DEVELOPMENTS IN RIVERWARE FOR WARSMP APPLICATIONS

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Abstract: RiverWare™ is an integral part of the Watershed and River System Management Program (WaRSMP) suite of DSS tools, serving as the primary model for operational decision-making. Researched and developed by the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems (CU-CADSWES) in collaboration with the Tennessee Valley Authority (TVA), the U.S. Bureau of Reclamation (USBR), and the U.S. Army Corp of Engineers (USACE), RiverWare is a generalized river and reservoir modeling tool that can be run either as a stand-alone application, or in concert with other models and databases. RiverWare simulates the hydrologic response of the river system, given unregulated inflows and management decisions such as reservoir releases and diversions. The most recent WaRSMP applications, including the Upper Rio Grande, the Truckee-Carson and the Columbia Basins Project, have resulted in the development in RiverWare of several sophisticated modeling and analysis tools. In order to better track water ownership and use on the Rio Grande and the Truckee-Carson Rivers, functionality was added to RiverWare to present a fully customizable interactive graphical view of the accounting networking. This tool is extremely useful to help model developers communicate with decision makers and stakeholders in the basin. To help users better understand their RiverWare Policy Language sets, an interface called the Rules Analysis Tool was developed in RiverWare. The Rules Analysis Tool provides a tree-view for displaying the relationship amongst rules, functions, and assignments. Rulebased simulation was further enhanced to allow a rule to execute a Data Management Interface (DMI) group. This provides users with more flexibility to manage modeling data. To support modeling of a complex system of distribution canals on the Columbia Basins Project, the distribution canal object was enhanced to compute and track storage. At a specified time of the year, the canal fills to a certain storage level and remains full until the canal is drained at a later date. To facilitate stakeholder participation in operational policy evaluation, a tool called the Scenario Manager was developed to provide non-expert modelers and stakeholders a framework to input sensible and feasible alternative input values, make runs and compare the results of these alternative runs without impacting the underlying base model. This paper describes these new modeling capabilities in RiverWare.

INTRODUCTION

The Watershed and River System Management Program (WaRSMP) is sponsored by Reclamation and the U.S. Geological Survey. This program provides a data centered framework for water resources decision-making (Frevert and Lins, 2006). Today's complex water resources management issues require flexible, comprehensive decision support tools that display timely information to water managers. River systems operate under laws, compacts, treaties and court decrees, while meeting increasing demands that compete for limited fresh water supplies. The WaRSMP suite of decision support tools include databases, data collection systems, and hydrologic models. RiverWare is one of these hydrologic modeling tools; it facilitates operational decision-making on the river system.

RiverWare is a general river and reservoir modeling tool researched and developed at the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems (CU-CADSWES), as part of the WaRSMP, and also collaboration with the Tennessee Valley Authority (TVA), several offices of the U.S. Bureau of Reclamation (USBR), and the U.S. Army Corp of Engineers (USACE). RiverWare is available to the public through the University of Colorado Office of Technology Transfer.

This paper briefly describes RiverWare's capabilities and its WaRSMP applications. Next, recent developments in RiverWare for WaRSMP projects are described. These involve enhancements to the water accounting system, enhancements to the rulebased simulation system, new functionality on the distribution canal, and a new feature called the scenario manager.

RIVERWARE CAPABILITIES

RiverWare is a fully supported and documented general river and reservoir computer modeling application supported on Sun Solaris Unix and Windows operating systems (Zagona et al., 2001; Zagona et al., 2005). RiverWare can be run either as a stand-alone application, or in concert with other models and databases. RiverWare simulates the hydrologic response of the river system, given unregulated inflows and management decisions such as reservoir releases and diversions. The basic approach to modeling is as follows: objects represent features like reservoir, reaches, and diversions. For each object, the user selects methods that best represent physical processes such as evaporation, seepage, spill, or stage depending on the object type. The objects are then linked together to form a network representing the basin. Data is entered through the user interface or the model can be connected to a database or data files through the Data Management Interface (DMI). Figure 1 shows the workspace, palette and open object window.

There are three selectable solution methods: simulation, rulebased simulation, and optimization. In simulation, the user enters all of the data necessary for the objects to solve. For example, the user must input inflow and outflow in order to solve for storage on a reservoir object. Conversely, the user could input inflow and storage and RiverWare will solve for outflow. Rulebased simulation builds on the simulation framework but the user is able to define a flexible ruleset of operating policies that sets data in the model thus causing the objects to solve. Using prioritized IF-THEN-ELSE type logic, the user is able to set values based on the state of the system. For example, on a certain date, the outflow from a reservoir is set to the monthly minimum required release if specified conditions in the basin are true. Once the rule has set the outflow, the simulation system forces the object to solve given outflow and the user specified inflow. By prioritizing the logic, the user is able to simulate complex operating objective. Typical objectives reflect such policies as meeting downstream demands, adhering to accepted flood control operations, maintaining depths for navigation, providing flows for water quality and riparian habitat, providing flows and lake levels for recreation, and producing economical hydropower. In addition to the simulation and rulebased simulation, there is an optimization solution method that strives to meet the objectives using a linear goal programming solution.

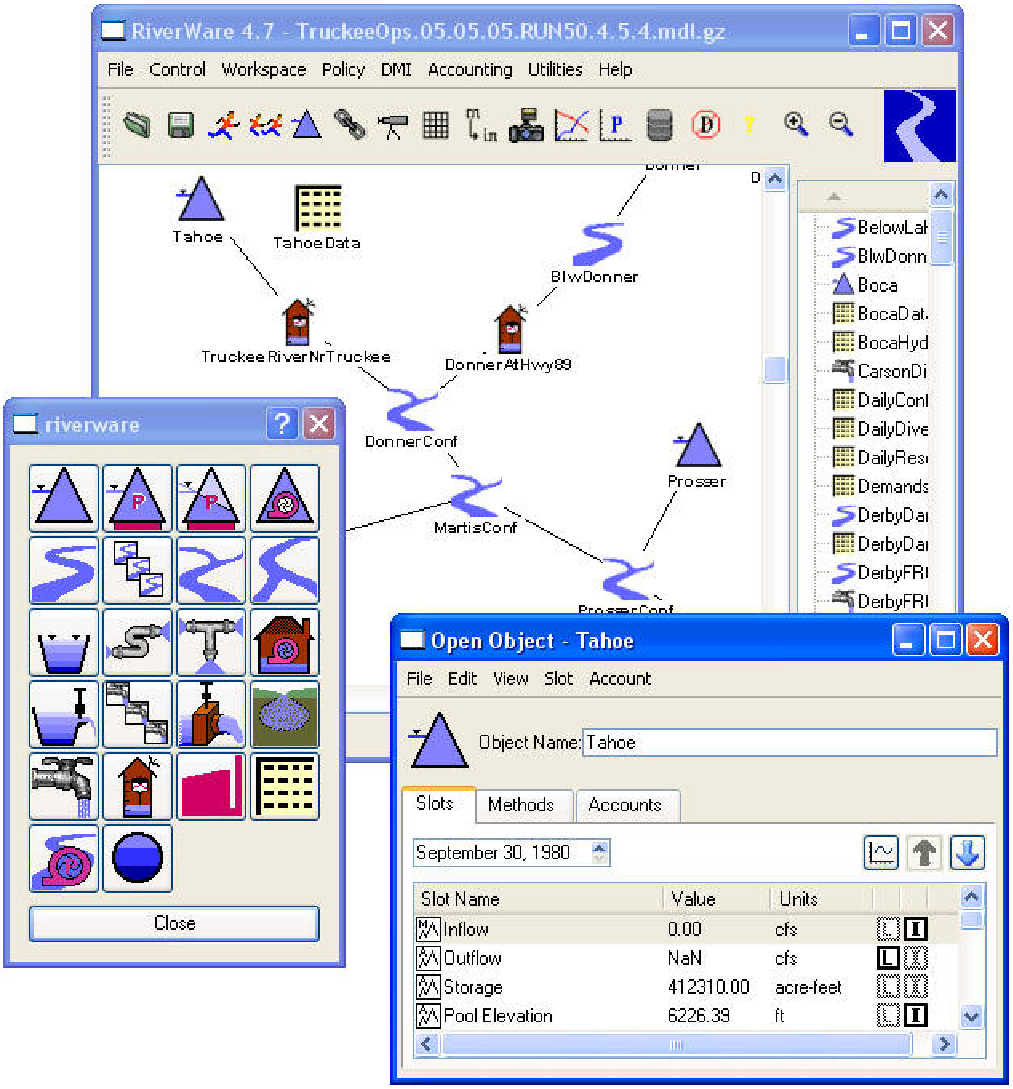

Figure 1 RiverWare Workspace, Palette, and Open Object view

RiverWare also has the following features:

- Water accounting – The user is able to define a water accounting network to track water type and ownership in the basin. This is described in more detail in following sections.
- Water quality – The user can simulate stream temperature, total dissolved solids and dissolved oxygen
- Uncertainty modeling – The user can track uncertainty
- Data Management Interface (DMI) – RiverWare provides a system to move data between a model and any data base.
- Plotting tool – The user can define and save plotting and output configurations
- Simulation Control Table (SCT) – A user defined table provides a spreadsheet view of the model
- Model run analysis tool – A tool is provided to display the solution procedure
- Scenario Manager – An interface is provided to allow alternate input data without affecting the underlying base model. This feature is described in more detail below.

The following basins use RiverWare as part of WaRSMP: Upper Colorado, Lower Colorado, Gunnison, San Juan, Yakima, Truckee/Carson, and the Upper Rio Grande. The basins use RiverWare for varied purposes such as operations, after-the-fact water accounting, short term forecasting, long term planning, and impact studies.

RECENT DEVELOPMENTS

There have been many developments in RiverWare as part of WaRSMP projects. The accounting system has been enhanced, and in particular, an account visualization tool has been added. Rulebased simulation has been updated so that users can now execute DMI's from rules and tools have been added to better analyze rulebased simulation runs. Storage and evaporation have been added to the distribution canal so that users can now model the filling and draining of these canals. Finally, a feature called the Scenario Manager has been added to allow modelers, stakeholders, and other decision makers to try alternative scenarios without affecting the underlying model. These features are described in the remainder of the paper.

Accounting In many basins, it is necessary to track water type and water ownership, not just the physical volume of water. In RiverWare, this is accomplished by creating a water accounting network. Currently, the Truckee/Carson basin (Coors, 2006) and the Upper Rio Grande (Sidlow et al., 2006) are WaRSMP applications using this functionality and driving its development.

In RiverWare "physical" water is modeled in the simulation object network and "paper" water (water type and ownership) is modeled in the accounting network. For example, a reservoir's storage indicates the quantity of physical water in the reservoir at each timestep. The storage account on a reservoir shows the volume of water in the reservoir owned by a separate entity or water of a different legal type. In RiverWare, water accounts are created on the simulation objects and linked together to form a network of accounts. These links are called "supplies" and represent supply and demand relationship between two accounts. The accounting network is controlled by user inputs or by rules; i.e. the user sets the outflow from an accounts. Predefined and user defined methods control how water is introduced into and removed from the accounting network, typically using information from the physical simulation. For example, the physical inflow to a reservoir may be shared between two accounts but the reservoir evaporation may be charged to just one of the accounts. Currently there are three types of accounts: storage, pass-through and diversion.

Accounting Visualization In the past, users found that a complex accounting network with many accounts and supplies was difficult to visualize. Users were required to construct and maintain a diagram or flowchart of the network. Recently, functionality was added to RiverWare to present a graphical view of the accounting networking. This tool is extremely useful to help model developers communicate with decision makers and stakeholders in the basin.

The accounting network is presented in a separate view from the standard schematic depiction of the physical network or workspace view. The accounting view provides a representation of the physical objects as well as the accounts on those objects. The user is able to toggle between the two views. Figure 2 shows a view of the accounting network. Accounts are displayed in a rectangle with its parent simulation object with the object icon and name in the upper left corner.

Storage accounts are represented by rectangular icons, pass-through accounts are represented by elliptical icons, and diversion accounts are represented by isosceles trapezoids. An arrow represents the directional supply-demand relationship. Transfers between accounts on the same object are represented by a curved line.

In this accounting view of the workspace, the user is able to set display properties of the system. This is accomplished by defining groups of accounts or supplies that have a unique feature such as water type or release type. Configurable account display properties include border color, background color, background fill pattern, width, visibility, depth/canvas layer, aggregation. Configurable supply display properties will include: line color, line style, line width, depth/canvas layering, and visibility. For example, in Figure 2 all of the supplies leading into or out of the Fish account are colored green.

In certain models, such as URGWOM, there are numerous accounts that represent similar users or contractors. To simplify the accounting view, it is possible to aggregate and/or hide accounts. When accounts are aggregated, all the accounts in the aggregation are represented by a single icon that looks like a "stack" of two accounts. This representation is labeled with the name of the display group that aggregated the accounts.

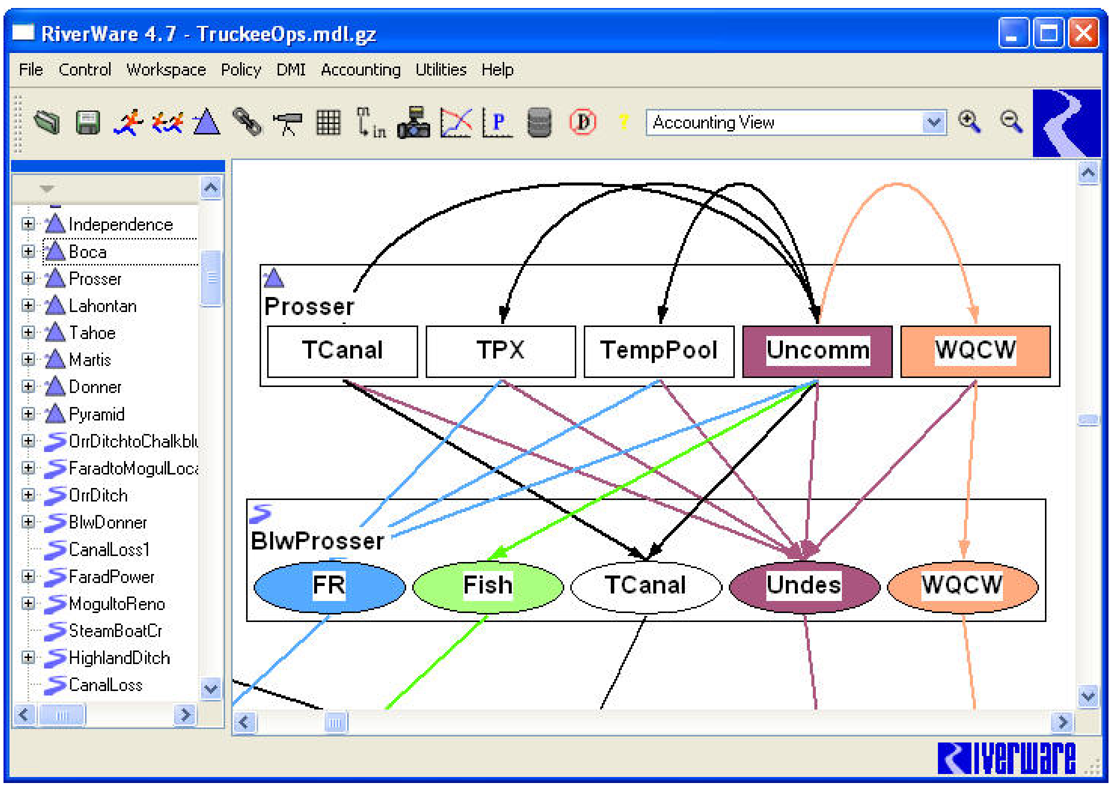

Figure 2 Screenshot of Accounting View

Rulebased Simulation There have been a number of recent developments in rulebased simulation including the Rules Analysis Tool and the ability to execute DMI groups from a rule.

Rules Analysis Tool To help users better understand, debug, and improve rulesets, an interface called the Rules Analysis Tool was developed in RiverWare. The Rules Analysis Tool shown in Figure 3 provides a tree-view for displaying the relationship amongst rules, functions, and assignments of a RiverWare Policy Language set. The user selects either the Groups, Descending, or Ascending tab. The Groups tab shows each policy and utility group and the rules, functions, and assignments contained. This is similar to the ruleset window. The Descending tab shows the functions and/or assignment statements that are called from a selected rule, function, or assignment. The Ascending view shows the opposite, the functions, rules, and assignment statements that call the selected function or assignment statement. For each tab, additional data about each item can be displayed. These include number of evaluations, time of evaluation, priority, description, and number of items called. These features are especially useful to improve the performance of the model, i.e. it can be used to identify functions that require a large number of computations or evaluation time, thus enabling the modeler to focus their efforts.

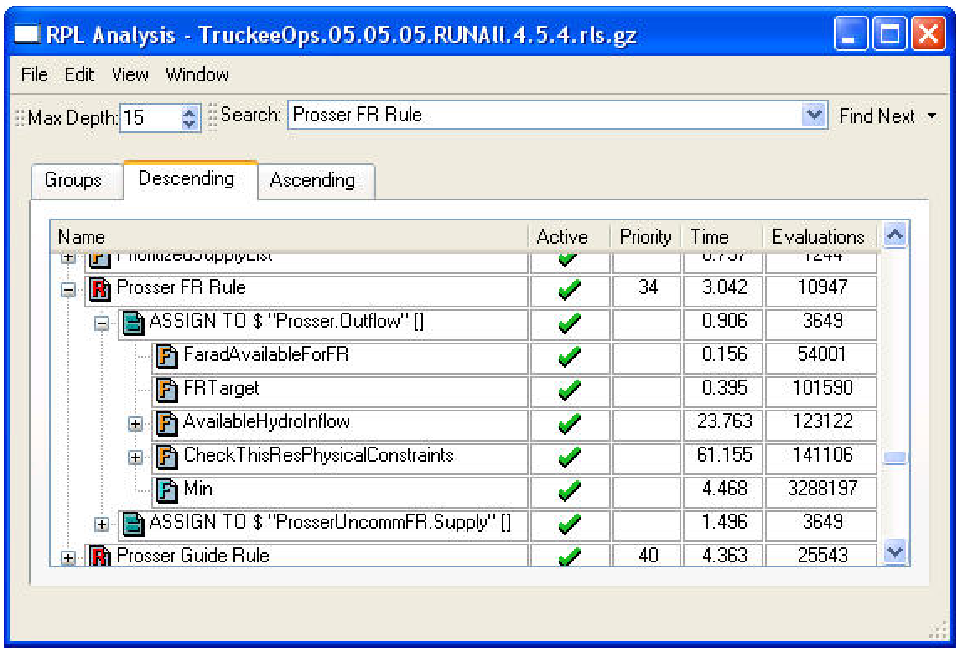

Figure 3 Screenshot of Rules Analysis Tool

Executing DMI's From Rules Rulebased simulation was enhanced to allow a rule to execute a Data Management Interface (DMI) group. The purpose of this development is to allow users to use a rule to call a DMI to move data into and out of the model. The user can associate one or two DMI groups with a rule. Whenever the rule is executed, the DMI groups are executed. The DMI groups execute as the first step of rule execution and/or as the last step. Values imported by the pre-execution DMI group are available for use by the rule's statements. This has been used for calling a water quality model from the Truckee River decision model by Reiker (2006).

Storage on Distribution Canals The distribution canal object was enhanced to compute and track storage. At a specified time of the year, the canal fills to a certain storage level and remains full until the canal is drained at a later date. In addition, an evaporation term was added to the distribution canal object's mass balance equation. This functionality allows the Pacific

Northwest USBR office to better track the volume of water that must be diverted to canals in the Columbia Basin Irrigation Project RiverWare Model.

Scenario Manager The Scenario Manager provides non-expert modelers (i.e. those not involved in the model development) a framework to enter sensible and feasible alternative input values, make model runs and compare the results of these alternative runs without impacting the underlying base model. Figure 4 shows a view of the Scenario Manager.

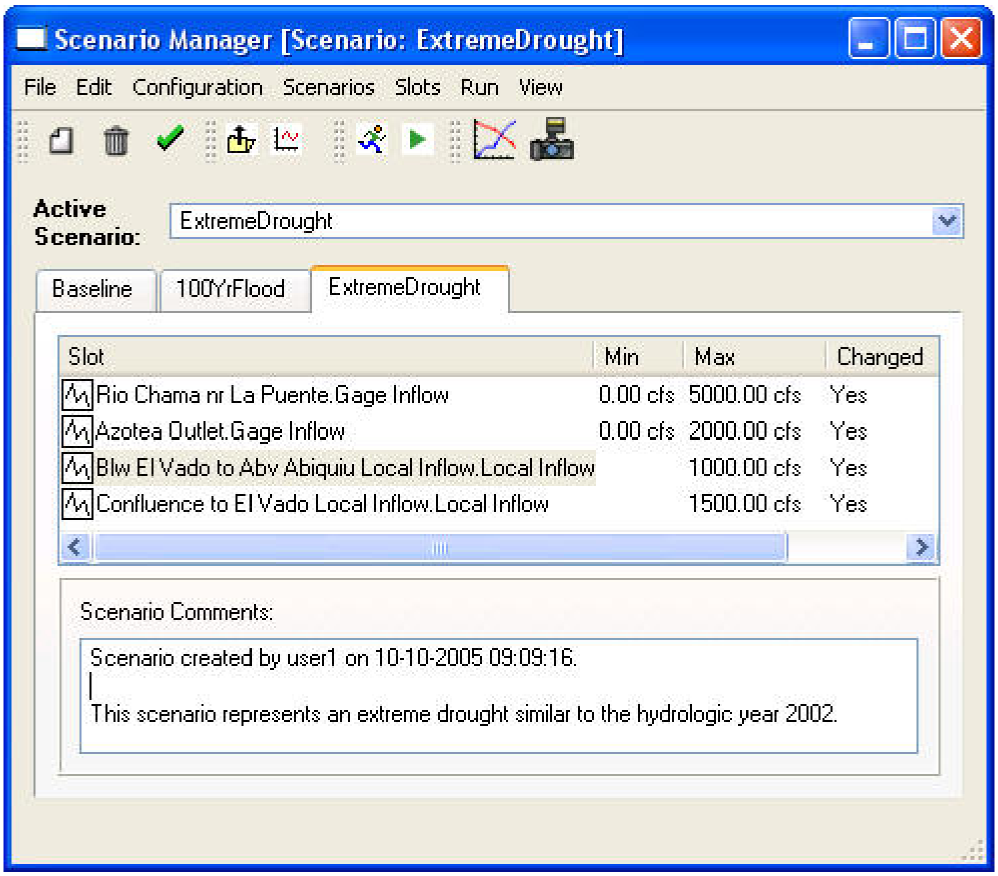

Figure 4 Screenshot of Scenario Manager

Scenario analysis consists of three parts: a set of scenario slots (data), a baseline model, and a set of alternative input data describing the scenario. The scenario slot list is a set of slots to be used in the scenario. These slots contain the input data that the user wants to modify and test. Typically the model developer selects this list of slots and is able to specify minimum and/or maximum values for this data which helps to prevent unrealistic input data. The modeler then saves the model specifying that it is a "baseline model." Once a model has been saved as a baseline model, topology, methods, and non-scenario slots become uneditable and slots cannot be added or deleted from the scenario slot list. By preventing editing of the baseline model and the scenario slot list, the integrity of the baseline model is preserved and the scope of the scenarios is limited.

The user, typically the stakeholder, creates a scenario and enters data on the scenario slots. The scenario data must be in the range defined in the scenario slot. This scenario data is saved separately from the model file making it easily shared between users and model developers. The user loads the scenario into the baseline model and activates the scenario to make a model run. Once a run has been made, the output in the model file represents the scenario. The baseline model cannot be overwritten with this new data, but the results can be re-saved as a non-baseline run. The scenario manager allows for comparisons between slots in the baseline run and scenario runs by creating a read-only "snapshot" of data. The snapshot is compared to output from other scenarios or baseline runs. RiverWare provides plotting tools for users to create plots that compare the scenarios.

The use of the scenario manager in RiverWare allows stakeholders to perform what-if scenarios without requiring thorough knowledge of the model, ruleset, and user interface. This lets stakeholders with knowledge of the river system, but not experts on the model itself to make alternative runs and review the results to see if they make sense and are reasonable representations of the real world operations and river dynamics. The scenario manager was recently used in the testing phase of the Upper Rio Grande Oprations Model (Sidlow et al., 2006). Stakeholders were provided with a baseline model and encouraged to test their own scenarios and provide comments and results to the model developers. This type of interaction allows for better understanding, acceptance, and use of the model.

SUMMARY

RiverWare, a modeling tool to help water managers make decisions, is an integral part of the WaRSMP suite of tools. Recent developments like accounting visualization, executing DMIs from rules, the rules analysis tool and the scenario manager will help WaRSMP projects better model their basins. More importantly, the tools will better allow modelers and stakeholders in the basin to view, understand, and use the model. These tools will ensure that a RiverWare model does not become a "black box" that non-experts cannot understand or trust. Hopefully, this will make RiverWare a useful tool that will help water managers make more informed decisions.

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