FRYINGPAN-ARKANSAS PROJECT RIVERWARE MODEL

Model Documentation

and

Model Scenario Descriptions for the Temporary Excess Capacity NEPA Analysis

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ABBREVIATIONS AND ACRONYMS

AF	acre-feet (common unit of water volume)
AGUA	Arkansas Groundwater Users Association
APOD	Alternate Point of Diversion
ARFG	Arkansas River Farms Group
Aurora	Aurora Water
AVC	Arkansas Valley Conduit
BLM	U.S. Bureau of Land Management
CC	Colorado Canal and Reservoir System
CDSS	Colorado's Decision Support System
CDWR	Colorado Department of Water Resources
cfs	cubic feet per second (common unit of water flow)
Corps	U.S. Army Corps of Engineers
CPW	Colorado Parks and Wildlife
CSU	Colorado Springs Utilities
CWPDA	Colorado Water Protective and Development Association
EA	Environmental Assessment
EC	Excess Capacity
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FryArk	Fryingpan-Arkansas Project
FVA	Fountain Valley Authority
HB	HydroBase
LAVWCD	Lower Arkansas Valley Water Conservancy District
LT EC	Long-Term Excess Capacity
M&I	Municipal and Industrial
MC	Long-Term Excess Capacity Master Contract
NEPA	National Environmental Policy Act
PBWW	Pueblo Water (fka Pueblo Board of Water Works)
PFMP	Pueblo Flow Management Plan
Pueblo West	Pueblo West Metropolitan District
PW/Project Water	Fryingpan-Arkansas Project Water
Reclamation	U.S. Bureau of Reclamation
RICD	Recreational In-Channel Diversion
ROY	Restoration of Yield
SCMWD	Saint Charles Mesa Water District
SDS	Southern Delivery System
SECWCD/Southeastern	Southeastern Colorado Water Conservancy District
TLCC	Twin Lakes Canal and Reservoir Company
UAWCD	Upper Arkansas Water Conservancy District
USGS	U.S. Geological Survey
VFMP	(Upper Arkansas) Voluntary Flow Management Plan
WW/WWSP	Winter Water/Winter Water Storage Program
WWTP	Wastewater Treatment Plant

PREFACE

This model documentation was written to be sufficient for Reclamation's needs and requests to support their Temporary Excess Capacity Contracts NEPA analysis. This documentation has been developed in a manner to broadly describe the many processes simulated by the model and the general methodologies used to simulate the basin's complex policy, administration, and operational procedures. It is assumed that readers will already have a good understanding of the complex water resources system that is the Arkansas River Basin, of general water resources engineering and management, and of Colorado water law.

Additionally, many informal descriptions and developer comments can be found throughout the model and supporting files that describe in more detail the purposes of various model components (e.g., the RiverWare rules and various objects/slots), the sources of various information, procedures, and model-driving data, and the logic, code, and calculations utilized by the model to simulate the basin's various processes and operations.

1 INTRODUCTION

1.1 BACKGROUND

The Fryingpan-Arkansas Project RiverWare Model (herein the "RiverWare model") simulates the surface water resources system of the Arkansas River basin in Colorado. This water resources system contains complex policy and is highly regulated and actively managed to provide efficient and effective water supply to many water users competing for limited resource, while attempting to limit negative impacts to the environment and to further downstream water users. The use of the basin's natural surface water supply (i.e., native flow) is administered through water rights by the Colorado Department of Water Resources under the "1st in time, 1st in right" Prior Appropriation Doctrine. On top of the intricate native water right system, the Bureau of Reclamation operates the Fryingpan-Arkansas Project, which imports Colorado River basin water from the west side of the continental divide to the Arkansas River basin on the east, to provide additional water supply for both municipal and agricultural use. Additionally, several large municipalities (notably Colorado Springs, Pueblo, and Aurora) and other water user and stakeholder organizations (e.g., ditch companies and conservancy districts) operate additional projects within the basin, utilizing both independent and shared resources and infrastructure. The policy and operations of the Arkansas River basin water resources system is continuously evolving and adapting to account for changing water uses and increasing demands in the face of highly variable natural water supplies, reductions in other water sources (such as groundwater), and stricter environmental regulations.

1.2 MODEL OBJECTIVES

The ultimate objective of the RiverWare model is to investigate the effects and impacts of various potential changes in the surface water resource system of the Arkansas River basin. Potential changes that may be investigated are wide ranging and may include changing water uses and demands, altered operational procedures, differing policy or regulations, new infrastructure, or varied hydrology, just to name a few.

The first step towards accomplishing this goal is for the model to provide appropriate and accurate simulation of the current state of the system in terms of the policy, operational procedures, water uses and demands, and infrastructure, throughout a wide range of potential hydrologic conditions. This will provide a baseline representation of the system's current conditions. Next, the system can be altered within the model by implementing a desired change, for example by changing a reservoir's operational procedures, and simulating the altered system. The potential impacts of the change can be investigated and estimated by comparing the model results representing the current state of the system to model results that represent the altered system.

The RiverWare model was originally developed to investigate the potential impacts of the Fryingpan-Arkansas Project's "Annual" or Temporary Excess Capacity Contracts that Reclamation may enter with various entities. These contracts create storage accounts within Pueblo Reservoir that may be operated by the entity to provide for storage and flexible utilization of their water supplies. The water supplies stored in these accounts must be allowable for storage according to Colorado water law and are subject to other applicable regulations and limits imposed by Colorado, Reclamation, or other entities.

1.3 Model Run Period and Input Hydrology

The RiverWare model is run on a daily timestep with a full model run period of 10/1/1990-12/31/2015, which currently corresponds to the historic observed hydrology between those dates. This period is 25.25 years long and contains 25 full water and calendar years (1991-2015). This period was selected after an initial review of historic data availability. The necessary hydrologic data to drive the model was developed from the historic data for this period. Shorter model runs are also possible, as are model runs driven by synthetic or modified input hydrology (e.g., re-sequenced or selectively sampled historic years). The model's initial conditions (i.e., reservoir and account storages) are also flexible and can be modified to represent variable starting conditions.

The model is designed to be flexible in terms of hydrologic inputs. This allows for analysis of the system's potential response to novel or altered hydrologic regimes such those that may reflect the effects of climate change or other conditions such as extended drought sequences.

To achieve this flexibility, the model and model-driving data were designed and developed in such a way as to limit the influence of historic basin conditions on the model runs as much as possible. This means that modeled policy, operational processes, water uses and demand levels, and other factors are designed to dynamically simulate the current state of the system rather than assuming they would be the same as they were historically. The model run period is not meant to be a recreation of the transient system as it existed historically, but a simulated representation of how the system would have behaved had the current policy, operational processes, water uses and demand levels, and other factors been present throughout the entire period.

The "Hydrologic Year Types" of the full model run period are shown below in Table 1. Years are classified as "Wet", "Average", or "Dry" based on the natural runoff conditions present in the basin relative to the historic distribution of conditions. "Wet" years are defined as being in the top 30% of the historic distribution, "Dry" years are in the lowest 30%, and "Average" years are those in between. This year type classification is defined in the ModSim model used for the SDS and AVC EIS reports (MWH, 2007). The Natural Resources Conservation Service's (NRCS) "most probable" (50% chance of exceedance) forecasts of natural flow volume at the Arkansas River at Salida gage are used to define the natural runoff conditions within this classification. These forecasts are published each year on an approximately monthly basis during the late winter snowpack accumulation and throughout the subsequent snowmelt runoff period. During simulation, the hydrologic year types are assumed to be known at the beginning of each year based on the last available historic Salida natural flow forecast of each historic year, and thus the year types within each simulation year are assumed to be static and not change as these forecasts would evolve during the year. This means that the effects of forecast error and changing forecasts are not simulated. Furthermore, the full historically available forecast period of 1966 to 2016 is used within the model to determine year types, not only the years present within the full model run period.

Table 1: Hydrologic Year Types of Full Model Run Period.

Year	Hydrologic Year Type
1990	Dry
1991	Average
1992	Dry
1993	Wet
1994	Average
1995	Wet
1996	Wet
1997	Wet
1998	Average
1999	Average
2000	Dry
2001	Dry
2002	Dry
2003	Average
2004	Dry
2005	Average
2006	Average
2007	Average
2008	Wet
2009	Wet
2010	Average
2011	Wet
2012	Dry
2013	Dry
2014	Average
2015	Average

1.4 Model Extent

The RiverWare model simulates the Arkansas River water resource system from its headwaters near Leadville, CO to the Colorado-Kansas state line. The model simulates the streamflow of the Arkansas River from East Fork Arkansas River near Leadville, CO gage downstream to the Arkansas River near Coolidge, KS gage.

The upper basin reservoirs of Turquoise Lake, Twin Lakes, and Clear Creek Reservoirs are simulated. Inflows and diversions on the mainstem of the Arkansas River are simulated as it flows generally southward through the headwaters basin in the Rocky Mountains, turning southeast and eventually east as it exits the mountains near Pueblo, CO where it flows into Pueblo Reservoir, which is simulated in detail.

Shortly below Pueblo Reservoir, Fountain Creek flows into the Arkansas River from the north. Fountain Creek is simulated from approximately Colorado Springs downstream to the mouth of the Arkansas

River. The Fountain and Monument Creek systems above Colorado Springs are not currently simulated in the model. Below Fountain Creek, the Arkansas River is simulated as it flows eastward across the semi-arid plains of southeast Colorado. Through this region, many significant diversions are simulated, including the Colorado Canal system and offstream reservoirs of Lakes Henry and Meredith and the Holbrook Canal system and offstream Holbrook and Dye Reservoirs.

The Purgatoire River flows into the Arkansas River near Las Animas, CO, just upstream of John Martin Reservoir. The Purgatoire River is simulated from just upstream of Trinidad Reservoir near Trinidad, CO downstream to its confluence with the Arkansas River. Trinidad Reservoir is simulated within the model.

Just downstream of the Purgatoire River, the Arkansas River flows into John Martin Reservoir, which is simulated in the model. Downstream of John Martin, the Arkansas River is simulated as it continues to flow eastward to the downstream end of the model extent near where the river exits Colorado into Kansas.

1.5 Summary of Major Simulated Processes

Broadly, the RiverWare model simulates the significant operations and policy of the basin, summarized below. These are each described in more detail later in the documentation.

- Water Rights – The model simulates the allocation of native flow to both direct flow water rights on the Arkansas River and simulated tributaries, and storage water rights of the simulated reservoirs. Many subsequent water right transactions are also simulated, including river exchanges, alternate points of diversion, and other operations associated with changed water rights.
- Winter Water Storage Program – The Winter Water Storage Program is simulated in Pueblo Reservoir, the Colorado Canal, the Fort Lyon Storage Canal, and John Martin Reservoir. Following each storage season, the allocation to the WW parties is simulated as are the subsequent deliveries of WW storage to water users.
- Fryingpan-Arkansas Project – The Fryingpan-Arkansas Project is simulated within the model. Project Water operations and accounting are simulated in Turquoise Lake, Twin Lakes, and Pueblo Reservoir, including the allocations and deliveries of Project Water to water users.
- Reservoir Operations and Storage Accounting – Reservoir operations and storage accounting are simulated for 11 major Upper Basin and mainstem Arkansas River reservoirs. These include:
  - Turquoise Lake, Mount Elbert Forebay, Twin Lakes, and Clear Creek Reservoir in the Upper Arkansas River Basin
  - Pueblo Reservoir and John Martin Reservoir on the mainstem of the Arkansas River
  - Lakes Henry and Meredith on the Colorado Canal system
  - Holbrook and Dye Reservoirs on the Holbrook Canal system
  - Trinidad Reservoir on the Purgatoire River
- Pueblo Reservoir Excess Capacity Storage Accounting – A major feature of the model is explicit simulation of the operations of many existing and potential Pueblo Reservoir Excess Capacity accounts, including the establishment of storage from different sources and the subsequent deliveries, other uses, and associated transactions associated with these accounts.

- Water User Demands and Diversions – Both agricultural and municipal water user demands and diversions of both in priority native flow and deliveries from various storage sources are simulated through the model extent.
- Major Municipal Entities Operations – The operations of the major municipal water users of Aurora Water (Aurora), Colorado Springs Utilities (CSU), and Pueblo Water (PBWW) are simulated. These entities each have complex and unique operational objectives, operating multiple storage accounts in different reservoirs to utilize multiple water supply sources and meet multiple demands.
- Minimum Flows and Flow Management Programs – The simulated operations of various entities are subject to the limitations provided by various minimum flow requirements and flow management plans, including the Upper Arkansas Voluntary Flow Management Plan (VFMP), the Pueblo Flow Management Program (PFMP), and minimum reservoir release criteria.

1.6 Model Limitations and Major Assumptions

Several significant and overarching model limitations and assumptions are discussed below. Many more specific modeling assumptions are discussed throughout the documentation.

1.6.1 Level of Detail of Modeled Accounting

Accounting is represented at various levels of detail throughout the model according to need and available information. Many entities represented in the basin have multiple water sources providing different types of water, each of which may be subject to different rules and requirements based on water right decrees or other policy (e.g., single use or fully consumable designation, specific limitations on locations of use, etc). Different types of water and the associated requirements can and do play significant roles in how each entity may utilize their different water sources and can become limiting in various ways. In actual operations, many entities are either required by the Colorado Department of Water Resources (CDWR) or elect to track various types of water from their original sources, through storage in one or multiple locations, through diversion and use, and in some cases through the generated return flows and on to other uses or back into storage if allowable. The complications posed by the multitude of different water types and the complex and changing operational decisions and requirements across different entities necessitate that broad assumptions and simplifications be made in the model.

The sub-accounting breakdowns of various water sources and types within individual accounts are in general not continued to be tracked individually once they are stored in Excess Capacity accounts in Pueblo Reservoir or other reservoir storage accounts. Instead, most subaccounts are lumped together as a total amount of water for each account. As an example, all water that may end up in CSU's Twin Lakes Reservoir and Canal Company (TLCC) storage account in Twin Lakes Reservoir is treated the same by the model, even though it may actually consist of many different types of water with specific rules and conditions for each type. Specific limits and requirements are maintained on the source side, e.g., maximum annual storage volumes from certain sources, however most specific and detailed rules and preferences that may come into play after the water being stored are not represented. A notable exception exists in Turquoise Lake's Homestake accounts owned by Aurora and CSU, which are tracked separately from Aurora's and CSU's other types of water within Turquoise Lake due to the important requirement that the Homestake accounts may only store Homestake water.

A major assumption here is that the lumping of different types of water through various entities storage accounts can still provide an appropriate level of detail for the model's purposes. In the real world each entity strives to operate as efficiently as possible and make the best use of their various types of water and thus it is assumed that the lumping of different water types in the model does not result in significantly different model results.

1.6.2 Unmodeled Tributaries and Reservoirs

Unmodeled tributary outflows, whether included as an explicit boundary inflow gage or lumped into a reach's local inflow, are assumed to be the same as they were historically. Therefore, differences in tributary outflows due to factors such as altered water right allocations, changing water uses and demands, and changing reservoir operations in the tributary basins are not captured. This includes the effects of altered river call dates that may be caused due to the varying basin conditions presented by different scenarios. It is currently assumed that these differences will cause negligible overall effects on the modeled system. It is recommended that these areas be further investigated and potentially added to the model in the future.

Some of these notable unmodeled tributaries and reservoir systems include:

- South Arkansas River
- Grape Creek and Deweese Reservoir
- Beaver Creek
- Fountain Creek and Monument Creek systems above Colorado Springs, CO
- Horse and Abobe Creeks and Reservoirs
- Great Plains Reservoirs system

1.6.3 Lack of Simulation of the Full Colorado Springs Utilities System

There are several major limitations and assumptions that stem from the limited representation of the Colorado Springs Utilities (CSU) system in the RiverWare model. Generally, these relate to broad assumptions that must be made regarding future flows in Fountain and Monument Creeks above Colorado Springs, future yields of CSU's sources not simulated by the model, future CSU demands on simulated Arkansas basin sources and the distribution of those demands between various potential delivery locations, and future potential CSU reusable return flows. Please see the further discussion later in the report in the section describing CSU's representation in the model.

1.6.4 Lack of Simulation of Exchange of FryArk Project Water Reusable Return Flows

Currently, FryArk Project Water reusable return flows and their end use, whether it be by sale for augmentation or return flow requirement purposes or by exchange or other recapture within Pueblo Reservoir or other storage locations, are not simulated due to a few main reasons.

First, the historic return flow data necessary to back out all of the historic return flows from the local inflows was not available or doesn't exist. Second, the historic project water deliveries to all users and the detailed accounting breakdown of the end use of the historic reusable Project Water return flows from all of those deliveries was not available or doesn't exist. Third, the current and future procedures and processes used to operate the generated Project Water reusable return flows were not provided or do not exist.

For these reasons, it must be currently assumed in the model that all FryArk Project Water reusable return flows are not exchanged or otherwise recaptured in storage. Instead, it is assumed that all FryArk Project Water reusable return flows are left in the river as native flow at their point of return for various purposes such as their sale for augmentation to allow for out-of-priority pumping depletions.

1.6.5 Use of Historical Transbasin Import Data

At the current level of model development and for the current study, Reclamation elected to use historic import data records. The main assumption here is that the imports produced by past hydrologic conditions would be approximately the same if similar hydrology were to occur in the future. Given that the water imported from the west slope originates in headwater basins, the fact that the west slope water rights of the imports are typically senior within their basins, and the fact that policy, operations, and water uses have changed relatively less in those basins than in the Arkansas River basin, this may in fact be a reasonable enough assumption.

Of potentially more impact is the fact that the historic imports data reflects past curtailments of imports that occurred in certain years due to high storage conditions in the Arkansas basin. Due to the changing policy, operations, and water uses in the Arkansas basin, especially those presented by the future model scenarios, there is no guarantee that imports that were curtailed historically would also need to be curtailed in future years of similar hydrology. Conversely, but also possible, changing operations in the Arkansas basin, such as changed water rights potentially causing more water to be available for storage, may lead to increased Arkansas basin storages and thus increased future import curtailments.

1.6.6 Limitations and Major Assumptions Associated with Model Local Inflows

There are several necessary assumptions and limitations associated with the calculated local inflows currently utilized by the model, the most significant of which are described below. The local inflow calculations used to generate the input local inflow data currently used by the model are completed with daily timestep mass balance calculations on a reach-by-reach basis, with reaches typically being divided by mainstem flow gages and reservoirs. Most of the assumptions and the limitations related to the local inflows currently being utilized by the model are due to the lack of adequate historic data records necessary in the local inflow calculations.

Ideally, the objective of the local inflow calculations is to produce "natural" local inflows that represent the historic ungaged, natural flow gains to each river reach by backing out historic water uses and the effects of historic regulation and other system operations. The model is then used to reallocate the total natural river flow and to re-operate the system based on the current water uses, policy, and operational procedures. These types of methods of calculating local inflows are generally data intensive, and the quality of the produced local inflows are highly dependent on the quality of the utilized historic data. However, these types of methods can produce the most reliable model results, including the most appropriate characterizations of potential future system conditions and the best estimates of the effects that may be caused by potential or proposed changes to the system.

In practice, the currently utilized calculated local inflows can generally be described as “naturalized” as some, but not all, of the historic water use and operational effects can be adjusted for. The calculated local inflows implicitly contain the effects of any water uses, operations, or other processes that are not explicitly represented in the mass balance calculations. Additionally, calculated local inflows contain the effects of gage and data errors that are prevalent in many of the available datasets and sources.

Overall, the current model local inflows are considered to be of better quality in the upper basin above Pueblo Reservoir, than in the lower basin. However, this is likely because most of the natural inflows occurs in the upper basin, while the majority of the water uses occurs in the lower basin. Thus, any uncertainty or errors in the lower basin data is more likely to cause significant and noticeable mass balance issues, which are relatively prevalent in the lower basin reaches. For many reaches and periods, both temporal and spatial smoothing and redistribution techniques are required to achieve satisfactory model input local inflows. Overall, it is assumed that the utilized model input local inflows provide a reasonable and appropriate characterization of the actual local inflows that occur in the basin.

1.6.6.1 Lumping of Most Water User Return Flows into Local Inflows

With a few notable exceptions mentioned below and discussed further elsewhere in the documentation, the majority of historic return flows have not been included as explicit terms in the calculations of the model input local inflows. This is primarily due to the lack of sufficient historic return flow data, or the otherwise necessary data, required to back out the return flows that resulted from historic water uses on a reach-by-reach basis. Ideally, the return flows of all modeled water users would be completely removed from the model’s local inflows and represented explicitly within the model, such that as simulated diversions and water uses vary from historic levels, the return flows can respond accordingly. It is recommended that addressing these issues should be a high priority in future work.

In the current model input local inflow calculations, only the historic return flows of CSU, PBWW, and Pueblo West have been accounted for. These three municipal entities are currently the only water users for which sufficient historic return flow data was readily available and was sufficient in both quality and period of record to be included in the local inflow calculations. Thus, these entities are also the only model water users whose return flows are explicitly simulated in the model.

For all other water users, the return flows from the water users represented in the model are not explicitly simulated. It is assumed that the historic return flows implicitly represented within the current model input local inflows are similar enough in timing, magnitude, and location to those that may occur in under current and future basin operations. On an overall basis, the model results for total water user deliveries, especially for those major agricultural water users that generate significant return flows, are reasonably similar to historic levels and thus the historic return flows should be representative. However, this assumption is less valid for water users with significantly changing demands, such as growing municipal water users whose return flows are expected to grow with their demands. Still, given the inherent uncertainty of all the various historic data used in the local inflows calculations, the uncertainty of return flow magnitudes and spatial and temporal patterns, and the fact that on an overall volumetric basis agricultural uses still constitute a large majority of water uses in the basin, the impacts of these assumptions on model results should be relatively minor.

1.6.6.2 Lumping of Augmentation Station Return Flows and Uses into Local Inflows

In the context of the local inflow calculations, augmentation station return flows refer to water that is diverted into a canal headgate and subsequently returned to the river in a near immediate fashion though “augmentation stations” that measure the amount of flow returned to the river. Generally, a portion of the returned flow is then used to offset out-of-priority river flows depletions caused by groundwater pumping or diversion at other structures. Augmentation stations are also often used to measure the flow that a water user may then be allowed to store elsewhere in the system, for example by exchange. This practice of changing water rights to allow for storage has been being used more and more as time goes on and is often also associated with the change of water rights from irrigation to municipal uses.

With some exceptions (e.g., Rocky Ford Ditch, Fountain Mutual Canal, Excelsior Ditch, etc, discussed later in the documentation), most historic augmentation station data records are insufficient in both period of record and data quality to include them in the local inflow calculations, which require complete and quality data for the full model period to generate reliable local inflows. As most local inflow calculations utilize the historic total headgate diversions, which tend to have better data records than augmentation stations, any flows that were historically returned to the river that are not explicitly backed out of the local inflow calculations will end up being present in the model’s local inflows. In the case of these historic returned flows being used to augment historic ungaged river depletions that are near in both time and location, and that are also not included in the local inflow calculations (see next item below), this increase in local inflows should approximately cancel out the decrease in local inflows caused by the depletions and the local inflow mass balance should be approximately correct. However, if the historic returns to the river and river depletions are not near in time or location, this will cause mass balance issues within the local inflows calculations. Additionally, in the case that augmentation station returns were historically made to the river alongside storage outside of the same local inflow calculation reach (i.e., an exchange from a diversion into storage), the calculations will show an errant net gain (i.e., “double-counting”) to the system unless the historically returned flow can be appropriately backed out. These types of issues can be further compounded if the same types of operations are simulated in the model where the effects of historic operations have not been properly accounted for.

These types of historic augmentation station return issues, along with other similar ones, have been adjusted and corrected for as much as possible given the currently available data and resources, however it is obvious that there is more work to be done on this front. It is highly recommended that additional augmentation station data collection, QA/QC, and development be completed so that these issues may be corrected in the local inflows utilized by the model and in the model’s representation of the canal systems with significant augmentation station operations.

At the current level of model input local inflow data development, it is assumed that the effects of historic augmentation station returns that remain in the local inflows would be similar to the effects that may occur in the future and that are not explicitly simulated within the model.

1.6.6.3 Lumping of Historic Groundwater Pumping Effects into Local Inflows

At the current level of model input local inflow data development, the effects that historic groundwater pumping had on streamflows have not been included as explicit terms. Thus, it is assumed that the historic groundwater pumping effects that are currently implicitly contained within the model input local inflows provide a reasonable characterization of the effects that current and future groundwater pumping will have on future streamflows.

1.6.6.4 Assumption that Model Local Inflows are Native Inflows

Throughout the local inflow calculations, efforts were made where possible to explicitly include specific terms that would have historically contained flows that were not entirely native water, or that were historically owned by an entity. Examples of terms that are explicitly represented in the local inflows calculations wherever possible for the purposes of backing out historically owned inflows include both mainstem and offstream reservoir inflows to local inflow reaches, transbasin imports, and historic return flows containing significant "reusable" flows. Thus, it is assumed that the model input local inflows used consist purely of native inflows to the system and would be available for water right allocation.

For example, by including the full historic PBWW WWTP return flow data as an explicit term in the applicable local inflow reach mass balance calculation, the portion of the total historic return flow that was reusable, i.e., was owned by PBWW, would have been backed out of the input local inflows. Then, during model simulation, the PBWW WWTP return flows are explicitly simulated and the portion of the simulated return flows that are reusable are dynamically estimated in the model based on the currently simulated PBWW deliveries.

2 SIMULATION OF RIVER BASIN POLICY, PROJECTS, PROGRAMS, AND PROCESSES

2.1 WATER RIGHTS

2.1.1 Background

The use of the Arkansas River basin's natural surface water supply (i.e., native flow) is administered through water rights by the Colorado Department of Water Resources under the "1st in time, 1st in right" Prior Appropriation Doctrine. Water users own water rights that grant them a legal right to use the system's native flow according to availability. When native flow is insufficient to meet all of the water rights, the demands are met in priority order based on the date of the water right appropriation ("priority date"). This is achieved through the use of "calls" placed on the river that dictate which water rights are allowed to divert. The native flow in the Arkansas River basin is highly appropriated and only in very wet periods is there enough native flow to satisfy all of its water rights. When this happens, there is no river call and it is considered a "free river".

In the Arkansas River basin, it is common for a single diversion location (referred to within the model and documentation as a water user) to contain a group of several unique water rights each with their own priority date, maximum native flow diversion rate, and other potential limits and rules defining their allowable uses. Many times, these groups of water rights represent the aggregation of multiple historic diversion structures to a single diversion location or the collective water rights of many unique water users that divert water from a single river diversion location into a shared canal. These groups of multiple water rights can lead to "piecemeal" water right allocations at single diversion locations when the total native flow diversion is made up from allocations to multiple distinct water rights. This also lead to complex situations when the ownership of a group of water rights, for example those of an agricultural canal company, is subdivided between multiple shareholders and/or partially sold off to other entities with different desired uses of the water rights, as is the case for the Colorado Canal system for example.

2.1.2 Simulation of Water Right Allocations

The model utilizes RiverWare's Water Rights Solver (WRS) to simulate the allocation of the systems native inflow to the direct flow and storage water rights by priority date throughout the model network on each day of a model run. This initial, native flow solution provided by the WRS serves as each timestep's base native flow condition. Simulated operations such as river exchanges and deliveries from storage are subsequently layered on to the base native flow solution in an appropriate order that represents the way that these operations occur within the basin.

Each day's total native inflow to the model network is available for allocation by the WRS. This consists of the combined daily total native inflow from the model's Boundary Inflows, Local Inflows, and Reservoir Hydrologic Inflows, which are spatially distributed throughout the model network. All of these model inflows are assumed to consist entirely of native inflow with the exception of the Boundary Inflows that represents transbasin imports to the system.

On each model timestep of a model run, and prior to the WRS firing, the allocation requests of water rights may be adjusted for various reasons such as to reflect reduced demands that are below a modeled water user's full water right rates or to reflect decreed limits such as maximum monthly diversion volumes. When the daily demand of a water user is below the total combined rates of its multiple water rights, the water right requests are turned off or limited in a junior-to-senior priority date order until the total water right request equals the total demand. Importantly, this step takes place following the imposition of limits specific to each water right. Limits are also applied to storage water rights to account for total annual accrual limits and available reservoir storage capacity are also applied.

Also prior to the WRS firing on each timestep, other potential additions of native inflows to the system may be simulated, such as releases of reservoir storage to native flow, so that these native inflows are made available to the WRS for allocation. All of these adjustments are made using RiverWare rule logic that can efficiently reference and use current basin conditions and simulated results up to the current timestep, as well as things such as future demands and target storage levels, within its calculations.

Following this initial water right and native flow configuration, the WRS is called via the "Solve Water Rights" rule and the native flow solution is set to the model networks applicable accounts on the simulation objects. All native flow diversions are set on diversion supplies from the native passthrough account network and reservoir storage right allocations are set as transfer supplies from the reservoir native passthrough accounts. The total initial diversion to each water user is then set as the sum of its individual water right allocations. The initial reservoir releases are set as the total native flow that passes through each reservoir in the native flow solution, which represents the native release called through that reservoir to meet the water rights of downstream water users. This is considered the initial, native flow solution.

A summary of the water rights currently simulated within the model is shown in Appendix D.

2.1.3 Alternative Points of Diversion for Water Rights

An Alternative Point of Diversion (APOD) for a water right refers to a diversion location that is physically different than the original decreed location within the river system from which the allocation of that water right may alternatively be legally diverted. Some APOD decrees, especially older ones, simply allow different diversion locations. Others stipulate that various conditions and criteria be met and maintained for the native flow allocation of the water right to be diverted at the APOD. These criteria are typically designed with the purpose of ensuring no injury to other water rights.

In the RiverWare model, some APODs are simulated simply by placing the water right at the "alternate" diversion location, which is typically on the modeled water user. Generally, this is done for those water rights that are now consistently diverted at an APOD rather than the original decreed diversion locations. This is also generally limited to APOD water rights that are close in proximity to the original decreed locations on the river. This is done largely for simplicity reasons and to limit the number of subsequent transactions necessary to move the diversion between various locations.

For the APOD water rights simulated in this way, it is assumed that the native flow allocation provided by the WRS will be sufficient for the model's purpose and that it will not impact the native flow allocations of other water rights. Another way to state this assumption is that it is assumed that if a certain water right is in-priority at its APOD location, it would have also been in-priority at its original decreed location and that the allocations to any water rights that may exist between the two locations are not affected. For example, PBWW's collection of water rights is simply simulated as being located on their water user object at Pueblo Reservoir.

For some APOD water rights whose native flow allocations are simulated at their APOD location for various reasons but for that the above assumptions may be less valid, the initial water right allocation requests are adjusted prior to the WRS being called to simulate the potential limitations in the native flow available for allocation at the original decreed location. This type of technique is used for some water rights with original decreed locations on tributaries for which the tributary flow is not explicitly represented in the model. For example, the changed Muddy Creek storage water right that is used to provide storage to John Martin Reservoir's Permanent Pool account is actually administered based on the flow of Muddy Creek, a tributary that flows directly into John Martin Reservoir. In the model however, this water right is simulated as a storage water right on John Martin Reservoir and the Muddy Creek flow is not represented. To account for this discrepancy, the storage water right's daily request is limited to that day's Local Inflow to John Martin Reservoir in addition to its other decreed limits. This is not a perfect limitation, however, it does prevent this water right from effecting upstream water rights in the Arkansas and Purgatoire River basin and allows for it to be called out by senior downstream water rights, while still providing some level of representation of this important source of storage for John Martin's Permanent Pool.

Additionally, some changed water rights that are officially decreed as APODs contain sufficient limitations and criteria such that they are more appropriately treated as if they are river exchanges. As such, these types of APOD water rights are simulated as river exchanges within the model. Aurora's changed Rocky Ford ditch water rights are an example of these types of APODs.

2.2 River Exchanges

Exchanges represent an important means of moving water from downstream locations to upstream locations in the Arkansas River basin and are regularly utilized by many basin entities for various reasons. The general concept of an exchange is that some type of reduction in the would-be flow of a river, such as a hold back or reduction in a reservoir's would-be release, can be "made whole" at a downstream location through an addition of flow to the river that would not otherwise occur. Exchanges result in a decrease in river flow between the upstream exchange point, where the flow is initially reduced below what it would otherwise be if the exchange were not occurring, and the downstream exchange point, where the flow is made whole again. The amount of the flow decrease is the rate of the exchange.

2.2.1 Types of Simulated Exchanges

There are several different types of exchanges currently simulated in the model, including:

- Downstream onstream reservoir to upstream reservoir
    - Occurs when an upstream reservoir's release is reduced (aka "heldback", "cut", or "diverted" to storage) below what it would otherwise be, causing water to be stored, and the river flow is made whole by a matching increase in release from a downstream reservoir.

- Downstream offstream or tributary reservoir to upstream reservoir
  - Same as onstream reservoir exchange except that flow in the offstream release channel or tributary is locally increased and the mainstem flow is made whole at the confluence with the release.
- Downstream diversion to upstream reservoir
  - Occurs when an upstream reservoir's release is reduced, causing water to be stored, and the river flow is made whole by foregoing or reducing an in-priority diversion that would have otherwise been made if the exchange weren't occurring. In the Arkansas basin, for administration purposes (i.e., to "prove" that the amount of exchange is available at the diversion location), the standard practice is to continue to divert the in-priority flow at the diversion headgate rather than simply reducing the headgate diversion, and then nearly immediately return a portion or all of the diverted flow back to the river through an "augmentation station" that measures the flow returned. In other basins (e.g., the Truckee River basin in California and Nevada), administrative and operational river system models are used to prove the exchange ability, eliminating the need for augmentation stations and measurements.
- Downstream reservoir to upstream diversion ("delivery exchange")
  - Occurs when storage is released from a reservoir to make the river whole following an upstream, out-of-priority diversion.
- Downstream reusable return flow to upstream reservoir
  - Occurs when an upstream reservoir's release is reduced, causing water to be stored, and the river flow is made whole by the addition of a reusable return flow to the river at a downstream location.

2.2.2 Simulation of River Exchanges

Many exchanges are simulated in the RiverWare model with standardized exchange rule logic. Exchanges with basic and standard limits can be added to the model in a straightforward way. These exchanges can be built with RiverWare's "Data Object Exchange Builder" and configured in the "TradesandExchanges.Trades and Exchanges" slot. A rule must be added in the appropriate location in the ruleset to execute the exchange. This same exchange rule and function logic can also be used to simulate exchanges with more complicated and non-standard types of limits, with minimal custom logic added to the functions to account for specific exchange limits. Some very complicated and non-standard exchanges are also simulated with completely custom rule logic to appropriately execute the exchange, as is the case for Aurora's Rocky Ford Ditch exchanges.

The priority of river exchanges relative to one another can be very important in the system as exchange potential is often limited. This is especially true in dry hydrology years. Due to the way that the model solves, the exchanges that are executed first will reduce the remaining exchange potential through the affected reaches. Thus, the rules executing the exchanges are set to execute from highest priority to lowest priority. Please note that RiverWare's rule priority convention is the opposite of this, and the rule priority does not reflect the exchange priority. For various reasons, all of the exchange rules are not always grouped together within the ruleset, although they are grouped when possible. Some exchanges are simulated in a slightly different order than reflected by the actual exchange priorities for various reasons. Shared exchange potential is simulated only for select exchanges with a defined or assumed procedure for doing so, such as exchanges from storage in the Colorado Canal system into Pueblo Reservoir when multiple stakeholders desire to move water into Pueblo Reservoir concurrently.

Exchanges through Pueblo Reservoir are not simulated as single exchanges, but rather as separate exchanges from downstream into Pueblo Reservoir and then from Pueblo Reservoir to upstream locations. For example, the model does not simulate direct exchanges of CSU's reusable return flows from Fountain Creek all the way up into the upper basin reservoirs. On any given timestep, it will first attempt to execute exchanges from CSU's LT EC storage in Pueblo Reservoir to upper basin reservoirs, and then subsequently, attempt to execute the exchange from the mouth of Fountain Creek into CSU's LT EC account in Pueblo Reservoir. Exchanges out of Pueblo Reservoir into the upper basin are assumed to happen prior to exchanges into Pueblo Reservoir on any given timestep because it is generally assumed that the exchange capacity in the lower basin reaches will be more limiting than that in the upper basin reaches. Flow that was exchanged into Pueblo Reservoir on a given model day is then available for subsequent upstream exchange on the next model day.

Exchanges from the same source to multiple potential upstream locations are simulated as separate exchanges, with the exchange to the preferred upstream location being attempted first. For example, the CSU exchange into Twin Lakes is attempted prior to their exchange into Turquoise Lake. Similarly, delivery exchanges from different source accounts in the same reservoir to an upstream water user are simulated as separate exchanges, with the exchange from the preferred storage source first.

All simulated exchanges are subject to the "global" minimum flow criteria at specific flow locations. These minimum flows are defined on the Minimum Flow Criteria data object and in the "Minimum Flow Reaches" subbasin. Currently, these global minimum flow requirements include the Upper Arkansas Voluntary Flow Management Plan (VFMP) minimum flows imposed at the Wellsville gage and the Pueblo Flow Management Plan (PFMP) minimum flows at the "Above Pueblo Location" and the "Combined Flow Location" between Pueblo Reservoir and Fountain Creek. These minimum flows are described in more detail elsewhere in the documentation. The defined Minimum Releases from Turquoise Lake, Twin Lakes Reservoir, and Clear Creek Reservoir are also assumed to limit all exchanges to those reservoirs. Some simulated exchanges are also subject to additional or unique minimum flow limitations or stipulations that are defined in their decrees. These limits are simulated as custom exchange limits with the exchange logic for those certain exchanges.

Additionally, simulated exchanges are currently assumed to be allowed on native river flow only. Exchanges are not allowed to cause negative native flow at any point in the river, even if there may be other account water in the river at that point. In practice, some exchanges may in fact be allowed on other types of water (e.g., deliveries from reservoir storage to a water user), however these considerations are not currently modeled due to the lack of the specific details of which exchanges can exchange on what types of water and other necessary information.

Minimum flow limits are, however, applied on the total river flow at those locations. During the simulation of any given exchange, many potential limits are checked, including but not limited to:

- The minimum available native flow to exchange upon in all reaches affected by the exchange.
- The minimum amount of total physical flow above the minimum criteria for all "global" minimum flow reaches and minimum reservoir releases potentially affected by the exchange.

- Total flow (or total storage volume) available for exchange at the exchange's source point. This may be the total storage available or may contain criteria to not exchange below a certain account storage level.
- Total available storage capacity (or total diversion capacity or demand) at the exchange's destination point.
- Any applicable maximum exchange rate or volume limits (e.g., maximum total annual exchange volume) for the exchange, which tend to be defined within the decree.
- Any other applicable unique or custom limits that may be defined in the decree or elsewhere.
- An additional exchange limitation is applied only on exchanges into Pueblo Reservoir during the Joint Use Pool restriction period. During this period, simulated exchanges into Pueblo Reservoir are not allowed when Pueblo Reservoir is at or very near the spill level.

The simulated exchange will then be executed at the rate allowed by the minimum of the various limitations. Due to the dependencies of many of these limits on simulated results, such as the total river flow at minimum flow reaches, it is very important that the operational rules and processes be simulated in the appropriate order. For example, as exchanges into Pueblo Reservoir from downstream locations may be limited by the total river flow at certain reaches, it is imperative that any releases or deliveries of water from Pueblo Reservoir that may potentially pass through the controlling reaches (and therefore may increase the total exchange potential) be executed prior to the exchanges being attempted.

The main river exchanges currently simulated within the model are shown below in Table 2 and Table 3. The objectives of some of these exchanges and the roles that they play within the entities operations are discussed within the sections describing their simulated operations in the basin. Please note that some additional potential exchanges simulated within the model that represent storage sources of various Excess Capacity accounts within Pueblo Reservoir, but that may not yet be decreed or otherwise defined, may not be explicitly shown in this table.

Table 2: Simulated River Exchanges above or out of Pueblo Reservoir.

Simulated Priority[1]	Exchange	Notes
1	Aurora Imports to Turquoise	
2	PBWW Imports to Turquoise	
3	PBWW Imports to Clear Creek[2]	If any imported flow remains after prior exchanges
4	Aurora Imports to Twin Lakes[2]	If any imported flow remains after prior exchanges
5	PBWW Imports to Twin Lakes[2]	If any imported flow remains after prior exchanges
6	Victor EC Delivery Exchange[3]	
7	BLM Deweese EC Delivery Exchange[3]	
8	Penrose EC Delivery Exchange[3]	
9	Salida EC Delivery Exchange[3]	
10	Poncha Springs EC Delivery Exchange[3]	
11	Florence EC Delivery Exchange[3]	
12	Canon City MI EC Delivery Exchange[3]	
13	Penrose PW Delivery Exchange[2,4]	If any exchange demand remains after EC exchange
14	Salida PW Delivery Exchange[2,4]	If any exchange demand remains after EC exchange
15	Poncha Springs PW Delivery Exchange[2,4]	If any exchange demand remains after EC exchange
16	Florence PW Delivery Exchange[2,4]	If any exchange demand remains after EC exchange
17	Canon City MI PW Delivery Exchange[2,4]	If any exchange demand remains after EC exchange
18	Other West of Pueblo PW Users PW Delivery Exchange[4]	
n/a[5]	PBWW Pueblo EC to Upstream Locations	Not currently simulated
20	CSU Pueblo EC to Twin Lakes Res	
21	CSU Pueblo EC to Turquoise Lake[2]	
22	Aurora Pueblo EC to Twin Lakes Res	Subject to unique limits, varying max exchange rates depend on river flows at Wellsville.
23	Aurora Pueblo EC to Turquoise Lake[2]	

Simulated exchanges are subject to multiple potential limits and criteria not explained here due to immense detail.
1: During simulation, the exchanges are attempted to be executed in the priority order shown. During the solution of each timestep, after each simulated exchange, the system conditions will update accordingly, for example reflecting the reduced flows in affected reaches, reduced reservoir releases, and increased reservoir storage. Thus, the remaining exchange potential will be reduced as the exchanges execute, although exchanges may not necessarily be limited by the exchange potential in the same reach. Note that the minor delivery exchanges from Pueblo Res EC/PW to upstream water users are assumed to occur before the CSU and Aurora exchanges because they are simulated in a generally way and tend to be low magnitude.
2: Denotes exchanges that are "second" options of locations to exchange to, or storage sources to exchange from.
3: Denotes exchanges from Pueblo Reservoir EC account to an upstream water user/tributary location.
4: Denotes exchanges of Project Water in Pueblo Reservoir to an upstream water user/tributary location.
5: PBWW exchanges from Pueblo Res to upper basin not currently simulated due to lack of information and procedures.

Table 3: Simulated River Exchanges below or into Pueblo Reservoir.

<table>
<tr><th>Simulated Priority[1]</th><th>Exchange</th><th>Notes</th></tr>
<tr><td>1</td><td>Downstream WW Delivery Exchanges</td><td>From WW storage in John Martin/Fort Lyon Storage Canal system to water users downstream of Holbrook</td></tr>
<tr><td>2</td><td>Holbrook Canal Ag Delivery Exchange</td><td>From Dye/Holbrook storage to Holbrook headgate. Limited to 600 cfs.</td></tr>
<tr><td>3</td><td>Colorado Canal Ag Delivery Exchange</td><td>From Meredith storage to CO Canal headgate. Limited to the maximum CO Canal ag demand, which is well <100 cfs.</td></tr>
<tr><td>4</td><td>PBWW Reusable Return Flows to Pueblo Res EC</td><td>Limited to 60 cfs</td></tr>
<tr><td>5</td><td>“Other” CO Canal Storage in Meredith to Pueblo Res EC</td><td rowspan="5">Limited to 100 cfs total. CO Canal exchanges are simulated in this order shown to ensure the exchange of the minor yield volumes into Pueblo Res EC first. Then and for the remainder of the years, CSU and Aurora share the remaining CO Canal exchange potential.</td></tr>
<tr><td>6</td><td>Pueblo West CO Canal Storage in Meredith to Pueblo Res EC</td></tr>
<tr><td>7</td><td>Fountain CO Canal Storage in Meredith to Pueblo Res EC</td></tr>
<tr><td>8</td><td>CSU CO Canal Storage in Meredith to Pueblo Res EC</td></tr>
<tr><td>9</td><td>Aurora CO Canal Storage in Meredith to Pueblo Res EC</td></tr>
<tr><td>10</td><td>CSU Fountain Creek Reusable Return Flows to Pueblo Res EC – Primary</td><td>Limited to 100 cfs initially, before Aurora’s Rocky Ford Ditch exchanges are simulated, in an attempt to simulate shared exchange potentials.</td></tr>
<tr><td>11</td><td>Aurora Rocky Ford Ditch to Pueblo Res EC</td><td>Exchange of “Rocky Ford 1” and “Rocky Ford 2” water rights are simulated together. Limits and other criteria vary by date.</td></tr>
<tr><td>12</td><td>CSU Fountain Creek Reusable Return Flows to Pueblo Res EC – Secondary</td><td>Limited to 475 cfs more, after Aurora’s RFD exchanges are simulated.</td></tr>
<tr><td>13</td><td>Pueblo West Reusable Return Flows to Pueblo Res EC</td><td>Limited to 6 cfs</td></tr>
<tr><td>14</td><td>AGUA Excelsior Ditch to Pueblo Res EC</td><td>Limits and other criteria vary by date</td></tr>
<tr><td>15</td><td>Other Exchanges from Ditches to Pueblo Res EC (Catlin Canal, FMIC, Chilcotte)</td><td>These are multiple other exchanges into Pueblo Reservoir EC that are important EC storage sources. These exchanges may not be yet decreed and not a lot of information is known about how they operate.</td></tr>
<tr><td colspan="3">Simulated exchanges are subject to multiple potential limits and criteria not explained here due to immense detail.
1: During simulation, the exchanges are attempted to be executed in the priority order shown. During the solution of each timestep, after each simulated exchange, the system conditions will update accordingly, for example reflecting the reduced flows in affected reaches, reduced reservoir releases, and increased reservoir storage. Thus, the remaining exchange potential will be reduced as the exchanges execute, although exchanges may not necessarily be limited by the exchange potential in the same reach.</td></tr>
</table>

2.3 Flow Management Programs and Minimum Flows

There are several important minimum flow criteria and flow management programs within the Arkansas River basin that are simulated within the RiverWare model. Generally, the priority dates of actual, decreed minimum instream flow water rights are very junior in relation to the basin's many decreed direct flow, storage, and exchange water rights. However, due to the recognition that maintaining minimum flows are integrally important in terms of general river basin health and provide many overall benefits to various basin stakeholders, two main voluntary flow management programs have been created, agreed upon, and implemented in the basin. Despite not being "officially" decreed as so within Colorado's Prior Appropriation Doctrine, the minimum flow criteria that they define are simulated as being "universal" minimum flows since all major stakeholders and exchangers are parties to these agreements. Furthermore, recently decreed exchanges generally contain provisions or stipulations that impose the criteria defined by these flow management programs.

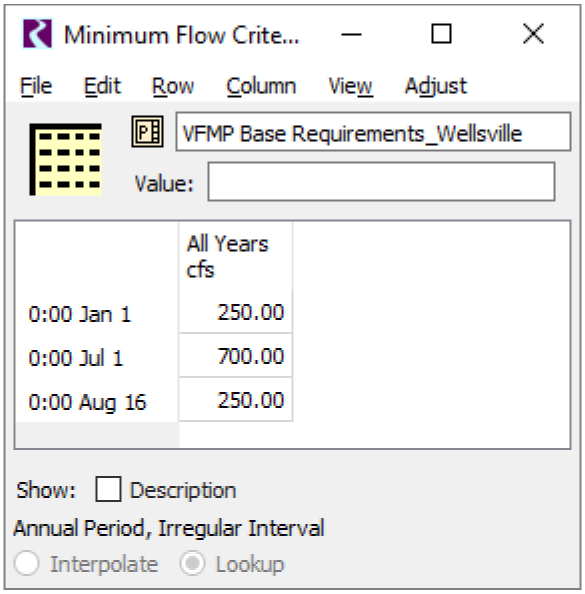
2.3.1 Upper Arkansas Voluntary Flow Management Plan (VFMP)

The goal of the Upper Arkansas Voluntary Flow Management Plan (VFMP) is to provide flows for fisheries and rafting in the Upper Arkansas River. The FryArk Project operations are especially obliged to plan operations to meet VFMP targets, and many other entities have also voluntarily agreed to comply with the program's flow recommendations as much as possible. As simulated, it is assumed that all applicable entities are subject to limitations provided by the VFMP flows. All simulated exchanges are not allowed to decrease the flows at the Wellsville gage below these levels. Aurora has additional exchange rate limits that are dependent on the total physical flow at Wellsville gage, which are also simulated.

Up to 10,000 AF of FryArk Project Water (PW) may be released each year to maintain the VFMP Wellsville flows when native river flows drop below the requirements. These releases are simulated when necessary, first from Twin Lakes if there is PW available, and then from Turquoise Lake.

The base VFMP flow requirements are shown below in Table 4. The highest priority is the maintenance of a minimum flow of 250 cfs year-round. During the July 1 to August 15 period, the Wellsville flow target is 700 cfs. During the November 16 to April 30 period, the minimum winter incubation flow levels may be increased above the base minimum of 250 cfs if dictated by the flow levels observed during the preceding October 15 – November 15 spawning period.

Table 4: Base VFMP Flow Requirements at the Arkansas River near Wellsville gage.



2.3.2 Pueblo Flow Management Plan (PFMP)

The Pueblo Flow Management Plan (PFMP) was developed shortly after the filing of the Pueblo Recreational In-Channel Diversion (RICD) water right in the early 2000s, which has a very junior official priority date of May 15, 2000. The interagency PFMP agreement dictates a voluntary reduction of existing decreed exchanges to meet instream flow requirements very similar to the RICD water right criteria.

The PFMP defines minimum flow criteria at two locations below Pueblo Reservoir and above Fountain Creek, the “Above Pueblo Location” and the “Combined Flow Location”. The “Above Pueblo Location” is a calculated flow location just downstream of the reservoir that includes the Arkansas River above Pueblo, CO USGS gage and the Pueblo Fish Hatchery return flows. The “Combined Flow Location” is a calculated flow location a little further downstream, below the Moffat St. gage, SCMWD pump diversion, and the Pueblo Riverwalk return flows and Runyan Lake inflows, and just upstream of the confluence with Fountain Creek.

2.3.2.1 Definition of PFMP Year Types

The PFMP hydrologic year type is determined by the Natural Resources Conservation Service’s (NRCS) “most probable” (50% chance of exceedance) forecasts of natural flow volume at the Arkansas River at Salida gage. These forecasts are published each year on an approximately monthly basis during the late winter snowpack accumulation and throughout the subsequent snowmelt runoff period. During simulation, the hydrologic year types are assumed to be known at the beginning of each year based on the last available historic Salida natural flow forecast of each historic year, and thus the year types within each simulation year are assumed to be static and not change as these forecasts would evolve during the year. This means that the effects of forecast error and changing forecasts are not simulated. The full historically available forecast period of 1966 to 2016 is used within the model to determine year types.

Hydrologic year types used for the PFMP are defined in the 2004 PFMP agreement. Based on the NRCS Salida natural flow forecast:

- “Above Average” – years when the forecast is 100% of average or higher.
- “Drier” – years when the forecast is between 70% and 100% of average.
- “Dry” – years when the forecast is below 70% of average.

Please note that an additional hydrologic year type classification, also based on the NRCS Salida natural flow forecasts, is also used within the model to determine “Wet”, “Average”, and “Dry” years. Those year types designations are different than the PFMP year types shown above.

2.3.2.2 PFMP Flow Criteria

The simulated PFMP minimum flows for the “Above Pueblo Location” are shown below in Figure 1, and depend of the PFMP hydrologic year type. The overall minimum flow is 100 cfs at the “Above Pueblo Location”. Additionally, a constant minimum flow of 85 cfs is designated by the PFMP for the “Combined Flow Location” in all year types. During simulation, exchanges or other operations are not allowed to decrease the total physical flows at these locations below the minimum flow criteria. Additional releases to maintain these flows are not simulated in periods when native flows drop below these levels. These flow limits are assumed to be daily average flows and sub-daily timestep variations in these flow requirements are not simulated.

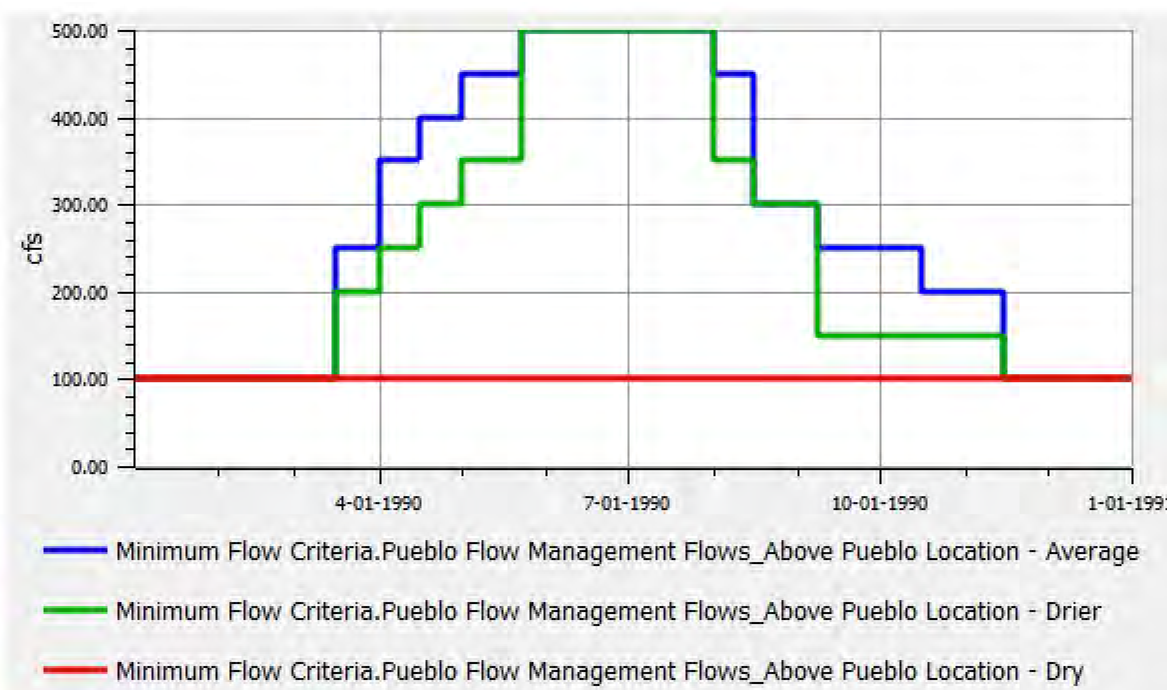


Figure 1: Minimum Flow Criteria Defined by the Pueblo Flow Management Plan (PFMP) for the “Above Pueblo Location”

2.3.3 Minimum Reservoir Releases

The following minimum reservoir releases are currently simulated in the model. These minimum releases are used to limit the total exchange potential into the reservoirs. They may also be used to dictate releases of stored water if native passthrough flows drop below the minimum.

- Turquoise Lake
    - March 15 to November 14 – Minimum of Native Inflows and 15 cfs
    - November 15 to March 14 – 3 cfs
        - CSU may exchange/store native flows down to 0. If this occurs, FryArk Project Water is released to maintain the 3 cfs minimum.
- Twin Lakes Reservoir
    - 15 cfs Year-round

2.3.4 Additional Minimum Flow Considerations

In addition to the minimum flow limits and criteria of the two flow management programs described above, several important exchange and APOD decrees contain additional limits, criteria, or stipulations that provide further minimum flow criteria, which may be required for only those particular exchanges. Thus, additional limits and minimum flow criteria are simulated as needed within certain exchanges. These types of specific limits aren't considered overall minimum flow criteria as they only effect certain parties and not others.

For example, as mentioned above, Aurora has additional upstream exchange rate limits in addition to the base VFMP requirements that are dependent on the total physical flow at Wellsville gage, which are also simulated and shown below in Table 5. Additionally, Aurora's further 260 cfs minimum flow requirement at the Salida gage in the last two weeks of August is simulated.

Table 5: Aurora's Upstream Exchange Limits Based on Total Physical Flow at Wellsville Gage.

Custom Exchange Limit Info.Aur...

Aurora Upstream Exchange Limits by Wellsville Flow

	Lower Bound cfs	Upper Bound cfs	Exchange Limit cfs
0	0.00	250.00	0.00
1	250.00	500.00	50.00
2	500.00	1,000.00	75.00
3	1,000.00	1,500.00	125.00
4	1,500.00	2,000.00	175.00
5	2,000.00	3,000.00	250.00
6	3,000.00	99,999.00	500.00

2.3.5 Unmodeled, Below Pueblo Reservoir Low Flow Mitigating Factor

A mitigating factor during low flow periods in the Arkansas River below Pueblo Reservoir is that PBWW can elect to change where they take diversion of some or all of their demand from their direct outlet in Pueblo Dam to their Northside Diversion Intake on the Arkansas River between the Above Pueblo and Moffat St. gages. This adapted operation is currently not simulated in the model; however, it is expected that they will continue to operate in this manner when needed to eliminate the occurrence of flows below 50 cfs in this reach.

2.4 Winter Water Storage Program

2.4.1 Simulation of Winter Water Storage Processes

The Winter Water Storage Program (WWSP) is simulated within the RiverWare model. The Winter Water (WW) storage period is from November 15 to March 14. During the WW period, the decreed "fixed call" priority date of March 10, 1910 is applied by turning off all water rights with a more junior priority date. Further, the water rights of other water users may be limited or turned off to reflect reduced or eliminated winter diversion demands based on recent data. Storage water rights in the simulated headwaters reservoirs (Turquoise, Twin Lakes, and Clear Creek) are allowed to store water during the WW period while remaining subject to their decreed limitations and any potential native release demands to senior water rights diverting in the winter. The "2250 AF" WW repayment provision to the Colorado Canal is currently assumed to be negligible and is not simulated.

During the WW period, the Water Rights Solver continues to be used in each timestep to provide an initial distribution of the system's native flow to those water rights still active and requesting native diversions in the winter. The water rights of the WWSP parties are assumed to be turned off during the WW period.

Winter Water is simulated as being stored in the following locations as described below:

- Pueblo Reservoir
  - Pueblo Reservoir WW storage operations are simulated by storing the majority of all simulated inflows to Pueblo Reservoir during the WW period. A minimum winter release of the minimum of the total native inflows or 100 cfs. Pueblo Reservoir may also pass additional native inflows to water users who continue to divert their water rights during the WW period if releases are determined to be necessary by the Water Right Solver.
  - During the WW period, the only simulated exchanges into Pueblo Reservoir that are allowed are the exchange of CSU reusable return flows. This exchange is limited to the stipulated maximum WW period exchange volume of 17,000 AF.
- Colorado Canal Reservoirs (Lake Henry and Lake Meredith)
  - Simulated WW diversions are assumed to be used to fill Lake Meredith first, and then Lake Henry.
  - Based on recent WW diversion data, simulated Colorado Canal WW diversions are limited in the first part of the WW storage season (before Jan 1) in order to allow more flow to remain in the river to be diverted at the downstream FLSC. Following Jan 1, the Colorado Canal WW diversions are allowed to divert more of the flow. This process allowed for better matching of the recent WW diversion "balancing" between the Colorado Canal and the FLSC.
- Holbrook Canal is not assumed to divert and store WW within its system, as it has not done so for some time. However, it still receives it's WW volume allocations in other storage locations.
- Fort Lyon Storage Canal (FLSC)
  - WW diversions to the storage reservoirs (Adobe Creek Reservoir and Horse Creek Reservoir) on the FLSC are simulated. These storage reservoirs are not explicitly simulated in the model, however the WW storage is "pseudo"-simulated in a simplified manner in order to be able to estimate the WW volumes available for delivery after the WW season. At the end of the WW period, the total WW diversion volume is reduced by an assumed total loss factor of 50% to account for canal losses, evaporation, and other losses. This assumed loss does not affect the WW volume allocation process as that uses the total FLSC headgate WW diversion volume. Note that this simplification assumed that the FLSC WW diversions are not ever significantly limited due to full storage conditions in the FLSC reservoirs.
- John Martin Reservoir
  - The storage of winter inflows to John Martin Reservoir is simulated following the operating procedures described in the "Super Ditch Delivery Engineering Report" (LAVWCD, 2014). As inflows as stored, they are divided between the Article II accounts (John Martin's "Conservation Storage") and Article III accounts (WWSP and other upstream user accounts) by the "Winter Baseflow" and "Enhanced Baseflow" at the Las Animas gage, as well as the Purgatoire River outflows. The 35% transfer of all the Article

III storage to the Article II accounts is also simulated as defined in the John Martin operating plan (Arkansas River Compact Administration, 2010).

2.4.2 Allocation and Distribution of WW Volumes to Parties

During the WW storage period, WW is stored and accounted for in all locations as “Unallocated WW”. While unallocated, no entities have access to the WW for use. Following the end of the WW storage period, the total WW volume stored in the system is allocated to the decreed WW parties (i.e., the ag canals) following the distribution percentages defined in the WWSP decree, shown below in Table 6. This calculation results in the WW volume yield for each party, however, since the total WW volume is stored in multiple locations throughout the system, it does not define where each party’s WW actually is stored.

Thus, immediately following the overall WW volume allocation, the distribution of the parties WW volumes between the actual physical storage locations is simulated. This process is completed using an algorithm developed that considers the usual and preferred WW storage locations for each party as observed within the recent years. The “Allocation by Location Procedure Order”, shown below in Table 7, is used within the algorithm to complete this distribution. Briefly, the algorithm cycles through the parties and WW storage locations in priority order, “claiming” the parties WW volumes in the storage locations, until each party has received its full volume and the total WW in each storage location has been distributed. Due to the upstream most five WW parties only receiving their volume in Pueblo Reservoir, the total WW volume stored in Pueblo Reservoir will be prorated between them if it is less than the sum of those parties total WW allocations.

Several of the main WW parties are owned in part by multiple other explicitly modeled entities (e.g., municipalities), for whom WW yields represents a significant water source. Following the WW storage season, the prorated distribution of WW to these owners is simulated and transferred to their storage accounts in the appropriate reservoirs. This occurs for the Colorado Canal Company owners by the ownership percentages shown in that section of the documentation. This also occurs within the Pueblo Reservoir Excess Capacity accounts for various shareholders of other WW parties, as discussed in that section of the documentation.

Deliveries of WW volumes are simulated explicitly when native or other diversions are insufficient to meet water user demands. This is simulated by including the appropriate WW accounts as storage sources for the applicable water users. Thus, throughout each model run, the WW accounting is tracked for each party’s total WW volume and its distribution within each of the storage locations where it physically resides. Likewise, the total WW volumes (of all owners) and accounting for each of the storage locations is also tracked. Unused WW is converted to Carryover WW on Nov 15, at the beginning of the next WW storage season, in Pueblo and John Martin Reservoirs. If still unused by May 1 of the following year, the Carryover WW is released as native flows.

Table 6: Winter Water Allocation Percentages

Party	Allocation Percentage of Part's Volume			
	First 100,000 AF	Next 2,750 AF	Next 356 AF	Over 103,106 AF
Bessemer	6.1900%			5.3750%
Highline	8.3100%			7.2175%
Oxford	2.0000%			1.7400%
Catlin	9.1400%			7.9300%
LA Consolidated	2.7600%			2.3925%
Riverside-West Pueblo	0.4000%			0.3450%
CO Canal	10.6900%			12.8025%
Holbrook	8.5200%		100%	10.5375%
Fort Lyon	38.1600%			38.1600%
Amity	13.8300%	100%		13.5000%

Table 7: Procedure Table Used for Winter Water Allocation Volume Distribution to Parties by Storage Location

WW Totals.Allocation by Location Procedure Order

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Allocation by Location Procedure Order

Value:

	Pueblo Res NONE	Lake Meredith NONE	Lake Henry NONE	Holbrook Res NONE	Dye Res NONE	Fort Lyon Storage Canal NONE	John Martin Res NONE
0: Bessemer WW	1.00	0.00	0.00	0.00	0.00	0.00	0.00
1: Riverside Dairy WW	2.00	0.00	0.00	0.00	0.00	0.00	0.00
2: High Line WW	3.00	0.00	0.00	0.00	0.00	0.00	0.00
3: Oxford WW	4.00	0.00	0.00	0.00	0.00	0.00	0.00
4: Catlin WW	5.00	0.00	0.00	0.00	0.00	0.00	0.00
5: CO Canal WW	20.00	6.00	7.00	0.00	0.00	0.00	0.00
6: Holbrook WW	21.00	10.00	11.00	8.00	9.00	0.00	0.00
7: Fort Lyon WW	23.00	18.00	19.00	0.00	0.00	12.00	17.00
8: LA Consolidated WW	22.00	15.00	16.00	0.00	0.00	0.00	14.00
9: Amity WW	0.00	0.00	0.00	0.00	0.00	0.00	13.00

Show: ☐ **Description**

2.5 FRYINGPAN-ARKANSAS PROJECT

The Fryingpan-Arkansas (FryArk) Project is a multi-purpose, transmountain diversion project constructed by Reclamation to supplement municipal and agricultural demands in the Arkansas basin. The FryArk Project is operated by Reclamation and the allocations of Project Water (PW) are managed by the Southeastern Colorado Water Conservancy District (SECWCD). FryArk Project Reservoirs include the simulated Turquoise Lake, Mount Elbert Forebay, Twin Lakes Reservoir, and Pueblo Reservoir in the Arkansas basin. Ruedi Reservoir, the FryArk Project reservoir in the Roaring Fork River basin on the western slope of the Continental Divide, is not simulated.

FryArk Project Water (PW) is imported into Turquoise Reservoir through the Boustead Tunnel. The simulated imports are currently input data to the model and thus are assumed to be equal to the historic import data records. This assumption is discussed previously. Imported PW is referred to as "West Slope" PW and has different rules than "East Slope" PW, which is PW that is stored under the FryArk Project storage water rights in any of the FryArk Reservoirs. The FryArk water rights have a junior Arkansas River basin priority date of June 25, 1962, and therefore do not come into priority often, typically only in years with very wet hydrology conditions and high native inflows. As currently simulated and in order to simplify the accounting, East Slope PW is assumed to be used prior to West Slope PW when it does come into priority.

The allocation of annual PW yields to water users is managed by SECWCD and water users are grouped into 6 main categories: municipal entities west of Pueblo, municipal entities east of Pueblo, Fountain Valley Authority, PBWW, other municipal entities, and agricultural users. At the current level of model development, the PW accounting in Pueblo Reservoir is simulated in a lumped fashion based on those 6 groups. Generally, the individual entities within those groups have access to the PW volume in the applicable group, however specific entities may have limits on their annual PW usage. In reality, PW is allocated between water users on discrete and varying dates, usually twice per year, based on estimates of each year's total PW yields, which are unknown at the time of initial allocation. Typically, an initial allocation is completed around the middle of May based on 80% of the current estimated total PW yield volume, and the additional PW is allocated in the later summer. Water users may request variable PW allocation volumes depending on their anticipated demands, yields from other sources, or other factors. SECWCD digests the allocation requests from all entities and then allocates the water, based on factors such as total PW yields, requests of other entities, and subject to various potential limits such as maximum total percentages of each group. The historic requests and allocations of individual water users can vary widely and are difficult to explicitly simulate on an individual basis.

For modeling purposes, it is assumed that all PW in Turquoise Lake, Mt Elbert Forebay, and Twin Lakes Reservoir is PW that has not yet been allocated to water users. Furthermore, allocated PW (that available to water users) is only currently simulated in Pueblo Reservoir. During simulation, PW eventually makes its way into Pueblo Reservoir through various upstream reservoir operations described elsewhere. As PW accumulates in Pueblo Reservoir, it is accounted for as "Unallocated PW". The initial allocation of PW to the 6 simulated lumped PW subaccounts (i.e., the SECWCD groupings mentioned above) is simulated on May 15 of each year. On this date, the total accumulated Unallocated PW is distributed between the 6 PW subaccounts. The maximum potential distribution to each PW subaccount is simulated as a percentage of the total volume available for allocation and based on the SECWCD allocation percentages, which are shown below in Table 8. The allocation is also limited based on the simulated assumed maximum total PW subaccount storage capacity, shown below in Table 9. Additionally, "target" maximum PW storages below the maximum PW subaccount capacities are simulated for the following PW subaccounts: East of Pueblo PW = 24,000 AF, West of Pueblo PW = 10,000 AF, Pueblo PW = 22,000 AF. These targets are based on the general tendency of some PW entity groups to operate to PW storages lower than their maximum capacities for various reasons. These maximum PW storage targets are simulated for the 2017 model scenario only. It is assumed that the accounts will be operated up to their maximum capacity in all future scenarios.

Following the initial simulated PW allocations on May 15 of each year, additional PW inflows to Pueblo Reservoir between May 16 and August 31 may be continuously allocated to the PW subaccounts, subject to the same distribution percentages and limits described above. These subsequent allocations are meant to simulate the additional allocations of PW that occur later in the year, and also the fact that in reality, PW that is allocated to the groups during each year's initial allocation may not already be actually present in Pueblo Reservoir storage, and thus that PW inflows to Pueblo Reservoir during the summer period may in fact already be allocated.

Once storage is allocated and transferred to the PW subaccounts in Pueblo Reservoir, it can be accessed by that group's water users during the simulated deliveries of storage. Additionally, in order to simulate the potential loss of carryover agricultural PW, any PW still remaining in the lumped Agricultural PW account on May 1 of the following year is transferred back to unallocated PW. Carryover PW is not explicitly simulated in the other PW subaccounts and it is assumed that PW storages will operate in a way such to avoid any significant carryover effects.

Table 8: Simulated FryArk Project Water Allocation Percentages

PW Totals.Allocati...

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Allocation Percentages

Value: 0 NONE

	Percentage NONE
0: Unallocated PW	0.0000
1: Agriculture PW	0.4541
2: Fountain Valley Pipeline PW	0.2545
3: East of Pueblo PW	0.1273
4: West of Pueblo PW	0.0427
5: Pueblo PW	0.1000
6: Other PW	0.0214

Show: ☐ **Description**

Table 9: Simulated FryArk Project Water Maximum Account Capacities

PW Totals.Max Pueb...

Max Pueblo PW Account Capacities

Value: 228827.999999737 acre-feet

	Max Capacity acre-feet
0: Unallocated PW	228,828.00
1: Agriculture PW	50,000.00
2: Fountain Valley Pipeline PW	78,000.00
3: East of Pueblo PW	37,400.00
4: West of Pueblo PW	12,400.00
5: Pueblo PW	31,200.00
6: Other PW	4,000.00

Show: ☐ **Description**

2.6 Other Transbasin Imports

In addition to Boustead Tunnel imports of FryArk Project Water, several other transbasin imports to the Arkansas Basin are explicitly represented. These simulated imports are currently input data to the model and thus are assumed to be equal to the historic import data records. This assumption is discussed previously. The simulated imports are:

- ***Busk-Ivanhoe Tunnel Imports.*** These imports are split evenly (50% each) between PBWW and Aurora and flow directly into their storage accounts in Turquoise Lake.
- ***Homestake Tunnel Imports.*** These imports are split evenly (50% each) between CSU and Aurora, however the first 2500 AF of Aurora's annual yield is leased to PBWW. These imports flow directly into their storage accounts in Turquoise Lake.
- ***Twin Lakes Tunnel Imports.*** These imports flow into Lake Creek and then into Twin Lakes Reservoir, and are split between the Twin Lakes Reservoir and Canal Company (TLCC) stakeholder accounts in Twin Lakes Reservoir based on their ownership percentages (shown in the Twin Lakes Reservoir operations section).
- ***Wurtz Ditch Imports.*** These imports flow into Tennessee Creek and then into the Arkansas River near Leadville, CO, and are owned by PBWW. As simulated, these flows are attempted to be exchanged into PBWW's storage accounts in Turquoise Lake, Clear Creek Reservoir, or Twin Lakes Reservoir, and if not fully possible, the unexchanged amount flows down the Arkansas River and into the PBWW LT EC account in Pueblo Reservoir.

- ***Ewing Ditch Imports.*** These imports flow into Tennessee Creek and then into the Arkansas River near Leadville, CO, and are owned by PBWW. As simulated, these flows are attempted to be exchanged into PBWW's storage accounts in Turquoise Lake, Clear Creek Reservoir, or Twin Lakes Reservoir, and if not fully possible, the unexchanged amount flows down the Arkansas River and into the PBWW LT EC account in Pueblo Reservoir.
- ***Columbine Ditch Imports.*** These imports flow into the East Fork Arkansas River near Leadville, CO, and are owned by Aurora. As simulated, these flows are attempted to be exchanged into Aurora's storage accounts in Twin Lakes Reservoir or in Turquoise Lake, and if not fully possible, the unexchanged amount flows down the Arkansas River and into the Aurora LT EC account in Pueblo Reservoir.

2.7 Augmentation Releases and Delayed Return Flow Requirements

2.7.1 Augmentation Overview

Within the context of the Arkansas River basin's water resource system, the term augmentation generally refers to additions of water to the native river flow that would not have otherwise occurred through the natural hydrology and normal water supply and demand operations. Augmentation is typically used to replace various types of out-of-priority, or otherwise not specifically allowed, depletions to the native river flow, such as increased flow losses in a river reach due to the pumping of groundwater or increased evaporation due to reservoir storage. There are many uses of augmentation present throughout the Arkansas River basin of various magnitudes.

Broadly, augmentation can be subdivided into the following three main types described below.

Releases of stored water to native river flow. In practice, and as the necessary releases tend to be miniscule and immeasurable, these releases tend to be made as discrete (rather than continuous) transfers from reservoir account storages to a native admin account that is managed in a way to effectively blend the storage into the native river flow. While individual augmentation releases from reservoir storage may be miniscule, the aggregated effect of many augmentation releases from a reservoir can represent a measurable and important outflow of storage in the reservoirs total water balance. Many of Pueblo Reservoir's Excess Capacity Accounts are operated primarily for this purpose.

Non-diversion of would be, in-priority, flow diversions. In practice and for administrative purposes, this is typically accomplished by the diversion and subsequent, near-immediate return of the would be used in-priority native flow back to the rivers native river system. This is very similar to the process of an exchange from a diversion to storage, however rather than being used to offset a flow reduction in the river due to the diversion of native river flow to storage, the flow returned to the native system is used to offset various types of out-of-priority depletions of native river flow such as those from groundwater pumping from an alluvial aquifer.

Change/transfer of reusable or fully consumable return flows that are accruing to the river from owned flow to native river flow. This type of augmentation is prevalent in the Arkansas River basin and is often utilized to represent the final use of imported and other fully consumable water. This is especially true for reusable return flows generated from FryArk Project Water uses as managed by SECWCD.

In many ways, the various types of augmentation releases are actually deliveries of water supply to water users, although they tend not to be viewed in that way due to the abstract nature of the delivery path (e.g., through the flow from the surface water system to and through the groundwater system to a well).

2.7.2 Delayed Return Flow Requirements Overview

Within the RiverWare model and this documentation, delayed (or non-irrigation season) return flow requirements refer to the various requirements and stipulations present in numerous water right change decrees throughout the basin. These requirements dictate that storage releases, or other mechanisms of addition to native river flow, be made to replace the estimated return flows that would have accrued to the river system had the yield of the changed water right been used for its original purpose rather than being changed to new uses. These requirements typically pertain to irrigation water rights that have been changed to municipal uses. In effect, they are designed to prevent injury to downstream water rights by mimicking the additional inflows (i.e., the delayed return flows that would have been in addition to the natural inflows) that would have accrued to the river system during the fall and winter months following the irrigation season, had the changed water right instead been used for its original purpose of irrigating the lands specified in the decree.

Many of the municipal water users, and other types of entities, represented in the RiverWare model have delayed return flows requirements associated with their water supply sources. These requirements can represent operationally important demands on various entity's storage sources, such as Pueblo Reservoir's Excess Capacity accounts, and when aggregated can represent significant accretions of native flow to the system during the non-irrigation season when the system's native inflows are typically at minimum levels.

2.7.3 Simulation of Augmentation Uses and Delayed Return Flow Requirements

For the current purposes of the model, it is convenient to simulate both augmentation uses and delayed return flow requirements in a similar manner as they both represent releases of reservoir storage to native river flows. Several augmentation releases from storage and storage releases to meet delayed return requirements are current, explicitly simulated by the model at various levels of detail. Those simulated are included primarily because they represent primary or other significant outflows from storage accounts in various reservoirs. This is especially true for many of the simulated Pueblo Reservoir Excess Capacity accounts.

Specific descriptions of the current, explicitly simulated augmentation releases are discussed elsewhere in the model documentation within the sections discussing the operations of the entity making the release.

Simulation of these releases is performed within the model via the "Augmentation Release Data Object" methodology and the associated "Set Augmentation Releases" rule. This methodology allows for the simple and efficient addition or modification of simulated augmentation releases without the need for additional rule or logic development. Augmentation releases are configured on mostly-standardized data objects using a similar methodology to the "Demand Data Object" methodology used to configure the storage delivery demands of various water users. Augmentation Release Data Objects are identified within the model logic by setting the "Demand or Augmentation Data Object" attribute to the "Augmentation Release DO" value.

Each "Augmentation Release Data Object" is used to configure a single release from a reservoir storage account to native river flow. Generally, the releases are defined by an input total "Annual Release Volume" and "Monthly Release Pattern" that is used to distribute the release to daily average flows by an Initialization Rule, although several other configuration options also exist. The source reservoir and storage account are also specified on the data object.

For the most part, the Augmentation Release objects are configured either manually, for those that currently assume the same releases for all model scenarios, or by Initialization Rules at the beginning of a model run for those that vary by scenario but assume the same release demands for each year of a model run. Functionality also exists that allows Augmentation Release data objects to be dynamically configured by rules within a model run, which allows for the simulation of dynamic release demands that may be dependent on mid-run simulated model results, such as the previous seasons total yield from a certain water right.

Near the beginning of each timestep, and prior to the Water Rights Solver firing, the "Set Augmentation Releases" rule cycles through all of the Augmentation Release Data Objects and releases the appropriate amount of water by transferring it from the source storage account to the native passthrough account on the reservoir where it is available for allocation by the Water Rights Solver on the same timestep. By setting these releases as a transfer to the reservoir's native passthrough account, rather than setting it as a release to the native flow account on the reach below the reservoir, the water may be allocated to water rights on or directly diverted from the reservoir, or otherwise held in the reservoir's storage. This regularly occurs in Pueblo Reservoir during the Winter Water storage season. At the current level of development, there are no adjustments made to future release demands if past release demands were not met or were incomplete due to insufficient available storage in the source account storage.

2.7.4 Associated Assumptions

The use of various types of augmentation has evolved through time within in the Arkansas River basin. Thus, the aggregated and various effects on the system are present in a transient manner within the historic observed data, including streamflow gages, reservoir storages, and water user diversions. This creates various issues in the calculation of historic natural flows and model reach local inflows where the goal is to back out the effects of the historic operations so that the current operations may be simulated.

As the purpose of the historic augmentation use was to offset various historic depletions, it can be appropriately assumed that there was no overall net effect on the system. However, due to the fact that sources of augmentation to the river may occur in different river reaches as simulated by the model, the historically transient effects may be present in the calculated reach local inflows used for simulation. Due to the lack of appropriate historic data necessary to account for these issues, it must be assumed that the associated effects on the model's reach local inflow are negligible. This means that it is assumed that the model's local inflows calculated from the historic data are a sufficient approximation of the local inflows that would occur if the same hydrology repeated itself under current operations, even though the historic data was a product of historic operations and water uses (e.g. river depletions from groundwater pumping) that are different than those of today.

For simulated augmentation releases from storage, it is assumed that the associated native flow depletions are implicitly represented in the model's local inflows (i.e., that the model's local inflows are lower than they would otherwise be due to that depletion). This is a tenuous assumption due to the fact that the magnitudes and mechanisms of the associated historic river depletions are in many ways different than they are today, however it is required due to the substantial effort that would be involved to do so and the fact that the historic data required to account for this issue is for the most part unavailable.

Those augmentation uses and delayed return flow requirements that are not explicitly represented through reservoir releases are assumed to be met by the utilization of the reusable return flows and/or augmentation station returns to the river that are implicitly included in the local inflows. Additionally, it is assumed that the various un-simulated reusable return flows are used to meet the multitude of augmentation and delayed return flow requirements that are not explicitly modeled, or are forfeited to native river flow and thus are contained within the local inflows

Finally, in practice, administrative measures may be taken to protect some sources of augmentation flow to ensure that it remains in the native river flow from its point of accrual to the point of the associated depletion. In the RiverWare model, the augmentation releases that are simulated are simply released to the native river flow and thus made available for allocation by the Water Rights Solver. It is assumed that this representation is sufficient for the current model purposes.

2.7.5 Reusable or Fully Consumable Return Flows

Reusable return flows (RRFs) refer to the portion of the calculated or measured return flows to the river from water users that are classified as reusable or fully consumable. RRFs are the portion of a water user's return flows that result from the delivery of fully consumable water to that water user. The most significant source of fully consumable water is imported, transbasin water (e.g., FryArk Project water), although other types of water such as the consumptive use portion of changed water rights can also be considered reusable.

It is currently infeasible to explicitly represent the full extent of RRFs and their uses in the Arkansas River Basin due to the lack of the detailed historic data that would be required to back out these RRFs from the model's local inflows that are necessary avoid the double counting of water. For this reason, as well as due to the many variable and changing ways that RRFs have been and are currently utilized throughout the basin, the majority of RRFs and their subsequent and ultimate uses in the basin are assumed to be implicitly represented through the local inflows and the simulated transit losses.

Reusable return flows are explicitly represented in the model only in the limited cases where they represent important sources of water for storage in Pueblo Excess Capacity Accounts or other locations AND where sufficient information and data was available. Currently, reusable return flows are simulated only for Colorado Springs Utilities and for Pueblo Water. Please see the specific sections of the model documentation for those entities for more information.

2.7.6 Reusable Return Flows as Excess Capacity and Other Storage Sources

Reusable return flows are mentioned as potential storage sources for many Excess Capacity Accounts in Pueblo Reservoir and other locations. Especially notable are reusable return flows generated from deliveries of FryArk Project Water that can be exchanged by SECWCD back into Pueblo Reservoir and subsequently resold to various entities. In present Excess Capacity operations, these storage mechanisms are generally preliminary and have only been utilized by a limited number of entities. Therefore, standard, typical, or expected practices and procedures for these types of mechanisms are generally unknown. Thus, it is currently not possible to simulate these types of EC storage sources for most claiming entities. In addition to undefined procedures and operational criteria, the necessary data of the historic deliveries, return flows, and the appropriate accounting breakdowns also do not exist or were not available. The storage sources that are simulated for the EC accounts are discussed later in this documentation.

2.8 CONTRACT EXCHANGES

Contract exchanges, also known as trades, are "paper water" transactions used in reservoir accounting, and thus there are no direct physical changes to the system as reservoir releases and streamflows do not change. Contract exchanges are frequently utilized by many Arkansas basin entities as a means of moving account water between reservoirs when two (or more) entities have stored water in locations that are preferable for the other entity. In historic Arkansas basin operations, CSU and Aurora tend to be the most prolific users of contract exchanges, and typically use them to move stored water from lower basin reservoirs to upper basin reservoirs for subsequent diversion through the Otero Pump Station. Contract exchanges are expected to be utilized in an increasing manner in future Arkansas basin operations.

Contract exchanges are simulated in relatively simple manner in the RiverWare model. The simulation methods utilized were originally developed for use in the ModSim model. The following contract exchanges are currently simulated:

- CSU (LT EC storage in Pueblo, upstream to Twin Lakes or Turquoise) and PBWW (storage in Twin Lakes or Turquoise, downstream to PBWW LT EC in Pueblo)
- CSU (LT EC storage in Pueblo, upstream to Twin Lakes or Turquoise) and FryArk PW (storage in Twin Lakes or Turquoise, downstream to FryArk PW storage in Pueblo)
- CSU (LT EC storage in Pueblo, upstream to Twin Lakes) and Pueblo West (storage in Twin Lakes, downstream to Pueblo West LT EC in Pueblo)
- Aurora (LT EC storage in Pueblo, upstream to Twin Lakes or Turquoise) and PBWW (storage in Twin Lakes or Turquoise, downstream to PBWW LT EC in Pueblo)
- Aurora (LT EC storage in Pueblo, upstream to Twin Lakes or Turquoise) and FryArk PW (storage in Twin Lakes or Turquoise, downstream to FryArk PW storage in Pueblo)

During simulation, contract exchanges between various parties are attempted on set schedules by the day of the month, shown in Table 10 and Table 11 below for CSU and Aurora respectively. This schedule only allows for one contract exchange per day and the competing exchanges between CSU and Aurora are attempted in a back-and-forth manner to not favor either entity. The amount of each contract exchange is assumed to be up to 500 AF per transaction and is limited by both the available storages and the available empty storage space of both entities. A minimum volume of 50 AF per transaction is also assumed. Contract exchanges are not attempted between May 15 to July 14 each year, to help ensure that upstream native water right yields and imports are not impacted.

Table 10: Simulated Monthly Contract Exchange Schedule for CSU

Contract Exchange Data.CSU Contract Exchange Table

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CSU Contract Exchange Table

Value:

	Twin Lakes Res^PBWW NONE	Turquoise Lake^PBWW NONE	Twin Lakes Res^PROJ WEST SLOPE NONE	Turquoise Lake^PROJ WEST SLOPE NONE	Twin Lakes Res^PUEBLO WEST NONE
Day 1	0.00	0.00	0.00	0.00	0.00
Day 2	0.00	0.00	0.00	0.00	0.00
Day 3	0.00	0.00	1.00	0.00	0.00
Day 4	0.00	0.00	0.00	0.00	0.00
Day 5	0.00	0.00	0.00	0.00	0.00
Day 6	0.00	0.00	0.00	1.00	0.00
Day 7	0.00	0.00	0.00	0.00	0.00
Day 8	1.00	0.00	0.00	0.00	0.00
Day 9	0.00	0.00	0.00	0.00	0.00
Day 10	0.00	0.00	0.00	0.00	0.00
Day 11	0.00	1.00	0.00	0.00	0.00
Day 12	0.00	0.00	0.00	0.00	0.00
Day 13	0.00	0.00	0.00	0.00	0.00
Day 14	0.00	0.00	0.00	0.00	0.00
Day 15	0.00	0.00	0.00	0.00	0.00
Day 16	0.00	0.00	0.00	0.00	0.00
Day 17	0.00	0.00	1.00	0.00	0.00
Day 18	0.00	0.00	0.00	0.00	0.00
Day 19	0.00	0.00	0.00	0.00	0.00
Day 20	0.00	0.00	0.00	1.00	0.00
Day 21	0.00	0.00	0.00	0.00	0.00
Day 22	0.00	0.00	0.00	0.00	0.00
Day 23	0.00	0.00	0.00	0.00	0.00
Day 24	1.00	0.00	0.00	0.00	0.00
Day 25	0.00	0.00	0.00	0.00	0.00
Day 26	0.00	0.00	0.00	0.00	0.00
Day 27	0.00	1.00	0.00	0.00	0.00
Day 28	0.00	0.00	0.00	0.00	1.00
Day 29	0.00	0.00	0.00	0.00	0.00
Day 30	0.00	0.00	0.00	0.00	0.00
Day 31	0.00	0.00	0.00	0.00	0.00

Show: ☐ Description

Monthly Period, Daily Interval

○ Interpolate ◉ Lookup

Table 11: Simulated Monthly Contract Exchange Schedule for Aurora

Contract Exchange Data.Aurora Contract Exchange Table

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Aurora Contract Exchange Table

Value:

	Twin Lakes Res^PBWW NONE	Turquoise Lake^PBWW NONE	Twin Lakes Res^PROJ WEST SLOPE NONE	Turquoise Lake^PROJ WEST SLOPE NONE	Twin Lakes Res^PUEBLO WEST NONE
Day 1	0.00	0.00	0.00	0.00	0.00
Day 2	1.00	0.00	0.00	0.00	0.00
Day 3	0.00	0.00	0.00	0.00	0.00
Day 4	0.00	0.00	0.00	0.00	0.00
Day 5	0.00	1.00	0.00	0.00	0.00
Day 6	0.00	0.00	0.00	0.00	0.00
Day 7	0.00	0.00	0.00	0.00	0.00
Day 8	0.00	0.00	0.00	0.00	0.00
Day 9	0.00	0.00	1.00	0.00	0.00
Day 10	0.00	0.00	0.00	0.00	0.00
Day 11	0.00	0.00	0.00	0.00	0.00
Day 12	0.00	0.00	0.00	1.00	0.00
Day 13	0.00	0.00	0.00	0.00	0.00
Day 14	0.00	0.00	0.00	0.00	0.00
Day 15	0.00	0.00	0.00	0.00	0.00
Day 16	1.00	0.00	0.00	0.00	0.00
Day 17	0.00	0.00	0.00	0.00	0.00
Day 18	0.00	0.00	0.00	0.00	0.00
Day 19	0.00	1.00	0.00	0.00	0.00
Day 20	0.00	0.00	0.00	0.00	0.00
Day 21	0.00	0.00	0.00	0.00	0.00
Day 22	0.00	0.00	0.00	0.00	0.00
Day 23	0.00	0.00	1.00	0.00	0.00
Day 24	0.00	0.00	0.00	0.00	0.00
Day 25	0.00	0.00	0.00	0.00	0.00
Day 26	0.00	0.00	0.00	1.00	0.00
Day 27	0.00	0.00	0.00	0.00	0.00
Day 28	0.00	0.00	0.00	0.00	0.00
Day 29	0.00	0.00	0.00	0.00	0.00
Day 30	0.00	0.00	0.00	0.00	0.00
Day 31	0.00	0.00	0.00	0.00	0.00

Show: Description

Monthly Period, Daily Interval

Interpolate Lookup

Additionally, contract exchanges are also currently simulated between Turquoise Lake and Twin Lakes Reservoir as a means to move CSU and Aurora water to Twin Lakes and Project Water that has been run through the Sugarloaf Conduit from Turquoise to Twin Lakes back up to Turquoise.

In actual basin operations, contract exchanges can occur between nearly any parties, at any time, and for any amounts. Additionally, the currently simulated contract exchanges are assumed to be executed with equal volumes on both ends. In reality, the executed contract exchanges may be of uneven volumes due to a “fee” being charged (typically as an additional percentage of water) by one entity. It is assumed that the simulated procedure is sufficient to capture the major effects of the basin’s potential contract exchanges.

2.9 Leases

The leases of already stored water volumes and/or prospective parts of annual water right yields that are currently simulated within the RiverWare model are almost entirely within the Pueblo Reservoir Excess Capacity (EC) accounts. For many of these accounts, leases represent a significant portion (or even all) of the simulated storage sources assumed to be available. Leases of already stored water can also represent significant simulated demands on EC accounts. Additionally, some leases of shares of various organizations (i.e., canal companies), and thus the variable annual yields that those water rights produce, are simulated as sources for some EC accounts. For example, for the Colorado Water Protective and Development Association’s (CWPDA) shares in the Twin Lakes Reservoir and Canal Company (TLCC), and the Lower Arkansas Valley Water Conservancy District (LAVWCD) shares in the Catlin Canal. Limited and incomplete information was available regarding the actual ownership stakes in these types of companies, and whether available data represented outright ownership or leases of shares. Thus, assumptions generally had to be made based on available information and/or targeted to produce expected results.

Little information was provided or available regarding the many other leases that take place in the Arkansas basin. Outside of operations and leases relating to Pueblo Reservoir Excess Capacity operations, the only leases that are explicitly simulated are shown below:

- Donala’s annual lease of up to 250 AF of PBWW water in Turquoise Reservoir that it uses to meet its Willow Creek Ranch delayed return flow requirements.
- Aurora’s annual lease of the first 2500 AF of Homestake water imported to Turquoise Lake.

It is assumed that the effects of the basin’s various leases that are not explicitly simulated within the model are either negligible or that similar effects of the leases may ultimately end up happening despite them not being simulated. For example, PBWW is one of the major leasers of water storage in the basin as its annual yields are typically well in excess of their direct demands. Thus, PBWW leases large volumes of water to various entities on an annual basis. Some of these leases are currently simulated within the Excess Capacity account operations in Pueblo Reservoir, however based on model results it is apparent that large volumes of lease demands are not currently being captured. In one way or another, many entities that lease water from PBWW may end up releasing the leased water to native river flow, for example to offset out-of-priority groundwater pumping depletions or to meet delayed return flow requirements. However, in the absence of these leases in simulation, a good deal of PBWW’s water sources in the basin will either go unutilized due to full storage conditions, thus leaving additional native flow in the river, or will “fill-and-spill” from PBWW’s LT EC account into native river flow. In this way, the effects of the leases on native river flows may be captured at some level without actually simulating the leases.

2.10 River Transit Losses

2.10.1.1 Arkansas River Transit Losses

Transit losses on the Arkansas River mainstem are simulated in the model in a dynamic fashion through the same reaches for which local inflows are calculated. These same transit loss ratios are used within the local inflow calculations on the historic river flows. This consistency in methods between the calculated model input local inflows and the transit losses simulated by the model helps to maintain overall mass balances.

Due to differences in the way they are calculated, the simulated transit loss charges (for example on a delivery of storage from Pueblo Reservoir to a downstream water user) may differ somewhat from what may be charged as a transit loss under actual basin operations. The main goal of the simulation is to reflect the fact that transit losses are charged on account flows in real world administration of the basin, and thus releases made for delivery at a downstream location may be required to be significantly higher than the delivery demand at the diversion structure. Thus, the transit losses can ultimately represent significant additional uses of available water supplies, especially for water users that are long distances from their storage locations or whose deliveries travel through reaches of particularly high transit losses.

Simulated transit losses are assumed to be a static ratio of the flow through the transit loss reach object at any given time. The ratios used are calculated by the “per mile” transit loss ratios used by the State and the approximate reach lengths. The transit loss reaches and ratios used are shown in Table 12.

Transit losses are simulated only at discrete model reach nodes, and thus are a function of the transit loss nodes that a particular flow (i.e., a delivery to a water user) travels through, rather than the particular distance that the flow travels. Also note that the simulated transit losses are also calculated in a compounding manner, meaning that the transit loss calculated through a second transit loss reach is based on the flow already reduced by the first transit loss. Simulated deliveries made through transit loss reaches are reduced as they travel downstream by any transit loss ratios along the way, and thus a demand for a certain delivery amount at a canal headgate will require an increased release based on the transit loss nodes between the release location and the delivery location.

Finally, simulated transit losses are prorated across the various passthrough account flows that make up the total physical flow, and thus the transit loss charged to each account flow is only dependent on its own flow. In this way, as the flow through a transit loss reach changes as a model timestep solves (i.e., as the rules fire), the transit losses will update accordingly but still maintain consistency across the various account flows, i.e., an increase in flow in one passthrough account will not lead to an increase in transit loss in another passthrough accounts flow, which would make it impossible to maintain reconcile between total physical and account flows during a timestep’s solution.

To illustrate how this important consideration occurs, consider a simulated reach with a 10% transit loss ratio. If the initial native solution of a transit loss reach is 500 cfs of native flow, which is also the mid-solution total physical flow. The initial transit loss will be 10% of that flow, or 50 cfs, and thus the reach outflow is 450 cfs. Now, a rule fires to deliver storage to a 100 cfs diversion demand below the transit loss reach. Due to the 10% transit loss, the required upstream reservoir release is 111.11 cfs. This is a bit counterintuitive, but it must be remembered that the transit loss is calculated based on the reach inflow, and thus the required release is calculated by the desired downstream flow divided by 1 minus the transit loss ratio, or 100/ (1-0.1) = 111.11 cfs (so the required reservoir release is not simply 110 cfs). Now, the inflow to the transit loss reach is 500 + 111.11 = 611.11 cfs and the updated total reach transit loss = 0.1 * 611.11 = 61.11 cfs. Now comes the important point about the consistency of the transit losses charged to the account flows and that each calculated account transit loss is still only dependent on its own inflow to the reach. The native account transit loss is still 50 cfs, and the delivery account transit loss is 0.1 * 111.11 cfs = 11.11 cfs, and the two account transit losses sum perfectly to the total physical transit loss of 61.11 cfs, maintaining the reconcile between the physical and accounting.

This method for dynamically simulating transit losses allows for as many changes (both increases and decreases) to a reach's flow as are needed during the solution of a timestep, allowing for multiple deliveries, exchanges, or other operations to be "layered" upon each other, without impacting the solutions of any of the previous "layers" of operations.

Table 12: Simulated Transit Loss Ratios by Reach Used Within the Model

Arkansas River Data.Transit Loss Percentages by Reach

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Transit Loss Percentages by Reach

Value:

	Reach Length mi	Loss Ratio Per Mile NONE	Total Reach Loss Ratio NONE
0: Above Blw Granite Transit Losses	22.50	0.0007	0.016
1: Below Granite to Salida Transit Losses	33.00	0.0007	0.023
2: Salida to Wellsville Transit Losses	4.50	0.0007	0.003
3: Wellsville to Parkdale Transit Losses	42.00	0.0007	0.029
4: Parkdale to Canon City Transit Losses	9.00	0.0007	0.006
5: Canon City to Portland Transit Losses	16.00	0.0007	0.011
6: Portland to Pueblo Res Transit Losses	30.00	0.0007	0.021
7: Pueblo to Moffat Street Transit Losses	8.50	0.0010	0.009
8: Moffat Street to Avondale Transit Losses	14.50	0.0010	0.015
9: Avondale to Nepesta Transit Losses	21.00	0.0013	0.027
10: Nepesta to Catlin Dam Transit Losses	17.60	0.0013	0.023
11: Catlin Dam to Rocky Ford Transit Losses	18.00	0.0013	0.023
12: Rocky Ford to La Junta Transit Losses	14.20	0.0013	0.018
13: La Junta to Las Animas Transit Losses	33.70	0.0015	0.051
14: John Martin to Lamar Transit Losses	10.00	0.0150	0.150
15: Lamar to Granada Transit Losses	10.00	0.0150	0.150
16: Granada to Coolidge Transit Losses	10.00	0.0080	0.080

Show: ☐ **Description**

2.10.1.2 Fountain Creek and Purgatoire River Transit Losses

Transit losses and the associated accounting on Fountain Creek is very complex. For that reason, and the fact that the model currently has a very simplified representation of the Fountain Creek system, the total physical transit losses are assumed to be implicitly simulated in the model's Fountain Creek Local Inflows. The flow loss effects of transit losses of CSU-owned flows in Fountain Creek are included in the assumed and "forced" CSU Reusable Return Flows in Fountain Creek. This data was provided by CSU and is assumed to be sufficient for the current purposes of the model, although future development on these fronts is recommended.

Transit Losses on the Purgatoire River are also assumed to be implicitly represented in the model's Purgatoire River Local Inflows.

2.11 Flow Lag Times

Simple lag times are simulated in the model. The utilization of the RiverWare Water Right Solver requires that the simulated lag times be integer of days. The total lag time simulated from the headwaters to the Colorado-Kansas state line is 4 days. The lag times are static and do not vary by flow rate or other factors.

The representation of lag times causes the network objects to be at different timesteps depending on their location in the basin relative to the model's Run Controller's "Current Timestep" and thus to the rule logic. The model’s rules are built to account for the lag time throughout the basin. In simple terms, a release made from an upper basin reservoir will be seen at Pueblo Reservoir the day after it was made, a release from Pueblo Reservoir will be seen in John Martin two days after it was made, and a release from John Martin will be seen at the Colorado-Kansas state line a day after it was made.

Exchanges that are simulated through lag reaches also account for the lag time. For example, in a river exchange from storage in Pueblo Reservoir upstream to Twin Lakes Reservoir, a single day hold back of a native flow release from Twin Lakes Reservoir causes a flow reduction in the river below Twin Lakes on the day that it was held back.

However, due to the lag time, this flow reduction will not be seen in the river at Pueblo Reservoir until the following day. Thus, in order to appropriately eliminate the flow reduction and make the native flow of the river whole, Pueblo Reservoir must release storage to the native river flow on the day after the release from Twin Lakes was held back.

All simulated operations and other transactions occurring between network objects with a lag reach between them, such as the exchange example above, are made to account for the objects being on different timesteps.

Lag times are simulated in the following 4 locations through the river network:

- ***Above Pueblo Reservoir Lag:*** A lag time of 1 day is assumed from the headwaters basin to Pueblo Reservoir. This lag time is applied on a reach node immediately above Pueblo Reservoir. This causes the upper basin reservoirs (Turquoise Lake, Mount Elbert Forebay, Twin Lakes Res, and Clear Cr Res) and water users to all be on the same timestep, which is 1 day before Pueblo Reservoir.

- ***Pueblo Reservoir to Las Animas Lag:*** A lag time of 2 days is assumed from Pueblo Reservoir to the Las Animas gage. This lag time is applied on a reach node immediately above the Las Animas gage. As this is below the Colorado Canal and Holbrook Canal systems and reservoirs, they are all assumed to be on the same timestep as Pueblo Reservoir for modeling purposes, as are all the water users between Pueblo Reservoir and the Las Animas gage. All the Fountain Creek nodes represented are also on the Pueblo Reservoir timestep. Due to this lag, the John Martin Reservoir model timestep is 2 days after the Pueblo Reservoir timestep.
- ***John Martin Reservoir to Coolidge gage Lag:*** A lag time of 1 day is assumed from John Martin Reservoir to the Coolidge gage. This lag currently causes the last few objects at the bottom of the system to have a model timestep that is 1 day ahead of John Martin Reservoir, 3 days ahead of Pueblo Reservoir, and 4 days ahead of the Arkansas basin headwaters.
- ***Trinidad Reservoir to Las Animas Lag:*** A lag time of 2 days is assumed from Trinidad Reservoir to the Purgatoire River near Las Animas gage. This lag is applied at a reach node immediately above the gage node. This causes Trinidad Reservoir and all of the the Purgatoire River water users to be on the same model timestep as Pueblo Reservoir

3 Simulated Reservoir Operations

3.1 Turquoise Lake

Turquoise Lake sits on Lake Fork Creek, a headwater tributary of the Arkansas River near Leadville, CO, and is a component of Reclamation's Fryingpan-Arkansas Project. Turquoise Lake has a small natural drainage area, ~28 square miles, for a reservoir of its size, with a total storage capacity of ~130,000 AF, as three transbasin imports flow directly into Turquoise Lake, the FryArk Project's Boustead Tunnel, the Homestake Tunnel, and the Busk-Ivanhoe Tunnel, which are all simulated as direct inflows.

3.1.1 Simulated Storage Accounting and Water Rights

Aurora, CSU, and PBWW each have storage accounts in Turquoise Lake, with Aurora and CSU each having two distinct storage accounts. The current account distribution has originated from two historic storage accounts, the Homestake account and the CF&I account. The Homestake account is evenly split between Aurora and CSU and can only be used to store imported Homestake Project water and is simulated in this way. The CF&I account has been divided into three accounts for CSU, Aurora, and PBWW.

The remainder of the storage account space in Turquoise Lake is reserved for FryArk Project Water (PW). Officially, the PW capacity is 63,062 AF, however as actually operated, PW can encroach into the unused storage space of other accounts. Thus, the total PW storage capacity is simulated as being flexible and depends on the current storages of the other accounts. An overall maximum PW capacity of 100,000 AF was applied based on recently observed actual PW storages. The simulated Turquoise Lake account capacities are shown below in Table 13. Please note that the East Slope PW account ("PROJ EAST SLOPE") is subject to the same limitation as the West Slope (imported) PW in the rare instances when it is in priority to store water.

There are three storage water rights that are simulated on Turquoise Lake, two of which belong to CSU from their CF&I ownership, with priority dates of July 1, 1864 and May 1, 1902, which are subject to rate, date, and volume limits and to specific return flow obligation requirements. The FryArk East Slope Project Water storage right, with a junior priority date of June 6, 1962, is also simulated.

Table 13: Simulated Turquoise Lake Storage Account Capacities

Turquoise Lake Data.Max Storage Account Capacities

Max Storage Account Capacities

	PROJ WEST SLOPE acre-feet	PROJ EAST SLOPE acre-feet	AURORA acre-feet	CSU acre-feet	PBWW acre-feet	HS AURORA acre-feet	HS CSU acre-feet
0: Maximum Storage	63,062.00	NaN	5,000.00	17,416.00	5,000.00	15,000.00	15,000.00

Note: "HS" refers to each entity's portion of the Homestake storage account.

3.1.2 Simulated Reservoir Operations

A guide curve is utilized to simulate the general operations of Turquoise Lake and to approximate the annual movement of FryArk Project Water imports downstream to Pueblo Reservoir, where it can be accessed by water users. The guide curve, shown below in Figure 2, was developed based on annual storage patterns observed in recent years and discussions with Reclamation operators. Generally, the guide curve approximates the drawdown of reservoir storage in the late fall, winter, and early spring to and allowing it to fill through the early summer with runoff and the seasons imports. As utilized during simulation, the guide curve is based on total reservoir storage, but only dictates releases of PW, i.e, it can't cause releases of CSU, Aurora, or PBWW account water.

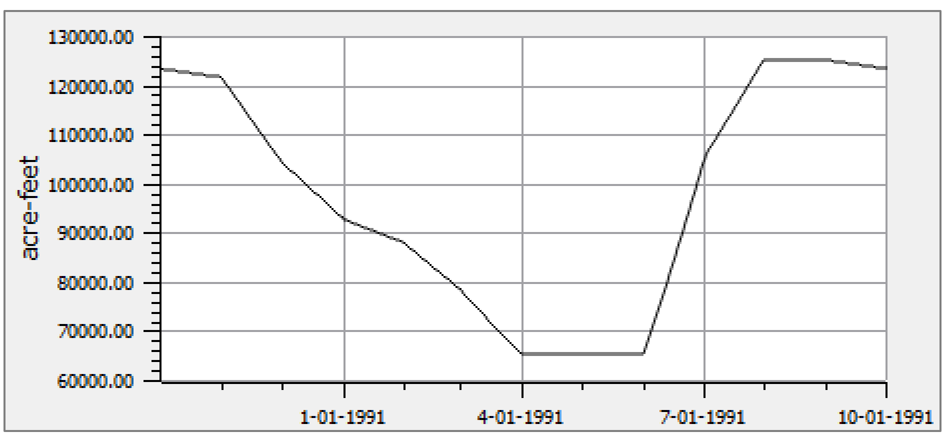

Figure 2: Turquoise Lake Guide Curve Used for Simulation

Turquoise Lake has two outlets used to release water. It is preferential to release most water through the Sugarloaf Conduit to Mt. Elbert Forebay and Twin Lakes Reservoir, so that they may be used to generate hydropower. However, releases are also made to Lake Fork Creek to maintain minimum flows in Lake Fork Creek, to pass native inflows to water users when required, or to release additional water when high inflows and guide curve targets or storage limits demand higher releases than the conduit capacity alone. A maximum reservoir release of 400 cfs is also simulated for the Turquoise Lake releases to Lake Fork Creek according to flood constraints and may only be exceeded during unregulated spillway flows.

Downstream on the Sugarloaf conduit from Turquoise, the native diversion from Halfmoon Creek into the conduit are simulated. These diversions are subject to the decreed limits of a maximum diversion of 150 cfs, a minimum bypass in the creek of 7 cfs, and can be further limited if the Water Rights Solver determines that the diversions would impact water rights allocations between the Halfmoon Creek and the confluence of Lake Creek and the Arkansas River, where the diversion returns as native releases from Twin Lakes. Furthermore, the Halfmoon diversion to the conduit is simulated in the model using additional criteria developed to mimic the historic diversion records. These methods were developed due to initially simulated diversions well in excess of those that occurred historically.

The Sugarloaf Conduit capacity is currently assumed to be a static 370 cfs throughout its full length, and thus the releases from Turquoise Lake to the conduit are limited by the downstream inflows from the Halfmoon Creek. Base releases from Turquoise Lake to the conduit are only PW, however native passthrough flows to downstream water rights that would otherwise be released down Lake Fork Creek may instead be diverted through unused conduit capacity and subsequently released through Twin Lakes Reservoir, provided that it does not impact any of the water right allocations between Turquoise and the confluence of Lake Creek and the Arkansas River.

Additionally, a constant release to the Leadville fish hatchery of 5.4 cfs is made through the conduit, which the hatchery diverts directly from. This release is made with PW and it is assumed that it fully returns to Lake Fork Creek above its confluence with the Arkansas River and flows downstream into Pueblo Reservoir.

Following the simulated Sugarloaf conduit release, the PW that is released through the conduit from Turquoise to Twin Lakes may be transferred right back up to Turquoise by simulating contract exchanges with Aurora and/or CSU storage in Turquoise. These contract exchanges are utilized regularly in real world operations to move Aurora and CSU's storage to Twin Lakes where they can divert it through the Otero Pump Station, while still being able to run flows through the conduit to generate hydropower.

Along with the simulated Turquoise Lake releases through the Sugarloaf conduit and Lake Fork Creek. The potential exchanges by CSU and Aurora into their Turquoise Lake CF&I storage accounts from downstream storage in Pueblo Reservoir LT EC accounts are also simulated. However, these exchanges into Turquoise are only made after their preferred exchanges into their Twin Lakes accounts (or if their Twin Lakes accounts are already full) and if there is remaining exchange potential in the Arkansas River and on Turquoise Lake native releases, so they tend to be less frequent and of less overall volume than their exchanges into Twin Lakes. Contract exchanges of both PW and PBWW storages in Turquoise with Aurora or CSU storage in Pueblo Reservoir are also simulated, as discussed elsewhere.

The minimum release criteria and operations from Turquoise Lake to Lake Fork Creek are also simulated. Between March 15 and November 14 of each year, the minimum release is equal to the minimum of the native inflow to Turquoise or 15 cfs. During this period, exchanges into Turquoise Lake during this period are not allowed to reduce the native release below 15 cfs. Between November 15 and March 14, the minimum release is 3 cfs. However, during this period, exchanges and/or storage under CSU's Turquoise

Lake storage water rights can reduce the native outflow down to 0 cfs. If this happens, Reclamation must release PW to meet the 3 cfs minimum.

3.2 Mount Elbert Forebay

The Mount Elbert Forebay Reservoir is an off-stream, pumped-storage reservoir and a component of Reclamation's Fryingpan-Arkansas Project. It is operated primarily for hydropower generation at the Mount Elbert Powerplant via pumped-storage operations between itself and Twin Lakes Reservoir, which sits directly below it. The reservoir has minimal natural drainage area and it's primary inflows are pumped inflows from Twin Lakes Reservoir and Sugarloaf Conduit flow from Turquoise Lake and Halfmoon Creek. The pumped-storage hydropower operations make use of combination pump-generator turbines to pump water from Twin Lakes up to the Mount Elbert Forebay during times of low power demand and releasing water down through the generators during high power demands. This is typically done in a diurnal fashion, pumping water up in the early morning hours and releasing it down during the rest of the day.

Mount Elbert Forebay is simulated in a basic manner in the RiverWare model. The "hydrologic inflow", or reservoir local inflow, is assumed to be zero due to the small drainage area and thus its only simulated inflows come from the Sugarloaf Conduit. The sub-daily inflows and outflows of the pumped-storage hydropower operations are assumed to net to zero and the reservoir is assumed to have a constant daily target storage of 9,367 AF throughout the entire model run. Thus, normally, each day's total outflow is the inflow from the Sugarloaf Conduit minus the simulated reservoir evaporation loss. The storage is the Mt. Elbert Forebay is assumed to be all Fry Ark Project Water, and thus that is charged all of the evaporation loss. If the inflows from the Sugarloaf Conduit are reduced or stopped such that the reservoir evaporates below its target elevation, it is refilled when the inflows begin again.

The accounting of the inflows from the Sugarloaf Conduit may consist of FryArk Project Water from Turquoise Lake and native flows diverted from Halfmoon Creek. It is assumed that these native flows must be passed through Mount Elbert Forebay, and subsequently through Twin Lakes Reservoir, as to not impact any downstream water rights.

The FryArk Project East Slope storage water right is included on the reservoir, but as the reservoir is assumed to have no native inflows it never receives allocation of water, even when the FryArk Project East Slope storage rights are in-priority in the basin.

3.3 Twin Lakes Reservoir

3.3.1 Simulated Storage Accounting and Water Rights

The Twin Lakes Reservoir and Canal Company (TLCC) has a 54,452 AF capacity storage account in Twin Lakes Reservoir. This capacity is assumed to be split between the TLCC shareholders by its ownership percentages, as shown below in Table 15. Thus, the TLCC account is simulated as 5 separate storage accounts: CSU, PBWW, Pueblo West, Aurora, and “TLCC Balance”, which represents the minor shareholders within a lumped storage account. TLCC water yields, whether through Twin Lakes Tunnel imports that flow into Lake Creek and then Twin Lakes Reservoir or by TLCC storage water right yields, are split between these 5 accounts by the same ownership percentages. The operations of the first 4 accounts are simulated explicitly, including direct diversions, releases, and potential exchanges. No operations of the individual minor TLCC shareholders are simulated within Twin Lakes, including direct use from Twin Lakes or any other transactions. However, simulated releases from the lumped "TLCC Balance" account are split between the EC accounts of the minor shareholders upon arrival in Pueblo Reservoir.

Officially, Twin Lakes Reservoir has a total FryArk PW capacity is 13,465 AF, however as actually operated, PW can encroach into the unused storage space of other accounts. Thus, the total PW storage capacity is simulated as being flexible and depends on the current storages of the other accounts. An overall maximum PW capacity of 25,000 AF was applied based on recently observed actual PW storages. The simulated Twin Lakes Reservoir account capacities are shown below in Table 14. Please note that the East Slope PW account ("PROJ EAST SLOPE") is subject to the same limitation as the West Slope (imported) PW in the rare instances when it is in priority to store water. Twin Lakes Reservoir also has a large amount of "inactive", unaccounted storage, which is simulated with a "Dead and Inactive" storage account with a static 54,580 AF.

There are three storage water rights that are simulated on Twin Lakes Reservoir, two of which belong to TLCC, with priority dates of December 15, 1896 and March 29, 1897, 1902. The FryArk East Slope Project Water storage right, with a junior priority date of June 6, 1962, is also simulated.

Table 14: Simulated Twin Lakes Storage Account Capacities

Twin Lakes Res Data.Max Storage Account Capacities

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Max Storage Account Capacities

Value:

	PROJ WEST SLOPE acre-feet	PROJ EAST SLOPE acre-feet	TLCC BALANCE acre-feet	AURORA acre-feet	CSU acre-feet	PBWW acre-feet	PUEBLO WEST acre-feet
0: Maximum Storage	13,465.00	NaN	2,835.00	2,722.00	29,962.00	12,602.00	6,332.00

Show: ☐ **Description**

Table 15: Simulated Twin Lakes Reservoir and Canal Company Ownership Breakdown.

Entity		Simulated Shares[1]	Simulated Ownership Percent
Total Shares		49588.97	
Simulated Major Shareholders	CSU	27286.36	55.0%
	PBWW	11476.16	23.1%
	Pueblo West	5766.41	11.6%
	Aurora	2478.48	5.0%
	Subtotal	47007.41	94.8%
Other Shares ("TLCC Balance"[2])		2581.56	5.2%
Unclaimed Shares		730.46	n/a
Total Simulated Minor Shares[3]		1851.10	**Simulated % of TLCC Balance**
Simulated Minor Shareholders[4]	CWPDA EC	897.44	48.5%
	Ordway EC	445.40	24.1%
	UAWCD EC	182.66	9.9%
	Crowley County EC	142.00	7.7%
	LAVWCD EC	92.00	5.0%
	Olney Springs EC	91.60	4.9%

1: Ownership of shares as simulated was determined from a variety of sources and reflects best available information. Actual ownership changes as shares are sold or temporarily leased to other parties. Breakdown shown in this table is assumed static throughout model runs.
2: "TLCC Balance" is the simulated lumped storage account for minor shareholders
2: Unclaimed shares are not used in simulated distribution to minor shareholders
3: Individual minor TLCC shareholder operations within Twin Lakes are not simulated, including direct usage from Twin Lakes. Lumped "TLCC Balance" releases are split between minor shareholder EC accounts upon arrival in Pueblo Reservoir. If any minor shareholder's EC accounts are full, yields are distributed between others.

3.3.2 Simulated Reservoir Operations

As mentioned above, the total TLCC inflow yields are split between its subaccounts. The operations of the CSU, PBWW, Pueblo West, and Aurora storage accounts are simulated individually and can include direct diversions, releases to Pueblo Reservoir through Lake Creek and the Arkansas River, and potential exchanges into the accounts. Contract exchanges can occur into and out of Twin Lakes from both Pueblo Reservoir and Turquoise Lake and are discussed elsewhere.

Aurora and CSU diversions directly from Twin Lakes to the Otero Pump Station and Homestake Pipeline are simulated. Aurora's simulated capacity is 78.14 cfs, and CSU's is 105.21 cfs and is assumed to include Woodland Park, for a combined full capacity of 183.35 cfs. The pipeline is assumed to be fully shut down in September for maintenance, but diversions are simulated for the rest of the year. The simulated demands on the Otero Pump Station depend of the total demands of Aurora and CSU which vary by model scenario.

FryArk Project Water can make its way into Twin Lakes by way of release through Sugarloaf Conduit and Mt. Elbert Forebay from Turquoise or through the FryArk storage water rights in very wet years. Releases of PW are simulated when necessary due to PW account capacity constraints as the storage utilization of the other accounts changes and PW is also moved to Turquoise Lake and Pueblo Reservoir by contract exchange. Additionally, releases of PW from Twin Lakes Reservoir are also simulated when necessary to meet the VFMP flow requirements at the Wellsville gage when they are not met by native flows alone. PW releases for this purpose are limited to 10,000 AF/year.

The minimum release from Twin Lakes Reservoir is assumed to be a year-round 15 cfs, which is also assumed to be the minimum native passthrough and to limit exchanges into Twin Lakes. However, account releases to meet this minimum when native flows drop below it are not simulated. A maximum reservoir release of 1500 cfs is also simulated according to Lake Creek flood constraints and may only be exceeded during unregulated spillway flows.

3.4 Clear Creek Reservoir

Clear Creek Reservoir is wholly owned and operated by Pueblo Water (PBWW). It sits on Clear Creek, a headwater tributary of the Arkansas River, which enters just downstream of the Granite gage. The Clear Creek dam almost abuts directly to the Arkansas River and there are only a couple hundred yards between the reservoir outlet and the confluence. Thus Clear Creek essentially releases directly to the river.

Clear Creek Reservoir has two storage water rights, which are both simulated within the model, with priority dates of June 6, 1902 and August 20, 1910. As the senior right is senior to the Winter Water fixed call date of March 10, 1910, it is generally used to fill the reservoir with its inflows during the WW storage period. The storage rights can also fill during runoff in wet enough years for them to come into priority.

PBWW tracks many different types of account water in Clear Creek Reservoir. However, the model currently does not differentiate between these water types and lumps them all into a single account, with a total storage capacity of 9214 AF, which is the full capacity of the reservoir at its spillway invert. The spillway on Clear Creek Reservoir does have radial gates, however they generally not operated due to operational issues. Therefore, it is simulated as an unregulated spillway.

During real-world operations, PBWW operates several exchanges to move storage into or out of Clear Creek Reservoir for various purposes. They can also directly release water to the Arkansas River and allow it to flow into its LT EC account in Pueblo Reservoir when it is necessary.

As currently represented, the only simulated exchanges into Clear Creek Reservoir that may occur are those of its Wurtz and Ewing Ditch transbasin import water. Other potential exchanges are not currently simulated as not enough information is known about the criteria, triggers, and conditions that determine when and how these exchanges are used.

The “Upstream Storage Release” methodology developed within the RiverWare model is used to release water from Clear Creek Reservoir to Pueblo Reservoir when there is a downstream need for water. The same methodology is also used to simulate the typical late summer releases of storage to empty space and allow for storage of winter inflows.

3.5 Pueblo Reservoir Operations

3.5.1 Overview

Pueblo Reservoir has very complex and detailed operations and storage accounting. It serves as the primary storage location for FryArk Project Water and the primary storage location of the Winter Water Storage Program (WWSP). Additionally, the "excess capacity", or the potentially unused FryArk Project storage space within Pueblo Reservoir, is contracted out to various entities to create what are known as Excess Capacity (EC) accounts. The owners or water users with access to storage in the PW subaccounts, WW accounts, and EC accounts are generally allowed to operate their accounts in an independent manner (e.g., determining their own delivery schedules), while subject to some overarching criteria, rules, and limitations provided by Reclamation, SECWCD, and CDWR. The simulated operations of the FryArk Project, WWSP, and EC accounts are discussed elsewhere in this documentation. Due to many different entities operating independently within Pueblo Reservoir, the overall operations are non-standard and thus tend to emerge as the aggregate result of many independent entities operating for their own purposes.

The current Pueblo Reservoir allocation diagram is shown below in Figure 3. As simulated, the maximum WW storage capacity for Pueblo Reservoir is 120,000 AF. The maximum storage capacities of the EC accounts vary by model scenario and is discussed elsewhere. Technically, all of the useable storage capacity in Pueblo Reservoir is allocated for FryArk PW and thus it can push out all other types of water if needed. The FryArk East Slope PW storage right, with a junior priority date of June 6, 1962, is the only storage water right that is simulated on Pueblo Reservoir. When that water right stores during simulation, it is limited only by the Pueblo Reservoir maximum capacity and the amount of West Slope PW in the reservoir, which it isn't allowed to push out.

Direct diversions from Pueblo Reservoir are simulated through up to 6 reservoir outlets: Bessemer Ditch, the Fountain Valley Conduit (FVC), the Southern Delivery System (SDS) pipeline, the Arkansas Valley Conduit (AVC, for selected scenarios only), the PBWW pipeline, and the Pueblo West pipeline. The total demands for these diversions are the aggregate of any applicable water users and the deliveries will depend on the demands, available storages, and other factors. Additionally, the direct release to the Pueblo Fish Hatchery is simulated and returns to the Arkansas River just below the "Above Pueblo gage" just downstream of the reservoir.

The flood control operations of Pueblo Reservoir are simulated and attempt to maintain flow limits of 6,000 cfs in the river directly below the reservoir and at the Avondale gage whenever possible. In real world operations, to exceed 6,000 cfs, the COE must approve the release. Outside of flood control operations, the State can request releases that cause the Avondale gage to exceed 6,000 cfs after assuming any liability for downstream damages. However, in the model, only simulated flood control releases may exceed the 6,000 cfs limit. Water stored for flood control purposes is stored as native water and is released back to the river's native flow as quickly as possible subject to the flood limits.

The simulation order of the various Pueblo Reservoir's operations is very important. Broadly, the native flow solution of the initial water rights solution provides the initial native inflows, diversions, and releases. Then, deliveries from various storage sources to various water users are simulated as these releases can affect account storage capacities and river exchange potentials. These operations are followed by exchanges from Pueblo Reservoir to upstream locations, and then by exchanges from downstream into Pueblo Reservoir.

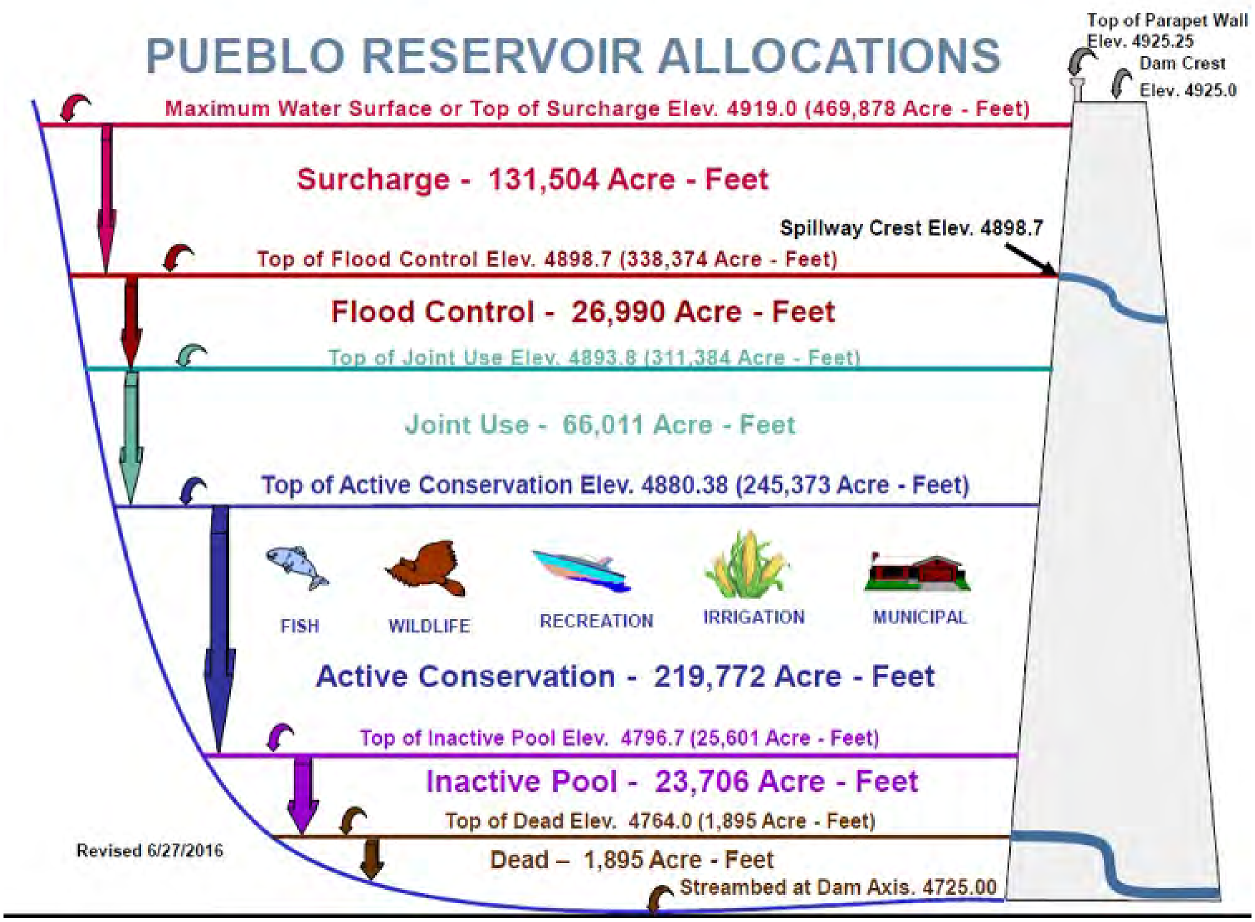

Figure 3: Pueblo Reservoir Allocation Diagram (from Reclamation).

3.5.2 Joint Use Pool Restrictions and Evacuation Priorities

Pueblo Reservoir's 66,011 AF Joint Use Pool is subject to flood control restrictions imposed by the U.S. Army Corps of Engineers, which requires it to be empty between April 15 and November 1. As currently simulated, it is assumed that the drawdown to this constraint from the full capacity begins on April 1 and is linear. This restriction significantly reduces the "excess capacity" storage potential available within this period, and thus can lead to "spills" of non-project water from their storage accounts depending on the levels of PW currently in Pueblo Reservoir. The term "spill" has generally been used to describe the emptying of storage from the Joint Use Pool space when required to meet the flood space restriction. However, this is a bit of a misnomer since more typically in reservoir operations "spill" refers to uncontrolled outflows that occur over an unregulated (or sometimes regulated) spillway, and not to controlled, deliberate drawdowns. A better term to describe the emptying of storage from Pueblo Reservoir's Joint Use Pool is "evacuation", as it is done preemptively to meet the flood control requirements when necessary.

The simulated Pueblo Reservoir Joint Use Pool evacuation priorities are shown below. Note that the general group descriptions of the EC account types are not perfect and that the priorities depend on the specific contracts with Reclamation. The evacuation priorities of the individual EC accounts are shown elsewhere in the documentation in the excess capacity section. As simulated, all storage volume of lower priority accounts is released before that of higher priority accounts. The daily release of this storage may also be limited by other criteria such as flood control release limits.

1. Out-of-District Excess Capacity account storage
2. Annual EC account storage (and select other specific EC account storage)
3. Winter Water storage over 70,000 AF
4. Long-Term and Master Contract EC account storages (except those with specific lower priorities)
5. Remaining Winter Water storage
6. East Slope Project Water

As an additional consideration to avoid and reduce the simulated occurrence of these evacuations, a method was developed to simulate the potential "pre-emptive" evacuation of both Carryover WW storage and Aurora LT EC storage in the period leading up to the JU pool restriction if it appears that evacuation is going to be necessary. As currently simulated, these releases can begin on March 16 and will release their storage at the calculated rate that would cause them to completely empty on April 15. Currently, this storage is simply assumed to be released as native river flow due to lack of definition regarding potential recapture operations. The model will cease these preemptive releases if they are no longer determined to be necessary.

3.6 Colorado Canal System and Reservoirs

The Colorado Canal system consists of the Colorado Canal (CO Canal), several laterals, and two off-stream storage reservoirs, Lake Henry and Lake Meredith. Most of the system has been sold to municipal entities and under 10% of the system uses remain agricultural. The ownership of the CO Canal system and the reservoirs is split by shareholders and varies by entity between the full system and each reservoir. The simulated ownership breakdown is shown below in Table 16. Separate accounts are simulated for each of the major shareholders. The ownership of minor individual shareholders are lumped into an "Other" account and individual operations within the system reservoirs are not simulated, however when simulated exchanges are executed from the "Other" storage accounts to Pueblo Reservoir, the total exchanged volumes are distributed to the applicable EC accounts by the additional breakdown shown in Table 17. Please note that this ownership breakdown was determined from a variety of sources and reflects the best available information. The actual ownership may change as shares are sold or temporarily leased to other parties, but the breakdowns used are assumed to be static throughout all model runs.

Multiple types of diversions to the CO Canal system are simulated, including both native direct flow water right diversions and storage deliveries to the remaining ag demands, and both native storage water right diversions and Winter Water diversions to Lake Henry and Lake Meredith. The recapture or diversion and storage of Arkansas River flow owned by the CO Canal owners is not simulated due to lack of necessary information and data regarding these operations. This includes any diversions relating to the Restoration of Yield (ROY) storage program. An assumed 23.5% flow loss is applied to all CO Canal diversions to storage in either reservoir, as reported in the "Super Ditch Delivery Engineering Report" (LAVWCD, 2014).

The operations of the Colorado Canal system's two reservoirs, Lake Henry and Lake Meredith, are simulated in a conjunctive fashion. The smaller Lake Henry can't release directly to the Arkansas River and must release to the larger Lake Meredith first. Very limited information and data was available regarding both current and past operational procedures and historic storage records of individual entities. Thus, operations are simulated in a simplified, albeit effective fashion. As currently simulated, releases are made from the Lake Henry accounts to the Lake Meredith accounts to attempt to keep the accounts in Lake Meredith full, as all uses are simulated from Lake Meredith. CO Canal agricultural storage is exchanged from Lake Meredith back up the Arkansas River to the CO Canal headgate as the agricultural users don't have direct access from the storage. The municipal owners' storages are moved to Pueblo Reservoir by means of exchanges that are executed whenever possible. Deliveries of WW storage in the CO Canal owned by downstream agricultural water users are simulated as needed by those water users through releases to the river. Releases from Lake Meredith directly to the Holbrook Canal are also possible and are simulated during the delivery of the Holbrook Canal's WW storage in the CO Canal system.

It is assumed that all CO Canal storage that is allocated to the municipal account owners, whether it be from storage water right yield or from winter water allocation, is subject to a basic 40% return flow obligation. This is simulated by transferring 40% of each of the applicable yields into the "Augmentation" accounts. Water stored in the Augmentation account in Lake Meredith is then released as native flow to the system in the late summer, fall, and winter.

Table 16: Simulated Colorado Canal, Lake Henry, and Lake Meredith Ownership Breakdown

Colorado Canal Data.CO Canal Ownershi...

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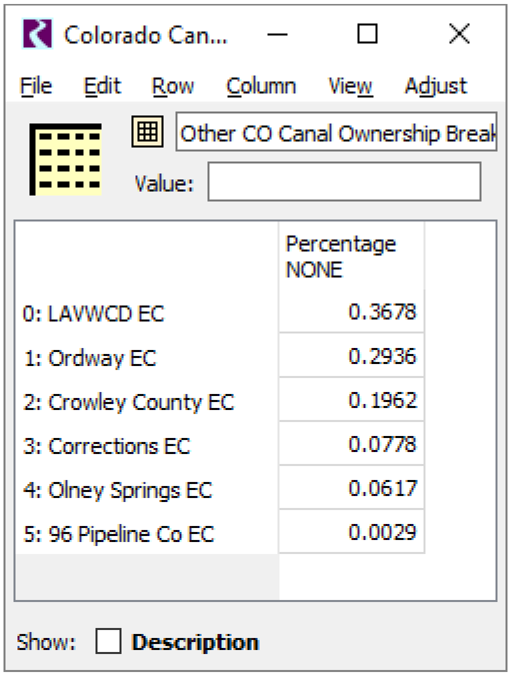
CO Canal Ownership Percentages

Value:

	Colorado Canal NONE	Lake Meredith NONE	Lake Henry NONE
0: CSU	0.5720	0.5220	0.7950
1: AURORA	0.2840	0.3180	0.1290
2: FOUNTAIN	0.0100	0.0120	0.0000
3: PUEBLO WEST	0.0070	0.0090	0.0000
4: AG	0.0960	0.1060	0.0560
5: OTHER	0.0310	0.0330	0.0200

Show: **Description**

Table 17: Simulated Breakdown of the Lumped "Other" Colorado Canal System Ownership



	Percentage NONE
0: LAVWCD EC	0.3678
1: Ordway EC	0.2936
2: Crowley County EC	0.1962
3: Corrections EC	0.0778
4: Olney Springs EC	0.0617
5: 96 Pipeline Co EC	0.0029

3.6.1 Lake Henry

The simulated maximum total storage of Lake Henry is 8,906 AF. The maximum storage capacities of the Lake Henry storage accounts simulated are shown below in Table 18. The maximum capacities may not add up to the total storage capacity as some accounts are assumed to be able to utilize the same storage space. Note that that as simulated, there is not a specific maximum capacity for WW, although it is limited by the total storage and is not allowed to push out other account water that happens to remain in storage into the WW season. Also note that Lake Henry is simulated with a "Dead and Inactive" storage of 1,500 AF. This storage is simulated as being unowned, and this storage must be "refilled" prior to any inflows being allocated to the owners if the other accounts empty and it is depleted by evaporation.

Table 18: Simulated Lake Henry Storage Account Capacities

Lake Henry Data.Max Storage Account Capacities

Max Storage Account Capacities

	Dead and Inactive acre-feet	CSU acre-feet	AURORA acre-feet	OTHER acre-feet	AG acre-feet	Augmentation acre-feet
0: Maximum Storage	1,500.00	5,887.77	955.37	148.12	7,406.00	2,962.40

3.6.2 Lake Meredith

The simulated maximum total storage of Lake Henry is 42,355 AF. The maximum storage capacities of the Lake Meredith storage accounts simulated are shown below in Table 19. The maximum capacities may not add up to the total storage capacity as some accounts are assumed to be able to utilize the same storage space. Note that that as simulated, there is not a specific maximum capacity for WW, although it is limited by the total storage and is not allowed to push out other account water that happens to remain in storage into the WW season. Also note that Lake Meredith is simulated with a "Dead and Inactive" storage of 15,000 AF. This storage is simulated as being unowned, and this storage must be "refilled" prior to any inflows being allocated to the owners if the other accounts empty and it is depleted by evaporation.

Table 19: Simulated Lake Meredith Storage Account Capacities

Lake Meredith Data.Max Storage Account Capacities

Max Storage Account Capacities

Value: 15000 acre-feet

	Dead and Inactive acre-feet	CSU acre-feet	AURORA acre-feet	FOUNTAIN acre-feet	PUEBLO WEST acre-feet	OTHER acre-feet	AG acre-feet	Augmentation acre-feet
0: Maximum Storage	15,000.00	14,279.31	8,698.89	328.26	246.19	902.71	27,355.00	10,942.00

3.7 Holbrook Canal System and Reservoirs

The Holbrook Canal system consists of the Holbrook Canal, several laterals, and two off-stream storage reservoirs, Holbrook Reservoir and Dye Reservoir. The real-world operations of the reservoirs have been inconsistent and has varied greatly in the recent past which presents significant modeling challenges. Various entities (e.g., Aurora) have at times contracted to store water in the reservoirs at times when they can't store it elsewhere, however there are no long-term agreements and these types of operations have been inconsistent and not followed regular procedures and are therefore not currently simulated.

As currently simulated, it is assumed that the Holbrook Canal reservoirs do not store during the Winter Water Storage Program as it appears that they have not so in recent years. As described elsewhere, Holbrook Canal WW is preferred to be allocated first in the Colorado Canal Reservoirs and then in Pueblo Reservoir.

The Holbrook Canal reservoirs have been identified as potential storage locations within the Restoration of Yield (ROY) storage program but have only been used for those purposes in a limited and unpredictable fashion. Thus, ROY storage is not simulated in the Holbrook Canal system in any years or in any current model scenarios.

An assumed 11.9% flow loss is applied to Holbrook Canal diversions to storage in either reservoir, which is same as is used in the Hydrologic-Institutional (H-I) Model.

3.7.1 Holbrook Reservoir

Holbrook Reservoir is represented in a simple manner as part of the Holbrook Canal system. Holbrook Reservoir may store under its storage water rights when they are in priority. It is assumed that all water stored in Holbrook Reservoir is owned by the Holbrook Canal system and is subsequently used by river exchange from the Holbrook Reservoir outlet back up to the Holbrook Canal headgate to meet the Holbrook Canal Ag demand when the canal's water rights are not in priority for direct flow diversion. It is assumed that water stored in Holbrook Reservoir is used after water stored in Dye Reservoir.

The simulated maximum allowable storage in Holbrook Reservoir is 6300 AF.

3.7.2 Dye Reservoir

Dye Reservoir is represented in a simple manner as part of the Holbrook Canal system. Dye Reservoir may store under its storage water rights when they are in priority. It is assumed that all water stored in Dye Reservoir is owned by the Holbrook Canal system and is subsequently used by river exchange from the Dye Reservoir outlet back up to the Holbrook Canal headgate to meet the Holbrook Canal Ag demand when the canal's water rights are not in priority for direct flow diversion. It is assumed that water stored in Dye Reservoir is used before water stored in Holbrook Reservoir.

The simulated maximum allowable storage in Dye Reservoir is 2500 AF.

3.8 John Martin Reservoir

3.8.1 Simulated Storage Accounting and Water Rights

John Martin Reservoir is currently modeled in a simplified fashion relative to the complex level of detail to which it is actually operated, accounted, and administered. Still, several important reservoir operations and accounting processes are modeled including flood control operations and various storage and delivery operations and flood control operations. Storage accounting in John Martin Reservoir is simulated in a lumped fashion in several reservoir storage accounts. Many important accounting processes are represented including storage water rights, the storage of various canal water rights, the "Conservation Storage" processes and the subsequent, rationed distribution to both John Martin water users (aka CO District 67 water users, lumped into the "John Martin Storage" account) and Kansas (lumped into the "Kansas Storage" account), and Winter Water Storage Program storage (lumped into the "WW" storage account), and the subsequent deliveries and transactions to and from these various storage accounts. John Martin's storage accounts are generally referred to as either Article II accounts, which are the accounts for water users below John Martin Reservoir and for Kansas, and Article III accounts, which are accounts for the WWSP and other upstream water users.

The simulated maximum storage account capacities for the simplified, lumped accounts are shown below in Table 20. Note that the Conservation Storage account does not have an explicit capacity limit but is limited to John Martin's simulated maximum allowable storage of 340,771 AF less the other current simulated account storages. Please also note that the simplified, lumped "John Martin Storage" and "Kansas Storage" accounts are assumed to have maximum storage capacities of 60% and 40%, respectively, of the same maximum simulated maximum allowable storage. Although these limits are not explicitly defined in the 2010 John Martin operating plan, they are applied during simulation in order to prevent these accounts from overtaking the entire reservoir during the potential alternative hydrology and operations that may occur during modeling.

Table 20: Simulated John Martin Reservoir Storage Account Capacities

John Martin Res Data.Max Storage Account Capacities

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Max Storage Account Capacities

Value: 204462.999999612 acre-feet

	Permanent Pool acre-feet	Conservation Storage acre-feet	John Martin Storage acre-feet	Kansas Storage acre-feet	WW acre-feet
0: Maximum Storage	15,000.00	NaN	204,463.00	136,308.00	75,000.00

Show: ☐ **Description**

There are two storage water rights that are simulated on John Martin Reservoir. The main storage right has a priority date of May 31, 1949. During periods of very wet hydrology, this storage right stores the excess native flow of the basin. The upstream FryArk Project storage water rights will only come into priority when this storage right is satisfied, and John Martin's Conservation Storage pool is full. Additionally, the changed Muddy Creek storage right (priority date of April 18, 1915), used to provide storage to John Martin's Permanent Pool, is also simulated. This storage right is actually administered based on the flow of Muddy Creek, a tributary that flows directly into John Martin Reservoir. In the model however, this water right is simulated as a storage water right on John Martin Reservoir and the Muddy Creek flow is not explicitly represented. To account for this discrepancy, the storage water right's daily request is limited to that day's simulated Local Inflow to John Martin Reservoir, in addition to its other decreed limits. This is not a perfect limitation, however, it does prevent this water right from effecting upstream water rights in the Arkansas and Purgatoire River basin and allows for it to be called out by senior downstream water rights, while still providing some level of representation of this important source of storage for John Martin's Permanent Pool.

In addition to the two traditional storage water rights, the storage of the applicable water right yield of Highland Canal (on the Purgatoire River) are simulated by foregoing the diversions and allowing them to flow into John Martin. Additionally, exchanges of Keesee Ditch's water right yield from its diversion location below John Martin into storage are also simulated.

The storage of winter inflows to John Martin Reservoir is simulated following the operating procedures described in the "Super Ditch Delivery Engineering Report" (LAVWCD, 2014). As inflows are stored, they are divided between the Article II accounts (John Martin's "Conservation Storage") and Article III accounts (WWSP and other upstream user accounts) by the "Winter Baseflow" and "Enhanced Baseflow" at the Las Animas gage, as well as the Purgatoire River outflows. The 35% transfer of all the Article III storage to the Article II accounts is also simulated as defined in the 2010 John Martin operating plan. Following the WWSP allocation described elsewhere, Amity Canal's WW storage in John Martin Reservoir is transferred to the lumped John Martin Storage account, from where it can be delivered to any John Martin water user. Given Amity's high demands in relation to the other water users, it is assumed that this simplified representation is sufficient.

3.8.2 Simulated Operations

As described in the 2010 John Martin operating plan, storage inflows of "Article II" water are accumulated into the "Conservation Storage" account. Beginning on April 1 of each year, this storage is distributed between the John Martin water users and Kansas at a 60%/40% ratio, respectively. The rate of this distribution is also rationed and varies based on the total remaining Conservation Storage to distribute. The distribution to accounts is made at a total rate of 1,250 cfs when this volume is above 20,000 AF, and 1,000 cfs when it is below. The distribution rate is also split by the 60%/40% ratios. Once distributed to the "John Martin Storage" and "Kansas Storage" accounts the water is available for simulated deliveries.

Several types of deliveries are simulated from John Martin Reservoir. Winter water owned by upstream water users (i.e., LA Consolidated and Fort Lyon Canals) that is stored in John Martin is delivered as possible and needed through upstream delivery exchanges from the "WW" storage account to the canal headgates. Deliveries from the lumped "John Martin Storage" account to the John Martin water users are simulated through releases to the Arkansas River and subsequent diversion. These simulated deliveries are also subject to and adjusted for the significant transit losses present in the Arkansas River below John Martin. As administered, the direct flow water rights of the John Martin water users are removed from the priority system each year until the Conservation Storage is exhausted. This is simulated simply by turning off those water rights until that occurs. Thus, deliveries from the "John Martin Storage" account are simulated to meet the water user demands until the "Conservation Storage" has been completely distributed. After this point, the water rights are turned back on and native flow can be called through to the water users from upstream junior water users, which is simulated by the RiverWare Water Rights Solver as described elsewhere.

Deliveries from the "Kansas Storage" account in John Martin to the Colorado-Kansas Stateline at the bottom of the model extent are also simulated. The Kansas flow demand is simulated to be just upstream of the Frontier Ditch headgate, which is just upstream of the Colorado-Kansas Stateline and the Arkansas River near Coolidge, KS gage. Thus, the currently simulated Kansas flow demands are based on the sum of the historic Coolidge gage data and the historic Frontier Ditch diversion data with some minor smoothing applied to prevent erratic deliveries. These deliveries from storage are assumed to be made only in April – October of each year.

Additionally, John Martin's flood control operations are simulated to maintain a maximum flow of 3,400 cfs at the Below John Martin gage, and 3,000 cfs at the downstream Coolidge gage.

3.9 Trinidad Reservoir

3.9.1 Simulated Storage Accounting and Water Rights

The Trinidad Project, Trinidad Reservoir, and water users on the Purgatoire River below the reservoir are currently simulated in a simplified fashion in the RiverWare model relative to the level of detail in which the project is actually operated and administered. The current operational criteria and procedures for the Trinidad Project are dictated by the "Operating Principals - Trinidad Dam and Reservoir Project" and are further defined within the "Purgatoire River Water Conservancy District Operating Criteria". Even at a simplified level, several important reservoir and accounting operations of Trinidad Reservoir are simulated, including flood control operations and the storage and subsequent delivery of water supply to the projects water users.

Storage accounting in Trinidad Reservoir is currently simulated in a lumped fashion with two main reservoir storage accounts, the "Permanent Pool" account and the "Trinidad Storage" account. The capacities of the simulated Trinidad Reservoir storage accounts are shown below in Table 21. The total capacity of the Permanent Pool storage account is 15,967 AF, however the minimum pool of 9010 AF (currently modeled as Dead and Inactive storage) is assumed to be part of the Permanent Pool account and thus the maximum effective account storage is 6,957 AF. The simulated Trinidad Storage account with a total maximum capacity of 20,000 AF is defined by the Operating Principals as being for irrigation and M&I uses. In reality, this account is split into several different subaccounts for varying purposes, however, it is currently simulated as a single lumped account in the model. The expanded Joint Use Pool storage account, and the associated storage water right with a very junior May 6, 1989 priority date, is present in the model although the water right is turned off and the account is not currently simulated due to lack of information regarding how it is operated and accounted.

Two storage water rights are currently simulated on Trinidad Reservoir. The "Model storage right" has a priority date of January 22, 1908 and a maximum storage rate of 700 cfs and maximum total annual volume of 20,000 AF. Additionally, as allowed by 03CW108 decree, the 14% portion of the 200 cfs Model canal diversion water right (which is separate from the Model storage right) now owned by Colorado Parks and Wildlife is simulated as a storage right on Trinidad Reservoir. Due to return flow replacement requirements, they can store 65% of their portion, or a total rate of 18.2 cfs. Storage under this water right is also subject to additional monthly volume limits. The decreed date of this water right is January 22, 1908, which is the same as the Model storage right, but it is simulated in the model with a priority date of January 21, 1908 to first supply the limited allowed storage volume to the Permanent Pool account.

Table 21: Simulated Trinidad Reservoir Storage Account Capacities

Trinidad Res Data.Max Storage Account Capacities

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Max Storage Account Capacities

Value:

	Permanent Pool acre-feet	Trinidad Storage acre-feet	Joint Use acre-feet
0: Maximum Storage	6,957.00	20,000.00	39,000.00

Show: ☐ **Description**

3.9.2 Simulated Operations

In general, basic Trinidad Reservoir operations are simulated as storing nearly all inflows during its winter storage season and subsequently delivering the storage to its water users as needed during the following irrigation season to supplement native flow diversions from water rights. Winter storage is simulated from October 16 to April 30 of each year and deliveries from storage may be simulated in the rest of the year, depending on available storage and water user demands.

There are 9 simulated water users on the Purgatoire River between Trinidad Reservoir and the confluence with the Arkansas River. Six of these 9 water users are part of the Purgatoire River Water Conservancy District and thus can receive deliveries from stored water in Trinidad Reservoir. The upper most water user, Antonio Lopez Ditch, and the two furthest downstream water users, Nine Mile Canal and Highland Canal, do not receive deliveries from storage and thus only native water right diversions to them are simulated.

Deliveries of Trinidad Project storage to demanding water users are simulated in a simple upstream to downstream priority fashion due to lack of detailed sub-accounting and water user prioritization techniques. Additionally, a minimum storage of 2,000 AF in the Trinidad Storage account in simulated to account for subaccount water that is not available for delivery to water users, which is based on comparison of model results with historic storage data.

3.10 Future SDS Reservoirs: Upper Williams Creek and Williams Creek Reservoirs

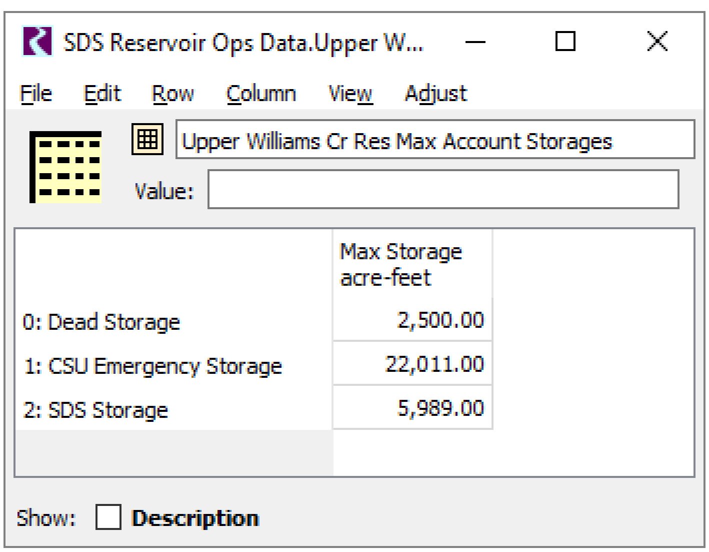
The two prospective Southern Deliveries System reservoirs, the terminal storage Upper Williams Creek Reservoir and the return flow storage Williams Creek Reservoir, are simulated in the model for the future 2047 and 2058 Annual Excess Capacity Account NEPA Analysis scenarios only.

3.10.1 Simulated Upper Williams Creek Reservoir Operations

Upper Williams Creek Reservoir operations are currently simulated in a basic manner consistent with the potential operations described in the ModSim model documentation. The simulated account capacities are shown in Table 22. Native inflows to Upper Williams Creek Reservoir are not simulated and thus neither are native passthrough releases. It is assumed that there is no impact on the native flows of Williams Creek, which are currently lumped into the model input local inflows. The "CSU Emergency Storage" account is currently simulated to remain full, and thus only receives small transfers from active storage to refill simulated evaporation losses.

In general, when there is additional capacity in the Southern Delivery System (SDS) pipeline from Pueblo Reservoir, additional SDS deliveries are made from the CSU LT EC account to the "SDS Storage" in Upper Williams Creek Reservoir. Then, when the daily demand to the SDS water treatment plant (WTP) is in excess of their SDS capacity from Pueblo Reservoir, additional deliveries are made from the "SDS Storage" account to the WTP.

Table 22: Simulated Maximum Account Capacities for Upper Williams Creek Reservoir



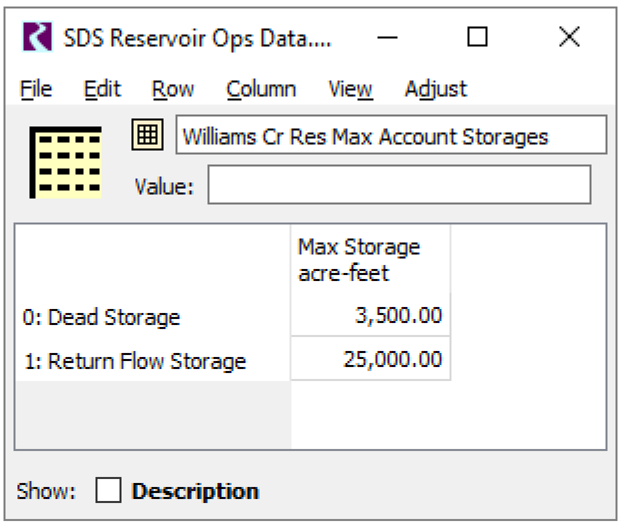
	Max Storage acre-feet
0: Dead Storage	2,500.00
1: CSU Emergency Storage	22,011.00
2: SDS Storage	5,989.00

3.10.2 Simulated Williams Creek Reservoir Operations

Williams Creek Reservoir operations are simulated in a basic manner consistent with the potential operations described in the ModSim model documentation. The simulated account capacities are shown in Table 23. As with Upper Williams Creek reservoir, no native inflows and native passthrough releases are simulated and it is assumed that there is no impact on the native flows of Williams Creek, which are currently lumped into the model input local inflows.

In general, CSU reusable return flows in Fountain Creek that can't be immediately exchanged into Pueblo Reservoir are diverted to Williams Creek Reservoir through the planned Chilcotte Ditch Extension, which has a simulated capacity of 130 cfs. Then, when sufficient exchange potential exists in the Arkansas River, stored water is released back to Fountain Creek and exchanged into the CSU LT EC account in Pueblo Reservoir. These releases to Fountain Creek are simulated through the planned return flow pipeline, which has a capacity of 300 cfs.

Table 23: Simulated Maximum Account Capacities for Williams Creek Reservoir



	Max Storage acre-feet
0: Dead Storage	3,500.00
1: Return Flow Storage	25,000.00

4 SIMULATED WATER USERS AND DEMANDS

The RiverWare model simulates the diversions of many water users on the mainstem of the Arkansas River from the headwaters to the Colorado-Kansas border, on Fountain Creek from its confluence with Monument Creek down to the Arkansas, and on the Purgatoire River from Trinidad Reservoir down to the Arkansas.

4.1 GENERAL SIMULATION PROCEDURES OF DELIVERIES TO WATER USERS

Diversions to meet the diversion demands of simulated water users are generally first assumed to be met by native water right allocations, if they are available. Next, several potential types of deliveries from various storage sources are simulated to any remaining demand not previously met by water rights. The simulation order (i.e., order of execution of the delivery rules) is very important and is configured to use preferred storage sources before others. Furthermore, the order that deliveries are made is interdependent with the simulation of various exchanges and other operations throughout the basin.

Generally, water user diversions and deliveries are simulated in the following order:

1. Native water right diversions
2. Deliveries from Trinidad Reservoir to Purgatoire River water users
3. Deliveries from John Martin Reservoir to below John Martin water users
4. Otero Pump Station diversions from Twin Lakes Reservoir
5. Winter Water deliveries from Lake Meredith, Fort Lyon Storage Canal, and John Martin Res
6. Holbrook Canal agricultural delivery exchanges
7. Colorado Canal agricultural delivery exchanges
8. Deliveries of Pueblo Reservoir storage to direct diversions from Pueblo Reservoir
9. Deliveries of Pueblo Reservoir storage to diversion below Pueblo Reservoir
10. Delivery exchanges from Pueblo Reservoir storage to upstream water users

When simulated water users have access to multiple storage sources in Pueblo Reservoir (i.e., multiple different types of account water), a priority order is assumed to determine the order that the storage sources are utilized. These priority orders may be customized for each water user; however, the typical priority order is shown below:

1. Excess Capacity storage
2. Winter Water storage (Carryover WW is used first)
3. FryArk Project Water storage

4.2 SIMULATED MUNICIPAL WATER USERS

Please note that all the municipal water users discussed in this section also have simulated Excess Capacity accounts in Pueblo Reservoir. Further information regarding these water users may be found in the documentation section describing the simulation of those accounts. Simulated demands for these water users depend on model scenario and are shown elsewhere in the documentation. Annual demand volumes are distributed to daily or monthly average flow demands in the model by various methods. Pueblo Water's monthly release patterns, calculated from 2011-2015 historic delivery data provided by PBWW, are used by default if more specific information is not available. The various patterns used can be found in the model.

4.2.1 Aurora Water

While the City of Aurora is physically located within the South Platte River basin, Aurora Water (Aurora) has significant water sources in the Arkansas River basin. Aurora exports large volumes of water from Twin Lakes Reservoir through the Otero Pump Station and Homestake Pipeline and into the South Platte basin. As simulated, Aurora's general objectives are to move water from various sources scattered throughout the basin by various water movement methods into Twin Lakes Reservoir where it is diverted through the Otero Pump Station.

Aurora operates storage accounts in several basin reservoirs, including Turquoise Lake, Twin Lakes Reservoir, a Long-Term Excess Capacity account in Pueblo Reservoir, and Lake Henry and Lake Meredith in the Colorado Canal system. These storage accounts are further discussed in the documentation sections for those reservoirs.

Aurora has various water sources in the basin that are simulated within the model, including:

- Majority ownership in the Rocky Ford Ditch
- 50% Ownership of Homestake Imports into Turquoise Lake
- 50% Ownership of the Busk-Ivanhoe Imports into Turquoise Lake
- Ownership in the Twin Lakes Canal Company
- Ownership in the Colorado Canal Company
- Two small direct flow water rights on the Otero Pump Station
- Several minor water rights in the Upper Arkansas basin (the "Leadville ranches")

The only actually delivery location for Aurora is the Otero Pump Station export out of Twin Lakes Reservoir, of which Aurora's capacity is 78.14 cfs. Their total annual demand is assumed to be a constant 44,579 AF (44,712 AF in leap years) for each year of a model run. This is assumed to be the same in all model scenarios. This volume reflects their maximum Otero Pump Station capacity for all months except September, when the pipeline is assumed to be fully shut down for maintenance every year. Aurora's demands are assumed to be the maximum possible as their principal objective is to export as much water as possible to meet their municipal demands. The model does not simulate any potential curtailments of Otero Pump Station exports, or otherwise modified Arkansas basin operations, that may be the result of Aurora's operations or other conditions in the South Platte River basin.

An additional demand is simulated on the Aurora LT EC account to reflect their delayed return flow requirements associated with the Rocky Ford Ditch water right change decrees. This is currently simulated using the "Augmentation Release" methodology, which releases a maximum annual volume of 1,618 AF, distributed to monthly flows by the release patterns shown in the decrees, to native river flows.

4.2.2 Colorado Springs Utilities

Colorado Springs Utilities (CSU) is the largest municipal water user in the Arkansas River basin and is located just north of the confluence of Fountain and Monument Creeks. Due to its complexity, a large portion of the CSU system (their "local system") is not contained within the current model extent and therefore is not simulated. This includes the Fountain and Monument Creek basins above Colorado Springs and contains significant water sources and complex operations including many reservoirs, the largest of which is the 40,871 AF Rampart Reservoir. This also includes the transbasin "Blue River Pipeline" which imports water from the western slope near Breckenridge, CO, through the South Platte River basin and into the Monument Creek basin. For the 1994-2015 period, the CSU local system and Blue River imports provided averages of 17% and 8%, respectively, of total yields (2016 CSU Water Tour summary). Based on these numbers, approximately 75% of the CSU demands have been on sources simulated within the RiverWare model.

The operations in the Arkansas River basin are affected on CSU's local system operations in various direct and indirect ways, which presents a significant limitation to the RiverWare model. Due to this limitation, the RiverWare model must utilize several important model inputs based on historic data, previous ModSim model results, and other information provided by CSU and other sources.

As part of this limitation, it must be assumed that the historic flows of Fountain and Monument Creeks into the RiverWare model's extent are sufficiently representative of the flows that may occur in the future during years of corresponding hydrologic conditions. Potential changes to these flows that may occur for various reasons, such are changing utilization of upstream water rights and changing operational procedures, will not be captured.

CSU has various water sources in the Arkansas basin that are simulated within the model, including:

- 50% Ownership of Homestake Imports into Turquoise Lake
- Ownership of the CF&I water rights in Turquoise Lake
- Ownership in the Twin Lakes Canal Company
- Ownership in the Colorado Canal Company

CSU operates storage accounts in several reservoirs, including Turquoise Lake, Twin Lakes Reservoir, a Long-Term Excess Capacity account in Pueblo Reservoir, and Lake Henry and Lake Meredith in the Colorado Canal system. Various simulated CSU operations are discussed throughout the documentation. As simulated, CSU's general objectives are to move as much water as possible, primarily by both river and contract exchanges, into its upper basin reservoir storage accounts for diversion through the Otero Pump Station from Twin Lakes Reservoir. Based on recently observed storage levels (~2011-2016), a minimum storage of 5000 AF is simulated for the CSU LT EC account which can sometimes limit their exchange demands into the upper basin. Releases from their storage accounts in upstream reservoirs to the CSU LT EC account in Pueblo Reservoir may also be simulated if triggered by certain basin conditions (e.g., high upper basin storages and very low CSU LT EC account storage).

CSU's Otero Pump Station diversions from Twin Lakes Reservoir are delivered via the Homestake Pipeline through the South Platte River basin and into CSU's local system in the upper Fountain Creek basin. However, since their local system is not represented in the RiverWare model, only the Otero Pump Station diversion is simulated. The model does not simulate any potential curtailments to CSU's

Otero Pump Station demands, or otherwise modified Arkansas basin operations, that may be the result of CSU's yields and operations in their local system, which may occur during periods of high local system yields and full reservoir conditions.

Currently, deliveries to CSU are simulated through three distinct pathways, the Otero Pump Station out of Twin Lakes Reservoir, and the Fountain Valley Authority's conduit (FVA, FVC) and Southern Delivery System (SDS) pipeline out of Pueblo Reservoir. These three pipelines are all shared with other entities; the Otero Pump Station with Aurora, the FVC with Fountain, Security, Widefield, and Stratmoor Hills, and the SDS with Pueblo West, Fountain, and Security. The breakdown of the FVC capacities between the member entities is shown below in Table 24. The breakdown of the SDS capacities between the member entities is shown below in Table 25.

Table 24: Simulated Fountain Valley Conduit Capacities

Demand Set Up for CSU FVA SDS and Otero.FVA Conduit Capacities

File Edit Row Column View Adjust

FVA Conduit Capacities

Value: 1646.18999999809 acre-feet

	Max Annual Volume Perfect acre-feet	Max Volume with Downtime acre-feet	Max Flow with Downtime cfs
0: CSU	14,353.41	13,635.74	18.83
1: Fountain	1,999.95	1,899.95	2.62
2: Security	1,646.19	1,563.88	2.16
3: Stratmoor Hills	600.99	570.94	0.79
4: Widefield	1,499.46	1,424.49	1.97
5: Total	20,100.00	19,095.00	26.38

Show: **Description**

Table 25: Simulated Southern Delivery System Pipeline Capacities

Demand Set Up for CSU FVA SDS and Otero.SDS Pipeline Capacities

File Edit Row Column View Adjust

SDS Pipeline Capacities

Value:

	Max Annual Volume Perfect acre-feet	Max Volume with Downtime acre-feet	Max Flow with Downtime cfs
0: CSU	83,394.60	79,224.87	109.43
1: Fountain	2,520.32	2,394.30	3.31
2: Security	1,456.19	1,383.38	1.91
3: Pueblo West	20,162.56	19,154.43	26.46
4: Total	107,533.66	102,156.98	141.11

Show: **Description**

4.2.2.1 Simulated CSU Demands on Arkansas River Basin Sources

The total annual CSU demands simulated vary by model scenario and were defined by Reclamation based on the demands used for the SDS and AVC EIS analyses. These demands are shown later in the section describing the model scenarios.

A primary issue stemming from the limited representation of the CSU system is that future potential local system and Blue River import yields are not simulated. For lack of a better method, it is currently assumed that the historic yields from these sources are representative of potential future yields. The historic yields by source were provided by CSU and are shown below in Table 26. It is also assumed that for all model scenarios, the demand on the Otero Pump Station is CSU's maximum annual capacity of 69,908 AF (70,117 AF in leap years). It is further assumed that this demand will be fully met in all years of a model run.

Therefore, the remaining CSU demand volume to be met by FVC and SDS deliveries is determined by reducing the total annual CSU demand by the historic local system and Blue River import yields for the corresponding years and the maximum Otero Pump Station delivery capacity. This is completed on an annual volume basis and provides a total annual CSU demand volume for FVC/SDS deliveries. Note that these total FVC/SDS demand volumes are not the same every year of a model run, which reflects the variable local system and Blue River yields.

Next, the annual FVC/SDS demand volumes are distributed to monthly average flow demands based on the patterns from the ModSim model. Finally, each month's flow demand is split between the FVC and the SDS by first using the FVC up to its capacity and then using the SDS. This distribution process is very similar to that illustrated below in Figure 4 for Fountain. Any potential remaining demands above CSU's total FVC and SDS capacity, which occur in the future model scenarios assuming very high CSU demands, can be met by additional simulated deliveries from the Upper Williams Creek Reservoir.

As currently simulated, it is assumed that CSU will use storage from their LT EC account to meet their FVC demands *before* they use FryArk Project Water from the “Fountain Valley Pipeline PW” account. This assumption is based on comparison of preliminary model results with recently observed CSU LT EC and Fountain Valley Pipeline PW storage levels, which compare much better when this assumption is made. Note that this assumption may result in reduced simulated usage of Project Water by CSU depending on simulated yields of their LT EC account storage sources. It is assumed that CSU will only use storage from their EC account to meet their SDS demand, and that they can’t take PW deliveries through the SDS. These assumptions must be made as insufficient information has been provided to better simulate CSU's decisions regarding when and how much of either water type to use and how these deliveries are split between pipelines. It is highly recommended that model representation be enhanced to simulate these operational distinctions.

It should additionally be noted that during simulation, there are no adjustments made to other simulated demands, either in the future or at other diversion locations, when simulated deliveries do not meet demands. For example, if CSU’s Otero Pump Station demands are not met due to insufficient simulated CSU storages in Twin Lakes Reservoir, their present and/or future FVC or SDS demands are not increased and are thus assumed to remain the same. This is another significant but necessary assumption resulting from the limited current representation of CSU’s system in the RiverWare model.

Table 26: Historic CSU System Yields Used for Estimation of Future Demands on Simulated Sources

Demand Set Up for CSU FVA SDS and Otero.CSU Collection System Historic...

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CSU Collection System Historic Annual Yields

Value: 22723.0000000062 acre-feet

1989 C.E.

	Local System acre-feet	Blue River Imports acre-feet	Otero Pipeline acre-feet	FVC acre-feet	Total Production acre-feet
1989	22,723.00 I 0	10,675.00 I 0	30,146.00 I 0	1,137.00 I 0	64,681.00 I 0
1990	22,723.00 I 0	10,675.00 I 0	30,146.00 I 0	1,137.00 I 0	64,681.00 I 0
1991	22,336.00 I 0	11,202.00 I 0	44,497.00 I 0	1,090.00 I 0	79,126.00 I 0
1992	21,049.00 I 0	8,157.00 I 0	37,934.00 I 0	1,115.00 I 0	68,255.00 I 0
1993	19,008.00 I 0	11,747.00 I 0	44,104.00 I 0	1,124.00 I 0	75,983.00 I 0
1994	23,025.00 I 0	8,209.00 I 0	45,234.00 I 0	1,641.00 I 0	78,109.00 I 0
1995	21,527.00 I 0	8,702.00 I 0	40,787.00 I 0	1,141.00 I 0	72,157.00 I 0
1996	19,824.00 I 0	11,577.00 I 0	47,767.00 I 0	1,158.00 I 0	80,326.00 I 0
1997	22,333.00 I 0	8,529.00 I 0	49,971.00 I 0	1,165.00 I 0	81,998.00 I 0
1998	20,347.00 I 0	11,368.00 I 0	57,177.00 I 0	1,149.00 I 0	90,042.00 I 0
1999	20,167.00 I 0	12,612.00 I 0	53,294.00 I 0	482.00 I 0	86,555.00 I 0
2000	19,083.00 I 0	9,989.00 I 0	59,972.00 I 0	1,188.00 I 0	90,232.00 I 0
2001	20,649.00 I 0	6,786.00 I 0	55,830.00 I 0	4,262.00 I 0	87,527.00 I 0
2002	13,586.00 I 0	4,534.00 I 0	56,734.00 I 0	7,870.00 I 0	82,724.00 I 0
2003	17,315.00 I 0	6,776.00 I 0	58,025.00 I 0	5,483.00 I 0	87,600.00 I 0
2004	16,720.00 I 0	5,077.00 I 0	50,014.00 I 0	4,733.00 I 0	76,543.00 I 0
2005	15,102.00 I 0	12,456.00 I 0	57,179.00 I 0	3,518.00 I 0	88,255.00 I 0
2006	11,447.00 I 0	10,313.00 I 0	54,779.00 I 0	3,419.00 I 0	79,957.00 I 0
2007	16,631.00 I 0	8,758.00 I 0	52,668.00 I 0	2,026.00 I 0	80,082.00 I 0
2008	13,213.00 I 0	12,870.00 I 0	53,740.00 I 0	863.00 I 0	80,685.00 I 0
2009	15,697.00 I 0	15,068.00 I 0	49,487.00 I 0	895.00 I 0	81,147.00 I 0
2010	15,865.00 I 0	11,716.00 I 0	44,806.00 I 0	810.00 I 0	73,197.00 I 0
2011	10,249.00 I 0	4,178.00 I 0	59,624.00 I 0	3,508.00 I 0	77,559.00 I 0
2012	7,438.00 I 0	3,425.00 I 0	65,266.00 I 0	4,916.00 I 0	81,046.00 I 0
2013	14,162.00 I 0	7,878.00 I 0	53,224.00 I 0	6,047.00 I 0	81,311.00 I 0
2014	12,016.00 I 0	13,906.00 I 0	39,895.00 I 0	1,480.00 I 0	67,296.00 I 0
2015	12,392.00 I 0	12,145.00 I 0	37,013.00 I 0	1,680.00 I 0	63,230.00 I 0

Show: **Description**

Demand Set Up for CSU FVA SDS and Otero.CSU Collection System Historic Annual Yields [@ 24:00 December 31, 1

1 value: 22,723.00 [acre-feet] (Priority 0)

4.2.2.2 Simulation of Reusable Return Flows

Reusable return flows represent a significant and important water source for CSU in the Arkansas basin, and are expected to become even more important in the future with rising demands and uncertain hydrology. Furthermore, CSU's reusable return flows have both direct and indirect impacts throughout the Arkansas basin as their exchanges reduce river flows and available exchange between Pueblo Reservoir and Fountain Creek, as well as between the upper basin reservoirs and Pueblo Reservoir. CSU reusable return flows can also represent significant amounts of storage in basin reservoirs. Due to these reasons and others, it is necessary to simulate CSU return flows within the RiverWare model. However, achieving this presents some significant challenges and requires some broad assumptions due to the limited representation of the CSU system. Simulated CSU return flows are estimated based on an assumption that CSU's total annual demands are fully met in all years for all model scenarios and thus are not dependent on the deliveries to CSU in the Arkansas basin simulated in the model.

CSU return flows, and an estimated breakdown of their native and reusable portions, are simulated within the model for the following locations:

- JD Phillips Water Resource Recovery Facility
- Las Vegas Water Resource Recovery Facility
- Clear Spring Regional Water Reclamation Facility (2047 and 2058 model scenarios only)
- Lumped unsewered return flows

Total CSU demands are assumed to be split between indoor and outflow deliveries based on the ratios from the ModSim model, as were return flow percentages from each type of delivery. Historic return flow data was provided by CSU and various other sources and was used to develop general monthly return flow distribution patterns and average monthly ratios of the native and reusable portions. Based on different demand levels, calculated monthly sewered return flows were divided between facilities following the procedure used in the ModSim model.

The CSU return flows used for the 2017 model scenario are shown below in Table 27 and Table 28.

Table 27: CSU Sewered Return Flow Breakdown for 2017 Model Scenario

Municipal Return Flow Data.CSU Distributed WWTP Return Flows_2017

File Edit Row Column View Adjust

CSU Distributed WWTP Return Flows_2017

Value:

	Total LV cfs	LV Reusable cfs	LV Native cfs	Total JDP cfs	JDP Reusable cfs	JDP Native cfs	Total CSR cfs	CSR Reusable cfs	CSR Native cfs
Jan	71.85	55.83	16.02	15.47	12.02	3.45	0.00	0.00	0.00
Feb	72.52	55.77	16.75	15.47	11.90	3.57	0.00	0.00	0.00
Mar	68.91	51.96	16.95	15.48	11.67	3.81	0.00	0.00	0.00
Apr	65.64	43.85	21.79	15.48	10.34	5.14	0.00	0.00	0.00
May	64.98	35.74	29.24	15.47	8.51	6.96	0.00	0.00	0.00
Jun	64.63	40.20	24.43	15.47	9.62	5.85	0.00	0.00	0.00
Jul	65.97	41.10	24.87	15.47	9.64	5.83	0.00	0.00	0.00
Aug	66.95	42.38	24.57	15.47	9.79	5.68	0.00	0.00	0.00
Sep	66.65	42.86	23.79	15.47	9.95	5.52	0.00	0.00	0.00
Oct	65.97	45.65	20.32	15.48	10.71	4.77	0.00	0.00	0.00
Nov	69.69	49.27	20.42	15.47	10.94	4.53	0.00	0.00	0.00
Dec	70.87	52.66	18.21	15.48	11.50	3.98	0.00	0.00	0.00

Show: ☐ **Description**

Annual Period, Monthly Interval

Interpolate Lookup

Table 28: CSU Unsewered Return Flow Breakdown for 2017 Model Scenario

Municipal Return Flow Data.CSU Distribut...

File Edit Row Column View Adjust

CSU Distributed Unsewered Return Flows_2017

Value:

	Total Unsewered cfs	Unsewered Native cfs	Unsewered Reusable cfs
Jan	9.01	2.01	7.00
Feb	9.08	2.10	6.98
Mar	8.71	2.14	6.57
Apr	8.37	2.78	5.59
May	8.31	3.74	4.57
Jun	8.27	3.13	5.14
Jul	8.41	3.17	5.24
Aug	8.51	3.12	5.39
Sep	8.48	3.03	5.45
Oct	8.41	2.59	5.82
Nov	8.80	2.58	6.22
Dec	8.91	2.29	6.62

Show: **Description**

Annual Period, Monthly Interval

Interpolate Lookup

4.2.3 Pueblo Water (PBWW)

Pueblo Water (formerly known as the Pueblo Board of Water Works, PBWW) is the municipal water provided of the City of Pueblo. PBWW operates storage accounts in several basin reservoirs, including Turquoise Lake and Twin Lakes Reservoir, and wholly owns Clear Creek Reservoir. They also have a Long-Term Excess Capacity account in Pueblo Reservoir. These storage accounts are further discussed in the documentation sections for those reservoirs. Further PBWW operations and transactions are discussed throughout the model documentation.

PBWW has many simulated water sources in the Arkansas basin, including:

- Several Arkansas River native water rights, with a variety of allowable uses including municipal uses and storage, provided by several change decrees
- 2500 AF/year of Aurora's Homestake Tunnel yield in Turquoise Lake
- 50% Ownership of the Busk-Ivanhoe Imports into Turquoise Lake
- Wurtz and Ewing Ditch Imports

- Ownership in the Twin Lakes Canal Company
- Clear Creek Reservoir Storage Water Rights
- Several Arkansas River native water rights, with a variety of allowable uses including municipal uses and storage, provided by several change decrees

PBWW can take delivery of its demands at multiple delivery locations, including a direct outlet from Pueblo Reservoir and the North and South Intakes on the Arkansas River just downstream of the reservoir. As currently simulated, it is assumed that PBWW only diverts through their Pueblo Reservoir outlet.

Simulated deliveries to meet the PBWW municipal demand consist first of native water right allocations that are not used for Comanche Power Plant diversions (discussed below). The model also uses water rights that can't be stored before those that can be stored, and will store additional, storable water right yields if native water right allocations are in excess of their daily diversion demand. If any demand remains unmet following native diversions, the model will make deliveries of storage from Pueblo Reservoir. It is currently assumed that PBWW will always use storage from their LT EC account prior to using FryArk Project Water from the "Pueblo PW" account, which is their dedicated PW account available only to them. This is a necessary assumption due to lack of a defined method to simulate how PBWW determines which water types to use at any given time.

Additionally, due to PBWW's many reliable water sources, including senior water rights and reliable transbasin imports, and high overall yields relative to their demands, PBWW provides surplus water to many basin entities through various transactions such as leases. In reality, PBWW leases water to many parties from its various storage accounts throughout the basin, however there is insufficient information to currently simulate leases that are not explicitly claimed by other simulated entities. Thus, all simulated leases of PBWW water are currently from the PBWW LT EC in Pueblo Reservoir, with the sole exception of the lease to Donala that partially occurs in Turquoise, as discussed elsewhere in the documentation. No other leases from PBWW storage accounts outside of Pueblo Reservoir are currently simulated. Based on preliminary model results, it is apparent that a large amount of PBWW leases to other parties are not currently being simulated in the model.

PBWW also delivers water to the Comanche Power Plant, which diverts from the Arkansas River just downstream of Pueblo Reservoir. As currently simulated, PBWW first uses the native water rights that are decreed for Comanche use to meet the demand. If native water right diversions are insufficient to meet the daily demand, PBWW will supplement with deliveries of storage from the PBWW LT EC account. The annual Comanche Power Plant demand volumes are assumed to be a static 12,763 AF/year in all model scenarios. The annual demand is distributed to monthly average flow demands based on patterns developed from 2011-2015 Comanche delivery data provided by PBWW.

4.2.3.1 Simulation of Reusable Return Flows

Reusable return flows are simulated in a basic manner for PBWW and only for their WWTP ("sewered") return flows. "Unsewered" return flows are currently lumped into the model input local inflows and are assumed to not be reusable. The PBWW WWTP outflows return to the Arkansas River just below the confluence with Fountain Creek.

Total daily WWTP return flows are estimated based on the previous days total PBWW diversion amount using the indoor/outdoor delivery ratios and return flow percentages from the ModSim model. No return flow lagging effects are currently simulated. As the simulated storage and delivery accounting is not currently detailed enough to dynamically calculate the reusable portion of the simulated return flows based on the water types of the simulated deliveries, a basic percentage of 4.35% is used to calculate the reusable portion of the total daily return flows. This percentage is based on the overall reusable ratio of the historic 2011-2015 delivery data provided by PBWW. This is a significant simplification and assumption but does provide a basic representation of PBWW's important reusable return flow source at approximate overall magnitudes. As the composition of water types used for PBWW deliveries will likely change in the future as PBWW's demand changes, this simplification and assumption will be less appropriate for future scenarios.

Reusable return flows are currently not simulated for Comanche Power Plant return flows, which are not currently explicitly represented in the model and are assumed to be lumped into the model input local inflows.

4.2.4 Pueblo West

Pueblo West Metropolitan District (Pueblo West) is a municipal water user situated just to the north of Pueblo Reservoir. Pueblo West receives direct deliveries through its own outlet from Pueblo Reservoir. In addition, they can also receive deliveries through the SDS, however, as their dedicated Pueblo Reservoir outlet can meet the maximum simulated demands even in the future model scenarios, no demands through the SDS are simulated in any model scenario.

Pueblo West has various simulated water sources and storage accounts throughout the basin, including ownership in the Twin Lakes Reservoir and Canal Company (TLCC) and Colorado Canal Company. Through various simulated processes, Pueblo West's water yields eventually make their way into the Pueblo West LT EC account in Pueblo Reservoir. They also have access to the FryArk Project Water in the "Other PW" subaccount.

Simulated deliveries to meet the Pueblo West demand consist first of any native flow allocation from their small, single direct flow water right, and next from storage sources in Pueblo Reservoir. All available EC storage is assumed to be used prior to any PW due to lack of a defined method to simulate how Pueblo West determines which water types to use at any given time.

Pueblo West is also one of three entities with two distinct Excess Capacity storage accounts, the main "Pueblo West LT EC account" and the "Pueblo West EC" account which is a subaccount within the Master Contract EC account. In reality, some storage sources may only be allowable for storage in a specific EC account, however insufficient information was provided regarding these specific criteria and how their different EC accounts will be operated to allow for simulation at this level of detail. Thus, their MC EC account is currently modeled simply as a spillover account from the LT EC account and only receives storage when the LT EC account is full. Storage from the MC EC account is used before the LT EC account storage is used.

4.2.4.1 Simulation of Reusable Return Flows

Reusable return flows are simulated in a basic manner for Pueblo West and only for their WWTP ("sewered") return flows. "Unsewered" return flows are currently lumped into the model input local inflows and are assumed to not be reusable. The Pueblo West WWTP outflows return to the Arkansas River through Wild Horse Creek just above the Moffat St. gage.

Total daily WWTP return flows are estimated based on the previous days total Pueblo West diversion amount using the indoor/outdoor delivery ratios and return flow percentages from the ModSim model. No return flow lagging effects are currently simulated. As the simulated storage and delivery accounting is not currently detailed enough to dynamically calculate the reusable portion of the simulated return flows based on the water types of the simulated deliveries, a basic percentage of 4.35% is used to calculate the reusable portion of the total daily return flows. Due to lack of better data, this percentage is assumed to be the same as that currently used for PBWW, described above. This is a significant simplification and assumption.

4.2.5 St. Charles Mesa Water District

St. Charles Mesa Water District (SCMWD) is located on the St. Charles Mesa, east of Pueblo and south of the Arkansas River. The SCMWD system can take deliveries directly from Pueblo Reservoir through the Bessemer Ditch, which they do during the summer period (assumed to be from March 15 to November 14), or from the Arkansas River through their pump station just below the Moffat St. gage, which they do during the winter period (assumed to be November 15 to March 14). As simulated, their demands are first met by native water right diversions. If necessary, deliveries from storage are simulated, first from their EC storage account and then from the "East of Pueblo PW" account.

4.2.6 Donala

Donala is a small municipal water user north of Colorado Springs in the tributary Monument Creek/Fountain Creek basin of the Arkansas basin. The actual physical location of Donala is out of the current model extent, however Donala has water sources that are simulated within the model extent and a simulated Excess Capacity account in Pueblo Reservoir.

As one of the EC accounts currently being analyzed, there are actually two separate Donala EC accounts in the model, the "Donala LT EC" account and the "Donala Annual EC" account. Only one of the EC accounts is active in a given model run and the active account depends on the model scenario. The Simulated Storage Sources and simulated demands are the same regardless of which EC account is used. The only simulated difference for Donala between these scenarios is that in the future scenarios with their LT EC account (as opposed to their Annual EC account), they can only "trade" their delivery water to CSU in Pueblo Reservoir and not by exchange into Twin Lakes Reservoir.

4.2.6.1 Willow Creek Ranch Water Rights

Donala's primary simulated water source are the Willow Creek Ranch water rights in the upper Arkansas River basin. The actual location of these water rights is on Willow Creek, a headwaters tributary that flows into Lake Fork Creek in the reach between Turquoise Lake and the confluence with the Arkansas

River. As this is a small, unmodeled tributary, its actual inflows are lumped into the model's input local inflows. Thus, for simulation of allocations to these water rights, they are placed on the lumped "Dist 11 Above Lake Creek" water user. Due being simulated on the mainstem of the Arkansas River, these water rights will have access to more allocable native flow then they actually would at their true Willow Creek diversion locations. It must be assumed that the simulated water right yields are sufficient for the purposes of the model.

The Willow Creek Ranch water rights consist of 6 individual water rights with varying rates and priority dates. These rights are May-August only and are subject to max rates, max monthly and annual volumes, and 38-year long-term volume limits. The changed water rights also have non-irrigation season return flow (NISRF) requirements dynamically based on total annual available water yield from the prior season and variable depending on which of and when the 6 water rights were in priority.

- Max Gross Annual "Storable" (consumptive use, CU) Yield = 692 AF (not accounting for variable amounts of transit losses depending on variable locations of WCR water storage)
- Max NISRF Volume = 183 AF (before transit losses, = 190 AF release requirement from Turquoise with 3.6% TL, min annual NISRF volume = 48 AF, = 50 AF with TL)
- Max Net Annual "Usable" (CU) Yield = 509 AF (not accounting for variable TL)

Also simulated for Donala is the 250 AF/year lease agreement with PBWW. In the model, it is assumed that the total volume required for the NISRF requirements is taken directly from PBWW's Turquoise account throughout the non-irrigation season. The excess PBWW lease volume is assumed to be transferred directly from PBWW's LT EC account in Pueblo Res to Donala's EC Account in Pueblo reservoir. Following the Willow Creek Ranch report's procedure, the excess lease volume is divided evenly between the 8 NIS months (Sep-April) and the monthly excess volume is transferred from PBWW's EC to Donala's EC account in Pueblo at the beginning of each month.

- Total Annual Lease = 250 AF
- Max Annual NISRF Release from Turquoise = 190 AF (min = 50 AF) (including TL)
- Min Excess Annual Lease = 60 AF (max = 200 AF)
- ***Maximum Total Annual "Usable" Yield*** = 752 AF = 692 AF + 250 AF – 190 AF (not accounting for variable transit losses on the WCR CU yield)

4.2.6.2 Simulated "Deliveries" to Donala

Under current conditions, Donala transfers its stored water to CSU and CSU delivers the same amount of water to Donala on the north side of CSU's system (outside of the model's extent). The actual amounts of delivery that Donala gets from CSU is not stated in any of the documents. Thus, it is assumed that Donala takes delivery of the entire net yield of usable water from the prior season, and thus Donala owes CSU the same amount. The total annual amount of water that Donala gets in the Arkansas basin is known in the model each year on August 31. On Aug 31, the gross annual volumes from the WCR water rights are known, that seasons NISRF requirements are calculated, and the excess lease from PBWW is known. The total useable yield is the gross CU from WCR plus the PBWW lease minus the seasons NISRF requirement volume. This volume is divided evenly over the following 12 months (Sept – Aug) and a transfer is completed on the first day of each month from PBWW's EC account to Donala's EC account.

On the first day of each month following an irrigation season month (i.e. the first of June – Sept), the total amount of the WCR water rights that was exchanged into Twin Lakes during the previous month is summed. If that amount is less than Donala's monthly demand (delivered by CSU), Donala transfers the balance from their EC account to CSU's EC account in Pueblo. If the exchanged amount is greater than the Donala monthly demand, CSU transfers the overage from their EC account to Donala's EC account in Pueblo Reservoir.

All related transfers to/from Donala's, CSU's, and PBWW's EC and other reservoir storage accounts relating to the Donala representation are limited to both the available storage of the transfer's "from" account and the maximum capacities of the transfers "to" account. In the case that any given transfer doesn't fully occur, it is "forgotten" by the model, and thus it does not have any effect on any next transfer amounts. For example, if PBWW owes Donala 50 AF but the Donala EC account only has 20 AF of empty space available, the transfer amount is limited to 20 AF and the remaining 30 AF is considers lost by Donala. However, the 30 AF remains in PBWW's EC account, it is NOT lost by PBWW, "spilled", etc.

Another potential storage source to Donala's EC account consists of transfers from CSU's EC account on the first day of June - Sept of the potential amount of WCR water that was "over-exchanged" into Twin Lakes (the total exchange amount in the previous month minus the amount that CSU delivered to Donala). For example, if in a July Donala exchanged 60 AF into Twin Lakes but CSU only delivered 40 AF to Donala, on August 1, CSU transfers the overage of 20 AF from their EC account to Donala's EC account in Pueblo Reservoir.

4.2.7 Arkansas Valley Conduit

The Arkansas Valley Conduit (AVC) will divert directly from Pueblo Reservoir and deliver FryArk Project Water to many minor municipal water users east of Pueblo Reservoir. Deliveries to the Arkansas Valley Conduit are simulated only in the 2047 and 2058 future model scenarios. A static annual demand of 10,256 AF was assumed by Reclamation for use in these scenarios and is distributed to monthly average flow demands using a pattern from the AVC EIS ModSim model. Deliveries to the AVC are assumed to be made only from the "East of Pueblo PW" FryArk Project Water account.

4.2.8 Other Fountain Valley Authority and Southern Delivery System Water Users

4.2.8.1 Fountain

Fountain is located south of Colorado Springs in the Fountain Creek basin. Fountain receives deliveries from both the FVA and SDS, and pumps groundwater from several aquifers, which require augmentation. These augmentation needs can be met with reusable return flows from FVC FryArk Project Water deliveries and other sources. Fountain's augmentation uses are not explicitly simulated in the model due to insufficient data and information, and it must be assumed that the effects of their historic groundwater pumping and various augmentation sources that are currently implicitly contained in the model input local inflows are sufficient for the purposes of the current analysis.

Currently, the model explicitly simulates deliveries to Fountain through both the FVC and the SDS, which have simulated maximum annual capacities of ~1,900 AF (2.62 cfs) and ~2,394 AF (3.31 cfs), respectively. As currently simulated, Fountain’s total annual demand, which varies by model scenario, is first distributed to monthly average flow demands with the pattern from the ModSim model. Then, each month’s flow demand is distributed between the FVC and the SDS by first using the FVC up to its capacity and then using the SDS up to its capacity or the remaining monthly flow demand. Any remaining demand above Fountain’s total capacity in the FVC and SDS is assumed to be met by groundwater pumping. This distribution process is illustrated below in Figure 4.

It is important to note that any effects of changing groundwater pumping demands and associated augmentation uses by Fountain will not result in differing effects on related depletions to Fountain Creek due to the major assumption that pumping effects are sufficiently lumped into the model local inflows. As with the other FVC and SDS entities, it is highly recommended that these issues be corrected by backing out the historic groundwater pumping effects and augmentation uses from the calculated model input local inflows. This would then allow these items to be explicitly simulated within the model based on current operational procedures and demand levels, and thus allow for much more appropriate representation of the potential effects of increasing these demands or modifying how they are met.

As currently simulated, it is assumed that Fountain will first use FryArk Project Water from the “Fountain Valley Pipeline PW” account to meet their FVC demand. As their full annual FVC capacity is currently assumed to be equal to their annual PW allocation, the use of EC account storage for FVC deliveries can only occur if the total “Fountain Valley Pipeline PW” account storage is limiting, which does not occur in any simulated scenarios. It is assumed that they will only use storage from their EC accounts to meet their SDS demand, and that they can’t take PW deliveries through the SDS. These assumptions must be made as insufficient information has been provided to better simulate Fountain's decisions regarding when and how much of either water type to use and how these deliveries are split between pipelines. It is highly recommended that model representation be enhanced to simulate these operational distinctions.

Fountain is also one of three entities with two distinct Excess Capacity storage accounts, the main “Fountain LT EC account” and the “Fountain EC” account which is a subaccount within the Master Contract EC account. In reality, some storage sources may only be allowable for storage in a specific EC account, however insufficient information was provided regarding these specific criteria and how their different EC accounts will be operated to allow for simulation at this level of detail. Thus, their MC EC account is currently modeled simply as a spillover account from the LT EC account and only receives storage when the LT EC account is full. Storage from the MC EC account is used before the LT EC account storage is used.

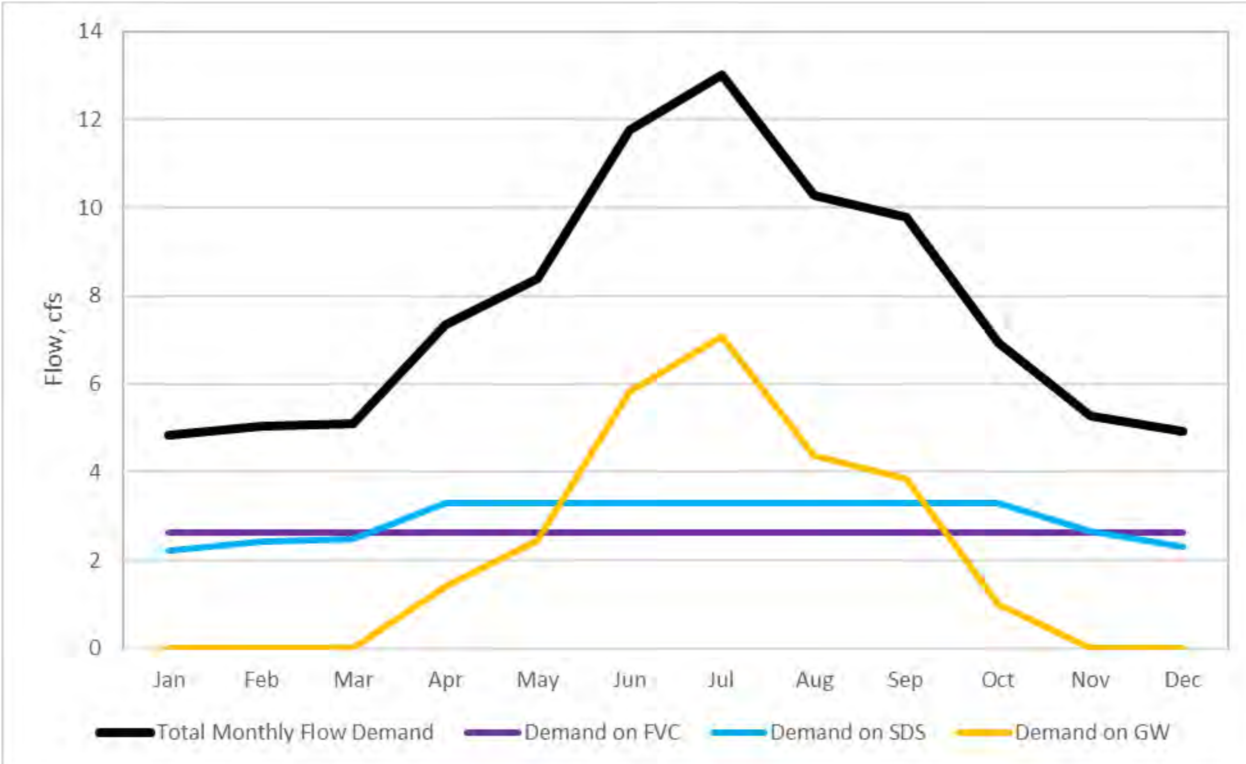

Figure 4: Example of Simulated Distribution of Fountain's Total Demands between FVC, SDS, and GW

4.2.8.2 Security

Security is located just south of Colorado Springs in the Fountain Creek basin. Security receives deliveries from both the FVA and SDS, and pumps groundwater from several aquifers, which require augmentation. These augmentation needs can be met with reusable return flows from FVC FryArk Project Water deliveries and other sources. Security's augmentation uses are not explicitly simulated in the model due to insufficient data and information, and it must be assumed that the effects of their historic groundwater pumping and various augmentation sources that are currently implicitly contained in the model input local inflows are sufficient for the purposes of the current analysis.

Currently, the model explicitly simulates deliveries to Security through both the FVC and the SDS, which have simulated maximum annual capacities of ~1,564 AF (2.16 cfs) and ~1,383 AF (1.91 cfs), respectively. As currently simulated, Security's total annual demand, which varies by model scenario, is first distributed to monthly average flow demands with the pattern from the ModSim model. Then, each month's flow demand is distributed between the FVC and the SDS by first using the FVC up to its capacity and then using the SDS up to its capacity or the remaining monthly flow demand. Any remaining demand above Security's total capacity in the FVC and SDS is assumed to be met by groundwater pumping. This is the same distribution process that is used for Fountain and illustrated in the figure above.

It is important to note that any effects of changing groundwater pumping demands and associated augmentation uses by Security will not result in differing effects on related depletions to Fountain Creek due to the major assumption that pumping effects are sufficiently lumped into the model local inflows.

As with the other FVC and SDS entities, it is highly recommended that these issues be corrected by backing out the historic groundwater pumping effects and augmentation uses from the calculated model input local inflows. This would then allow these items to be explicitly simulated within the model based on current operational procedures and demand levels, and thus allow for much more appropriate representation of the potential effects of increasing these demands or modifying how they are met.

As currently simulated, it is assumed that Security will first use FryArk Project Water from the "Fountain Valley Pipeline PW" account to meet their FVC demand. As their full annual FVC capacity is currently assumed to be equal to their annual PW allocation, the use of EC account storage for FVC deliveries can only occur if the total "Fountain Valley Pipeline PW" account storage is limiting, which does not occur in any simulated scenarios. It is assumed that they will only use storage from their EC accounts to meet their SDS demand, and that they can't take PW deliveries through the SDS. These assumptions must be made as insufficient information has been provided to better simulate Security's decisions regarding when and how much of either water type to use and how these deliveries are split between pipelines. It is highly recommended that model representation be enhanced to simulate these operational distinctions.

Security is also one of three entities with two distinct Excess Capacity storage accounts, the main "Security LT EC account" and the "Security EC" account which is a subaccount within the Master Contract EC account. In reality, some storage sources may only be allowable for storage in a specific EC account, however insufficient information was provided regarding these specific criteria and how their different EC accounts will be operated to allow for simulation at this level of detail. Thus, their MC EC account is currently modeled simply as a spillover account from the LT EC account and only receives storage when the LT EC account is full. Storage from the MC EC account is used before the LT EC account storage is used.

4.2.8.3 Widefield

Widefield is located just south of Colorado Springs in the Fountain Creek basin. Widefield receives deliveries from the FVA and pumps groundwater from the Widefield and Jimmy Camp Aquifers, which require augmentation. These augmentation needs can be met with reusable return flows from FVC FryArk Project Water deliveries and other sources. Widefield's augmentation uses are not explicitly simulated in the model due to insufficient data and information, and it must be assumed that the effects of their historic groundwater pumping and various augmentation sources that are currently implicitly contained in the model input local inflows are sufficient for the purposes of the current analysis.

Currently, the only explicitly simulated deliveries to Widefield are the FVC deliveries, which have a simulated maximum annual capacity of ~1,425 AF. As this volume is less than the total simulated annual demands for all model scenarios, this is assumed to be evenly distributed throughout the year, which leads to a simulated constant Widefield FVC delivery demand of 1.97 cfs. It is assumed that the additional annual demand above this capacity is met with groundwater pumping.

It is important to note that the effects of increasing Widefield demands above their FVC capacity will not result in differing effects on related depletions to Fountain Creek due to the major assumption that pumping effects are sufficiently lumped into the model local inflows. To state plainly, this means that a simulated total Widefield demand of 1,425 AF/year will lead to the exact same model results as a demand of 5,000 AF/yr, or any other demand above 1,425 AF/year. As with the other FVC and SDS entities, it is highly recommended that these issues be corrected by backing out the historic groundwater pumping effects and augmentation uses from the calculated model input local inflows. This would then allow these items to be explicitly simulated within the model based on current operational procedures and demand levels, and thus allow for much more appropriate representation of the potential effects of increasing these demands or modifying how they are met.

As currently simulated, it is assumed that Widefield will use storage from their EC account to meet their FVC demands *before* they use FryArk Project Water from the "Fountain Valley Pipeline PW" account. This assumption is made based on the information provided in Widefield's 2016 and 2017 EC Questionnaires, which shows deliveries of EC account storage through the FVC, and due to insufficient information being available to better simulate their decisions regarding when and how much of either water type to use. It is highly recommended that model representation be enhanced to simulate these operational distinctions. Note that this assumption may result in reduced simulated usage of Project Water by Widefield depending on simulated yields of their EC account storage sources.

4.2.8.4 Stratmoor Hills

Stratmoor Hills is located just south of Colorado Springs in the Fountain Creek basin. Stratmoor Hills receives deliveries from the FVA and pumps groundwater from the Widefield Aquifer, which requires augmentation. These augmentation needs can be met with reusable return flows from FVC FryArk Project Water deliveries and other sources. Stratmoor Hills' augmentation uses are not explicitly simulated in the model due to insufficient data and information, and it must be assumed that the effects of their historic groundwater pumping and various augmentation sources that are currently implicitly contained in the model input local inflows are sufficient for the purposes of the current analysis.

Currently, the only explicitly simulated deliveries to Stratmoor Hills are the FVC deliveries, which have a simulated maximum annual capacity of ~571 AF. As this volume is less than the total simulated annual demands for all model scenarios, this is assumed to be evenly distributed throughout the year, which leads to a simulated constant Stratmoor Hills FVC delivery demand of 0.79 cfs. It is assumed that the additional annual demand above this capacity is met with groundwater pumping.

It is important to note that the effects of increasing Stratmoor Hills demands above their FVC capacity will not result in differing effects on related depletions to Fountain Creek due to the major assumption that pumping effects are sufficiently lumped into the model local inflows. To state plainly, this means that a simulated total Stratmoor Hills demand of 571 AF/year will lead to the exact same model results as a demand of 1,000 AF/yr, or any other demand above 571 AF/year. As with the other FVC and SDS entities, it is highly recommended that these issues be corrected by backing out the historic groundwater pumping effects and augmentation uses from the calculated model input local inflows. This would then allow these items to be explicitly simulated within the model based on current operational procedures and demand levels, and thus allow for much more appropriate representation of the potential effects of increasing these demands or modifying how they are met.

As currently simulated, it is assumed that Stratmoor Hills will use storage from their EC account to meet their FVC demands *before* they use FryArk Project Water from the "Fountain Valley Pipeline PW" account. This assumption is made based on the information provided in Stratmoor Hills' 2016 EC

Questionnaire, which shows deliveries of EC account storage through the FVC, and due to insufficient information being available to better simulate their decisions regarding when and how much of either water type to use. It is highly recommended that model representation be enhanced to simulate these operational distinctions. Note that this assumption may result in reduced simulated usage of Project Water by Stratmoor Hills depending on simulated yields of their EC account storage sources.

4.2.9 Other Simulated Municipal Water Users

The following other municipal water users are simulated in the model to varying extents and at various levels of detail. The annual demands for each of these water users depend on model scenario and are shown elsewhere in the documentation.

4.2.9.1 Salida

Salida is located at the confluence of the mainstem Arkansas River and the South Arkansas River. Currently, the South Arkansas River is an unmodeled tributary that is lumped into the model input local inflows. As Salida’s primary water sources are native water rights on the South Arkansas River, they can’t currently be simulated within the model. Thus, Salida's total demand and primary sources are not currently simulated in the model and the Salida water user in the model does not represent their actual diversion location but instead the approximate location of the confluence with the South Arkansas River, which is where delivery exchanges from Pueblo Reservoir would travel to. Note that when the simulated delivery exchanges are made, this does not reflect an actual diversion from the river at that point even though it is simulated as a diversion on a water user object. Instead, this represents the decrease in the local inflow that would occur at that approximate river location due to the exchange.

Delivery exchanges to Salida can be made from both the “Salida EC” and “West of Pueblo PW” accounts in Pueblo Reservoir. However, due to the lack of ability to simulate their primary water sources, it is also not possible to determine the portion of their total demand that would rely on Pueblo Reservoir storage sources. Further, as the Salida EC account currently doesn’t have any simulated storage sources (see discussion in EC section), there is no EC storage for exchange. Thus, the only simulated delivery exchanges to Salida are FryArk Project Water from the “West of Pueblo PW”. Furthermore, due to the lack of simulation of detailed PW accounting on an individual water user basis, Salida’s use of PW is assumed to be limited to 146 AF/year, which is the annual average PW yield as reported in the AVC EIS Appendix A.1. This assumption must be made to prevent Salida from having access to the full “West of Pueblo PW” storage and draining the account to meet its entire demand. The result of these several significant issues regarding simulating Salida’s demands are that there are almost no discernable changes due to the increased total Salida demands present in future scenarios. It is highly recommended that the representation of Salida be enhanced to address some or all these issues and allow for more appropriate simulation.

4.2.9.2 Poncha Springs

Poncha Springs is located on the South Arkansas River, upstream from Salida. The model’s current representation of Poncha Springs has all the same simulation issues of Salida that are discussed above. Poncha Springs’ use of “West of Pueblo PW” is limited to 100 AF/year, which is the annual average PW yield as reported in the AVC EIS Appendix A.1. It is highly recommended that the representation of

Poncha Springs be enhanced to address some or all these issues and allow for more appropriate simulation.

4.2.9.3 Canon City

Canon City is located on the Arkansas River upstream of Pueblo Reservoir. Canon City's complete demand and major water sources are explicitly simulated in the model. As simulated, their demands are first met by native water right diversions, which are senior and are typically sufficient to meet the full demand. If necessary, simulated delivery exchanges from Pueblo Reservoir can be attempted, first from their EC storage account and then from the "West of Pueblo PW" account, however given the seniority of their direct flow water rights, it is likely that exchange potential would prove limiting. Canon City's use of "West of Pueblo PW" is limited to 1000 AF/year, which is the annual average PW yield as reported in the AVC EIS Appendix A.1.

4.2.9.4 Florence

Florence is located on the Arkansas River downstream of Canon City. Florence's complete demand and major water sources are explicitly simulated in the model. As simulated, their demands are first met by native water right diversions, which are senior and are typically sufficient to meet the full demand. If necessary, simulated delivery exchanges from Pueblo Reservoir can be attempted, first from their EC storage account and then from the "West of Pueblo PW" account, however given the seniority of their direct flow water rights, it is likely that exchange potential would prove limiting. Florence's use of "West of Pueblo PW" is limited to 327 AF/year, which is the annual average PW yield as reported in the AVC EIS Appendix A.1.

4.2.9.5 Penrose

Penrose is located on the Arkansas River downstream of Florence. Penrose's complete demand and major water sources are explicitly simulated in the model. As simulated, their demands are first met by native water right diversions from their changed Pleasant Valley/Alexander Ditch water rights. If necessary, delivery exchanges from Pueblo Reservoir are simulated, first from their EC storage account and then from the "West of Pueblo PW" account. Penrose's use of "West of Pueblo PW" is limited to 115 AF/year, which is the annual average PW yield as reported in the AVC EIS Appendix A.1.

4.2.9.6 Victor

Victor is a small town in the Arkansas basin located well up various minor tributaries of the Arkansas River north of Canon City. Victor's total demand and primary sources are not currently simulated in the model and the Victor water user in the model does not represent their actual diversion location due to that being outside of the model extent. Currently, the demand simulated on the Victor EC account is a delivery exchange from Pueblo Reservoir upstream to the approximate location of the confluence of Beaver Creek in the model. Please see the further description of the simulated Victor demands in the documentation section regarding its EC account. Note that when the simulated delivery exchanges are made, this does not reflect an actual diversion from the river at that point even though it is simulated as a diversion on a water user object. Instead, this represents the decrease in the local inflow that would occur at that approximate river location due to the exchange.

4.2.9.7 Other West of Pueblo PW Users

Small deliveries of FryArk Project Water from the “West of Pueblo PW” account to miscellaneous “west of Pueblo” municipal PW users are simulated with a simple delivery exchange to a lumped water user situated just upstream of Pueblo Reservoir. This does not represent any specific water users or delivery locations and is only meant to represent some minor additional usage of “West of Pueblo PW”. This demand is currently assumed to be equal to 676 AF/year, which is based on AVC EIS ModSim results, and is assumed to be uniformly distributed throughout the entire year, which is 0.93 cfs.

4.2.9.8 East of Pueblo PW Augmentation Release

While not an explicit water user, this release is intended to simulate the current levels of use of “East of Pueblo PW”. This release is meant to simulate releases to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses. This is simulated as a release of 2000 AF/year from the “East of Pueblo PW” account to native river flows. This is assumed to be evenly distributed in July - February of each year, with no releases in April – June. This annual volume and release pattern were developed based on observed “East of Pueblo PW” account storages in recent years. These releases are assumed to occur in all model scenarios, including those with the AVC demands turned on.

4.3 Simulated Agricultural Water Users

Most water user demands, especially those for agricultural water users and except those discussed in the description of the future scenarios elsewhere in this documentation, are assumed to be the same each for each year throughout an entire model run and for each model scenario. Thus, the total simulated annual diversions are determined by each year’s native flow yield from water rights and by the simulated storage available for delivery from various sources.

Because the historic diversions of many water users (primarily agricultural users) are lower than their total water right rates, maximum water right diversions levels were defined for some water users based on available historic diversion data. Additionally, because many water users tend to have different demand levels depending on whether they are diverting in-priority native water or delivering from storage, reduced demand patterns were developed for use when the users’ water rights are not in priority, or not fully in priority. When simulated native flow diversions from water rights are not sufficient, deliveries of stored water were simulated from the storage accounts available to the water user. These reduced demands were developed on a monthly or sub-monthly average flow demand basis and were also based on historic diversion data. For applicable water users, deliveries from potential storage sources in multiple reservoirs are simulated. This includes deliveries by exchange from the Colorado Canal and Holbrook Canal system reservoirs and from John Martin Reservoir.

The simulated water users and demands are summarized in the tables below, which are broken down by river area. Table 29 shows the simulated water users on the Arkansas River between Pueblo Reservoir and John Martin Reservoir. Table 30 shows the simulated water users on the Arkansas River below John Martin Reservoir. Table 31 shows the simulated water users on the Arkansas River above Pueblo Reservoir. Table 32 shows the simulated water users on Fountain Creek. Finally, Table 33 shows the simulated water users on Fountain Creek. These tables do not contain the simulated municipal water user demands, which are discussed elsewhere. The “Maximum Demand from Storage” is the maximum demand within the variable patterns used. Please note that the effects of changed water right operations, such as storage through exchanges or APODs, may not be represented in these tables.

Table 29: Arkansas River Water Users – Pueblo Reservoir to John Martin Reservoir

Water User	Simulated Diversion Season	Total Water Rights Rate, cfs	Simulated Maximum Demand, cfs	Maximum Demand from Storage, cfs	Available Storage Sources (in order of preference)
Bessemer Ditch Ag	Mar 15 - Nov 14	392.7	270	200	WW (Pueblo Res Only), Ag PW
Riverside Dairy Ditch	Mar 15 - Nov 14	1	1	1.2	WW (Pueblo Res only), Ag PW
Excelsior Ditch	Mar 15 - Oct 31	60	30	n/a	n/a
Collier Ditch	Mar 15 - Oct 31	26	10	n/a	n/a
Colorado Canal Ag	Mar 15 - Nov 14	756.3	59	59	WW (Colorado Canal reservoirs, Pueblo Res), Ag PW
Colorado Canal Storage WR Diversions	Mar 15 - Nov 14	n/a	756.3	n/a	n/a
High Line Canal	Mar 15 - Nov 14	501.6	400	275	WW (Pueblo only), Ag PW
Oxford Farmers Ditch	Mar 15 - Nov 14	129.4	120	80	WW (Pueblo only), Ag PW
Otero Canal	Jan 1 - Dec 31	457.9	41	n/a	n/a
Catlin Canal	Mar 15 - Nov 14	345	300	200	WW (Pueblo only), Ag PW
Holbrook Canal Ag	Apr 15 - Oct 31	600	150	150	WW (CC, Pueblo), Ag PW
Holbrook Canal Storage WR Diversions	Mar 15 - Nov 14	n/a	600	n/a	n/a
Rocky Ford Ditch	Mar 15 - Oct 31	117.2	109.8	n/a	n/a
Fort Lyon Storage Canal Storage WR Diversions	Mar 15 - Nov 14	n/a	900	n/a	n/a
Fort Lyon Canal	Mar 15 - Nov 14	2083	1000	300	WW (CC, John Martin, FLSC, Pueblo), Ag PW
LA Consolidated Ditch	Mar 15 - Nov 14	174.6	110	40	WW (CC, JM, Pueblo), Ag PW

Table 30: Arkansas River Water Users –Below John Martin Reservoir

Water User	Simulated Diversion Season	Total Water Rights Rate, cfs	Simulated Maximum Demand, cfs	Maximum Demand from Storage, cfs	Available Storage Sources (in order of preference)
Fort Bent Canal	Apr 1 - Oct 31	228.3	90	60	John Martin Conservation Storage
Keesee Ditch	n/a	28.5	0	0	n/a
Amity Canal	Apr 1 - Oct 31	783.5	500	300	John Martin Conservation Storage, Winter Water
Lamar Canal	Apr 1 - Oct 31	285.8	250	140	John Martin Conservation Storage
Hyde Ditch	Apr 1 - Oct 31	23.4	15	8	John Martin Conservation Storage
Manvel Canal	n/a	54	0	0	n/a
XY Irrigating Canal	n/a	69	0	0	n/a
Buffalo Canal	Apr 1 - Oct 31	67.5	67.5	60	John Martin Conservation Storage
Sisson Stubbs Ditch	n/a	7	0	0	n/a

Table 31: Arkansas River Water Users –Above Pueblo Reservoir

Water User	Simulated Diversion Season	Total Water Rights Rate, cfs	Simulated Maximum Demand, cfs	Maximum Demand from Storage, cfs	Available Storage Sources (in order of preference)
Lumped Diversions Above Lake Fork[1]	May 1 - Sep 30	33.6	15	n/a	n/a
Lumped Diversions Lake Fork Creek to Lake Creek[2]	May 1 - Sep 30	50.3	0	n/a	n/a
Lumped Diversions Lake Creek to Buena Vista[3]	Apr 15 - Oct 31	39.4	18	n/a	n/a
Lumped Diversions Buena Vista to Salida[4]	May 1 - Oct 31	136.9	58	n/a	n/a
Rogers Ditch	May 15 - Jul 31	2	0.5	n/a	n/a
Canon City Hydraulic Ditch	Apr 15 - Oct 31	77	77	n/a	n/a
South Canon Ditch	Apr 1 - Oct 31	48.5	40	n/a	n/a
Minnequa Canal	Jan 1 - Dec 31	275.3	108	n/a	n/a
Lumped Other Diversions Salida to Pueblo[5]	Mar 15 - Dec 15	80.8	40	n/a	n/a

Many water rights from the lumped diversions are now exchanged to storage/used at APODs.
1. Water rights from DeLappe, Martin, Bob Berry, Wells and Star, Younger 1&2, Young and Smith ditches.
2. Contains water rights from Derry, Upper River, Pioneer, Champ, Wheel, Section House ditches. All now used at APODs.
3. Contains water rights from Langhoff, Dryfield, Riverside-Allen ditches.
4. Contains water rights from Helena, Reformatory, Bray-Allen, Cogan-Day, Kraft, Salida, Sunnyside Park, and William-Hamm ditches.
5. Contains water rights from Pickett, Canon City-Oil Creek, Davis and McComber/Fremont County, Lester and Attebery, Hannenkratt, and Ideal Cement ditches.

Table 32: Fountain Creek Water Users

Water User	Simulated Diversion Season	Total Water Rights Rate, cfs	Simulated Maximum Demand, cfs	Maximum Demand from Storage, cfs	Available Storage Sources (in order of preference)
Fountain Mutual Canal	Jan 1 - Dec 31	415	23	n/a	n/a
Stubbs and Miller Ditch	Jan 1 - Dec 31	2.5	1.5	n/a	n/a
Chilcotte Ditch	Apr 1 - Oct 31	90.8	15	n/a	n/a
Owen and Hall Ditch	Apr 1 - Oct 31	45.9	12.5	n/a	n/a
Liston and Love South	Apr 1 - Aug 31	2.6	0.3	n/a	n/a
Talcott and Cotton Ditch	Apr 1 - Oct 31	17.8	2.5	n/a	n/a
Dr Rogers Ditch	Mar 15 - Dec 7	5.6	2	n/a	n/a
Burke Ditch	Apr 1 - Dec 31	18.6	3	n/a	n/a
Toof and Harman Ditch	Jan 1 - Dec 31	8.3	1.3	n/a	n/a
Wood Valley Ditch	Jan 1 - Nov 30	8	2.3	n/a	n/a
Greenview Ditch	Mar 15 - Nov 15	2.8	0.6	n/a	n/a
Cactus Ditch	Jan 1 - Dec 31	0.8	0.3	n/a	n/a

Table 33: Purgatoire River Water Users

Water User	Simulated Diversion Season	Total Water Rights Rate, cfs	Simulated Maximum Demand, cfs	Maximum Demand from Storage, cfs	Available Storage Sources (in order of preference)
Antonio Lopez Ditch	May 1 - Oct 15	8	4	n/a	n/a
Baca Joint Ditch	May 1 - Oct 15	103.4	35	20	Trinidad Project Storage
Chilili Ditch	May 1 - Oct 15	7	4	3	Trinidad Project Storage
South Side Ditch	May 1 - Oct 15	162.4	80	80	Trinidad Project Storage
Model Inlet Canal	May 1 - Oct 15	123.6	75	40	Trinidad Project Storage
Hoehne Ditch	Apr 1 - Sep 15	22.2	22.2	22.2	Trinidad Project Storage
River Canyon	Apr 1 - Oct 15	23.9	7	6	Trinidad Project Storage
Nine Mile Canal	Jan 1 - Dec 31	75	17	n/a	n/a
Highland Canal	May 1 - Oct 15	55.9	55.9	n/a	n/a

5 Simulation of Pueblo Reservoir Excess Capacity Accounts

5.1 Background

Excess Capacity (EC) Accounts in Pueblo Reservoir refer to the storage accounts that are created by Reclamation leasing out the potentially unutilized storage space in Pueblo Reservoir to other entities. In general, EC Accounts are used in the same manner as other types of storage accounts within reservoirs as entities can store various water sources and manage their storage in flexible ways, including making subsequent deliveries of stored water to diversions, storing emergency water supplies, and making various types of transactions with other entities. An important consideration is that EC accounts are subject to evacuation, or "spill", if the storage space that is occupied by EC account water is needed for flood control purposes or for storage of FryArk Project Water or other water types with higher storage preferences in Pueblo Reservoir.

For the purposes of this model, there are three broad categories of EC accounts and different accounts, even within the same broad category, different accounts may have varying rules depending on the entity's contract with Reclamation.

The first main category of EC accounts are "Long-Term Excess Capacity Contracts", which are accounts that are part of multi-year contracts between their owners and Reclamation. Long-Term (LT) EC Accounts tend to be owned by parties with significant and consistent water supplies, demands and operational need for reservoir storage. Several of the LT EC Accounts are related to the Southern Delivery System project (CSU, Fountain, and Security) and others are owned by larger municipalities who have the ability to take direct diversion of their water from Pueblo Reservoir (Pueblo Water and Pueblo West). Additionally, Aurora has a Long-Term EC Account and Donala is in the process of obtaining one. LT EC accounts tend to have lower spill priorities and therefore will spill only after other types of accounts spill, although this is not true for all the LT EC accounts.

The second broad category of EC accounts, referred to as the "Master Contract EC Accounts" are actually the many sub-accounts within what's considered a single Long-Term Account. The "Master Contract Long-Term Excess Capacity Account" is a broad scoping and flexible Long-Term EC Account that is sub-divided to a wide variety of different basin entities within the SECWCD. For the purposes of this model, it is convenient to refer to the various sub-accounts within the MC EC account as its own category EC account types as each of these sub-accounts may be operated similarly to a LT or Annual EC account within the MC EC Account.

The final broad category of EC accounts are "Short-Term Excess Capacity Contracts" (aka Annual or Temporary Contracts) that are typically only contracted for a year at a time. For modeling purposes however, as many of these Annual EC accounts are renewed on a year-to-year basis, they are however modeled as existing during each year in a multi-year model run unless specific scenarios dictate otherwise. These types of accounts tend to be owned by smaller entities or those with more variable water supply sources or storage needs. They also tend to have the highest spill priority and therefore will spill first if the space that their water is occupying is needed for storage of other water types. In addition to known Annual EC accounts, “Flex” Annual EC are also simulated in an attempt to represent currently undefined potential Annual EC accounts that may be requested in the future. Please see the specific section below for more information.

5.2 Overview of Storage Sources for Excess Capacity Accounts

Storage sources for Excess Capacity accounts refer to any type of operations, transactions, or other processes that represent an inflow, or a gain in storage, to an EC account. Note that inflow in this context does not necessary indicate an inflow to Pueblo Reservoir from upstream or even a net gain in storage in Pueblo Reservoir, as many EC account inflows correspond with outflows from other EC accounts. Many different types of EC account storage sources are simulated. These may include:

- Owned parts of actual river inflow to Pueblo Reservoir from upstream, such as:
    - Releases from upper basin reservoirs
    - Imports that are not exchanged into upper basin reservoirs
    - In priority upstream water rights that are not diverted and allowed to flow into Pueblo
- Exchanges of flow from downstream such as:
    - Storage in offstream reservoirs
    - In priority water right diversions
    - Owned parts of tributary inflows or reusable return flows
- Trades, leases, or other transactions from other accounts in Pueblo Reservoir (e.g., EC or WW)

5.3 Overview of Demands on Excess Capacity Accounts

Demands on Excess Capacity Accounts refer to any type of operations, transactions, or other processes that represent a release, transfer, exchange, or other outflow of storage from the EC Account. This does not include evaporation losses. Demands on Excess Capacity Accounts come in many different forms. Some of the most common types of demands that are simulated in the model are:

- Direct diversion from Pueblo Reservoir
- Deliveries via release to the river and subsequent diversion downstream
- Delivery exchanges via out-of-priority upstream diversion locations with concurrent release of stored water from Pueblo Res to native flow
- Exchanges from Pueblo Res to upstream storage locations
- Augmentation or delayed return flow requirement releases to native flow
- Contract exchanges or trades to various locations
- Leases/sales to other entities with EC storage accounts

5.4 Validation of Simulation of Excess Capacity Accounts

Plots of simulated Excess Capacity account storages are shown in Appendix A. These plots show the simulated Excess Capacity account storages from the results of the 5-year (10/1/2011 – 12/31/2015) current conditions comparison run along with historic EC account storages from the same period for general comparison. A discussion of the displayed results is also included.

5.5 Simulated Long-Term Excess Capacity Accounts

5.5.1 Aurora LT EC

Simulated Storage Sources

InflowFromUpstream_AURORA - This source is inflow of water from upstream sources into Pueblo Reservoir through the AURORA passthrough account chain. This could be outflows from upstream reservoirs or unexchanged imports.

RF1 Storage Establishment - This source is storage establishment of Aurora's RF1 water rights.

RF2 Storage Establishment - This source is storage establishment of Aurora's RF2 water rights.

AuroraMeredithPuebloECExchange - This source is exchange of Aurora's water yields from Lake Meredith to Pueblo Reservoir from to its ownership in the Colorado Canal system.

CO Canal WW Direct in Pueblo - This source is Colorado Canal Winter Water storage that is distributed within Pueblo to its municipal shareholders following its initial allocation. As the allocation of Colorado Canal WW favors allocation in the Colorado Canal system reservoirs, this will likely not happen very often.

Simulated Demands

The primary simulated demands on the Aurora LT EC account are river exchanges and contract exchanges from Pueblo Reservoir to the upper basin reservoirs, primarily Twin Lakes Reservoir, for subsequent diversion through the Otero Pump Station.

An additional simulated demand on the Aurora LT EC account are releases to meet the delayed return flow requirements associated with the Rocky Ford Ditch water right change decrees. This is currently simulated using the “Augmentation Release” methodology, which releases a maximum annual volume of 1,618 AF, distributed to monthly flows by the release patterns shown in the decrees, to native river flows.

5.5.2 CSU LT EC

Simulated Storage Sources

InflowFromUpstream_CSU - This source is inflow of water from upstream sources into Pueblo Reservoir through the CSU passthrough account chain, such as outflows from upstream reservoirs.

CSUMeredithPuebloECExchange - This source is exchange of CSU's water yields from Lake Meredith to Pueblo Reservoir from to its ownership in the Colorado Canal system.

CSUFountainCreekReturnFlowPuebloECExchange - This source represents exchanges of CSU's reusable return flows from the mouth of Fountain Creek upstream into Pueblo Reservoir. This may include exchanges of reusable return flows from FryArk Project Water, although those are not explicitly simulated.

CSUFountainCreekReturnFlowPuebloECSecondaryExchange - These are additional reusable return flow exchanges following the execution of other exchanges as part of the simulation of the shared exchange potential procedures.

DonalaTrade - This source represents transfers into the CSU LT EC account from the Donala EC account, which represent the "trade" of Donala's water to CSU in conjunction with CSU's deliveries to Donala on the other side of their system.

CO Canal WW Direct in Pueblo - This source is Colorado Canal Winter Water storage that is distributed within Pueblo to its municipal shareholders following its initial allocation. As the allocation of Colorado Canal WW favors allocation in the Colorado Canal system reservoirs, this will likely not happen very often.

Simulated Demands

There are several simulated demands on the CSU LT EC account. Primary demands include both direct deliveries from Pueblo Reservoir and exchanges to upstream storage locations. Direct deliveries are simulated from the CSU LT EC account through the FVC and the SDS to meet the simulated CSU demands on those conduits. Both river exchanges and contract exchanges are simulated from Pueblo Reservoir to the upper basin reservoirs, primarily Twin Lakes Reservoir, for subsequent diversion through the Otero Pump Station.

The CSU CF&I return flow requirements based on their Turquoise Lake storage water right yields are also simulated as releases to native flow from the CSU LT EC account through the "CSU CFI Augmentation Release".

Additional simulated demands on the CSU LT EC account include potential leases to various other simulated EC accounts. The leasing EC accounts currently simulated include: AGUA EC, CPW EC, and LAVWCD EC, although other EC accounts generally mention leases from CSU as sources with not enough information to simulate. The amounts and timing of these simulated leases vary and are shown in source descriptions for those EC accounts.

5.5.3 Fountain LT EC

Simulated Storage Sources

Fountain Mutual Canal Water Rights - These storage sources are simulated exchanges of Fountain's native flow yields from their ownership in the Fountain Mutual Irrigation Canal, which is currently assumed to be ~10.1%, and is shown in the Ditch Ownership Data.FMIC Ownership Breakdown slot. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

Chilcotte Ditch Water Rights - These storage sources are simulated exchanges of Fountain's native flow yields from their ownership in the Chilcotte Ditch, which is currently assumed to be ~24.5%, and is shown in the Ditch Ownership Data.Chilcotte Ownership Breakdown slot. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

FountainMeredithPuebloECExchange - This source is exchange of Fountain's water yields from Lake Meredith to Pueblo Reservoir from to its ownership in the Colorado Canal system.

CO Canal WW Direct in Pueblo - This source is Colorado Canal Winter Water storage that is distributed within Pueblo to its municipal shareholders following its initial allocation. As the allocation of Colorado Canal WW favors allocation in the Colorado Canal system reservoirs, this will likely not happen very often.

Several other potential sources mentioned in the AVC EIS App. A-1 and available EC Questionnaires are not simulated due to lack of sufficient information required to do so.

Fountain also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the simulated demands on the Fountain LT EC account are their demand through the SDS and the FVC. Fountain's FVC demand is met first by deliveries of FryArk Project Water, and the full annual FVC delivery capacity to Fountain is assumed to be equal to their annual PW allocation and thus EC is never used through the FVC. However, EC account storage is the first source for their SDS demands which are present in future model scenarios with higher Fountain demands. These assumptions must be made as insufficient information has been provided to better simulate Fountain's decisions regarding when and how much of either water type to use.

5.5.4 PBWW LT EC

Simulated Storage Sources

InflowFromUpstream_PBWW - This source is inflow of water from upstream sources into Pueblo Reservoir through the PBWW passthrough account chain. This could be outflows from upstream reservoirs or unexchanged imports.

West Pueblo Ditch Water Rights Storage - This source is storage of PBWW's West Pueblo Ditch water rights.

Hamp_Bell Water Rights Storage - This source is storage of PBWW's Hamp Bell water rights.

Riverside Dairy WW - This source is PBWW's WW yield from its ownership of the West Pueblo Ditch (which is included in the Riverside Dairy WW). This yield gets transferred into the PBWW LT EC account following the WW distribution at the end of the WW storage season.

PBWWReturnFlowPuebloECExchange - This source represents exchanges of PBWW's reusable return flows from their return location upstream into Pueblo Reservoir. This may include exchanges of reusable return flows from FryArk Project Water, although those are not explicitly simulated.

ContractExchange_AURORA_Twin Lakes Res - This source represents simulated contract exchanges with Aurora from Twin Lakes Reservoir, which results in a transfer into the PBWW LT EC account from the Aurora LT EC account, and a like transfer from PBWW to Aurora in Twin Lakes Reservoir.

ContractExchange_AURORA_Turquoise Lake - This source represents simulated contract exchanges with Aurora from Turquoise Lake, which results in a transfer into the PBWW LT EC account from the Aurora LT EC account, and a like transfer from PBWW to Aurora in Turquoise Lake.

ContractExchange_CSU_Twin Lakes Res - This source represents simulated contract exchanges with CSU from Twin Lakes Reservoir, which results in a transfer into the PBWW LT EC account from the CSU LT EC account, and a like transfer from PBWW to CSU in Twin Lakes Reservoir.

ContractExchange_CSU_Turquoise Lake - This source represents simulated contract exchanges with CSU from Turquoise Lake, which results in a transfer into the PBWW LT EC account from the CSU LT EC account, and a like transfer from PBWW to CSU in Turquoise Lake.

Simulated Demands

The primary simulated demand on the PBWW LT EC account are direct deliveries to PBWW through their Pueblo Reservoir outlet. Deliveries from this account to the Comanche Power Plant by way of release to the Arkansas River and subsequent diversion may also be made.

Additional simulated demands on the PBWW LT EC account include potential leases to various other simulated EC accounts. The leasing EC accounts currently simulated include: ARFG EC, AGUA EC, CPW EC, CWPDA EC, LAVWCD EC, UAWCD EC, and Victor EC, although other EC accounts generally mention leases from PBWW as sources with not enough information to simulate. The amounts and timing of these simulated leases vary and are shown in source descriptions for those EC accounts.

Although not currently simulated, an additional potential demand on the PBWW LT EC account are exchanges upstream to storage in Clear Creek Reservoir, Turquoise Lake, or Twin Lakes Reservoir.

5.5.5 Pueblo West LT EC

Simulated Storage Sources

InflowFromUpstream_PUEBLO WEST - This source is inflow of water from upstream sources into Pueblo Reservoir through the PUEBLO WEST passthrough account chain.

PuebloWestMeredithPuebloECExchange - This source represents exchange of Pueblo West's water yields from Lake Meredith to Pueblo Reservoir from to its ownership in the Colorado Canal system.

CO Canal WW Direct in Pueblo - This source is Colorado Canal Winter Water storage that is distributed within Pueblo to its municipal shareholders following its initial allocation. As the allocation of Colorado Canal WW favors allocation in the Colorado Canal system reservoirs, this will likely not happen very often.

ContractExchange_CSU_Twin Lakes Res - This source represents simulated contract exchanges with CSU from Twin Lakes Reservoir, which results in a transfer into the Pueblo West LT EC account from the CSU LT EC account, and a like transfer from Pueblo West to CSU in Twin Lakes Reservoir.

PuebloWestReturnFlowPuebloECExchange - This source represents exchanges of Pueblo West's reusable return flows from their return location upstream into Pueblo Reservoir. This may include exchanges of reusable return flows from FryArk Project Water, although those are not explicitly simulated.

Simulated Demands

The primary simulated demand on the Pueblo West LT EC account are direct deliveries to Pueblo West through their Pueblo Reservoir outlet.

An additional demand is an annual lease to the AGUA EC account of up to 500 AF/year, which is assumed to occur each year in May.

5.5.6 Security LT EC

Simulated Storage Sources

Fountain Mutual Canal Water Rights - These storage sources are simulated exchanges of Security's native flow yields from their ownership in the Fountain Mutual Irrigation Canal, which is currently assumed to be ~10.4%, and is shown in the Ditch Ownership Data.FMIC Ownership Breakdown slot. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

Chilcotte Ditch Water Rights - These storage sources are simulated exchanges of Security's native flow yields from their ownership in the Chilcotte Ditch, which is currently assumed to be ~9.8%, and is shown in the Ditch Ownership Data.Chilcotte Ownership Breakdown slot. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

Several other potential sources mentioned in the AVC EIS App. A-1 and available EC Questionnaires are not simulated due to lack of sufficient information required to do so.

Security also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the simulated demands on the Security LT EC account are their demand through the SDS and the FVC. Security’s FVC demand is met first by deliveries of FryArk Project Water, and the full annual FVC delivery capacity to Security is assumed to be equal to their annual PW allocation and thus EC is never used through the FVC. However, EC account storage is the first source for their SDS demands which are present in future model scenarios with higher Security demands. These assumptions must be made as insufficient information has been provided to better simulate Security's decisions regarding when and how much of either water type to use.

5.5.7 Donala LT EC (specific scenarios only)

Note that this is one of two potential Donala EC accounts, the other being the Donala LT EC account. Only one of the EC accounts is active in a given model run and the active account depends on the model scenario. The Simulated Storage Sources and simulated demands are the same regardless of which EC account is used. The only simulated difference for Donala between these scenarios is that in the future scenarios with their LT EC account (as opposed to their Annual EC account), they can only “trade” their delivery water to CSU in Pueblo Reservoir and not by exchange into Twin Lakes Reservoir.

Simulated Storage Sources

Willow Creek Ranch Water Rights - This source is yield from the Willow Creek Ranch Water Rights when they are stored directly within Pueblo Reservoir (i.e., not exchanged into Twin Lakes). See the Donala decree and excess capacity questionnaires for more info.

CSUTrade - This source is used if more of the WCR WRs are exchanged into Twin Lakes than the monthly CSU-Donala "delivery trade" amount. It is assumed that CSU gives Donala the difference into their Donala's EC account in Pueblo.

PBWW Lease - This source is Donala's 250 AF/year lease from PBWW. This source is first used to provide Donala the volume that they need to release from Turquoise for the WCR NISRF requirements, and the remainder volume is assumed to be given to Donala's EC account in Pueblo.

Simulated Demands

Currently, the only simulated demands on the Donala EC account is their delivery “trade” with CSU. The effect of this trade is that water is transferred from the Donala EC account to the CSU LT EC account in Pueblo Reservoir, and CSU delivers a like amount of water to Donala on the other side of their system, which is not currently represented in the model.

5.6 SIMULATED MASTER CONTRACT EXCESS CAPACITY ACCOUNTS

5.6.1 Canon City EC

Simulated Storage Sources

Currently, storage sources for the Canon City EC account are simulated for the 2032, 2047, and 2058 scenarios, but not for the 2017 scenario as most of their water rights are currently not decreed for storage.

Canon City Upstream Water Rights - This source represents storage of Canon City's water rights (upstream of Pueblo Res). Currently, Canon City's direct flow water rights are used for municipal purposes and the majority are not decreed for storage. However, it is assumed that for the 2032, 2047, and 2058 Excess Capacity scenarios that Canon City will change its water rights to allow for storage in Pueblo Res. It is assumed that these changes are not yet utilized for the 2017 EC scenario. As Canon City's direct flow water rights are senior and typically sufficient to meet their demands, it is assumed that for most of the time, their EC account will remain full, holding emergency storage for use during drought periods. Based on other recent change decrees, there are likely to be complex and strict regulations on storage, however it is assumed that Canon City will receive sufficient changes to allow to fill their EC account space as needed when their water rights are in priority following any use or spill from their EC account.

Canon City also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

The demands simulated on the Canon City EC account are delivery exchanges from Pueblo Reservoir upstream to their diversion location. Typically, their senior direct flow water rights are sufficient to meet their demands, and thus their EC account will typically sit full and only be used for deliveries during drought periods (although the exchange potential at these times may also prove limiting), or be refilled following EC spill.

5.6.2 Florence EC

Simulated Storage Sources

Florence Upstream Water Rights - This source represents Florence's various water rights allowable for storage under its various decrees. As simulated, Florence currently stores when their water rights are in priority for more than their daily diversion request, limited to EC Account available space.

Florence also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

The demands simulated on the Florence EC account are delivery exchanges from Pueblo Reservoir upstream to their diversion location. Typically, their senior direct flow water rights are sufficient to meet their demands, and thus their EC account will typically sit full and only be used for deliveries during drought periods (although the exchange potential at these times may also prove limiting), or be refilled following EC spill.

5.6.3 Penrose EC

Simulated Storage Sources

Penrose Upstream Water Rights - This source represents Penrose's Pleasant Valley (and Alexander) Ditch water rights allowable for storage under decree 06CW0012 . As simulated, Penrose currently stores when their water rights are in priority for more than their daily diversion request, limited to EC Account available space and the monthly depletion volume and depletion rate limits following the decree.

Penrose also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the Penrose EC Account is simulated to be operated along the lines described in the 2016 Excess Capacity Questionnaire and AVC EIS Appendix A.1. Storage of Penrose's in priority water rights (above what is needed for direct diversion) are simulated as allowable in their decree 06CW0012. When their water rights are not in priority for diversion to meet their demands, deliveries of EC storage are simulated via a "delivery" exchange from Pueblo Reservoir to their diversion location (their well field) on the Arkansas River.

5.6.4 Poncha Springs EC

Simulated Storage Sources

There are currently no simulated EC storage sources for the Poncha Springs EC account. The water rights claimed as storage sources within the AVC EIS Appendix A.1 are on the South Arkansas River which is outside the current model boundaries and thus are not currently simulated.

Poncha Springs also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Since there are no storage sources simulated, no demands can currently be simulated on the EC Account. If storage sources were simulated, the demands would be upstream exchange of EC storage to their diversion structure when direct flow water rights are not in priority (although the exchange potential at these times may also prove limiting).

5.6.5 Salida EC

Simulated Storage Sources

There are currently no simulated EC storage sources for the Salida EC account. The water rights claimed as storage sources within the AVC EIS Appendix A.1 are on the South Arkansas River which is outside the current model boundaries and thus are not currently simulated.

Salida also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Since there are no storage sources simulated, no demands can currently be simulated on the EC Account. If storage sources were simulated, the demands would be upstream exchange of EC storage to their diversion structure when direct flow water rights are not in priority (although the exchange potential at these times may also prove limiting).

5.6.6 Fountain EC

This is Fountain's Master Contract EC Account. Fountain also has a LT EC account. This MC EC account is currently modeled simply as a spillover account from the LT EC account and only receives storage when the LT EC account is full. Storage from this MC EC account is used by Fountain's demands before the LT EC account storage is used.

5.6.7 Pueblo West EC

This is Pueblo West's Master Contract EC Account. Pueblo West also has a LT EC account. This MC EC account is currently modeled simply as a spillover account from the LT EC account and only receives storage when the LT EC account is full. Storage from this MC EC account is used by Pueblo West's demands before the LT EC account storage is used.

5.6.8 Security EC

This is Security's Master Contract EC Account. Security also has a LT EC account. This MC EC account is currently modeled simply as a spillover account from the LT EC account and only receives storage when the LT EC account is full. Storage from this MC EC account is used by Security's demands before the LT EC account storage is used.

5.6.9 Stratmoor EC

Simulated Storage Sources

LAVWCD EC - This source is an assumed annual lease of up to the Max Content of the Stratmoor EC account for the currently selected scenario, from the LAVWCD EC account if it has the storage available. The requested Annual Volume of the lease is set by an IR depending on the selected scenario. This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage. This is assumed to take place in July as LAVWCD should have storage by then, and this places Stratmoor a month behind other LAVWCD leasers. Note that the 2015 and 2016 EC Questionnaires only list Reusable FryArk Project Water Return Flows as storage sources. The LAVWCD lease is assumed based on the information shown in AVC EIS Appendix A.1 and is included to provide some water to this EC account.

Stratmoor also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the only simulated demand on the Stratmoor EC account is their demand through the FVC. Since Stratmoor's FVC demand is met by deliveries of both FryArk Project Water ("Fountain Valley Pipeline PW") and non-project water, it is assumed that Stratmoor will utilize their EC storage before PW. This must be assumed as insufficient information has been provided to better simulate Stratmoor's decisions regarding when and how much of either water type to use. Note that this assumption may result in reduced simulated usage of Project Water by Stratmoor.

5.6.10 Widefield EC

Simulated Storage Sources

Fountain Mutual Canal Water Rights - These storage sources are simulated exchanges of Widefield's native flow yields from their ownership in the Fountain Mutual Irrigation Canal, which is currently assumed to be ~11.2%, and is shown in the Ditch Ownership Data.FMIC Ownership Breakdown slot. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

There are several additional potential sources of EC storage mentioned in the AVC EIS Appendix A.1 that are not currently simulated. These include various water rights that are not yet decreed for storage. The Bell Ditch water rights mentioned in both the AVC EIS Appendix A.1. and in the 2016 and 2017 EC Questionnaires are on Grape Creek, which is an unmodeled tributary of the Arkansas River above Pueblo Reservoir and thus storage of these water rights is not currently be simulated.

Widefield also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the only simulated demand on the Widefield EC account is their demand through the FVC. Since Widefield's FVC demand is met by deliveries of both FryArk Project Water ("Fountain Valley Pipeline PW") and non-project water, it is assumed that Widefield will utilize their EC storage before PW. This must be assumed as insufficient information has been provided to better simulate Widefield's decisions regarding when and how much of either water type to use. Note that this assumption may result in reduced simulated usage of Project Water by Widefield.

5.6.11 96 Pipeline Co EC

Simulated Storage Sources

OtherCOCanalMeredithPuebloECExchange - This source represents 96 Pipeline Co's minor ownership in the Colorado Canal Company, as defined in the "Colorado Canal Data.Other CO Canal Ownership Breakdown" slot. When the lumped "OtherCOCanalMeredithPuebloECExchange" exchange from the "OTHER" storage account in Lake Meredith to Pueblo Reservoir is executed, 96 Pipeline Co's portion is transferred to its EC account up to the its simulated max capacity.

In the future, 96 Pipeline Co also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the only simulated demand on the 96 Pipeline Co EC Account is the 96 Pipeline Co Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The Annual Release Volume for this Augmentation Release is assumed to be released at a constant rate during June-December if there is storage available in the source EC Account. This is meant to simulate releases of EC Account storage to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses.

5.6.12 Crowley County EC

Simulated Storage Sources

InflowFromUpstream_TLCC BALANCE - This source represents Crowley County's minor ownership in the Twin Lakes Canal Company, as defined in the "Twin Lakes Res Data.TLCC Balance Ownership Breakdown" slot. When lumped TLCC BALANCE account water is released from Twin Lakes Res and flows into Pueblo Res, Crowley County's portion is transferred to its EC account.

OtherCOCanalMeredithPuebloECExchange - This source represents Crowley County's minor ownership in the Colorado Canal Company, as defined in the "Colorado Canal Data.Other CO Canal Ownership Breakdown" slot. When the lumped "OtherCOCanalMeredithPuebloECExchange" exchange from the "OTHER" storage account in Lake Meredith to Pueblo Reservoir is executed, Crowley County's portion is transferred to its EC account.

In the future, Crowley County also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the only simulated demand on the Crowley County EC Account is the Crowley County Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The Annual Release Volume for this Augmentation Release is assumed to be released at a constant rate during June-December if there is storage available in the source EC Account. This is meant to simulate releases of EC Account storage to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses.

5.6.13 Eads EC

Simulated Storage Sources

LAVWCD EC - This source is an assumed annual lease of up to the Max Content of the Eads EC account for the currently selected scenario, from the LAVWCD EC account if it has the storage available. The requested Annual Volume of the lease is set by an IR depending on the selected scenario. This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage. This is assumed to take place in June as LAVWCD should have storage by then.

Simulated Demands

Currently, the only simulated demand on the Eads EC Account is the Eads Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The Annual Release Volume for this Augmentation Release is assumed to be released at a constant rate during June-December if there is storage available in the source EC Account. This is meant to simulate releases of EC Account storage to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses.

5.6.14 Fowler EC

Simulated Storage Sources

Ordway EC - It is assumed that Fowler leases up to 50 AF/year (their EC Account capacity in all scenarios) from the Ordway EC Account in September, according to their 2015 Excess Capacity Questionnaire. This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage.

In the future, Fowler also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, based on their 2015 Excess Capacity questionnaire, the only simulated demand on the Fowler EC Account are potential leases to the CWPDA EC Account of up to 50 AF/year during May-August. Note that the CWPDA EC Account is an Annual EC Account and is therefore is not simulated in all scenarios.

5.6.15 Las Animas EC

Simulated Storage Sources

LA Consolidated WW - This source represents Las Animas' ownership in the LA Consolidated Canal (the portion of which is currently unknown). It is assumed that Las Animas' only mechanism of storage of its LACC water in its EC Account occurs when it has Winter Water allocated within Pueblo Reservoir. When this happens, it is assumed that Las Animas will be transferred the lower of the full volume needed to fill its EC Account or the full amount of LACC WW allocated in Pueblo. As Pueblo is not a preferred allocation location for LACC's WW, it does not always receive WW allocation there.

In the future, Las Animas also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the only simulated demand on the Las Animas EC Account is the Las Animas Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The Annual Release Volume for this Augmentation Release is assumed to be released at a constant rate during June-December if there is storage available in the source EC Account. This is meant to simulate releases of EC Account storage to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses.

5.6.16 La Junta EC

Simulated Storage Sources

Holbrook Canal WW - This source represents La Junta's ownership in the Holbrook Canal system (the portion of which is currently unknown). It is assumed that La Junta's only mechanism of storage of its Holbrook water in its EC Account is Holbrook Canal Winter Water allocated within Pueblo Reservoir. When this happens, it is assumed that La Junta will be transferred the lower of the full volume needed to fill its EC Account or the full amount of Holbrook WW allocated in Pueblo.

In the future, La Junta also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the only simulated demand on the La Junta EC Account is the La Junta Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The Annual Release Volume for this Augmentation Release is assumed to be released at a constant rate during June-December if there is storage available in the source EC Account. This is meant to simulate releases of EC Account storage to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses.

5.6.17 Manzanola EC

Simulated Storage Sources

Catlin WW - This source represents Manzanola's minor ownership in the Catlin Canal, defined in the "Ditch Ownership Data.Catlin Canal Ownership Breakdown" slot. It is assumed that Manzanola's only mechanism of storage of its Catlin water in its EC Account is Catlin Winter Water allocated within Pueblo Reservoir. When this happens, it is assumed that Manzanola will be transferred its portion of the Catlin WW up to its simulated max capacity.

High Line WW - This source represents Manzanola's ownership in the High Line Canal (the portion of which is currently unknown). It is assumed that Manzanola's only mechanism of storage of its High Line water in its EC Account occurs when it has Winter Water allocated within Pueblo Reservoir. When this happens, it is assumed that Manzanola will be transferred up to the full volume needed to fill its EC Account. It is assumed that Manzanola receives its minor portion of the Catlin WW prior to receiving its High Line WW.

In the future, Manzanola also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

Currently, the only simulated demand on the Manzanola EC Account is the Manzanola Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The Annual Release Volume for this Augmentation Release is assumed to be released at a constant rate during June-December if there is storage available in the source EC Account. This is meant to simulate releases of EC Account storage to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses.

5.6.18 May Valley EC

Simulated Storage Sources

LAVWCD EC - This source is an assumed annual lease of up to the Max Content of the May Valley EC account for the currently selected scenario, from the LAVWCD EC account if it has the storage available. The requested Annual Volume of the lease is set by an IR depending on the selected scenario. This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage. This is assumed to take place in June as LAVWCD should have storage by then.

Simulated Demands

Currently, the only simulated demand on the May Valley EC Account is the May Valley Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The Annual Release Volume for this Augmentation Release is assumed to be released at a constant rate during June-December if there is storage available in the source EC Account. This is meant to simulate releases of EC Account storage to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses.

5.6.19 Olney Springs EC

Simulated Storage Sources

InflowFromUpstream_TLCC BALANCE - This source represents Olney Springs' minor ownership in the Twin Lakes Canal Company, as defined in the "Twin Lakes Res Data.TLCC Balance Ownership Breakdown" slot. When lumped TLCC BALANCE account water is released from Twin Lakes Res and flows into Pueblo Res, Olney Springs' portion is transferred to its EC account.

OtherCOCanalMeredithPuebloECExchange - This source represents Olney Springs' minor ownership in the Colorado Canal Company, as defined in the "Colorado Canal Data.Other CO Canal Ownership Breakdown" slot. When the lumped "OtherCOCanalMeredithPuebloECExchange" exchange from the "OTHER" storage account in Lake Meredith to Pueblo Reservoir is executed, Olney Springs' portion is transferred to its EC account.

Simulated Demands

Currently, the only simulated demand on the Olney Springs EC Account is the Olney Springs Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The Annual Release Volume for this Augmentation Release is assumed to be released at a constant rate during June-December if there is storage available in the source EC Account. This is meant to simulate releases of EC Account storage to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses.

5.6.20 Ordway EC

Simulated Storage Sources

InflowFromUpstream_TLCC BALANCE - This source represents Ordway's minor ownership in the Twin Lakes Canal Company, as defined in the "Twin Lakes Res Data.TLCC Balance Ownership Breakdown" slot. When lumped TLCC BALANCE account water is released from Twin Lakes Res and flows into Pueblo Res, Ordway's portion is transferred to its EC account.

OtherCOCanalMeredithPuebloECExchange - This source represents Ordway's minor ownership in the Colorado Canal Company, as defined in the "Colorado Canal Data.Other CO Canal Ownership Breakdown" slot. When the lumped "OtherCOCanalMeredithPuebloECExchange" exchange from the "OTHER" storage account in Lake Meredith to Pueblo Reservoir is executed, Ordway's portion is transferred to its EC account.

Simulated Demands

Currently the only simulated demand on the Ordway EC Account are potential leases to Fowler EC of up to 50 AF/year during September, and potential leases to CPW EC of up to 500 AF/year in June-July. Note that the CPW EC Account is an Annual EC Account and is therefore is not simulated in all scenarios.

5.6.21 Rocky Ford EC

Simulated Storage Sources

Catlin WW - This source represents Rocky Ford's minor ownership in the Catlin Canal, defined in the "Ditch Ownership Data.Catlin Canal Ownership Breakdown" slot. It is assumed that Rocky Ford's only mechanism of storage of its Catlin water in its EC Account is Catlin Winter Water allocated within Pueblo

Reservoir. When this happens, it is assumed that Rocky Ford will be transferred its portion of the Catlin WW up to its simulated max capacity.

In the future, Rocky Ford also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated. Rocky Ford's minor ownership of the Rocky Ford Ditch is also not currently simulated as an EC storage source.

Simulated Demands

Currently, the only simulated demand on the Rocky Ford EC Account is the City of Rocky Ford Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. Based on the 2016 EC Questionnaire, the total annual release volume is evenly distributed in Dec-Feb.

5.6.22 SCMWD EC

Simulated Storage Sources

Bessemer WW - This source represents Bessemer's ownership in the Bessemer Ditch, defined in the "Ditch Ownership Data.Bessemer Ditch Ownership Breakdown" slot. It is assumed that SCMWD's only mechanism of storage of its Bessemer water in its EC Account is Bessemer Winter Water allocated within Pueblo Reservoir. When this happens, it is assumed that SCMWD EC will be transferred its portion of the Bessemer WW up to its simulated max capacity.

In the future, SCMWD also plans on storing Reusable FryArk Project Water Return Flows, and potentially their other water rights that are not currently decreed as allowable for storage, which are not currently simulated.

Simulated Demands

The simulated demands on the SCMWD EC account are the "SCMWD Bessemer Demand" (used during the summer) and the "SCMWD River Intake Demand" (used during the winter). These demands also have access to "East of Pueblo PW", but it is assumed that they will always use their EC account storage first.

5.6.23 LAVWCD EC

Simulated Storage Sources

InflowFromUpstream_TLCC BALANCE - This source represents LAVWCD's minor ownership (and/or assumed leased shares) in the Twin Lakes Canal Company, as defined in the "Twin Lakes Res Data.TLCC Balance Ownership Breakdown" slot. When lumped TLCC BALANCE account water is released from Twin Lakes Res and flows into Pueblo Res, LAVWCD's portion is transferred to its EC account.

PBWW LT EC - This source is an assumed annual lease of up to 500 AF from the PBWW LT EC account in July of each year.

CSU LT EC - This source is an assumed annual lease of up to 1000 AF from the CSU LT EC account in July of each year.

OtherCOCanalMeredithPuebloECExchange - This source represents LAVWCD's minor ownership in the Colorado Canal Company, as defined in the "Colorado Canal Data.Other CO Canal Ownership Breakdown" slot. When the lumped "OtherCOCanalMeredithPuebloECExchange" exchange from the "OTHER" storage account in Lake Meredith to Pueblo Reservoir is executed, LAVWCD's portion is transferred to its EC account.

Catlin WW - This source is LAVWCD's WW yield from its ownership (and/or assumed leased shares) in the Catlin Canal. This yield gets transferred into the LAVWCD EC account following the WW distribution at the end of the WW storage season. Currently, LAVWCD is assumed to receive up to 19% of the total Catlin WW yield.

Catlin Water Rights - These storage sources are simulated exchanges of native flow yields from Catlin Canal to the LAVWCD EC account. Due to a largely unspecified Catlin Canal ownership breakdown, and further unknowns regarding variable leasing of shares and/or water yields and the potential exchange procedures and limits, it is currently assumed that when these exchanges are simulated, a total of up to 40% of the total Catlin Canal water right allocation at the headgate may be exchanged. Of this 40%, it is currently assumed that 25% would be transferred to the LAVWCD EC account. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

Various other storage sources are mentioned in the AVC EIS Appendix A.1 and available EC Questionnaires with insufficient information to allow for appropriate simulation. This includes other potential lease-fallow operations from other Arkansas River agricultural water users.

Simulated Demands

The primary simulated demand on the LAVWCD EC account is the LAVWCD Augmentation Release. The annual augmentation release volume is assumed to be 40% the selected scenario's Max Content for the EC account, which is based on release volumes shown in the 2016 and 2017 EC Questionnaires. The release pattern used is based on the total outflow shown in the 2016 LACWCD EC Questionnaire. This release is meant to simulate releases to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses, for a variety of basin water users that may utilize LAVWCD EC storage.

Additional simulated demands on the LAVWCD EC account include potential leases to various other simulated EC accounts. The leasing EC accounts currently simulated include: Eads EC, May Valley EC, and Stratmoor EC, although other EC accounts generally mention leases from LAVWCD EC as sources with not enough information to simulate. The amounts and timing of these simulated leases vary and are shown in source descriptions for those EC accounts.

5.6.24 UAWCD EC

Simulated Storage Sources

PBWW LT EC - This source is an assumed annual lease of up to the Max Content of the UAWCD EC account for the currently selected scenario, from the PBWW LT EC account if it has the storage available. The requested Annual Volume of the lease is set by an IR depending on the selected scenario. This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage. This is assumed to take place anytime during the year.

InflowFromUpstream_TLCC BALANCE - This source represents UAWCD's minor ownership in the Twin Lakes Canal Company, as defined in the "Twin Lakes Res Data.TLCC Balance Ownership Breakdown" slot. When lumped TLCC BALANCE account water is released from Twin Lakes Res and flows into Pueblo Res, UAWCD's portion is transferred to its EC account.

In the future, UAWCD also plans on storing Reusable FryArk Project Water Return Flows, which are not currently simulated.

Simulated Demands

There are currently multiple demands simulated on the UAWCD EC Account, the UAWCD Augmentation Release, and potential leases from the UAWCD OUD EC Account, and the BLM EC Account. Note that these leasing EC Accounts are an Annual EC Account and are therefore not simulated in all scenarios. The UAWCD Augmentation Release simulates an augmentation release demand on the UAWCD EC account. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The release pattern used to distribute the annual volume to monthly flows is based on the augmentation releases shown in the 2016 UAWCD EC Questionnaire.

5.6.25 Other Master Contract EC

This EC Account represents the lumped Master Contract EC accounts that are not currently represented explicitly. There are no sources or demands currently simulated on this account and thus it remains empty throughout the model runs. The Other Master Contract EC includes Beehive Water Association, Fayette Water Co., Hilltop Water Co., Holbrook Center Soft Water, Homestead, Newdale-Grand Valley Water Co., Patterson Valley, Southside Water Assoc., South Swink Water Co., Valley Water Co., Vroman, and West Grand Valley.

5.7 Simulated Annual (Temporary) Excess Capacity Accounts

5.7.1 AGUA EC

Simulated Storage Sources

Pueblo West LT EC - This source is an assumed annual lease of up to 500 AF from the Pueblo West LT EC account in May of each year.

PBWW LT EC - This source is an assumed annual lease of up to 500 AF from the PBWW LT EC account in the first half of September of each year (to be executed prior to the CSU lease).

CSU LT EC - This source is an assumed annual lease of up to 500 AF from the CSU LT EC account in the last half of September of each year (to be executed after the PBWW lease).

Excelsior Ditch Water Right Exchange - This storage source is the simulated AGUA exchange of Excelsior Ditch native water right yields into the AGUA EC account in Pueblo Reservoir. This exchange is simulated in a detailed manner and is subject to the various limits and criteria presented by the AGUA decrees.

Simulated Demands

As currently simulated, the AGUA EC account is a storage source used for subsequent delivery to Excelsior Ditch. The demand patterns for storage deliveries from the AGUA EC account were assumed based on the information provided in the 2016 and 2017 AGUA EC Questionnaires. These demands are assumed to be 10 cfs from March 15 – May 31 and 6 cfs from September 1 – October 31 of each year. These storage deliveries are meant to simulate Excelsior Ditch diversions for recharge or augmentation purposes.

5.7.2 ARFG EC

Simulated Storage Sources

Catlin WW - This source is ARFG's WW yield from its ownership (and/or assumed leased shares) in the Catlin Canal. This yield gets transferred into the ARFG EC account following the WW distribution at the end of the WW storage season. Currently, ARFG is assumed to receive up to ~13% of the total Catlin WW yield.

Catlin Water Rights - These storage sources are simulated exchanges of native flow yields from Catlin Canal to the ARFG EC account. Due to a largely unspecified Catlin Canal ownership breakdown, and further unknowns regarding variable leasing of shares and/or water yields and the potential exchange procedures and limits, it is currently assumed that when these exchanges are simulated, a total of up to 40% of the total Catlin Canal water right allocation at the headgate may be exchanged. Of this 40%, it is currently assumed that 25% would be transferred to the ARFG EC account. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

Simulated Demands

Currently, the only simulated demand on the ARFG EC account is the ARFG Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. This release pattern is based on the total outflow shown in the 2017 ARFG EC Questionnaire.

5.7.3 BLM EC

Simulated Storage Sources

UAWCD EC - All of these current sources represent leases from the UAWCD EC account. Based on the 2016 and 2017 EC Questionnaires, it is assumed that they are able to lease up to 200 AF/month during November-March from UAWCD EC, limited by the UAWCD EC storage available and the BLM EC account Max Content. This is assumed to be the same in each year of the model run.

Note that the 2016 and 2017 EC Questionnaires list other several other potential sources of water for storage in the BLM EC account. This includes water from the Deweese-Dye Ditch and Reservoir Company's water rights on Grape Creek that can't currently be simulated because Grape Creek is an unmodeled tributary, as well as other unmodeled water rights. Also listed are potential leases from other entities, with insufficient definition or criteria to allow for appropriate simulation of the potential utilization of these sources. Thus, the simulated sources above are assumed to be sufficient for the current purposes of the model and provide a reasonable representation of potential BLM EC account activity.

Simulated Demands

Currently, the only simulated demand on the BLM EC Account is the BLM Deweese Exchange. In reality, this exchange is an exchange from Pueblo Reservoir, upstream on the Arkansas to the mouth of Grape Creek, and upstream on Grape Creek to Deweese Reservoir. As Grape Creek is an unmodeled tributary, and as Deweese Reservoir is not modeled, the simulation of this exchange is basic and is from Pueblo Reservoir to the approximate location of the confluence of Grape Creek in the model (Grape Creek is currently lumped into the local inflows). As it is not currently possible to simulate the exchange potential on Grape Creek, and the exchange demand for Deweese Reservoir, the exchange demand is simulated following the 2016 and 2017 EC Questionnaires that show potential exchanges of up to 400 AF/month during April-November. It is assumed that these are spread evenly throughout the months which results in an exchange demand of ~6.5 cfs throughout that period. Other uses of the BLM EC account water are not simulated due to lack of sufficient detail.

5.7.4 Catlin EC

Simulated Storage Sources

Catlin WW - This source is Catlin's WW yield from its ownership (and/or assumed leased shares) in the Catlin Canal. This yield gets transferred into the Catlin EC account following the WW distribution at the end of the WW storage season. Currently, Catlin is assumed to receive up to ~41% of the total Catlin WW yield.

Catlin Water Rights - These storage sources are simulated exchanges of native flow yields from Catlin Canal to the Catlin EC account. Due to a largely unspecified Catlin Canal ownership breakdown, and further unknowns regarding variable leasing of shares and/or water yields and the potential exchange procedures and limits, it is currently assumed that when these exchanges are simulated, a total of up to 40% of the total Catlin Canal water right allocation at the headgate may be exchanged. Of this 40%, it is currently assumed that 25% would be transferred to the Catlin EC account. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

Simulated Demands

Currently, the only simulated demand on the Catlin EC account is the Catlin Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. This release pattern is based on the total outflow shown in the 2017 Catlin EC Questionnaire.

5.7.5 Corrections EC

Simulated Storage Sources

OtherCOCanalMeredithPuebloECExchange - This source represents Corrections' minor ownership in the Colorado Canal Company, as defined in the "Colorado Canal Data.Other CO Canal Ownership Breakdown" slot. When the lumped "OtherCOCanalMeredithPuebloECExchange" exchange from the

"OTHER" storage account in Lake Meredith to Pueblo Reservoir is executed, Corrections' portion is transferred to its EC account. Please note that the parameters in the table for this custom (Type -9) EC storage sources do not reflect the actual source simulated.

Simulated Demands

There are currently no demands simulated on the Corrections EC Account.

5.7.6 CPW EC

Simulated Storage Sources

Ordway EC - This source is an assumed annual lease of up to 500 AF from the Ordway EC account if it has the storage available during June-July of each year (so that it occurs before the other simulated leases and still allows Ordway to potentially refill some water in August before other potential lease demands in the fall). This is Annual Volume lease request is assumed to be the same in each year of the model run. This source is based on the 2016 and 2017 EC Questionnaires, which each show explicit leases from Ordway in September, however the leases are assumed to occur in June-July so that water is available for the simulated CPW demands in July-August (as well as due to how Ordway's sources and demands are simulated).

PBWW LT EC - This source is an assumed annual lease of up to 500 AF from the PBWW LT EC account if it has the storage available during July - August of each year (so that it occurs after the Ordway lease). This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage. Although this lease is not explicitly shown in the EC Questionnaires, PBWW is a listed as a potential lease source in the questionnaires and is assumed to occur due to the Ordway lease being insufficient to fully fill the CPW EC account by itself.

CSU LT EC - This source is an assumed annual lease of up to 500 AF from the CSU LT EC account if it has the storage available during August of each year (so that it occurs after the Ordway and PBWW leases). This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage. Although this lease is not explicitly shown in the EC Questionnaires, CSU is a listed as a potential lease source in the questionnaires and is assumed to occur due to the Ordway and PBWW leases being insufficient to fully fill the CPW EC account, especially in future scenarios.

Note that the 2016 and 2017 EC Questionnaires list many potential sources of water for storage in the CPW EC account by lease from other entities, with insufficient definition or criteria to allow for appropriate simulation of the potential utilization of these sources. Thus, the simulated sources above are assumed to be sufficient for the current purposes of the model and provide a reasonable representation of potential CPW EC account activity.

Simulated Demands

Currently, the only simulated demand on the CPW EC Account is the CPW Augmentation Release. In reality, based on the 2016 and 2017 EC Questionnaires, the CPW EC account will be used to supplement Arkansas River flows (both above and below Pueblo Reservoir) and the John Martin permanent pool storage, however the criteria for how and when they would use their stored EC water for these purposes was not provided. Thus, the CPW Augmentation Release is used to provide an ambiguous demand on the CPW EC account by releasing storage to native flow in the Arkansas River, generally following the limited information in the EC Questionnaires, and to provide a reasonable representation of potential CPW EC account activity. Note that this assumption will not directly result in supplemental flows in the Arkansas River above Pueblo Reservoir and may not actually always result in supplemental flows in the Arkansas River below Pueblo as it is not protected against river exchanges. It will also not be directly captured in the John Martin permanent pool.

The annual CPW Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The release pattern used is based on the total outflow shown in the 2017 CPW EC Questionnaire which only shows releases in July and August.

5.7.7 CWPDA EC

Simulated Storage Sources

InflowFromUpstream_TLCC BALANCE - This source represents CWPDA's minor ownership (and/or assumed leased shares) in the Twin Lakes Canal Company, as defined in the "Twin Lakes Res Data.TLCC Balance Ownership Breakdown" slot. When lumped TLCC BALANCE account water is released from Twin Lakes Res and flows into Pueblo Res, CWPDA's portion is transferred to its EC account.

PBWW LT EC - This source is an assumed annual lease of up to 300 AF from the PBWW LT EC account in July of each year.

Fowler EC - This source is an assumed annual lease of up to 50 AF from the Fowler EC account during May - August of each year. Note that this is currently the only simulated demand on the Fowler EC account.

Catlin WW - This source is CWPDA's WW yield from its ownership (and/or assumed leased shares) in the Catlin Canal. This yield gets transferred into the CWPDA EC account following the WW distribution at the end of the WW storage season. Currently, CWPDA is assumed to receive up to ~25% of the total Catlin WW yield.

Catlin Water Rights - These storage sources are simulated exchanges of native flow yields from Catlin Canal to the CWPDA EC account. Due to a largely unspecified Catlin Canal ownership breakdown, and further unknowns regarding variable leasing of shares and/or water yields and the potential exchange procedures and limits, it is currently assumed that when these exchanges are simulated, a total of up to 40% of the total Catlin Canal water right allocation at the headgate may be exchanged. Of this 40%, it is currently assumed that 25% would be transferred to the CWPDA EC account. These simulated exchanges are currently lumped into the simplified "Type 1" EC storage establishment exchanges, which are assumed to be the lowest priority exchanges into Pueblo Reservoir.

Simulated Demands

The only simulated demand on the CWPDA EC account is the CWPDA Augmentation Release. The annual augmentation release volume is assumed to be 76% the selected scenario's Max Content for the EC account, which is based on release volumes shown in the 2016 and 2017 EC Questionnaires. The release pattern used is based on the total outflow shown in the 2017 CWPDA EC Questionnaire. This release is meant to simulate releases to native river flow to augment for out-of-priority river depletions due to pumping, or for other similar uses, for a variety of basin water users that may utilize CWPDA EC storage.

5.7.8 UAWCD OUD EC

Simulated Storage Sources

UAWCD EC - This source is an assumed annual transfer of up to the Max Content of the UAWCD OUD EC account for the currently selected scenario, from the UAWCD EC account if it has the storage available. The requested Annual Volume of the lease is set by an IR depending on the selected scenario. This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage. This is assumed to take place between Mar-Dec.

Simulated Demands

Currently, the only simulated demand on the UAWCD OUD EC account is the UAWCD OUD Augmentation Release. The annual Augmentation Release Volume is assumed to be the selected scenario's Max Content for the EC account. The release pattern used is based on the total outflow shown in the 2017 UAWCD OUD EC Questionnaire.

5.7.9 Victor EC

Simulated Storage Sources

PBWW LT EC - This source is an assumed annual lease of up to 50 AF from the PBWW LT EC account if it has the storage available. This is Annual Volume lease request is assumed to be the same in each year of the model run, however it will only request the amount needed to fill it's EC account if it comes in with storage. This is assumed to take place each year during March. This source is based on the 2016 and 2017 EC Questionnaires.

Simulated Demands

Currently, the demand simulated on the Victor EC account is a delivery exchange from Pueblo Reservoir upstream to the approximate location of the confluence of Beaver Creek in the model. Beaver Creek is not explicitly modeled and is lumped into the local inflows. In reality, Victor's demand on its EC storage are delivery exchanges to their pump station on West Beaver Creek (a tributary of Beaver Creek) during times when their demands exceed their primary, local sources. As Victor's total demand and primary sources are not currently simulated, it is not possible to simulate when these exchanges would actually be necessary, and thus it is assumed that these exchange demands occur within each year of a model run. From the 2016 and 2017 EC Questionnaires, it is assumed that these exchange demands are 12.5, 25, 25, and 12.5 AF in May-August of each year, respectively. These exchange demand volumes are assumed to be spread evenly throughout each month, leading to demands of 0.20, 0.42, 0.41, and 0.20 cfs in those months.

5.7.10 Donala Annual EC (specific scenarios only)

Note that this is one of two potential Donala EC accounts, the other being the Donala LT EC account. Only one of the EC accounts is active in a given model run and the active account depends on the model scenario. The Simulated Storage Sources and simulated demands are the same regardless of which EC account is used. The only simulated difference for Donala between these scenarios is that in the future scenarios with their LT EC account (as opposed to their Annual EC account), they can only “trade” their delivery water to CSU in Pueblo Reservoir and not by exchange into Twin Lakes Reservoir.

Simulated Storage Sources

Willow Creek Ranch Water Rights - This source is yields from the Willow Creek Ranch Water Rights when they are stored directly within Pueblo Reservoir (i.e., not exchanged into Twin Lakes). See the Donala decree and excess capacity documents for more info.

CSUTrade - This source is used if more of the WCR WRs are exchanged into Twin Lakes than the monthly CSU-Donala "delivery trade" amount. It is assumed that CSU gives Donala the difference into their Donala's EC account in Pueblo.

PBWW Lease - This source is Donala's 250 AF/year lease from PBWW. This source is first used to provide Donala the volume that they need to release from Turquoise for the WCR NISRF requirements, and the remainder volume is assumed to be given to Donala's EC account in Pueblo.

Simulated Demands

Currently, the only simulated demands on the Donala EC account is their delivery “trade” with CSU. The effect of this trade is that water is transferred from the Donala EC account to the CSU LT EC account in Pueblo Reservoir, and CSU delivers a like amount of water to Donala on the other side of their system, which is not currently represented in the model.

5.8 “FLEX” ANNUAL EXCESS CAPACITY ACCOUNTS

5.8.1 “Flex” Annual EC Account Background

For Reclamation's Excess Capacity Analysis, it was desired to simulate several additional Annual EC Accounts to attempt to account for the fact that the varying or new entities might request Annual EC Accounts and that the requested Max Content of the accounts may also vary from year to year. In response to this need, three "Flex Annual EC Accounts" were developed to provide a limited representation of this potential variability. The three accounts are: “Flex Annual EC – Upper Arkansas M&I”, “Flex Annual EC – Lower Arkansas M&I”, and “Flex Annual EC – Lower Arkansas Ag”.

Since potential storage sources for these ambiguous accounts are unknown, these accounts may obtain storage when various other EC accounts overfill and would otherwise be forced dump their excess water to native in the river. In scenarios with the Flex Annual EC Accounts turned on, instead of spilling directly to native river flow, the storage will first be attempted to be transferred to the Flex accounts. This is not a perfect method as the storage establishment of most EC account storage sources will be initially limited if it will cause their account to overfill, but it does provide some representation of potential additional and ambiguous Annual EC Account storage in Pueblo Reservoir and is assumed to be sufficient for the current purposes of the model. This methodology should be expanded in the future to provide a better representation of these types of accounts when more information regarding potential storage sources is known.

Given that the demands of potential and ambiguous future Annual EC Accounts are also unknown, the demands on the Flex Annual EC Accounts are simulated simply as "Augmentation Releases" of their storage to native flow in the river. This could represent many system processes such as delivery exchanges upstream or deliveries downstream. In effect, the releases simulate that the Flex EC Account storage will somehow be released from storage in Pueblo Reservoir.

To demonstrate proof of concept for these Flex Annual EC account methods, simulated total combined Flex Annual EC account storages are shown below in Figure 5. These are shown in relation to the total combined Flex Annual EC account maximum capacities for the 2032, 2047, and 2058 model scenarios. No Flex Annual EC account capacity is simulated in the 2017 scenario. It is observed that the simulated Flex Annual EC account storages appear to do a good job of annually storing and releasing water in the majority of simulated years. It is further observed that very little Flex Annual EC account activity is observed in the late 1990s, the wettest years of the model period, and in the early 2000s and 2012-2013, the driest years of the model period. This is consistent with expectations as available EC storage space is generally limiting during wet periods, and available water sources are generally limited during dry periods.

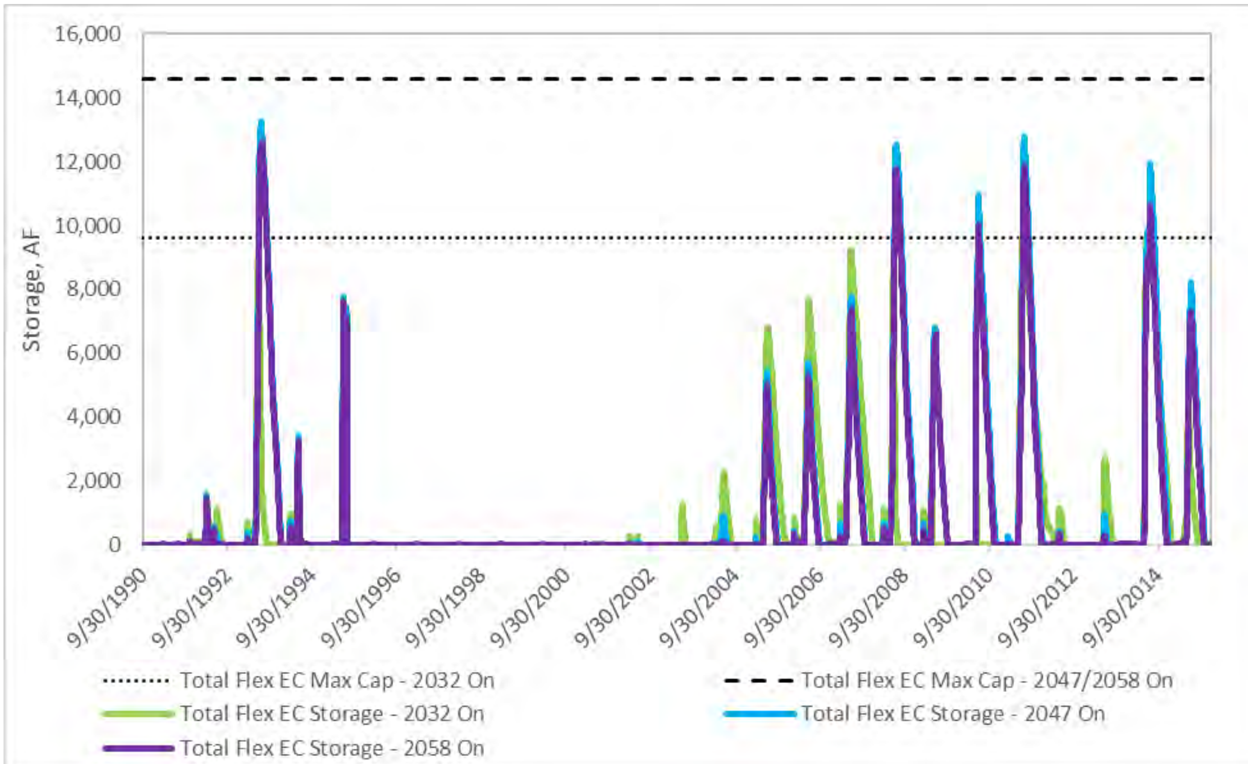

Figure 5: Simulated Total Combined Flex Annual EC Account Storages by Model Scenario

5.8.2 Limitations on Flex Annual EC Account Simulated Supplies and Demands

Maximum Annual Supply and Demand Scalars are applied to provide maximum annual supply and demand volumes to the accounts, based on the Max Contents of the Flex EC Accounts in a given scenario. This is to prevent these accounts from remaining full or being used too quickly in the case that a given model run ends up having a very high or low storage supplies to these accounts. These scalars are currently assumed to be 1.5 for the maximum annual supply, and 2 for the maximum annual demand. These were developed based on initial potential “Flex” Annual EC account supply and demand patterns provided by Reclamation and based on past EC accounts.

5.8.3 Flex Annual EC – Upper Arkansas M&I

Simulated Storage Sources

From Overfull EC Accounts - This source represents flexible storage of various water sources in all of the Flex Annual EC Accounts. In scenarios with the Flex Annual EC Accounts turned on, instead of spilling directly to native river flow, the overage storage will first be attempted to be transferred to the Flex accounts. This is meant to simulate the sales of extra water by various EC entities to other potential Annual EC Entities not already represented. This supply is split between the 3 Flex accounts and is subject to maximum annual supply volumes defined in the "Excess Capacity Account Setup Data.Flex Annual EC Account Modeled Max Supply and Demand Volumes" slot. The maximum annual supply volumes are assumed to be dependent on the maximum capacities of the Flex accounts in a given scenario. This source is simulated within the rule "2. Over Capacity EC Account Operations".

Simulated Demands

The only simulated demand on the “Flex Annual EC - Upper Ark MI EC Account” is the “Flex Annual EC - Upper Ark MI Augmentation Release”. The simulated annual release volume is dependent of the Max Content of the “Flex Annual EC - Upper Ark MI EC Account” for a given model scenario. The annual release volume is distributed to average monthly releases based on a release distribution typical of minor upper basin municipal water users.

5.8.4 Flex Annual EC – Lower Arkansas M&I

Simulated Storage Sources

From Overfull EC Accounts - This source represents flexible storage of various water sources in all of the Flex Annual EC Accounts. In scenarios with the Flex Annual EC Accounts turned on, instead of spilling directly to native river flow, the overage storage will first be attempted to be transferred to the Flex accounts. This is meant to simulate the sales of extra water by various EC entities to other potential Annual EC Entities not already represented. This supply is split between the 3 Flex accounts and is subject to maximum annual supply volumes defined in the "Excess Capacity Account Setup Data.Flex Annual EC Account Modeled Max Supply and Demand Volumes" slot. The maximum annual supply volumes are assumed to be dependent on the maximum capacities of the Flex accounts in a given scenario. This source is simulated within the rule "2. Over Capacity EC Account Operations".

Simulated Demands

The only simulated demand on the “Flex Annual EC - Lower Ark MI EC Account” is the “Flex Annual EC - Lower Ark MI Augmentation Release”. The simulated annual release volume is dependent of the Max Content of the source EC Account for a given model scenario. The annual release volume is distributed to average monthly releases based on a release distribution typical of minor lower basin municipal water users.

5.8.5 Flex Annual EC – Lower Arkansas Ag

Simulated Storage Sources

From Overfull EC Accounts - This source represents flexible storage of various water sources in all of the Flex Annual EC Accounts. In scenarios with the Flex Annual EC Accounts turned on, instead of spilling directly to native river flow, the overage storage will first be attempted to be transferred to the Flex accounts. This is meant to simulate the sales of extra water by various EC entities to other potential Annual EC Entities not already represented. This supply is split between the 3 Flex accounts and is subject to maximum annual supply volumes defined in the "Excess Capacity Account Setup Data.Flex Annual EC Account Modeled Max Supply and Demand Volumes" slot. The maximum annual supply volumes are assumed to be dependent on the maximum capacities of the Flex accounts in a given scenario. This source is simulated within the rule "2. Over Capacity EC Account Operations".

Simulated Demands

The only simulated demand on the “Flex Annual EC - Lower Ark Ag EC Account” is the “Flex Annual EC - Lower Ark Ag Augmentation Release”. The simulated annual release volume is dependent of the Max Content of the source EC Account for a given model scenario. The annual release volume is distributed to average monthly releases based on a release distribution typical of minor lower basin ag water users.

5.9 Evacuation Priorities of Simulated Excess Capacity Accounts

The Joint Use Pool evacuation (or “spill”) operations in Pueblo Reservoir are described previously in the model documentation. When Joint Use Pool evacuation occurs, the total simulated evacuation volumes at each spill priority level are then prorated across all EC accounts of the same spill priority level. The prorated evacuation amounts are then released from the EC accounts by adding the simulated evacuation amount to the day's outflow. At the current level of development, all EC account spill is assumed to be released to native flow. No subsequent recapture operations are currently simulated.

The general Pueblo Reservoir Joint Use Pool evacuation priorities are shown below. Note that the general group descriptions of the EC account types are not perfect and that the priorities depend on the specific contracts with Reclamation

1. Out-of-District Excess Capacity account storage
2. Annual EC account storage (and select other specific EC account storage)
3. Winter Water storage over 70,000 AF
4. Long-Term and Master Contract EC account storages (except those with specific lower priorities)
5. Remaining Winter Water storage
6. East Slope Project Water

The evacuation priorities used for the simulated EC accounts are shown below in Table 34.

Table 34: Simulated Excess Capacity Account Joint Use Pool Evacuation Priorities

Account Type	Excess Capacity Account	Evacuation Priority
Long-Term	Aurora LT EC	1
Long-Term	CSU LT EC	4
Long-Term	PBWW LT EC	4
Long-Term	Pueblo West LT EC	2
Long-Term	Fountain LT EC	4
Long-Term	Security LT EC	4
Long-Term	Donala LT EC	1
Master Contract	96 Pipeline Co EC	4
Master Contract	Canon City EC	4
Master Contract	Crowley County EC	4
Master Contract	Eads EC	4
Master Contract	Florence EC	4
Master Contract	Fountain EC	4
Master Contract	Fowler EC	4
Master Contract	Las Animas EC	4
Master Contract	La Junta EC	4
Master Contract	LAVWCD EC	2
Master Contract	Manzanola EC	4
Master Contract	May Valley EC	4
Master Contract	Olney Springs EC	4
Master Contract	Ordway EC	4
Master Contract	Penrose EC	4
Master Contract	Poncha Springs EC	4
Master Contract	Pueblo West EC	2
Master Contract	Rocky Ford EC	4
Master Contract	Salida EC	4
Master Contract	Security EC	4
Master Contract	Stratmoor EC	4
Master Contract	SCMWD EC	4
Master Contract	UAWCD EC	4
Master Contract	Widefield EC	4
Master Contract	Other Master Contract EC	4
Annual	AGUA EC	2
Annual	ARFG EC	2
Annual	BLM EC	2
Annual	Catlin EC	2
Annual	Corrections EC	2
Annual	CWPDA EC	2
Annual	CPW EC	2
Annual	Donala Annual EC	1
Annual	UAWCD OUD EC	1
Annual	Victor EC	1
Annual	Flex Annual EC_Upper Ark MI	2
Annual	Flex Annual EC_Lower Ark MI	2
Annual	Flex Annual EC_Lower Ark Ag	2

5.10 Excess Capacity Account Evaporation

Simulated daily evaporation losses are charged to all EC accounts. The total simulated Pueblo Reservoir daily evaporation is prorated to all reservoir accounts by storage content. First, an Object Level Accounting Method on Pueblo Reservoir is used to prorate the total simulated Pueblo Reservoir daily evaporation to the combined reservoir storage accounts on Pueblo Reservoir object. Next, the total evaporation charged to the total "EC" storage account is prorated between all of the EC proxy accounts by the "Distribute Evaporation to Proxy Accounts" rule.

5.11 Technical Excess Capacity Account Representation in RiverWare

5.11.1 Excess Capacity “Proxy” Accounts

Due to the large and variable number of Excess Capacity (EC) accounts on Pueblo Reservoir, it is infeasible to represent each as a separate, traditional RiverWare storage accounts on the Pueblo Reservoir object itself. Rather, there is one standard RiverWare storage account on Pueblo Reservoir that represents the aggregated total EC storage account, and the breakdown of individual EC accounts is represented by a collection of data object accounts called "Proxy Accounts". These EC Proxy Accounts consist of standardized data objects that each hold the same set of slots through which the EC accounts are configured. The standard sets of slots on a EC Proxy Account is as follows:

- Max Content - This scalar slot contains the simulated Maximum Content of the EC Account for the modeled scenario.
- Spill Priority - This scalar slot contains the Spill Priority of the EC account that is used during Pueblo Reservoir Joint Use Pool evacuation operations.
- SourceAccounts - This slot contains a table that defines the storage sources of the EC account. Standardized storage sources may be configured in this table and additional custom sources are mapped to distinct columns in the SourceYields slot so that the storage yields of various sources can be tracked individually.
- SourceYields - This multi-column daily series slot contains the yields, or inflows to storage, of the various sources defined in the SourceAccounts table. The sum of all of the SourceYields columns is set to the day's Inflow slot.
- Inflow - This daily series slot is the total simulated inflow to the EC account (meaning inflows to the EC account, which may or may not be actual inflows to the reservoir). The Inflow slot is the sum of all of the columns of the SourceYields slot.
- Outflow - This daily series slot is the simulated outflow from the EC account. By convention, outflow refers to actual releases of storage from the storage account that may be in the form of direct diversions from Pueblo Reservoir, delivery releases to downstream water users, and releases to native flow associated with river exchanges, augmentation releases, or spill.
- Exchange - This daily series slot is the simulated outflows from an EC account that remain in Pueblo Reservoir, which is typically a transfer of water to another EC account representing a lease, sale, or trade. By convention, exchange values that are negative represent outflows from the EC account.
- Evap - This daily series slot contains the evaporation loss charged to the EC account.

- Storage - This daily series slot is the simulated storage of the EC account, which is calculated by the water balance of the other daily series slots.

The Excess Capacity Proxy Account methodology is very similar to that used to represent the subaccount breakdowns of Pueblo Reservoir's FryArk Project Water accounts and the Winter Water subaccounts in Pueblo and other reservoirs.

Additionally, EC Accounts may be listed as "Source Storage Accounts" on both "Demand Data Objects" and "Augmentation Data Objects" in the model. These storage sources are then available for use within the rules used to simulate various deliveries to water users or augmentation releases to native flow.

5.11.2 Simulation of Storage Establishment in Excess Capacity Accounts

As this model was initially developed for detailed analysis relating to the potential impacts of Pueblo Reservoir's Annual Excess Capacity Accounts on the Arkansas River basin system, complex rule logic was developed to allow for detailed simulation of the individual operations of many of the Excess Capacity (EC) accounts in Pueblo Reservoir.

RiverWare rules are used to execute the various transactions and establish storage in EC Accounts in Pueblo Reservoir. Many different rules can establish storage in EC Accounts, some rules respond to changes in the system caused by other basin operations or processes (such as the various rules that release account water from upstream reservoirs) and direct the owned inflow into the storage of the appropriate EC account(s). Other rules are used to execute more complicated transactions, including but not limited to various river and contract exchanges, other storage of changed water rights subject to many rules and stipulations, leases/purchases of storage from other entities, and post-storage season distribution of a ditch’s Winter Water allocation to its municipal shareholders.

In addition to many custom rules developed to simulate storage of specific water supply sources in Pueblo Reservoir, several "standardized" rules are used to establish storage in EC accounts from similar water supply sources and storage mechanisms, or transaction types, described below. The EC Source "Type" is a parameter used to identify sources that are simulated through the use of general rules that establish EC storage for several EC accounts at the same time through the same mechanism.

EC Account Storage Establishment Source/Transaction Types:

- Type 1 is the exchange from water user to storage of water rights from downstream of Pueblo Reservoir (including Fountain Creek) into this EC account.
- Type 2 is the storage of in-priority water rights from upstream of Pueblo Reservoir through foregone or reduced diversions (a type of upstream to downstream exchange).
- Type 3 is a transfer (by trade/lease/purchase/other transaction) of storage from another account already in Pueblo Res.
- Type 4 is Arkansas River flow into Pueblo Reservoir from upstream that is owned (wholly or partially) by this EC account.
- Other Types (e.g., "-9") are custom sources that are mapped to a unique rule that does the establishment. The row name then must match here and in the associated rule/functions. For these, the values for the other columns aren't used. Also, a 0 for OnOff doesn't turn these sources off.

6 Model Scenarios for Annual Excess Capacity Account NEPA Analysis

6.1 Hydrology Period and Initial Conditions

The WY1991-2015 input hydrology data was used to drive the model for the Annual Excess Capacity Analysis model runs. This hydrology was developed during the initial RiverWare model development and is based on the historically observed basin conditions and associated historic data from 10/1/1990 to 12/31/2015. The initial condition for these model runs is based on the basin conditions, i.e., the total reservoir storages and accounting breakdowns, that existed on 9/30/2016.

The model run configurations selected for this analysis were each 25.25 years long. For each run, the model was initialized with the 9/30/2016 basin storage conditions and was run continuously and in sequence for the full 25.25-year period. Therefore, in each model run, the first water year's hydrology was that of 10/1/1990-9/30/1991, the second water years hydrology is that of 10/1/1991-9/30/1992, and so on, ending on 12/31/2015.

It is important to note that while the model dates do match the dates of the historic hydrology for these runs, it is not appropriate to directly compare the model results to the historic observed basin conditions on the corresponding dates. This is due to both the difference in the initial conditions and, more importantly, since the model is simulating the system as it currently exists (or will potentially exist for the future scenarios) in terms of the policy, operational procedures, water uses and demands, and other factors, and not the system as it existed historically in WY1991. The only factors assumed to be equivalent to historic through the model period are the basins hydrologic inputs or inflows, which also currently includes the transbasin imports into the basin. This assumption is discussed earlier in the report.

6.2 Excess Capacity Account Configurations by Scenario

In general, the Max Content of the simulated EC accounts is the main parameter modified across the Excess Capacity Analysis Scenarios. The storage sources for each EC account that are used to configure storage establishment are assumed to be the same across each scenario. This assumption is necessary given that there is not detailed knowledge of the potential future storage sources for each EC account and of the operational procedures or transactions that may be used to establish storage from those sources. Some of the storage transactions (such as some lease request volumes) are simulated as being dependent or otherwise limited by the size of the EC account and thus they may ultimately request and/or receive greater amounts of water supply in scenarios with a larger EC account. Additionally, as future demands on EC storage are assumed to be higher for some water users in future scenarios, an EC account's sources may be able to yield more storage supply due to a higher turnover of storage in their account.

6.2.1 Turning Annual EC Accounts On and Off

To support the Excess Capacity Analysis, the model can be run with the Annual EC Accounts turned on or turned off universally. If the accounts are turned off, the Max Contents are set to 0 at the beginning of the model run. The result is that the Annual EC Accounts are not allowed to establish storage and thus, any other of their operations are also eliminated.

When the Annual EC Accounts are turned off, there are no other adjustments made in the model other than the accounts being turned off. This means that the various other water user demands and basin operations are assumed to be the same as the scenario with the EC accounts turned on. This is a broad assumption, but it must be made since modeling the many altered operations that would occur throughout the basin if Reclamation were to cease the use of Annual EC Contracts is infeasible. Many of the current operations of the Annual EC and related entities are currently assumed to be implicitly represented in the Local Inflows, which are calculated based on the historic data within which various Annual EC Accounts did exist. It is assumed that this is sufficient for the current model uses.

6.2.2 Tables Defining Excess Capacity Analysis Scenarios

This section contains the tables that are used to configure the various model scenarios used for the Annual Excess Capacity Account NEPA analysis. The EC account storages for each scenario were defined by Reclamation.

Table 35: Total Combined Excess Capacity Account Type Maximum Storages by Model Scenario

Excess Capacity Account Type	Total Simulated Excess Capacity Storage Capacity, AF			
	Model Scenario			
	2017	2032	2047	2058
Overall Total	72,705	107,571	122,009	126,938
Total Long-Term	62,876	82,571	92,009	97,437
Total Long-Term (no MC)	55,475	66,500	67,000	67,499
Total Master Contract	7,401	16,071	25,009	29,938
Total Annual	9,829	25,000	30,000	29,501
Total Annual (no Flex)	9,829	15,399	15,399	14,900
Total Flex Annual	0	9,601	14,601	14,601

Table 36: Long-Term Excess Capacity Account Maximum Storages by Model Scenario

Excess Capacity Account	Total Simulated Excess Capacity Storage Capacity, AF			
	Model Scenario			
	2017	2032	2047	2058
Aurora LT EC	10,000	10,000	10,000	10,000
CSU LT EC	20,000	27,500	28,000	28,000
Donala LT EC	0	0	0	499
Fountain LT EC	2,100	2,500	2,500	2,500
PBWW LT EC	12,000	15,000	15,000	15,000
Pueblo West LT EC	9,875	10,000	10,000	10,000
Security LT EC	1,500	1,500	1,500	1,500
Master Contract LT EC	7,401	16,071	25,009	29,938

Table 37: Master Contract Excess Capacity Account Maximum Storages by Model Scenario

Excess Capacity Account	Total Simulated Excess Capacity Storage Capacity, AF			
	Model Scenario			
	2017	2032	2047	2058
Canon City EC	25	400	775	1,000
Crowley County EC	25	400	775	1,000
Eads EC	1	20	39	50
Florence EC	56	900	1,744	2,250
Fountain EC	200	508	815	1,000
Fowler EC	50	50	50	50
Las Animas EC	8	120	500	300
La Junta EC	50	800	1,550	2,000
LAVWCD EC	3,830	4,280	4,730	5,000
Manzanola EC	2	24	47	60
May Valley EC	8	120	233	300
Olney Springs EC	3	50	97	125
Ordway EC	100	350	600	750
Penrose EC	50	377	704	900
Poncha Springs EC	5	80	155	200
Pueblo West EC	150	2,400	4,650	6,000
Rocky Ford EC	100	523	946	1,200
Salida EC	625	1,154	1,683	2,000
Security EC	255	734	1,213	1,500
SCMWD EC	600	1,139	1,677	2,000
Stratmoor EC	150	169	189	200
UAWCD EC	700	815	931	1,000
Widefield EC	400	497	592	650
96 Pipeline Co EC	1	10	20	25
Other Master Contract EC	7	151	294	378

Table 38: Annual Excess Capacity Account Maximum Storages by Model Scenario

Excess Capacity Account	Total Simulated Excess Capacity Storage Capacity, AF			
	Model Scenario			
	2017	**2032**	**2047**	**2058**
AGUA EC	2,600	3,600	3,600	3,600
ARFG EC	50	1,000	1,000	1,000
BLM EC	400	500	500	500
Catlin EC	100	1,000	1,000	1,000
Corrections EC	80	150	150	150
CWPDA EC	5,000	7,000	7,000	7,000
CPW EC	1,000	1,500	1,500	1,500
Donala Annual EC	499	499	499	0
UAWCD OUD EC	50	100	100	100
Victor EC	50	50	50	50
Flex Annual EC_Upper Ark MI	0	1,440	2,190	2,190
Flex Annual EC_Lower Ark MI	0	6,049	9,199	9,199
Flex Annual EC_Lower Ark Ag	0	2,112	3,212	3,212

6.3 Simulated Water User Demands by Scenario

The following tables show the simulated annual demands by scenario for water users that are assumed to have increased future demands. These annual demand volumes are patterned to monthly average flows using monthly ratios from historic data, the ModSim model, or other sources. The patterns used can be found in the model. The distribution of annual demands to entities with both FVC and SDS deliveries is simulated in the model with a procedure developed for this purpose. The annual demand volumes for each scenario were estimated by Reclamation.

Table 39: Simulated Municipal Water User Annual Demand Volumes by Model Scenario

Demand Set Up for Others.Annual Total Demand Volumes by Scenario

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Annual Total Demand Volumes by Scenario

Value:

	PBWW Demand acre-feet	Comanche Power Plant Demand acre-feet	AVC Demand acre-feet	SCMWD acre-feet	Salida MI acre-feet	Canon City MI acre-feet	Florence acre-feet	Penrose acre-feet	Poncha Springs acre-feet
0: 2017	29,696.00	12,763.00	0.00	1,776.00	1,641.00	6,238.00	1,628.00	646.00	172.00
1: 2032	32,003.00	12,763.00	0.00	2,023.00	2,144.00	7,606.00	2,009.00	939.00	225.00
2: 2047	34,489.00	12,763.00	10,256.00	2,271.00	2,647.00	8,973.00	2,390.00	1,231.00	278.00
3: 2058	36,434.00	12,763.00	10,256.00	2,453.00	3,016.00	9,976.00	2,670.00	1,445.00	317.00

Show: ☐ Description

Table 40: Simulated Municipal FVC and SDS Water User Annual Demand Volumes by Model Scenario

Demand Set Up for CSU FVA SDS and Otero.Annual Total D...

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Annual Total Demand Volumes FVC and SDS Entities by Scenario

Value:

	CSU acre-feet	Fountain acre-feet	Security acre-feet	Widefield acre-feet	Stratmoor acre-feet	Pueblo West acre-feet
0: 2017	102,427.78	5,599.00	3,832.00	2,870.00	655.00	6,073.00
1: 2032	151,344.44	8,235.00	4,215.00	3,681.00	688.00	6,405.00
2: 2047	197,000.00	10,871.00	4,598.00	4,492.00	721.00	6,736.00
3: 2058	197,000.00	12,805.00	4,879.00	5,087.00	746.00	6,979.00

Show: ☐ **Description**

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APPENDIX A: SIMULATED EXCESS CAPACITY ACCOUNT STORAGE PLOTS

APPENDIX B: LIST OF SIMULATED WATER RIGHTS

APPENDIX C: MODEL DATA DEVELOPMENT

APPENDIX D: MODEL CALIBRATION AND VALIDATION

Appendix A: Simulated Excess Capacity Account Storage Plots

The following are plots of the simulated excess capacity (EC) account storages for the 5-year (10/1/2010-12/31/2015) current conditions comparison run. The similarities and differences between this model scenario run and the matching historic period are described elsewhere in the main documentation. Note that the Max Content shown on the plots are the maximum EC account capacities for the current conditions comparison run and the 2017 scenario runs. Please also note that historic total Master Contract (MC) storage is the sum of the historic individual EC accounts that would now be within the Master Contract, however that all historic Pueblo West, Fountain, and Security EC storages, who now have both Long-Term (LT) and MC EC accounts, are assumed to be in their current LT account, as it is not currently possible to divide their past storages between the accounts. Finally, note that the simulated dates shown on the plots are 10/1/1990-11/30/1996, but that these correspond to the historic dates of 10/1/2010-11/30/2016.

Comparison plots are provided for total EC storage, total storages by EC account types, and individual EC accounts with available historic data for comparison. Although not in the simulated period, historic data through 2016 is shown to allow simulated storages to be compared to the most recent available actual EC storages, given that the operations of many of the accounts have been recently evolving. These plots are provided as corroboration that the simulated EC account storages are reasonable approximations of potential future EC storages, given the large amount of uncertainty relating to EC account operations.

It is important to note that simulated EC account storages are not intended to match or reproduce historic storages, as in many cases the historic EC account sizes, sources, and demands have varied but are simulated with the most recent understanding of the operations and with static EC account sizes. Additionally, due to lack of information, many EC accounts are simulated as operating in the same manner for each year of the model runs and therefore may not capture the actual year-to-year variations due to hydrology year type and overall water availability. In reality, these factors and others may have important effects on the operations of many EC accounts, such as effecting how different storage sources are utilized, how demands vary, and desired carryover or other target storages.

As an additional consideration in these comparisons, the 5-yr current conditions comparison run results in Pueblo Reservoir total storage conditions that require evacuation (“spill”) of storage from the Joint Use Pool for flood protection during April 2012 and summer 2015. In contrast, historically in April 2012, Pueblo Reservoir’s total storage was below the Joint Use Pool restriction and did not require an evacuation. In 2011 and into 2012, the historic system storage conditions were affected by non-standard operations in FrkArk Project reservoirs, notably Turquoise Lake and Pueblo Reservoir, to help accommodate maintenance on the west slope Homestake Reservoir. The model results show that these altered operations likely led to lower reservoir storages historically than would have occurred had more normal operations occurred, and likely unintentionally eliminated the need for Joint Use Pool evacuation in the spring of 2012. Thus, the decrease in simulated EC storage observed in several of the first-to-spill EC accounts is not observed in the historic data. A good example of this is the Aurora LT EC account, which empties completely in the simulated April 2012, due both to pre-spill evacuation measures and spill, but did not historically. The result of this is significantly lower Aurora LT EC storage throughout the remainder of 2012 and until the summer of 2013 when it can be refilled. This same evacuation period is also present in other EC accounts with higher evacuation priorities such as Annual EC accounts.

The summer of 2015 presents another interesting situation when high river flows both above and below Pueblo Reservoir led to utilization of the Joint Use Pool for flood control purposes as prescribed by flood control operations. This process occurs similarly in the model as it happened historically. However, due to the post-flood drawdown of the temporarily stored native flood waters combined with high tributary and local inflows downstream of Pueblo Reservoir, a large volume of EC storage was fortunate to not be evacuated even while Pueblo Reservoir encroached into the Joint Use Pool for flood control. A relatively minor amount of EC evacuation does still occur throughout the summer of 2015 in the simulated results that does not appear to have happened historically. However, this can be largely attributed to slightly higher simulated overall Pueblo Reservoir storages compared to historic combined with continued EC inflows to lower spill priority accounts causing evacuation from higher spill priority EC accounts.

An overall observation relating to the interaction between the Pueblo Reservoir Joint Use Pool restrictions and the EC account storages is that Joint Use Pool evacuation can create significant discontinuities in EC storages. These discontinuities are driven by the almost binary nature of the evacuation process, i.e., either accounts spill or don't in any given year due to the overall Pueblo Reservoir storage conditions and basin hydrology, and many times when evacuation occurs, many accounts are forced to empty entirely, and it can take some time for accounts to rebuild storage to the pre-evacuation levels. Further, and intuitively, EC account storage sources tend to yield the most potential storage during the same periods of high hydrology that tend to lead to Joint Use Pool evacuation conditions. These types of situations are prevalent in the high hydrology period of the later 1990s, where simulated EC storages tend to quickly build before they are evacuated on a year-to-year basis. Historically, the maximum EC account capacities and the utilization of EC storage space was very minor through that same period of high hydrology relative to the present utilization.

LIST OF SIMULATED EXCESS CAPACITY STORAGE PLOTS

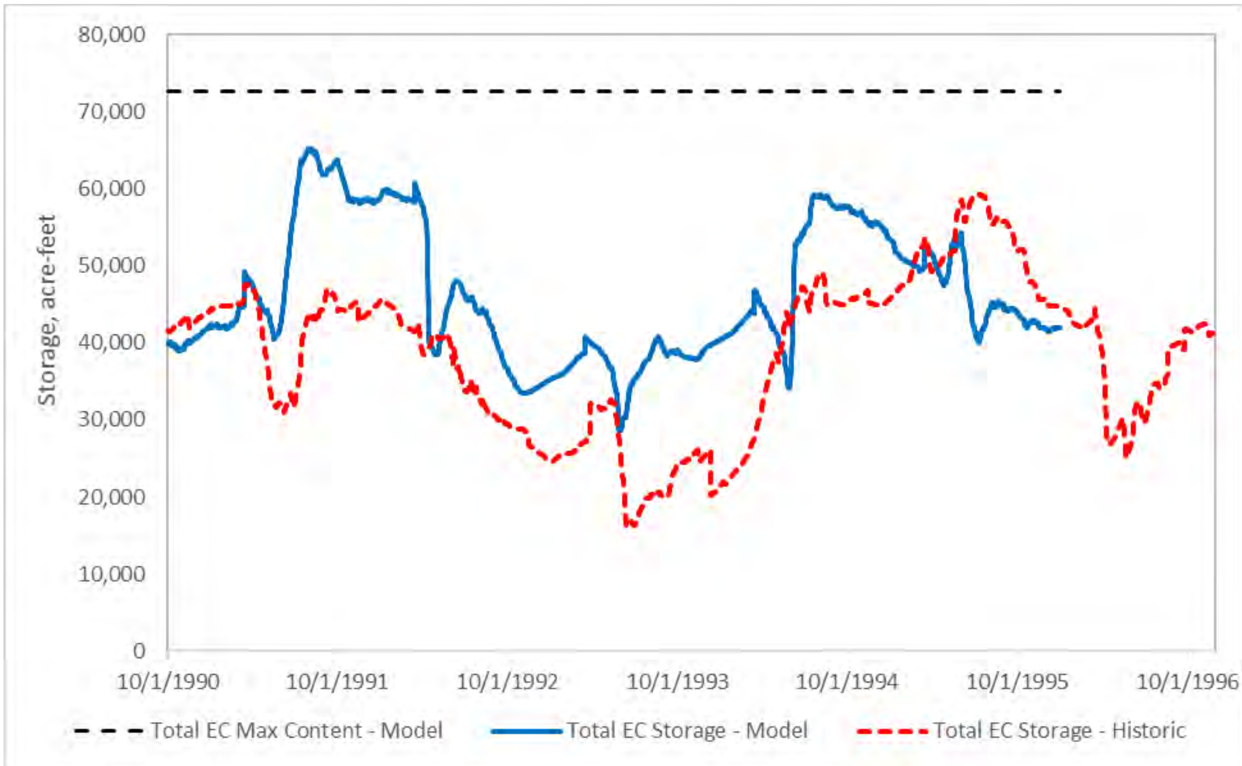

Figure 1: Total Excess Capacity Storage, 2011-2015 Current Conditions Run.

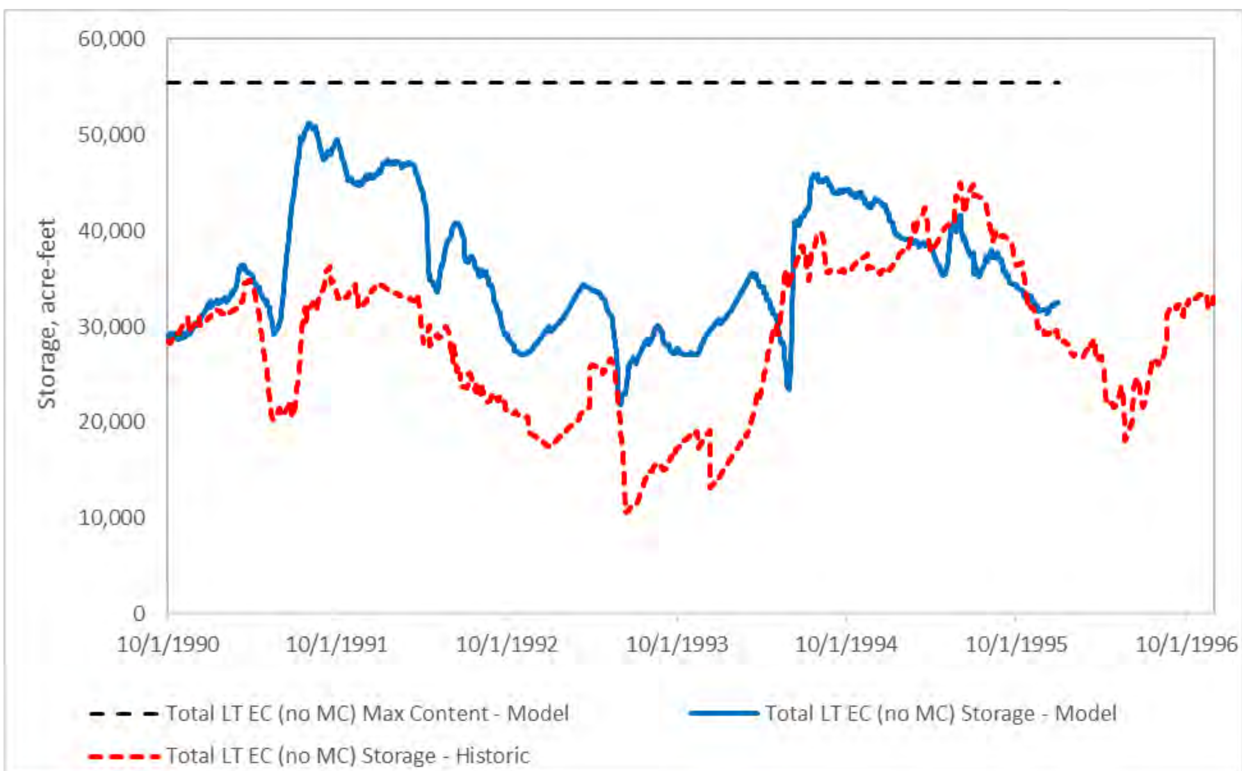

Figure 2: Total Long-Term Excess Capacity Storage (not incl. MC), 2011-2015 Current Conditions Run.

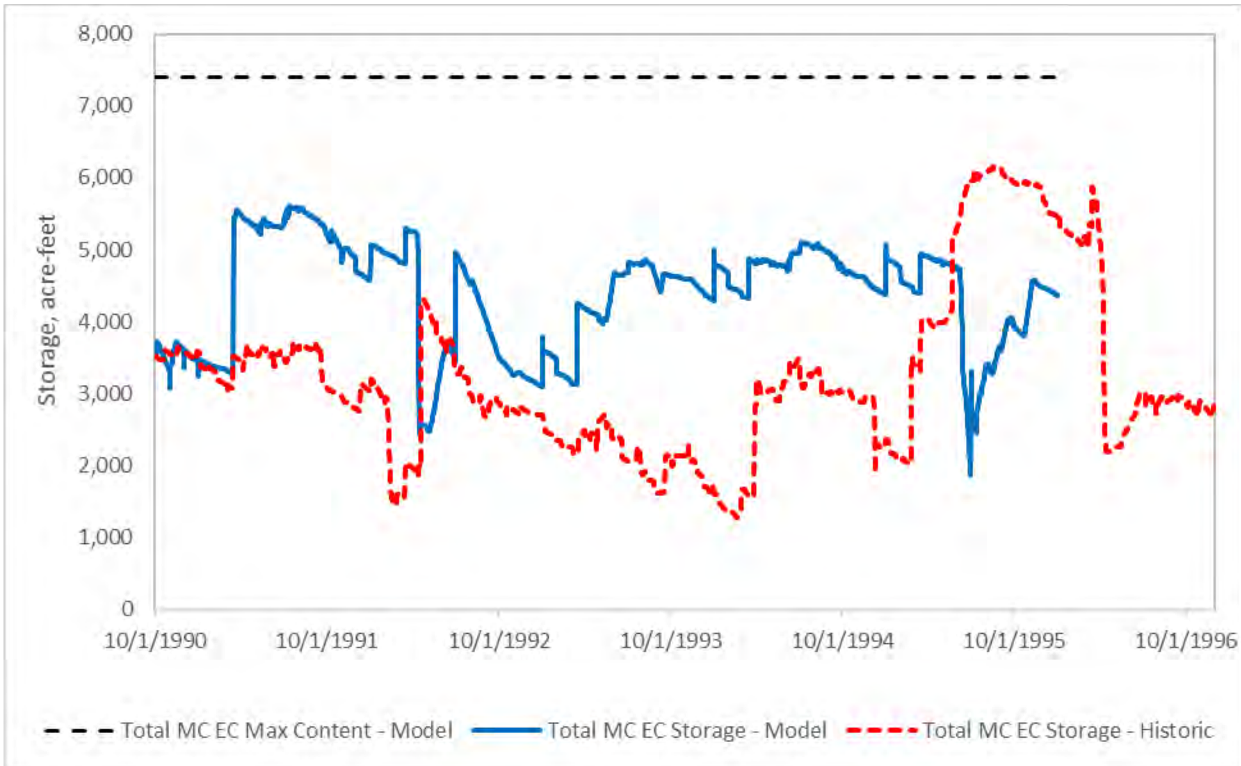

Figure 3: Total Master Contract Excess Capacity Storage, 2011-2015 Current Conditions Run.

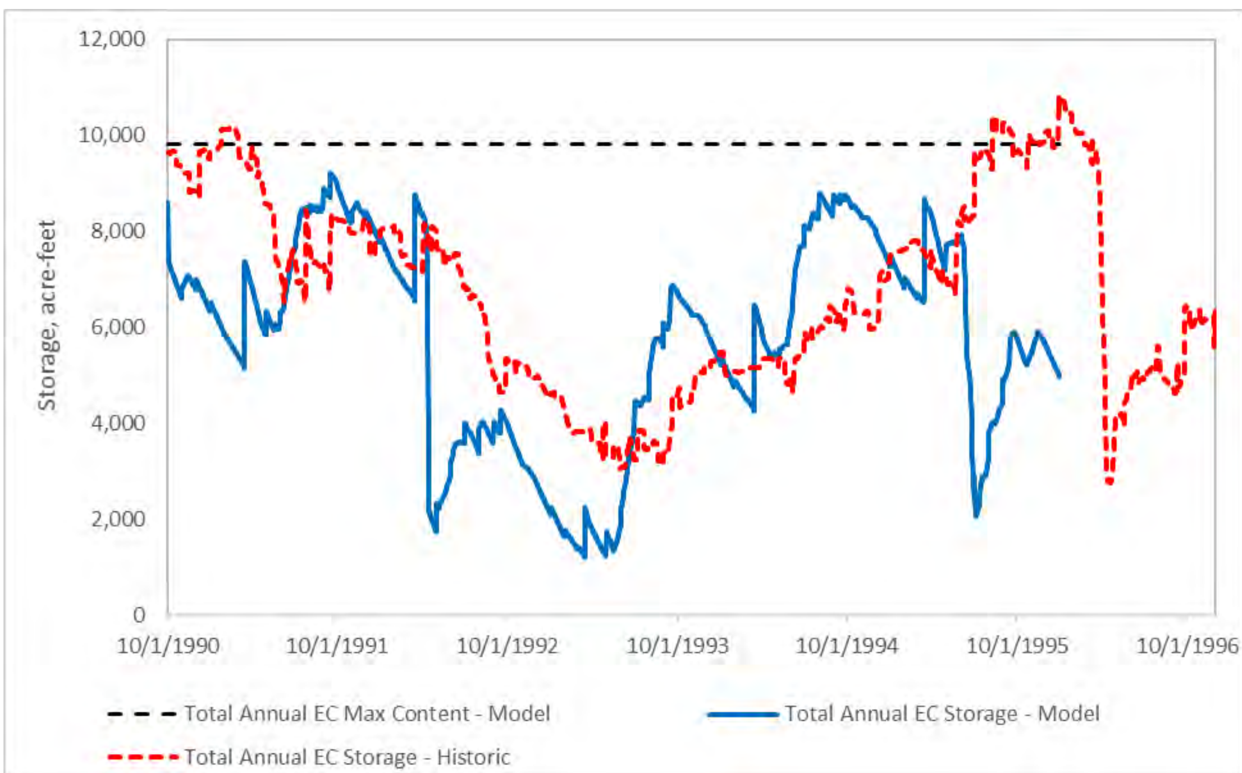

Figure 4: Total Annual Excess Capacity Storage, 2011-2015 Current Conditions Run.

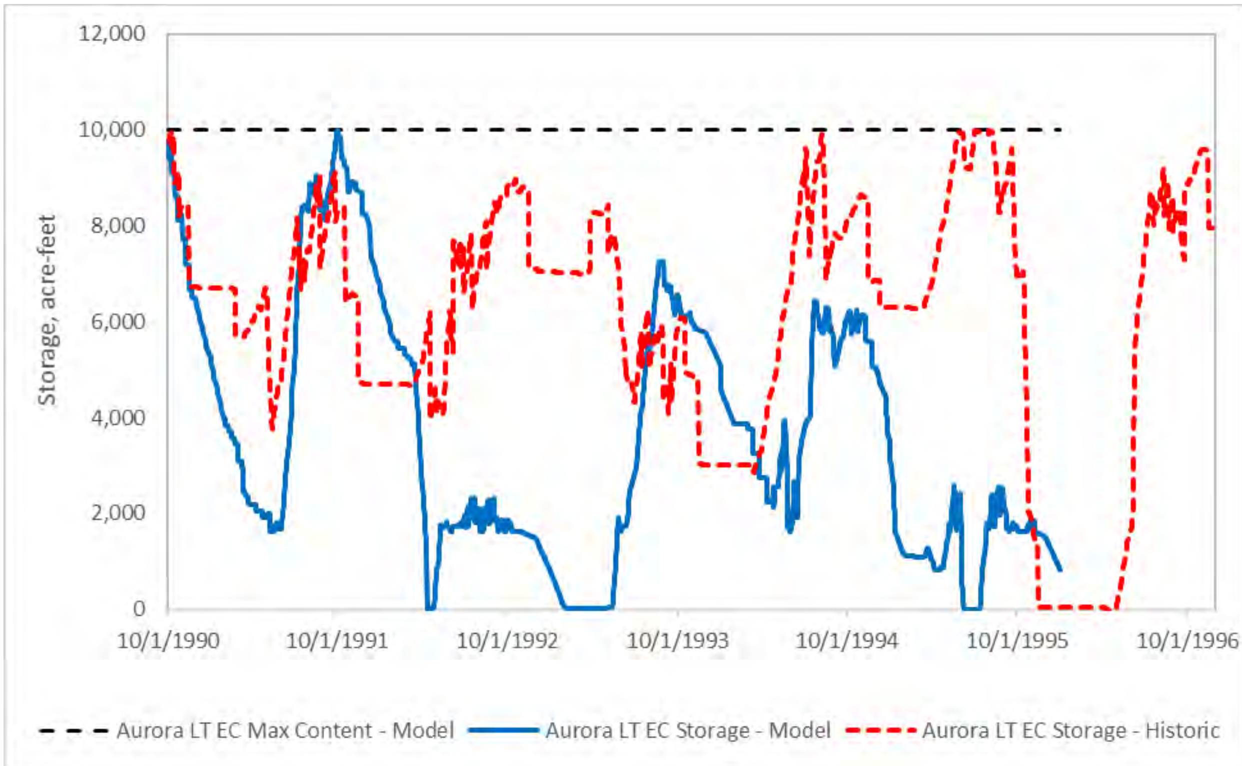

Figure 5: Aurora Long-Term Excess Capacity Storage, 2011-2015 Current Conditions Run.

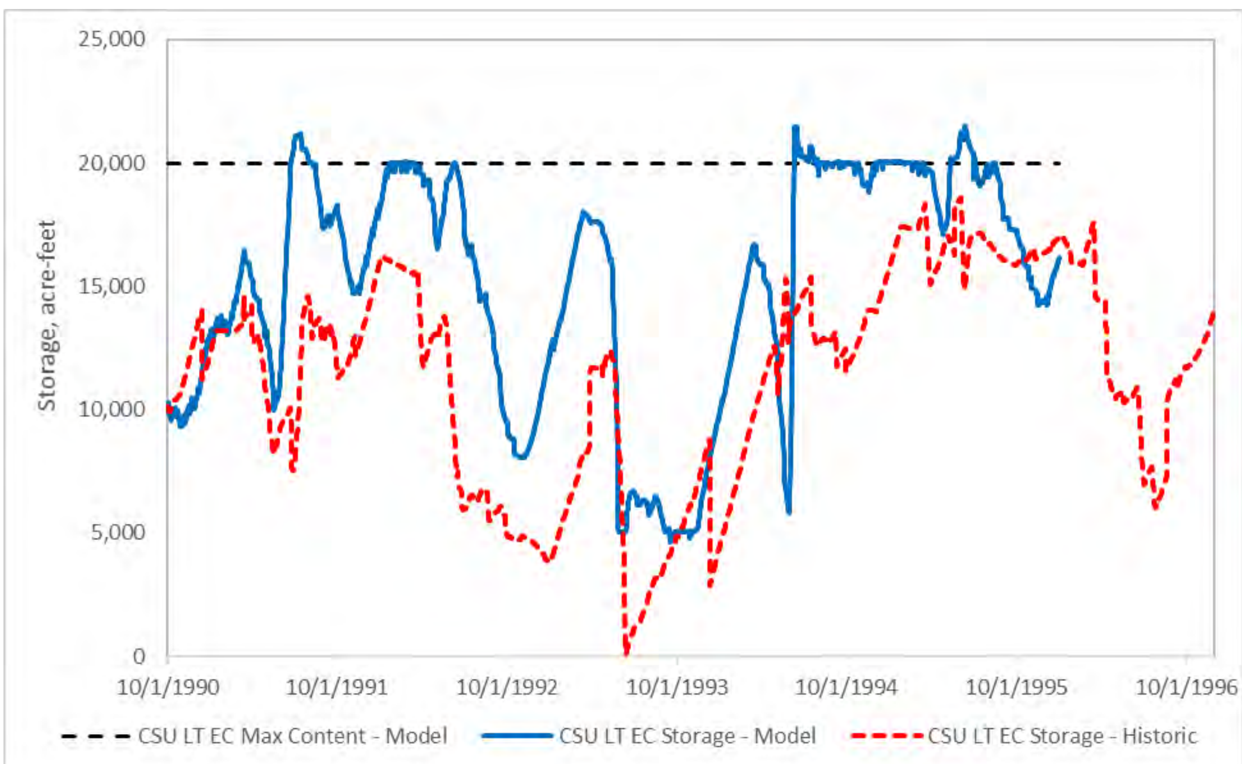

Figure 6: CSU Long-Term Excess Capacity Storage, 2011-2015 Current Conditions Run.

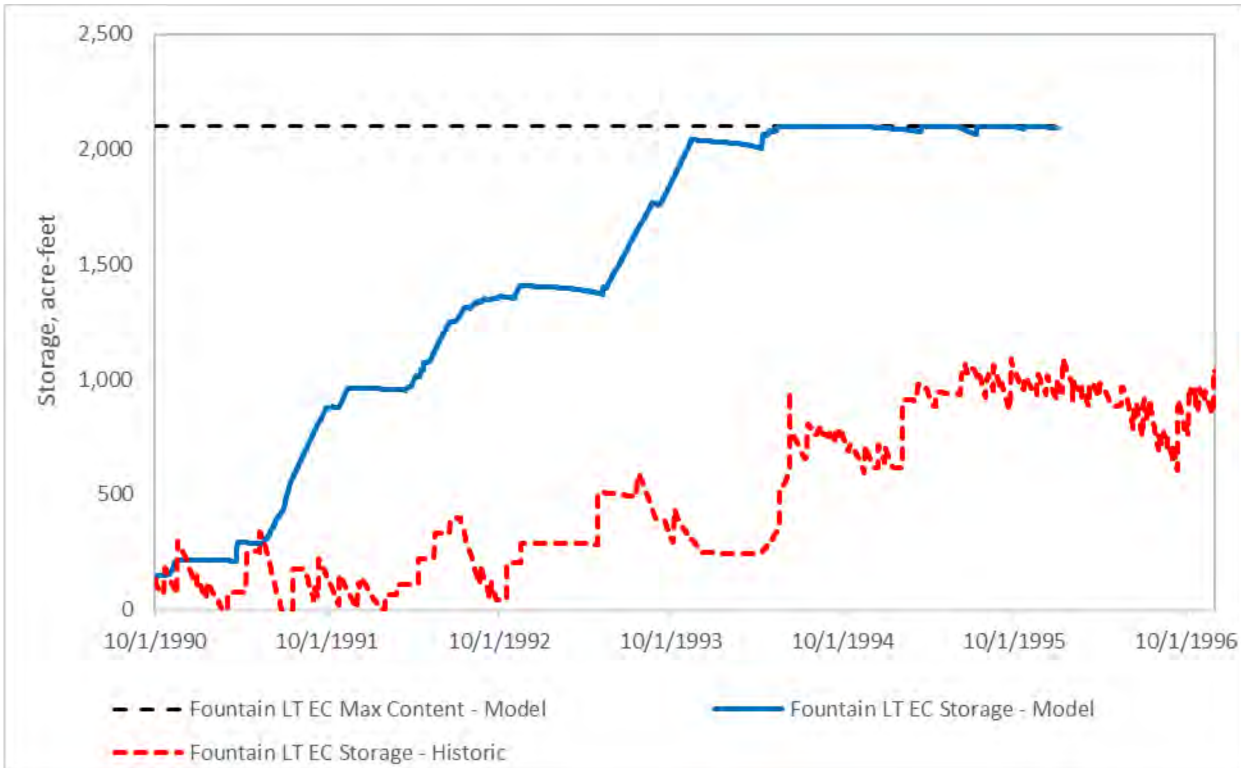

Figure 7: Fountain Long-Term Excess Capacity Storage, 2011-2015 Current Conditions Run.

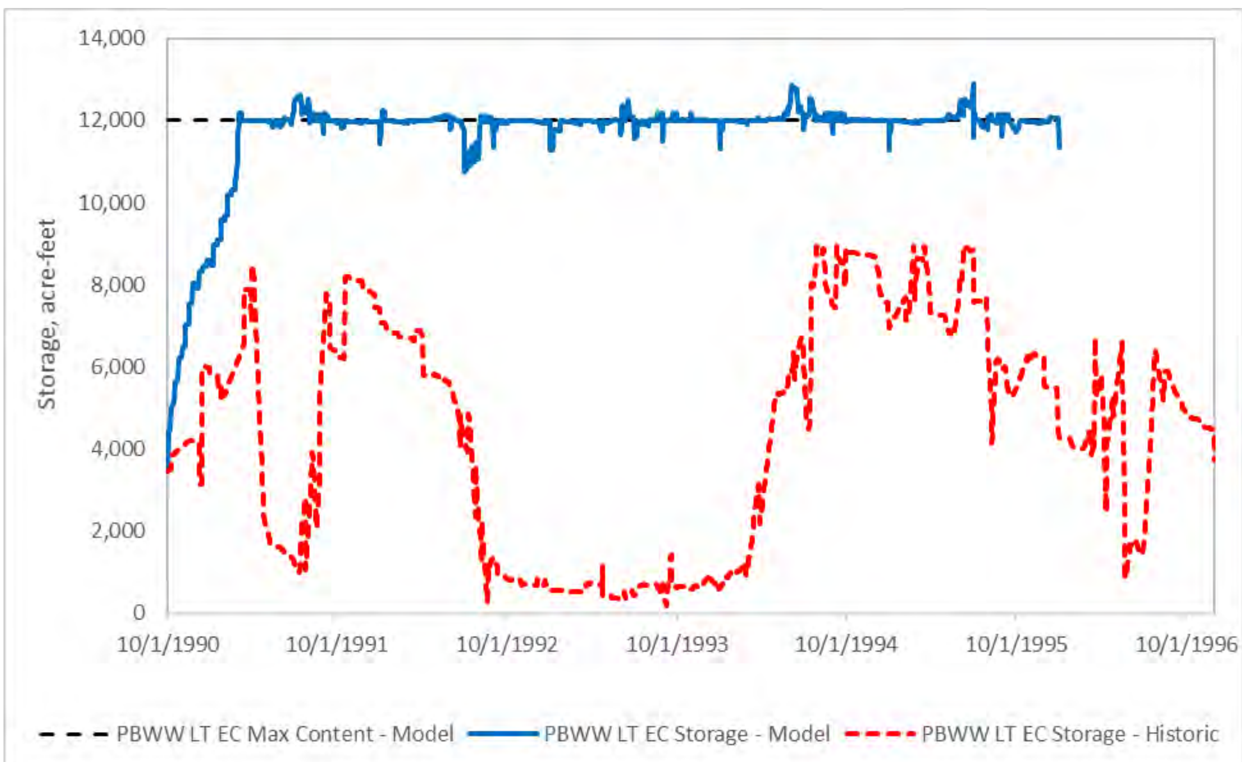

Figure 8: PBWW Long-Term Excess Capacity Storage, 2011-2015 Current Conditions Run.

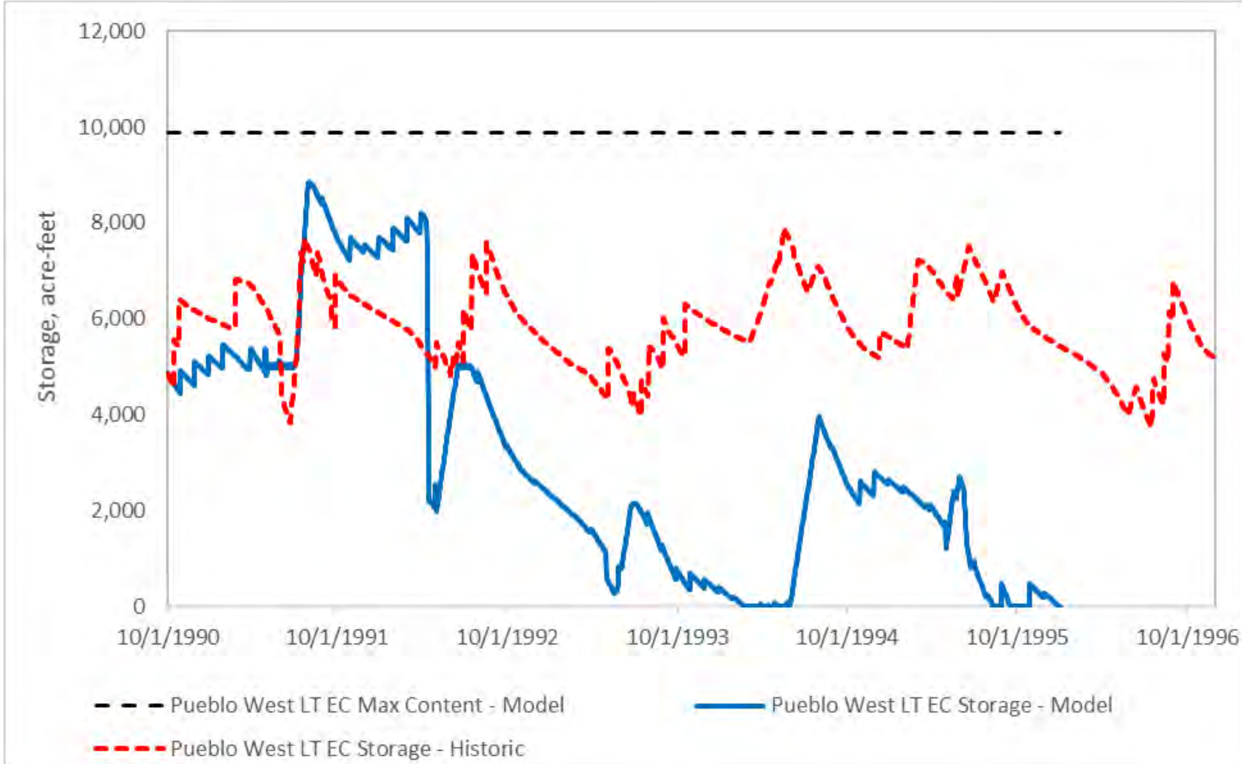

Figure 9: Pueblo West Long-Term Excess Capacity Storage, 2011-2015 Current Conditions Run.

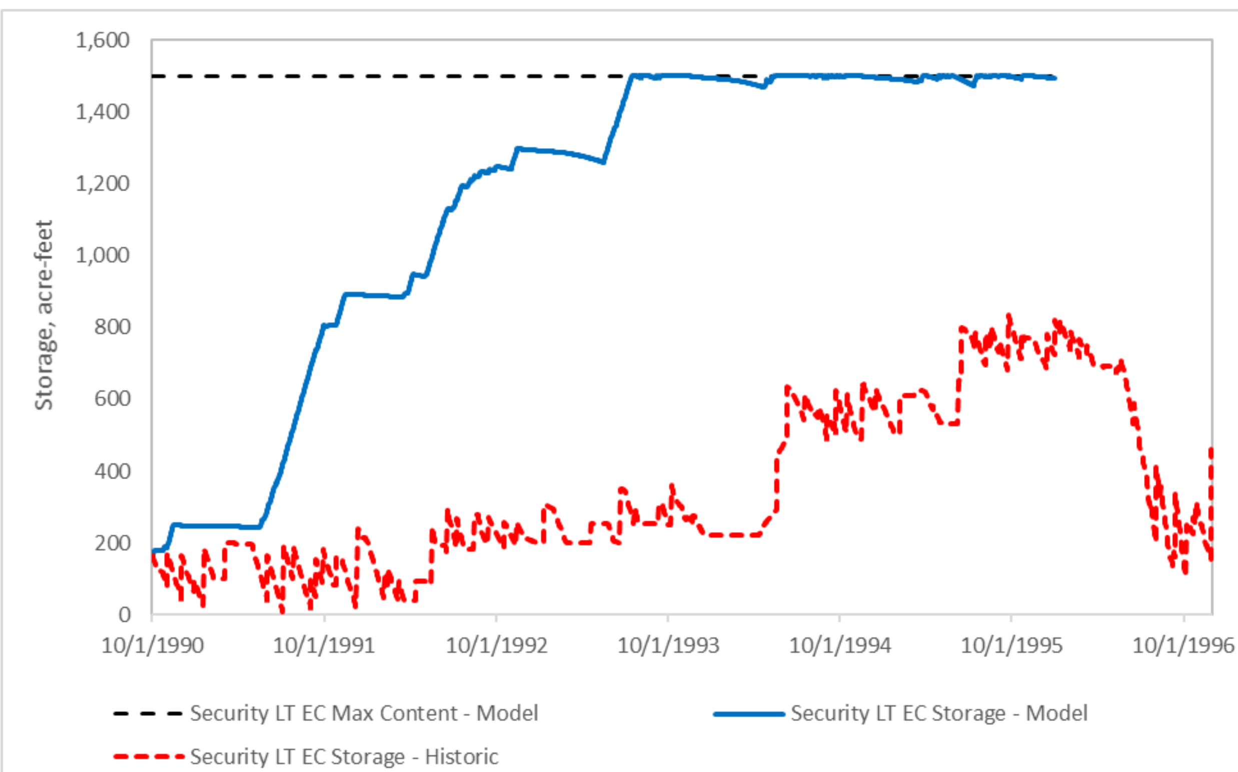

Figure 10: Security Long-Term Excess Capacity Storage, 2011-2015 Current Conditions Run.

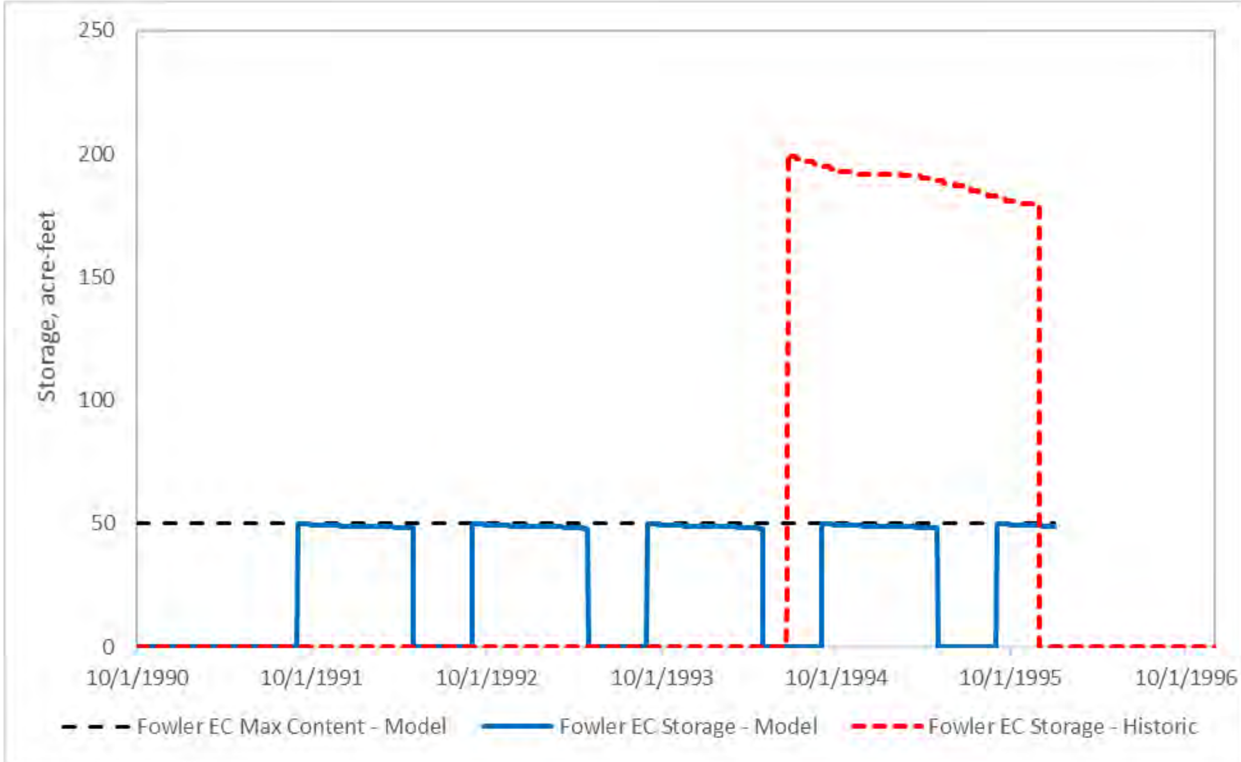

Figure 11: Fowler (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

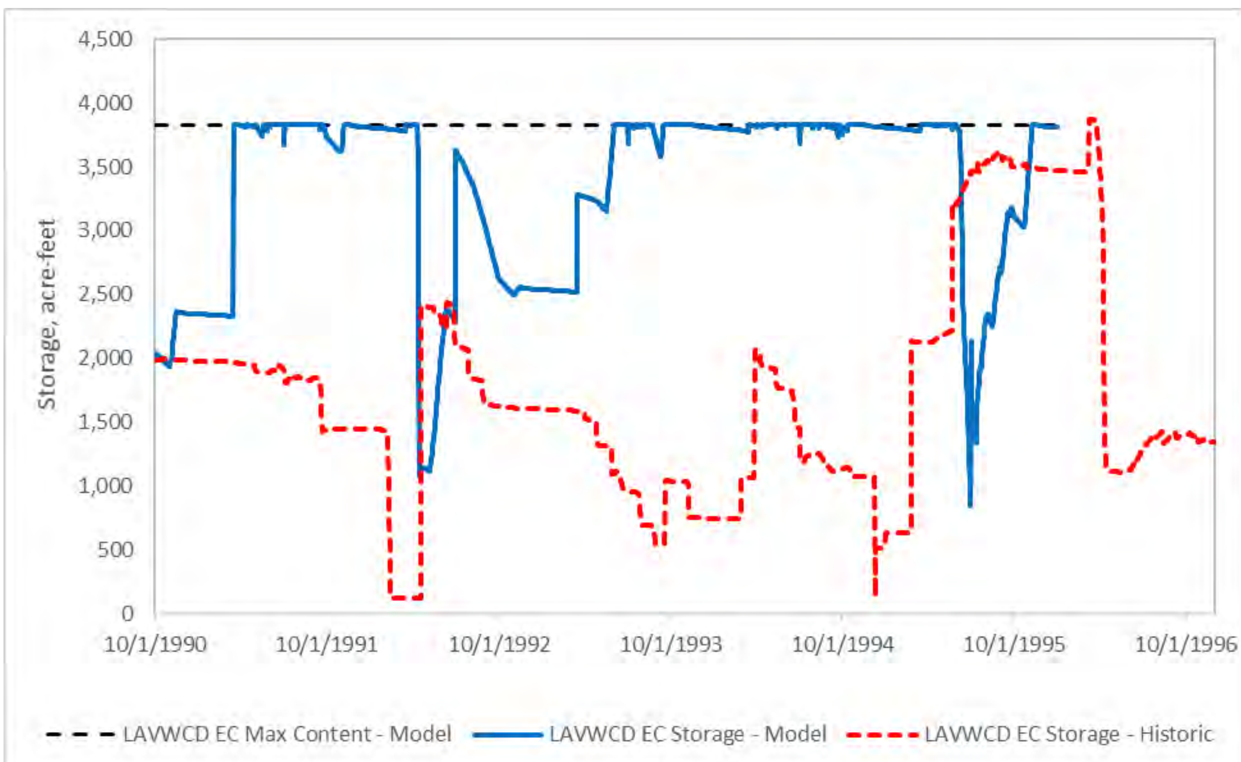

Figure 12: LAVWCD (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

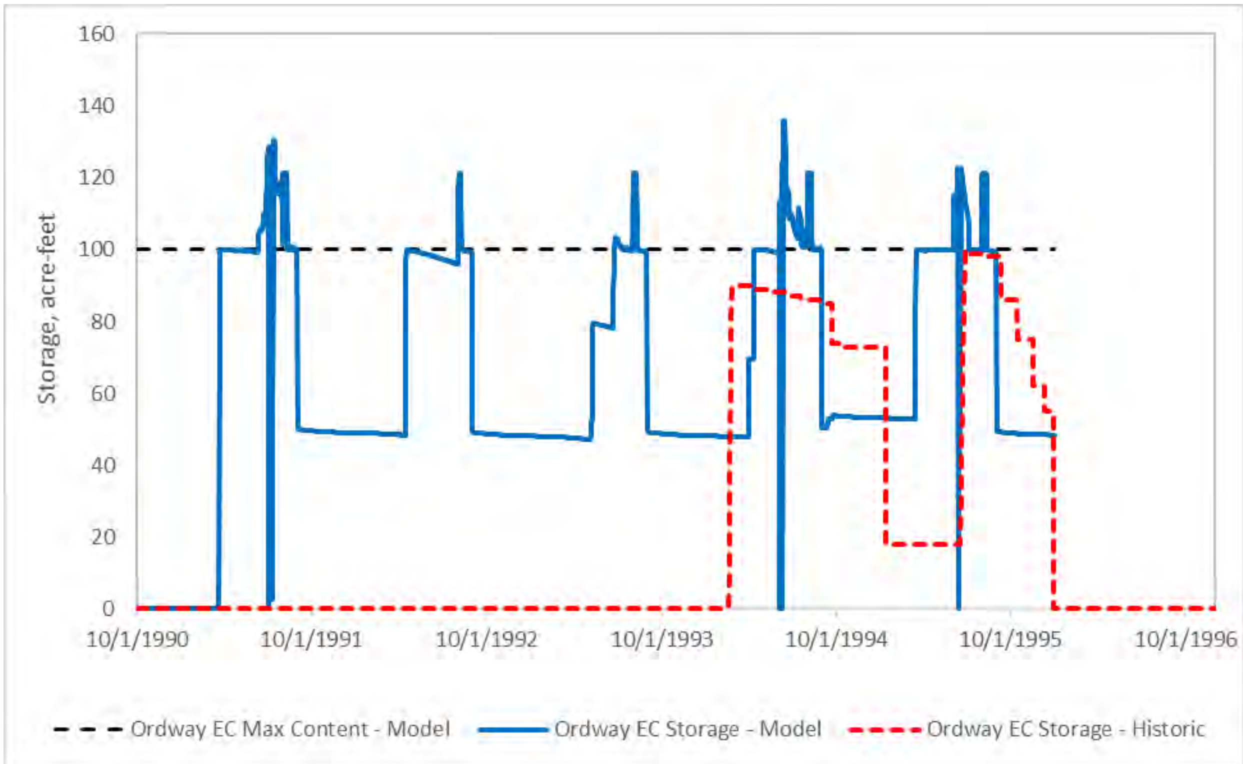

Figure 13: Ordway (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

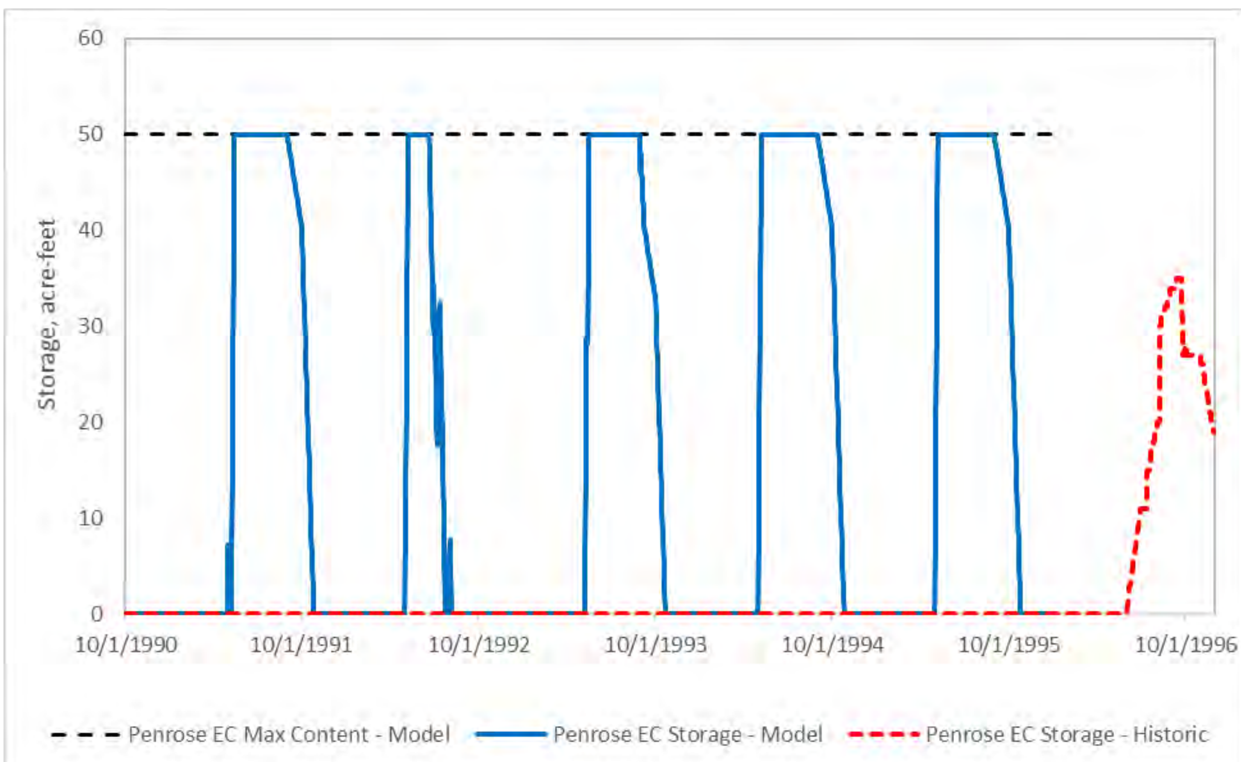

Figure 14: Penrose (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

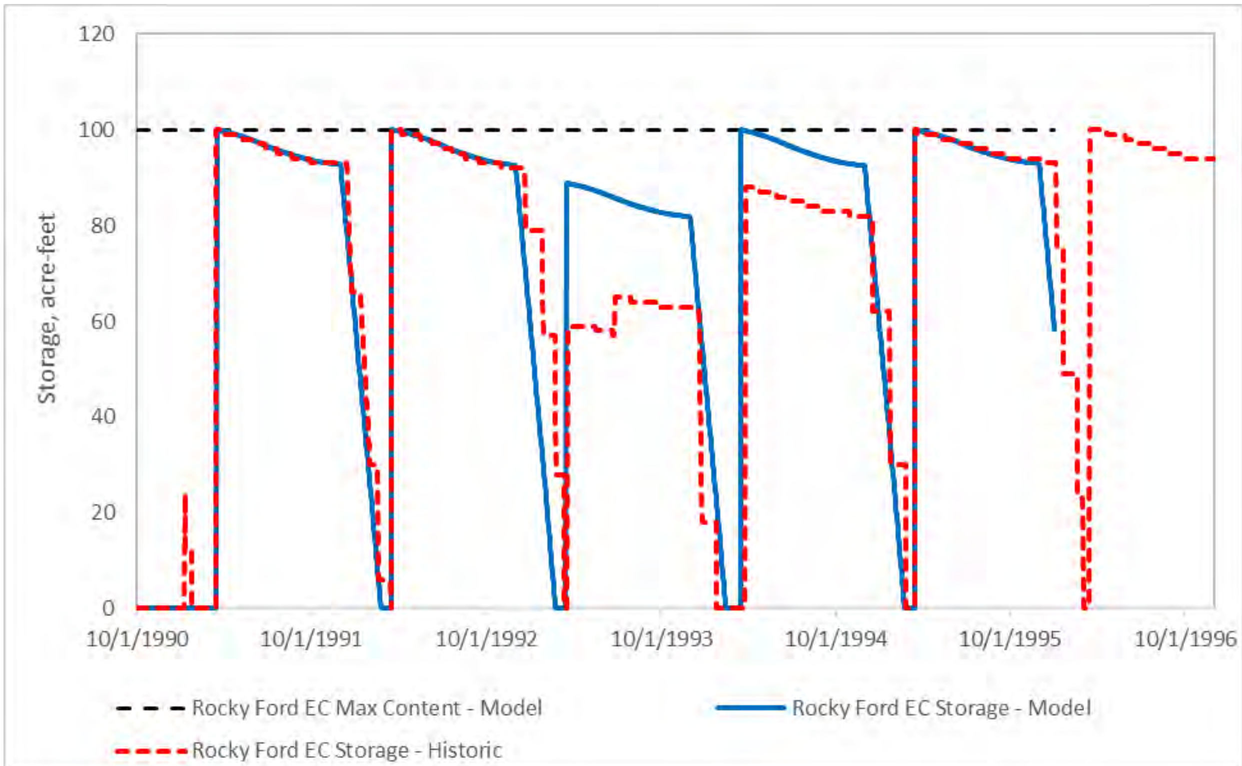

Figure 15: Rocky Ford (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

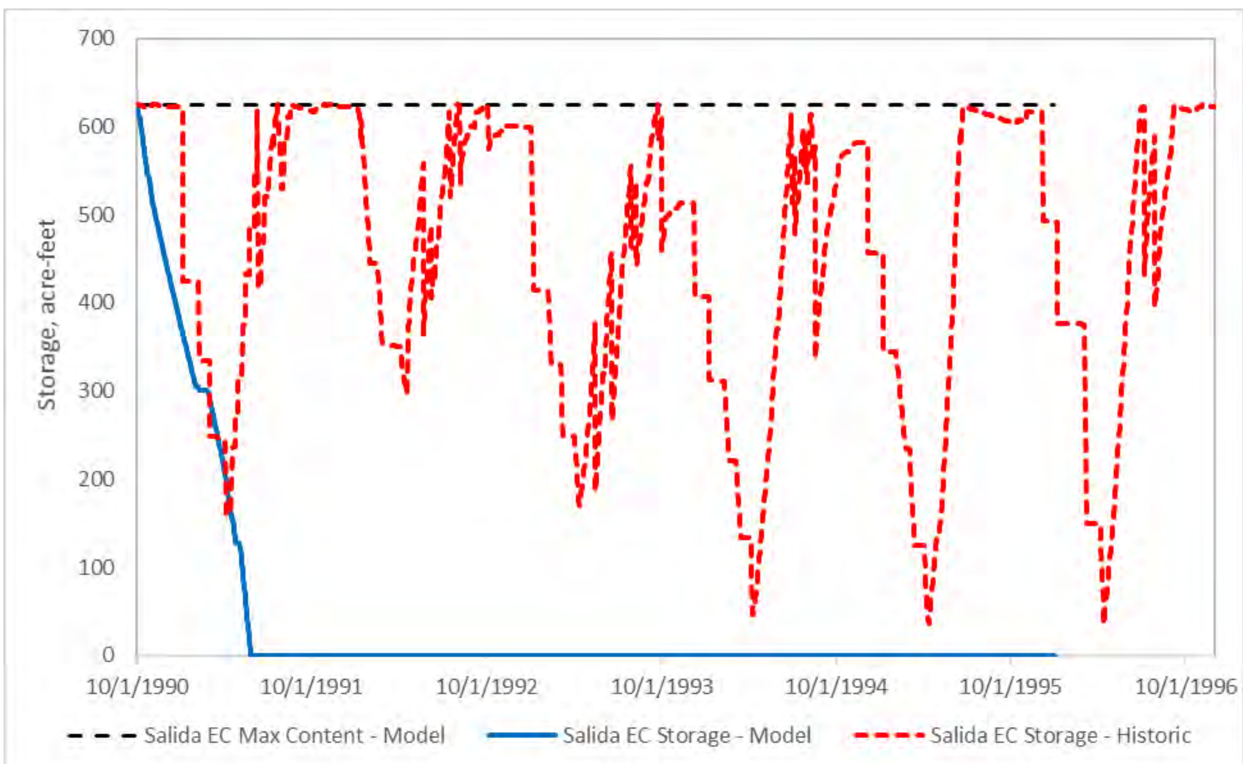

Figure 16: Salida (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

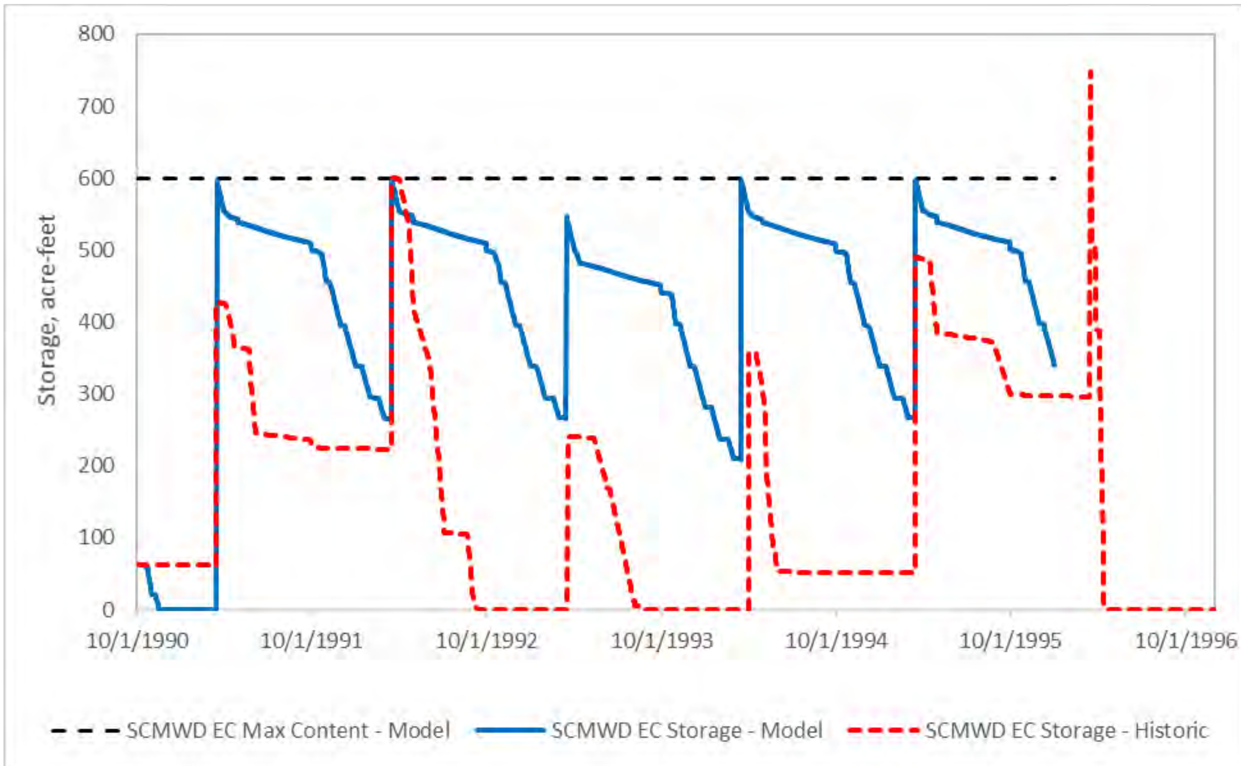

Figure 17: SCMWD (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

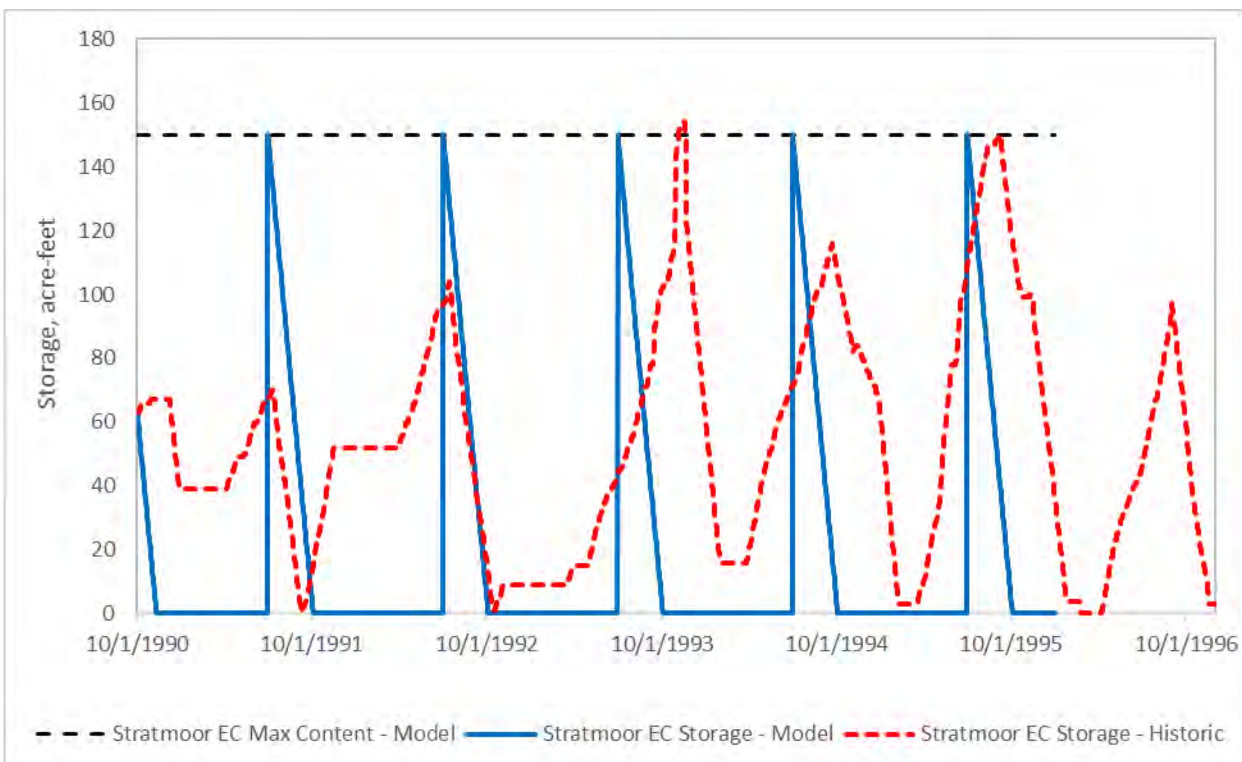

Figure 18: Stratmoor (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

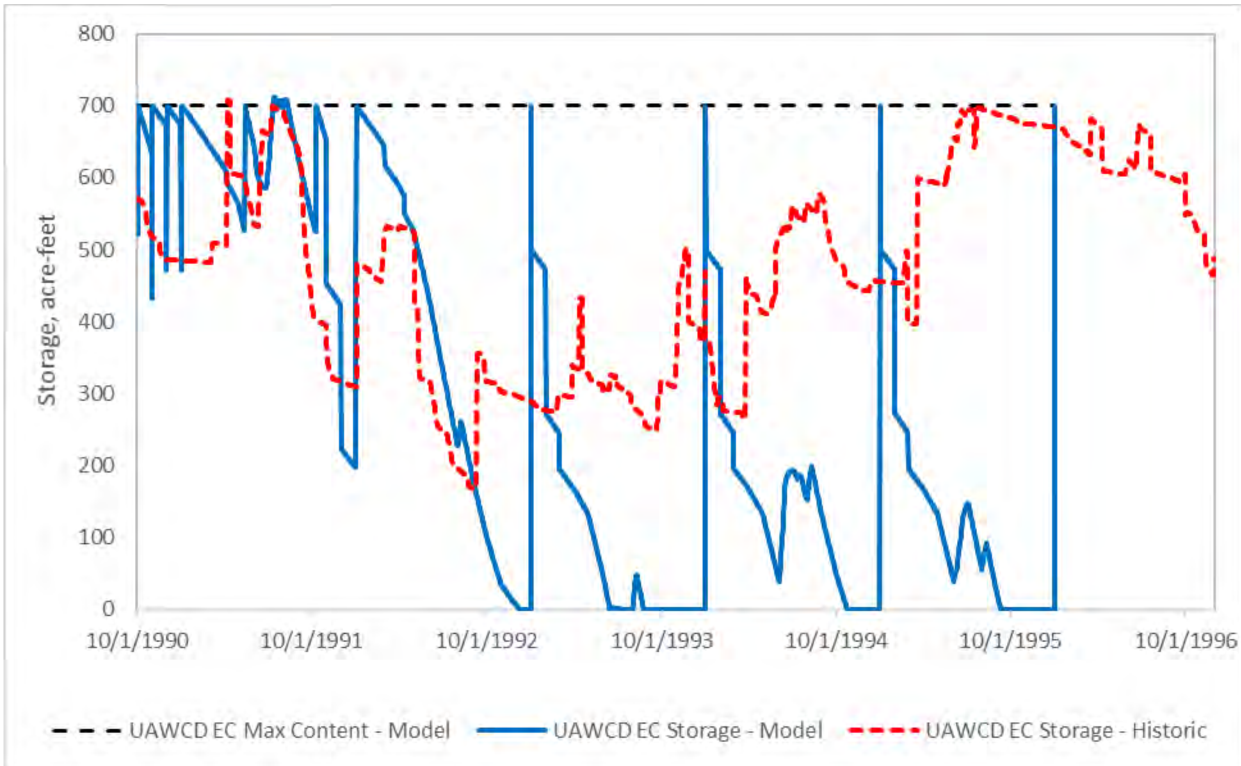

Figure 19: UAWCD (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

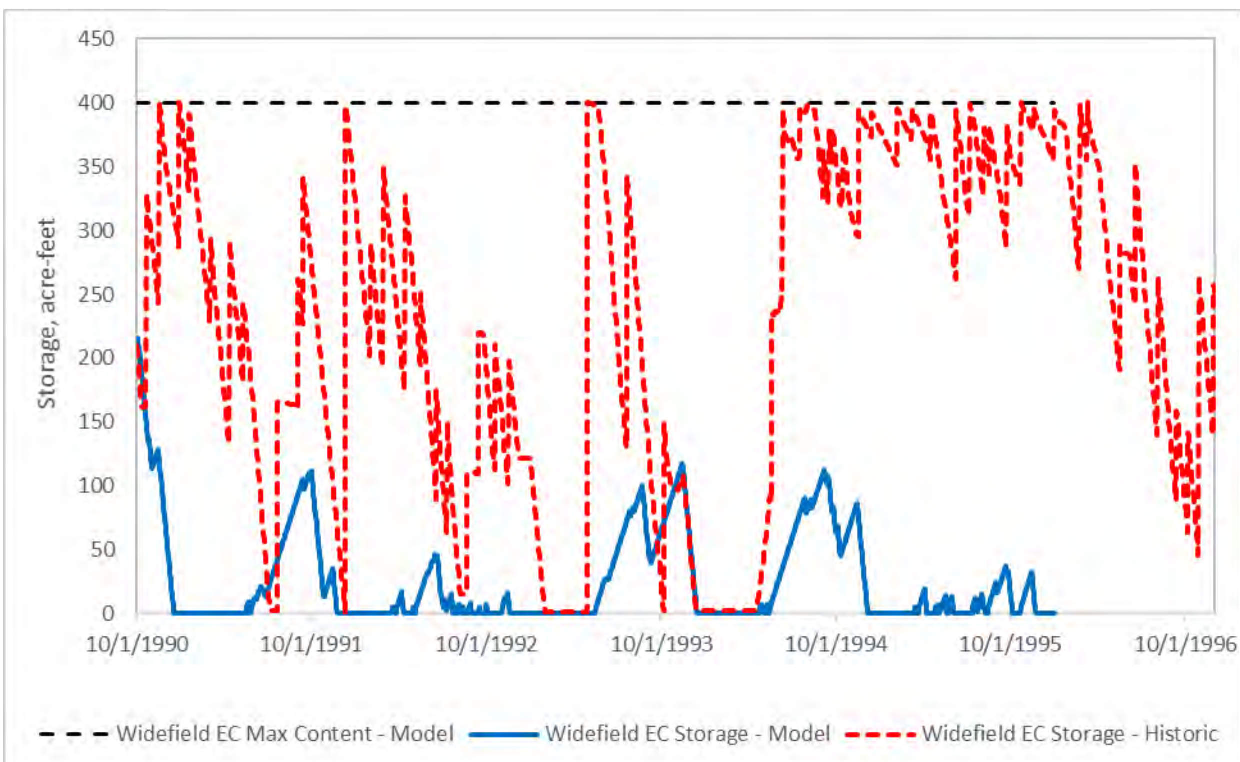

Figure 20: Widefield (Master Contract) Excess Capacity Storage, 2011-2015 Current Conditions Run.

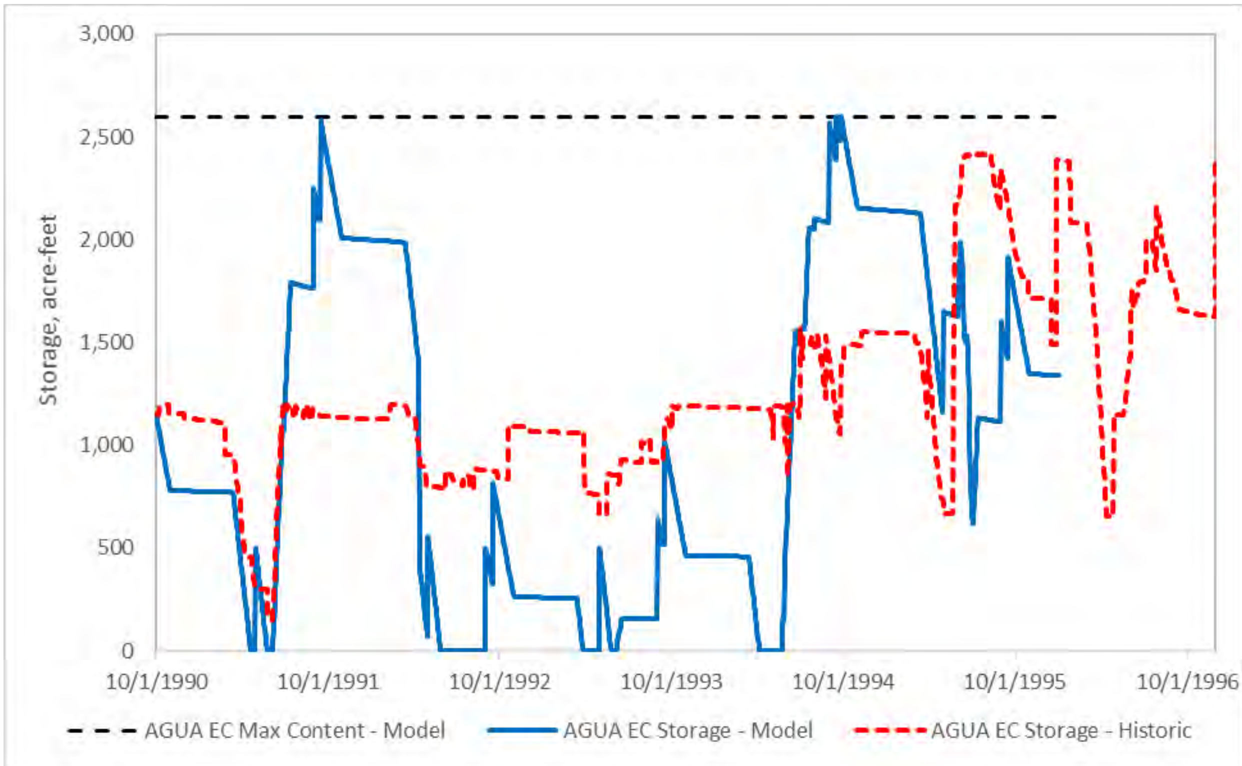

Figure 21: AGUA (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

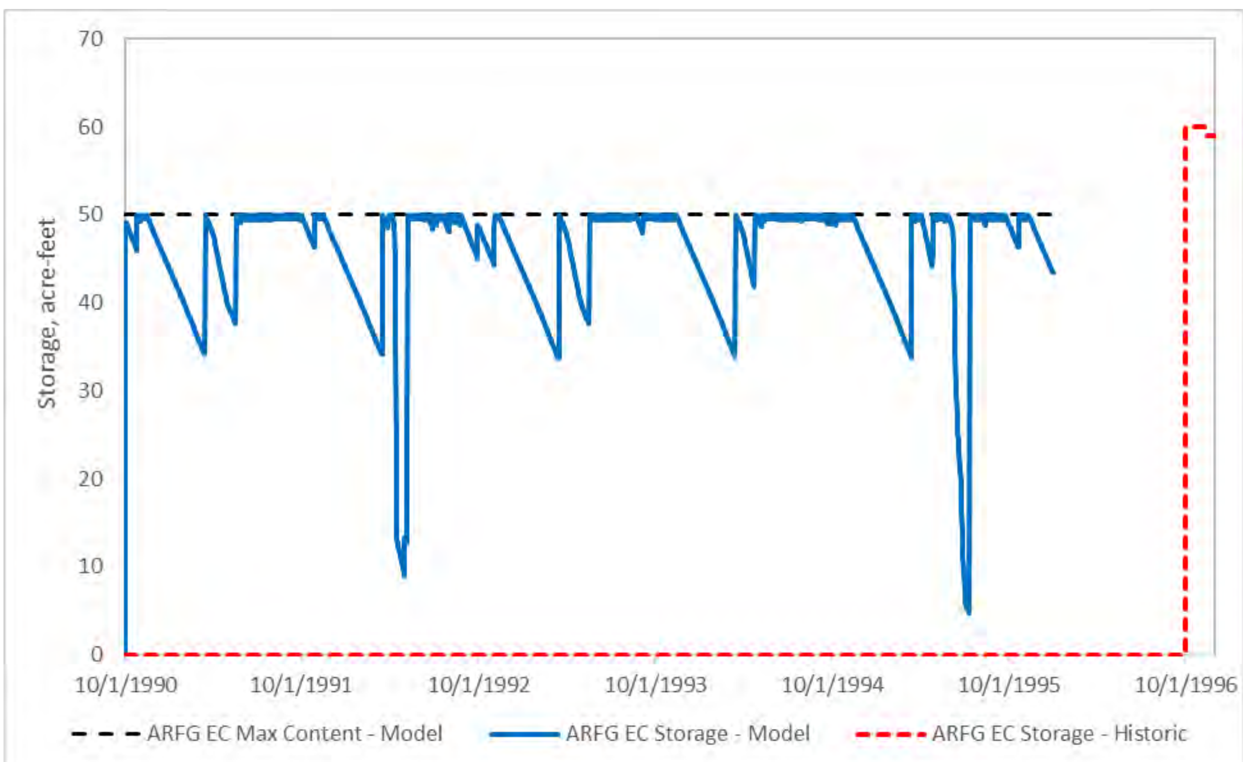

Figure 22: ARFG (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

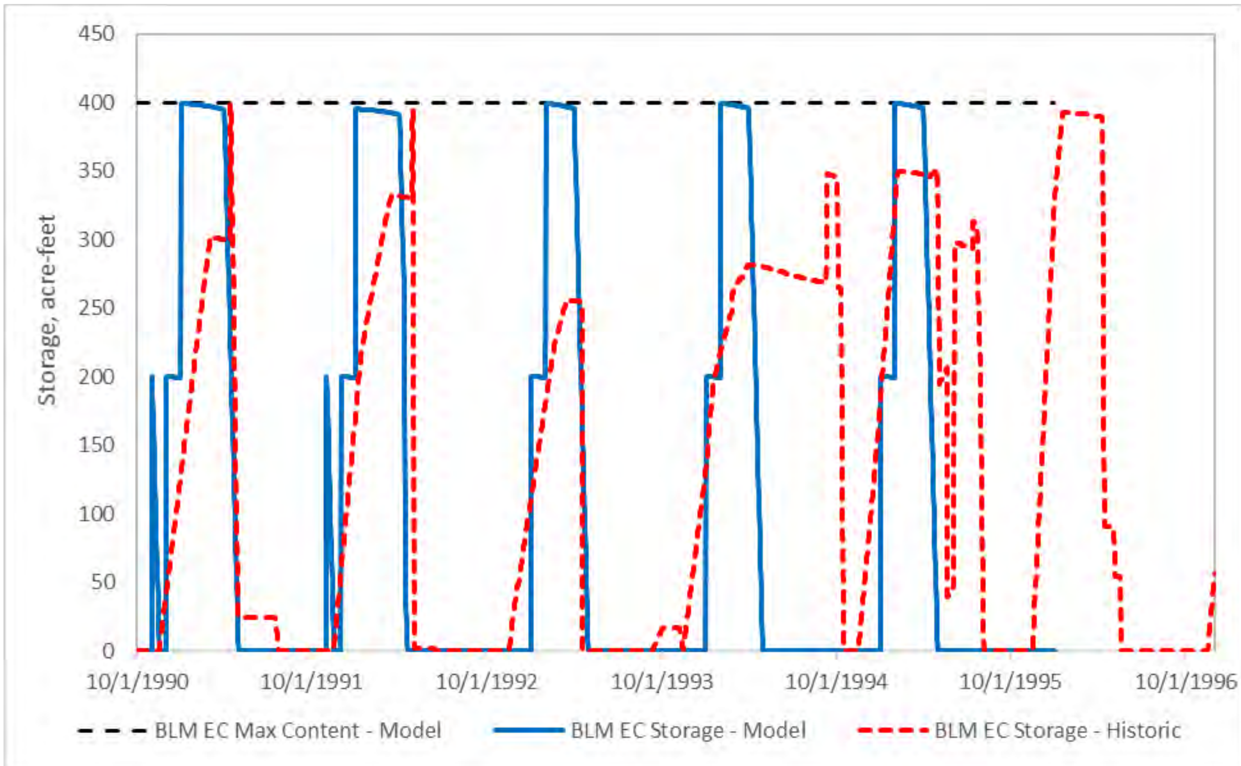

Figure 23: BLM (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

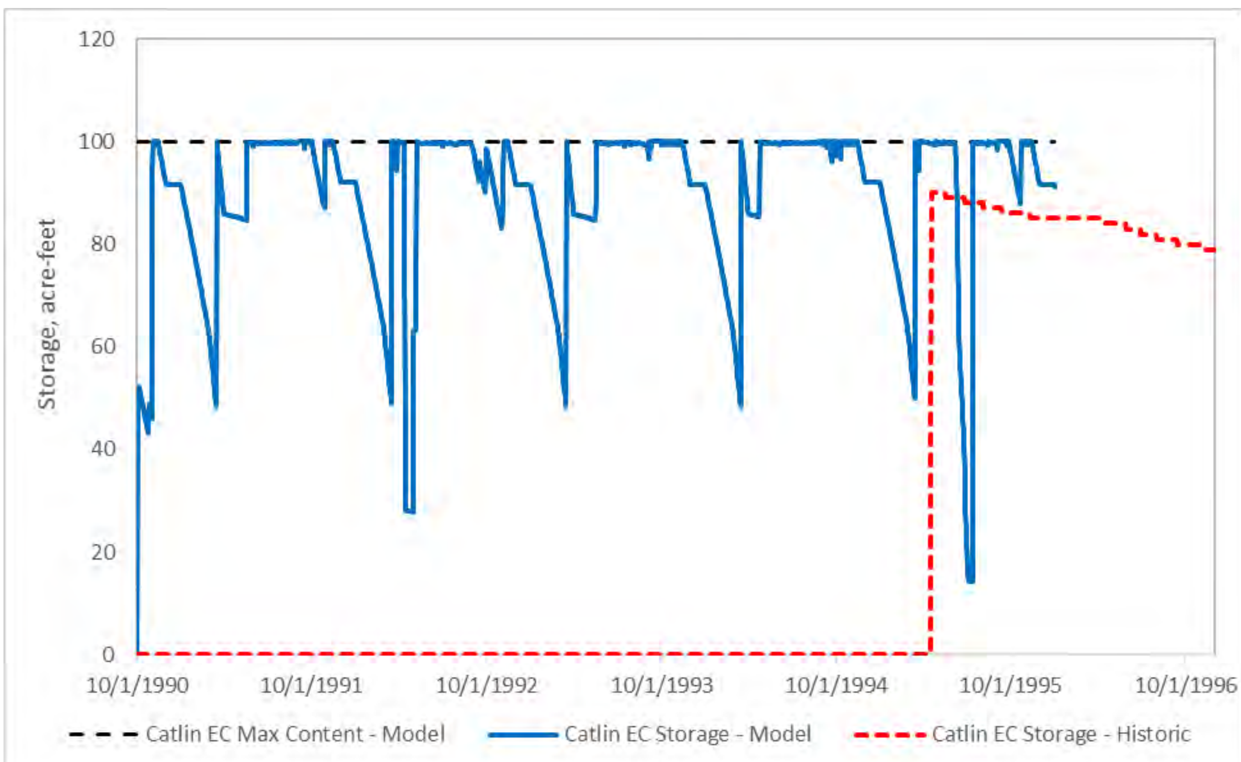

Figure 24: Catlin (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

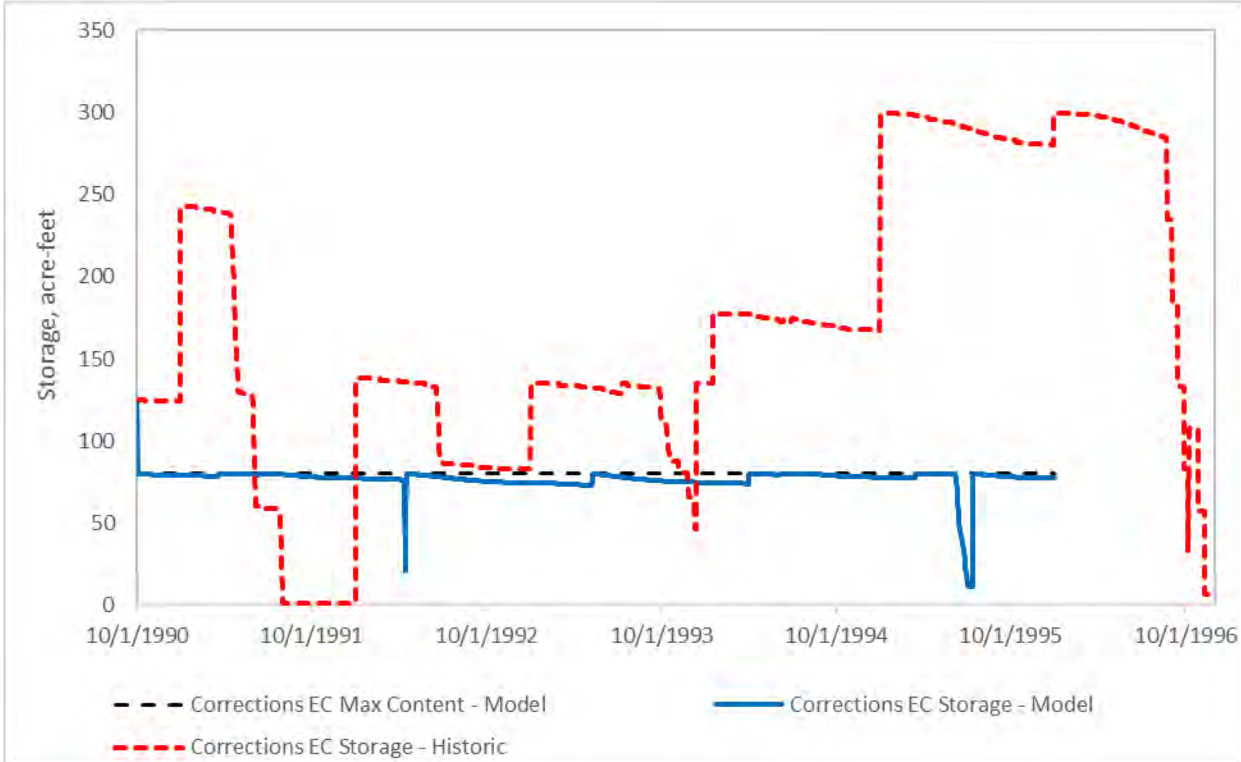

Figure 25: Corrections (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

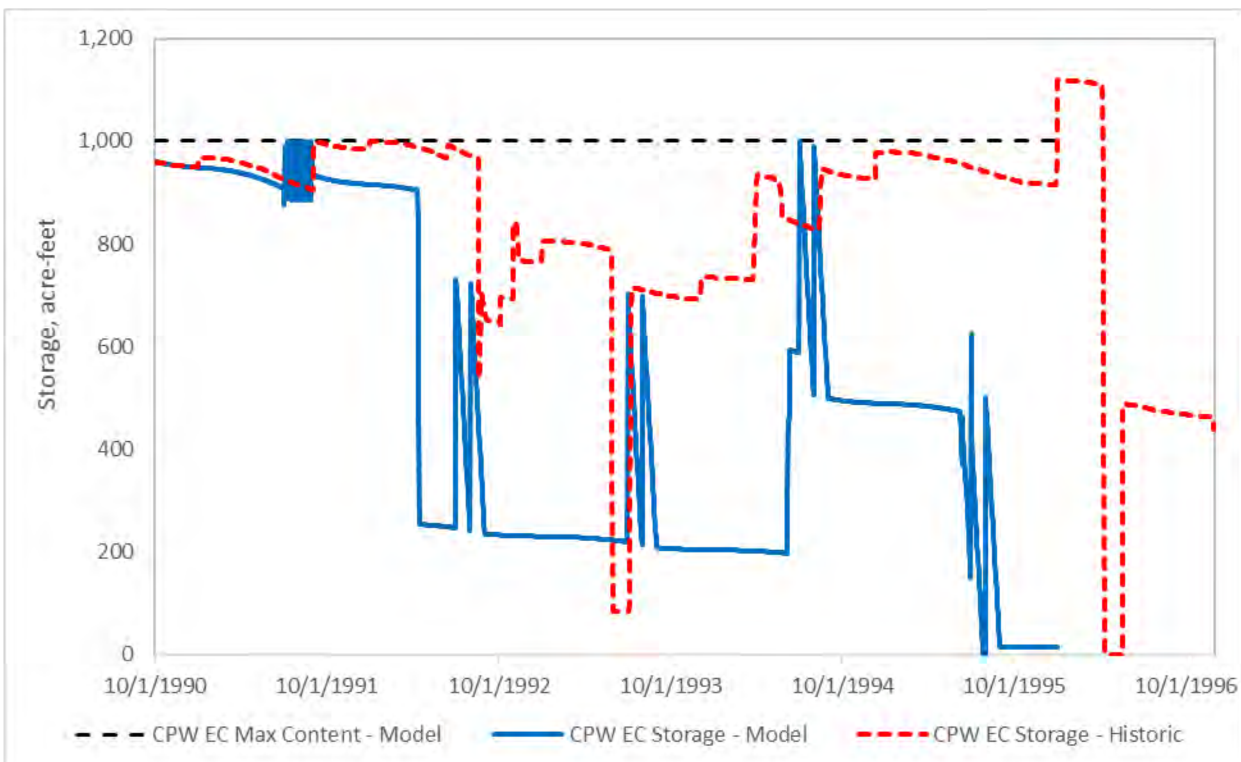

Figure 26: CPW (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

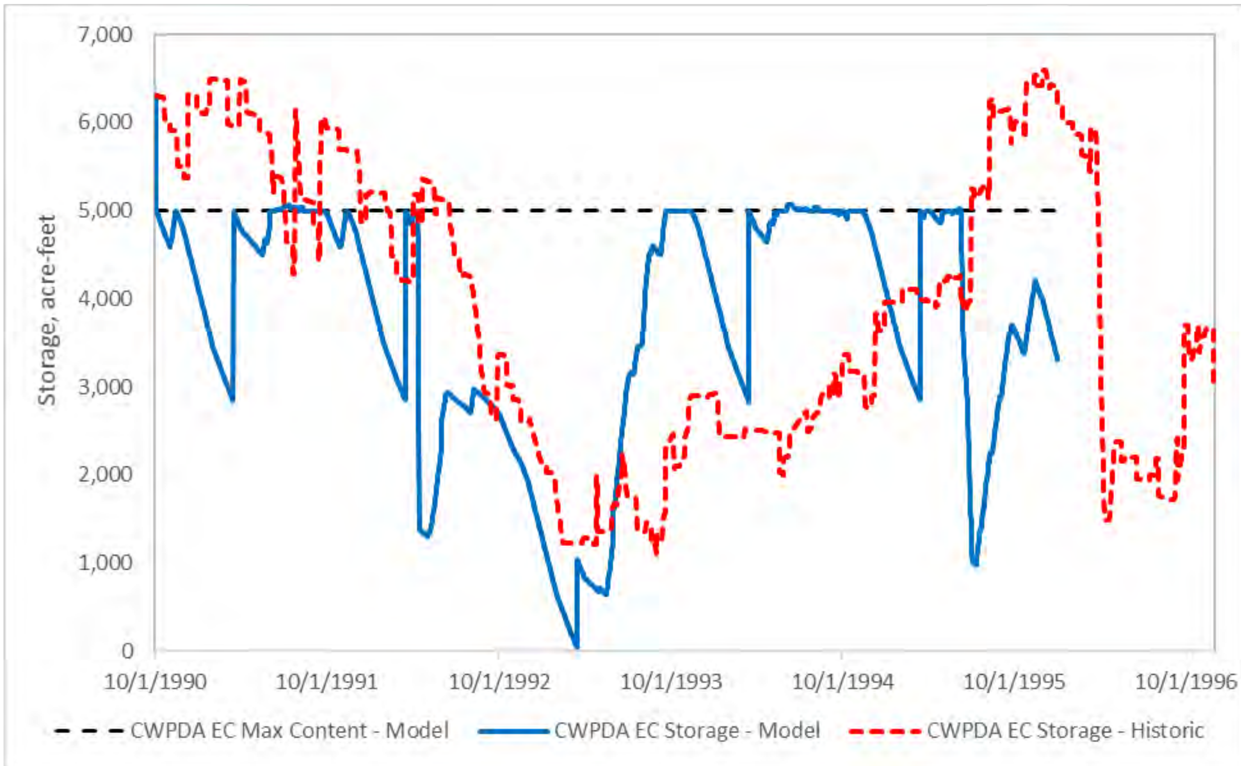

Figure 27: CWPDA (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

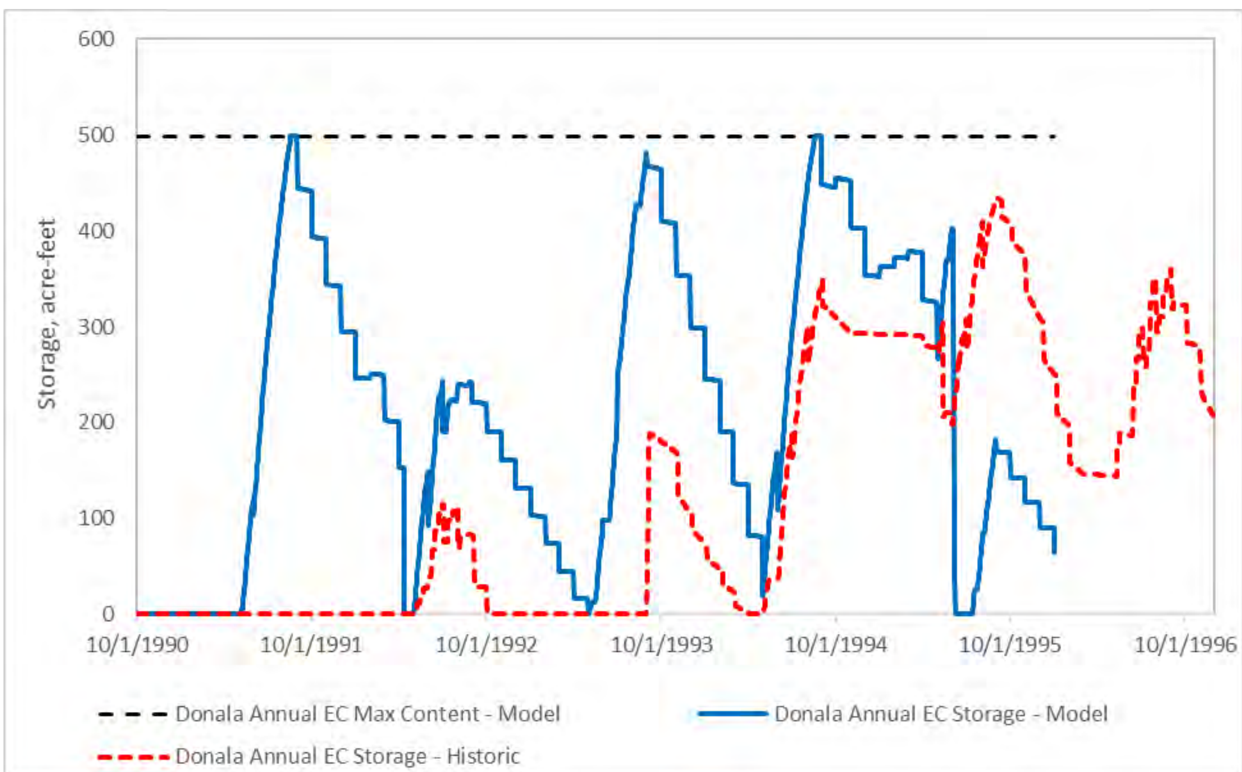

Figure 28: Donala (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

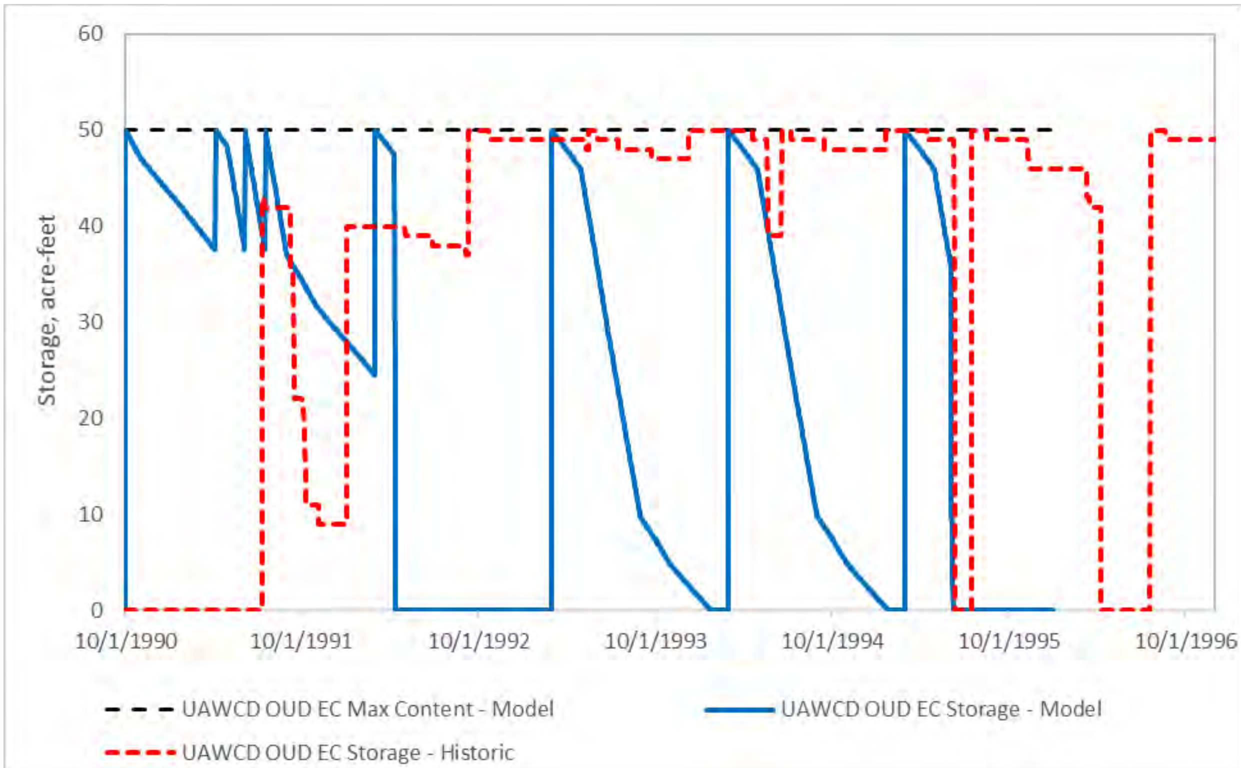

Figure 29: UAWCD OUD (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

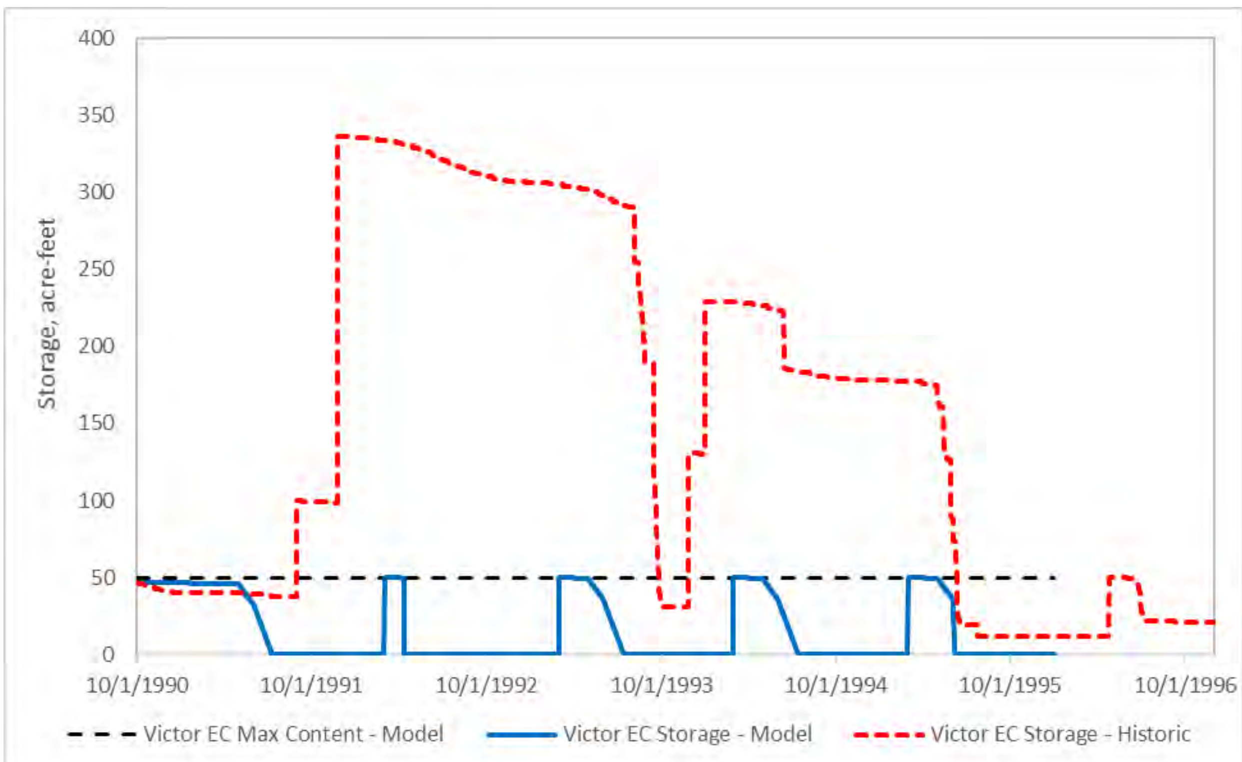

Figure 30: Victor (Annual) Excess Capacity Storage, 2011-2015 Current Conditions Run.

APPENDIX B: LIST OF SIMULATED WATER RIGHTS

This appendix contains basic summary tables showing all simulated water rights within the FryArk RiverWare model. Both direct flow and storage water rights are included. Please note that the water right rate shown is only the base water right request and may not be reflective of the full decreed water right rate and will also not reflect many other potential simulated limits, criteria, or other water right rate adjustments. Additional, detailed information can be found in the model.

LIST OF WATER RIGHT TABLES

Table 1: Simulated Arkansas River Water Rights

Simulated Water User	Water Right Priority Date	Base Water Right Rate, cfs
Dist 11 Above Lake Fork	12/31/1871	1.5
Dist 11 Above Lake Fork	5/15/1874	3
Dist 11 Above Lake Fork	5/20/1875	3.43
Dist 11 Above Lake Fork	7/1/1875	5
Dist 11 Above Lake Fork	5/15/1879	3.01
Dist 11 Above Lake Fork	5/15/1881	0.66
Dist 11 Above Lake Fork	5/1/1882	8
Dist 11 Above Lake Fork	6/15/1887	4
Dist 11 Above Lake Fork	6/16/1887	5
Dist 11 Above Lake Creek	6/25/1877	5
Dist 11 Above Lake Creek	5/15/1879	14
Dist 11 Above Lake Creek	5/5/1880	16
Dist 11 Above Lake Creek	3/10/1881	2
Dist 11 Above Lake Creek	4/15/1881	1.6
Dist 11 Above Lake Creek	4/30/1881	0.8
Dist 11 Above Lake Creek	5/31/1881	1.3
Dist 11 Above Lake Creek	11/30/1881	1
Dist 11 Above Lake Creek	4/30/1882	1.6
Dist 11 Above Lake Creek	6/19/1890	7
Otero Pipeline	5/15/1879	1.62
Otero Pipeline	5/15/1881	0.08
Dist 11 Lake Creek to Buena Vista	11/1/1872	3
Dist 11 Lake Creek to Buena Vista	9/8/1880	4.23
Dist 11 Lake Creek to Buena Vista	2/22/1882	0.95
Dist 11 Lake Creek to Buena Vista	10/23/1882	6.2
Dist 11 Lake Creek to Buena Vista	8/9/1883	9
Dist 11 Lake Creek to Buena Vista	7/6/1888	16
Dist 11 Buena Vista to Salida	5/1/1872	5
Dist 11 Buena Vista to Salida	12/31/1875	16
Dist 11 Buena Vista to Salida	3/1/1882	1
Dist 11 Buena Vista to Salida	5/1/1882	20
Dist 11 Buena Vista to Salida	9/28/1882	5
Dist 11 Buena Vista to Salida	1/3/1884	14.17
Dist 11 Buena Vista to Salida	11/27/1886	19
Dist 11 Buena Vista to Salida	3/1/1890	6
Dist 11 Buena Vista to Salida	6/20/1890	3
Dist 11 Buena Vista to Salida	10/1/1891	25
Dist 11 Buena Vista to Salida	1/1/1892	16
Dist 11 Buena Vista to Salida	12/31/1898	3.7
Dist 11 Buena Vista to Salida	5/3/1918	3
Rogers Ditch	3/1/1873	2
Canon City MI	12/30/1863	19
Canon City MI	8/13/1864	3.5

Canon City MI	11/1/1872	4.68
Canon City Hydraulic Ditch	12/30/1863	77
South Canon Ditch	5/1/1862	2
South Canon Ditch	2/28/1866	12.91
South Canon Ditch	5/31/1866	1
South Canon Ditch	10/1/1880	3.4
South Canon Ditch	3/4/1882	3
South Canon Ditch	5/31/1882	23.2
South Canon Ditch	8/31/1904	3
Minnequa Canal	7/22/1861	2
Minnequa Canal	11/30/1861	43.53
Minnequa Canal	12/31/1863	48
Minnequa Canal	12/31/1864	20
Minnequa Canal	12/15/1881	5.7
Minnequa Canal	2/13/1890	1.64
Minnequa Canal	2/24/1933	150
Florence	11/30/1861	4.47
Florence	5/31/1866	1
Florence	5/31/1867	0.5
Florence	5/31/1870	0.5
Florence	6/21/1870	3.5
Florence	9/30/1870	0.5
Florence	4/29/1873	0.5
Florence	6/1/1873	0.5
Florence	3/31/1883	0.5
Florence	3/5/1884	1
Florence	12/31/1890	0.67
Florence	2/28/1898	3.5
Other Dist 12	5/1/1861	1.05
Other Dist 12	5/1/1862	17
Other Dist 12	8/31/1863	1.6
Other Dist 12	5/31/1864	10.46
Other Dist 12	5/31/1867	14.27
Other Dist 12	5/31/1870	0.5
Other Dist 12	4/1/1875	3.5
Other Dist 12	6/30/1875	2
Other Dist 12	9/12/1878	3.8
Other Dist 12	1/30/1881	1
Other Dist 12	2/28/1881	0.56
Other Dist 12	3/1/1881	1.5
Other Dist 12	6/30/1883	1
Other Dist 12	4/15/1884	1
Other Dist 12	4/1/1885	1
Other Dist 12	3/20/1886	1
Other Dist 12	5/31/1886	0.24
Other Dist 12	4/1/1887	3.6

Other Dist 12	5/31/1887	0.28
Other Dist 12	5/31/1891	0.41
Other Dist 12	3/15/1902	11.5
Other Dist 12	4/23/1903	3.5
Penrose	12/31/1877	1.71
Penrose	5/31/1883	6.85
Pueblo Res Divs:Bessemer Ditch	4/1/1861	2
Pueblo Res Divs:Bessemer Ditch	12/31/1861	20
Pueblo Res Divs:Bessemer Ditch	5/31/1864	3.74
Pueblo Res Divs:Bessemer Ditch	6/30/1866	3
Pueblo Res Divs:Bessemer Ditch	1/8/1867	2.5
Pueblo Res Divs:Bessemer Ditch	5/31/1867	5.13
Pueblo Res Divs:Bessemer Ditch	11/30/1870	1.47
Pueblo Res Divs:Bessemer Ditch	12/31/1870	3.4
Pueblo Res Divs:Bessemer Ditch	9/18/1873	2
Pueblo Res Divs:Bessemer Ditch	12/31/1876	3
Pueblo Res Divs:Bessemer Ditch	12/31/1878	0.41
Pueblo Res Divs:Bessemer Ditch	5/4/1881	14
Pueblo Res Divs:Bessemer Ditch	6/20/1881	2
Pueblo Res Divs:Bessemer Ditch	3/31/1882	8
Pueblo Res Divs:Bessemer Ditch	5/1/1887	322
Pueblo Res Divs:PBWW Pipeline	4/1/1861	7
Pueblo Res Divs:PBWW Pipeline	4/1/1864	8
Pueblo Res Divs:PBWW Pipeline	3/21/1870	2.5
Pueblo Res Divs:PBWW Pipeline	11/30/1870	1.03
Pueblo Res Divs:PBWW Pipeline	1/31/1871	1.2
Pueblo Res Divs:PBWW Pipeline	3/31/1871	1.6
Pueblo Res Divs:PBWW Pipeline	12/31/1871	1
Pueblo Res Divs:PBWW Pipeline	3/21/1872	4.6
Pueblo Res Divs:PBWW Pipeline	4/1/1872	1.16
Pueblo Res Divs:PBWW Pipeline	4/1/1874	45
Pueblo Res Divs:PBWW Pipeline	4/2/1874	0.96
Pueblo Res Divs:PBWW Pipeline	10/1/1878	0.58
Pueblo Res Divs:PBWW Pipeline	12/31/1878	0.29
Pueblo Res Divs:PBWW Pipeline	12/31/1881	2
Pueblo Res Divs:PBWW Pipeline	12/31/1883	0.39
Pueblo Res Divs:PBWW Pipeline	4/1/1886	2.46
Pueblo Res Divs:PBWW Pipeline	12/17/1887	14.44
Pueblo Res Divs:PBWW Pipeline	12/31/1888	1
Pueblo Res Divs:Pueblo West	3/31/1891	1.5
Pueblo Riverwalk	4/14/1926	200
SCMWD	7/31/1866	1.2
SCMWD	12/31/1866	1.2
SCMWD	12/31/1872	2.6
SCMWD	12/31/1873	0.15
SCMWD	12/31/1882	0.6

SCMWD	12/31/1884	0.6
SCMWD	12/31/1889	0.53
Riverside Dairy Ditch	1/1/1883	1
Excelsior Ditch	5/1/1887	20
Excelsior Ditch	1/6/1890	40
Collier Ditch	3/10/1887	4
Collier Ditch	5/1/1887	22
Colorado Canal:Colorado Canal Ag	6/8/1890	756.28
Colorado Canal:Lake Henry Div	12/31/1891	756.28
Colorado Canal:Lake Henry Div	9/10/1900	756.28
Colorado Canal:Lake Henry Div	6/15/1909	756.28
Colorado Canal:Lake Meredith Div	3/9/1898	756.28
High Line Canal	12/31/1861	40
High Line Canal	9/21/1867	0.6
High Line Canal	7/1/1869	16
High Line Canal	3/7/1884	32.5
High Line Canal	6/30/1885	30
High Line Canal	3/11/1886	2
High Line Canal	1/6/1890	378
High Line Canal	12/31/1890	2.5
Oxford Farmers Ditch	9/21/1867	13.4
Oxford Farmers Ditch	2/26/1887	116
Otero Canal	3/3/1890	123
Otero Canal	2/2/1903	334.92
Baldwin Stubbs Ditch	11/30/1907	22
Catlin Canal	4/10/1875	22
Catlin Canal	12/3/1884	226
Catlin Canal	11/14/1887	97
Holbrook Canal:Holbrook Canal Ag	9/25/1889	155
Holbrook Canal:Holbrook Canal Ag	8/30/1893	445
Holbrook Canal:Holbrook Res Div	3/2/1892	600
Holbrook Canal:Holbrook Res Div	10/10/1903	595
Holbrook Canal:Holbrook Res Div	9/15/1909	400
Holbrook Canal:Dye Res Div	10/10/1903	600
Holbrook Canal:Dye Res Div	9/3/1909	400
Holbrook Canal:Dye Res Div	9/15/1909	230
Rocky Ford Ditch	5/15/1874	111.76
Rocky Ford Ditch	5/6/1890	5.46
Potter Ditch	2/21/1890	4.25
Fort Lyon Storage Canal	1/25/1906	840
Fort Lyon Storage Canal	6/12/1908	840
Fort Lyon Storage Canal	12/29/1908	840
Fort Lyon Canal	4/15/1884	164.64
Fort Lyon Canal	3/1/1887	597.16
Fort Lyon Canal	8/31/1893	171.2
Fort Lyon Canal	8/1/1896	1150

LA Consolidated Ditch	4/10/1875	22.3
LA Consolidated Ditch	3/7/1884	5.5
LA Consolidated Ditch	12/3/1884	22
LA Consolidated Ditch	3/13/1888	80
LA Consolidated Ditch	4/15/1909	44.8
Fort Bent Canal	4/1/1886	27.09
Fort Bent Canal	3/10/1889	32.77
Fort Bent Canal	9/11/1889	11.7
Fort Bent Canal	8/12/1890	26.77
Fort Bent Canal	1/1/1893	50
Fort Bent Canal	12/31/1900	80
Keesee Ditch	3/13/1871	9
Keesee Ditch	12/31/1883	4.5
Keesee Ditch	9/3/1893	15
Amity Canal	2/21/1887	283.5
Amity Canal	4/1/1893	500
Lamar Canal	11/30/1875	15.75
Lamar Canal	11/4/1886	72.09
Lamar Canal	4/16/1887	13.64
Lamar Canal	7/16/1890	184.27
Hyde Ditch	5/10/1887	23.44
Manvel Canal	10/14/1890	54
XY Irrigating Canal	7/22/1889	69
Buffalo Canal	1/29/1885	67.5
Sisson Stubbs Ditch	12/1/1891	7
Turquoise Lake	7/1/1864	3
Turquoise Lake	5/1/1902	999999
Turquoise Lake	6/25/1962	999999
Mt Elbert Forebay	6/25/1962	999999
Twin Lakes Res	12/15/1896	999999
Twin Lakes Res	3/29/1897	999999
Twin Lakes Res	6/25/1962	999999
Clear Cr Res	6/12/1902	999999
Clear Cr Res	8/20/1910	999999
Pueblo Res	6/25/1962	999999
John Martin Res	4/18/1915	999999
John Martin Res	5/31/1949	999999

Table 2: Simulated Fountain Creek Water Rights

Simulated Water User	Water Right Priority Date	Base Water Right Rate, cfs
Fountain Mutual Canal	9/21/1861	9.84
Fountain Mutual Canal	4/1/1862	1.13
Fountain Mutual Canal	2/1/1863	16.69
Fountain Mutual Canal	12/31/1863	4.25
Fountain Mutual Canal	12/31/1864	4.65
Fountain Mutual Canal	12/31/1866	8.48
Fountain Mutual Canal	12/31/1867	9.68
Fountain Mutual Canal	9/21/1874	17.05
Fountain Mutual Canal	1/31/1903	343.2
Stubbs and Miller Ditch	12/31/1861	2.45
Chilcotte Ditch	12/31/1861	0.25
Chilcotte Ditch	3/21/1863	6.61
Chilcotte Ditch	12/31/1863	13.67
Chilcotte Ditch	12/31/1864	8.38
Chilcotte Ditch	3/21/1866	27
Chilcotte Ditch	12/31/1871	2.7
Chilcotte Ditch	3/21/1874	20.63
Chilcotte Ditch	12/31/1880	3.77
Chilcotte Ditch	12/18/1905	7.81
Owen and Hall Ditch	12/31/1862	14.9
Owen and Hall Ditch	2/18/1891	31
Liston and Love South	3/21/1863	1.87
Liston and Love South	12/31/1871	0.77
Talcott and Cotton Ditch	12/31/1864	6
Talcott and Cotton Ditch	3/21/1872	11.79
Dr Rogers Ditch	3/1/1866	5.55
Burke Ditch	12/31/1862	7.72
Burke Ditch	3/21/1872	10.85
Toof and Harman Ditch	12/31/1893	2.75
Toof and Harman Ditch	11/14/1910	5
Toof and Harman Ditch	12/31/1910	0.5
Wood Valley Ditch	3/1/1866	8
Greenview Ditch	3/21/1862	2
Greenview Ditch	4/30/1882	0.6
Greenview Ditch	12/31/1893	0.2
Cactus Ditch	1/9/1869	0.5
Cactus Ditch	12/31/1879	0.25

Table 3: Simulated Purgatoire River Water Rights

Simulated Water User	Water Right Priority Date	Base Water Right Rate, cfs
Trinidad Res	1/21/1908	18.2
Trinidad Res	1/22/1908	700
Trinidad Res	5/6/1989	999999
Antonio Lopez Ditch	11/1/1861	8
Baca Joint Ditch	11/30/1861	6
Baca Joint Ditch	11/15/1862	3.73
Baca Joint Ditch	3/11/1877	4
Baca Joint Ditch	11/4/1883	14.38
Baca Joint Ditch	6/21/1886	14.73
Baca Joint Ditch	3/12/1887	15
Baca Joint Ditch	6/12/1920	45.56
Chilili Ditch	4/30/1862	7
South Side Ditch	6/30/1863	0.5
South Side Ditch	4/30/1868	0.77
South Side Ditch	11/1/1875	6
South Side Ditch	2/17/1876	34
South Side Ditch	12/25/1876	4
South Side Ditch	4/7/1877	18.6
South Side Ditch	12/15/1882	4
South Side Ditch	11/23/1883	16.84
South Side Ditch	4/30/1884	60
South Side Ditch	2/15/1888	9.7
South Side Ditch	3/1/1888	8
Model Inlet Canal	3/20/1862	4
Model Inlet Canal	1/1/1863	1.28
Model Inlet Canal	1/1/1864	1.25
Model Inlet Canal	4/10/1864	5.1
Model Inlet Canal	10/7/1865	7.35
Model Inlet Canal	5/31/1866	2.25
Model Inlet Canal	4/1/1873	2.4
Model Inlet Canal	10/20/1902	100
Hoehne Ditch	1/1/1863	4.72
Hoehne Ditch	4/10/1864	0.8
Hoehne Ditch	10/7/1865	16.65
River Canyon	1/1/1864	3.75
River Canyon	4/10/1864	0.85
River Canyon	6/1/1865	4
River Canyon	1/1/1866	3.25
River Canyon	2/1/1866	1.34
River Canyon	5/31/1866	0.75
River Canyon	10/21/1886	10
Nine Mile Canal	5/10/1887	18
Nine Mile Canal	7/1/1930	57

Highland Canal	5/31/1866	14.86
Highland Canal	4/1/1884	6.62
Highland Canal	3/1/1909	34.47

APPENDIX C: MODEL DATA

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1 INTRODUCTION

This appendix discusses the various types and sources of data utilized for the FryArk RiverWare Model. This includes that used directly as model input data and that used to generate other model input data. This also includes data used for model development purposes such as calibration, validation, and verification, as well as identification and development of modeling procedures such as guide curves, exchange or other transaction criteria, and water user demand patterns.

As the model is run on a daily timestep, daily timestep data was preferred and was utilized wherever available. When daily data wasn't available, monthly or other period data was sometimes used and was often disaggregated to daily values using various methods as necessary. The model period is currently from 10/1/1990 to 12/31/2015, and thus daily data for this entire period was required for the model input hydrology data at minimum. As the full necessary data period for these input nodes wasn't always available, various filling and extrapolation procedures were utilized.

Overall, a significant amount of data work was required as part of the FryArk RiverWare Model development. While some data sources were more contiguous, continuous, and complete than others, it was very often necessary to analyze, compare, and combine data from different sources, including reconciling various differences and/or further analyzing data to identify which was the most appropriate and accurate. This was particularly true for water user diversion and reservoir release data, especially the accounting breakdowns of diversions and releases.

Due to the many data availability, quantity, and quality issues encountered, significant quality assurance and quality control (QA/QC) measures were undertaken to ensure suitability and accuracy. These QA/QC measures included but were not limited to reservoir mass balance calculations, comparisons of aggregated accounting data with total physical storage or flow data, and manual review and analysis of various data sources and issue areas. Professional judgement was regularly utilized when data sources did not agree and when mass balances issues or discontinuities existed. Missing data was filled using various methods including interpolation and extrapolation, regressions to index gages or well-correlated parameters, and repeating of values from hydrologically similar years.

The data currently utilized within the model is considered the best available data given the limitations of source data and resources available.

2 DATA SOURCES

Various data sources were utilized throughout model development. A summary of the major sources utilized is presented below. Often, data for the same parameter was available from multiple sources. Where discrepancies exist between data sources, which were very common, the data from the more trusted source is generally used, however, the most trusted sources are generally not consistent across data types or locations and time periods and thus vary by node and parameter.

Most major stream gages in the model's extent are operated by either the USGS or the Colorado Division of Water Resources (CDWR) and the CDWR data sources often contain USGS data although for some flow locations and periods the data may differ due to aggregation periods, gage discharge curves, and applied shifts.

2.1 USGS National Water Information System

The USGS National Water Information System (NWIS) was the primary source utilized for most stream gage flow data. The USGS NWIS also contains data for several of the basin's reservoirs including pool elevations and total storages. USGS NWIS data was accessed through several outlets including directly through the USGS NWIS web interface (https://waterdata.usgs.gov/nwis), the HEC-DSS application, and the CDWR HydroBase system.

2.2 Pueblo Field Office (Reclamation) Local Database

Reclamation's Pueblo Field Office maintains a local database for housing data directly related to Reclamation's facilities and operations, including significant amounts of reservoir storage accounting data. This database generally contains daily data beginning in September 1996 through present. Historic daily storage accounting data breakdowns for Turquoise Lake, Twin Lakes Reservoir, and Pueblo Reservoir were largely informed with data from this source.

As with most other sources, data from this database was often of questionable quality with many inconsistencies between total physical values and overall accounting and sub-accounting values, and data from other sources. Mass balance calculations often did not work out indicating incorrect or missing values. Thus, manual review, QA/QC, and verification with other data sources was an important part of the data development process. It should be noted that this database was not directly accessed by the RiverWare model developers and data from this database was obtained through Reclamation staff.

2.3 Hydromet

The Reclamation's Great Plains region Hydromet system was used to obtain historic reservoir data, including historic evaporation and other meteorological data, and some flow and diversion data. In general, except for historic evaporation data which was used in the Reclamation reservoir mass balances and to generate some necessary evaporation rate curves, this data was used to verify other data sources. More information is available at https://www.usbr.gov/gp/hydromet/.

2.4 HydroBase

The Colorado Water Conservation Board (CWCB) and Colorado Division of Water Resources (CDWR) maintain the HydroBase dataset as part of Colorado's Decision Support Systems (CDSS). HydroBase data was accessed both through the downloadable database files and the TSTool application and the web interfaces (such as that available through the CDSS Structures/Diversions information system). The downloaded databases most heavily utilized were dated 12/20/2016 and 10/16/2017. It should be noted that many parameters in the HydroBase system ended prior to the 12/31/2015 model period end date, often ending at 9/30/2015, and thus were manually filled with CDWR web data (the next source discussed).

HydroBase was the primary source for most of the water user diversion data utilized, as well as the augmentation station return data. Diversion and measured return flow data is heavily utilized within the mass balance calculations used to generate model input local inflow data as well as for developing water user diversion demand patterns for use during simulation. Where available, actual canal flow gage data was preferred over the daily "DivTotal" data that consists of summed accounting delivery data, which is referred to as "DivClass" data within HydroBase. Many issues were found in HydroBase's daily "DivTotal" data, which are discussed further later in this appendix, and a significant amount of QA/QC was completed in order to make the data useable.

More information about HydroBase can be found on the CDWR website at https://dnrftp.state.co.us/#/DWR/Modeling/HydroBase/. The Structures/Diversions information website is available at http://cdss.state.co.us/onlineTools/Pages/StructuresDiversions.aspx.

2.5 Colorado's Surface Water Conditions Website

The CDWR also maintains the Colorado's Surface Water Conditions website accessible at http://www.dwr.state.co.us/Surfacewater/data/division.aspx?div=2. This website contains queryable data for many stream flow, canal/diversion, and reservoir gages. The data available through this outlet is sometimes identical to the HydroBase data, however it also sometimes deviates significantly. Where differences arose the data that seemed the most appropriate or reasonable was generally selected, or additional sources were used for verification.

2.6 Other Sources

Many other data sources were also utilized through the data development process. Various municipal water supply entities such as Colorado Springs Utilities, Pueblo Water, Aurora Water, and Pueblo West provided data specific to their systems. Southeastern Colorado Water Conservancy District (SECWCD) and Reclamation provided data relating to allocations of Project Water from the Fryingpan-Arkansas Project and related operations. Data was also obtained from the Arkansas basin MODSIM model used for the SDS and AVC EIS's and the various databases surrounding that model. Some limited data was also obtained from the U.S. Army Corps of Engineers. Other sources not mentioned here also provided data during the development effort.

3 Historic Data Development, Issues, and Discussion

3.1 Historic Streamflow Data

Historic streamflow data for the model period of record of 10/1/1989 – 12/31/2015 was collected and/or developed for all major, important, or otherwise necessary streamflow gages throughout the model extent. This includes the "boundary" gages that may be used directly as input boundary inflows and "internal" mainstem or tributary gages that may be used only in model input local inflow calculations and for model calibration and validation purposes. Additionally, historic daily data was collected or developed for outflows from all simulated reservoirs.

A list of the gages for which full model period of record datasets were developed in shown below in Table 1. Complete data records for the entire model period were not available for many important gages (those with complete records are indicated in the table), necessitating a significant amount of filling and extending be completed. Complicating this process, for many gages that required filling/extending, automated methods such as standard and complete time period regression to hydrologically similar gages produced unsuitable and inappropriate results, which were often identified through issues arising from model calibration and validation processes and verified through analysis of the reach mass balance calculated local inflows used as model input. Thus, a significant amount of time was spent on filling/extension of the many necessary gages using variable and "custom" methods. These techniques included using unique regressions to certain subsets of other gage data, such as using different regressions during different seasons, distinct time periods, or regressing to adjusted gage data. Additionally, care was also taken to reduce (e.g., smooth) discontinuities at the boundaries between actual gage data and filled/extended data to limit the effects of these issues on the calculated local inflows. Furthermore, as with other data types, there were frequently issues with historic data for the same stream flow location varying depending on source, sometimes significantly. This was frequently observed between flow data obtained from USGS/HydroBase and that from the CDWR's "Colorado's Surface Water Conditions" website. In general, "approved" USGS and HydroBase data was considered to be more accurate than the CDWR web data and was preferentially used when available.

To provide an example of a typical "custom" gage data extension method used, the Arkansas River near Rocky Ford gage record, which begins on 10/1/1999, needed to be extended back in time through the beginning of the model period. To accomplish this to a satisfactory level, a 2-variable multiple regression was used that was based on calculated historic river flows at locations directly above and below the Rocky Ford gage location. The two "independent" variables used in the regression were calculated by the appropriate reach mass balances utilizing all available data. Specifically, the upstream "independent" variable used in the regression was calculated by adjusting the flow at the next upstream stream flow gage, the Arkansas River below Catlin Dam gage, for the known historic daily inflows and outflows in the reach between that gage and the Rocky Ford gage location. For this reach, that means subtracting the reach outflows of the Holbrook Canal, Rocky Ford Ditch, Fort Lyon Storage Canal, and Potter Ditch daily diversions, and adding back in the reach inflows of the "Rocky Ford 1" augmentation station returns, and outflows from Lake Meredith and Dye Reservoir. Similarly, the "independent" variable directly downstream of the Rocky Ford gage location was calculated by adjusting the next most downstream gage, the Arkansas at La Junta gage, upstream in an opposite manner by adding back in Fort Lyon Canal diversion and subtracting out the reach inflows from Timpas Creek, Holbrook Reservoir outflow, and Crooked Arroyo. The r-squared value of this multiple regression was excellent at 0.98. Other extension methods, such as a very similar multiple regression but using the original, unadjusted independent variables of the base Arkansas River below Catlin Dam and Arkansas River at La Junta gage records, produced unsatisfactory results that created issues within the dependent local inflow calculations such as a large increase in the amount of negative local inflows calculated. The r-square value of this regression was only 0.91, compared to the 0.98 achieved with the adjusted independent variable described above.

As would be expected based on the above example, the filling/extending of streamflow gage data was largely done in conjunction with the local inflow calculations which provided additional verification and quality controls for both quantities.

Table 1: List of Streamflow Gages for which Full Model Period of Record Datasets were Developed.

USGS Station ID	CDWR Station ID	Gage Name
07084500	LAKATLCO	Lake Creek above Twin Lakes Reservoir, CO
n/a	LKCTURCO	Lake Fork Creek above Turquoise Lake, CO
07079300	**ARKEFOCO**	**East Fork Arkansas River at Hwy 24, nr Leadville, CO**
07081200	**ARKLEACO**	**Arkansas River near Leadville, CO**
07082500	LFCBSLCO	Lake Fork Creek below Sugar Loaf Dam nr Leadville, CO
n/a	LAKBTLCO	Lake Creek below Twin Lakes Reservoir, CO
07083000	**HALMALCO**	**Halfmoon Creek near Malta, CO**
07086000	**ARKGRNCO**	**Arkansas River at Granite, CO**
07086500	**CCACCRCO**	**Clear Creek above Clear Creek Reservoir, CO**
n/a	CCBCCRCO	Clear Creek below Clear Creek Reservoir, CO
07087050	ARKBGNCO	Arkansas River below Granite, CO
07087200	ARKBUECO	Arkansas River at Buena Vista, CO
07091200	ARKNATCO	Arkansas River near Nathrop, CO
07091500	**ARKSALCO**	**Arkansas River at Salida, CO**
07093700	**ARKWELCO**	**Arkansas River near Wellsville, CO**
07094500	ARKPARCO	Arkansas River at Parkdale, CO
07096000	**ARKCANCO**	**Arkansas River at Canon City, CO**
07097000	**ARKPORCO**	**Arkansas River at Portland, CO**
07099400	**ARKPUECO**	**Arkansas River above Pueblo, CO**
07099970	**ARKMOFCO**	**Arkansas River at Moffat Street at Pueblo, CO**
07104000	**MONPIKCO**	**Monument Creek at Pikeview, CO**
07104905	MONBIJCO	Monument Creek at Bijou St. at Colo. Springs, CO
07103700	**FOUNCOCO**	**Fountain Creek near Colorado Springs, CO**
07105500	**FOUACSCO**	**Fountain Creek at Colorado Springs, CO**
07105530	FOUJANCO	Fountain Creek blw Janitell Rd blw Colo. Springs, CO
07105800	**FOUSECCO**	**Fountain Creek at Security, CO**
07106000	**FOUFOUCO**	**Fountain Creek near Fountain, CO**
07106300	**FOUPINCO**	**Fountain Creek near Pinon, CO**
07106500	**FOUPUECO**	**Fountain Creek at Pueblo, CO**
07108900	**STCHARCO**	**St. Charles River at Vineland, CO**
07109500	**ARKAVOCO**	**Arkansas River near Avondale, CO**
07116500	**HUEBOOCO**	**Huerfano River near Boone, CO**
07117000	**ARKNEPCO**	**Arkansas River near Nepesta, CO**
07119500	**APIFOWCO**	**Apishapa River near Fowler, CO**
07119700	ARKCACCO	Arkansas River and Catlin Canal (Combined)
n/a	ARKCATCO	Arkansas River at Catlin Dam near Fowler (Blw canal)
n/a	ARKROCCO	Arkansas River near Rocky Ford, CO
07121500	**TIMSWICO**	**Timpas Creek at Mouth near Swink, CO**
07122400	CANSWKCO	Crooked Arroyo near Swink, CO
07123000	**ARKLAJCO**	**Arkansas River at La Junta, CO**
07123675	HRC194CO	Horse Creek at Highway 194
07124000	**ARKLASCO**	**Arkansas River at Las Animas, CO**
07124200	**PURMADCO**	**Purgatoire River at Madrid, CO**
07124410	**PURBTRCO**	**Purgatoire River below Trinidad Lake, CO**
07126500	**PURNINCO**	**Purgatoire River at Ninemile Dam, nr Higbee, CO**
07128500	**PURLASCO**	**Purgatoire River near Las Animas, CO**
07130500	**ARKJMRCO**	**Arkansas River below John Martin Reservoir, CO**
07133000	**ARKLAMCO**	**Arkansas River at Lamar, CO**
07134100	BIGLAMCO	Big Sandy Creek near Lamar, CO
07134180	**ARKGRACO**	**Arkansas River near Granada, CO**
07137500	**ARKCOOKS**	**Arkansas River near Coolidge, KS**
Note: Bold text indicates gages with complete daily data records that didn't require any filling or extension. Identified errors or issues within complete data still may be corrected or adjusted for some of the gage records.		

3.2 Historic Reservoir Storage and Accounting Data

Historic reservoir storage and storage accounting data is used in many ways to support the FryArk RiverWare Model. Complete and quality total storage data is required to calculate a reservoir's "hydrologic" (or reservoir local) inflows. This data is also instrumental for model calibration and validation purposes. Historic storage accounting data can be used to infer important information regarding the objectives, triggers, criteria, and operational procedures of the many storage account owners present in the basin. This inferred information is used to write operational rules to simulate the operations of various entities to a suitable level of detail if the information is not otherwise available.

Unfortunately, there are issues with both the quantity and quality of the historic reservoir storage and accounting data that are available or have been provided for use with the model and during data development. These limitations have caused numerous difficulties throughout the model and data development process.

Available daily data records of historic total physical storages, pool elevations, and other reservoir parameters were collected, reviewed, and QA/QC'd. For most of the larger reservoirs in the system, relatively complete records exist and were able to be utilized. This is not true for some of the smaller and off-stream reservoirs, specifically for some of the Colorado Canal and Holbrook Canal reservoirs. Additionally, it was not uncommon for historic reservoir data to be different between sources, sometimes significantly. Some of these differences were found to be due to changing or different elevation-storage curves being used, however some differences were unable to be explained or reconciled. Overall, the data determined to be the most appropriate (e.g., the data that best corresponded with other historic parameter data or mass balance calculations) in the professional judgement of the model developer was used.

At a base level, it was preferential to use historic pool elevation data when it was available and to recalculate historic reservoir storages based on the current elevation-storage curves being used for operations, as those are the ones that are used in the model for simulation. This largely helped to eliminate major "step" issues that cause significant errors in historic reservoir mass balances and associated local or reservoir inflow calculations. Even when this was able to be accomplished, these step issues remained present in historic storage account data, which can not be adjusted in a straightforward manner based on the current elevation-storage curves. These types of discontinuities can cause complications during model calibration or validation with historic account storages were often taken into account during model development and calibration.

An example of this type of issue can be seen in the historic Pueblo Reservoir historic data for 9/30-10/1/2015, when the implementation of a new elevation-volume curve resulted in the immediate "loss" of >9000 acre-feet of water from the reservoir (from 198060 to 188882 acre-feet). This was handled in the storage accounting at the time simply by deducting this volume from the Project West Slope storage, and thus the historic accounting shows a drop of >9000 acre-feet. However, this was not an actual loss or usage of water, and thus the corresponding model results for this time will not (and should not) show this drop in volume. This complicates the validation of model resulting Project Water storages through comparison with historic data, as well as the calibration of the various model processes used to simulate Project Water in Pueblo Reservoir and throughout the rest of the system.

Another related issue is that, in many cases, the level of detail of historic storage account data available or provided was insufficient for the purposes necessary. For example, historic TLCC storage account data in Twin Lakes Reservoir was only available as lumped total TLCC storage and not further divided by subaccount owner (i.e., these records were not provided to Reclamation by the TLCC or their various stakeholders). This is a similar issue for the Homestake account in Turquoise Lake, for which only total lumped Homestake storages were available, not the ownership breakdown of those storages between Aurora and CSU. This severely limits the ability to infer important operational characteristics of the subaccounts and limits the ability to calibrate and validate the model's representation of the breakdown of those accounts.

3.3 Historic Diversion and Accounting Data

Water user historic diversion data is required for a couple very important reasons relating to the model. First, it is required to calculate the model's Local Inflows for which diversions are generally a major component. Second, diversion data is needed to determine appropriate water user demands for the modeled conditions. Available historic diversion data corresponding with the model period was collected for each water user in the model, which are listed in the primary model documentation.

Both the quantity and quality of historic diversion data is extremely variable for water users throughout the basin. Many diversion records contain periods of no data and it is difficult to tell if there were no diversions during those periods or if data was missing. Additionally, many changes to diversion structures and water rights occurred throughout the model period, including combination of multiple diversions to a single location, changes in location where various water rights were diverted, and types of use of water right diversions, such as changing from actual diversions from the river to diversions and immediate returns for augmentation use. Furthermore, due to the disordered way that a lot of diversion and water right yield data is collected, housed, reported, and commented, it is often very difficult to decipher whether certain diversion records represent total (i.e., aggregated) diversions at a particular structure, or only a subcomponent of the total diversions. CDWRs "Structure Summary Reports" and associated comments were helpful in accounting for these kinds of issues, although much uncertainty remains regarding the correct accounting of a lot of diversion data. This was especially true for diversions in the Upper Arkansas basin and on Fountain Creek where water right changes and diversion structure aggregations were particularly prevalent throughout the period. Furthermore, even where good diversion records exist, it can be very difficult to determine if the water diverted was in fact used for irrigation or other uses, or if it was subsequently returned to the river for augmentation, return flow replication requirements, or other reasons. Good augmentation station records are even more difficult to come by and contain even more suspect data than the diversion data.

HydroBase was the primary source for most of the water user diversion data utilized, as well as for augmentation station data. Where available, actual canal flow gage data was preferred over the daily "DivTotal" data that consisted of aggregated delivery data by water type or other accounting breakdowns (or "DivClasses" in HydroBase). Many issues were found in HydroBase's daily "DivTotal" data as described below. The historic diversion and augmentation station data was reviewed as possible and QA/QC was performed as found to be necessary based on other available data and water user information. The fact that data issues varied significantly between water users and the associated revision and correction needs being highly variable, it was very difficult to automate the QA/QC process in any effective manner and thus it was primarily a manual process.

Historic accounting breakdowns of diversion data can be used to determine whether diversions were of in-priority native flow or were deliveries from storage or other types of sources. This is important as many water users demands will vary significantly depending on the source of their water. An example of this is that many agricultural users will ration their storage and thus have lower diversion demands when they are delivering from storage rather than diverting native flow when their water rights are in priority. When developing diversion demand patterns for simulated water users, effort was made to utilize the correct accounting types as possible. For example, when developing diversion demands to be applied when water rights were in priority (e.g., native flow diversion demands), the historic native diversion data was utilized as possible. Similarly, developed diversion demands from storage sources were informed utilizing the total historic diversions when significant storage deliveries were being made, including during periods when only lower rate, more senior water rights were in priority. Additionally, when it was evident that a diversion structure was taking flow for other non-standard/unrepresentative reasons during a particular period (such as to help alleviate main channel flooding), the full historic diversion may not be used to inform the water user's simulated diversion demands.

Diversion accounting breakdown data is available for many water users within HydroBase, however the quality and quantity of the data is generally poor or non-existent and there were many issues with the total sums of accounting breakdowns not matching total diversion data, both due to issues with the accounting breakdown data and the total actual diversion data. Cases of double counting of various diversions and water types were found throughout the data for many water users due to duplicate HydroBase DivClasses, as were unit errors. Double counting and other issues were many times difficult to identify due to their very inconsistent nature. For example, issues could begin and end seemingly randomly during a given period (particularly for unit errors), and many HydroBase DivClasses would be duplicated for specific small periods of time leading to double counting of that water in the calculated DivTotal data calculated by HydroBase.

Another type of common diversion data error that was found throughout the diversion data and that can have significant effects on model accuracy happens when data for a diversion is not "turned off" at the end of the season when the canal actually stops diverting. Essentially, the end of season 0 diversion value is not input, and automated filling procedures repeat the final days diversion value throughout the entire winter season until the next seasons diversions begin. These errors essentially show historic diversion levels much higher than they actually were and can lead to significantly higher calculated local inflows being used. These types of errors are generally easier to locate because they occur when most diversion data should be 0s (although many diversions do also continue through the winter period) but they can also lead to more significant effects on model accuracy due to the effect of errantly making water in the model during the generally low flow winter periods. See the HydroBase diversion data for Bessemer Ditch during the winter of 2012-2013 for a good example of these errors.

Another issue with HydroBase daily DivTotal data is that it does not contain diversion data that is reported in HydroBase as "Monthly Infrequent" data. This type of data is present for many water users throughout the model period and has apparently been increasingly used in more recent years to report diversions of reusable return flow water types among many other uses. It is particularly troubling that actual water diverted through a canal is not also contained within the reported daily DivTotal data, as that terminology leads one to believe that it is in fact the total diversion.

Additionally, since monthly infrequent data is reported as monthly volumes, it contains no information about which days during the month and at what flow rates it was actually delivered. Due to these limitations, when monthly infrequent diversion data existed for a water user, it was added to the daily DivTotal data on an average monthly flow basis. Note that when actual canal flow gage data was used, the monthly infrequent diversions were assumed to already be captured within that diversion flow data.

Often these types of issues could only be located while backtracking issues identified within calculated local inflows, such as a significant inconsistency in the calculated local inflow that was determined to not be due to gage error or other issues. Additionally, many issues were located via direct comparison of HydroBase daily DivTotal data with actual canal flow gage data, for example when the daily DivTotal significantly exceeded the total gaged canal flow. Unfortunately, historic canal flow gage data was only available for limited diversions and generally had more limited available time periods than the DivTotal data.

An example of a water user with many typical diversion accounting data issues present in its historic data record is Bessemer Ditch. Within HydroBase, Bessemer Ditch has over 30 unique DivClasses, many of which have inconsistent identification information and that are used inconsistently during data entry and HydroBase's totaling calculations. For example, summing the data for all DivClasses on a particular day usually does but does not always equal that day's reported daily DivTotal, and further the subsets of DivClasses that are summed are not consistent throughout the entire time period (these inconsistencies were common in the DivTotal and DivClass data for many water users). Unlike many diversions, Bessemer Ditch does have a canal flow gage (CDWR ID BESDITCO), however this data does not start until October 2007 and thus this data was only available for approximately the last third of the model data period.

A specific example of a type of double-counting issue commonly encountered is highlighted below in Figure 1 for Bessemer Ditch. During the beginning of June 2015 there are 6 days, 6/3-6/8, where the HydroBase reported daily DivTotal contains a double counting of diversions of water from storage when the native diversion amount dropped, presumably due to a portion of their water rights falling out of priority. As observed in the table, the two right-most independent DivClasses report identical diversions from storage during this period (of ~89 cfs) and both are summed into the DivTotal (totaling ~253 cfs). However, the total actual diversion during this period was only ~164 cfs, as seen in the Bessemer Ditch canal flow gage data in the left-most column. This difference was how this error was initially located. These two DivClasses refer to diversions of storage from both Clear Creek Reservoir and Pueblo Reservoir and presumably water was released from Clear Creek Reservoir and subsequently diverted from Pueblo Reservoir but was not accounted for properly within the HydroBase data records. Unfortunately, this also leads to the significant error in the DivTotal data series. If this error were uncaught and was present in the local inflow calculations, this would lead to increased local inflows of ~89 cfs for the entire 6-day period and errantly adding >700 acre-feet of additional water to the system during this short period for this single simple error alone.

TSTool - Time Series - Table

DATE	BESDITCO, AdminFlow, CFS	1400533, DivTotal, CFS	1400533, DivClass-S:1 F: U:1 T: G:, CFS	1400533, DivClass-S:1 F:1100936 U:2 T:4 G:, CFS	1400533, DivClass-S:1 F:1500527 U:2 T:4 G:, CFS	1400533, DivClass-S:2 F:1403526 U:1 T: G:, CFS	1400533, DivClass-S:2 F:1103504 U:1 T: G:, CFS
2015-06-01	163.35	163.00	161.35	1.65	0.00	0.00	0.00
2015-06-02	163.90	164.00	162.35	1.65	0.00	0.00	0.00
2015-06-03	164.37	252.62	72.36	1.68	1.34	88.62	88.62
2015-06-04	164.34	252.62	72.36	1.68	1.34	88.62	88.62
2015-06-05	164.67	253.62	73.36	1.68	1.34	88.62	88.62
2015-06-06	164.19	252.62	72.36	1.68	1.34	88.62	88.62
2015-06-07	164.04	252.62	76.31	1.68	1.34	88.62	84.67
2015-06-08	164.04	248.90	160.98	1.68	1.34	84.90	0.00
2015-06-09	174.88	175.00	171.98	1.68	1.34	0.00	0.00
2015-06-10	191.01	191.00	187.98	1.68	1.34	0.00	0.00

Flags: Not shown | Graph | Summary | Save | Close

Currently-selected worksheet interval: Day

Figure 1: TSTool/HydroBase Screenshot Highlighting a Common Historic Diversion Data Issue for Bessemer Ditch.

4 Model Input Hydrology Data

4.1 Boundary Inflows and Transbasin Imports

For the purposes of the RiverWare model and documentation, "Boundary Inflows" refer to the main river inflows to the upstream ends of the model's network and explicit tributary outflows to the main river that are assumed to be constant in the model.

At the current level of development, transbasin imports to the system are also considered Boundary Inflows and are assumed to be the same as historic imports for the model period. This also means that they are the same between all model runs and are not dynamically simulated to respond to changes in Arkansas basin conditions, or changes in Colorado River basin conditions. This is a major model limitation as in reality these import operations do depend on current basin conditions, for example being curtailed due to limited Arkansas basin storage space. The historic imports currently used also reflect historic curtailments that may not occur in a corresponding fashion within a model run. It is highly recommended that the simulation of transbasin imports be enhanced in the RiverWare model to account for these considerations and more.

There are currently 21 Boundary Inflows in the model, described further below:

Upper Arkansas Basin Boundary Inflows

East Fork Leadville Gage: This is USGS 07079500 East Fork Arkansas River near Leadville, CO historic gage data adjusted to remove the Columbine Ditch imported inflows, which are a different boundary inflow. A minor amount of filling was required on the historic gage flow to complete the period of record and was done by regression to other similar upper basin gages.

Lake Fork Creek above Turquoise Gage: This input timeseries is based on available CDWR data for their LKCTURCO gage and Turquoise Lake data from Reclamation and other sources and was developed in conjunction with the Turquoise Lake historic water balance calculations. A lot of manual review and filling for the LKCTURCO gage data was performed due to poor records and quality. The overall native inflows to Turquoise Lake are informed by both this input and the Turquoise Lake reservoir (hydrologic) inflow input data, and thus the distribution between the two is not incredibly important. The creek gage is generally operated seasonally and thus is missing most winter data. When data was not available, winter inflows from Lake Fork Creek were assumed to be 2 cfs, which produced a reasonable distribution between the creek inflow gage and the calculated reservoir hydrologic inflow.

Halfmoon Creek Malta Gage: This is USGS 07083000 Halfmoon Creek near Malta, CO historic gage data.

Clear Creek above Clear Creek Reservoir Gage: This is USGS 07086500 Clear Creek above Clear Creek Reservoir, CO historic gage data.

Fountain Creek Basin Boundary Inflows

Monument Creek at Pikeview Gage below Pipeline: This is USGS 07104905 Monument Creek at Pikeview, CO historic gage data adjusted to remove the Monument Creek pipeline diversion that occurs just downstream of the gage.

Fountain Creek near CO Springs Gage below 33rd St Diversion: This is USGS 07103700 Fountain Creek near Colorado Springs, CO historic gage data adjusted to remove CSU's 33rd St. intake diversion that occurs just downstream of the gage.

Arkansas River below Pueblo Reservoir Boundary Inflows

St. Charles River at Mouth: This is USGS 07108900 St. Charles River at Vineland, CO historic gage data adjusted from the gage location to the mouth by removing the historic diversions of several structures between the gage and the confluence with the Arkansas River.

Huerfano Gage: This is USGS 07116500 Huerfano River near Boone, CO historic gage data.

Apishapa Gage: This is USGS 07119500 Apishapa River near Fowler, CO historic gage data.

Timpas Creek Gage: This is USGS 07121500 Timpas Creek at Mouth near Swink, CO historic gage data.

Crooked Arroyo at Mouth: This is USGS 07122400 Crooked Arroyo near Swink, CO historic gage data adjusted from the gage location to the mouth by removing the historic diversions of several structures between the gage and the confluence with the Arkansas River.

Horse Creek at Mouth: This is USGS 07123675 Horse Creek at Highway 194 historic gage data adjusted from the gage location to the mouth by removing the historic diversions of several structures between the gage and the confluence with the Arkansas River.

Purgatoire River and Arkansas River Below John Martin Boundary Inflows

Purgatoire River Madrid Gage: This is USGS 07124200 Purgatoire River at Madrid, CO historic gage data.

Big Sandy Creek Gage: This is USGS 07134100 Big Sandy Creek near Lamar, CO historic gage data.

Transbasin Imports Boundary Inflows

Wurtz Ditch near Tennessee Pass Gage: This is historic import gage data for the Wurtz Ditch. It should be noted that some variations exist between various data sources, the data used is the data from HydroBase.

Ewing Ditch at Tennessee Pass Gage: This is historic import gage data for the Ewing Ditch. It should be noted that some variations exist between various data sources, the data used is the data from HydroBase.

Columbine Ditch near Fremont Pass Gage: This is historic import gage data for the Columbine Ditch. It should be noted that some variations exist between various data sources, the data used is the data from HydroBase.

Boustead Tunnel Gage: This is historic import gage data for the Boustead Tunnel. It should be noted that some variations exist between various data sources, the data used is the data from HydroBase.

Busk Ivanhoe Tunnel Gage: This is historic import gage data for the Busk-Ivanhoe Tunnel. It should be noted that some variations exist between various data sources, the data used is the data from HydroBase.

Homestake Tunnel Gage: This is historic import gage data for the Homestake Tunnel. It should be noted that some variations exist between various data sources, the data used is the data from HydroBase.

Twin Lakes Tunnel Gage: This is historic import gage data for the Twin Lakes Tunnel. It should be noted that some variations exist between various data sources, the data used is the data from HydroBase.

4.2 Local Inflows

For the purposes of the RiverWare model and documentation, "Local Inflows" refer to tributary or other local inflows of water to a model reach. The Local Inflow reaches are generally divided by main-stem gages and reservoirs and are calculated based on the historic mass-balance of the reach. Unless specifically noted, the model's Local Inflows are assumed to be native flow only and thus they are available to be allocated to water rights by the Water Rights Solver. There are several important assumptions related to the use of historic calculated local inflows as model input, including the lumping of most historic return flows from water users into the local inflows due to the lack of availability of adequate historic return flow data and insufficient resources to develop that data. These assumptions and the associated limitations are discussed in depth within the model documentation.

For the current purposes of the RiverWare model, negative Local Inflows are not allowed and thus it is important that all feasible reach losses to a reach are incorporated into the historic mass-balance calculations. Mass balances that result in negative local inflow calculations were a significant issue during local inflow development due largely to the availability and quality of historic data, especially historic diversion data, main-stem streamflow gage errors, other non-specified river depletions (e.g. due to groundwater pumping) for which sufficient data was not available, as well as other factors.

Calculated local inflows were reviewed manually and where significant occurrences of negative calculated local inflows occurred, as well as where instances of uncharacteristically high calculated inflows occurred, the data involved in the calculations was reviewed manually. This review process uncovered many data errors including stream flow gage errors, inappropriate filling/extending, and errors in diversion datasets such as periods of missing diversions (e.g., datasets showed no diversions however verifiable diversions had actually occurred, as well as the reverse situation). These errors and issues were corrected to the extent possible and local inflows recalculated. Correcting local inflow issues by correcting input datasets was always preferred over adjusting or smoothing the issues away and was performed wherever possible.

Calculated local inflows were adjusted as needed, both temporally and spatially, and minimally smoothed to eliminate remaining negatives. Adjustment methods that conserved mass were used in order to prevent the creation or removal of water from the system. Furthermore, care was taken to reduce the amount of adjustment and smoothing necessary to limit the impact on the flow regime (magnitude, timing, etc.) of actual historic accretions of flow to the system (i.e., unmodeled tributary inflows). For example, over-smoothing of local inflows could easily result in reducing the peaks of actual local inflow runoff events and spreading the volumes out over long time periods, which can have significant effects on the accuracy of the simulation of allocation by water rights. To reduce these types of issues, custom smoothing algorithms were developed and used that used variable running average periods depending on relative average flow magnitudes over the period. For example, during true periods of high local inflow conditions, shorter running average periods were used, while longer periods were used during true areas of low local inflow conditions.

There are currently 29 Local Inflows in the model, which are listed below in Table 2. Subsequently, the components in each of the reach mass-balances used to calculate the model input Local Inflows are shown in the tables below. Note that inflows from all tributaries not included in the reach mass balance components are thus lumped into that local inflow.

Table 2: List of Model Input Local Inflow Nodes

FryArk RiverWare Model Input Local Inflow Nodes
Nodes above Pueblo Reservoir
Abv Twin Lakes Local
Abv Leadville Local
Abv Granite Local
Blw Granite Local
Abv Salida Local
Abv Wellsville Local
Abv Parkdale Local
Abv Canon City Local
Abv Portland Local
Abv Pueblo Res Local
Fountain Creek Nodes
Abv CO Springs Local
Abv Janitell Rd Local
Abv Security Local
Abv Fountain Local
Abv Pinon Local
Abv Fountain Cr at Pueblo Local
Nodes below Pueblo Reservoir
Abv Moffat Street Local
Abv Avondale Local
Abv Nepesta Local
Abv Catlin Dam Gage Local
Abv Rocky Ford Local
Abv La Junta Local
Abv Las Animas Local
Abv John Martin Local
Purgatoire River Nodes
Abv Higbee Local
Abv Purgatoire Nr Las Animas Local
Nodes below John Martin Reservoir
Abv Lamar Local
Abv Granada Local
Abv Coolidge Local

Table 3: Local Inflow Reach Mass-Balance Components – Abv Twin Lakes Local

Local Inflow Mass Balance Reach Components – Abv Twin Lakes Local	
Primary Inflow Gage	*none (this node represents all native inflows above Twin Lakes)*
Tributary Inflows to Reach	*none*
Diversions from Reach	*none*
Other Components	*Import inflow:* Twin Lakes Tunnel
Primary Outflow Gage	Lake Creek above Twin Lakes Reservoir, CO

Table 4: Local Inflow Reach Mass-Balance Components – Abv Leadville Local

Local Inflow Mass Balance Reach Components - Abv Leadville Local	
Primary Inflow Gage	East Fork Arkansas River at Hwy 24, nr Leadville, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Delappe
Other Components	*Import inflows:* Wurtz Ditch, Ewing Ditch
Primary Outflow Gage	Arkansas River near Leadville, CO

Table 5: Local Inflow Reach Mass-Balance Components – Abv Granite Local

Local Inflow Mass Balance Reach Components - Abv Granite Local	
Primary Inflow Gage	Arkansas River near Leadville, CO
Tributary Inflows to Reach	Lake Fork Creek below Sugar Loaf Dam near Leadville, CO Halfmoon Creek near Malta, CO Lake Creek below Twin Lakes Reservoir, CO
Diversions from Reach	Martin, Bob Berry, Wells and Star, Younger Ditch No 1, Younger Ditch #2, Young and Smith, Derry Ditch No 1, Upper River, Pioneer, Champ, Wheel
Other Components	*Inflow:* Leadville Hatchery return flow
Primary Outflow Gage	Arkansas River at Granite, CO

Table 6: Local Inflow Reach Mass-Balance Components – Blw Granite Local

Local Inflow Mass Balance Reach Components - Blw Granite Local	
Primary Inflow Gage	Arkansas River at Granite, CO
Tributary Inflows to Reach	Clear Creek below Clear Creek Reservoir, CO
Diversions from Reach	Langhoff
Other Components	*none*
Primary Outflow Gage	Arkansas River below Granite, CO

Table 7: Local Inflow Reach Mass-Balance Components – Abv Salida Local

Local Inflow Mass Balance Reach Components - Abv Salida Local	
Primary Inflow Gage	Arkansas River below Granite, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Dryfield, Riverside-Allen, Helena, Reformatory, Bray-Allen, Cogan and Day, Kraft, Salida Ditch, Sunnyside Park, Williams and Hamm
Other Components	*none*
Primary Outflow Gage	Arkansas River at Salida, CO

Table 8: Local Inflow Reach Mass-Balance Components – Abv Wellsville Local

Local Inflow Mass Balance Reach Components - Abv Wellsville Local	
Primary Inflow Gage	Arkansas River at Salida, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	*none*
Other Components	*none*
Primary Outflow Gage	Arkansas River near Wellsville, CO

Table 9: Local Inflow Reach Mass-Balance Components – Abv Parkdale Local

Local Inflow Mass Balance Reach Components - Abv Parkdale Local	
Primary Inflow Gage	Arkansas River near Wellsville, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Pickett, Pleasant Valley, Rogers, Rogers Clayborn Extension
Other Components	*none*
Primary Outflow Gage	Arkansas River at Parkdale, CO

Table 10: Local Inflow Reach Mass-Balance Components – Abv Canon City Local

Local Inflow Mass Balance Reach Components - Abv Canon City Local	
Primary Inflow Gage	Arkansas River at Parkdale, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Canon City WW, Royal Gorge Intake, Canon City Hydraulic, South Canon, Colorado P&L *(non-consumptive but bypasses gage)*
Other Components	*none*
Primary Outflow Gage	Arkansas River at Canon City, CO

Table 11: Local Inflow Reach Mass-Balance Components – Abv Portland Local

Local Inflow Mass Balance Reach Components - Abv Portland Local	
Primary Inflow Gage	Arkansas River at Canon City, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Canon City-Oil Creek, Fremont County Ditch, Minnequa Canal (*includes Union Ditch)*, Hannenkratt, Florence Div Works, Lester and Attebery, Banks No 1
Other Components	*Return inflow from bypass:* Colorado P&L
Primary Outflow Gage	Arkansas River at Portland, CO

Table 12: Local Inflow Reach Mass-Balance Components – Abv Pueblo Res Local

Local Inflow Mass Balance Reach Components - Abv Pueblo Res Local	
Primary Inflow Gage	Arkansas River at Portland, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Ideal Cement, Hayner, Brewer, Porter Woodruff and Tells, Woodruff and Tells
Other Components	*none*
Primary Outflow Gage	Pueblo Reservoir Inflow *(calculated inflow from Pueblo Reservoir mass balance)*

Table 13: Local Inflow Reach Mass-Balance Components – Abv CO Springs Local

Local Inflow Mass Balance Reach Components - Abv CO Springs Local	
Primary Inflow Gage	Fountain Creek near CO Springs Gage below 33rd St Diversion
Tributary Inflows to Reach	Monument Creek at Pikeview Gage below Pipeline
Diversions from Reach	*none*
Other Components	*Inflows:* JDP WWTP Outflow, CSU Unsewered Return Flow 1
Primary Outflow Gage	Fountain Creek at Colorado Springs, CO

Table 14: Local Inflow Reach Mass-Balance Components – Abv Janitell Rd Local

Local Inflow Mass Balance Reach Components - Abv Janitell Rd Local	
Primary Inflow Gage	Fountain Creek at Colorado Springs, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Fountain Mutual Canal
Other Components	*Inflows:* LV WWTP Outflow, CSU Unsewered Return Flow 2
Primary Outflow Gage	Fountain Creek blw Janitell Rd blw Colo. Springs, CO

Table 15: Local Inflow Reach Mass-Balance Components – Abv Security Local

Local Inflow Mass Balance Reach Components - Abv Security Local	
Primary Inflow Gage	Fountain Creek blw Janitell Rd blw Colo. Springs, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Stubbs and Miller Ditch
Other Components	*Inflows:* CSU Unsewered Return Flow 3
Primary Outflow Gage	Fountain Creek at Security, CO

Table 16: Local Inflow Reach Mass-Balance Components – Abv Fountain Local

Local Inflow Mass Balance Reach Components - Abv Fountain Local	
Primary Inflow Gage	Fountain Creek at Security, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Chilcotte, Crabb, Miller, Lock Ditch No 2, Owen and Hall, Liston and Love South *(old POD)*
Other Components	*none*
Primary Outflow Gage	Fountain Creek near Fountain, CO

Table 17: Local Inflow Reach Mass-Balance Components – Abv Pinon Local

Local Inflow Mass Balance Reach Components - Abv Pinon Local	
Primary Inflow Gage	Fountain Creek near Fountain, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Liston and Love South *(new POD)*, Talcott and Cotton, Dr. Rogers, Burke, Toof and Harman, Wood Valley
Other Components	*none*
Primary Outflow Gage	Fountain Creek near Pinon, CO

Table 18: Local Inflow Reach Mass-Balance Components – Abv Fountain Cr at Pueblo Local

Local Inflow Mass Balance Reach Components - Abv Fountain Cr at Pueblo Local	
Primary Inflow Gage	Fountain Creek near Pinon, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Greenview, Cactus
Other Components	*none*
Primary Outflow Gage	Fountain Creek at Pueblo, CO

Table 19: Local Inflow Reach Mass-Balance Components – Abv Moffat Street Local

Local Inflow Mass Balance Reach Components - Abv Moffat Street Local	
Primary Inflow Gage	Arkansas River above Pueblo, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Comanche PP, PBWW NS+SS Intakes, Riverside Dairy, SOCO/HARP, SCMWD Pump Station
Other Components	*Inflows:* Pueblo Hatchery returns, Pueblo West WWTP outflow *(from Wildhorse Creek)*
Primary Outflow Gage	Arkansas River at Moffat Street at Pueblo, CO

Table 20: Local Inflow Reach Mass-Balance Components – Abv Avondale Local

Local Inflow Mass Balance Reach Components - Abv Avondale Local	
Primary Inflow Gage	Arkansas River at Moffat Street at Pueblo, CO
Tributary Inflows to Reach	Fountain Creek at Pueblo, CO St. Charles River at Mouth
Diversions from Reach	Net Excelsior *(diversion – aug. return)*
Other Components	*Inflows:* HARP returns, PBWW WWTP outflow
Primary Outflow Gage	Arkansas River near Avondale, CO

Table 21: Local Inflow Reach Mass-Balance Components – Abv Nepesta Local

Local Inflow Mass Balance Reach Components - Abv Nepesta Local	
Primary Inflow Gage	Arkansas River near Avondale, CO
Tributary Inflows to Reach	Huerfano River near Boone, CO
Diversions from Reach	Collier, Colorado Canal, Rocky Ford Highline, Oxford Farmers
Other Components	*none*
Primary Outflow Gage	Arkansas River near Nepesta, CO

Table 22: Local Inflow Reach Mass-Balance Components – Abv Catlin Dam Gage Local

Local Inflow Mass Balance Reach Components - Abv Catlin Dam Gage Local	
Primary Inflow Gage	Arkansas River near Nepesta, CO
Tributary Inflows to Reach	Apishapa River near Fowler, CO
Diversions from Reach	Otero, Baldwin Stubbs
Other Components	*none*
Primary Outflow Gage	Arkansas River and Catlin Canal (Combined)

Table 23: Local Inflow Reach Mass-Balance Components – Abv Rocky Ford Local

Local Inflow Mass Balance Reach Components - Abv Rocky Ford Local	
Primary Inflow Gage	Arkansas River at Catlin Dam, near Fowler, CO *(below Catlin Canal)*
Tributary Inflows to Reach	*none*
Diversions from Reach	Holbrook Canal, Rocky Ford Ditch, Fort Lyon Storage Canal, Potter Ditch
Other Components	*Inflows:* Lake Meredith Outflow, Dye Reservoir Outflow, RF1 Returns
Primary Outflow Gage	Arkansas River near Rocky Ford, CO

Table 24: Local Inflow Reach Mass-Balance Components – Abv La Junta Local

Local Inflow Mass Balance Reach Components - Abv La Junta Local	
Primary Inflow Gage	Arkansas River near Rocky Ford, CO
Tributary Inflows to Reach	Timpas Creek *(includes RF2 returns)* Crooked Arroyo at Mouth
Diversions from Reach	Fort Lyon Canal
Other Components	*Inflow:* Holbrook Reservoir outflow
Primary Outflow Gage	Arkansas River at La Junta, CO

Table 25: Local Inflow Reach Mass-Balance Components – Abv Las Animas Local

Local Inflow Mass Balance Reach Components - Abv Las Animas Local	
Primary Inflow Gage	Arkansas River at La Junta, CO
Tributary Inflows to Reach	Horse Creek at Mouth
Diversions from Reach	Las Animas Consolidated
Other Components	*none*
Primary Outflow Gage	Arkansas River at Las Animas, CO

Table 26: Local Inflow Reach Mass-Balance Components – Abv John Martin Local

Local Inflow Mass Balance Reach Components - Abv John Martin Local	
Primary Inflow Gage	Arkansas River at Las Animas, CO
Tributary Inflows to Reach	Purgatoire River near Las Animas, CO
Diversions from Reach	*none*
Other Components	*none*
Primary Outflow Gage	John Martin Reservoir Inflow (calculated inflow from John Martin Reservoir mass balance)

Table 27: Local Inflow Reach Mass-Balance Components – Abv Lamar Local

Local Inflow Mass Balance Reach Components - Abv Lamar Local	
Primary Inflow Gage	Arkansas River below John Martin Reservoir, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Fort Bent, Keesee, Amity, Lamar
Other Components	*none*
Primary Outflow Gage	Arkansas River at Lamar, CO

Table 28: Local Inflow Reach Mass-Balance Components – Abv Granada Local

Local Inflow Mass Balance Reach Components - Abv Granada Local	
Primary Inflow Gage	Arkansas River at Lamar, CO
Tributary Inflows to Reach	Big Sandy Creek near Lamar, CO
Diversions from Reach	Hyde, Manvel, XY, Buffalo
Other Components	*none*
Primary Outflow Gage	Arkansas River near Granada, CO

Table 29: Local Inflow Reach Mass-Balance Components – Abv Coolidge Local

Local Inflow Mass Balance Reach Components - Abv Coolidge Local	
Primary Inflow Gage	Arkansas River near Granada, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Sisson Stubbs *(but no diversions during period)*
Other Components	*none*
Primary Outflow Gage	Arkansas River near Coolidge, KS

Table 30: Local Inflow Reach Mass-Balance Components – Abv Higbee Local

Local Inflow Mass Balance Reach Components - Abv Higbee Local	
Primary Inflow Gage	Purgatoire River below Trinidad Lake, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Antonio Lopez, Baca/Picketwire/El Moro, Chilili, Southside, Model, Hoehne, River Canyon Ditches, Ninemile
Other Components	*none*
Primary Outflow Gage	Purgatoire River at Ninemile Dam, nr Higbee, CO

Table 31: Local Inflow Reach Mass-Balance Components – Abv Purgatoire Nr Las Animas Local

Local Inflow Mass Balance Reach Components - Abv Purgatoire Nr Las Animas Local	
Primary Inflow Gage	Purgatoire River at Ninemile Dam, nr Higbee, CO
Tributary Inflows to Reach	*none*
Diversions from Reach	Highland
Other Components	*none*
Primary Outflow Gage	Purgatoire River near Las Animas, CO

4.3 Reservoir (Hydrologic) Inflows

Reservoir Inflows, also referred to as "Hydrologic Inflows", refer to the local inflows that flow directly into a reservoir. Importantly, in this context, Reservoir Inflows do not refer to the total inflow to the reservoir, only to that which is not captured in the inflows from the explicitly simulated river reach(es) into the reservoir. Typically, Reservoir Inflows are calculated by mass balance using historic reservoir data such as elevation, storage, surface area, gaged inflows, outflows, and direct diversions, measured or estimated evaporation, and other relevant data. As a result, Reservoir Inflows will implicitly contain unmodeled sources or sinks to a reservoir's water balance including ungaged inflows, outflows, diversions, and other unmodeled reservoir processes such as bank storage and seepage effects and direct precipitation onto a reservoir's surface. These may also possibly include local reach inflows that occur between the upstream gage and the reservoir that can't otherwise be backed out of the mass balance.

Time series slots of daily Reservoir Inflows for the complete 25-year model run period exist on the “Reservoir Inflows” data object. There is a Reservoir Inflow parameter for each of the 13 reservoirs currently represented within the model. As noted below, most of the Reservoir Inflows are currently assumed to be zero for the purposes of the model, either by necessity due to the lack of the necessary data required to sufficiently calculate the historic reservoir water balance, or due to the fact that the reservoir inflows for some reservoirs may be included in the Local Inflows in the reach directly above that reservoir.

Turquoise Lake: Calculated from the historic Turquoise Lake water balance.

Twin Lakes Res: Assumed to be 0 due to the complicated mass balance (largely due to the Mt. Elbert pumped storage power plant) and the lack of required historic data to be able to sufficiently calculate the historic water balance.

Mt Elbert Forebay: Assumed to be zero due to the small drainage area for the off-stream reservoir and the complicated mass balance due to pumped-storage operations.

Clear Creek Reservoir: Assumed to be zero due to small intervening drainage area between the upstream flow gage and the lack of necessary data.

Pueblo Reservoir: Assumed to be zero as the Reservoir Inflows are lumped into the upstream Local Inflow reach, “Abv Pueblo Res Local”.

Lake Henry: Assumed to be zero. Off-stream reservoir with insufficient historic data to determine water balance.

Lake Meredith: Assumed to be zero. Off-stream reservoir with insufficient historic data to determine water balance.

Holbrook Reservoir: Assumed to be zero. Off-stream reservoir with insufficient historic data to determine water balance.

Dye Reservoir: Assumed to be zero. Off-stream reservoir with insufficient historic data to determine water balance.

John Martin Reservoir: Assumed to be zero as the Reservoir Inflows are lumped into the upstream Local Inflow reach, “Abv John Martin Local”.

Trinidad Reservoir: Calculated from the historic Trinidad Reservoir water balance.

Upper Williams Cr Reservoir: Assumed to be zero due to unavailable data and the fact that the reservoir does not yet exist. Planned reservoir operations will pass native inflows.

Williams Cr Reservoir: Assumed to be zero due to unavailable data and the fact that the reservoir does not yet exist. Planned reservoir operations will pass native inflows.

5 Initial Reservoir Storage and Account Data

There are currently three (3) sets of Initialization Conditions that have been developed from historic data for use by the RiverWare model. The required initial conditions are total storages for all modeled reservoirs, and a complete accounting breakdown of the total storages into the accounts simulated. Where the appropriate historic account storage breakdowns exist, they were used and adjusted as needed so that total account storages sum to the total physical storage, which is a requirement for the RiverWare model. Where historic accounting data wasn't available or complete, it was made up to be as realistic as possible considering available data and information. Some of the initial account storages (especially those in the 9/30/2002 IC) were created from model run output to create a realistic estimate of conditions at that date when historic data was especially limited. These initial storage and account conditions are available within the model.

The three Initial Condition sets correspond to the storages that existed in the basin on:

September 30, 2010 - This is used for the 10/1/2010-12/31/2015 Current Conditions Comparison Run.

September 30, 2016 - This is used for the full EC analysis runs.

September 30, 2002 - This has been used for testing model sensitivity to a very low/dry initial storage condition, which this represents.

6 Reservoir Physical and Evaporation Data

6.1 Reservoir Physical Data

The model contains 13 reservoirs, 11 of which are real, existing reservoirs that are simulated in all scenarios. Two (2) reservoirs, Upper Williams Creek and Williams Creek Reservoirs, are proposed reservoirs that do not yet exist, and are only simulated in the future "2047" and "2058" Excess Capacity Analysis scenarios as defined by Reclamation.

Required physical reservoir data includes elevation-storage and elevation-area curves, max release or outlet capacity curves, and spillway tables. The most up-to-date data was collected for all simulated reservoirs from various sources. Parameters for some minor reservoirs with limited actual data (e.g. Holbrook and Dye Reservoirs) were estimated at simple levels based on the information that was available. The physical reservoir data used for all simulated reservoirs is available within the model.

6.2 Reservoir Evaporation Rates

Simulated evaporation rates are based on average historic evaporation amounts or available evaporation rate pattern data depending on availability and quality. The patterns used are available within the model. During simulation, monthly average evaporation rates (in inches/day) are set on the 15th day of each month and are interpolated for in between days. This allows for consistently changing evaporation rates to be simulated and avoids drastic month-to-month steps in modeled evaporation. Daily evaporation volumes are simulated by applying the interpolated daily rate to the currently simulated reservoir surface area.

Precipitation onto reservoir surfaces is not explicitly simulated, but instead these inflows are included implicitly in the reservoir's hydrologic inflows or the associated local inflow.

APPENDIX D: MODEL CALIBRATION AND VALIDATION

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1 INTRODUCTION

The objective of this appendix is to provide validation and verification of the ability of the FryArk RiverWare Model to reliably, appropriately, and reasonably simulate the Arkansas River basin's water resource system. For many reasons, validating the performance of this model presents a significant challenge as the use of more traditional methods to do so have limited suitability for the task. Generally, these traditional validation methods rely heavily upon comparing model results to historic conditions with an underlying expectation that a good model will accurately replicate historic results. These traditional methods can be of great value in more basic and static systems where past results can be reasonably expected to repeat given similar inputs. However, in complex, dynamic, and evolving systems this fundamental expectation is much less appropriate and the ability to replicate historic conditions does not actually mean that a model is adequately simulating a system.

The policy, water uses, and operational procedures with the Arkansas River basin's complex water resource system have changed significantly over time and will no doubt continue to evolve. For example, changing demands for water supply have been driven largely by municipal development and land use changes that has resulted in the change of many water rights from agricultural uses to municipal uses. Often, these types of changes and related infrastructure development have resulted in fundamental changes to operational procedures and objectives due to a demand for more ability to store water in the basin's reservoirs. The access to and utilization of storage accounts by various entities in reservoirs throughout the basin has increased substantially through the model period, most notably in Pueblo Reservoir's Excess Capacity (EC) storage. Often, storage is established by exchange processes, and the prevalence and utilization of exchanges by various entities has also been increasing, which has also led to the creation of various flow management plans and minimum flow criteria to limit environmental and other impacts. The result is that many important aspects of today's water resource system behave in significantly different ways than they have in recent decades. Thus, there should be very limited expectation that the system as a whole would respond in the same way today as it has in the past even given identical hydrologic inputs.

The objective of the FryArk RiverWare Model is not to recreate the historic conditions, but instead to simulate how the system would reasonably and likely respond to various hydrologic inputs under its current policy, water uses, and operational procedures. To accomplish this, the model dynamically simulates how various decisions are made as much as possible, rather than assuming those decisions would be the same as they were in the past and "forcing" them by using historic data as inputs. Thus, the operational decisions that shape conditions throughout the system, such as reservoir releases, water user demands and diversions, and exchanges and other accounting transactions, are explicitly simulated within the model. Ideally, the only inputs that are the same as the corresponding historic years is the overall hydrologic inflow to the system, or input hydrology, that is used to drive the model.

Other types of models that operate by relying more upon forcing previous operational decisions and other values (e.g., reservoir releases, exchanges and account transactions, and water user diversions) to those that have been observed historically will of course have more success in replicating historic basin conditions. However, this does not actually provide much real validation or verification that the model is in fact simulating the current state of the water resource system in a sufficient manner. All this would actually achieve would be a verification that the historic system mass-balances are configured and are adding up properly. Furthermore, these historic mass-balances often tend not to work out well due to the prevalence of significant issues and uncertainty in historic data, which often leads to the use of erratic calculated gain/loss terms, with limited relevance to actual basin hydrologic processes, to force simulated conditions to historic values.

While the FryArk RiverWare Model's advanced and dynamic simulation of the system provides many benefits, it can also complicate the validation and verification process. It is not as simple as comparing simulated results to historic conditions and showing a goodness of fit through various performance measures, as again, there is little underlying expectation that these should compare well in any given case. Rather, it entails verifying that the mechanisms used by the model (i.e., the rules) to simulate the various operational decisions and other processes are in fact simulating how these decisions are made in a reasonable and appropriate way. Often, simulation mechanisms can be verified not by comparing overall model results such as a reservoirs total storage, but by comparing specific results of simulated decisions to appropriate historic decision data from similar situations, such as decisions regarding the timing and rates of reservoir releases or exchanges. This can be an exhaustive process in some Arkansas basin reservoirs however, where the operations are driven by the aggregated decisions of many unique entities operating in an independent manner. This is especially notable in the operations of Pueblo Reservoir due to the dozens of unique storage accounts.

The validation process also entails thorough review of model simulations by system operators and other experts with a deep understanding of how various aspects of the system may behave under a variety of conditions and were often directly involved in the decision-making that shaped historic conditions. These experts can often intuitively see how past decisions may have been made differently under the current policy and operational procedures, and considering variable system conditions, and can quickly verify reasonable simulation or identify areas of concern. FryArk RiverWare Model results for various model scenarios and configurations have been reviewed by Reclamation operators and water managers throughout the model development process. When questions arose about why and how certain decisions were being made by the model, the operational rules and exact calculations behind those decisions were reviewed in depth and either verified or modified as necessary to more appropriately simulate the specific decision-making process. The high transparency and traceability of the model results afforded by the RiverWare platform allow for this detailed scrutiny throughout all parts of the simulation process.

Despite the various limitations and caveats of historic comparisons previously described, it is often still very useful, informative, and convenient to compare simulated results to historic conditions to help provide evidence for model validation. Thus, select comparisons of simulated model results to the corresponding historic conditions are presented and discussed. These comparisons are generally presented and discussed in a qualitative, rather than a quantitative, manner. The ability of the model to simulate reasonable system operations and conditions within the realm of what would be likely if the simulated situations were to arise under the basin's current policy, water uses, and operational procedures is considered much more important to validation of the model. Much less emphasis is placed on the ability of the model to replicate historic conditions as this is not an objective or an expectation. However, highlighting where notable deviations do arise between simulated and historic conditions and explaining how these differences occurred and why they would be reasonable to expect is an important aspect of this discussion. It should be noted that these comparisons are presented for model validation purposes only and drawing conclusions from these comparisons is considered inappropriate and is not an intended use of the model. In terms of performing analysis, investigating potential effects and impacts, and drawing conclusions, model results should only be compared to other model results of scenarios specifically and carefully configured to simulate the desired alternative system conditions.

Finally, the FryArk RiverWare Model has been developed in a flexible and adaptable manner with the anticipation of ongoing model development to meet a variety of modeling needs and objectives. Future development activities are expected to include enhancements to the model procedures used to simulate important system processes and operations, as well as level of detail refinements to the numerous subsystems of various entities within the Arkansas basin water resource system. Furthermore, the model is intended to evolve alongside the system as various changes to the system's current policy, water uses, and operational procedures occur. Accordingly, the validation and verification of the model is also intended to be an ongoing process with improvements continually being made.

2 DISCUSSION OF MODEL CALIBRATION

In an overall sense, there is relatively little "calibration" done in a traditional ("knob-turning") sense of the word for the FryArk RiverWare Model. The model simulates the physical nature of the system in terms of mass-balances of the various reservoirs, river reaches, and water users that comprise the system networks, which are defined by their actual physical characteristics such as elevation-volume/area and outlet capacity curves and canal capacities. Reservoir evaporation rate patterns were developed from historic evaporation data as possible or obtained from appropriate sources. Reach loss rates are simulated with the basic rates used by the state and actual reach lengths. The model's input local inflows could be described as a type of calibration term as they act as a catch-all term for the aggregated flow gains and losses to the river system that are not explicitly simulated, including the various uncertainties caused by stream gage and data errors, due to the way they are calculated from historic data, and although some smoothing and redistribution is preformed the overall historic volumes are maintained.

System policy and operations are represented with dynamic logic, or rules, that simulate the various objectives and constraints of numerous entities throughout the system, including demands, water right allocations, and operational decisions such as deliveries from storage accounts and other transactions. These rules are written with logical programming that mimics the actual calculations and decision-making processes to the extent possible or necessary considering the various simulated system conditions at the time. These rules often use various real-world constraints such as storage account capacities and legal limits defined in water right decrees and other policy. Additionally, rules regularly utilize specific parameters for various operational criteria and triggers, such as minimum, maximum, and target storages, release seasons, and transaction schedules. The values used for these parameters may are informed by real world operational plans, procedures, and targets wherever possible, but are also often inferred from observed historic conditions and this process could loosely be referred to as calibration.

The only notable use of a truly iterative, multiple model run calibration process was for the development of diversion demand patterns for the basin's agricultural water users. In contrast to simulated municipal demands, which are defined at set values according to current or projected needs (typically annual volumes distributed to daily flow demands with monthly patterns), the demands of agricultural water users are currently simulated in a more dynamic, flexible manner.

Previous basin models have utilized historic diversion data to simulate current and future agricultural demand levels, however historic diversions were controlled by variable factors such as access to, and available volumes in, storage sources and historic water right utilization and native flow availability, and in many cases likely differed from actual full demands. Furthermore, changes to water rights, land uses, irrigation practices, and canal and headgate infrastructure have also no doubt impacted the actual demands of many agricultural water users.

In the FryArk RiverWare Model, matching the agricultural water user diversion levels of historic years, or even matching overall average historic diversions, is not an explicit objective of the model. Rather, the objective is to simulate diversions that are of reasonable magnitudes and year-to-year variability that are consistent with those that have been observed in recent years of varying hydrology. Diversion demand seasons are currently simulated as being the same on a year-to-year basis and have been developed based on the typical patterns observed in historic diversion records, with bias towards those observed in more recent years to more appropriately simulate current conditions. Simulated maximum diversion rates are limited by total water right rates, canal capacities, or typical recent maximum observed diversion rates during periods when they would have had higher native flow allocation. Furthermore, to simulate the effects of conservation measures such as rationing and variable irrigation efficiencies, alternative, reduced demand patterns are used to inform deliveries from storage sources when direct flow water right diversions diminish.

Developing the current set of agricultural demand patterns was an iterative process that required adjusting demand patterns and parameters of water users through many successive model runs. This calibration process was necessary due to the interdependent nature of native flow allocation under water right priority system, as well as shared access to various storage sources. Because of these interdependencies, altering the demand patterns of one water user would not only affect the simulated diversions to that user, but also to other users who would receive higher native flow allocations or have increased access to storage volumes.

3 Description of the 5-Year (2011-2015) Current Conditions Comparison Run

The remaining sections in this appendix present comparisons and discussion of simulated model results to the corresponding historic conditions. The model run that has been used for this purpose is referred to as the “5-year, 2011-2015, current conditions comparison run”. This model scenario uses input hydrology from 10/1/2010 to 12/31/2015 and is initialized with reservoir and account storages from 9/30/2010. This period was selected for the comparison runs based on the relative stationarity of basin policy, water uses, and operational procedures, as well as data availability. Despite being a short period, it does contain a good sampling of natural hydrologic conditions. Based on the full 65-year period of record of Pueblo Reservoir natural inflow forecasts, this 5-year period contains the 4th driest year (2012) and the 3rd (2011) and 4th (2015) wettest years, as well as an average-dry year (2013) and an average-wet year (2014). The natural hydrologic conditions of these years is illustrated relative to the period of record in Figure 1.

This scenario was developed to aid in these types of historic comparisons by forcing only some select parameters to approximate historic observed values. However, it doesn’t simulate the variable and evolving policy and operations observed through this period, nor does it set all demands, storage accounts, accounting transactions, etc., to historic values. For everything not listed below, the simulation is equivalent to that in the 2017 scenario as defined in the model documentation.

The parameters that are set to approximate historic values in this model configuration are:

- Otero Pipeline (direct from Twin Lakes) demands are set to the historic monthly diversions. Note: CSU values were provided by CSU. Data was requested directly from Aurora but never obtained. Data provided by Reclamation for this diversion was missing a large amount of Otero diversions and the results of back-calculating “Aurora Monthly Volume” as “Total Monthly Otero Volume” – “CSU Monthly Volume” were poor. Thus, Aurora annual Otero demands for this run are set as the 2012 demands for 2013-2015, not as their actual historic deliveries.
- Pueblo Water and Comanche Power Plant demands are set to the historic monthly values provided by Pueblo Water. For their municipal demands, the model diverts them all from Pueblo Reservoir and doesn't use the NS river intake even though in the historic period there were some diversions through the NS intake.
- Historic CSU FVC diversions are forced to historic values provided by CSU. The other FVC entities are assumed to run at their total capacity, which is consistent with historic data.
- There are no SDS diversions simulated in this run, as the SDS diversion data received was incomplete, even though it appears that there were some actual SDS diversions in 2015.
- CSU return flows are set to the historic values provided by CSU, although the accounting of them is generated with the same general split ratios used by the other scenario runs.

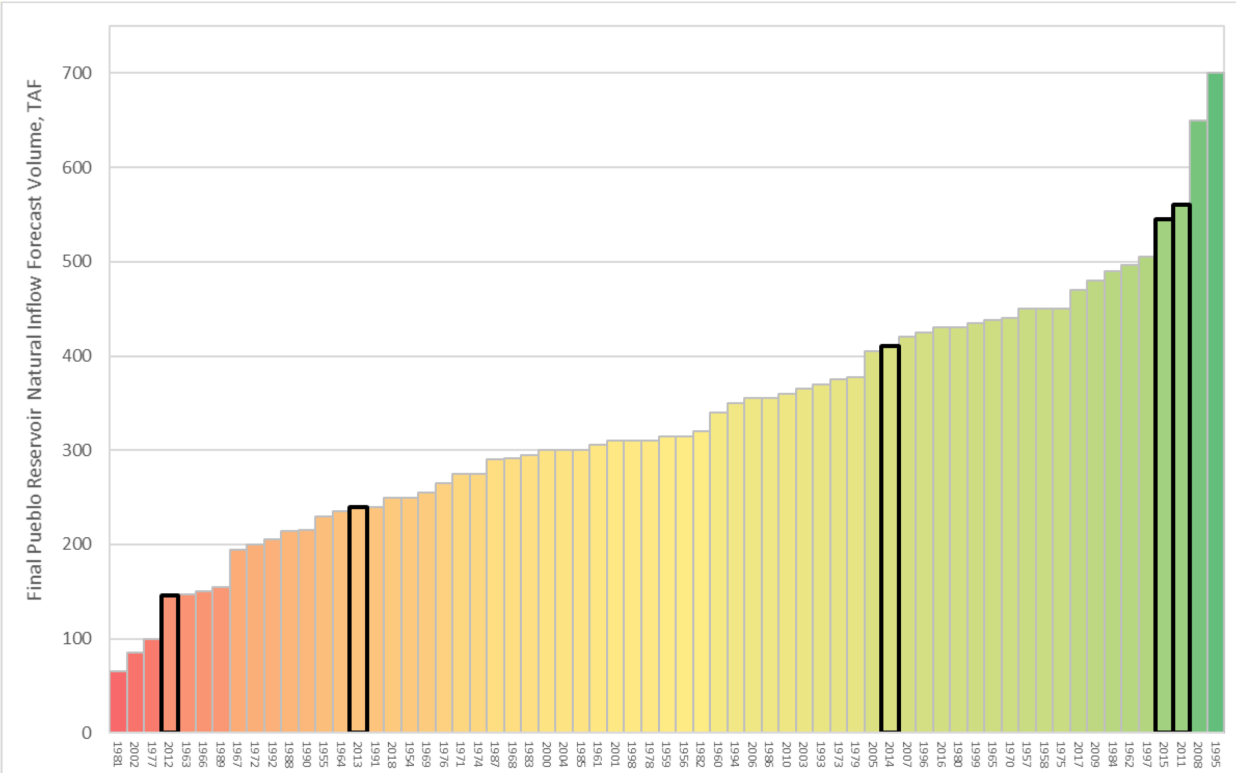

Figure 1: Relative Natural Hydrology Conditions of Comparison Run Years, 2011-2015.

4 SIMULATED RESERVOIR AND ACCOUNT STORAGES

This section presents comparisons of simulated and historic reservoir total physical storage and reservoir storage account storage data from 10/1/2010 to 12/31/2015 from the previously described "current conditions comparison" run. These comparisons are presented visually in plots, and similarities and differences between simulated and historic conditions are discussed in a narrative, qualitative manner. A main reason that this is done to emphasize that direct and quantifiable comparisons between simulated and historic conditions is not considered appropriate. It is imperative that quantifiable comparisons of simulated model results should only be made to other model results representing alternative scenarios.

One simple example of why such a comparison between model results and historic values would be inappropriate is that even over this short and recent 2011-2015 period, the maximum capacities of many EC storage accounts in Pueblo Reservoir varied significantly. Several long-term EC accounts grew in capacity according to their contracts and many annual EC accounts varied up and down in size or even existed in some years but not others. Contrarily, over the 5-year "current condition comparison" model run, all EC accounts are simulated as having the same capacity throughout the full run, and thus comparisons of any statistics (e.g., average total EC storage) between simulated and historic values are invalid; they are comparing apples to oranges.

Throughout all of these plots solid lines are used to display simulated storages and dashed lines show historic storages. Please note that dates in all plots in this section show 10/1/1990-12/31/1995 but translate to historic dates of 10/1/2010-12/31/2015.

4.1 FRYARK PROJECT WATER

The first three plots below display various simulated FryArk Project Water (PW) parameters in comparison to historic levels. Figure 2 shows the total combined PW (black lines) throughout the system, which is the sum of the PW volumes in Turquoise Lake (green), Twin Lakes Reservoir (pink), and Pueblo Reservoir (blue), which are also shown individually. As observed in the plots, general total PW volumes track reasonably well with respect to historic levels, including the order of magnitude of total volumes, timing of inflows and outflows, and distribution of the overall volume between the various reservoir where it is stored. However, there are some notable differences between simulated and historic conditions that may be discussed in more detail to help describe why certain deviations do exist.

For example, the irregular PW operations due to the Homestake maintenance project that occurred during late 2010 and into 2011 are obvious in Figure 2 when compared to the simulated system conditions that represent more typical PW operational patterns. During this period, the historic Turquoise PW storage decreased significantly more (almost to empty) than is simulated as the PW was atypically released downstream to Pueblo to make room for the irregular Homestake import inflows. The corresponding increase in historic Pueblo Reservoir PW storage with respect to simulated levels is also evident. This operational difference also leads to some additional cascading effects on the PW system as will be discussed shortly.

Figure 3 and Figure 4 show the PW volumes by PW group stored in Pueblo Reservoir. Figure 3 shows the Fountain Valley Authority (purple lines) and Pueblo Water (blue) PW storages and Figure 4 shows Agricultural (green), East of Pueblo (yellow), West of Pueblo (pink), and Other (teal) PW storages. It should be noted that as currently operated in the real world, the actual location of the PW storages of various entities is unspecified, while in the model, allocated PW is currently simulated as all being stored in Pueblo Reservoir.

It is entirely expected that reasonable deviations will exist between simulated and historic PW storages, and some of these differences can be explained quite simply. For example, simulated PW allocations to Pueblo Water are based on a PW storage volume target that is currently assumed to be the same for each year of the model run. Thus, there are some differences in their simulated PW storages when compared to historic levels, as can be seen during in the 2013-2015 period before their historic 2015 allocation increased their PW storage back up to near the simulated target level (which was developed based on their historic data). A very similar situation is also observed in the East of Pueblo PW group storage during the 2012-2014 period.

Many other differences between simulated and historic conditions can be thoroughly explained due to the successive and compounding effects of differences in simulated operational decisions and subsequent basin conditions that occurred earlier within the model run. As previously alluded to, a prime example of this type of situation presents itself in the comparison between simulated and historic Agricultural PW storages in 2011-2012 (green lines in Figure 4). In the historic condition, there was a large influx of PW into Pueblo Reservoir due to the need to empty storage space in Turquoise Lake for the Homestake maintenance project. This led to additional PW being made available for allocation in Pueblo Reservoir, a large amount of which ended up being allocated to agricultural users and used for irrigation in the later parts of the 2011 season (as seen as the large dashed-green peak). As simulated by the model, a much smaller amount of PW volume is allocated to agricultural use early in 2011, and although there is significant allocation to agricultural PW users later in 2011, the overall amount of PW remaining in the system during the end of 2011 and moving into 2012 is notably higher (as seen in the black lines in Figure 2). Subsequently, the model simulates this higher overall PW volume being allocated in 2012, with a large portion going to agricultural PW users (the solid-green spike in 2012) but also notably higher allocations being simulated to all other PW groups (seen as the steps up in all solid lines in 2012). Historically in 2012, however, there were very minimal allocations of PW, as seen by the lack of steps up in PW group storages (all dashed lines), including the very small amount of PW allocation to agricultural users (dashed-green line).

Furthermore, other direct and indirect differences between simulated results and historic conditions throughout the system can also often be traced back to the type of cascading deviations illustrated by the previous example. For example, due to the significantly higher simulated allocation of PW volume to agricultural users in 2012, it would also be reasonable to expect that the simulated total diversions made to the agricultural PW water users in 2012 would also be significantly higher than occurred historically due to the additional source of storage. This expected result can be observed later in this appendix in Figure 43. This situation presents a prime example of how the dynamicity of this model can capture potential impacts or effects that previous models of the system would have a limited ability to simulate. Models that force certain decisions and values to those that occurred historically will be very limited in their ability to adequately capture these kinds of effects.

Overall, the simulated PW storage levels, allocations (i.e., inflows), and uses (i.e., outflows) of the various groups compare quite well with respect to historic values. This is especially true considering that PW allocations and uses are simulated dynamically in a simplified lumped manner within the model and are not forced to match historic values. In reality, the historic PW allocations to the groups are the aggregated result of the independent decisions of the various entities that make up each group. This can range from a single to many entities, and each makes its own independent allocation requests based on the individual needs and conditions of its own system, while subject to the overall rules and limitations provided in the allocation principles. Furthermore, the total amount, and the timing of, the PW volume made available for allocation by SECWCD and Reclamation each year can be rather variable and dependent on imperfect hydrologic forecasts and other system conditions and needs, such as the Homestake maintenance project previously mentioned.

On the PW usage side, the way each individual entity decides to make use of its PW volumes can also vary significantly between entities, and even a given entity may not be consistent on a year-by-year basis. For example, the priority order by which an entity may elect to use its different water supply sources may vary from year to year depending on many complex factors that are currently infeasible to simulate based on the information available and current representation of their system within the model. Furthermore, the amount of PW that each entity might choose to carry over to the next season can also vary significantly.

Due to these important distinctions between the simulated and historic decisions and overall PW operations throughout the system, the model's current representation of PW operations is considered very adequate for its present uses.

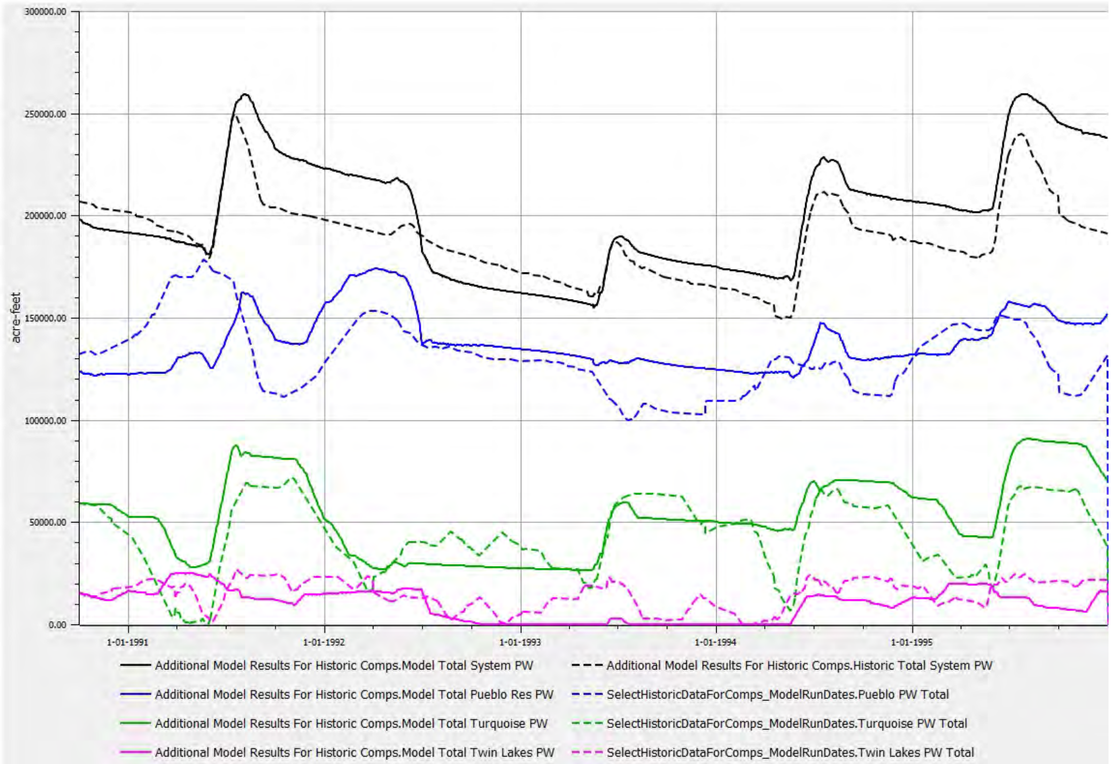

Figure 2: Total System and By Location Project Water Storages, Simulated vs. Historic

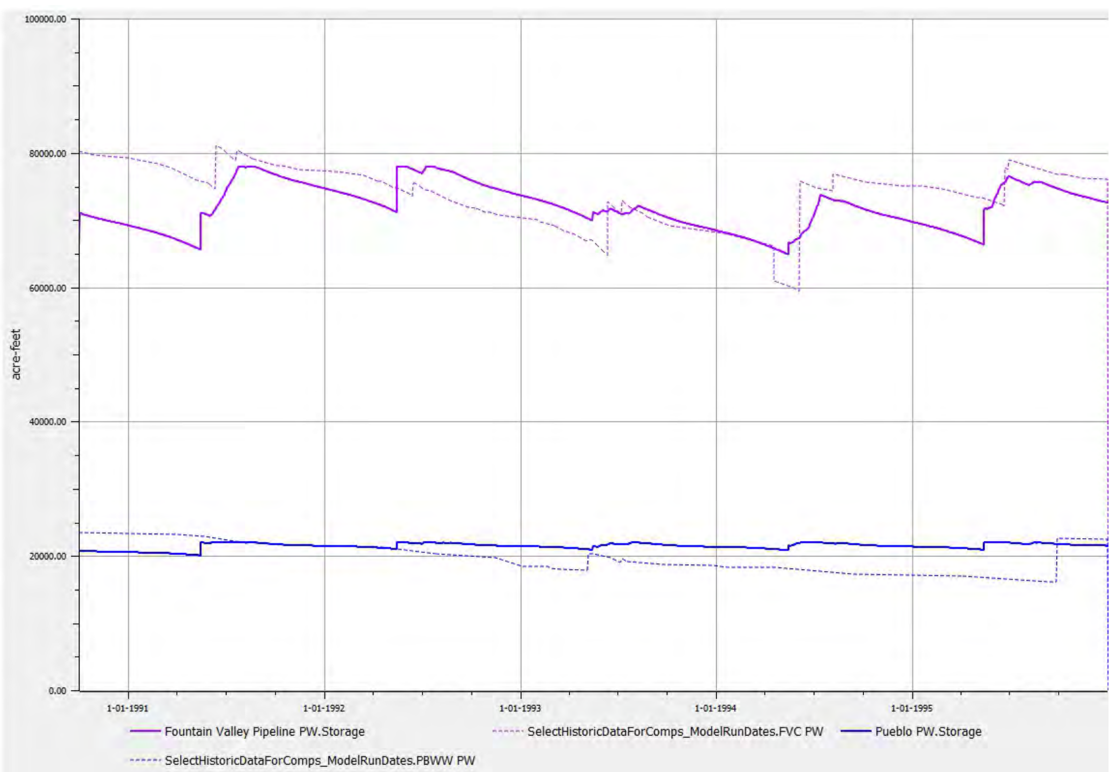

Figure 3: Pueblo Reservoir Project Water Storages by Group, Fountain Valley Authority & Pueblo Water, Simulated vs. Historic

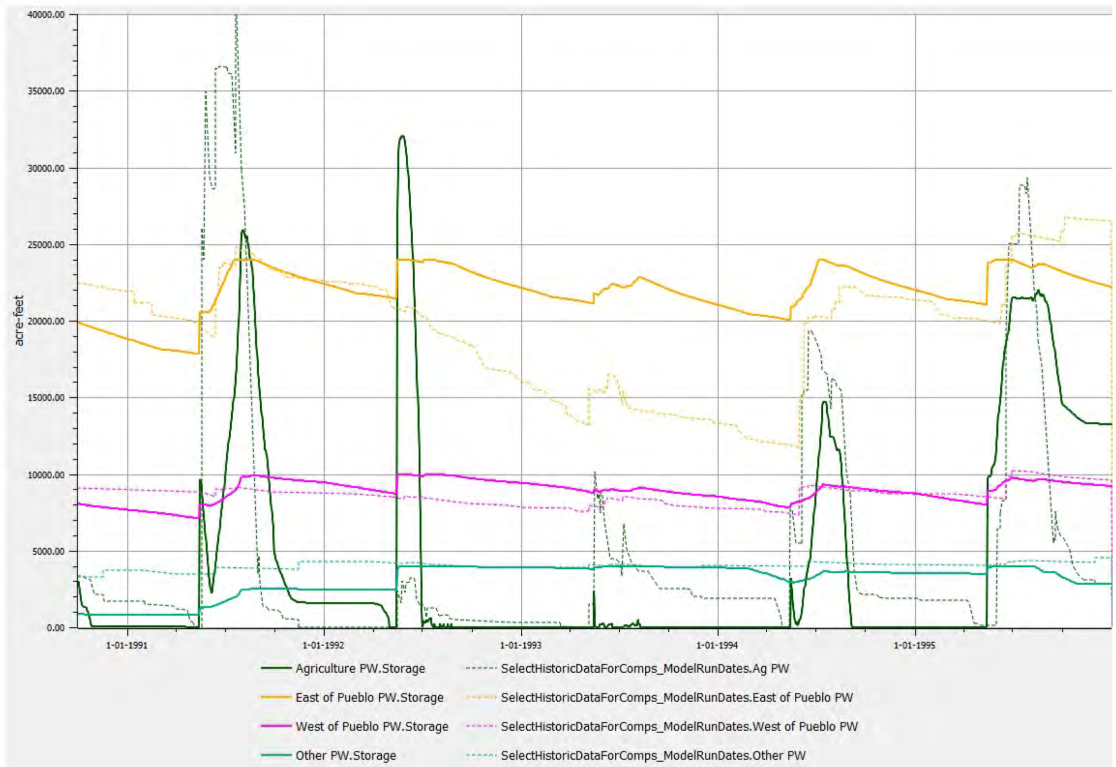

Figure 4: Pueblo Reservoir Project Water Storages by Group, Other Groups, Simulated vs. Historic

4.2 Turquoise Lake

The simulated total storage and Project Water storage of Turquoise Lake is shown in below in Figure 5 compared to the historic storages. Subsequently, Figure 6 shows the comparisons for the other account storages, including the total CSU and Aurora storages, which are each the sum of their Homestake and CFI account storages, and Pueblo Water's portion of the CFI storage account.

Overall, in most of the simulated years, the total Turquoise Lake storage tracks reasonably well with historic values, especially in respect to the timing and rates of the filling and drawdown periods, and the general peak storage levels. The historic operational procedures of Turquoise Lake are considered non-standard and can vary on a year-to-year basis at the operator's discretion for various purposes, but the model seems to simulate the overall conditions quite well. Additionally, Reclamation operator's have stated that a general operational objective into the future is to maintain higher minimum storages than the reservoir has been operated to in the past, and the operational rules were developed to account for this. The irregular operations due to the Homestake maintenance project and the associated effects near the beginning of the period have been previously discussed.

The simulated total storage deviates significantly from historic in late 2012 and into the spring of 2013 when it doesn't draw down to nearly as low of a level. As shown in the second plot, this is almost entirely because the historic 2012 drawdown of most of CSU's storage isn't simulated at all in the model. The reason for this deviation isn't entirely clear, although CSU balances its levels with its many other storage accounts throughout the basin and varied levels in Turquoise could be due to many factors. Aurora's simulated storage in Turquoise tends to be maintained at lower levels that historic, which may be because the model currently prefers to keep as much of their storage in Twin Lakes Reservoir as possible. The operational rules, targets, and various criteria used to operate and balance CSU and Aurora's accounts between Turquoise, Twin Lakes, and Pueblo Reservoir are relatively basic due to the lack of detailed historic data, such as the historic breakdown of total Homestake account storage between CSU and Aurora, and other operational information.

Pueblo Water's storage in Turquoise essentially remains full for the entire model run, which also occurs similarly in their other storage locations throughout the basin and is discussed later in the Clear Creek Reservoir subsection.

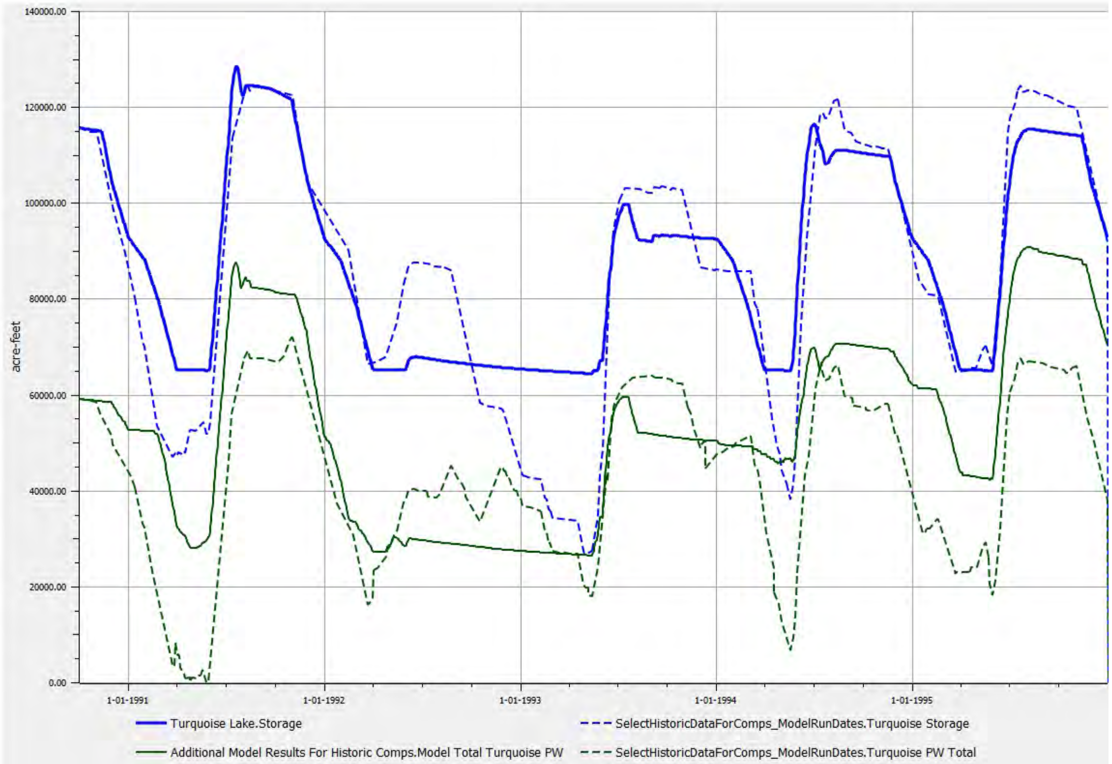

Figure 5: Turquoise Lake Total Storage and Project Water Storage, Simulated vs. Historic

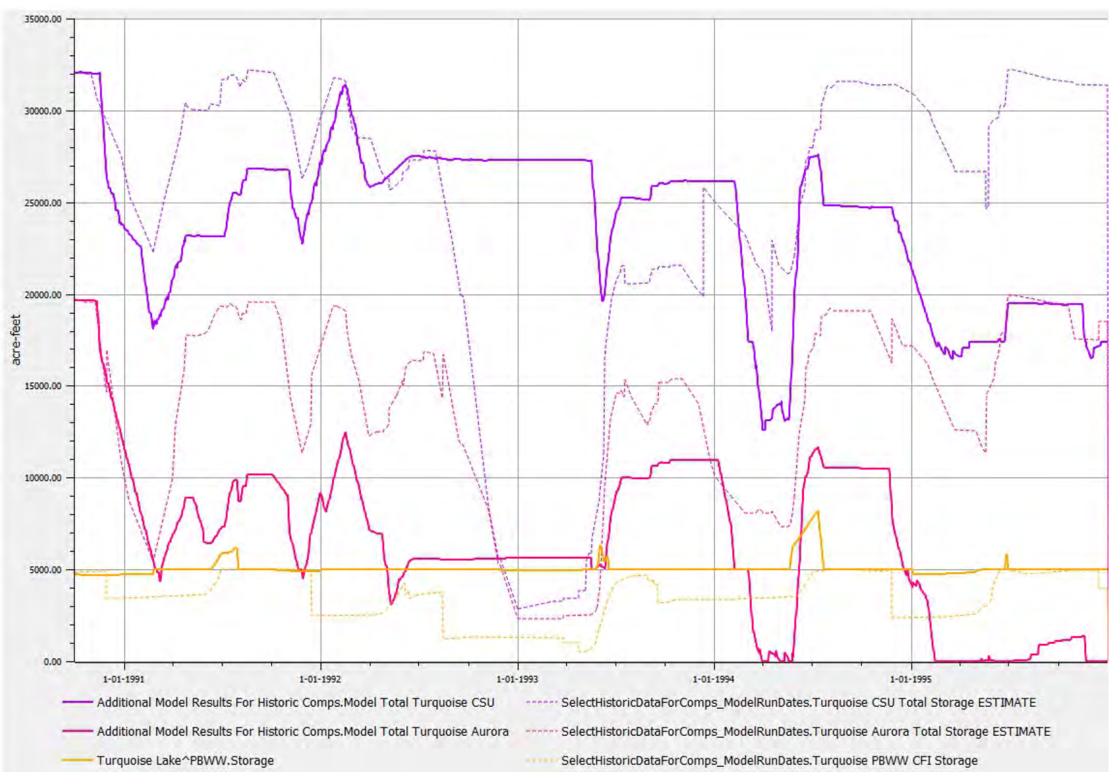

Figure 6: Turquoise Lake Grouped Account Storages, Simulated vs. Historic

4.3 Twin Lakes Reservoir

The simulated total storage in Twin Lakes Reservoir is shown below in Figure 7 compared to the historic storage. Subsequently, Figure 8 shows the comparisons of Project Water storage and lumped TLCC account storage, which includes subaccounts owned by CSU, Pueblo Water, Pueblo West, Aurora, and many other minor TLCC shareholders. Overall, the total physical and lumped account storages compare reasonably well to the historic storage levels and variability.

Detailed historic subaccount storages for the TLCC parties was not provided, and thus the operational rules, targets, and various criteria used to operate these accounts at individual levels are relatively simplified. Additionally, the total historic volumes of unaccounted and/or native admin storage (i.e., total physical storage minus aggregated account storages) varies significantly on a year-to-year basis for unspecified reasons (ranging from ~47,000 to 59,000 acre-feet in this 5 year period), but is simulated at a constant volume of 54,580 acre-feet throughout the model run.

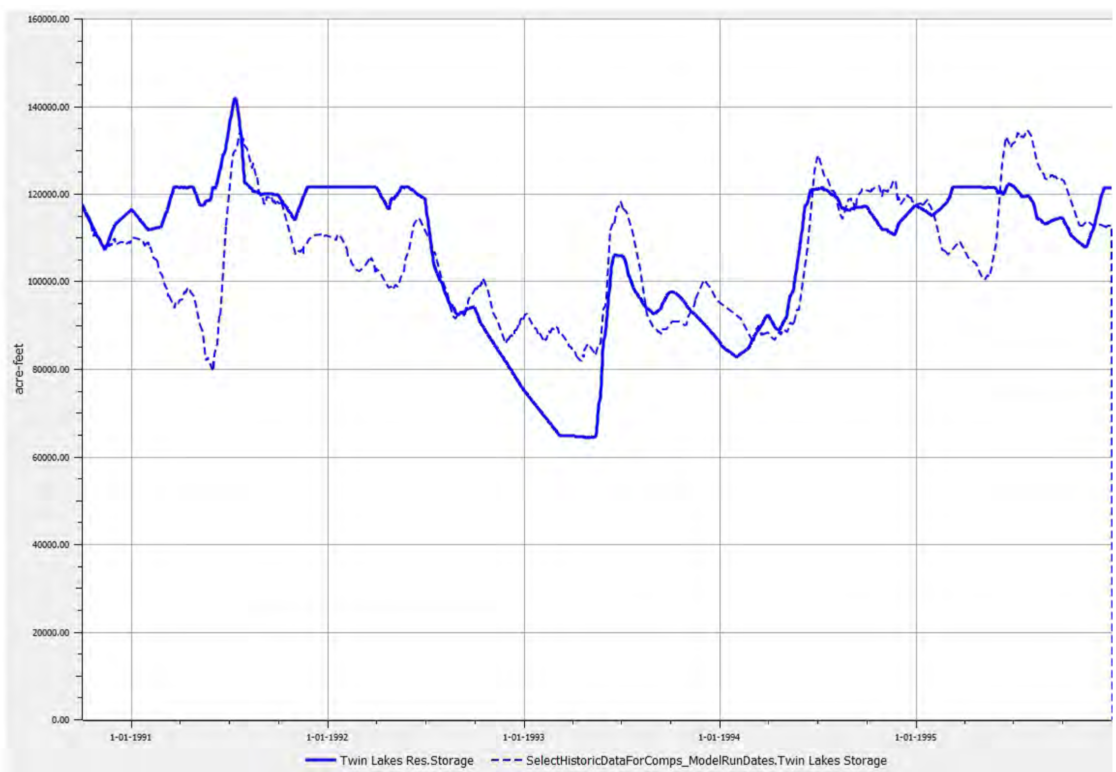

Figure 7: Twin Lakes Reservoir Total Storage, Simulated vs. Historic

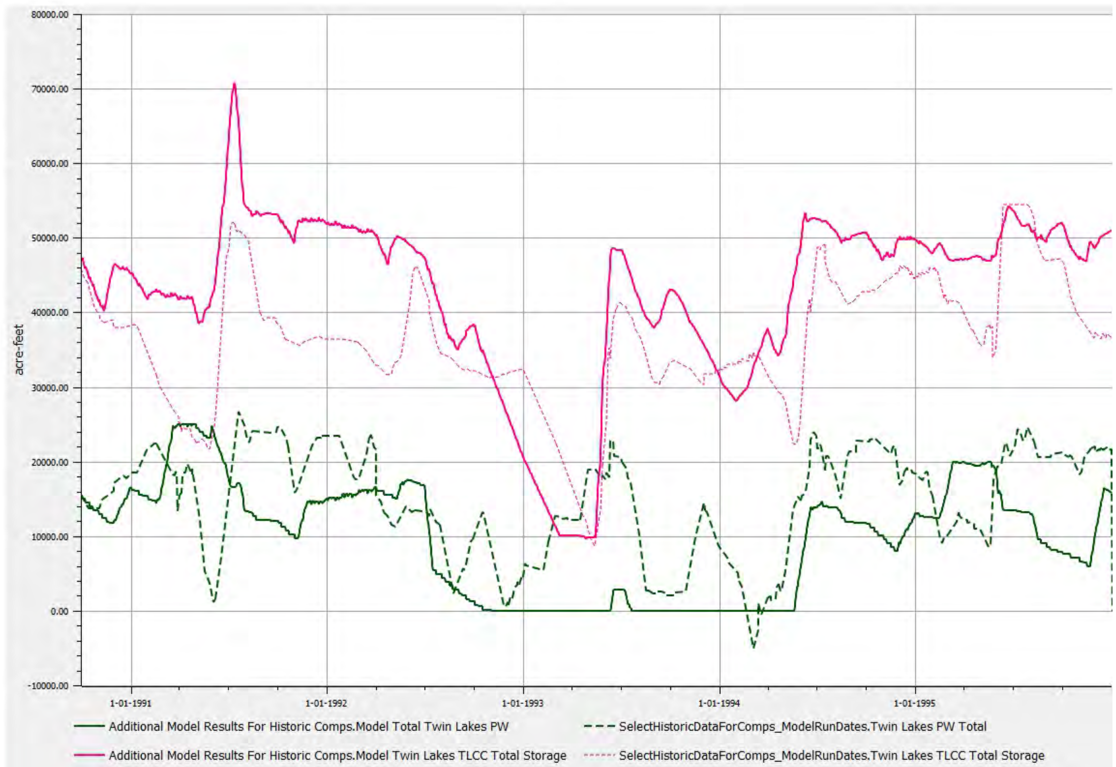

Figure 8: Twin Lakes Reservoir Grouped Account Storages, Simulated vs. Historic

4.4 Clear Creek Reservoir

The simulated storage of Clear Creek Reservoir is shown in Figure 9 below compared to the reservoir's historic storage. Clear Creek Reservoir is entirely owned and operated by Pueblo Water as a main part of their own complex, multiple source and demand water supply system that also includes storage accounts in Turquoise Lake, Twin Lakes, and Pueblo Reservoir. Due largely to the complicated management of multiple storage accounts and variable yields of their many sources, the operations of Clear Creek Reservoir can vary on a year-to-year basis and often do not follow any set procedures or guidelines. Generally, the reservoir stores under its two storage water rights during the winter and during spring runoff conditions, but generally otherwise must pass its native inflows to more senior downstream water rights, although they also can exchange into Clear Creek Reservoir from other sources including imports and other reservoirs.

Clear Creek Reservoir operations and accounting are currently simulated in a simplified manner, storing its native inflows as much as allowed by its storage rights and only releasing when nearly full or when the water is specifically needed in Pueblo Reservoir to meet its direct diversion demands. As currently simulated, this is considered a slightly more complex type of "fill and spill" operations. More advanced operational procedures along the lines of "look-ahead" forecasting are not currently simulated and likely account for some notable differences from historic conditions such as the lack of pre-storage period drawdowns in the spring of 2011 and later 2013-2014.

The maximum storage level that the reservoir is operated to has also been varied in recent years for various reasons and is simulated in the model at the current maximum level. Following Pueblo Water's current operational procedures, simulated storages can only exceed that level when caused by high inflows that exceed the reservoir's limited release capacity. This largely accounts for the lower simulated peak storages in 2011, 2014, and 2015 as compared to those that were observed historically. Additionally, the minimum storage levels that Clear Creek Reservoir has been operated to have varied slightly in recent years for various reasons, and the model is currently set to operate to a typical minimum storage based on recent historic conditions.

When releases are determined to be necessary by the model's rules, they are simulated at typical rates and schedules developed from the recent historic reservoir conditions. Thus, the simulated drawdown period in 2011 matches historic conditions nearly identical in rate and timing, while the simulated drawdowns in 2014 and 2015 occur following and before, respectively, and at slightly different rates than occurred historically in those years.

Finally, and notably, Pueblo Water often leases significant amounts of its water supply to other basin entities when its own system is in surplus conditions, which occurs quite regularly as their senior water rights and transbasin import sources generally provide adequate supply. The current lack of adequate simulation of these significant lease volumes very likely accounts for the higher simulated storages of all of Pueblo Water's reservoir accounts as compared to historic levels, as shown above for Turquoise Lake and Twin Lakes Reservoir, and in Appendix A for Pueblo Water's Excess Capacity account in Pueblo Reservoir. Due to lack of information and resource limitations, Reclamation elected to assume that the simulated spill from (and/or lack of exercise of their water rights due to) their full storage accounts to the system's native flow would be a reasonable approximation of the water that they would have otherwise leased to other entities. It is reasonable to expect that the regularly full conditions of Pueblo

Water's other storage accounts throughout the basin may result in a tendency to maintain higher storage levels in Clear Creek Reservoir. It is postulated that this may largely account for the higher simulated storages as compared to historic that are observed during the 2012-2014 period.

On an overall basis, the simulation of Clear Creek Reservoir operations and storage conditions is considered to be a reasonable representation of those that could be expected under the basin's current policy, water uses, and operations.

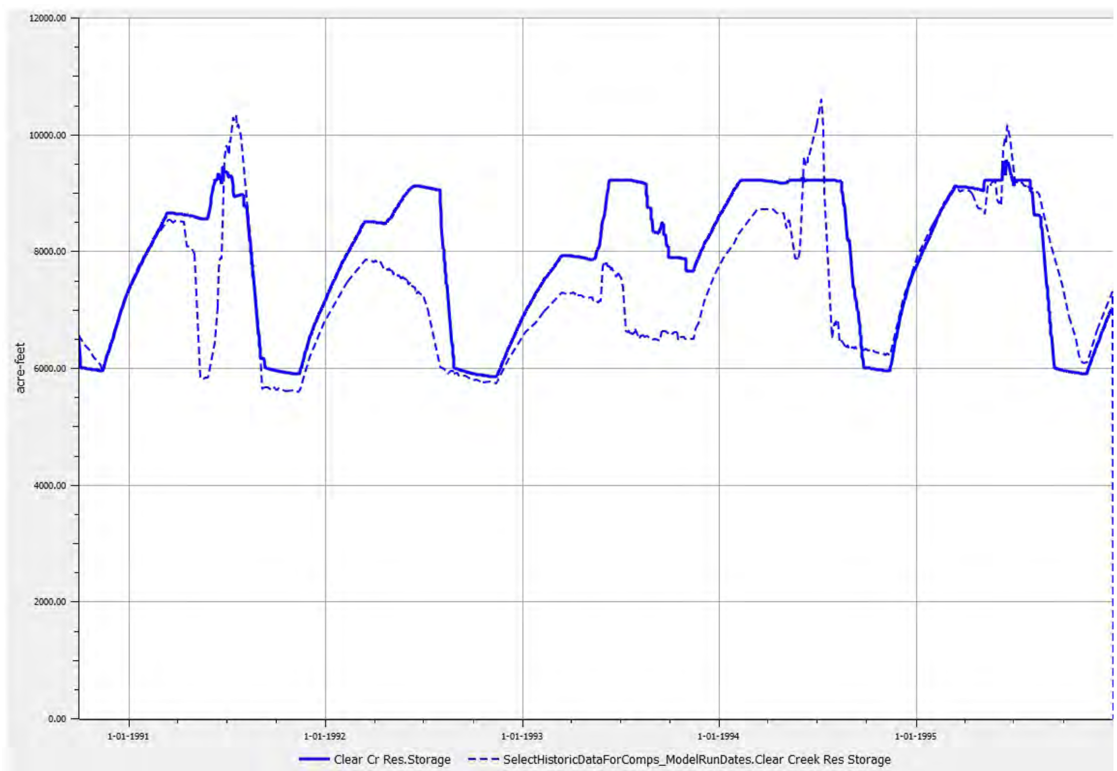

Figure 9: Clear Creek Reservoir Total Storage, Simulated vs. Historic

4.5 PUEBLO RESERVOIR

The simulated total physical and Project Water storage in Pueblo Reservoir is shown below in Figure 10 compared to the historic storage. Subsequently, Figure 11 shows the comparisons of total lumped Excess Capacity (EC) storage and total lumped Winter Water storage, each of which represent the aggregated storage of their many unique subaccounts.

Overall, the total physical, Project Water, and lumped account storages compare reasonably well to the historic storage levels and variability. The early deviations of simulated total and Project Water storages from historic levels can be largely explained by the altered operations for the Homestake maintenance project previously discussed.

The relatively higher total EC storage levels observed in the model results is likely because the model is configured to simulate the suite of EC accounts present in the 2017 scenario which represents higher total combined EC account maximum capacities than was historically present. Further breakdown of simulated EC account storages by type (Long-Term, Master Contract, and Annual/Temporary), as well as individual EC accounts, are shown in Appendix A: “Simulated Excess Capacity Account Storage Plots”.

The simulated Winter Water storages track quite well with historic levels in most years, both during the WW storage season and the subsequent period in which the storage is used.

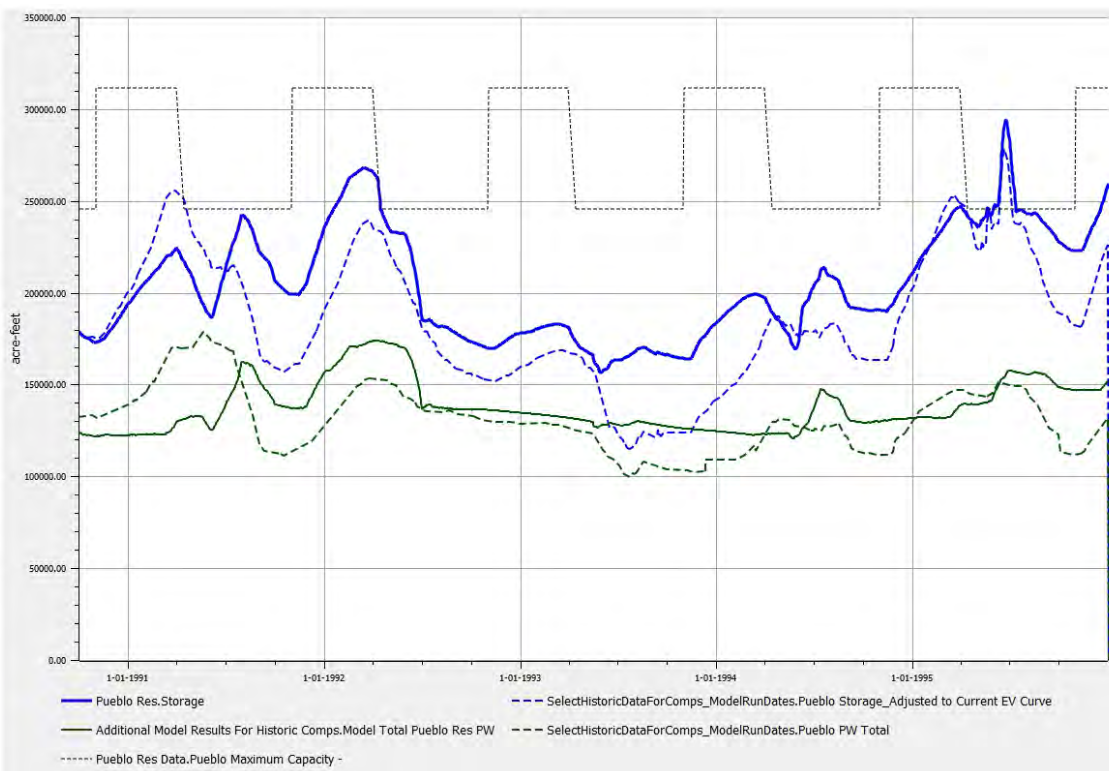

Figure 10: Pueblo Reservoir Total Storage and Project Water Storage, Simulated vs. Historic

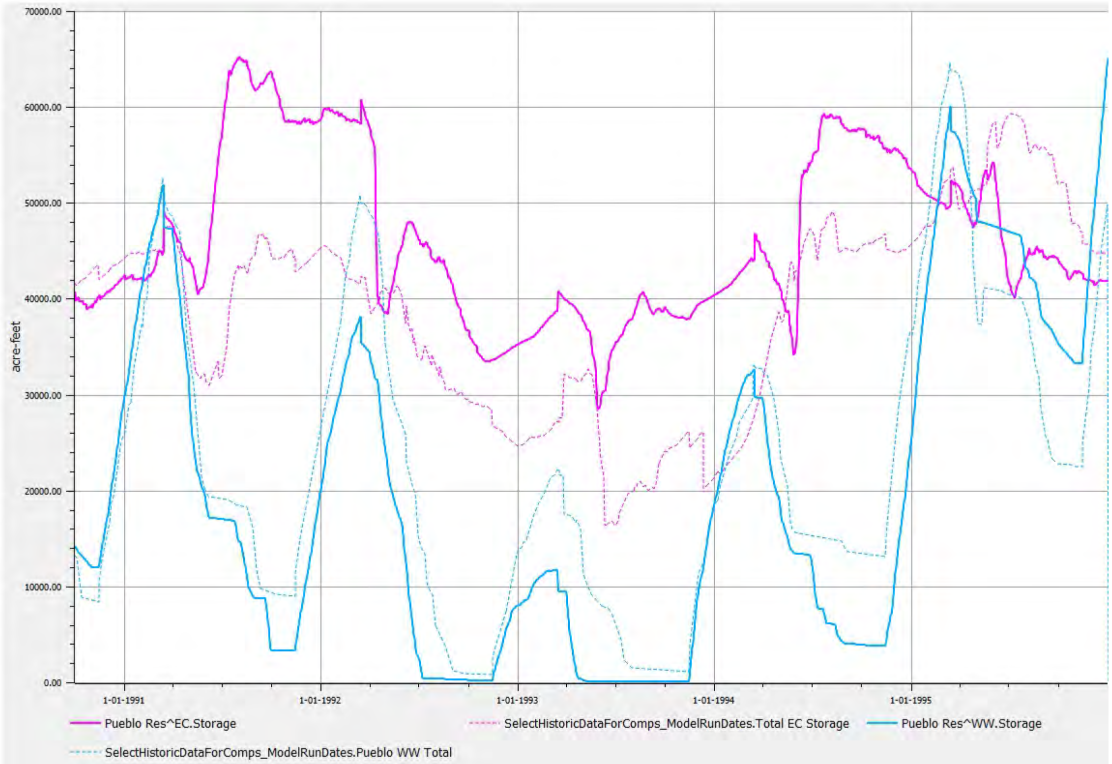

Figure 11: Pueblo Reservoir Consolidated Account Storages, Simulated vs. Historic

4.6 COLORADO CANAL SYSTEM STORAGE

The simulated combined storage in the Colorado Canal reservoirs of Lake Meredith and Lake Henry is shown below in Figure 12 compared to historic storages. In general, simulated storage magnitudes and operational patterns (such the timing of filling and drawdown periods) agree very well with historic. This is especially true considering the variable and evolving nature of actual system operations due largely in part to the evolving operations of their major municipal stakeholders. Furthermore, Colorado Canal system operations are currently simulated in a very basic, simplified manner in the model as compared to the complex nature of real world operations, such as detailed storage sub-accounting and the use of the system for recapture of owned river flows by entities such as CSU. Historic storage account breakdowns of Colorado Canal storages were not made available.

Adequate historic storage data for the Holbrook Canal reservoirs was not available for comparison of simulated storage in the Holbrook Canal system to historic. Furthermore, management of Holbrook Canal reservoirs has been variable in nature due to irregular operational procedures such as whether or not Winter Water is diverted or stored within the canal system or in other locations, such as Lake Meredith, and various temporary contracts with municipal entities (e.g., Aurora) to allow for temporary storage or their water within the system. Thus, even if comparisons were achievable they may be limited in their relevance and usefulness.

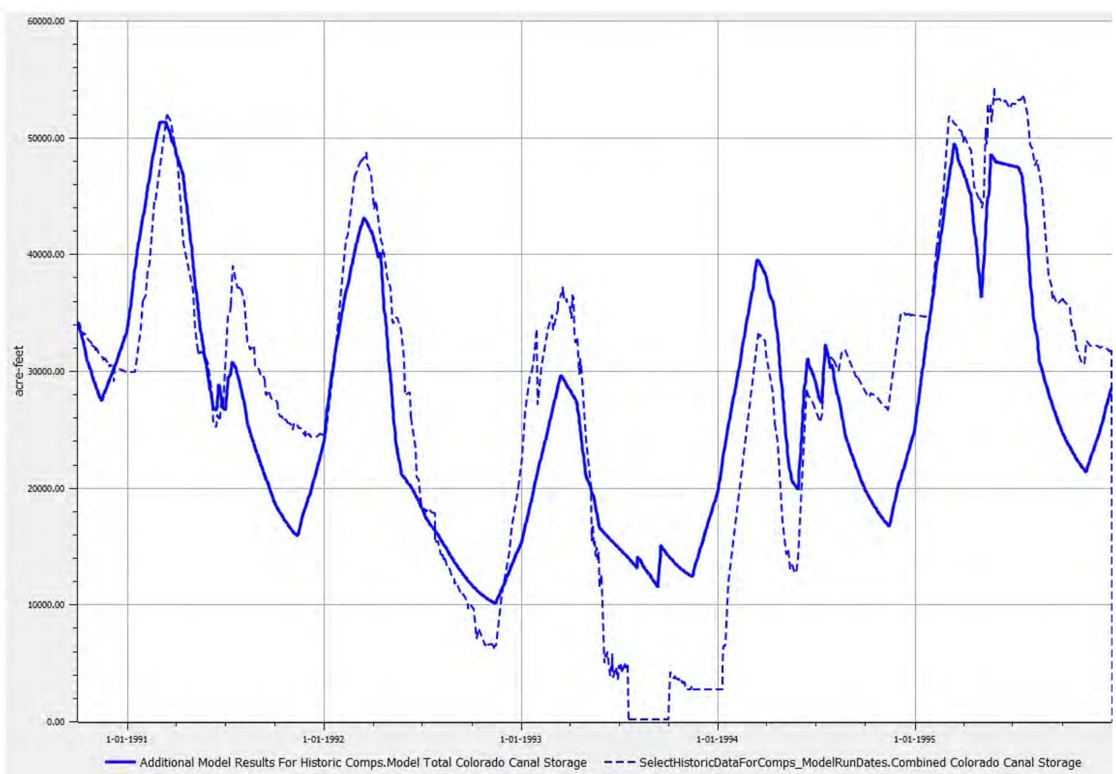

Figure 12: Total Colorado Canal Storage (Lakes Meredith and Henry Combined), Simulated vs. Historic

5 Simulated Streamflows

This section presents comparisons of simulated and historic streamflow gage data from 10/1/2010 to 12/31/2015 from the previously described "current conditions comparison" run. This analysis was performed with overlapping data from both datasets, simulated and historic. If historic data are missing, then the simulated data for that missing period was not considered.

As a reminder, these types of quantitative analysis between simulated and historic conditions are not recommended because the model represents an altered system condition than occurred historically. Despite this incompatibility, it was still desired to present these statistical comparisons of simulated and historic time series to maintain consistency with previous modeling efforts and studies. However, remember that there is no expectation that the simulated results should recreate the historic conditions, and thus that these comparisons have limited applicability in evaluating the ability of the model to reasonably and accurately simulate the system.

5.1 Lake Creek Below Twin Lakes Gage

This streamflow gage represents the outflow from Twin Lakes Reservoir, and thus is dependent on the reservoir's operations. Thus, the various differences observed in streamflow at this location can largely be attributed to the differences in simulated and historic Twin Lakes Reservoir operations, which have previously been discussed.

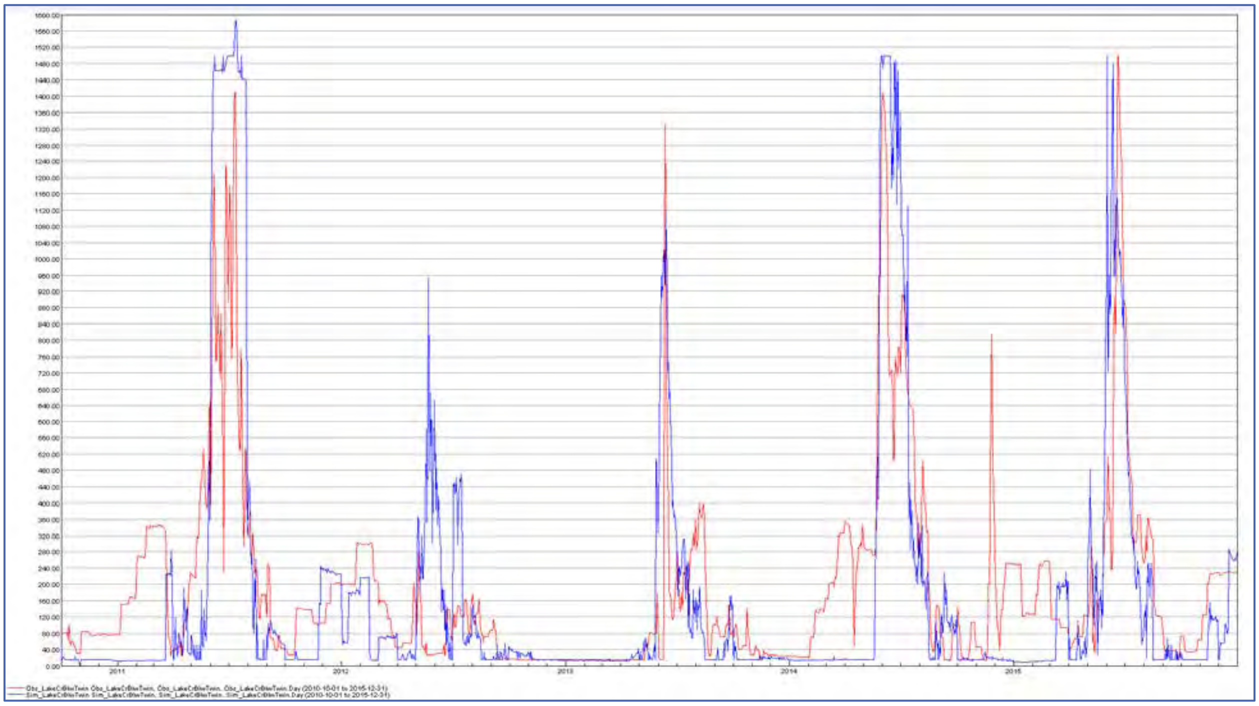

Figure 13: Lake Creek below Twin Lakes gage historic and simulated flow time series. Historic flow is red, simulated is blue.

Table 1: Summary Statistics for Lake Creek below Twin Lakes historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	2.7		2.8		4.8	
Mean	190.0		175.0		-8.6	
Std Deviation	241.2		348.0		30.7	
Variance	58160		121086		52.0	
Median	113		18.5		-510.7	
25th Percentile	36.1		15		-140.7	
75th Percentile	248		172		-43.7	
Minimum	12.8		3		-302.2	
Maximum	1500		1585		5.4	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	200.8	179.2	190.5	159.4	-5.4	-12.5

5.2 GRANITE GAGE

Flow at this gage in the Upper Arkansas River headwaters region is largely dependent on the operations of both Turquoise Lake and Twin Lakes Reservoir. Thus, the various differences observed can largely be attributed to the differences in simulated and historic operations of these reservoirs, which have previously been discussed.

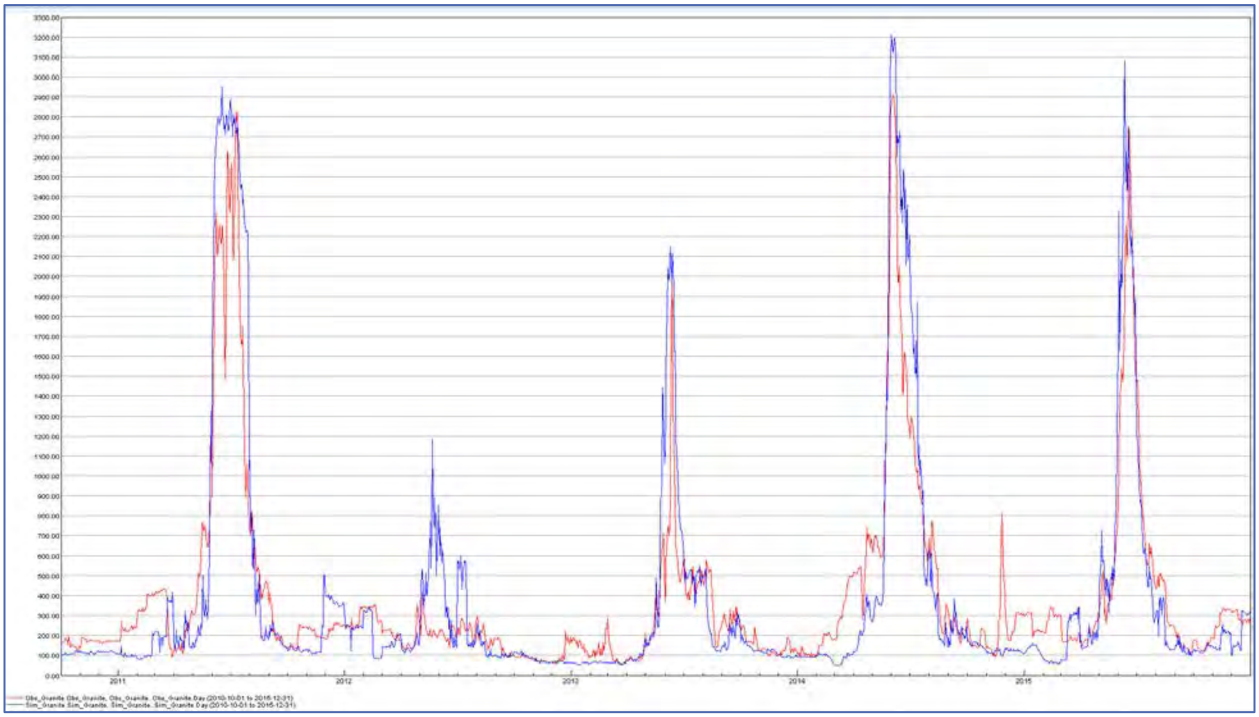

Figure 14: Granite gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 2: Summary statistics for Granite gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	3.1		2.8		-8.0	
Mean	391.4		393.1		0.4	
Std Deviation	483.3		629.3		23.2	
Variance	233617		396017		41.0	
Median	230		148.7		-54.6	
25th Percentile	159		107		-48.5	
75th Percentile	390		335		-16.5	
Minimum	57.1		51		-12.0	
Maximum	2910		3209		9.3	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	413.0	369.7	421.2	364.9	2.0	-1.3

5.3 WELLSVILLE GAGE

Flow at this gage in the remains dependent on the operations of both Turquoise Lake and Twin Lakes Reservoir, although this gage is further downstream and therefore also dependent on many diversions and tributary inflows that occur along the way. The various differences observed can still largely be attributed to the differences in simulated and historic operations of these reservoirs, which have previously been discussed. Overall, the orders of magnitudes and flow variability and timing compare quite well with historic flows.

Figure 15: Wellsville gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 3: Summary statistics for Wellsville gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	3.3		3.2		-4.6	
Mean	679.5		682.9		0.5	
Std Deviation	762.7		930.6		18.0	
Variance	581785		865926		32.8	
Median	435		365.6		-19.0	
25th Percentile	335		274		-22.2	
75th Percentile	597		553		-8.1	
Minimum	0		174		100.0	
Maximum	5360		5897		9.1	
Count	1916		1916			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	713.6	645.3	724.5	641.2	1.5	-0.6

5.4 Portland Gage

This streamflow gage is immediately upstream from Pueblo Reservoir and represents the mainstem inflows to the reservoir. The description of this comparison is essentially the same as that for the further upstream Wellsville gage, although there are numerous diversions and inflows between them.

Figure 16: Portland gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 4: Summary statistics for Portland gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	3.5		3.3		-3.8	
Mean	719.9		682.9		-5.4	
Std Deviation	903.1		1001.7		9.8	
Variance	815676		1003313		18.7	
Median	439		356.2		-23.3	
25th Percentile	295.25		246		-19.9	
75th Percentile	633		536		-18.1	
Minimum	68.7		55		-24.5	
Maximum	6850		7155		4.3	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	760.4	679.5	727.7	638.0	-4.5	-6.5

5.5 Above Pueblo Flow Location

This is a calculated flow location that represents the total outflow of Pueblo Reservoir to the Arkansas River and thus is dependent on Pueblo Reservoir operations. The various differences observed in streamflow at this location can largely be attributed to the differences between simulated and historic Pueblo Reservoir operations, which have previously been discussed.

During Reclamation's model review, attention was called to the short-duration, >2,000 cfs spike that occurs during the spring of 2012 in simulated results but not historic. These types of events also occurred in model output of other scenarios and hydrology periods. These were thoroughly investigated, and it was determined that they were caused by evacuation of EC storage from Pueblo Reservoir to meet Joint Use Pool restrictions set by the U.S. Army Corps of Engineers for flood control purposes. As is shown above in Figure 10, the simulated Pueblo Reservoir storage coming into this period is at higher levels than in the historic condition, and thus must evacuate some storage to meet this restriction. Through discussion with Reclamation operators, it was determined that this behavior in the model was warranted and well approximated the operations that would actually occur in these types of situations under current and future operational procedures.

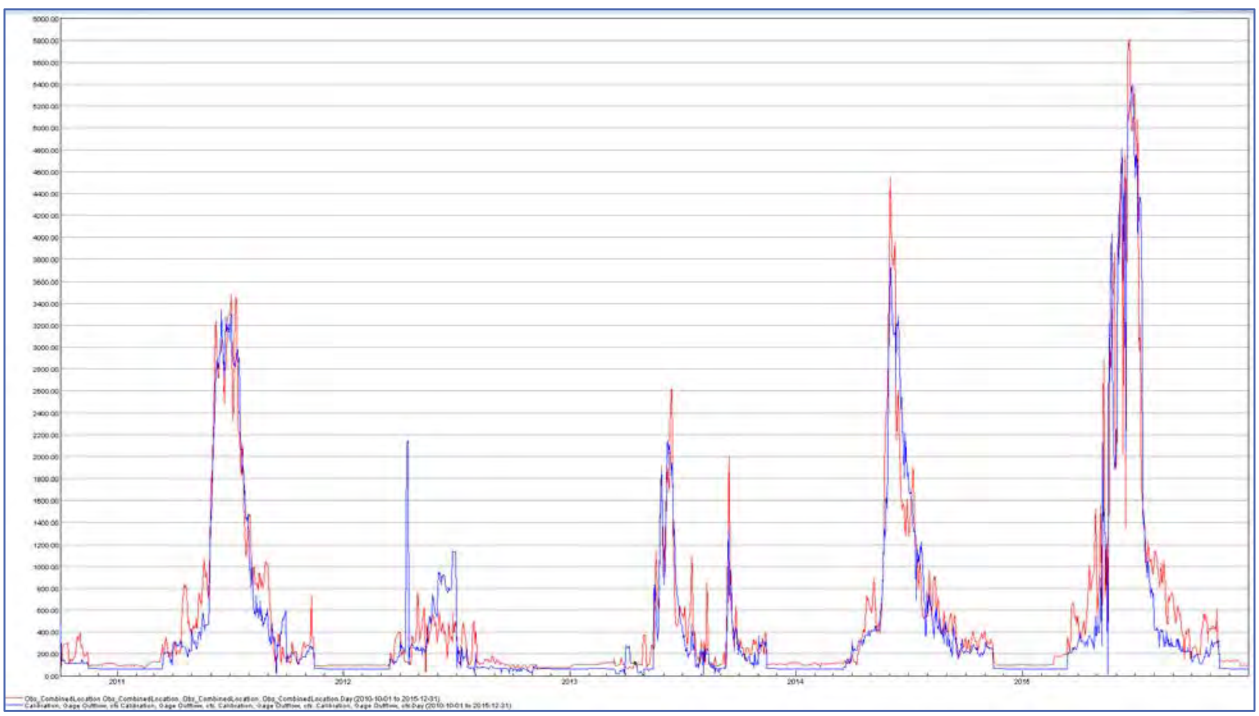

Figure 17: Above Pueblo Location historic and simulated flow. Historic flow is red, simulated is blue.

Table 5: Summary statistics for Above Pueblo Flow Location historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	3.2		3.2		-2.2	
Mean	537.5		478.1		-12.4	
Std Deviation	870.2		882.4		1.4	
Variance	757197		778674		2.8	
Median	192.335		144.5		-33.1	
25th Percentile	103.705		66		-57.0	
75th Percentile	514		366		-40.5	
Minimum	36.27		11		-225.9	
Maximum	5801.15		5393		-7.6	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	576.5	498.6	517.6	438.6	-11.4	-13.7

5.6 MOFFAT STREET GAGE

This streamflow gage is slightly downstream from the Above Pueblo Flow location previously discussed, and thus the description of the comparison is essentially the same.

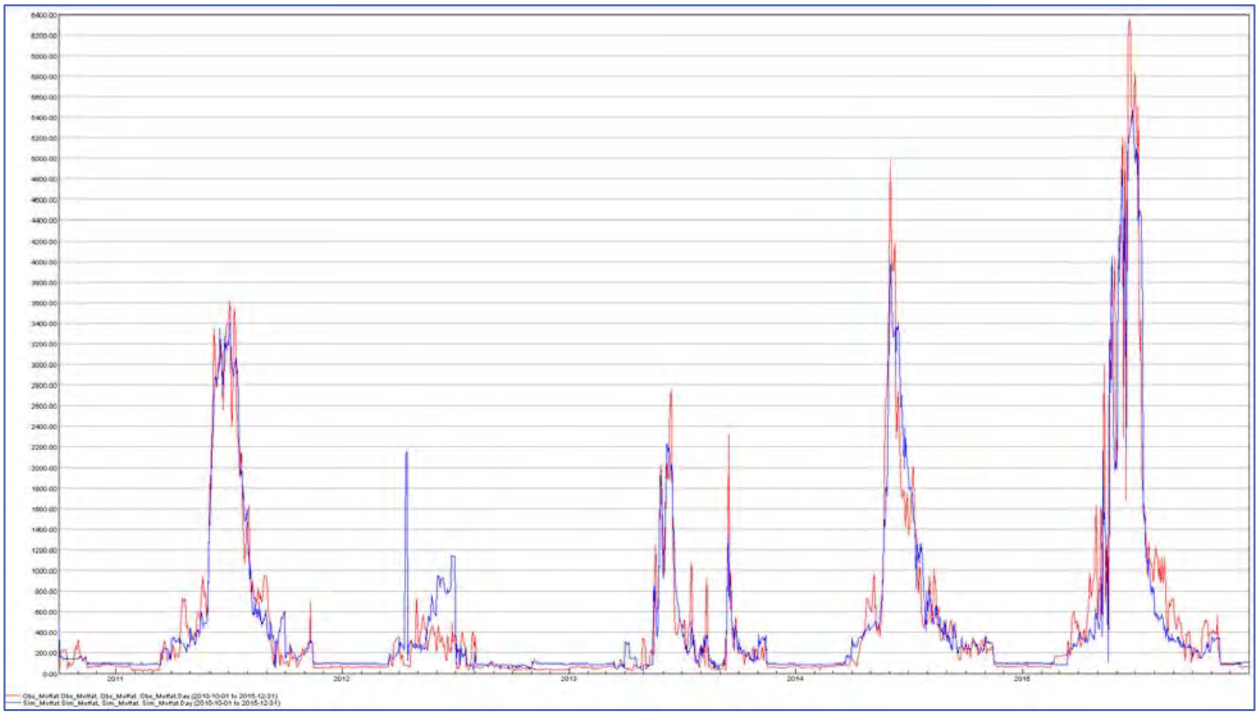

Figure 18: Moffat Street Gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 6: Summary statistics for Moffat Street Gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	3.3		3.2		-4.8	
Mean	513.5		513.8		0.1	
Std Deviation	938.0		902.1		-4.0	
Variance	879850		813869		-8.1	
Median	149		168.2		11.4	
25th Percentile	67		93		27.9	
75th Percentile	461		414		-11.3	
Minimum	12		32		62.3	
Maximum	6350		5468		-16.1	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	555.5	471.5	554.1	473.4	-0.2	0.4

5.7 Fountain Creek at Pueblo Gage

This streamflow gage represents the outflow of Fountain Creek to the Arkansas River. Simulated flows here compare quite well with those observed historically. The moderate reductions in peak average daily flows that sometimes occur can be attributed to the minor smoothing of the model input local inflows and noticeable here due to the high flashiness of the Fountain Creek system.

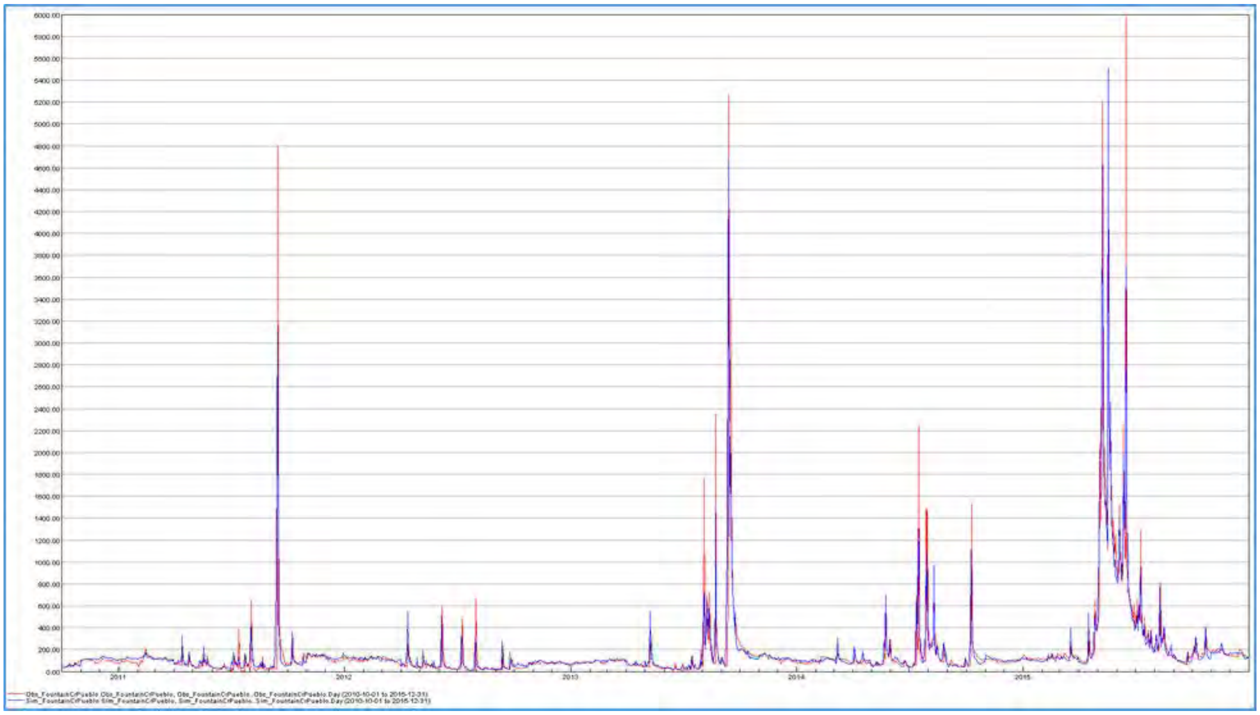

Figure 19: Fountain Creek at Pueblo Gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 7: Summary statistics for Fountain Creek at Pueblo Gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	8.6		7.7		-11.3	
Mean	168.7		170.4		1.0	
Std Deviation	390.9		346.9		-12.7	
Variance	152774		120359		-26.9	
Median	95		101.8		6.7	
25th Percentile	61		64		5.3	
75th Percentile	134		131		-1.9	
Minimum	4		7		44.8	
Maximum	5980		5510		-8.5	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	186.2	151.2	185.9	154.9	-0.1	2.4

5.8 AVONDALE GAGE

This streamflow gage is downstream from confluence of the Arkansas River and Fountain Creek but still upstream of most major agricultural diversions in the system. Thus, the description of the comparison is essentially the same as that for the upstream gages. It is observed that the model does a better job of maintaining the 6000 cfs flood control limit at this gage than was historically observed in 2015, however this is expected due to inherent difficulty of real-time flood control operations due to the significant uncertainty and forecasting errors involved.

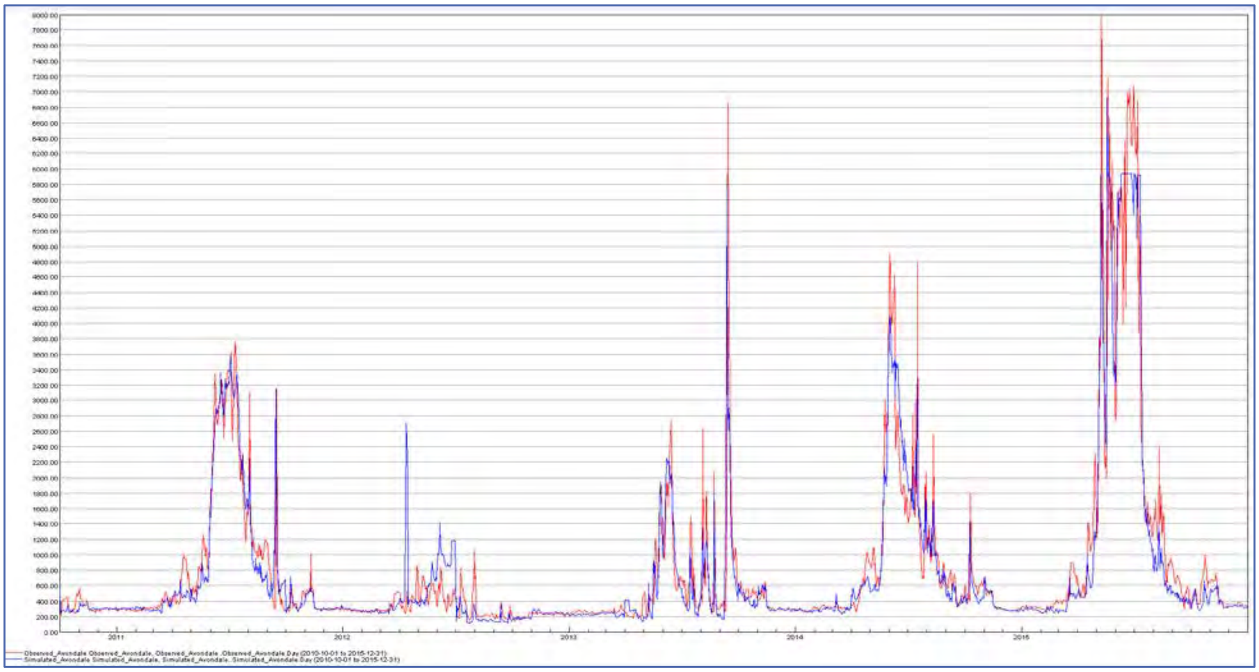

Figure 20: Avondale gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 8: Summary statistics for Avondale gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	3.3		3.2		-5.1	
Mean	812.2		768.0		-5.8	
Std Deviation	1132.1		1092.8		-3.6	
Variance	1281688		1194192		-7.3	
Median	380.5		342.9		-11.0	
25th Percentile	283		275		-2.7	
75th Percentile	731		631		-15.9	
Minimum	149		108		-38.4	
Maximum	7980		6924		-15.3	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	862.8	761.5	816.9	719.1	5.3	5.6

5.9 CATLIN GAGE

This streamflow gage is further downstream on the Arkansas River and below several major agricultural diversions, including diversions to off-stream storage in the Colorado Canal system, and can thus be additionally impacted by differences between simulated and historic in operations of those diversions. Still, the description of the comparison is essentially the same as that for the upstream gages.

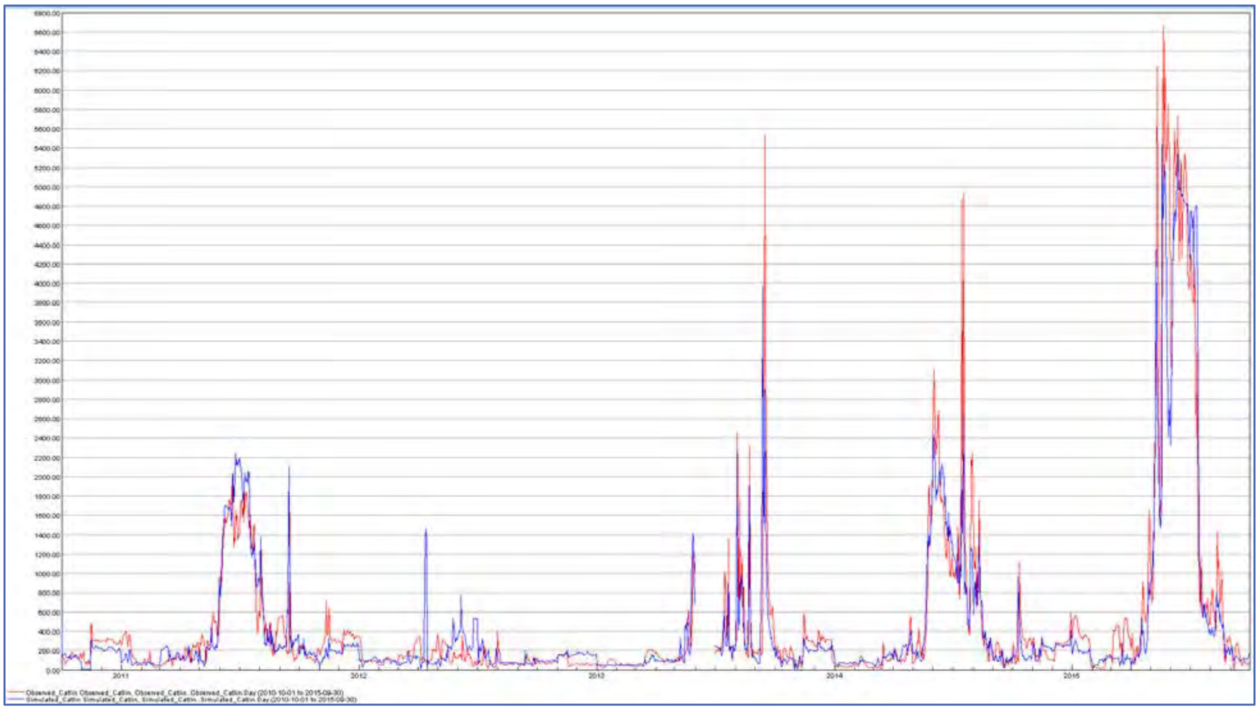

Figure 21: Catlin gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 9: Summary statistics for Catlin gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	3.8		3.7		-2.8	
Mean	490.5		452.2		-8.5	
Std Deviation	933.8		869.4		-7.4	
Variance	871991		755889		-15.4	
Median	186		166.0		-12.1	
25th Percentile	88		92		4.3	
75th Percentile	360		270		-33.5	
Minimum	4.5		1		-266.1	
Maximum	6660		5438		-22.5	
Count	1796		1796			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	533.7	447.3	492.4	411.9	7.7	7.9

5.10 La Junta Gage

This streamflow gage is further downstream on the Arkansas River and below several more major agricultural diversions, including diversions to off-stream storage by the Holbrook Canal and Fort Lyon Storage Canal, and the major Fort Lyon Canal. Thus, it can thus be additionally impacted by differences between simulated and historic in operations of those diversions, however, the description of the comparison is essentially the same as that for the upstream gages.

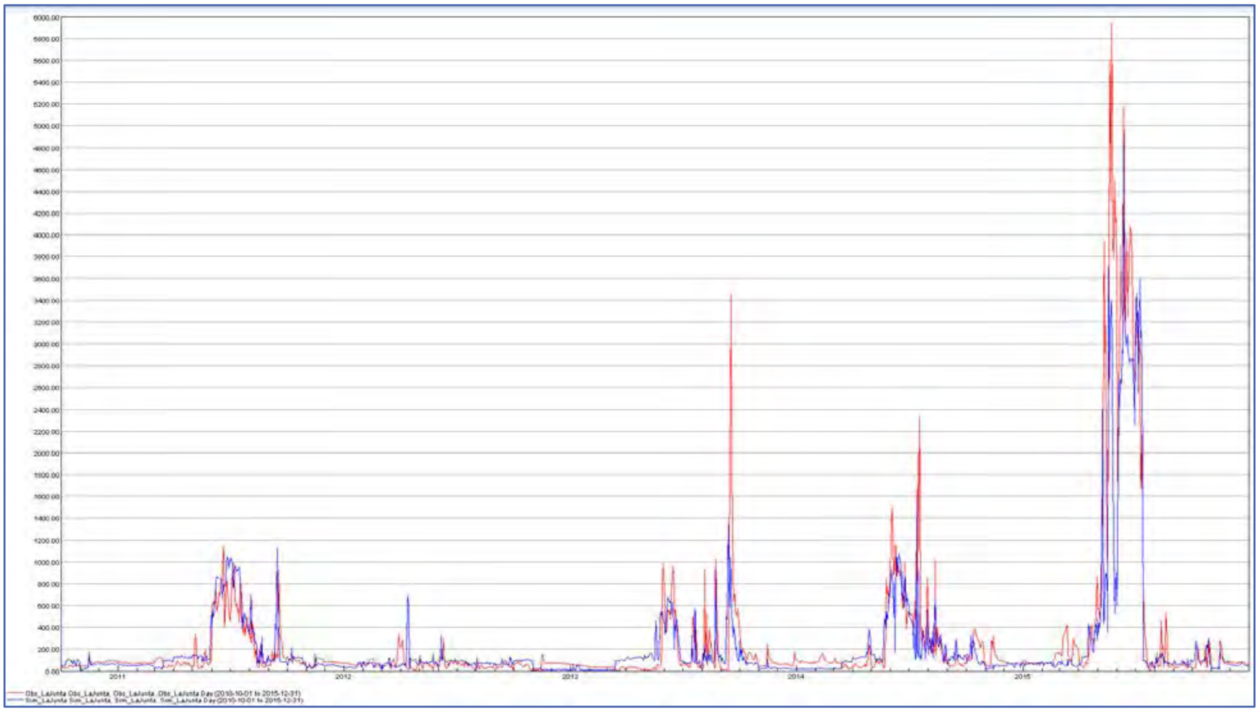

Figure 22: La Junta gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 10: Summary statistics for La Junta gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	4.9		4.9		-1.0	
Mean	257.8		214.8		-20.0	
Std Deviation	644.4		492.9		-30.7	
Variance	415259		242906		-71.0	
Median	71		73.8		3.7	
25th Percentile	44		46		5.2	
75th Percentile	138		125		-10.2	
Minimum	2.8		6		51.9	
Maximum	5940		4870		-22.0	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	286.6	228.9	236.8	192.7	-21.0	-18.8

5.11 Las Animas Gage

This streamflow gage is the furthest downstream on the Arkansas River before being joined by the Purgatoire River and entering John Martin Reservoir. The description of this comparison is essentially the same as that for the upstream gages.

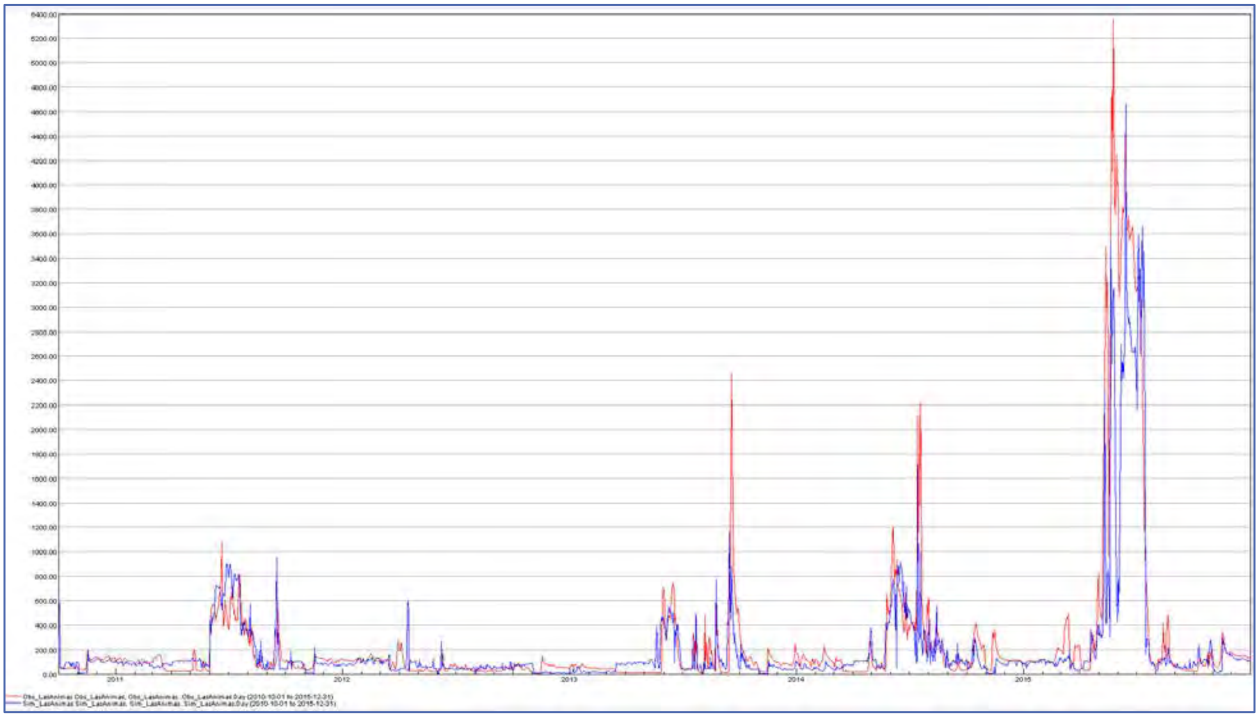

Figure 23: Las Animas gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 11: Summary statistics for Las Animas gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	4.8		5.2		7.2	
Mean	256.0		203.4		-25.9	
Std Deviation	635.8		470.2		-35.2	
Variance	404249		221043		-82.9	
Median	92		81.7		-12.6	
25th Percentile	41		47		13.6	
75th Percentile	153		118		-29.9	
Minimum	11		1		-1847.2	
Maximum	5360		4658		-15.1	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	284.5	227.5	224.4	182.3	-26.7	-24.8

5.12 BELOW JOHN MARTIN RESERVOIR GAGE

This streamflow gage represents the total outflow from John Martin Reservoir to the Arkansas River and its thus dependent on John Martin Reservoir operations and conditions. John Martin Reservoir operations are simulated in a relatively basic, lumped fashion in the model and real-world operations are significantly more complex. Still, the simulated flows compare quite well with those observed historically, especially regarding the order of magnitude, variability, and timing of the reservoir releases. The reservoir gates are closed during the winter storage period as observed by the periods of zero outflow in both simulated and historic conditions.

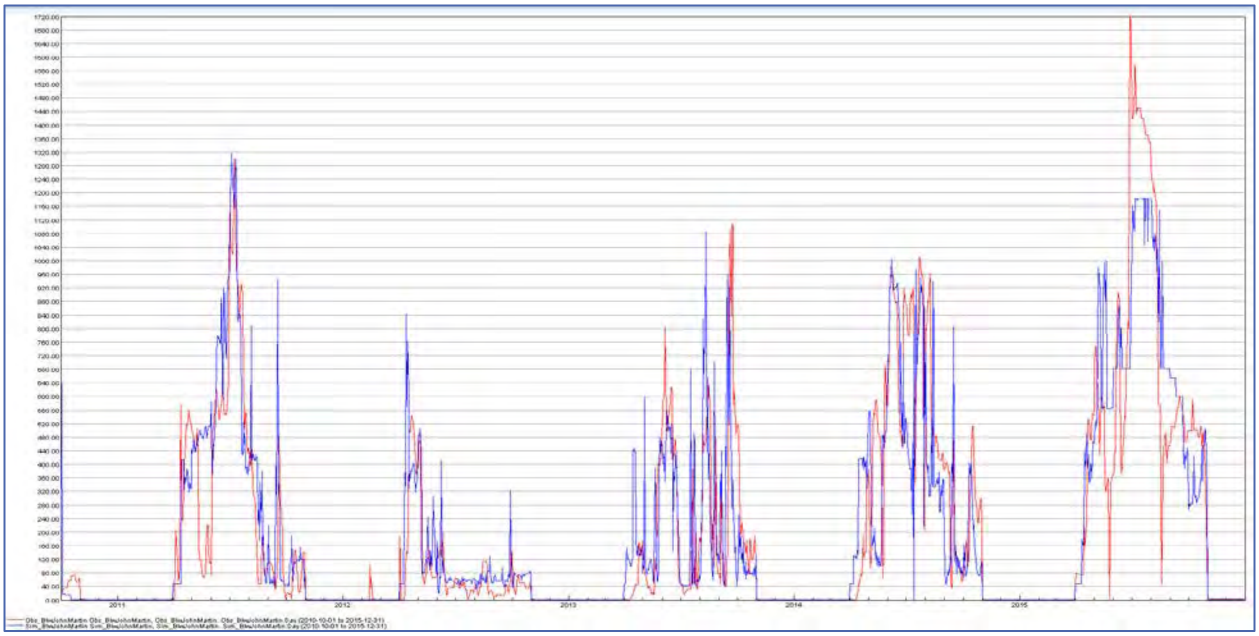

Figure 24: Below John Martin Reservoir gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 12: Summary statistics for Below John Martin Reservoir gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	2.0		1.6		-20.2	
Mean	201.2		202.6		0.7	
Std Deviation	316.8		297.9		-6.3	
Variance	100374		88746		-13.1	
Median	34		50.7		32.9	
25th Percentile	0.9		1		10.0	
75th Percentile	376		361		-4.0	
Minimum	0.17		1		77.1	
Maximum	1720		1317		-30.6	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	215.4	187.0	215.9	189.2	0.2	1.2

5.13 Coolidge Gage

This streamflow gage represents the Arkansas River's outflow from Colorado to Kansas, and simulated flows compare relatively well with historic flows, especially considering the basic nature of the simulated John Martin Reservoir operations including the operations of Kansas storage accounts.

Figure 25: Coolidge gage historic and simulated flow. Historic flow is red, simulated is blue.

Table 13: Summary statistics for Coolidge gage historic and simulated flow.

	Historic		Simulated		% Diff	
Skewness	4.2		4.3		2.2	
Mean	85.1		89.1		4.6	
Std Deviation	132.3		128.1		-3.2	
Variance	17494		16414		-6.6	
Median	54		56.9		5.0	
25th Percentile	18		26		31.5	
75th Percentile	83		101		17.6	
Minimum	0.31		0			
Maximum	1570		1674		6.2	
Count	1918		1918			
	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
95% Confidence Interval	91.0	79.1	94.9	83.4	4.1	5.1

5.14 Performance Measures and Target Values

Again, the simulated results presented here represent an altered system condition in respect to the corresponding historic period. Despite this incompatibility, it was still desired to present a comparison of simulated and historic time series with respect to certain performance measures as has been done in the past. This was largely to maintain consistency with previous modeling efforts and studies.

The following statistics, summarized below, compare the historic and simulated time series to measure the goodness of fit of the model data to the historic for the 10/1/2010 to 12/31/2015 period. These statistics are summarized below in Table 14. The grey cells do not meet the target values. However, remember that there is no expectation that the simulated results should recreate the historic conditions, and thus that these comparisons have limited applicability in evaluating the ability of the model to simulate the system.

- The maximum monthly percent difference was computed based on the average monthly flow for each month for each year.
- The maximum average monthly difference was computed based on the average monthly flow for each month across all years.
- The average annual difference was based on the annual average flow. So, there are only five values in the 2010 to 2015 time period.
- The K-S Test corresponds to the Kolmogorov-Smirnov Test which tests if the historic and simulated times series are from the same continuous distribution. If the computed D value is greater than the critical value, then the null hypothesis that the data are from the same distribution is rejected.

Table 14: Summary of Performance Measures and Target Values.

	Performance Measures / Target Values				
	Maximum Monthly Difference (%) 25%	Maximum Average Monthly Difference (%) 10%	Average Annual Difference (%) 2%	Correlation Coefficient (r^2)	Cumulative Distribution K-S Test (D) 0.031
Lake Creek Below Twin Lakes	-2238 (FEB 2011)	-248	-29	0.77	0.376
Granite	-347 (MAR2014)	-137	11	0.93	0.293
Wellsville	-129 (FEB 2011)	-57	6	0.97	0.199(3)
Portland	-234 (DEC 2013)	-66	-11	0.94	0.185
Above Pueblo Gage	-139 (MAR 2013)	-87	-21	0.95	0.404
Moffat Street	-91 (AUG 2015)	-33	40	0.95	0.364
Fountain Creek at Pueblo	34 (OCT 2012)	11	9	0.91	0.076
Avondale	-58 (AUG 2015)	-27	11	0.95	0.065
Catlin	-199 (MAR 2015)	-57	25 (1)	0.92	0.140 (2)
La Junta	-530 (DEC 2012)	-99	-35	0.87	0.079
Las Animas	-488 (DEC 2012)	-87	-44	0.87	0.121
Below John Martin Reservoir	-980 (FEB 2012)	-190	21	0.86	0.294
Coolidge	-254 (JUL 2013)	-44	-35	0.84	0.102

(1) This is the maximum annual difference out of three years, 2011,2012, and 2014.

(2) The critical value, which depends on the sample size, for Catlin is 0.032. This time series has a count of 1796 days.

(3) The critical value, which depends on the sample size, for Wellsville is 0.031. This time series has a count of 1916 days.

6 SIMULATED WATER USER DIVERSIONS

This section presents select comparisons of simulated and historic major water user and canal diversions from 10/1/2010 to 12/31/2015 from the "current conditions comparison" run. As previously described, the major municipal diversions are forced to historic values in this run and thus are not interesting or shown. It should be noted that although the specific diversions shown represent those with better historic diversion data, there is still a good deal of uncertainty associated with much of this data. These issues are discussed in more detail in Appendix C, "Model Data". It should also be noted that while the specific diverters shown are historically agricultural water users, not all these diversions are used exclusively for agricultural uses both as simulated or in historic conditions and may also include diversions that are subsequently returned to the river for various augmentation or exchange purposes.

In the FryArk RiverWare Model, matching the agricultural water user diversion levels of historic years, or even matching overall average historic diversions, is not an explicit objective of the model. Rather, the objective is to simulate diversions that are of reasonable magnitudes and year-to-year variability that are consistent with those that have been observed in recent years of varying hydrology. The dynamic way in which the agricultural demands are simulated has been previously discussed in the calibration section. The general comparisons below are intended to show that the general magnitudes and patterns of diversions are within the realm of those that have been recently observed. The comparisons are not discussed on an individual basis due to many reasons the simulated diversions can vary from historic levels. These reasons include but are not limited to varying access to, and available volumes in, storage sources (such as the higher PW volume available to ag users in 2012 previously discussed), variable canal operations or irrigation needs, and inconsistent historic utilization of water rights even when in priority.

Diversions for the following diverters and aggregated groups of water users are shown:

- Bessemer Ditch
- Colorado Canal
- Catlin Canal
- Holbrook Canal
- Fort Lyon Storage Canal
- Fort Lyon Canal
- Amity Canal
- Combined diversions from the Arkansas River above Pueblo Reservoir – includes District 11 and 12 mainstem water users
- Combined diversions from the Arkansas River between Fountain Creek and John Martin – includes Excelsior, Collier, Colorado Canal, High Line, Oxford Farmers, Otero, Catlin, Holbrook, Rocky Ford Ditch, Fort Lyon Storage, Fort Lyon, and L.A. Consolidated Ditch
- Combined diversions from the Arkansas River below John Martin Reservoir (District 67) – includes Fort Bent, Keesee, Amity, Lamar, Hyde, and Buffalo
- Combined Fountain Creek Diversions – includes Fountain Mutual, Stubbs & Miller, Chilcotte, Owen and Hall, Liston & Love South, Talcott & Cotton, Dr Rogers, Burke, Toof & Harman, Wood Valley, Greenview, Cactus
- Combined Purgatoire River Diversions – includes Antonio Lopez, Baca Joint, Chilili, South Side, Model Inlet, Hoehne, River Canyon, Nine Mile, and Highland

6.1 Bessemer Ditch

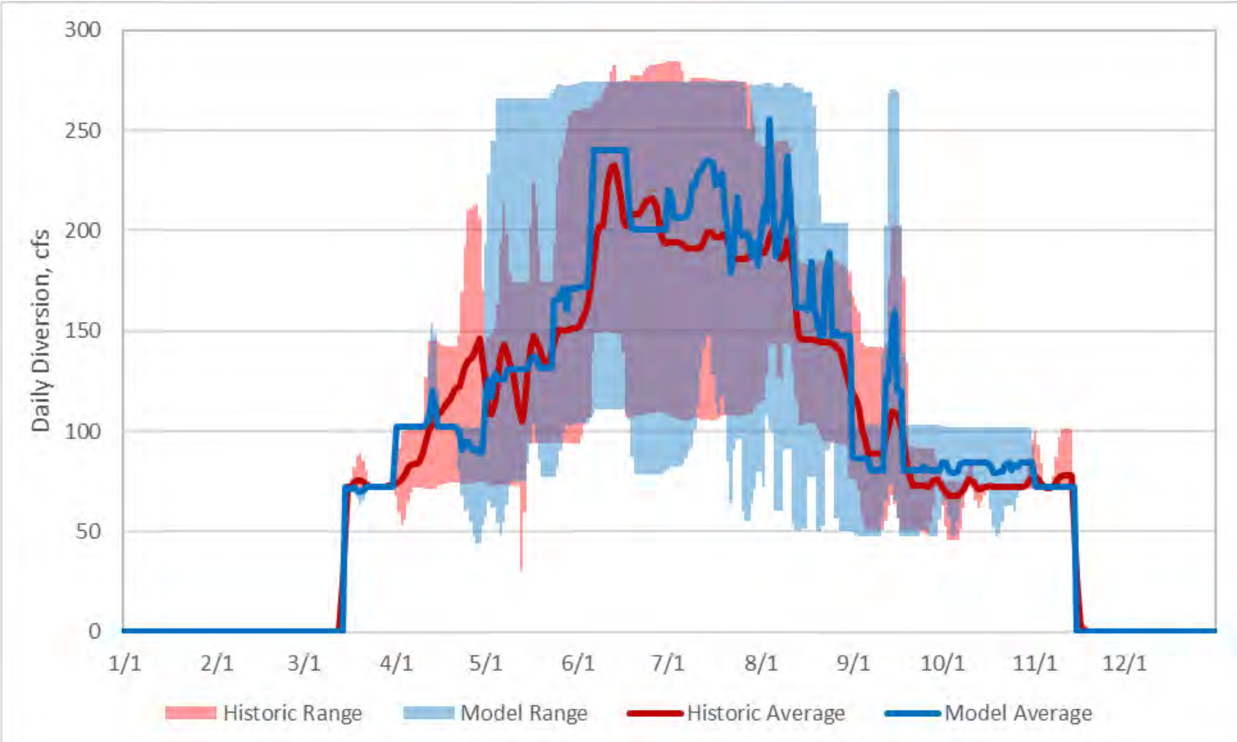

Figure 26: Bessemer Ditch, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

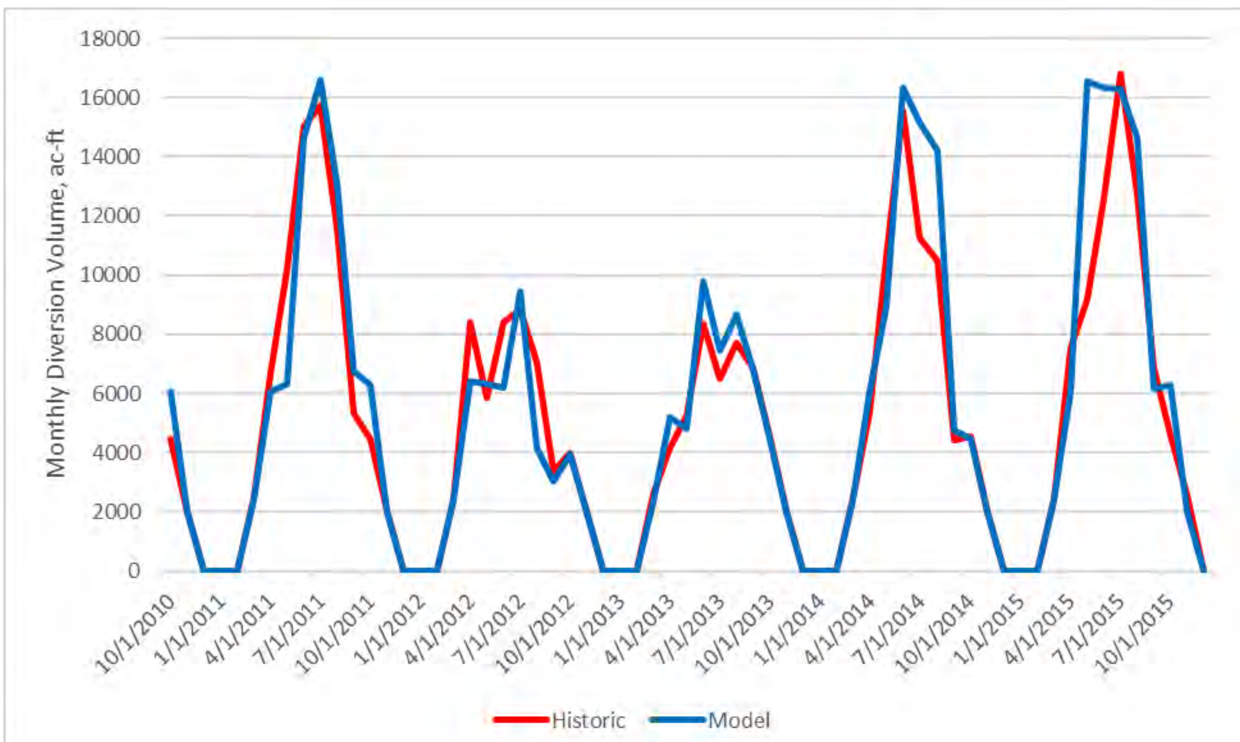

Figure 27: Bessemer Ditch, Total Monthly Diversion Volumes, Simulated vs. Historic

6.2 Colorado Canal

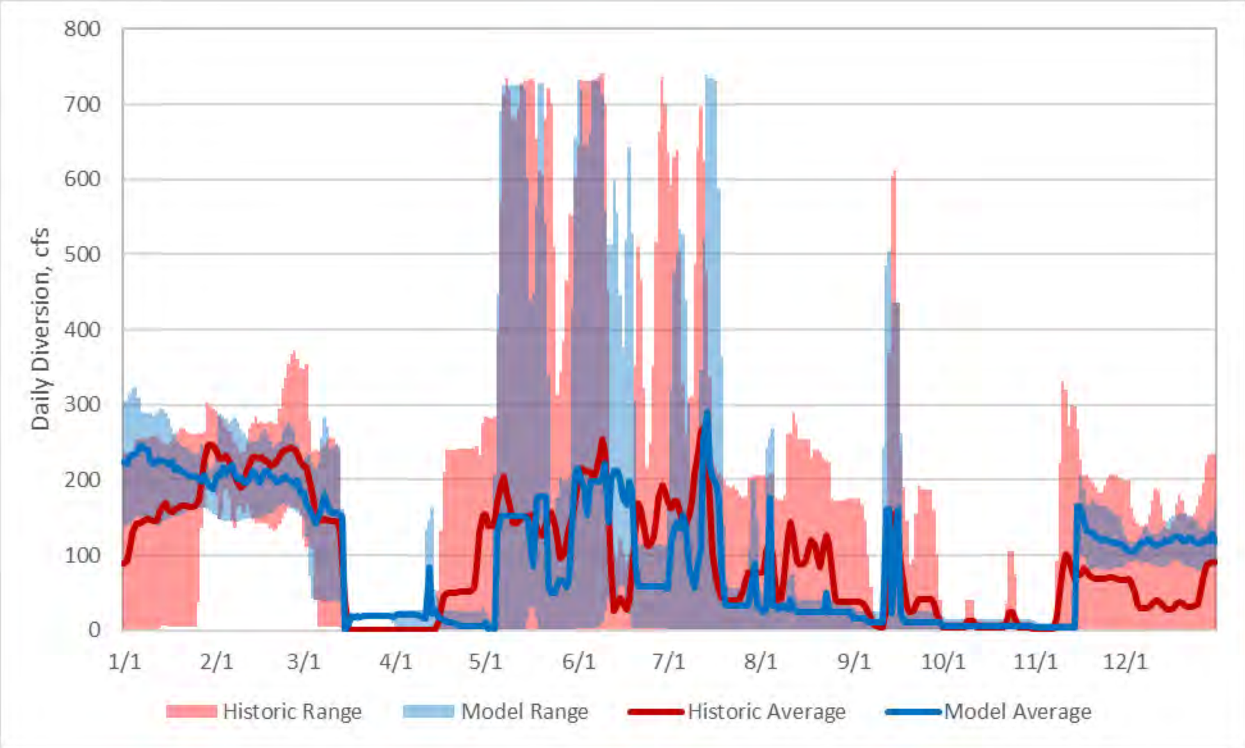

Figure 28: Colorado Canal, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

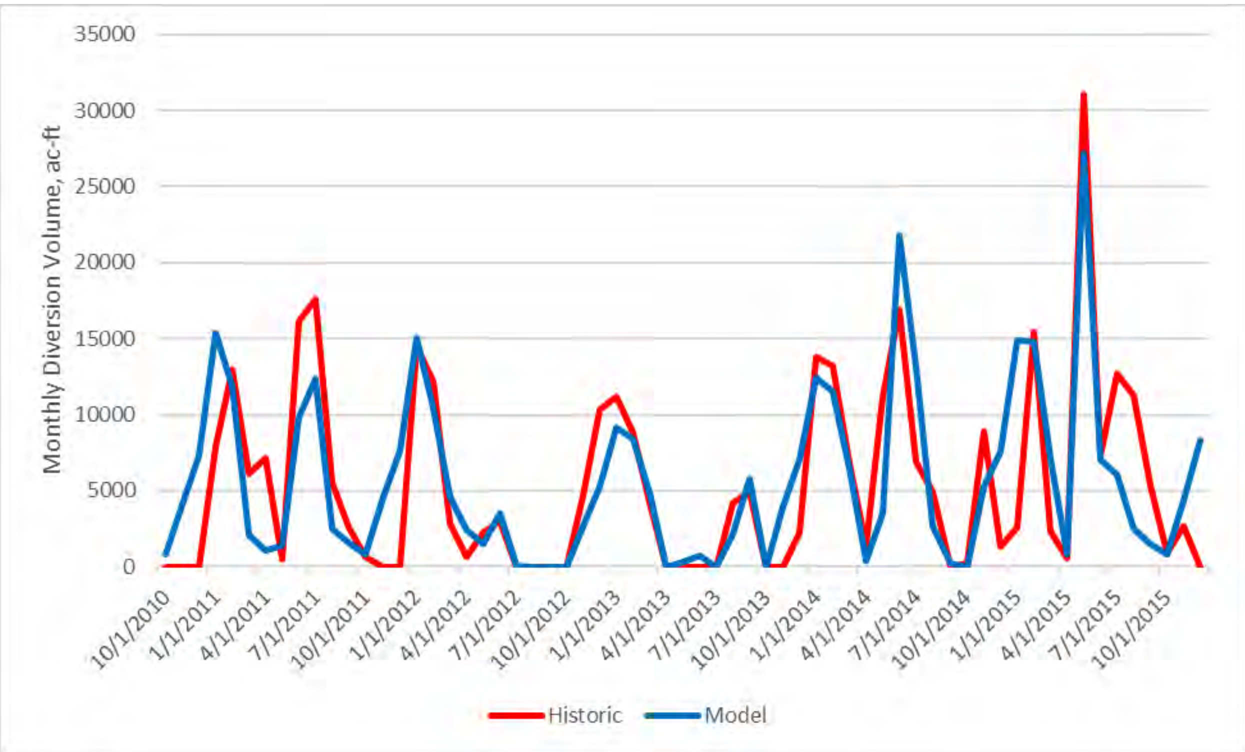

Figure 29: Colorado Canal, Total Monthly Diversion Volumes, Simulated vs. Historic

6.3 Catlin Canal

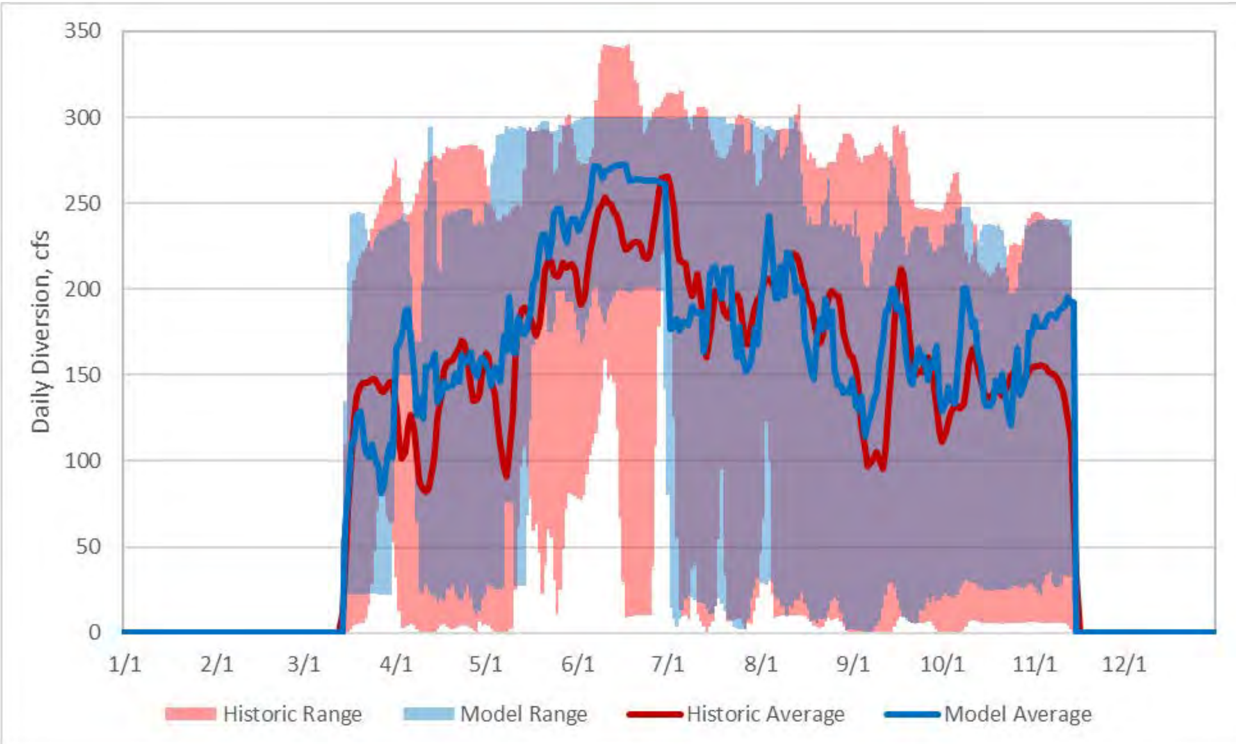

Figure 30: Catlin Canal, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

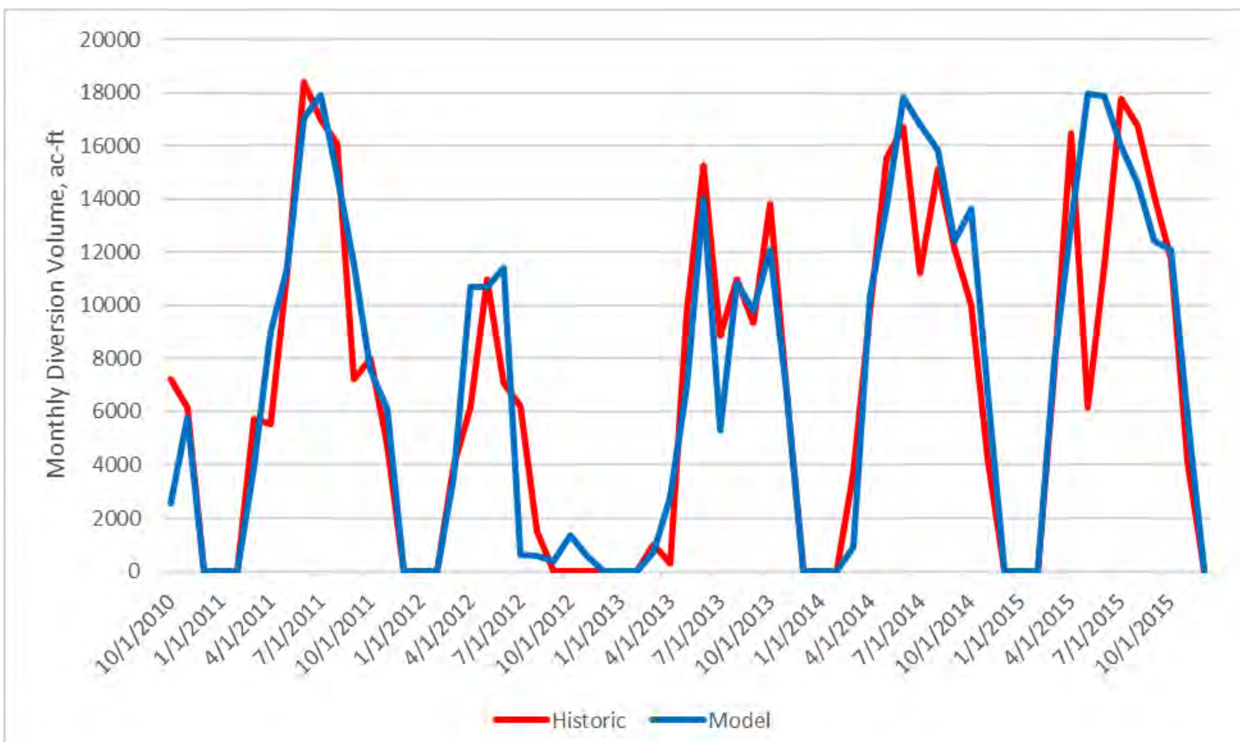

Figure 31: Catlin Canal, Total Monthly Diversion Volumes, Simulated vs. Historic

6.4 HOLBROOK CANAL

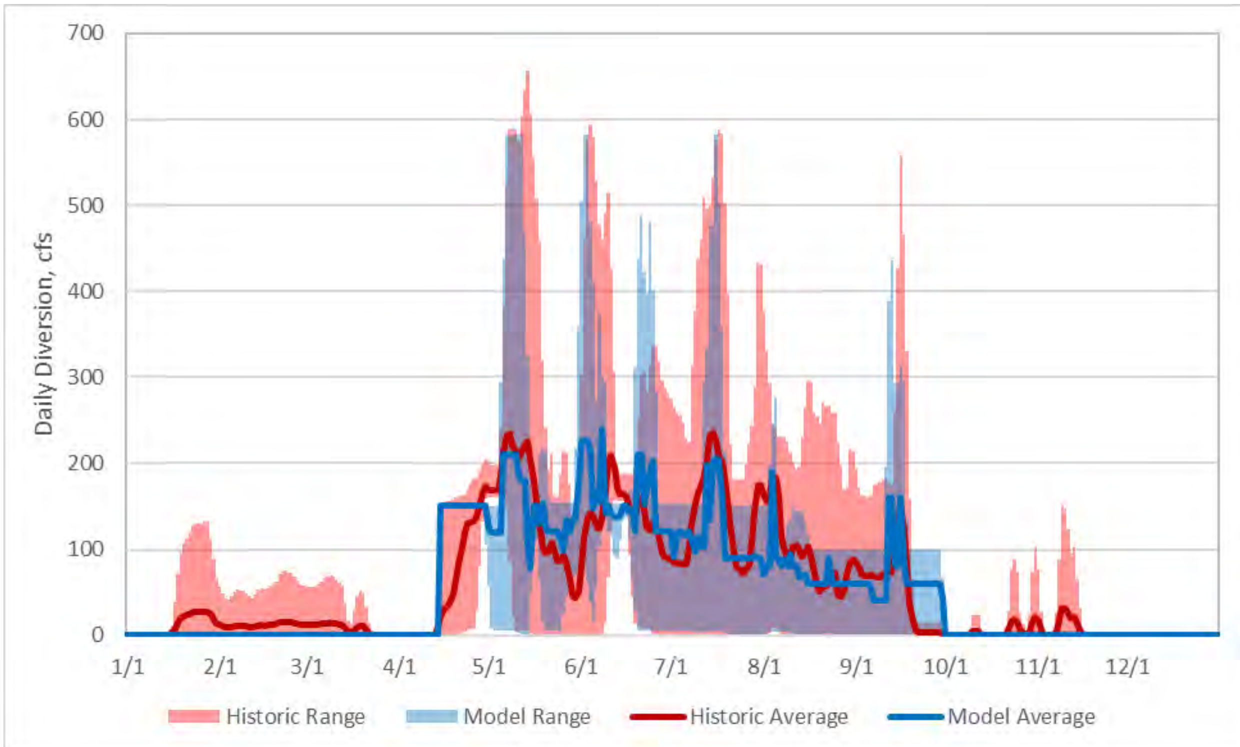

Figure 32: Holbrook Canal, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

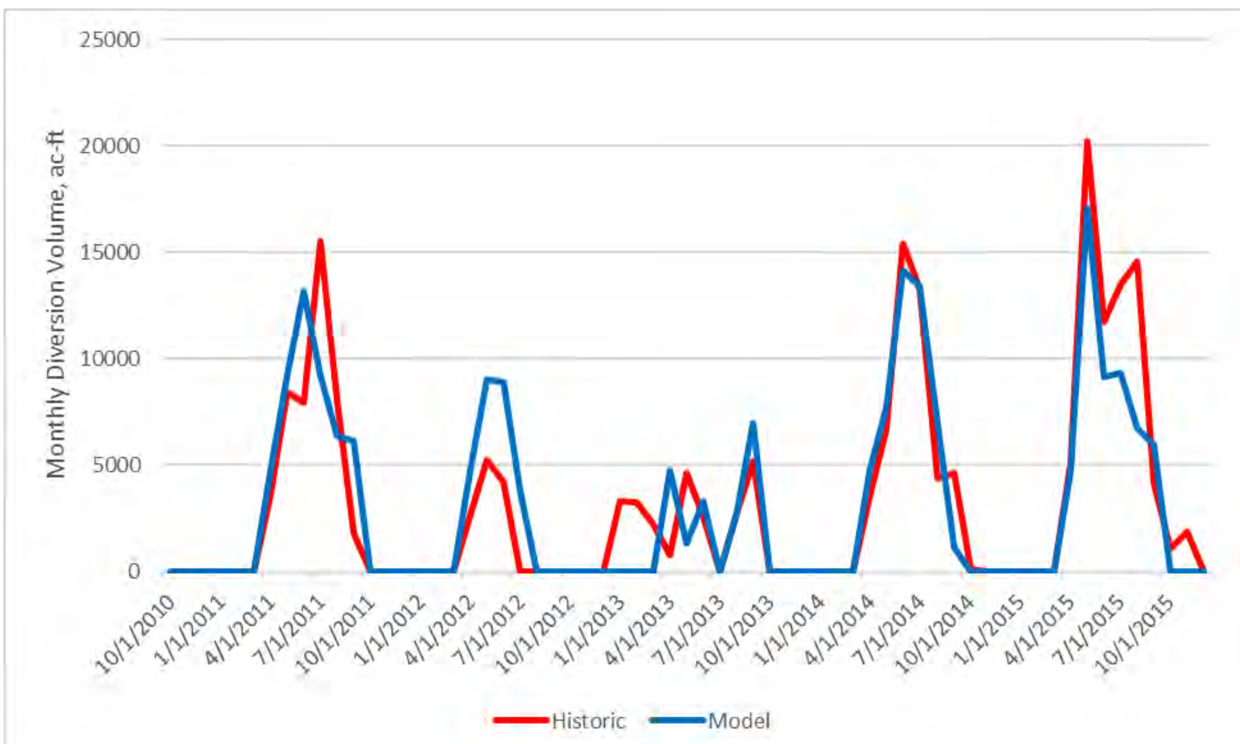

Figure 33: Holbrook Canal, Total Monthly Diversion Volumes, Simulated vs. Historic

6.5 Fort Lyon Storage Canal

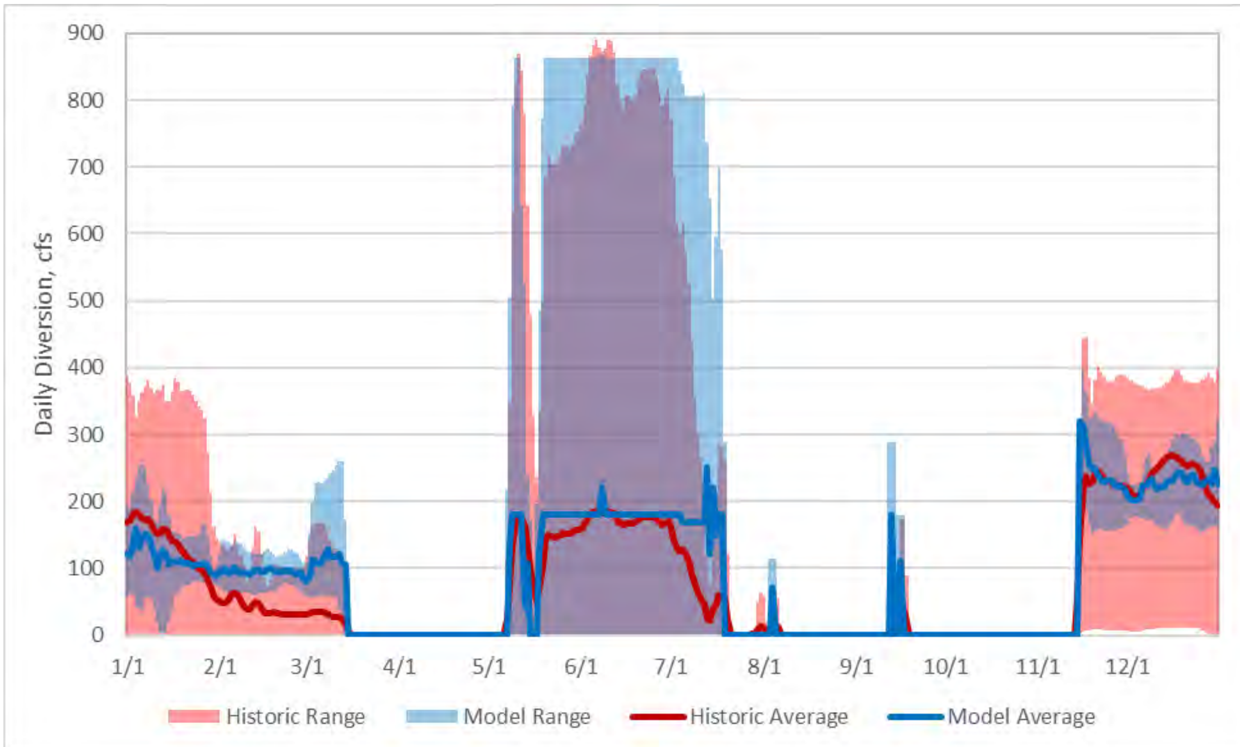

Figure 34: Fort Lyon Storage Canal, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

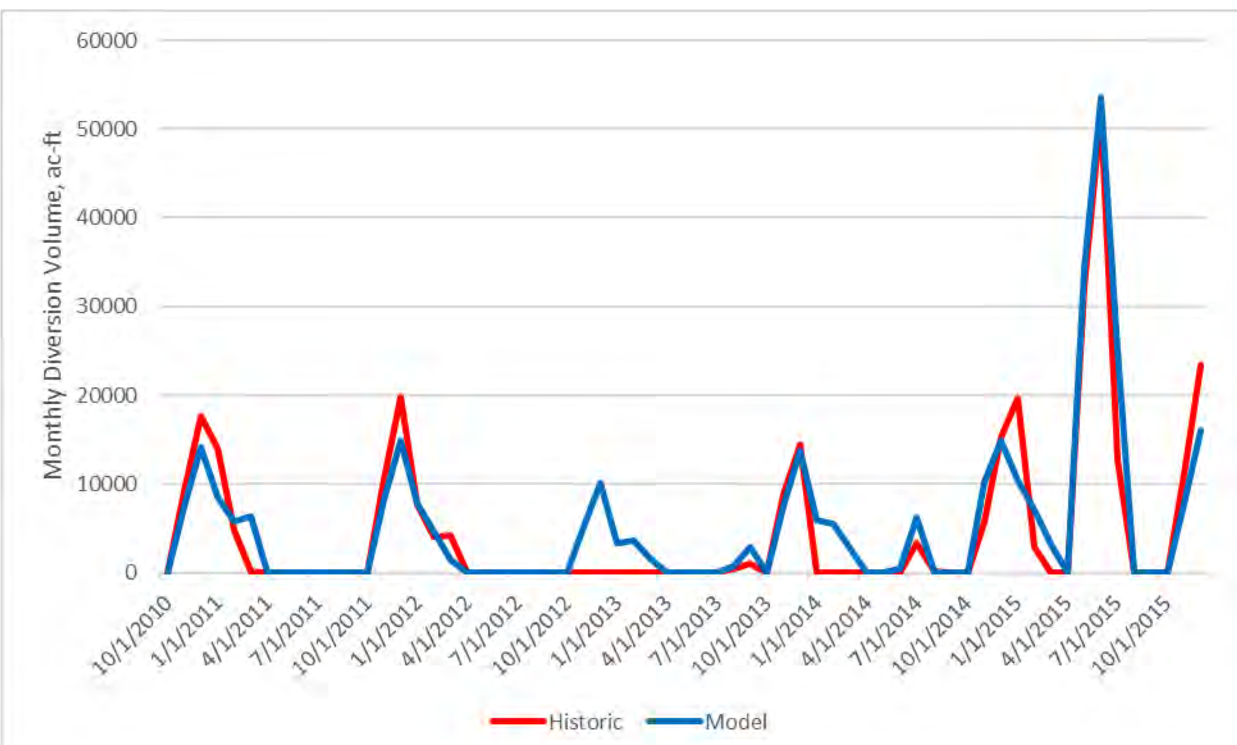

Figure 35: Fort Lyon Storage Canal, Total Monthly Diversion Volumes, Simulated vs. Historic

6.6 Fort Lyon Canal

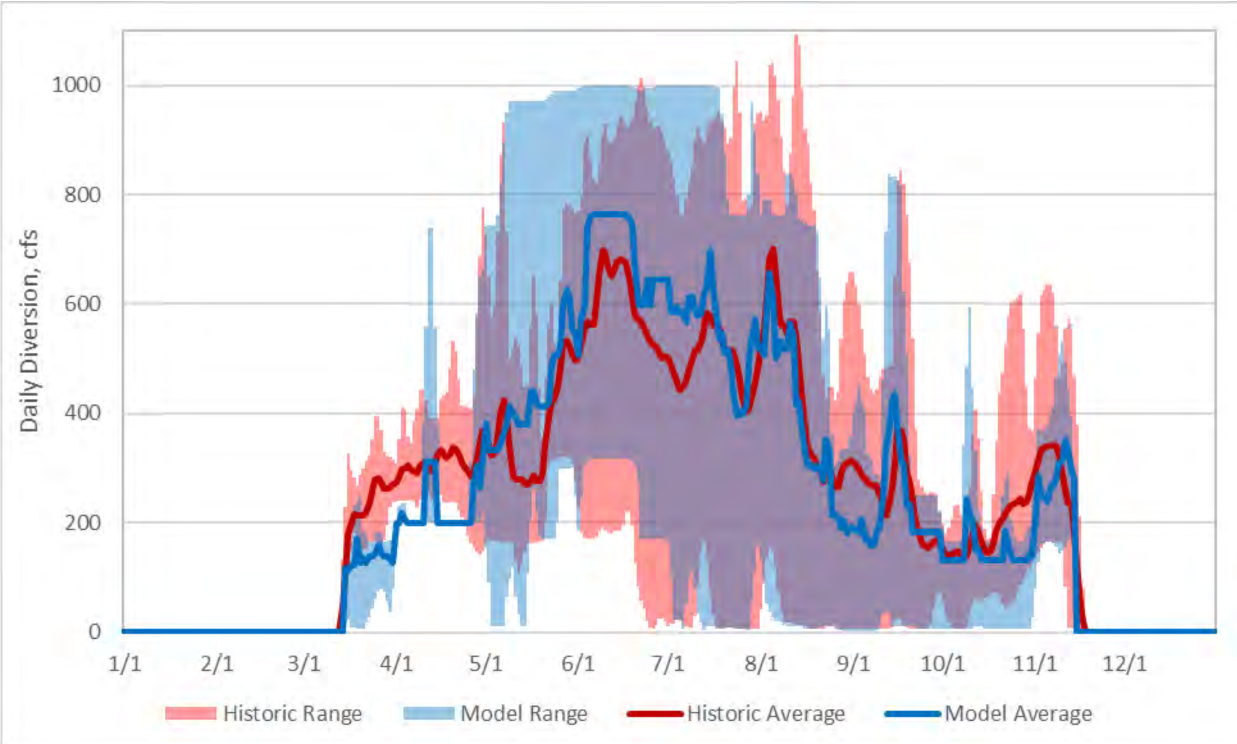

Figure 36: Fort Lyon Canal, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

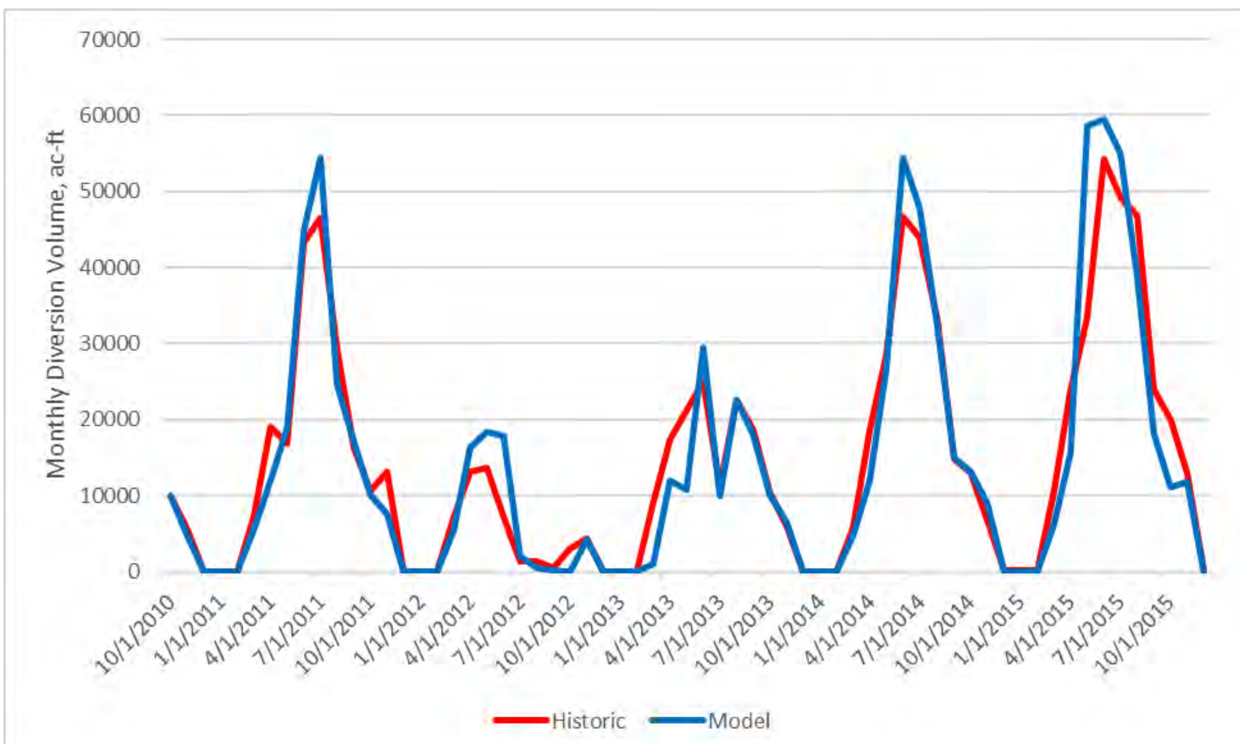

Figure 37: Fort Lyon Canal, Total Monthly Diversion Volumes, Simulated vs. Historic

6.7 Amity Canal

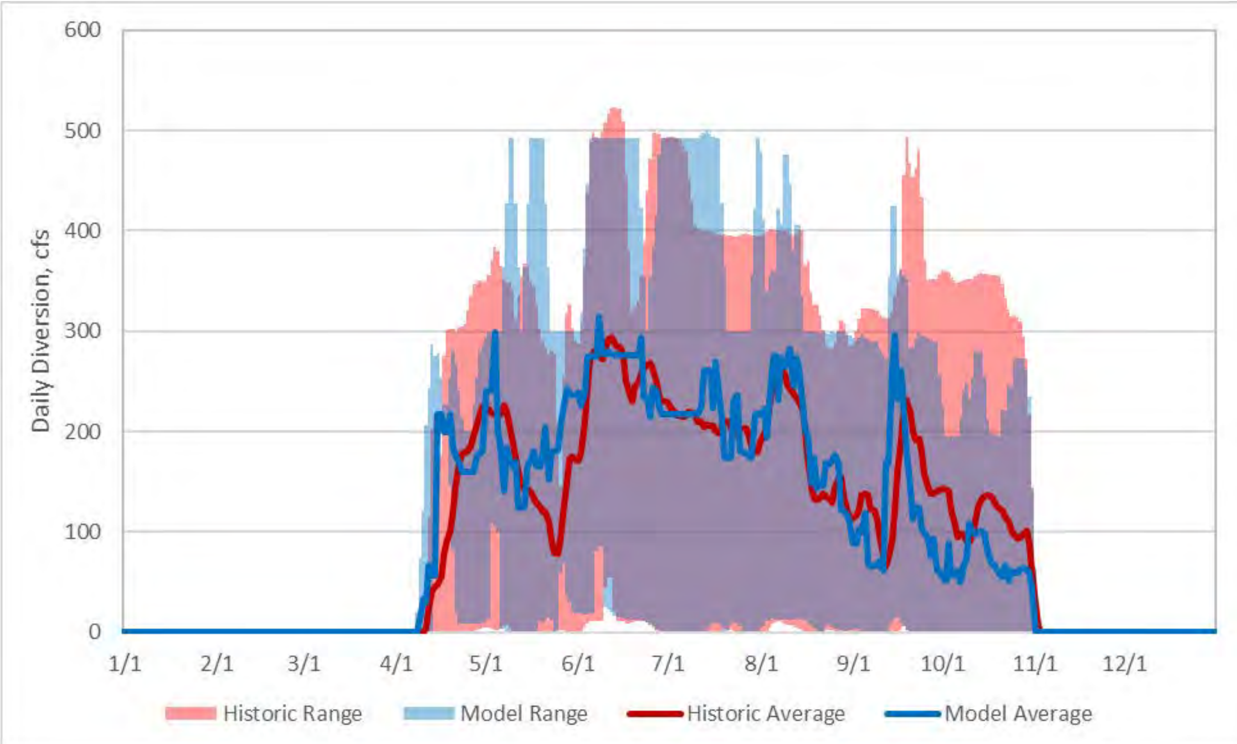

Figure 38: Amity Canal, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

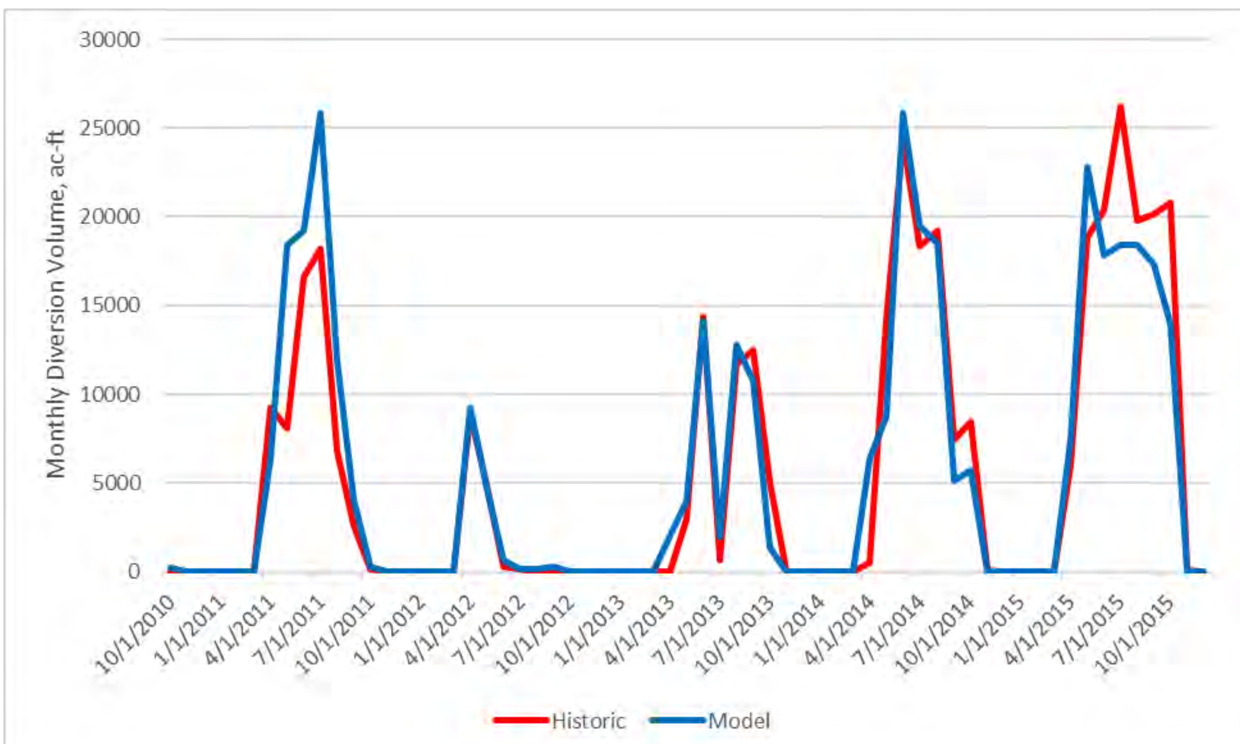

Figure 39: Amity Canal, Total Monthly Diversion Volumes, Simulated vs. Historic

6.8 COMBINED DIVERSIONS - ARKANSAS RIVER ABOVE PUEBLO RESERVOIR

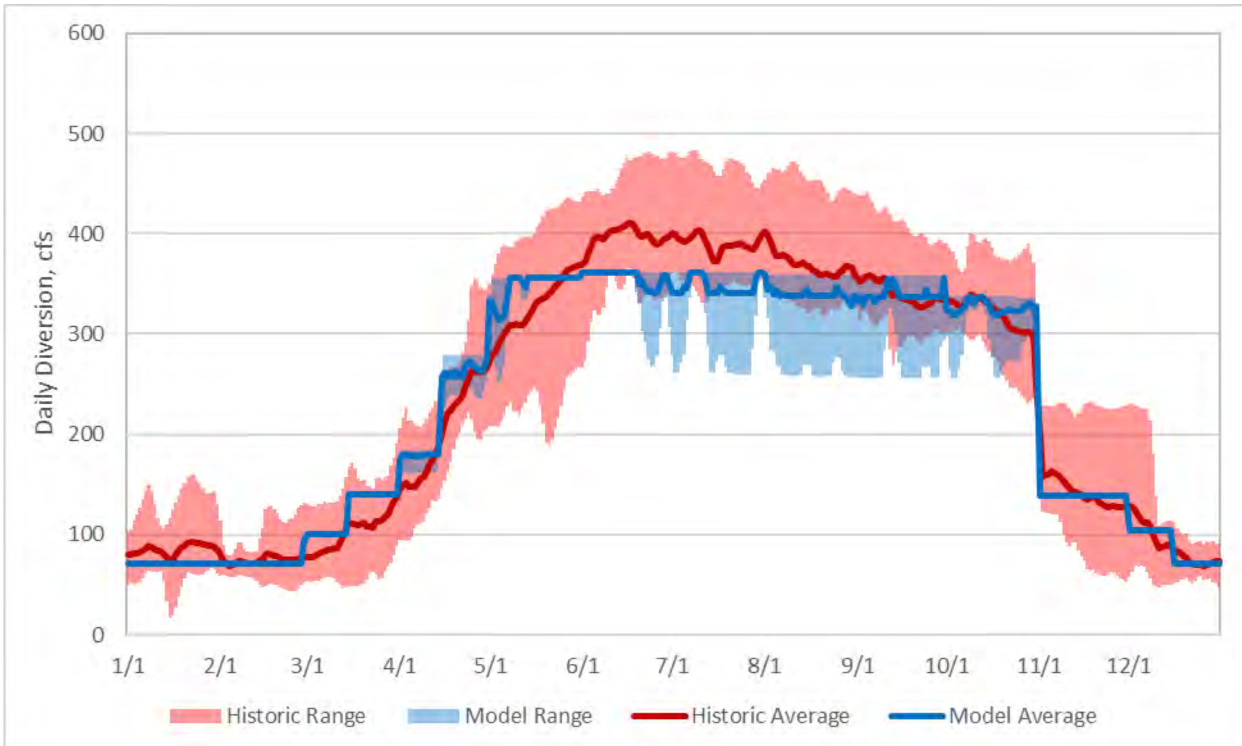

Figure 40: Combined Arkansas River above Pueblo Res, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

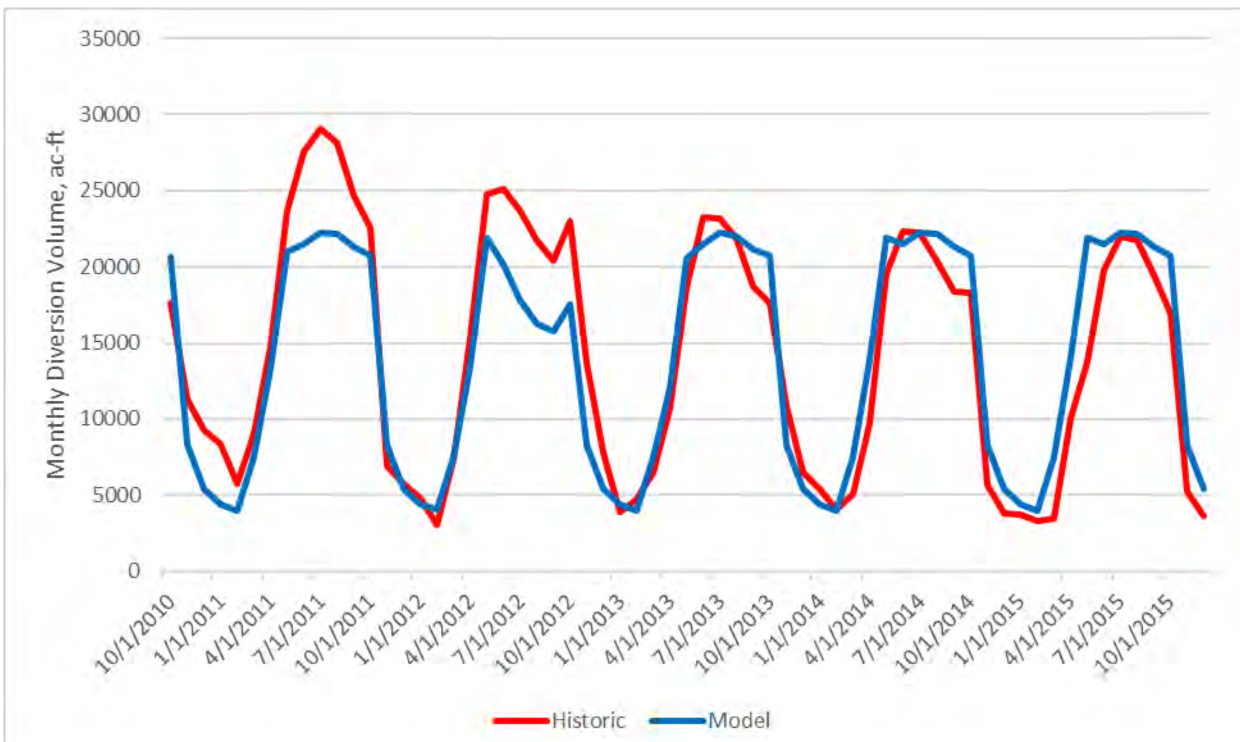

Figure 41: Combined Arkansas River above Pueblo Res, Total Monthly Diversion Volumes, Simulated vs. Historic

6.9 Combined Diversions - Arkansas River, Fountain Creek to John Martin

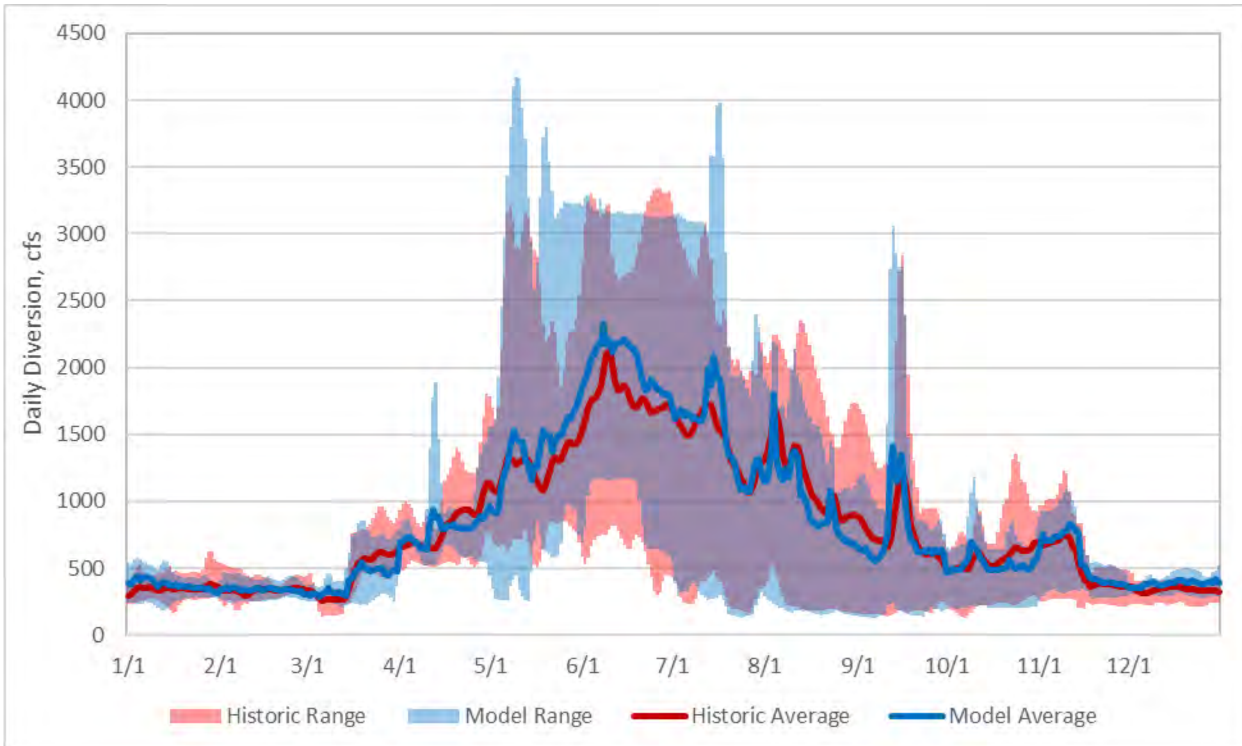

Figure 42: Combined Arkansas River, FC to JM, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

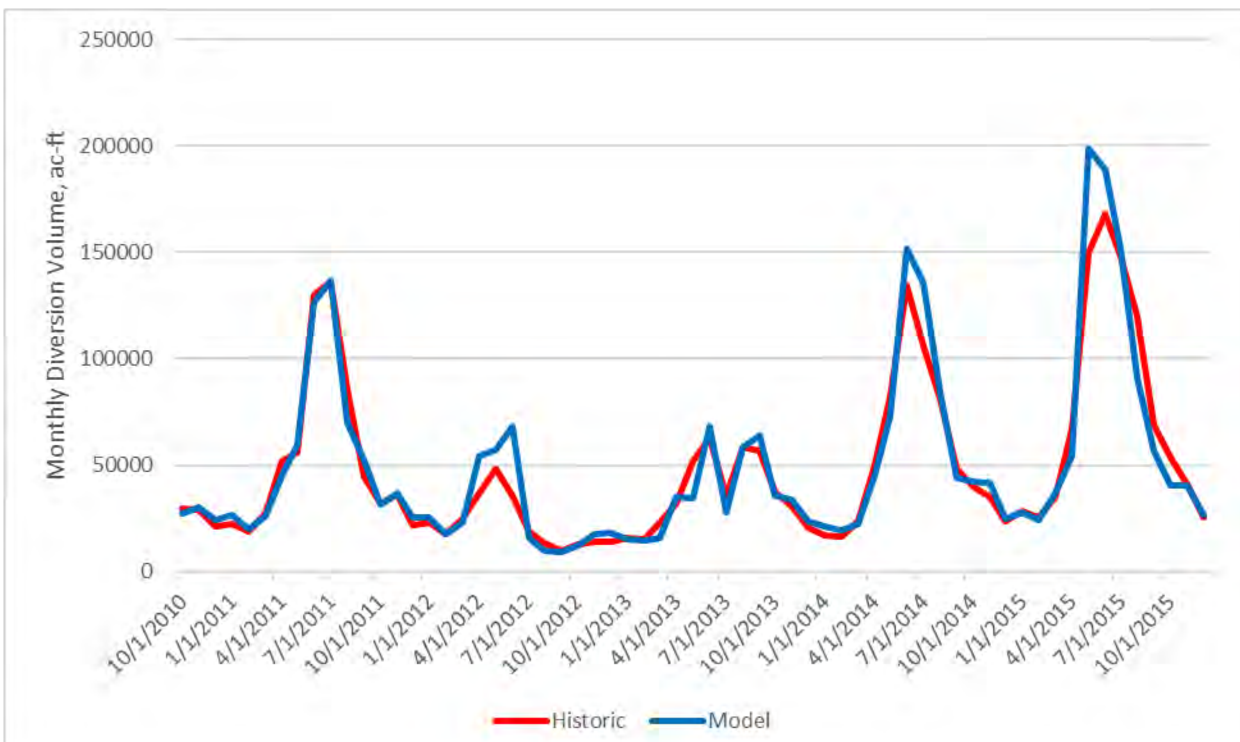

Figure 43: Combined Arkansas River, FC to JM, Total Monthly Diversion Volumes, Simulated vs. Historic

6.10 Combined Diversions - Arkansas River below John Martin (District 67)

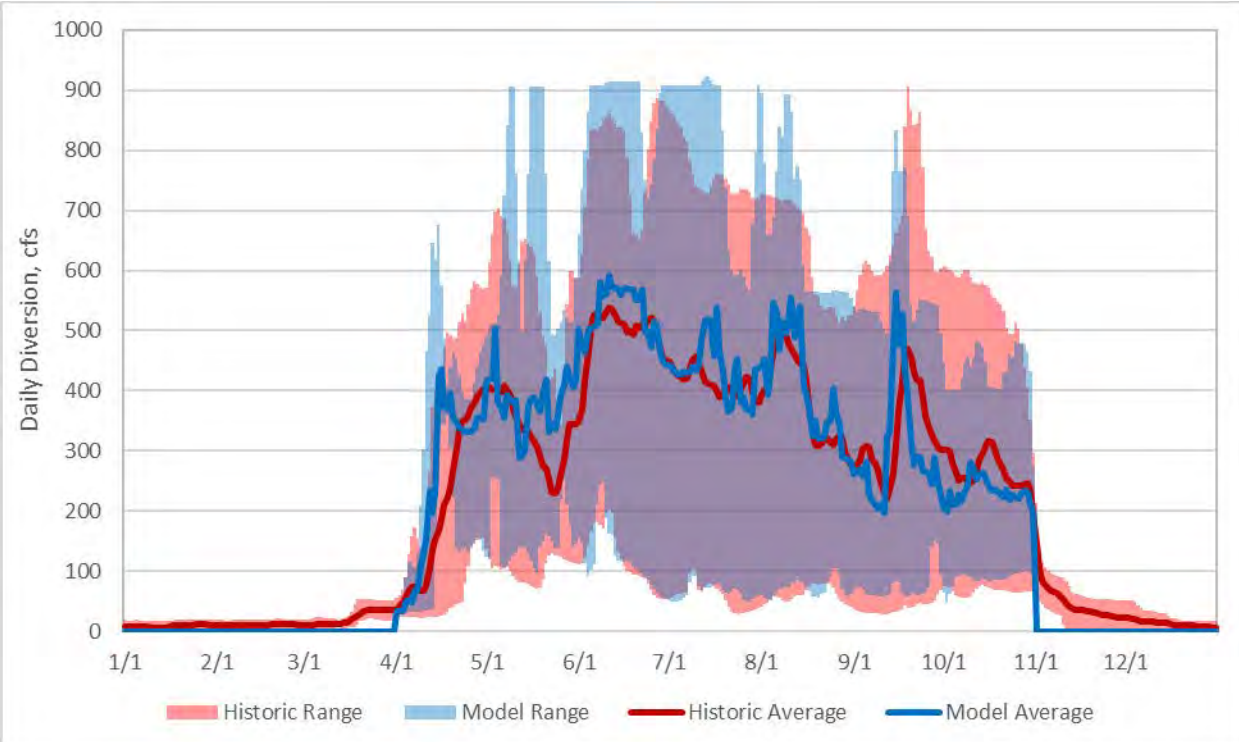

Figure 44: Combined Arkansas River below JM, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

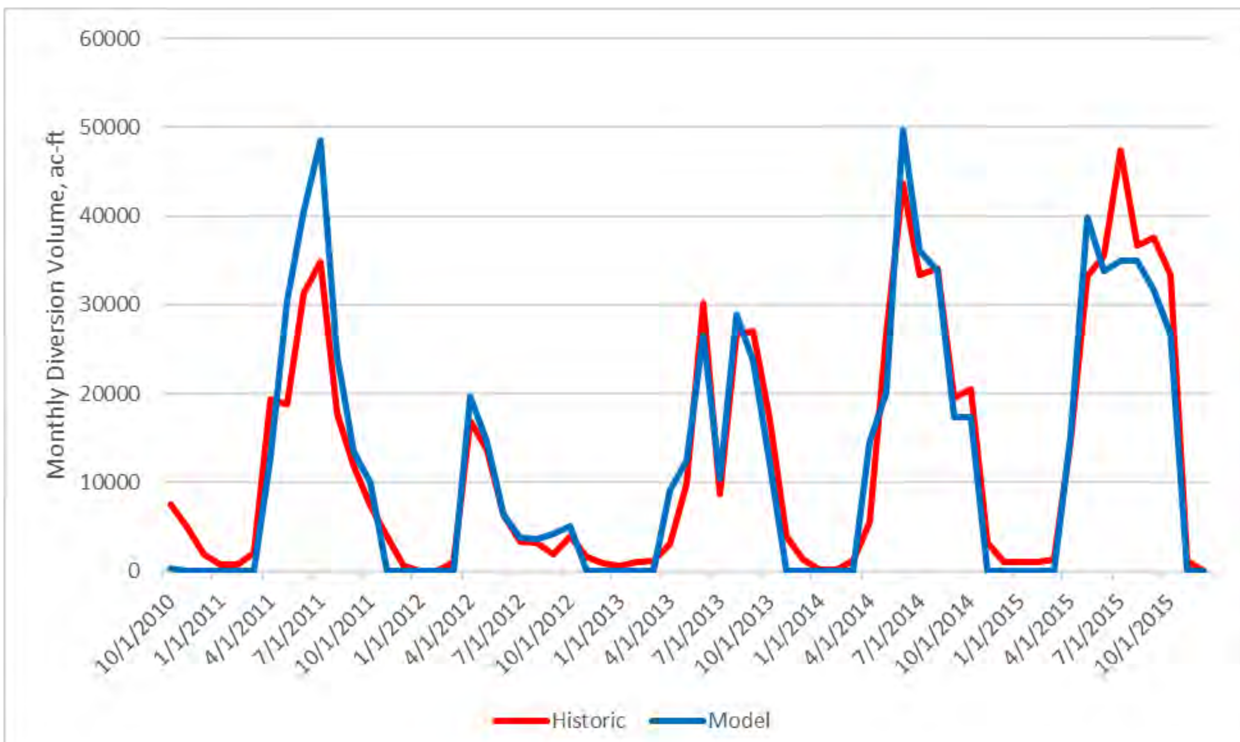

Figure 45: Combined Arkansas River below JM, Total Monthly Diversion Volumes, Simulated vs. Historic

6.11 Combined Diversions - Fountain Creek

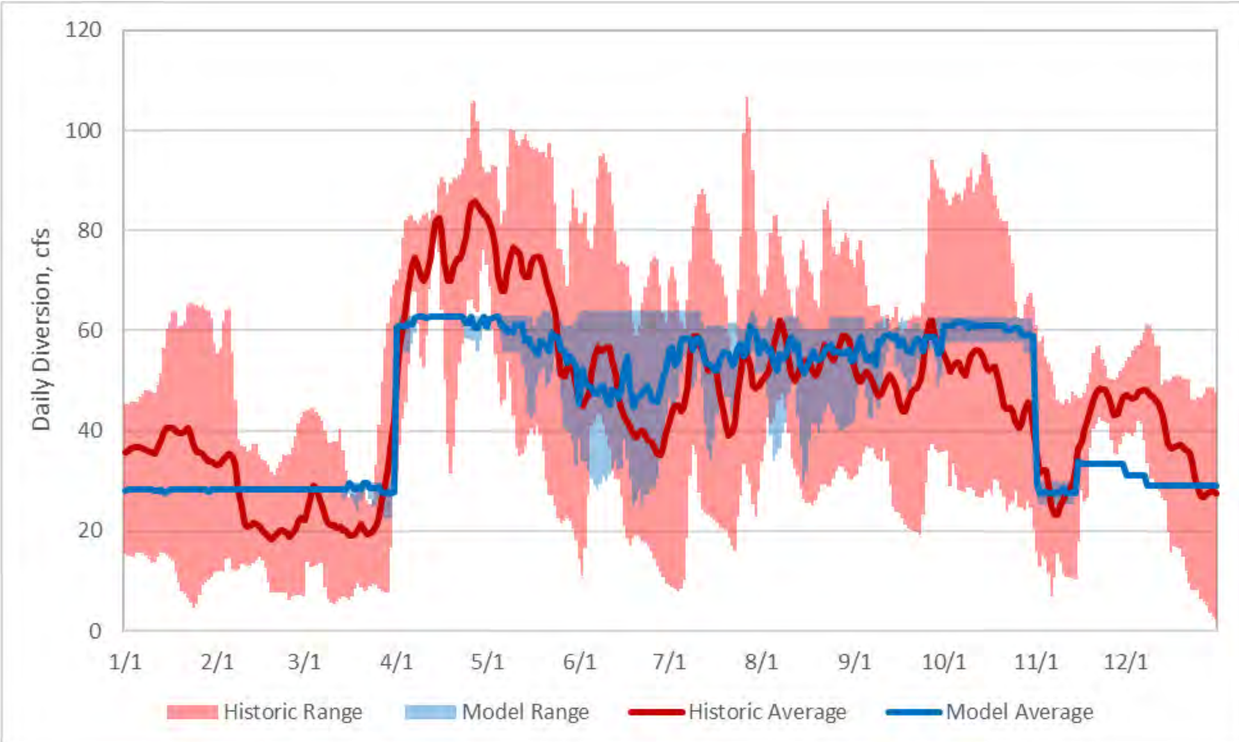

Figure 46: Combined Fountain Creek, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

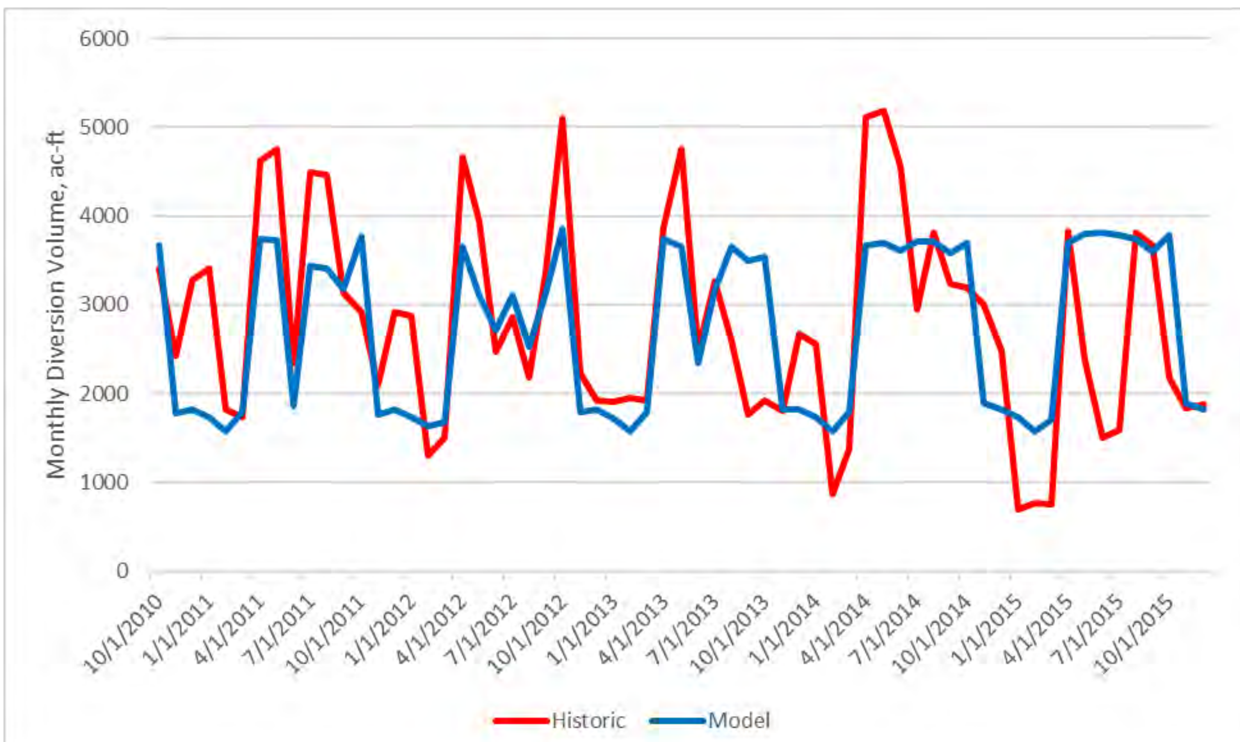

Figure 47: Combined Fountain Creek, Total Monthly Diversion Volumes, Simulated vs. Historic

6.12 COMBINED DIVERSIONS – PURGATOIRE RIVER

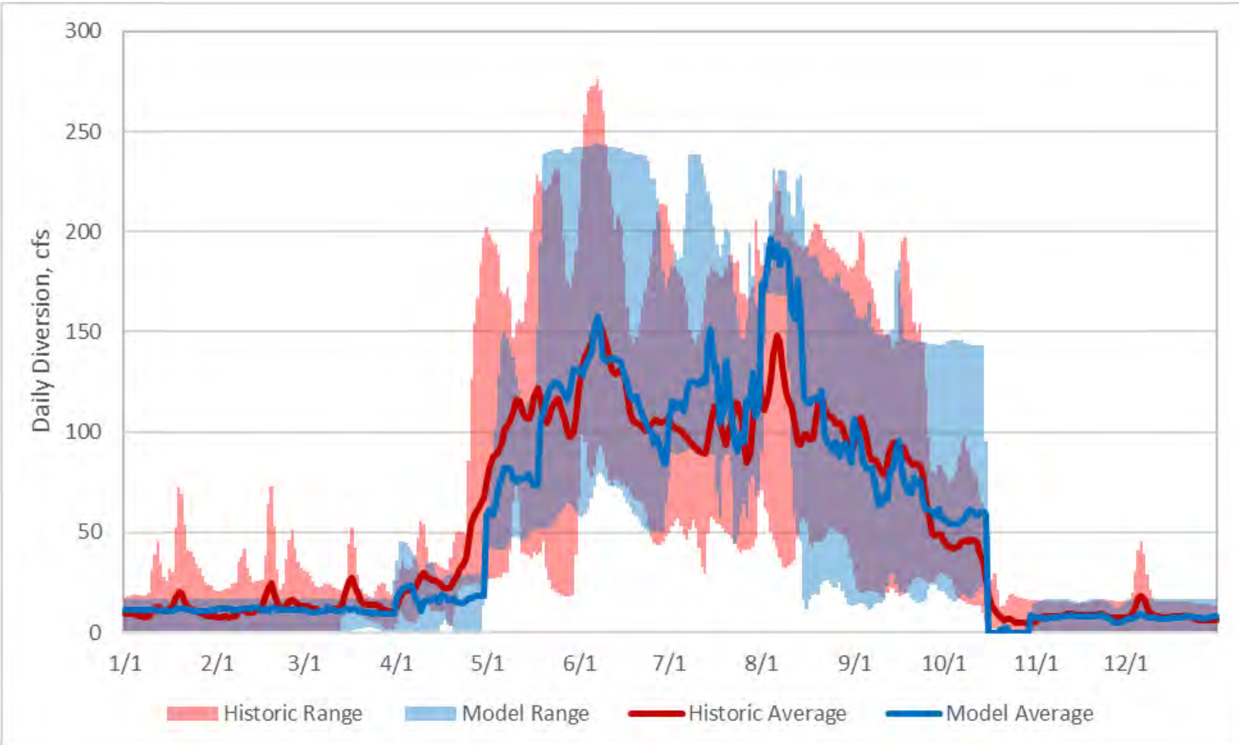

Figure 48: Combined Purgatoire River, Average and Range of 2011-2015 Daily Diversions, Simulated vs. Historic

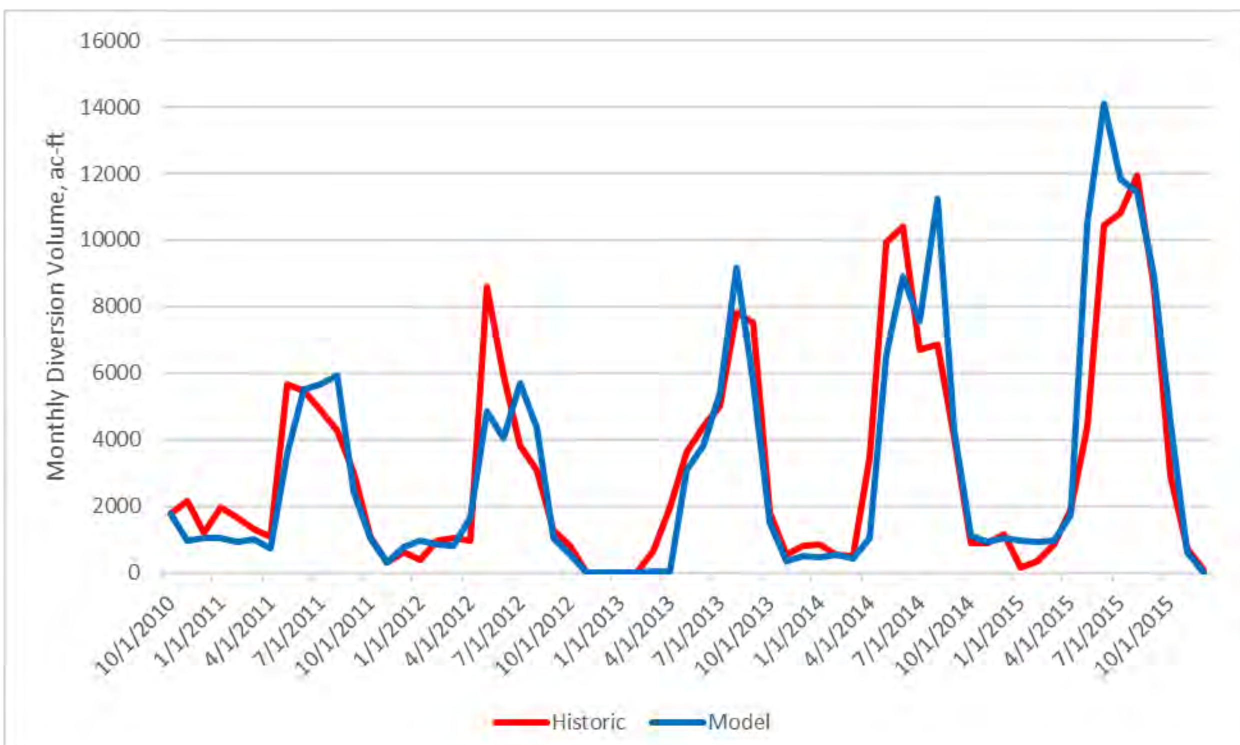

Figure 49: Combined Purgatoire River, Total Monthly Diversion Volumes, Simulated vs. Historic