ACCOUNTING FOR IMPERFECT RESERVOIR OPERATIONS IN THE TRUCKEE RIVER SYSTEM

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Abstract: The Truckee River System in California and Nevada contains seven reservoirs in its upper basin. Under the proposed Truckee River Operating Agreement (TROA), several parties are able to store and use their water supplies in new ways, consistent with their water rights. Prior to TROA and in TROA, all of the water that is impounded in the seven upper Truckee River basin reservoirs is allocated, and thus all storage and releases from reservoirs must be credited or charged to the appropriate account and owner. TROA provides new mechanisms for parties to establish credit waters, exchange water from one reservoir to another, and release water to meet their operational goals.

A RiverWare© model is used to determine the best operation of the reservoirs based on the TROA policy, the goals of the parties and the forecasted inflows to the system. Once operations are executed, the same RiverWare© model is then used to determine the final accounting of water in the system based on the measured release from each reservoir and the measured inflows. These measured outflows will differ from the intended or perfect operation of the system due to operational imperfections/imprecisions, inaccuracies in the forecast, and errors in gaging. It is necessary to account for these various imperfections so that the end-of-day accounting of the system correctly charges all of the water that was released to the appropriate accounts in the respective reservoirs.

An accounting method is under development that fully allocates the flow from each of the reservoirs, releases the desired amount of each party's water and closely matches the requests and availability to establish and exchange water throughout the system. Due to the complex and multi-objective nature of the releases a simple algorithm is not sufficient to provide an acceptable solution. Additional considerations must be taken when considering imperfections on reservoirs in series as opposed to reservoirs in parallel.

An overview of the RiverWare© model, the allocation process for imperfect operations, and an approach to testing the algorithm will be discussed in the following sections.

INTRODUCTION

Truckee River History: Water rights in the Truckee River Basin are well defined and fully appropriated. Original water rights from the Truckee River are mostly vested rights established by historic use for irrigation and power generation between 1861 and 1878. The vested rights were adjudicated between 1913 and 1926 and recorded in the Orr Ditch Decree (ODD), Orr Ditch Decree (1944).

Water management policy to satisfy ODD rights during the dry season and during more extended drought periods is established by the 1935 Truckee River Agreement (TRA), Truckee River Agreement (1935). The TRA provides for a simple-to-manage, supply driven system that specifies required rates of flow at the California/Nevada state line based on month of the year and the water surface level of Lake Tahoe. These specified flows are measured at the Farad Gage near the town of Floriston, California (see FaradGage in Figure 1) and are known as Floriston Rates (FR). The critical FR measurement point is down-stream from all Truckee Basin storage reservoirs. When the FR is met there is adequate water instream to satisfy all ODD water rights. During runoff season, water can be stored if the FR is met. FR storage is later released during the dry season to increase river flows up to the FR.

Water right markets (Nevada's water law that allows water right owners to apply to change manner and place of use) and a lengthy list of court rulings have accommodated the demand-shift for limited water resources from agricultural (Ag) to municipal and industrial (M&I) uses as well as for some newly recognized environmental purposes. However, the market transfers of ownership and use to date, have not been paired with suitable changes in reservoir operating policy. Specifically, M&I drought supplies have not been increased, because the FRs have not changed.

The proposed Truckee River Operating Agreement (TROA), Truckee River Operating Agreement (2008), system for river and reservoir management changes the operating system from one that is supply-driven and relatively simple to manage to one that is much more complex, but better meets separate, modern demands, Wilds (2010). TROA allows some water right owners to hold back a portion of their water right out of FR releases to establish Credit Waters to be released to directly meet their specific scheduled demands. The new TROA system is demand driven, adds many new Credit Water categories and sub-categories, responds to water right owners Scheduling requests and requires a very detailed, complex daily monitoring and accounting approach.

In October 2014, TROA was authorized, which will allow the parties to store and use their water more flexibly with much added complexity. A map of the Truckee River Basin is included in figure 1 for reference.

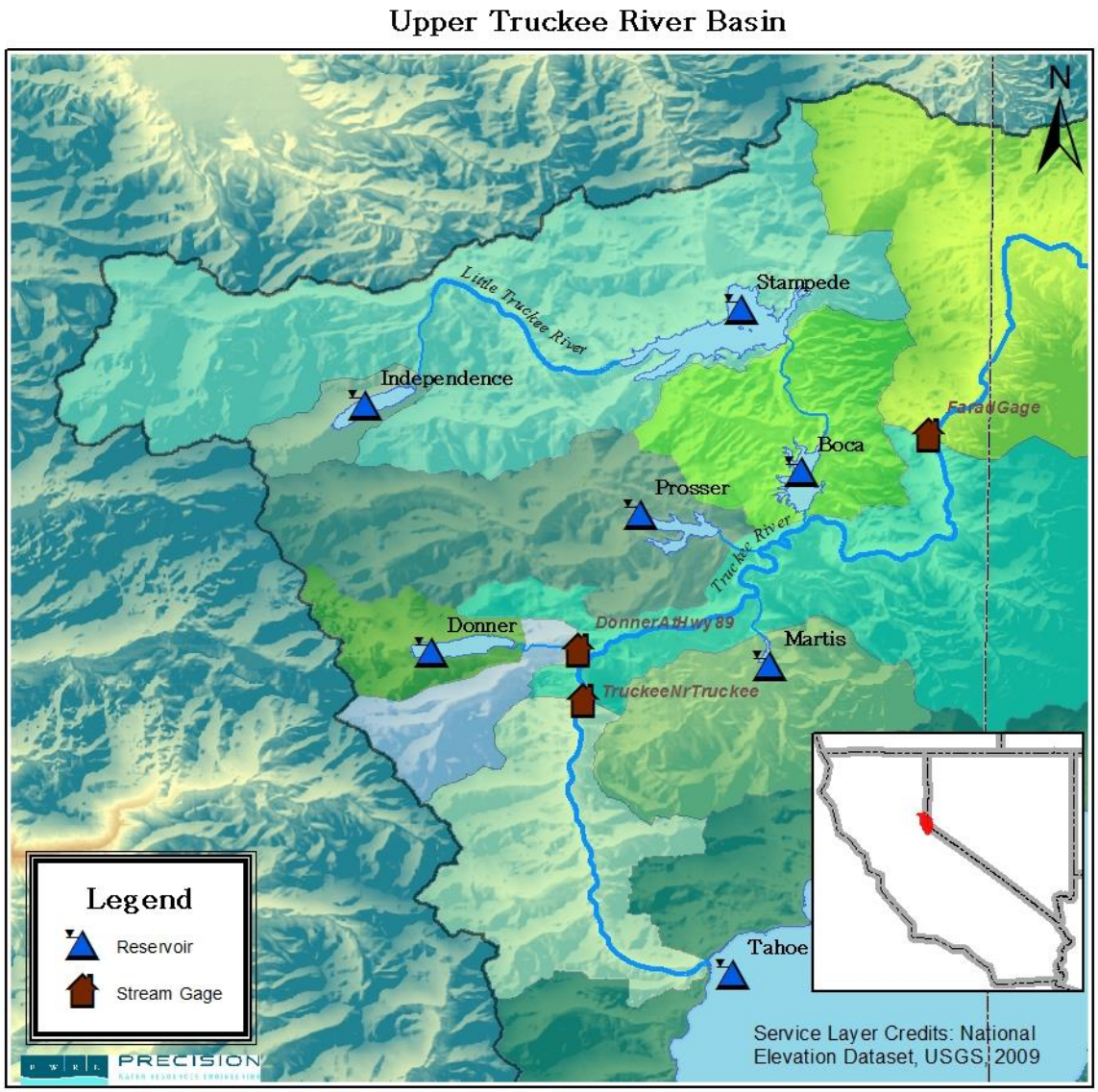

Figure 1 Map of the Truckee River Upper Basin Reservoirs

<u>TROA Policy:</u> TROA allows parties to establish credit water by holding back a portion of the FR release to establish credit water for later use at their scheduled request. A holdback can occur when FR water is being released from a reservoir to meet the Floriston Rate, as shown in the Pre-Holdback condition in Figure 2, the reservoir release is reduced and the amount that was held back is transferred from the FR account on the reservoir to the account of the party requesting the hold back on the reservoir. The net effect is that the outflow of the reservoir is reduced, the storage of a specific category of credit water in the reservoir is increased, credit water is established for Account B, and the storage of FR water in the reservoir is unaffected (i.e., FR Account is reduced by 150 cfs in both cases).

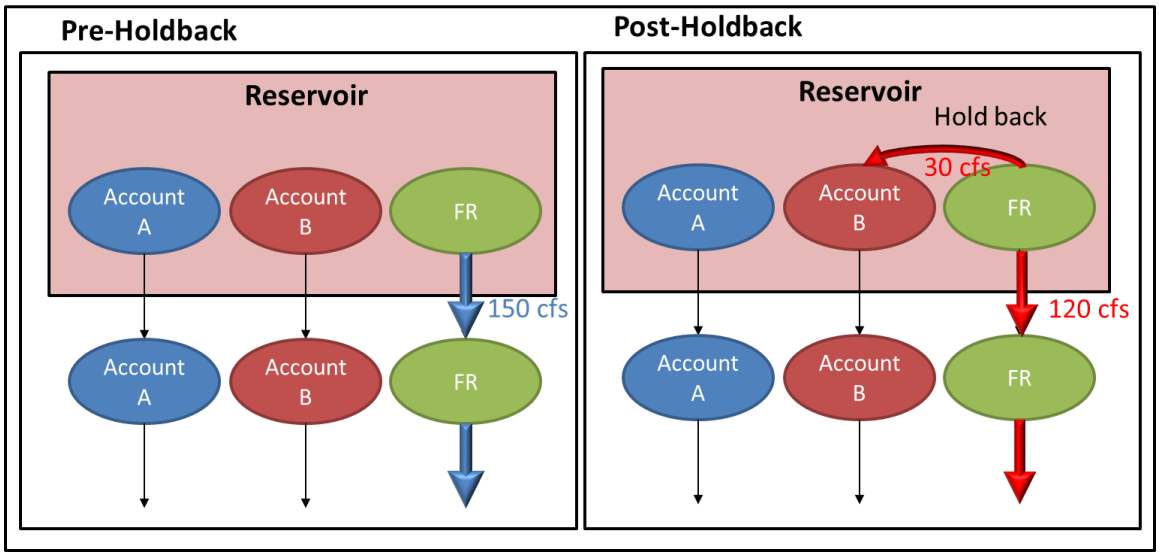

Figure 2 Typical Holdback of a FR Release on a Reservoir.

Once credit water is established TROA provides mechanisms for parties to move water between reservoirs, including trades and exchanges. For a trade, two parties with water in different reservoirs switch the location of an equal amount of water at the mutual consent of each party. If a party would like to move its credit water into a reservoir where a different party is releasing water then there is opportunity for an exchange. This process is best illustrated with the example shown in figure 3. The party that has a demand to release water, the FR Account, would be releasing 150 cfs of demanded water from Reservoir 2 as shown in the Pre-Exchange condition. The party that is moving its water, Account B, releases and transfers 30 cfs of its credit water from Reservoir 1 into the FR Account in the river. This is known as the Borrow as shown on Reservoir 1 in the Post-Exchange condition. Next the party releasing water for a demand (FR Account in Reservoir 2) reduces its release by 30 cfs and transfers 30 cfs of FR water into the account of the party that is moving water (Account B). This is known as the Payback as shown on Reservoir 2 in the Post-Exchange condition. Note that at the confluence below the two reservoirs, the river flow remains unchanged at 150 cfs. These processes give greater flexibility to the parties so that drought sources can be maintained in a secure location. Additionally, this same process can be used to increase streamflows in select reaches of the river to achieve other desirable goals set for recreation and the environment (e.g., rafting, fishing, and riparian habitat).

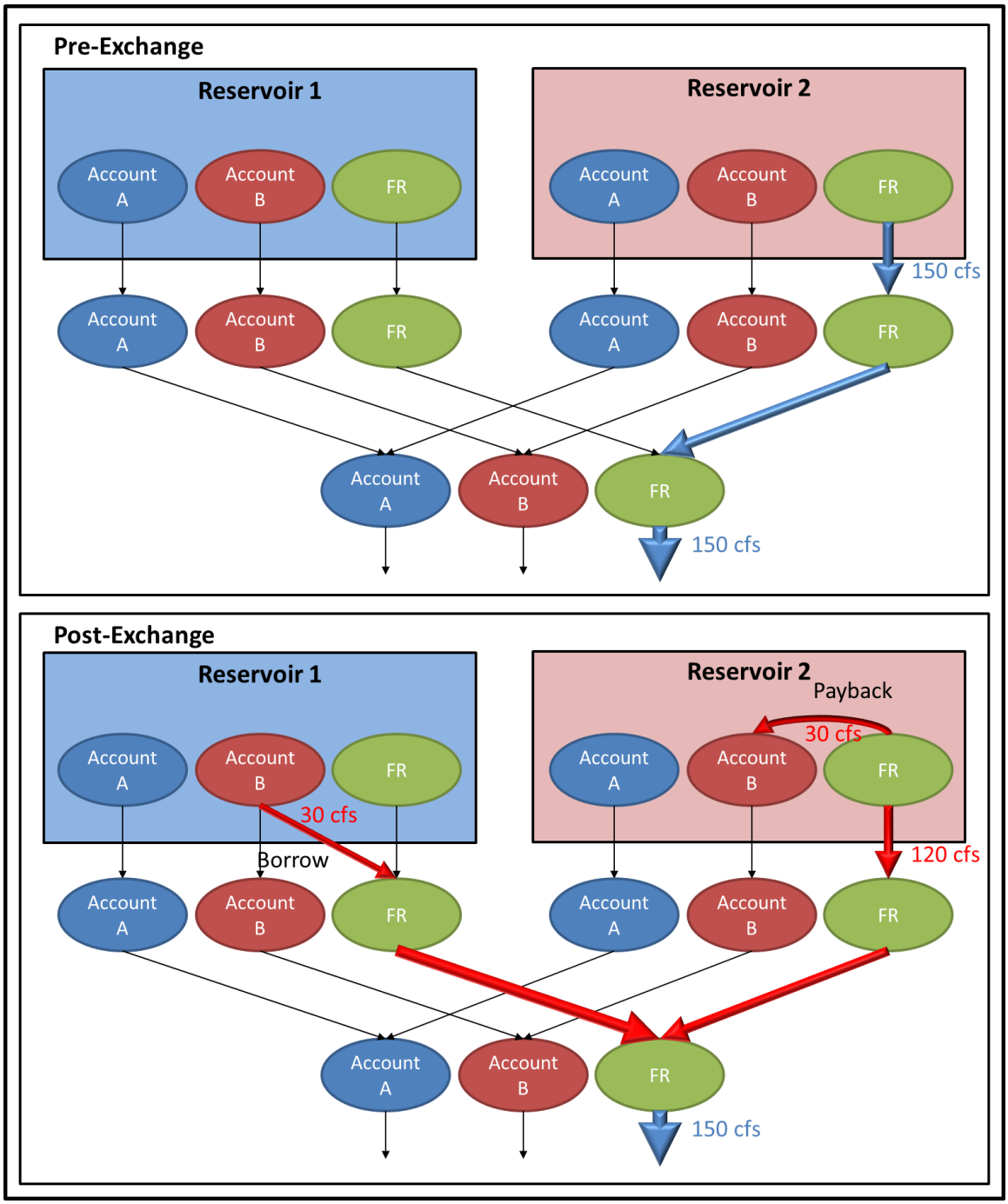

Figure 3 Typical FR exchange between two reservoirs showing the Pre-Exchange condition and the Post-Exchange condition.

<u>Accounting Approach:</u> A RiverWare© model is used to determine the best operation of the reservoirs based on the TROA policy, the goals of the parties and the forecasted inflows to the system. Once operations are executed the same RiverWare© model is then used to determine the final accounting of the system based on the actual release from each reservoir and the measured inflows. These measured outflows will differ from the intended or perfect operation of the system

for several reasons, including but not limited to: operational imperfections/imprecisions, inaccuracies in the forecast, and errors in gaging. It is necessary that the reservoir water accounting reflect these various imperfections so that the end-of-day accounting of the system charges all of the actually released water to the appropriate accounts in the respective reservoirs.

A method was developed to optimize allocations for the releases that fully allocates the flow from each of the reservoirs and releases the desired amount of flow from each party's storage account. Due to the complex and multi-objective nature of the releases, a simple algorithm is not sufficient to provide an acceptable solution. Additional considerations must be taken when considering imperfections on reservoirs in series as opposed to reservoirs in parallel. In the Truckee River system there are both reservoirs in series and reservoirs in parallel. To meet these objectives, a three step approach to reconciling imperfect accounting has been developed:

1. Determine Farad Process Allocation
2. Determine Main Truckee Reservoir Process Allocations
3. Determine Little Truckee Reservoir Process Allocations

Processes, as referred to in this paper, include the release, storage, establishment, or exchange of a specific category of water (e.g., M&I Credit Water Establishment). The three step approach is discussed in the following sections.

DETERMINE FARAD PROCESS ALLOCATION

In priority based systems such as the Truckee River Basin, it is desirable that the senior water rights be afforded higher protection than junior water rights. This is the practice when setting operations and it is desirable to approach accounting in a similar way such that the priority order is honored. With this approach we can use the imperfections as a way to perfect operations for the higher priority waters and their associated processes. Imperfections in the operations would be distributed to the lower priority waters. The advantage of a priority based system is that in most cases all processes achieve the desired allocation except for the lower priority process(es). A lower priority process, or floater, reconciles the imperfections to balance all or part of the system. By starting from the bottom of the system and working our way up we can use flexibility within the location of process releases to achieve the system goals. Setting a valid Farad allocation is the first step to ensure the success of the later steps in the imperfect operations accounting algorithm.

MAIN TRUCKEE ALLOCATION

Once the Farad allocation is set, the process allocation for the parallel reservoirs can be completed. These reservoirs include: Tahoe, Donner, Prosser, Martis, and the Little Truckee (LT) as shown in Figure 1. Because Boca is the outlet of the Little Truckee River and its release includes releases from Boca, Stampede and Independence, we will consider these three series reservoirs as a single reservoir, referred to as the LT, in this step.

This process has several goals:

1. Fully allocate the outflow of each reservoir.

2. The sum of the allocations on all main Truckee reservoirs for each process should match the Farad allocation for the respective process.
3. The allocation for each process on each reservoir should be as close as possible to the perfect operation.

The following loops outline the method that was found to give the best results in achieving the goals specified above, see Figure 4 for a flowchart that diagrams the steps below. These steps are meant to summarize the algorithm that has been developed and are therefore not comprehensive.

1. Loop over processes in order of increasing number of reservoirs involved (this is the loop in the upper left corner of Figure 4).
2. For each process, loop over the reservoirs that are releasing that process (this is the loop in the lower right corner of Figure 4). Each reservoir will fall into one of three categories (a-c) and will be allocated as specified below and in the respective part of Figure 4.
    a. If the current process is the floater process for the current reservoir, then set the reservoir process allocation to reconcile the reservoir while honoring the necessary limits and tolerances
    b. If the current reservoir is the last reservoir on the process list, reconcile the process while honoring the necessary limits and tolerances
    c. For all other cases allocate the theoretical perfect process allocation while honoring the necessary limits and tolerances.

The last allocation will reconcile the last process and the last reservoir at the same time, giving a reconciled system. This works because the sum of the Farad allocation for all processes is equal to the sum of the actual releases from the Main Truckee reservoirs.

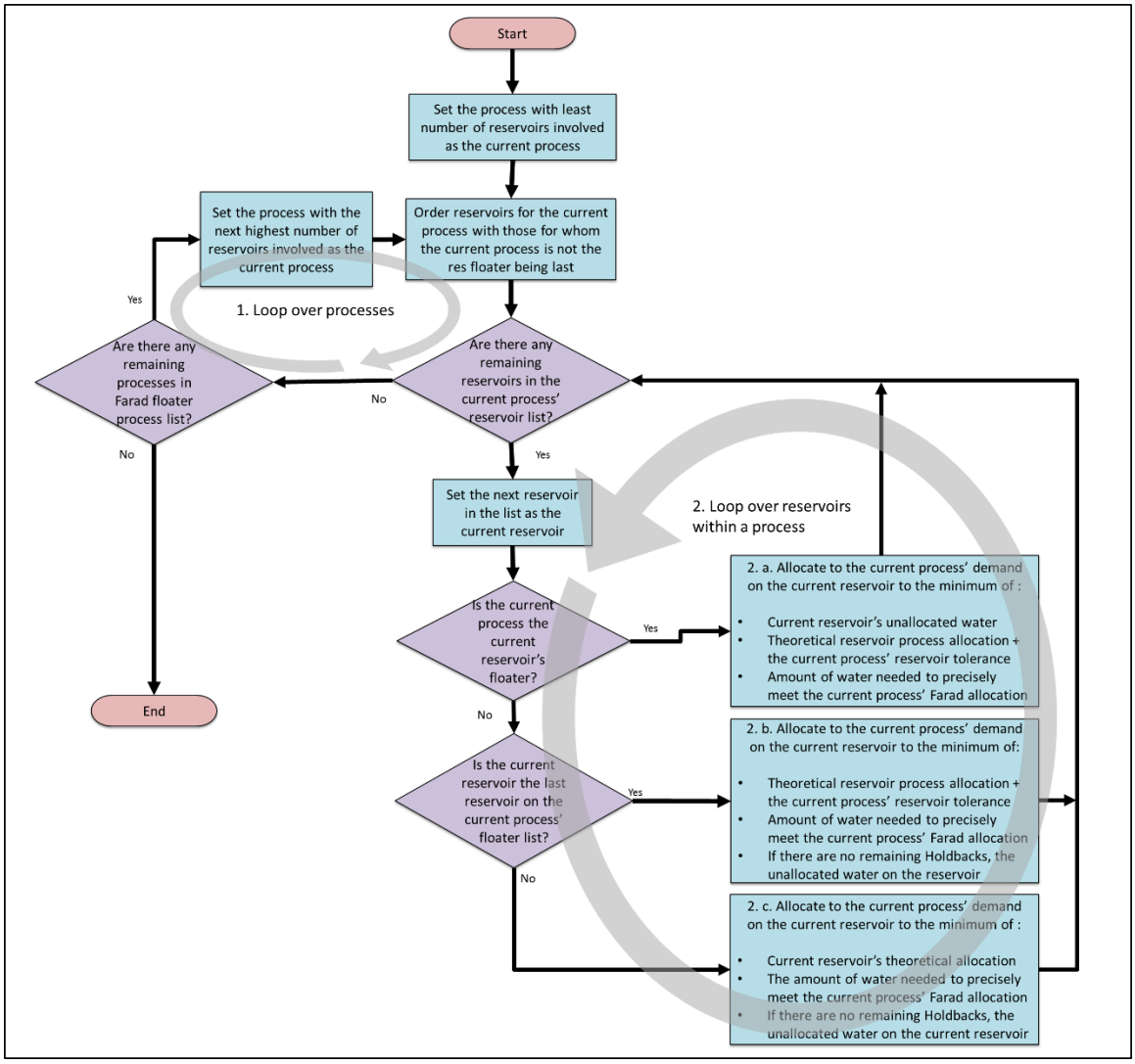

Figure 4 Flow chart for setting process allocations for the Main Truckee reservoirs**.**

LITTLE TRUCKEE ALLOCATION

Once the Main Truckee reservoirs are reconciled, the allocations for the LT aggregate reservoir can now be disaggregated into allocations for the three series reservoirs: Boca, Stampede and Independence.

Here, the remaining flow on a reservoir is difficult to determine until the flow from the upstream reservoir(s) are accounted for. Part of the release from a reservoir may be water being passed through from an upstream reservoir's release, and some of it may be a release from that reservoir. Another complication is that an upstream reservoir may release water with the intention of restoring it in a downstream reservoir. Considering these complications, it was determined that the best approach was to apportion releases to meet the LT allocation for each process letting the most downstream reservoir with each process float, if possible. Once this step is completed and the LT allocations set in the previous step are met, a check is made if the sum of the releases from

the reservoir and pass-through releases from upstream reservoir(s) is greater than the reservoir outflow. When this occurs it is necessary to re-label a process release on an upstream reservoir to a more downstream reservoir, if possible. If this is not a viable solution, an exchange can be created that moves credit water storage to a more upstream reservoir. The type of water moved is at the discretion of the TROA Administrator and may be used to meet standing requests of the parties. This allows reconciliation of the system even in dire scenarios. When the sum of the releases from storage for a reservoir and all pass-through releases from upstream reservoirs is less than the measured outflow from that reservoir, the remainder is labeled as a release to be restored in the next downstream reservoir. The account that is restored is prioritized based on the Administrator's discretion, and may meet a standing request of a party.

SYSTEM RELIABILITY AND TESTING

Because TROA has not been implemented, there is no measured data available to test the algorithm. Therefore, it is necessary to manufacture realistic synthetic data for testing purposes. Thorough testing of the algorithm discussed previously will provide for a smoother transition into administrating TROA when implementation begins.

In order to facilitate reasonable testing it is important that data be randomized to simulate the imperfections that will occur primarily from imprecise reservoir releases and imperfect knowledge of the system inflows. If data is randomized for too long of a period at once the perfect operation will diverge from the randomized operation due to changes in storage in the reservoirs. To avoid this and best simulate the day-to-day practice of setting releases and performing accounting of the measured flows the following day, it is important that the flows be randomized for each day and the operation for the next day be set based off of the storage from the accounting of the previous day's imperfect operations. This is done by coupling the RiverWare© operations and accounting model with a spreadsheet that randomizes the system flows and reservoir levels one day at a time. This process must be completed for each day in a water year which makes it a prime candidate for automation. To do this a RiverWare© batch mode script was written that simulates one day of reservoir operations based off of a forecast. The system operation is then sent to a spreadsheet via a RiverWare© Data Management Interface (DMI), where the reservoir outflows and system inflows are randomized. These randomized flows are then inputted to the RiverWare© model via another DMI as if they were measured in the field. The RiverWare© model is then run again and the newly randomized flows are accounted for using the accounting algorithm. The RiverWare© model then performs the best operation based off the supplied forecast and the process is repeated. This method allows for testing of a year of operations and accounting using the imperfect operations model by running a script overnight. In this way the RiverWare© accounting model can be tested for many hypothetical years with varying initialization and hydrological conditions. By analyzing the results of the hypothetical accounting years the accounting algorithm can be improved to address a wide variety of potentially difficult scenarios. This testing and development routine should provide a smoother transition once TROA is implemented.

PROVISIONS FOR NON-STANDARD OPERATIONS

Although it is desired to approach reservoir accounting in a systematic way it is understood that many obscure scenarios may occur where the systematic approach is insufficient to reconcile the

system. These scenarios may occur for a variety of reasons including maintenance, extreme natural phenomena, experimental reservoir operations, etc. Since many of these events are one time occurrence it is desired to have a method to complete the reservoir release accounting manually instead of developing special provisions in the RiverWare© accounting algorithm for these extra-ordinary scenarios. With this goal in mind, a method to review the daily results of the accounting algorithm was developed which provides the necessary information for the TROA Administrator to manually set the reservoir release allocation when deemed necessary.

SUMMARY

Considering the complexity that TROA introduces into Truckee River operations, it is necessary for the TROA Administrator to have a reliable and systematic method to perform the final reservoir accounting of the measured releases from the reservoirs. A three step priority based algorithm has been developed to perform the reservoir release accounting. These steps include:

1. Determine Farad Process Allocation,
2. Determine Main Truckee Reservoir Process Allocations, and
3. Determine Little Truckee Reservoir Process Allocations.

In order to provide a smooth transition into administering TROA, a method to generate realistic synthetic reservoir operations has been developed to test the reliability of the accounting algorithm.

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