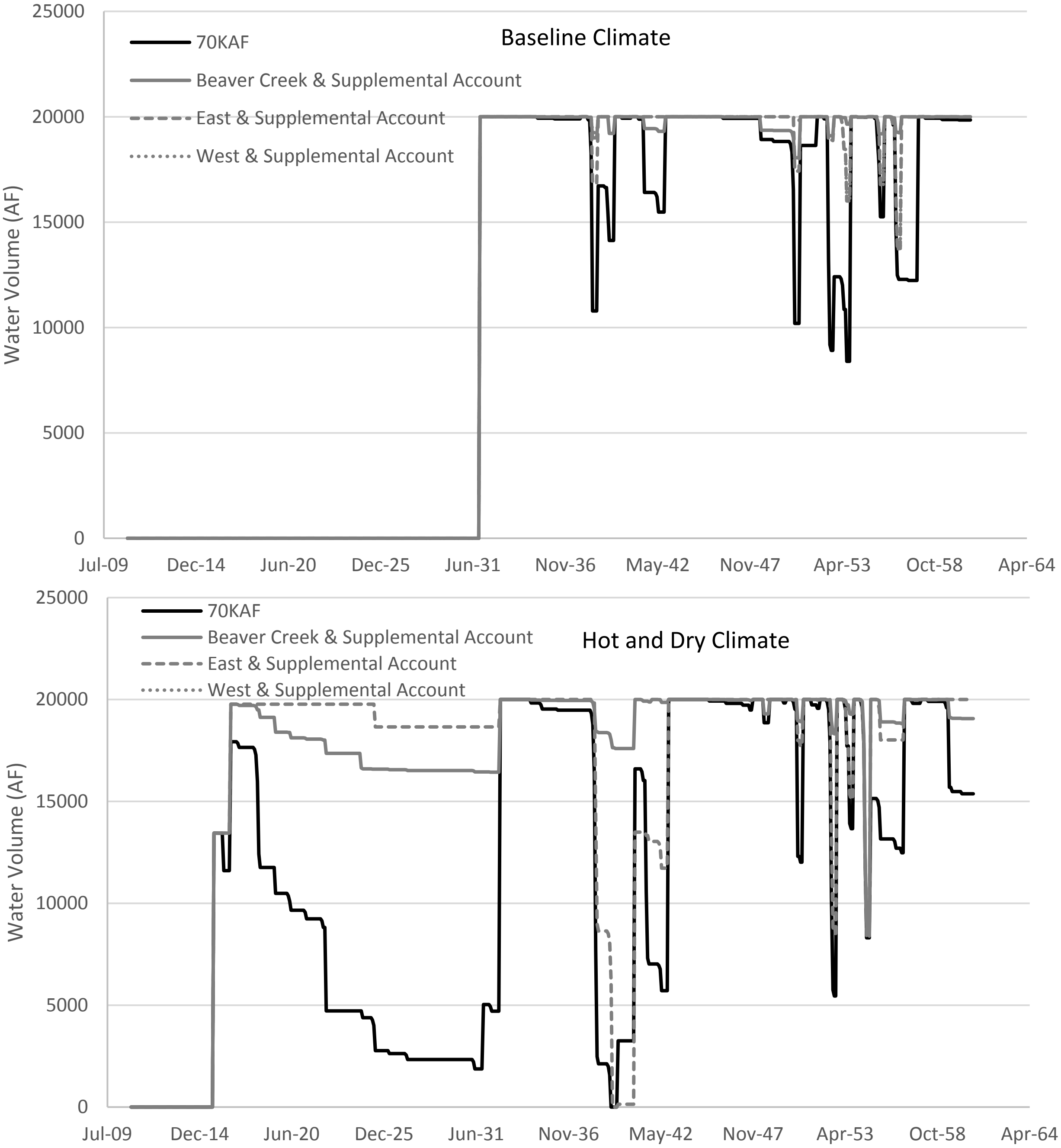

Figure 15 – Volume of water stored in the supplemental account for the simulations with the new reservoirs, all with a maximum augmentation water volume of 70k AF under the baseline (top) and hot and dry (bottom) climate scenarios. Supplemental account volumes are identical when either East or West reservoir is operating.

Reservoirs

Three potential reservoirs were developed in the OASIS LRRB model, and simulations were conducted with each of the reservoirs operating alone and in combination with the supplemental account to provide water to the access district during MDS administration. The ability of each reservoir to provide water to the access district can be analyzed by looking at water storage levels throughout the simulation; if there is no water in the reservoir, it cannot help reduce access district shortages.

West Reservoir

Water storage in West reservoir can provide water to the access district throughout most of the simulations (Figure 16). Under all scenarios, there are two periods—in late 2030s to early 2040s and in the early 2050s—when the reservoir frequently goes dry. The number of months the reservoir is dry ranges from 61 in the hot and dry scenario with a supplemental account to 26 in the baseline scenario with no supplemental account. When the supplemental account is operating, the reservoirs are used before the supplemental account because they are farther downstream. In addition, when the supplemental account is operating, there is less volume in HCL for project water, causing a slight decrease in water released to the river, which can be used to fill the reservoirs.

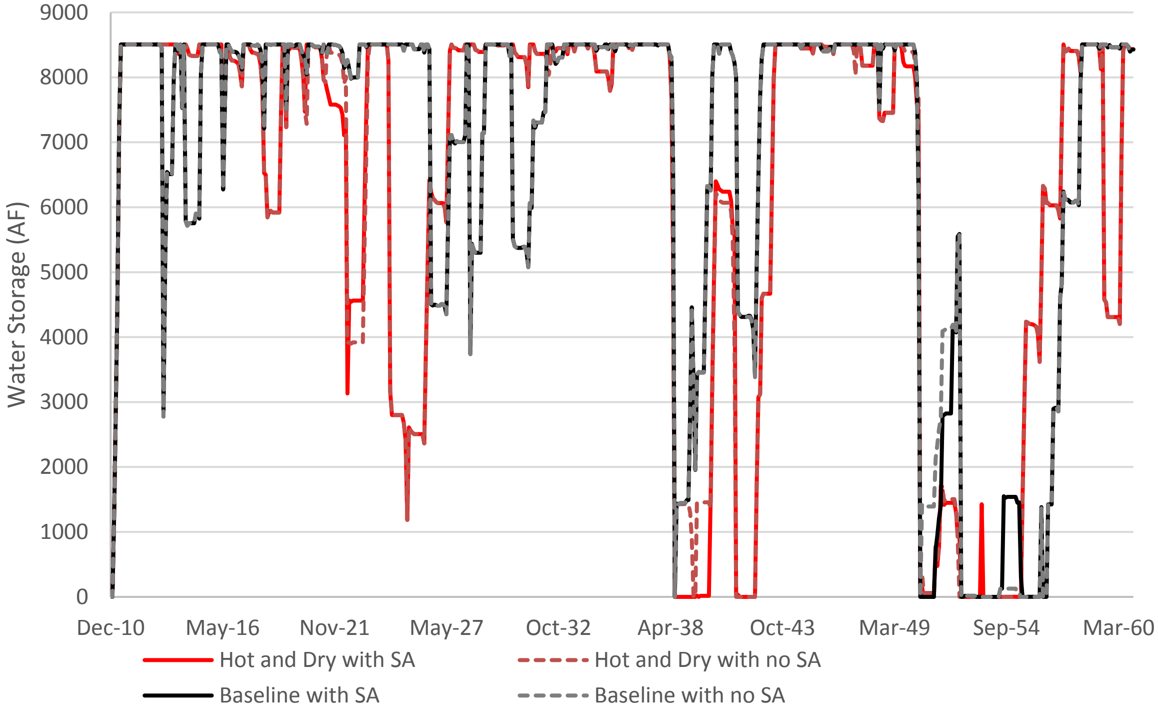

Figure 16 – Water storage in West reservoir for all scenarios. SA is supplemental account.

East Reservoir

Water storage in East reservoir can provide water to the access district throughout most of the simulations (Figure 17). Under all scenarios, there are two periods—in the late 2030s to early 2040s and in the early 2050s—when the reservoir frequently goes dry. Similar to West reservoir, the number of months the reservoir is dry ranges from 66 in the hot and dry scenario with a supplemental account to 26 in the baseline scenario with no supplemental account. East reservoir is the smallest of the three reservoirs considered in this work (Table 2) and goes dry the most frequently.

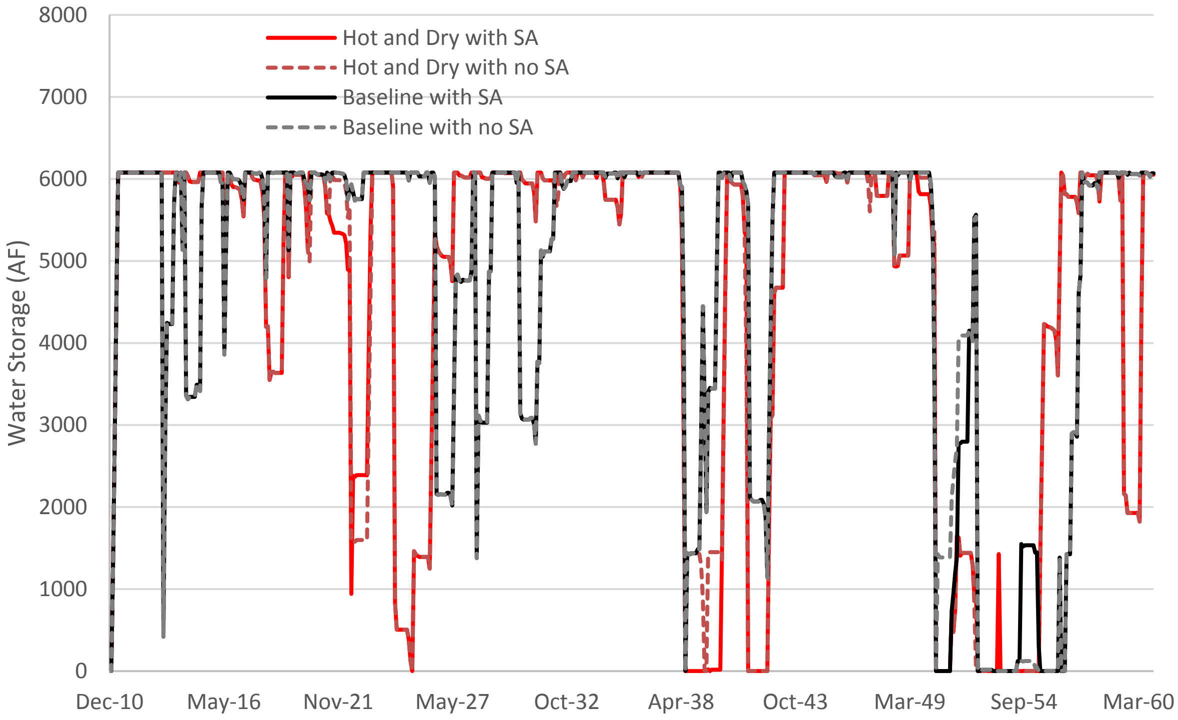

Figure 17 – Water storage in East reservoir for all scenarios. SA is supplemental account.

Beaver Creek Reservoir

Water storage levels in Beaver Creek reservoir can provide water to the access district throughout most of the simulations (Figure 18). Under the hot and dry scenarios, there is one period in the early 2050s when the reservoir frequently goes dry. The number of months the reservoir is dry ranges from 25 in the hot and dry scenario with no supplemental account to 2 in the baseline scenario with and without a supplemental account. Beaver Creek reservoir is significantly larger than both East and West reservoirs (Table 2) and is farther downstream in the basin, which doesn't allow it to provide water to all access district members (Figure 3).

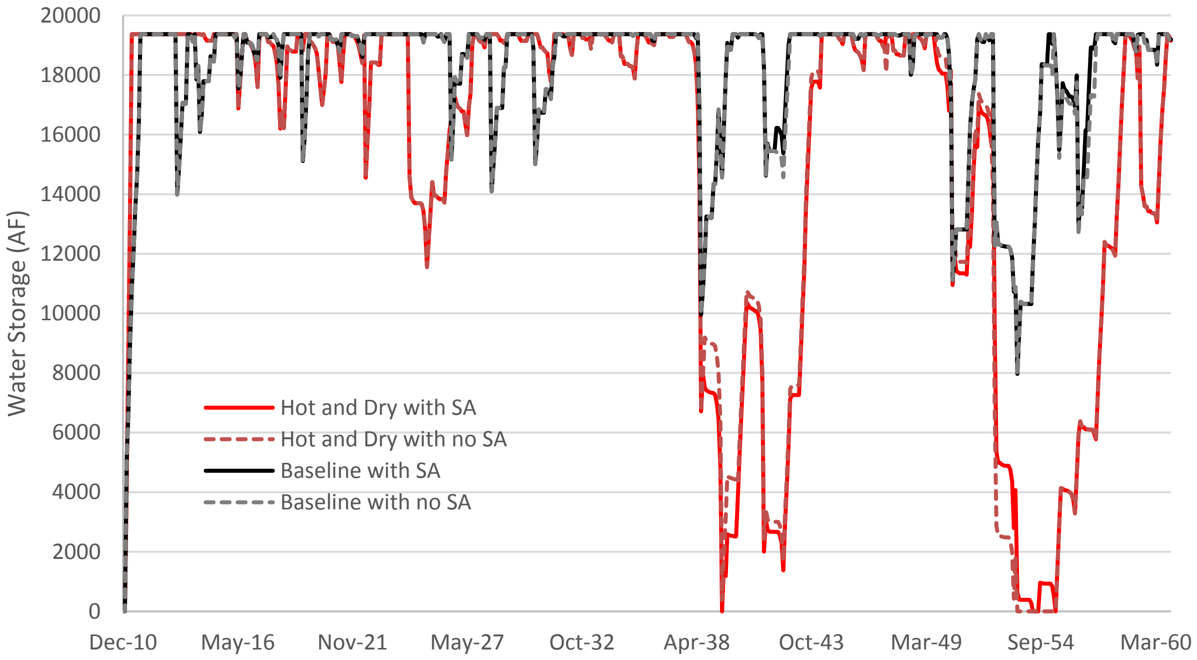

Figure 18 – Water storage in Beaver Creek reservoir for all scenarios. SA is supplemental account.

Discussion and Conclusions

The objective of this work is to assess the use of a supplemental account, Kansas account, and potential new reservoirs to optimize Kansas' beneficial use of water in the Lower Republican River Basin. Specifically, this work aims to assess how to reduce water shortages of the access district (the junior water rights between HCL and Milford reservoir in Kansas) under MDS administration, in addition to reducing KBID's water shortages. As can be seen in Figures 5 and 6, the best way to reduce water shortages is not the same for the access district as it is for KBID. KBID's water shortages are the lowest when the access district does not operate a supplemental account in HCL, whereas the access district's shortages are lowest when it operates a supplemental account in HCL in addition to either East or West reservoir.

Another part of optimizing Kansas' beneficial use of water in this basin is assessing how much water is lost from the system; that is, how much water had been available to Kansas users but was not used before it became unavailable. Aside from evaporation from reservoirs, which is not discussed here, there are two mechanisms in which Kansas can lose water from the system: (1) through item 10 of the resolution dated August 24, 2016, which indicates that in a non-compact call year, the volume stored in the RCCV will be reduced by 20% (Figure 10) and (2) when water in the Kansas account is not used by the end of the calendar year and is transferred to the irrigation pool, where approximately 35% of the water is used by Nebraska (Figure 13). When these are considered together, it is clear that operating a supplemental account in HCL reduces system losses (Figure 19). When considering system losses (Figure 19) and reductions in water shortages (Figures 5 and 6), it clear that operation of the supplemental account optimizes both. The operation of a reservoir in addition to the supplemental account benefits the access district (Figure 6) and, to a lesser extent, KBID (Figure 4).

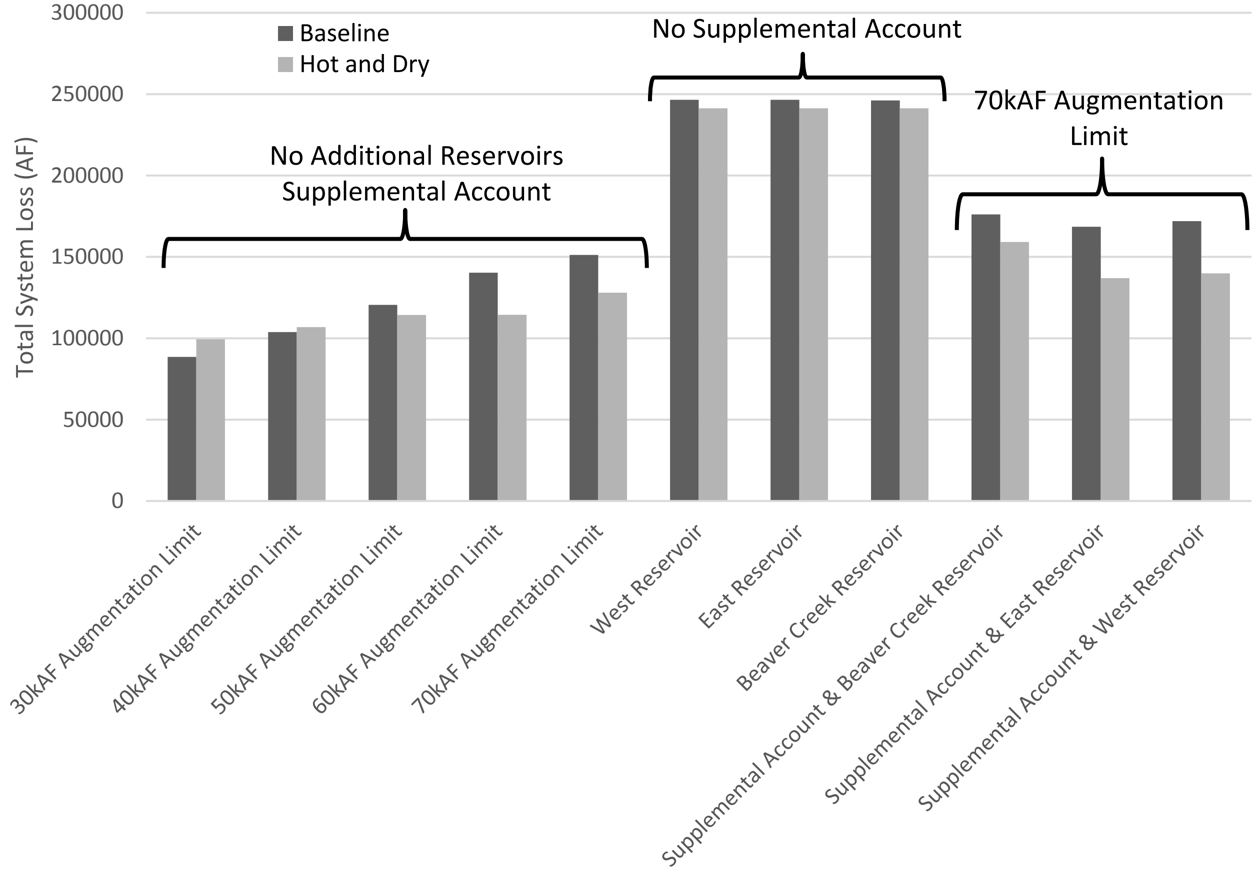

Figure 19 – Volume of water lost from the management system for all scenarios. These represent reductions to the RCCV due to item 10 of the resolution dated August 24, 2016, and water transferred from the Kansas account to project water, which is then subject to splitting with Nebraska.

These results are subject to a great deal of uncertainty, including, but not limited to, reservoir inflows, augmentation volumes, frequency of compact call years and MDS administration, climate uncertainty, water right involvement in access district, and reservoir management options. Therefore, the results of this work should not be considered representative of future conditions but rather indicators of trends in system behavior under the simulated management strategies. Future work, as discussed below, should attempt to assess these uncertainties to provide a better understanding of how the system will respond to changes in the uncertain parameters.

Future Work

As discussed above, it is recommended that future work assess uncertainty associated with a variety of model input parameters and variables. It is suggested that this assessment include the following:

1) Reservoir inflows – the model currently relies on outdated STELLA model results from Nebraska's WaterSMART simulations as HCL inflows. In addition, inflows into Lovewell, West, East, and Beaver Creek reservoirs are not modified for the hot and dry climate. It is recommended that these inflows be updated using a combination of recent measured inflows (particularly for HCL, where recent inflows would better reflect updated water management by Nebraska) and statistical approaches to modify the inflows to reflect simulated climate conditions.
2) Augmentation volumes – Kansas Department of Agriculture, Division of Water Resources has access to Nebraska's recent augmentation volumes, in addition to future estimates. It is recommended that scenarios of augmentation volume be developed to better simulate this important variable in this work.
3) Compact call years – the model also currently relies on outdated STELLA model results from Nebraska's WaterSMART simulations to determine whether a year will be a compact call year or not. It is recommended that the future simulations address the uncertainty in these estimates as they drive the timing and availability of the RCCV, by performing simulations with a variety of compact call year scenarios.
4) MDS administration – MDS administration is currently determined using monthly results. While conversion to a daily model would be excessively time consuming and would introduce even more error into the simulations, simulating a variety of MDS administration scenarios using perturbations of the originally simulated distributions could address uncertainty of this parameter.
5) Climate uncertainty – Additional climate scenarios were developed for the WaterSMART basin study, and simulations under these scenarios would better inform the robustness of the management strategies.
6) Water right involvement in access district – Current model simulations assume all junior water rights will choose to be part of the access district. Future simulations can include a variety of involvement to assess the ability of the supplemental accounts and new reservoirs to meet their modified demands.
7) Reservoir management options – There are several management options available for HCL reservoir that can be further investigated. These include the quantity of water reserved for KBID's future use in the RCCV, the maximum volume of the supplemental account, allowing for the ability to transfer water from the Kansas account to the supplemental account, and the yearly and monthly maximum augmentation volumes. In addition, better defining the operation of the new reservoirs based upon the availability of water in the supplement account can allow for optimized water management in the basin.

References

Brookfield, A., Gnau, C., and Wilson, B., 2017. Incorporating surface water operations in an integrated hydrologic model: Model development and application to the Lower Republican River Basin, USA. Journal of Hydrologic Engineering, Vol. 22, No. 4 doi: 10.1061/(ASCE)HE.1943-5584.

Kansas and Nebraska, 2016, Resolution approving long-term agreements related to the operation of Harlan county lake for compact call years. August 24, 2016. https://agriculture.ks.gov/docs/default-source/iwi---republican-river-compact/final_resolution_hcl_20160823.pdf?sfvrsn=4

USBR, Colorado, Nebraska, and Kansas, 2016, Republican River Basin Study. 322 p. https://www.usbr.gov/watersmart/bsp/docs/finalreport/republican/republican-river-basin-study-final-report.pdf