The Arkansas Basin RiverWare Model

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Extended Abstract

A RiverWare® model has been developed that simulates the Arkansas River basin's water resource system from the headwaters near Leadville, Colorado to the Kansas state line on a daily timestep and at a high level of detail. The model can support many potential water management functions for a wide range of stakeholders, ranging from long-term planning, policy development, and water supply evaluations, to short-term operational forecasting, administration support, scheduling, and coordination between parties. Because the basin's policy and operational procedures are complex, contentious, and continuously changing, maintaining flexibility and transparency were key objectives throughout the development of the model. During the presentation, the model will be introduced, the process of validating its results will be surveyed, and the range of water management questions in the Arkansas River basin that this model can help address will be outlined.

The Arkansas basin's native water supplies and several transbasin import projects, including Reclamation's Fryingpan-Arkansas Project, are relied upon by many water users including municipalities such as Colorado Springs and Pueblo, CO, industrial users, and over 400,000 acres of irrigated agriculture. The water resource system is remarkably complex and multifaceted, including integrated operations and detailed accounting throughout many reservoirs, centering on the 357,000-acre-foot Pueblo Reservoir. With limited and highly variable water supplies and growing and changing demands, water is an incredibly valuable resource in the basin. Reliable supply sources, even those yielding relatively small but consistent amounts of water, are worth millions of dollars. In such a water tight system, the ability to appropriately and accurately answer water management questions and estimate the impacts of changes is vital to the continued success of both individual entities and the overall system.

The Arkansas basin's real-world administration and operations demand and depend on an incredibly detailed water accounting and sub-accounting system. Dozens of users with shared and individual water supply sources and demands operate independently and jointly throughout the system. To ensure adequate water supply across variable hydrologic conditions, entities often have multiple water supply sources and storage locations throughout the basin and move their water around the basin with various physical and accounting mechanisms, such as releases, diversions, different types of exchanges, and trades with other entities. Still, other entities don't themselves own direct sources and must instead lease surplus water from others at highly variable costs.

Water supply sources can include collections of direct flow and storage water rights of assorted priorities, transbasin import projects, and reusable return flows that are generated from the delivery of fully consumable water types and recaptured through various mechanisms. The yields of many water supply sources are highly dependent on hydrologic conditions and can vary enormously from one year to the next. Many current water rights have been changed since their

original decree to allow for different uses or alternative diversion or storage locations, however water right change decrees typically contain detailed requirements, limits, and criteria meant to prevent negative impacts to other water rights. These types of complexities necessitate the detailed accounting systems that are used to distinguish and individually track many different classifications of water, or “water types”, that may each be subject to unique and dynamic limits, rules, and requirements that have real impacts on individual systems.

While some sources are independently owned and operated, many supply sources, such as a canal company’s water rights or a reservoir’s storage rights (and storage space), are shared and jointly operated between multiple parties with yields being divided by share ownership percentages. However, these parties may have very different end uses and locations for their share of the yields, different mechanisms for moving water, and/or different other uses for their portion of a storage account’s total space.

In a bottom-up manner, the Arkansas basin’s overall conditions and operations emerge as the collective result of the many subsystems operating within it according to their own unique objectives, constraints, and rules. Due to these types of complexities, simulating the complex policy, accounting, and operations of the basin in an accurate, detailed, but practicable manner presents numerous challenges and necessitates creative and innovative modeling solutions.

Due to the system’s complex and dynamic nature, past modeling efforts in the basin have been relatively limited in scope, applicability, and transferability. Many entities’ individual systems span large areas of the basin and are interdependent with other entities’ systems, but past models have tended to focus on individual systems alone and have had limited ability to account for the changing operations of others and the ensuing variations in conditions throughout the basin. However, since those changes can have significant impacts on the yields and operational constraints of individual systems, not appropriately accounting for them has presented significant limitations. Additionally, previous models were tied inextricably with historical hydrology, policies, and operations making it difficult to simulate the effects of non-historic hydrology and/or updated policy and operational procedures. Furthermore, other models have generally lacked transparency, obscuring how particular results were reached and limiting the ability for in-depth analysis of why the simulated system acted the way it did and how the effects of various changes can propagate through the system.

The Arkansas Basin RiverWare model is different. The foundation of the Arkansas basin’s water supply system is Colorado’s prior appropriation water rights system, and thus RiverWare’s powerful water rights solver is employed on each timestep to allocate native flow to hundreds of direct flow and storage water rights. Subsequently, the model simulates many operational layers including the Fryingpan-Arkansas Project and other imports, multi-purpose and integrated reservoir operations and storage deliveries, the basin’s multi-party Winter Water Storage Program, and numerous exchanges, trades, and accounting transactions. These processes are explicitly and dynamically simulated using customized RiverWare rules that mimic the real world operational decision-making processes. Consequently, the model captures the effects of interdependent operations of various entities under changing basin conditions, as well as subsequent, indirect effects that can propagate throughout the system. Furthermore, this simulation process is very transparent and model results can be traced down to the individual, intuitive calculations and logical decisions made by the model’s rules.

Additionally, due to the way that simulated operations are “layered on” by the model’s rules, various “mid-timestep” solutions are also created that further enhance model transparency and understanding. The full network initially solves early within each timestep as the model’s rules are executed. The first “mid-timestep” solution, referred to as the “native flow solution”, is achieved after water right allocation is simulated, water user diversions are set to their allocated direct flow water right supplies only, and reservoir releases are set to their “native passthrough” amounts. This initial, temporary solution represents what the system conditions would look like on that day if no other operations were to occur. Next, the operational rules fire one-by-one and adjust the previously solved network appropriately to reflect their simulated operations. For example, a “deliver from storage” rule will evaluate a water user’s total daily diversion demand and their daily water right allocation, and their storage available for delivery from one or more storage sources. If needed, the rule will execute a delivery from storage to supplement native water right diversions and meet its full demand. This delivery is layered on to the previous network solution by increasing the reservoir’s release and the water user’s diversion by the same amount, as well deducting that amount from the appropriate storage account in the reservoir. After the rule fires, the full network will re-solve based on the changes applied and represent the system with that storage delivery being made, resulting in increased flows in the reaches between the reservoir and water user. Another common operation simulated by the model is an exchange of water from a diversion into a reservoir’s storage, which a rule executes by reducing a reservoir release and downstream water user diversion by like amounts, thus “holding back” the water in the reservoir and transferring to the appropriate storage account. When an exchange like this is executed and the network re-solves, it will cause flows to decrease in the reaches between the reservoir and water user. These kinds of exchanges are typically subject to many criteria and limits (e.g., minimum flow requirements) that can be challenging to simulate, however this step-by-step rulebased process allows for transparent “pre-exchange” and “post-exchange” solutions that greatly facilitate the simulation of multiple, complex exchanges.

Managing the simulated level of detail throughout the complex system also presented a significant challenge. To address this, the model was designed to allow for variable levels of detail, allowing for detailed representation where necessary while not requiring it where it is not yet necessary or practicable. The various subsystems and storage accounts and subaccounts of entities are designed in a modular sense to allow for continued refinement and adaptation to meet variable needs. For example, the storage accounting of one water owner may track specific water types in detail though another’s may all be simply lumped together, and robust rule logic accounts for the disparity and still allows for interactions or joint operations to be simulated.

Finally, the Arkansas Basin RiverWare model brings state-of-the-art capabilities to the basin water managers because, the model, which simulates the basin’s network and operations, is decoupled from the driving hydrology and demand data. The model’s network and rules can be altered to represent physical changes to the system and/or operational scenarios, such as proposed reservoir enlargements or changed reservoir operation procedures. Independently, alternative driving data representing varied hydrologic conditions and demand scenarios can be efficiently moved in and out of the model. The model’s base naturalized hydrology dataset can be used in historical order, but can also be re-sequenced, sampled, and/or adjusted using various techniques to create novel hydrology scenarios, such as extended drought or flood periods or climate change impacts. This ability to drive the model with alternative hydrology scenarios can help answer many important water management questions relating to how the system might react under conditions very different than those observed in the recent past. On top of that, the ability to combine various system and operational changes with alternative driving data provides the ability to answer complex water management questions in the basin.