RiverWare Demonstration Tutorial

This RiverWare informational tutorial introduces you to the capabilities of RiverWare as an advanced water resource modeling tool and consists of three sections, **Simulation in RiverWare**, **Rulebased Simulation**, and **Multiple Run Management**. These tutorials are independent documents but later topics do build on skills you gain from earlier exercises, so if you have not gone through the earlier topics or have not used RiverWare recently it is recommended that you start with the tutorial on **Simulation in RiverWare**.

Before you start...You must have RiverWare 9.0.4 or later installed on your computer and have a valid license file. For more information about downloading RiverWare, visit RiverWare.org. To acquire a demonstration license, please email Installation Support (installsupport@colorado.edu).

You must have downloaded the files associated with this tutorial and moved them to a reasonable folder like `C:/temp`. The following files are used in this tutorial:

- MuddyBartlettBasin_RBS_Start.mdl.gz - Starting MODEL
- MuddyBartlett_Info_RBSstart.rls.gz - Starting RULESET
- MuddyBartlett_Info_RBSfinal.rls.gz (this is just the final resulting ruleset of this module)

2 Rulebased Simulation

This informational tutorial introduces you to Rulebased Simulation in RiverWare. You will be introduced to:

- Running a Rulebased Simulation
- Examining functions and rules
- Writing a rule using the RPL Editor and Palette
- Obtaining more information on a run using the diagnostics and debugger.

To get started let's open the model in RiverWare:

❑ Double-click the RiverWare icon on the desktop.

❑ Close the Quick Start window as we'll show you how to open a model from the workspace.

- ❑ Select **File** and then **Open Model...** from the main workspace menu bar or select the Open Model File toolbar button.

- ❑ Open the file `MuddyBartlettBasin_RBS_Start.mdl.gz`

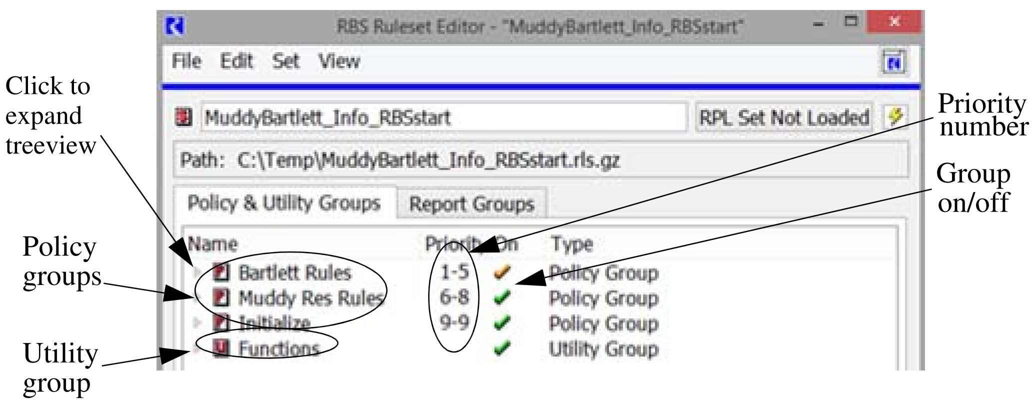
2.1 Running a Rulebased Simulation

Rulebased simulation is an extension of basic Simulation in which some of the data to solve an under-determined model is provided by a set of user-defined rules. Rule execution alternates with dispatching to simulate the effects of the rules in the model.

The policy for the basin is in the Ruleset.

- ❑ In the **Policy** menu of the main workspace, select **Ruleset** and then **Open...**

- ❑ In the file chooser, select the following ruleset:
  `MuddyBartlett_Info_RBSstart.rls.gz`



The Ruleset Editor initially displays three **Policy Groups** and one **Utility Group**. A Policy Group is a folder for holding rules; Utility Groups contain functions.

- ❑ Select the triangle/arrow to the left of each of the groups to expand the treeview.

Now you can see all individual rules within each Policy Group. Note that the check mark next to Bartlett Rules is orange because the priority 1 rule, **Bartlett Flood Control**, is turned off.

For this simple model, there are nine rules (indicated by a red **R** symbol) and eight functions (indicated by the **F** symbol).

Before running, you must tell RiverWare that this is the ruleset you wish to use, i.e. Loading the ruleset. Loading a ruleset validates it for unspecified expressions, illegal object and slot names, conflicting expression types, and syntax errors.

- ❑ Load your ruleset by clicking on the **RPL Set Not Loaded** button. This validates the ruleset and loads it into the model.

- ❑ Run the simulation by selecting in the main workspace.

  Notice that the controller is set to Rulebased Simulation

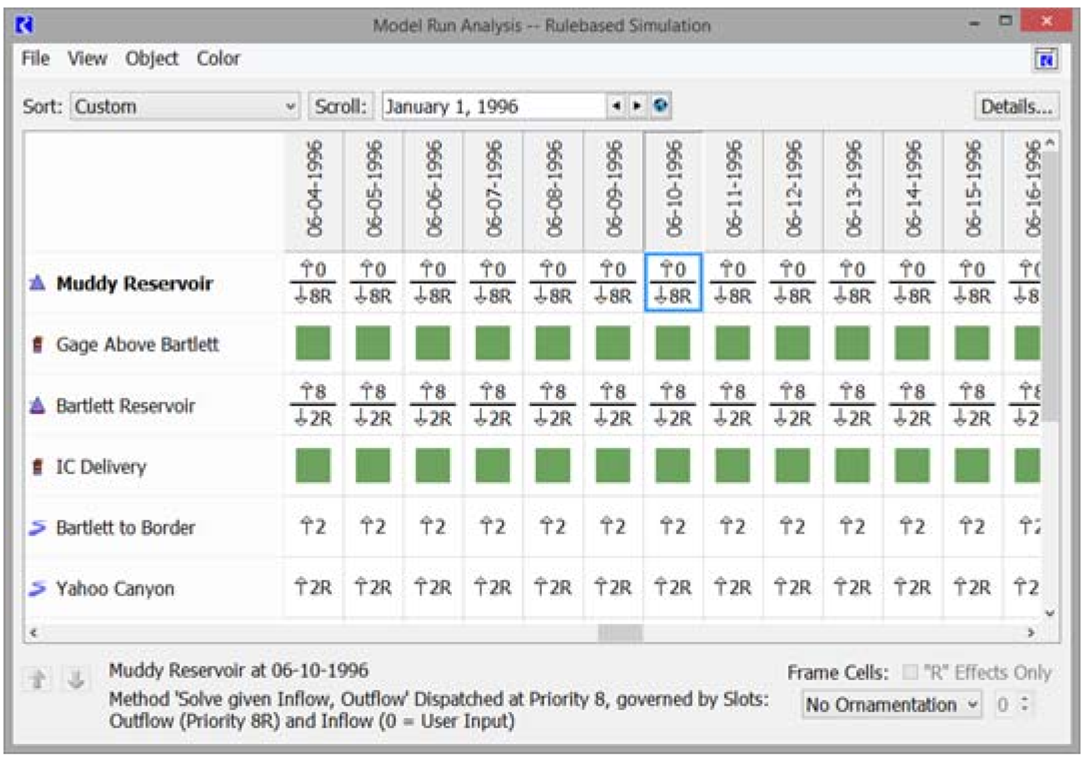
- ❑ Click Start.

- ❑ When the run is finished, close the **Run Status** and **Run Control** dialogs.

  On each timestep, each rule is executed, then the objects solve as necessary to simulate the effects of rules setting values. Rule #9, the lowest priority, is executed first, while rule #1, the highest priority, fires last. Now let's briefly examine the results of the run and see how the rules set values in the model:

- ❑ Open the **Model Run Analysis** dialog by clicking in the main workspace.

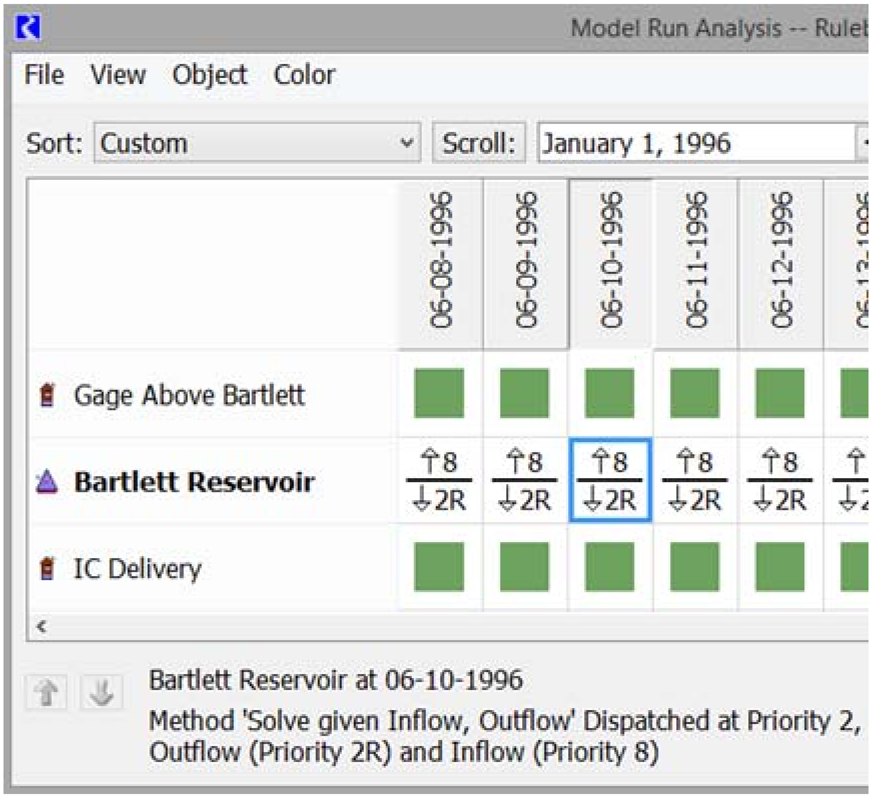
  For a more in depth explanation of the Model Run Analysis dialog, see pages 14-16 of the Introductory Information Tutorial.

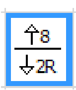


- ❑ Scroll through the timesteps horizontally and notice the reservoirs and reaches were dispatched in accordance with various rules in the model ruleset.

- ❑ Find the dispatch cell for **Bartlett Reservoir** on June 10 (**06-10-1996**) and select it.

Text at the bottom of the window gives details about dispatch method and the rules that set the values on the dispatch slots



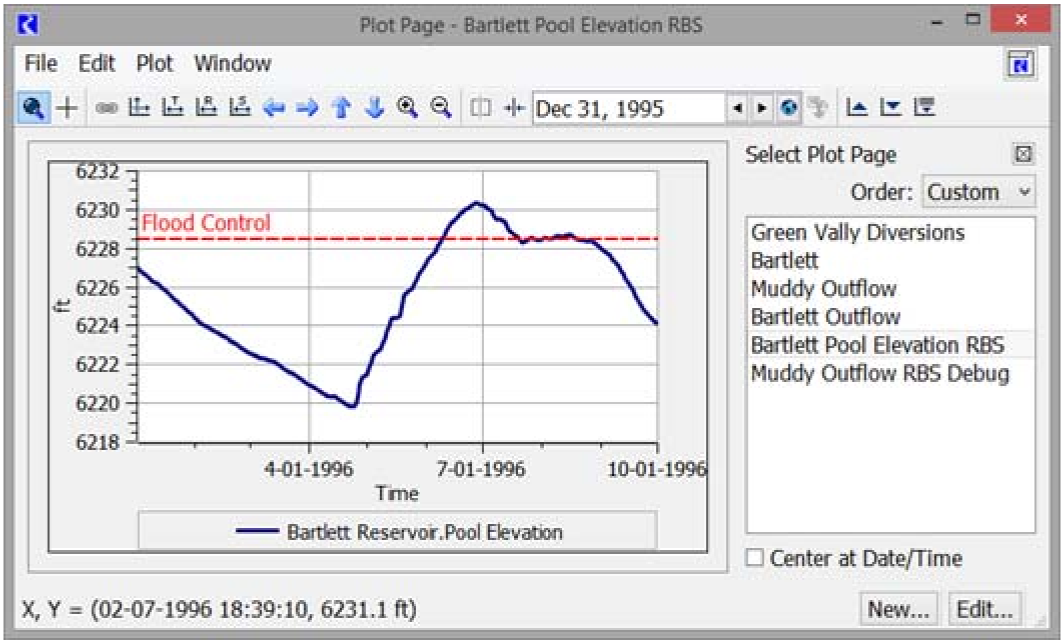


The Inflow was set by resulting output of rule 8- **Green Valley Diversion** requirements, the Outflow by rule 2- **IC Delivery** requirements. You can select **View** and then **Grid Cell Legend** for more information.

In this way, you can determine the policy in effect for each timestep and each object in the run.

❑ Close the Model Run Analysis dialog.

❑ Open the plot dialog by clicking in the main workspace and click the **Bartlett Pool Elevation RBS** plot to open it.



If you remember, we saw that the Flood Control rule is turned off. Therefore there is no logic or policy in effect to keep the Bartlett Pool Elevation from exceeding maximum prescribed elevation. We see this illustrated in the plot in July 1996. In the next section, we'll turn on the rule and see its effect.

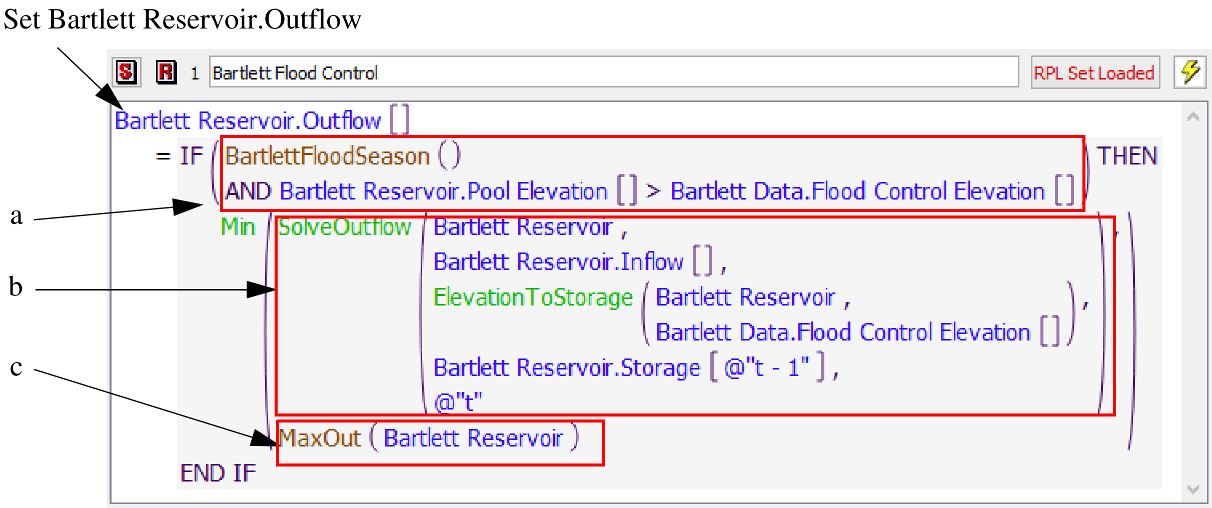
❑ Close the plot dialog.

2.2 Examining functions and a rule

The Ruleset contains the policy of your basin. You write the rules and then give each one a priority starting with 1 up through the number of rules you have.

Rules are set up using logic in the RiverWare Policy Language (RPL). You can make use of predefined as well as user-defined functions to build up your logic and make it understandable by others. Let's start by walking through the logic of a rule:

❑ Open the **Bartlett Flood Control** rule by double clicking on its name in the **Ruleset Editor**.



The rule contains logic (IF, THEN), slot names (e.g. Bartlett.Pool Elevation), and functions, both user defined and predefined functions. In general, it says:

Object.Slot [ ]= IF (A) THEN

Minimum (B, C)

END IF

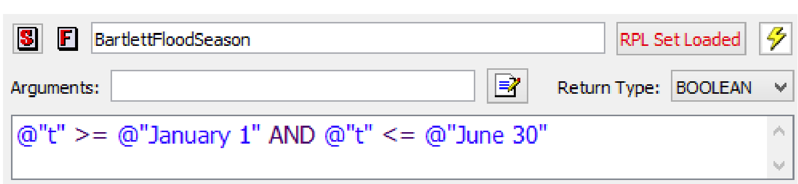
This rule is setting the value of the **Barlett Reservoir Outflow** slot at the current timestep. This rule is executed at each timestep, so the logic is written with that assumption.

We’ll go through each item a, b, and c to describe the logic:

a. If it is BartlettFloodSeason() AND the current Bartlett.Pool Elevation is above the Bartlett Data.Flood Control Elevation,

This expression is used to check the state of the system. We only want this policy in effect during specific conditions. Thus, we are defining the logic for which we want this policy. The first item BartlettFloodSeason is a User-defined function, which allows you to encapsulate an expression and give it a meaningful name. You can then call this function from any other rule or function. This allows you to simplify and modularize your policy.

❑ Open the **BartlettFloodSeason** function by double clicking on the function name in the rule.



This is a function created to define the time of year when there could potentially be flooding. It evaluates to of either True or False. The statement asks whether the current time (@ "t") is

- at least January 1st (>= @ "January 1") AND

- no later than June 30th (<= @ "June 30").

❑ Close the **Function Editor** window.

Now let's look at the two values to which the rule could evaluate: b or c. The rule computes the minimum of these two.

b. the Outflow to lower the Pool Elevation to the Flood Control Elevation

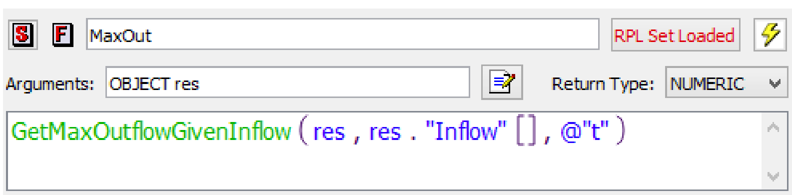
The **SolveOutflow** function (in green) is a predefined RiverWare function that performs a mass balance to compute a reservoir's outflow given its inflow, its previous storage, and the storage specified at the current timestep (in this case determined by the **ElevationToStorage** function).

For further information about this or any predefined function, see the RiverWare Help documentation, which can be accessed by clicking ? and choosing **RPL** and then **RPL Predefined Functions** from the bookmarks menu.

Let's look at the last possibility:

c. the maximum outflow allowed by the physical limitations of the reservoir's structures.

❑ Open the **MaxOut** function.



This function computes a number (it's return type is NUMERIC) by evaluating a predefined RiverWare function, **GetMaxOutflowGivenInflow**, at the current timestep when a reservoir, **res** is passed in as an argument.

The **GetMaxOutflowGivenInflow** is another predefined function that computes the maximum outflow from a reservoir considering the previous timestep storage, inflow, all sinks, side flows, and sources, and the physical characteristics of the outlet structures. In the case of a storage reservoir (like Muddy), the maximum release is interpolated from the Max Release table based on its elevation.

❑ Close the **Function Editor** window and close the **Bartlett Flood Control** rule

So now that we've looked at the details, let's go back to the overall rule. Basically, it assigns the Barlett Reservoir Outflow slot to the value that is computed on the right side of the assignment (i.e. the equal sign). During flood season and when the reservoir is high, this rule computes and sets the Outflow to ensure that the level of water in the reservoir is reduced to be able to accommodate possible flooding while not exceeding the flow that the turbines and spillways can handle.

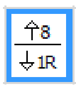
Now we will see how the rule affects reservoir operations:

❑ Turn on the **Bartlett Flood Control** rule by clicking the red **X** in the **Ruleset Editor.**

The X turns into a green check mark and the orange check mark next to Bartlett Rules turns green.

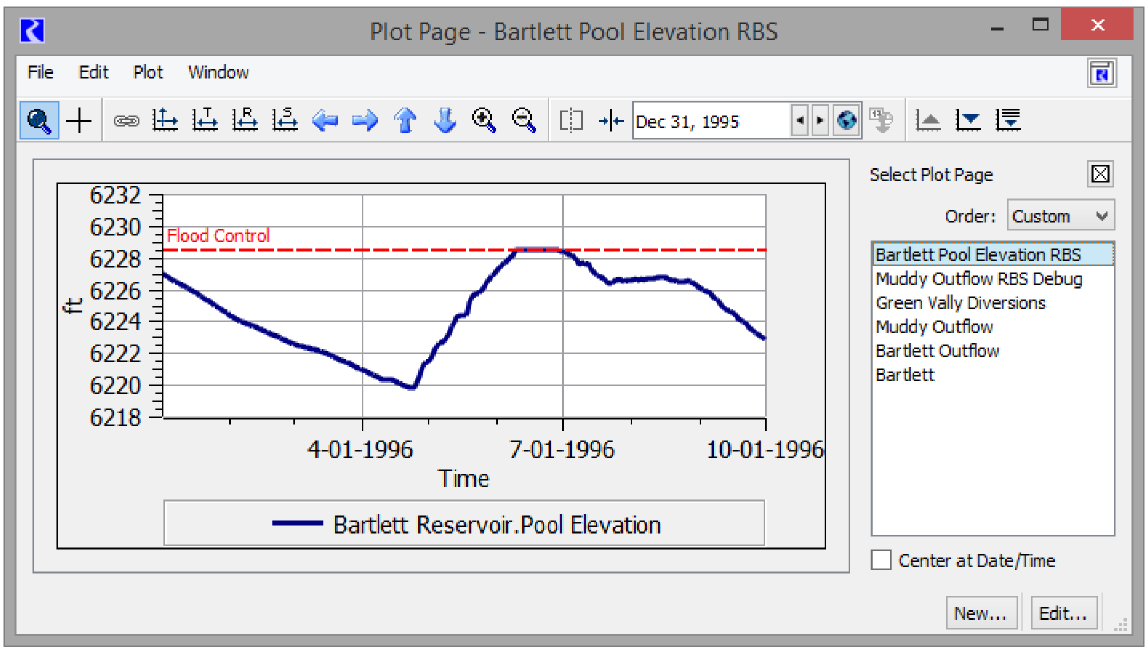
- [ ] Run the simulation again (click and then Start). Close the dialogs after the run finishes.

- [ ] Open the Model Run Analysis (click) and scroll to the June 10th entry for Bartlett Reservoir.



As you can see, the outflow is now set by rule 1 (1R) where before it was set by rule 2. In fact, all of the Bartlett Reservoir outflows through June 27th are set by rule 1.

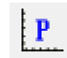
- [ ] Now open the Pool Elevation plot you looked at before by clicking and choosing **Bartlett Pool Elevation RBS** from the list on the right.



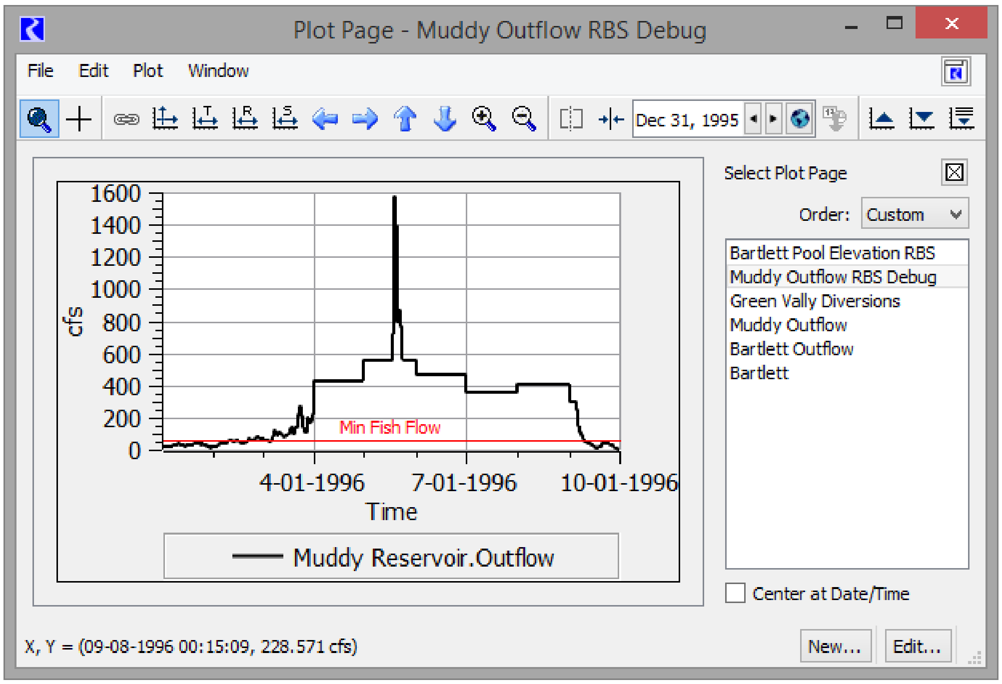
Now that the **BartlettFloodControl** rule is activated, Pool Elevation does not exceed the Flood Control height at any time. Because the rule has the highest priority, no other operation request (i.e. rule) can override it.

2.3 Building a rule

The current ruleset is overlooking a basin requirement to keep the downstream fish population healthy. This operation is especially important during the winter months when natural streamflow is generally low, as you can see in the following plot:

- [ ] Open the plot of Muddy Reservoir.Outflow by clicking on the plot icon  and clicking on the **Muddy Outflow RBS Debug** plot.

  The red line shows the minimum flow required for downstream fish health (55 cfs).



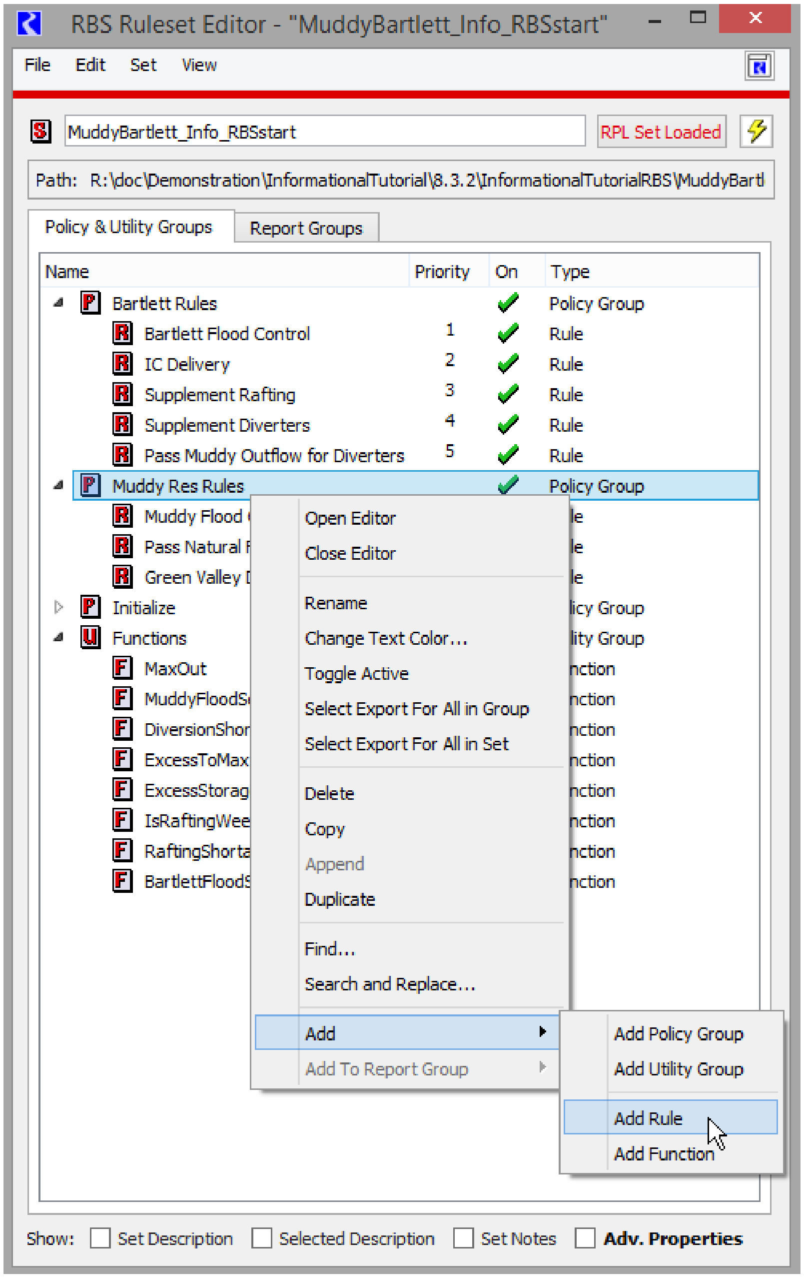
- [ ] Zoom in on the beginning of the simulation (January to April) by clicking and dragging a rectangle over the far left portion of the graph (resize the window if necessary).

  Notice the Outflow is below the minimum.

- [ ] Close the plot.

  You will now build a simple rule which sets Muddy Reservoir's Outflow to meet this downstream environmental flow requirement of 55cfs.

❑ Add a new rule to the Muddy Reservoir Policy Group by highlighting **Muddy Res Rules** and right clicking. In the menu, choose **Add** and then **Add Rule**.



A new entry called "Rule" appears in the Policy Group as priority 9.

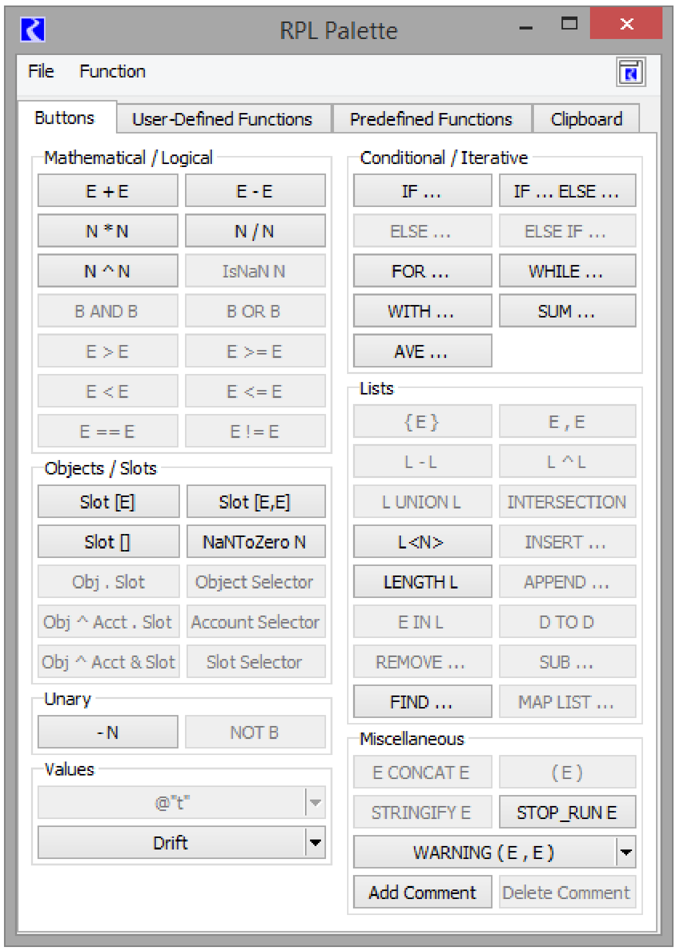
❑ Open **Rule** by double clicking on it and change the name from "`Rule`" to "`Min Fish Flow`" by entering it into the field at the top of the **Rule Editor** and pressing Enter.

Rules are constructed by adding statements at the top level and then filling in the expressions in the statements. Statements can be added from the **Rule** menu. The most common statement is the **Assignment** which is used to set a slot value.

- [ ] Add an assignment statement to the empty rule by selecting **Statement** and then **Add Assignment**.

Now we must now specify which slot to set (the left side) and logic to determine the value to set on the right side. We will fill in both of the unspecified expressions. Unspecified expressions are portions of the rule which have not yet been defined, for example: **<numeric expr>**. The two **<numeric expr>** expressions which appear in your rule indicate that both sides must eventually evaluate to a numeric value. Building rules involves coding the unspecified expressions one by one into functional expressions.

You specify the expressions using the **Palette.** Depending on the type of the expression highlighted, the Palette only enables the buttons for expressions of that type. In this way, the Palette provides syntax support and helps guide you in building rules.



- [ ] Open the **Palette** by selecting **Rule** and then **Palette....** Or right select the expression and select **Palette**.

When the Palette window is active, you can hover over any button on the Palette to get a “tool tip” describing that button.

- [ ] Highlight the left **<numeric expr>.** This will be the slot to which the rule will assign a value.

- [ ] In the **Objects/Slots** section of the **Palette,** select the **Slot[ ]** button. This replaces the unspecified numeric expression with a series slot expression.

  The square braces following a slot expression refer to the timestep or the row and column of the slot. The three possibilities are:

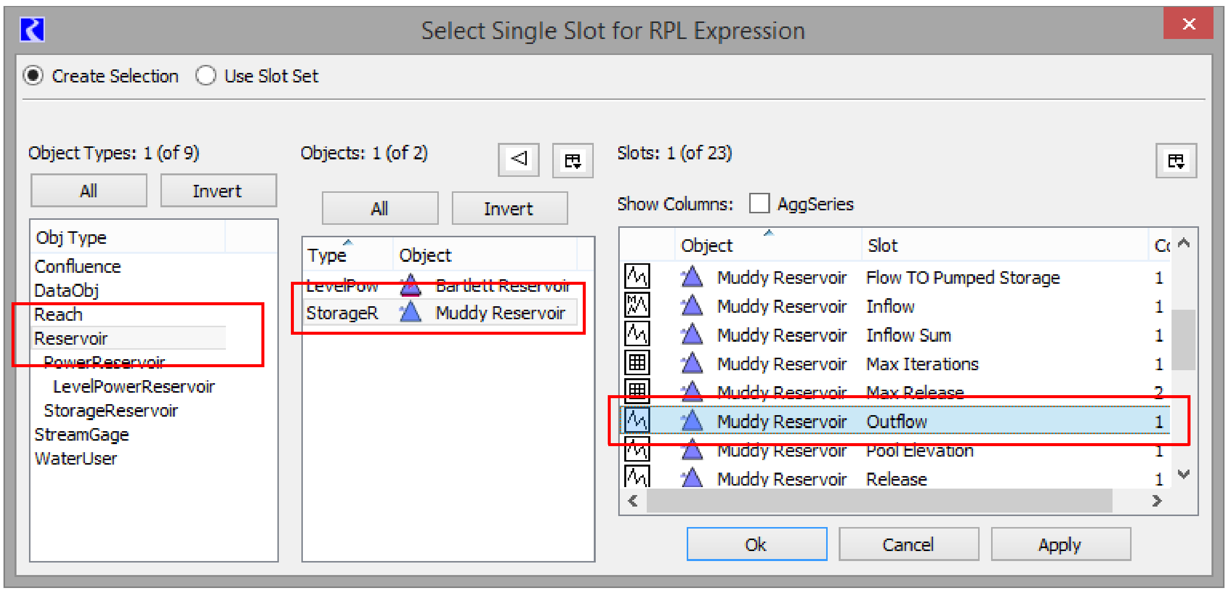
  1. **Slot [E]** A series slot at a given row (often specified by a date).
  2. **Slot [ ]** A series slot at the current controller timestep or a scalar slot.
  3. **Slot [E, E]** A table slot at a specified row and column.

- [ ] Mouse over each of these three buttons to see their description

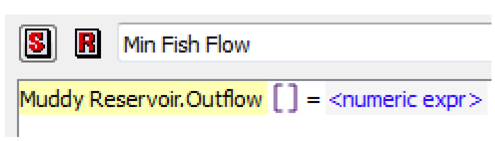
- [ ] Now highlight just the unspecified portion of the series slot expression, **<expr>**, and select the **Slot Selector** button on the Palette.

- [ ] In the slot selector, select the **Object Type**: **Reservoir**, **Object**: **Muddy Reservoir**, **Slot**: **Outflow**, then click **OK**.

  You will need to scroll down to locate Outflow.



You have finished the left-hand side (LHS) of the rule. When the rule is executed, the rulewill attempt to set a value on the Muddy Reservoir Outflow slot to the value returned from the right-hand side (RHS) of the assignment.



The right-hand side of the rule should check the existing flow and increase it if necessary:

- [ ] Highlight the RHS **<numeric expr>**.

- ❑ From the Palette choose the **IF ...** option under the Conditional/Iterative section.

- ❑ Highlight **<boolean expr>** to specify the type of condition, then select **E < E** to signify that you want to determine if the value of a slot is less than the value of another.

```
Muddy Reservoir.Outflow [] = IF ( <expr> < <expr> ) THEN
                                   <numeric expr>
                                 END IF
```

- ❑ Highlight the left **<expr>** and designate it as a slot at the current timestep, **Slot [ ]**, then highlight just **<expr>** again and select the **Slot Selector** button in the **Objects/Slots** section of the Palette.

- ❑ In the slot selector, select the **Object Type**: **Reservoir**, **Object**: **Muddy Reservoir**, **Slot**: **Outflow**, then click **OK**.

```
Muddy Reservoir.Outflow [] = IF ( Muddy Reservoir.Outflow [] < <numeric expr> ) THEN
                                   <numeric expr>
                                 END IF
```

- ❑ Highlight **<numeric expr>** and designate it as a slot at the current timestep, **Slot [ ]**, then highlight just **<expr>** again and select the **Slot Selector** button in the **Objects/Slots** section of the Palette.

- ❑ In the Slot Selector, select the **Object Type**: **DataObj**, **Object**: **Muddy Data**, **Slot**: **Min Fish Flow**, then click **OK**.

```
= IF ( Muddy Reservoir.Outflow [] < Muddy Data.Min Fish Flow [] ) THEN
     <numeric expr>
  END IF
```

  The conditional statement is complete. Now we will specify the value of the Outflow slot using a predefined RiverWare function.

- ❑ Highlight **<numeric expr>** and navigate to the **Predefined Functions** tab of the Palette.

- ❑ At the bottom of the Palette window, check the box next to "**Show only functions with a return type matching the selected expression**"

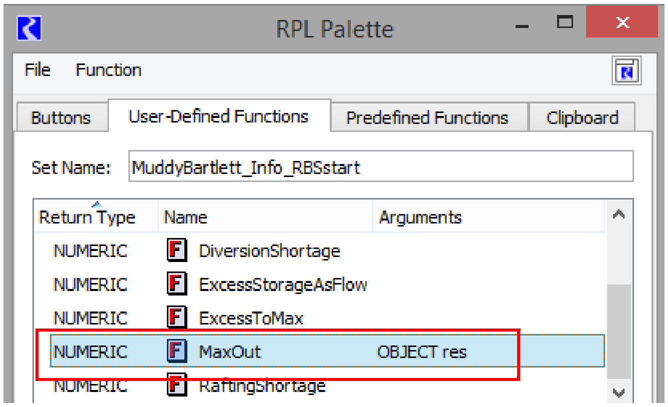
- ❑ Scroll through the alphabetical list to the **Min** function. Double select it to insert it into the rule.

  The rule now reflects that we want the rule to compare two values and choose the smallest.

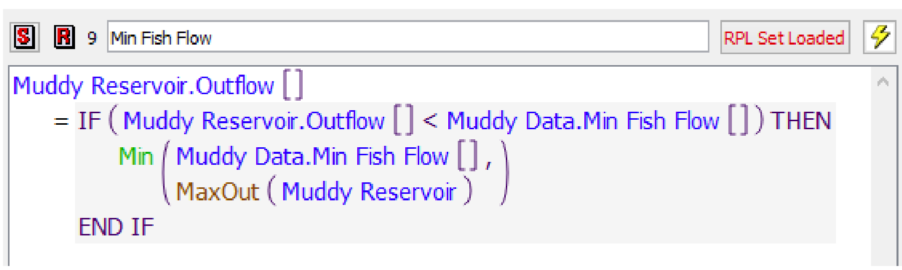
  The purpose of the rule is to set outflow to a level that protects the fish downstream, but that should not conflict with the maximum outflow possible for the reservoir, so the smaller of the two values will be used.

- ❑ Highlight the first **<numeric expr>** and make it a slot at the current timestep: **Slot [ ]**, then highlight **<expr>** and in the Slot Selector specify **Object Type**: **DataObj**, **Object**: **Muddy Data**, **Slot**: **Min Fish Flow**, then click **OK.**

❑ Highlight the remaining **<numeric expr>** and navigate to the **User-Defined Functions** tab of the Palette. Double select **MaxOut**.



❑ Highlight the <object expr> argument to specify which reservoir you want to look at and choose Object Selector (from the Palette Buttons tab). In the selector dialog choose **Object Type**: **Reservoir**, **Object**: **Muddy Reservoir**, then click **OK.**



Your finished rule should look like the above figure.

❑ Close the Rule Editor window and return to the Ruleset Editor window.

The Min Fish Flow rule you just wrote is currently at priority 9, but it needs to be at priority 7.

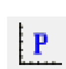
❑ Click and drag the rule to right on the **Muddy Flood Control** rule and release the left mouse button. A confirmation window will appear asking if you want to finalize the move from priority 9 to Priority 6 or Priority 7.

❑ Click **To Priority 6**.

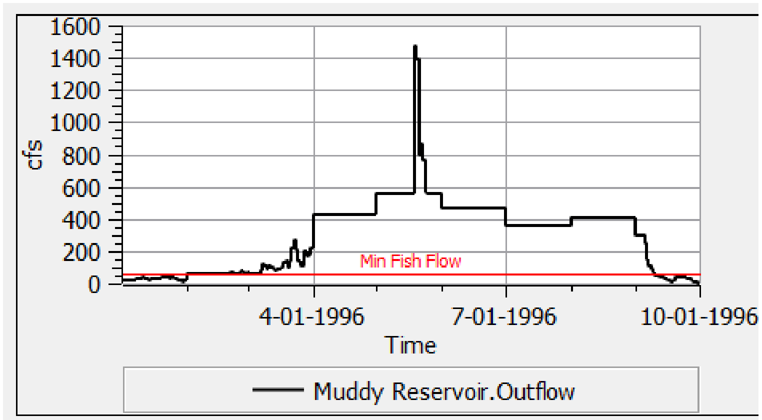
Now Min Fish Flow is priority 6 and the remaining rules have shifted down one priority.

❑ Save the new Ruleset via **File** and then **Save RBS Ruleset**

❑ Run the model.

❑ Open the same plot of Muddy Reservoir.Outflow you looked at in section Section 2.3, “Building a rule” by clicking on the plot icon  and clicking on the **Muddy Outflow RBS Debug** plot.

The red line shows the minimum flow required for downstream fish health (55 cfs).

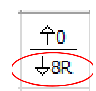


- ❑ Zoom in on January and February 1996 (resize the window if necessary).

After zooming in we can see that the violations were fixed starting in February, but not in January. Let's use the Model Run Analysis to see which rules were in effect for this month.

- ❑ Open the **Model Run Analysis** dialog by clicking on the  icon, and scroll left to the **January 1, 1996** timestep.

- ❑ Select the cell for Muddy on January 1.



Muddy Reservoir's Outflow was set by rule 8 for the whole month of January but the **Min Fish Flow** rule that you wrote is at priority 6, a higher priority that should have overwritten rule 8. Obviously there is a breakdown somewhere. In the next section we debug this rule to find the problem.

2.4 Debugging

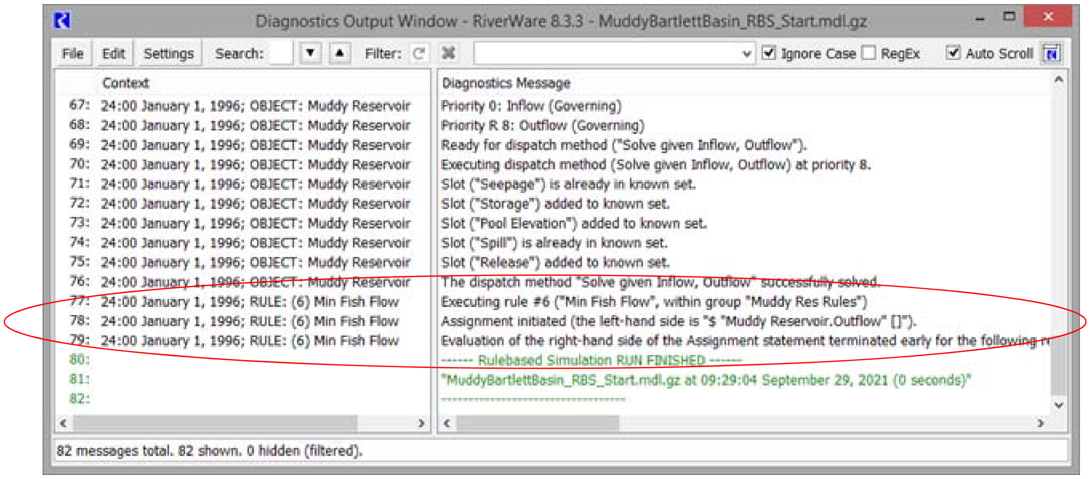
After setting up a rulebased simulation model, it is important to verify the results and debug any issues. Some problems within a model or ruleset will cause the run to abort generating an error message that can direct you to the problem. Other times a model may run to completion, but it may not produce the correct results. These problems can be more difficult to debug. This section will present two tools: Diagnostics and the RPL Debugger, which can assist in this debugging process.

- ❑ From the workspace, select **Utilities** and then **Diagnostics Output...** .

- ❑ Select click **Edit** and then **Clear Messages** from the menu, to clear the messages from all the previous runs.

- ❑ On the Run Control, start a new run.

Since we only want to look at diagnostics for how rules set the Muddy Reservoir Outflow in January, 1996, the diagnostics have been pre-configured using context filters.



❑ Scroll to lines which show "**24:00 January1, 1996 RULE: (6) Min Fish Flow**" in the context panel.

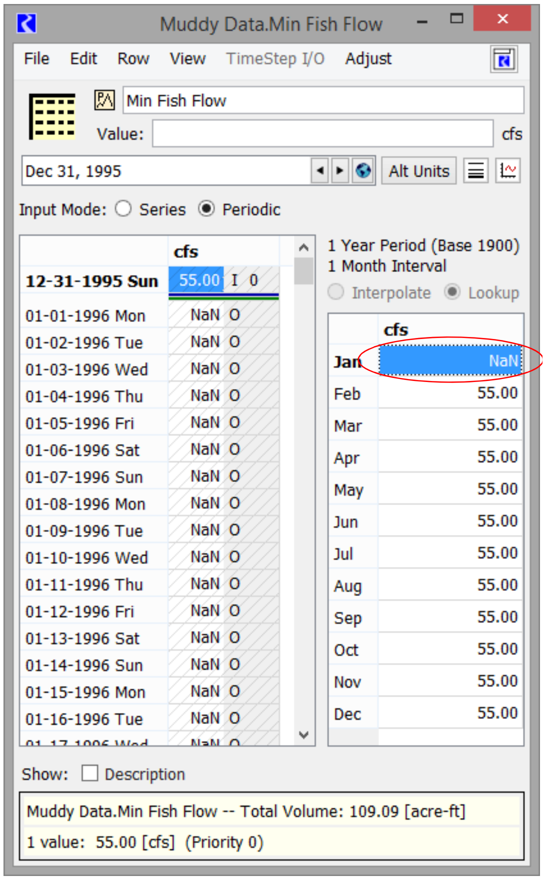
These entries show the process RiverWare went through to implement the Min Fish Flow rule. The third diagnostic message for the Min Fish Flow rule specifically illuminates the problem:

36: 24:00 January 1, 1996 RULE: (6) Min Fish Flow: Evaluation of the right-hand side of the Assignment statement terminated early for the following reason: Encountered invalid value in the series slot "Muddy Data.Min Fish Flow" at the date 24:00 January 1, 1996. This occurred at the following location within the expression: $ "Muddy Data.Min Fish Flow" [].

The first piece of important information that we get from this message is that the rule "terminated early." A rule terminates early when it does not have enough information to evaluate the rule, i.e. it finds a NaN ("Not a Number") in a referenced slot. When it terminates early, it does not set any values. This explains why rule 6 did not set the **Muddy Reservoir Outflow** for January, 1996. The message then tells us why the rule terminated early: **Encountered invalid value in the series slot "Muddy Data.Min Fish Flow" at the date 24:00 January 1, 1996.**

The diagnostic message suggests that we need to look at **Muddy Data.Min Fish Flow.**

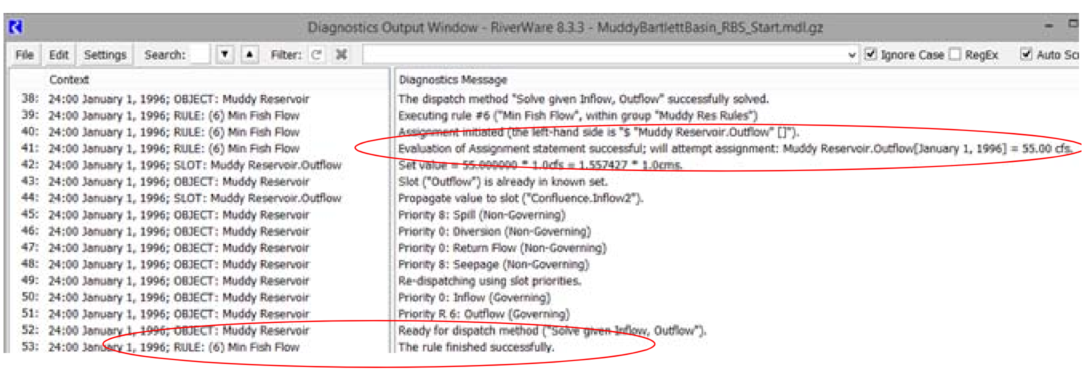
- [ ] Open the **Muddy Data** object, and open the **Min Fish Flow** slot.



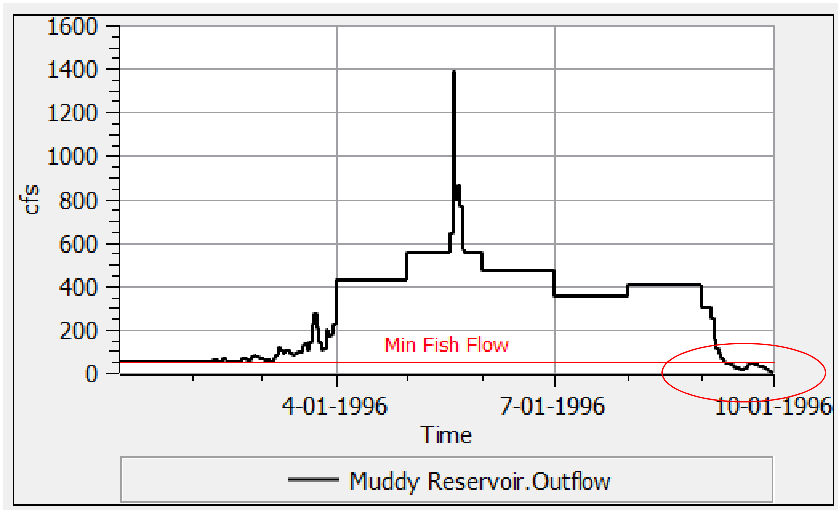
When the model was set up the January cell was left without a value, so for the whole month there was no minimum flow data for RiverWare to meet.

- [ ] Click in the cell, type "55" and press Enter.

- [ ] Rerun the model and see that the rule was successfully implemented.



The Muddy Outflows plot shows the min fish flow is now met in January.



Looking at the right side of the Muddy Outflows plot, we see that the Min Fish Flow is not being met at the end of the simulation period either. It appears that there could be another problem with either the policy or the date. We can use the RPL Debugger to find out why the minimum flow is not being met.

❑ In the RiverWare workspace menu bar, select **Policy** and then **RPL Debugger...**

This opens the RPL Debugger dialog. At this point the debugger is not yet enabled.

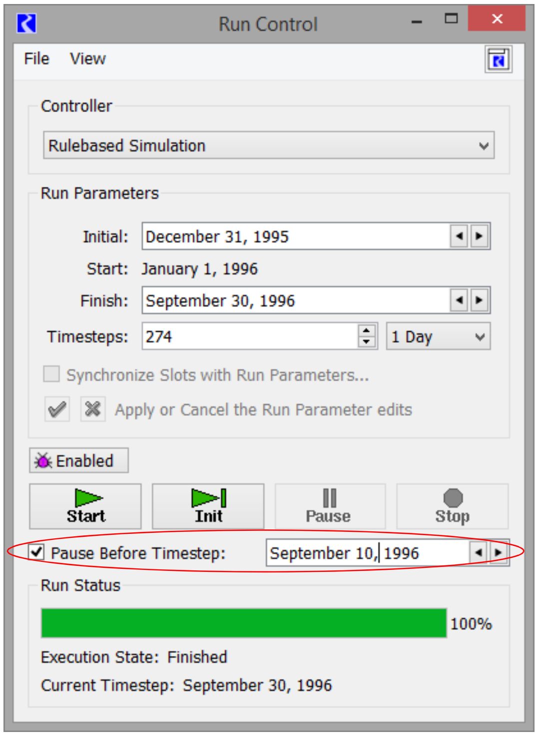
Rulesets can be very large and complicated, and consequently it can be difficult to determine why a set is doing what it is doing. The RPL debugger is designed to help understand the behavior of rulesets by pausing execution, looking at the values of RPL expressions as they are evaluated, and stepping through RPL execution.

❑ In the RPL Debugger dialog, select **Debug** and then **Enable RPL Debugging.**

We will set a breakpoint in the Min Fish Flow rule, but we only want to debug on a single timestep. If we set the breakpoint now, the debugger will stop the run once every timestep when it gets to the rule. Instead we will set the **Run Controller** to pause the run before the timestep we want. Then we can set our breakpoint.

❑ In **Run Control** dialog (click  to open), check the box for **Pause Before Timestep** at the bottom of the window.

❑ In the timestep field type "`Sept 10, 1996`" and press Enter.



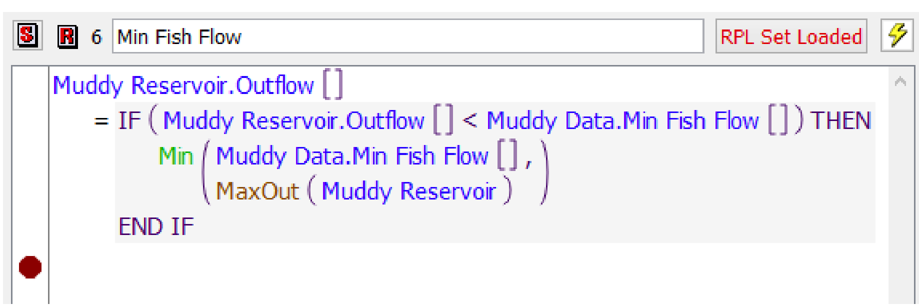
❑ Click Start to run the model

The run pauses at 93% completion, before September 10th.

❑ Open the **Min Fish Flow** rule (in the main workspace, select **Policy** and then **MuddyBartlett_Info_RBSstart** if the ruleset windows have been closed).

Note that there is now an added margin on the left of the **Rule Editor**.

❑ Click at the bottom of the column on the left of the **Rule Editor** (below all of the expressions in the rule) to set a breakpoint at the end of the rule.



A red stop sign (octagon) appears indicating that a breakpoint has been set. If the octagon appears at the top of the rule accidentally, select it twice to remove it and try again.

❑ In the **Run Control** dialog, click **Step**.

The run will pause at the breakpoint, and the **RPL Debugger** dialog will come to the front. Note that the middle panel of the debugger lists the single breakpoint. The top panel shows the current location in the evaluation of rules and functions, called the call stack.

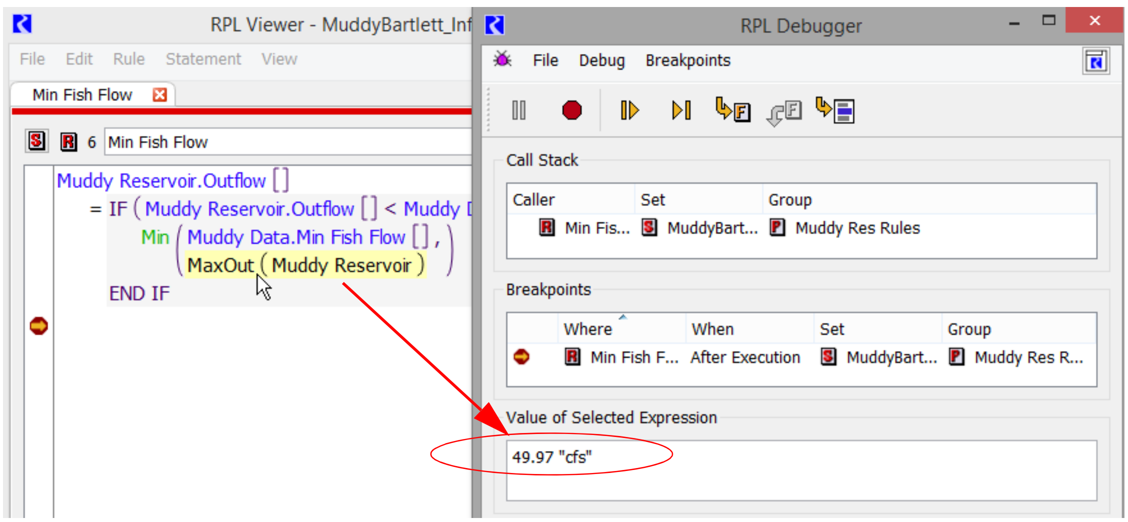
Now we can see what values the different parts of the rule produce:

- ❑ First, in the **Min Fish Flow** rule, select the brackets **[ ]** after **Muddy Data.Min Fish Flow**

The bottom panel in the Debugger reads "55 cfs".

- ❑ Next, select the **MaxOut** function.

The bottom panel in the Debugger reads "49.97 cfs".



- ❑ Finally, select the brackets **[ ]** after **Muddy Reservoir.Outflow**

The bottom panel in the Debugger reads "49.97 cfs".

As the rule dictates, **Muddy Reservoir.Outflow** is set to the minimum of the two values. Although we wanted to release 55cfs, the **MaxOut** function computed that only 49.97cfs could be released based on the amount of water currently in the reservoir. This is the purpose of including the **MaxOut** function in the rule. It assures that the rule will not try to release more water than is physically possible, so an Outflow below the Min Fish Flow is the correct outcome of the operating rules.

- ❑ Stop the debugging process by clicking the red **Stop** buttonin the **RPL Debugger**, then disable the Debugger in the **Run Control** dialog by clicking Enabled.

- ❑ Un-check the box next to **Pause Before Timestep** and click **Start** to complete a run before ending the RiverWare session.

The run status reaches 100%.

Although debugging is a very advanced RiverWare topic, it is useful for even the novice user to know that it is possible to understand exactly what the software is doing. Debugging is critical for determining how the simulation proceeds. This section presented two tools for accessing the details within a rulebased simulation:

- **Diagnostics** provide a play-by-play of every step in the simulation. Once context filters are applied, you can pinpoint the exact interaction you want to analyze. More information on this topic can be found in the **Diagnostics** section of the help.
- The **RPL debugger** takes you inside a rule to see what values are produced, in order to check that you have the proper logic. More information on this topic can be found in the **RPL Debugging Tools** section of the help.