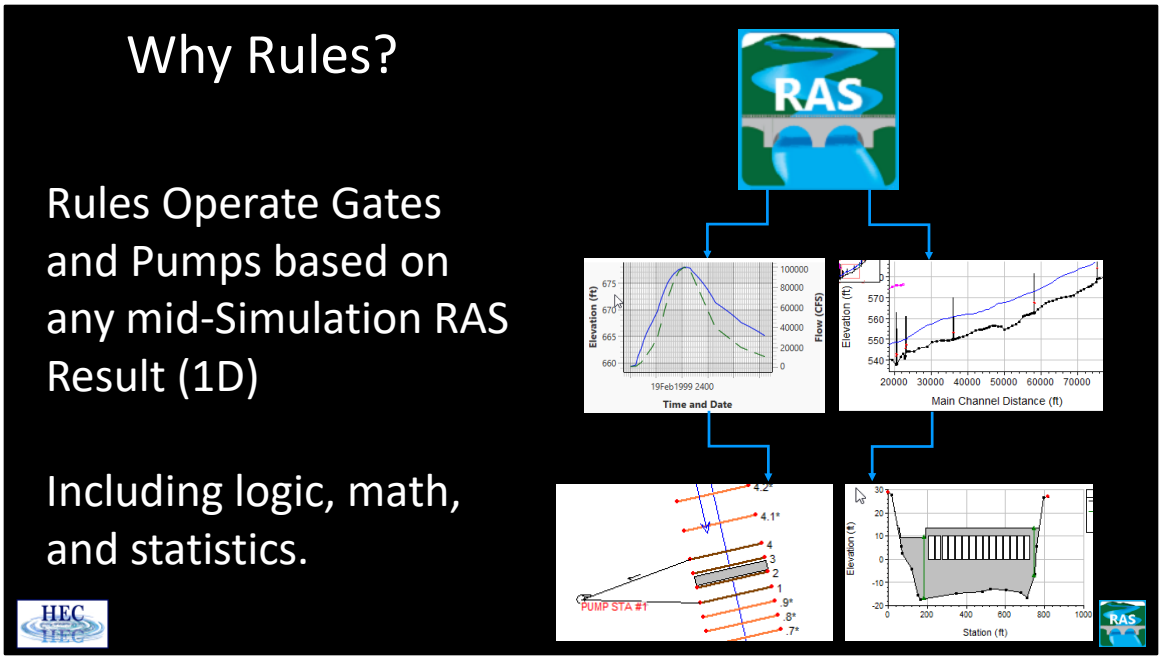
Operational Rules

Stanford Gibson, PhD
Hydrologic Engineering Center

Objective:

To convince you that you can use Rules.

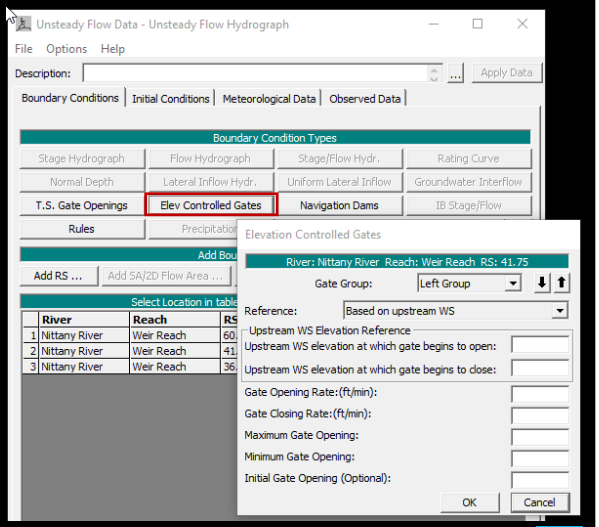


The operating procedures for determining and controlling the releases from reservoirs and other types of hydraulic structures can be quite complex. HEC-RAS allows flexibility in modeling and controlling the operations of hydraulic structures through the use of rules. The rules can be used to operate the height of the gate openings. Alternately, the rules can directly control (or constrain) the flow despite the gate openings (or even without gates at all). Examples of variables that could be used to control releases from a hydraulic structure are: current flows and water surfaces at the structure, current flows and stages at downstream or upstream cross section locations, time considerations (winter, morning, etc), and/or previously computed values (accumulated outflows, running averages, etc). Rule operations in HEC-RAS are available for inline hydraulic structures, lateral hydraulic structures, and storage area connections.

Rules for controlling hydraulic structures can be entered after an inline structure, lateral structure, or storage area connection has been added to the project. From the Unsteady Flow Data editor, add or select the given structure and then click on the Rules button. This will bring up the Gate Rule Operation editor (as shown in the next slide). In the Gate Parameters table at the top of the editor, some initial information can be entered for any gate groups that are in the hydraulic structure.

How Rules Work

- Rules are a set of instructions for operating a hydraulic structure (eg gates)
- At the beginning of each time step, RAS evaluates Rules and changes hydraulic structure operations
- Elevation controlled gates can be thought of as a simple set of rules

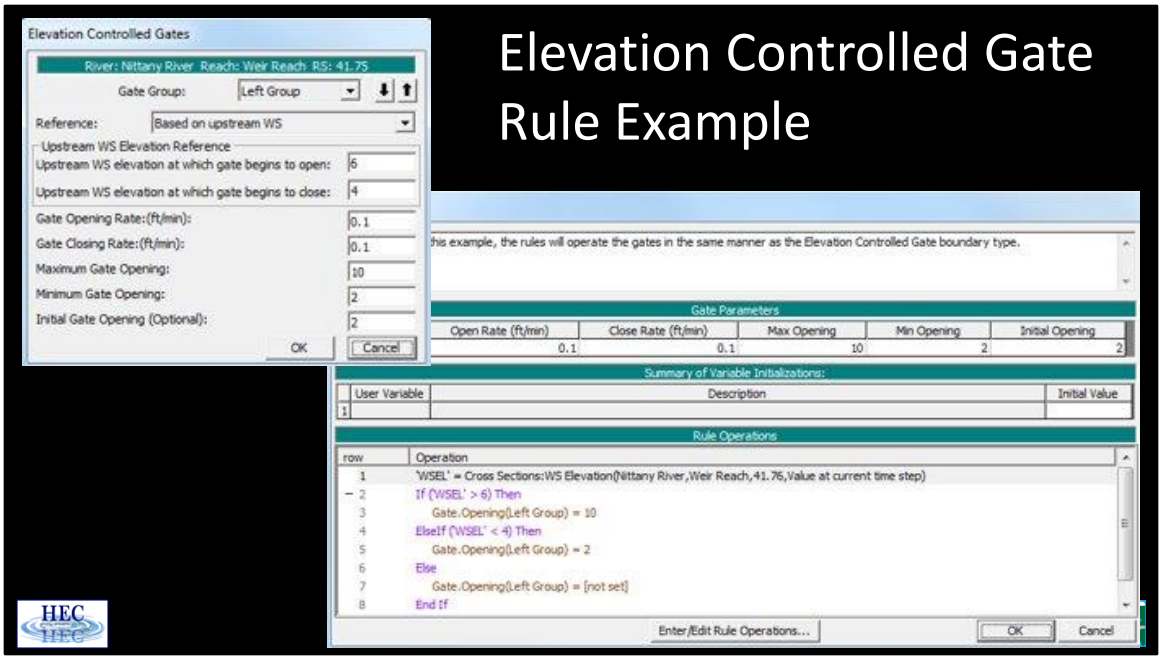


For each hydraulic structure that has rules, the rules are checked at the beginning of each time step. The rules are analyzed from the top to bottom one time. Each rule is analyzed one time (per time step). However, some rules may be skipped because of the operation of If/Then tests.

At the start of any given time step, the rules may or may not make any changes to the operation of the hydraulic structure. In general, a rule that has been put into effect stays in effect until it is expressly changed. So if a rule has put a limit on the maximum flow through a structure, that rule will still constrain the maximum flow until either the maximum limit is adjusted or that rule is explicitly “turned off”.
Also, some operations may take several time steps to complete. For instance, if a rule operation calls for a gate to be opened 10 feet, but the gate can only be opened 1 foot/minute and the user has selected a 1 minute time step, it will take 10 time steps for the operation to be

completed.

Elevation controlled gates can be thought of as a simple set of rules.



In the above example, the rule operations will behave in an identical manner as the elevation controlled gates. (This is just an example to show how the rules work. If this was all that was desired, the elevation controlled gates would be simpler than the rules).

Just as with the elevation controlled gates, the user enters an opening and closing rate, a maximum and minimum gate opening, and the initial opening for each gate group.

Just like the elevation controlled gates, this rule set is checked at the start of each time step to see if the gates should be opened or closed.

Rule Example for Elevation Controlled Gates

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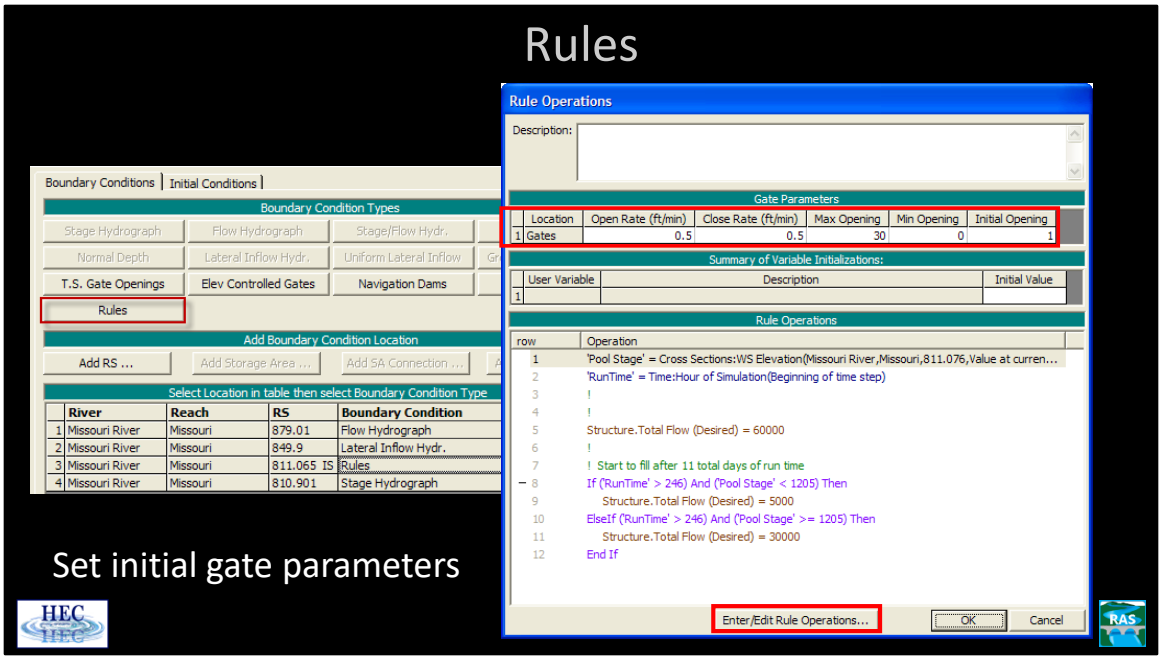
Rule 2 (in row 2), which is the first rule that actually does something, gets the water surface just upstream of the inline structure and stores it in a variable called WSEL. The next rule (row 3) checks to see if the water surface is greater than 6 feet. If this is true, then control goes to row 4 and that rule will start opening the gate by setting the opening to 10 feet. (If the gate is already at 10 feet, then this rule does not have any effect.) If the water surface is greater than 6 feet, then row 4 is the last rule that is analyzed.

If the water surface was not greater than 6 feet, then control jumps to row 5 and the water surface is checked to see if it is less than 4 feet. If it is, then the gate opening is set to 2 feet. If the water surface is less than or equal to 6 feet and greater than or equal to 4 feet, then control jumps to row 8. Row 8 turns the gate opening "off" so that the current gate opening is kept. The reason for this is explained in the example below:

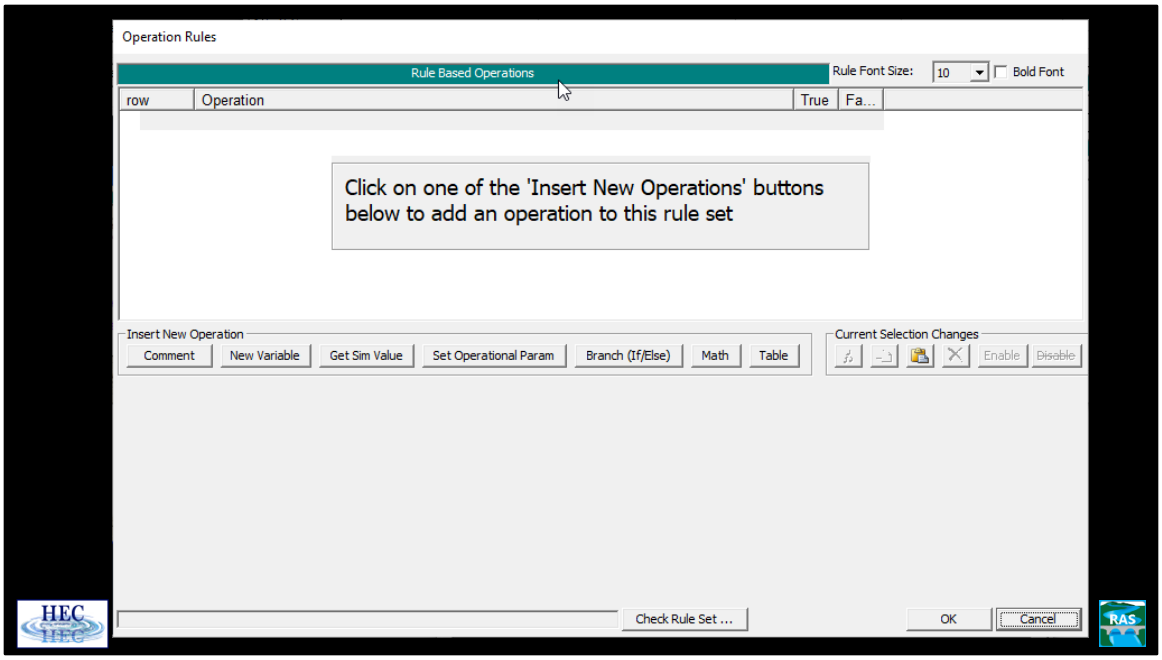
Say the gate opening is 5 feet and the water surface for a given time step increases to greater than 6 feet. The gate starts opening (based on the opening rate and the length of the time step). Assume that the gate opening has increased to 5.5 feet when the water surface just drops below 6 feet. If nothing is done, the command to open the gate to 10 feet stays in effect (the command does not have to be "renewed" each time step). Row 8 turns the command off and in this example the gate opening will be left at 5.5 feet until the row 4 or row 8 is called. Every time the water surface is between 4 and 6 feet, the command is turned off. If it was already off, then this has no effect.

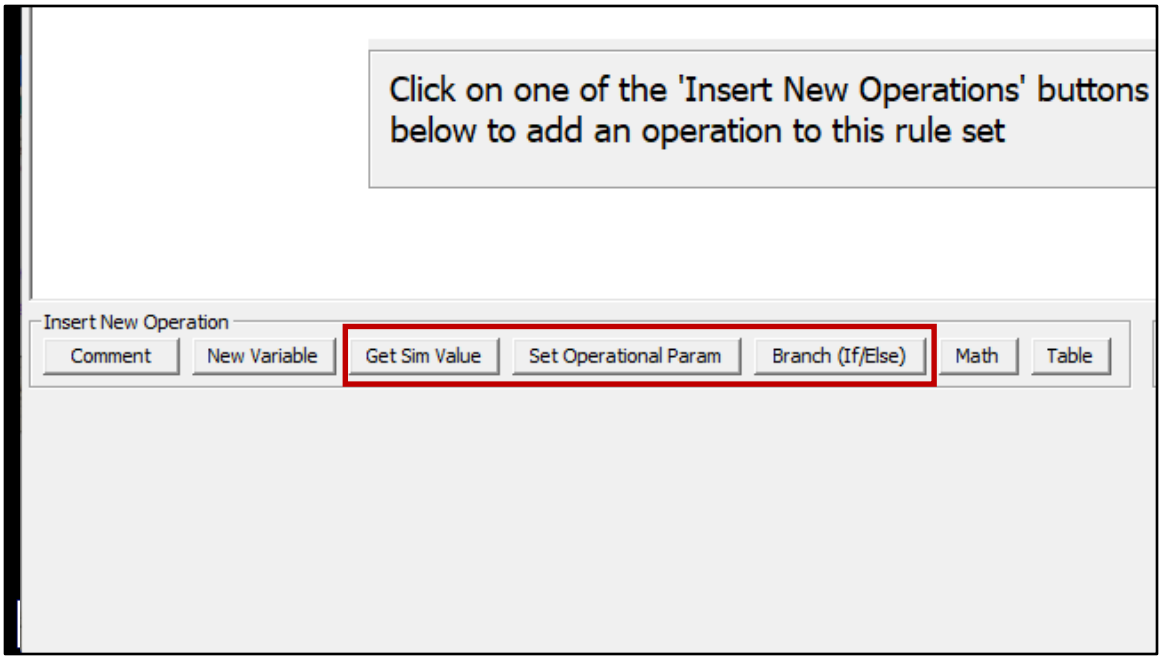


The Open and/or Close Rate can be left blank, which means the gate can move to any new setting in a single time step.
The Max and Min Opening will constrain the maximum and minimum gate opening settings. Building on the previous example of opening the gate one additional foot, if the gate was at 3.5 feet and the maximum was set to 4 feet (even though the gate was 6 feet tall), over a five minute period, the gate would open to 4 feet and then stop. If the Max is left blank, then the gate maximum opening is limited only by the height of the gate. If the Min is left blank, then the minimum opening is fully closed (i.e. 0.0).

The Initial Opening provides the first setting for the gate. This opening height will be used during the initial backwater computation. The gate will be left at this setting until it is changed by a rule operation. The Initial Opening is required for all gate groups, if any, in the hydraulic structure and may not be left blank.

In this example, row 7 is getting the wsel at the dam. Row 13 is checking to see if it is 0600 hours. If it is, then rows 17 and 22 are executed. Row 17 computes a new gate opening elevation for the drop gates. The new elevation is 3.5 feet below the wsel at the dam. Row 22 converts the elevation into an actual gate opening and tells the program to use the new gate opening. The final result is that at 0600 hours the drop gates are adjusted to have 3.5 feet of head on them.
To enter or edit the rule operations, click the Enter/Edit Rule Operations button.


Operation Rules
Rule Based Operations
Rule Font Size:
10
Bold Font
row
Operation
True
Fa...
Click on one of the 'Insert New Operations' buttons below to add an operation to this rule set
Insert New Operation
Comment
New Variable
Get Sim Value
Set Operational Param
Branch (If/Else)
Math
Table
Current Selection Changes
Enable
Disable
Check Rule Set ...
OK
Cancel
HEC
RAS



Operation Types:

Comment. Provides a user entered line of text (for documentation only).

New Variable. Allows the user to create a variable and give it a custom name.

Get Simulation Value. A variable is set equal to a given value in the simulation, such as the flow at a cross section or the time of day.

Set Operation Parameter. Changes the operation of the hydraulic structure, for example, adjusting the gate height or setting a maximum discharge.

Branch (If/Else). Controls which operations are executed on the basis of an If-Then test (e.g., do different gate operation checks based on seasonal considerations).

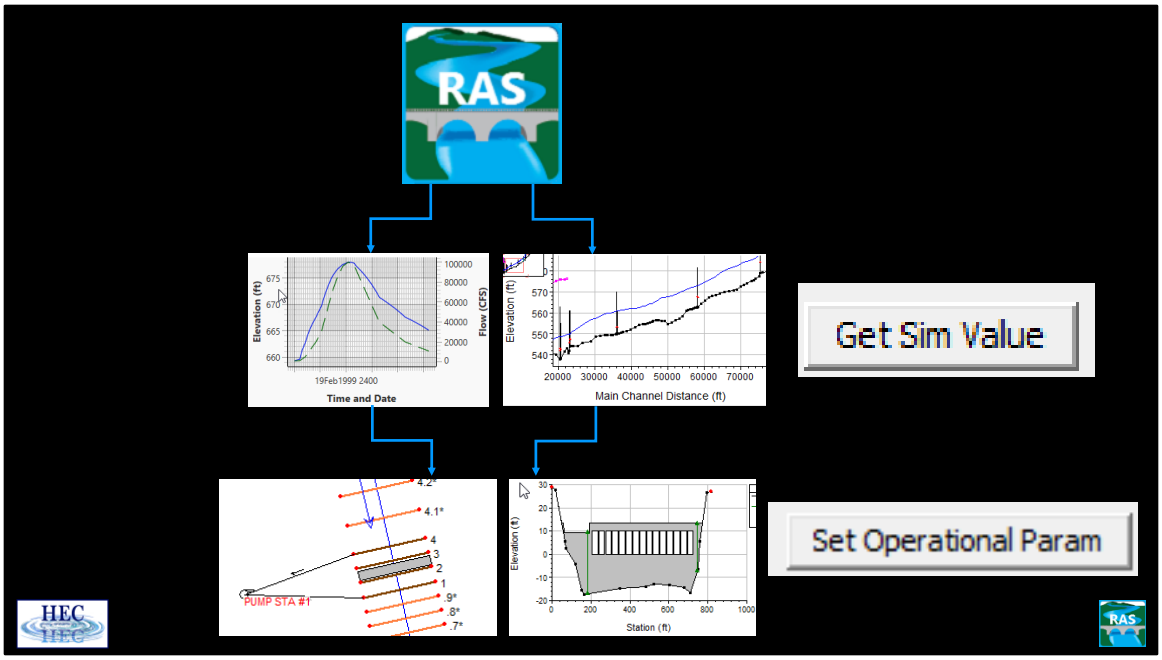
Math. Performs math operations such as summing flows or averaging water surfaces.

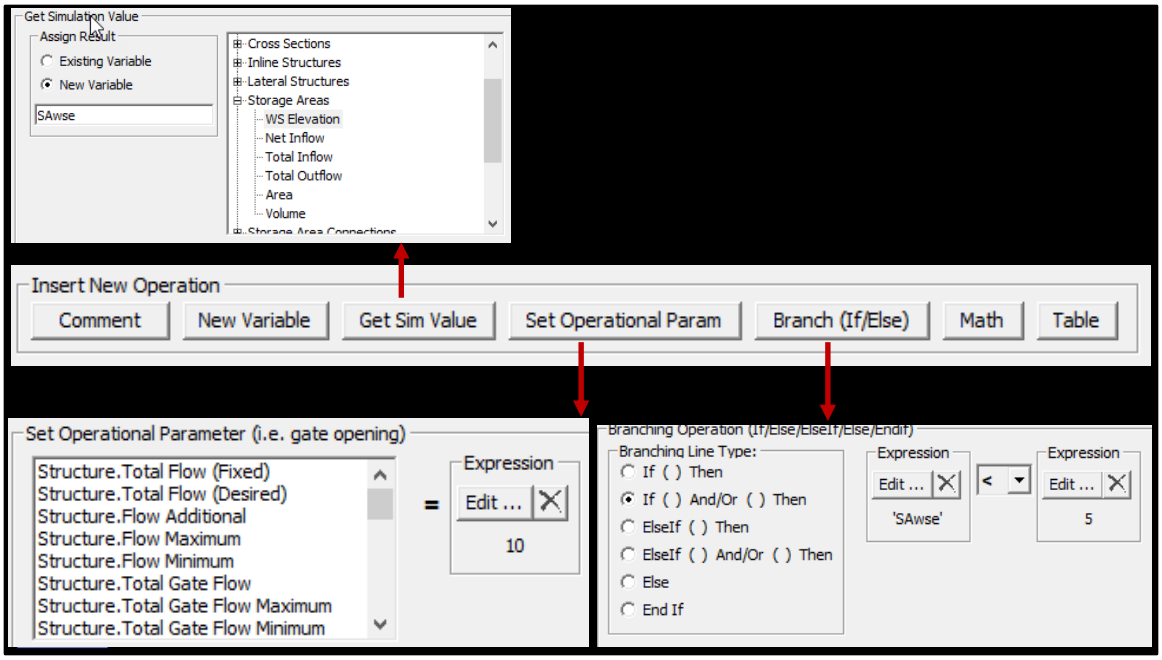
Table. This operation allows the user to enter a table and perform table lookups to get a value.

Rules

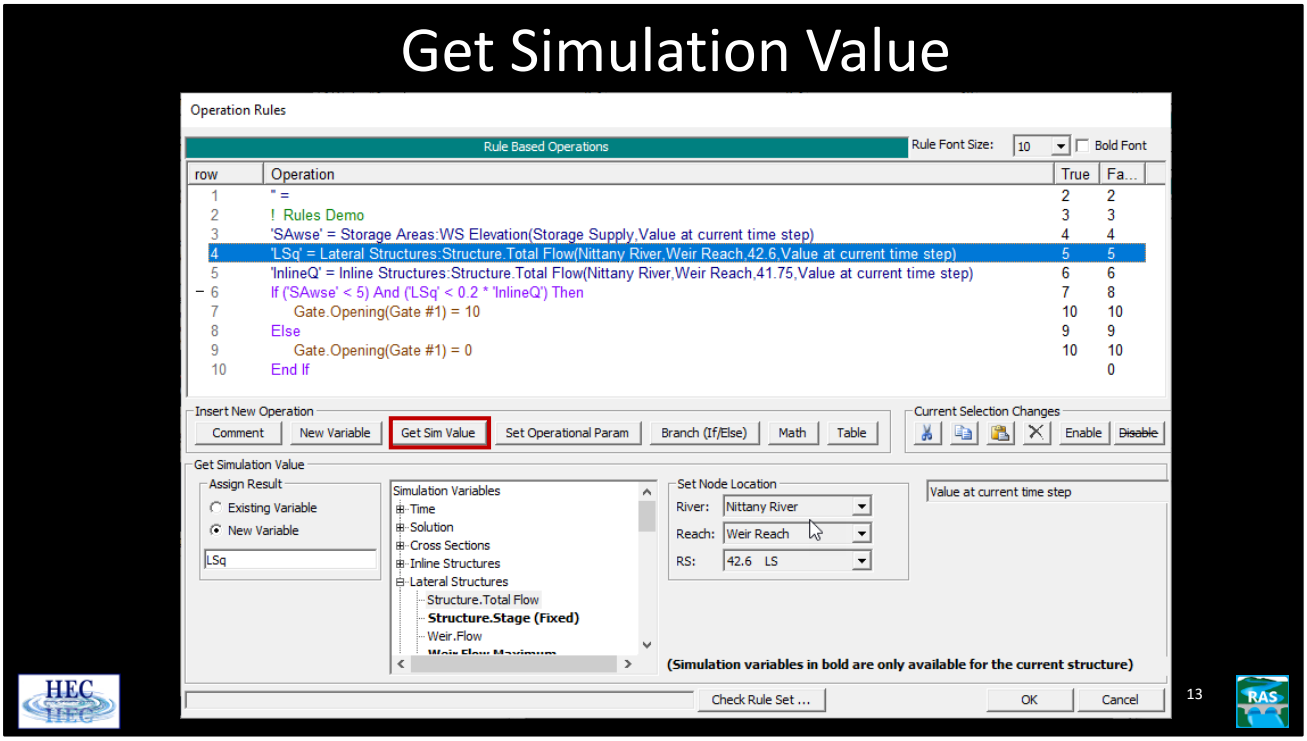
“HEC-RAS Output” WSE/Q/Time	Change Something in RAS	If/Then/Else And/Or
Turn HEC-RAS Results into a Variable	e.g. Open/Close a Gate	Programming Logic

Get Sim Value | Set Operational Param | Branch (If/Else)


RAS
Elevation (ft)
Flow (CFS)
Time and Date
19Feb1999 2400
Main Channel Distance (ft)
Get Sim Value
PUMP STA #1
Station (ft)
Set Operational Param
HEC
RAS


Get Simulation Value
Assign Result
Existing Variable
New Variable
SAwse
Cross Sections
Inline Structures
Lateral Structures
Storage Areas
WS Elevation
Net Inflow
Total Inflow
Total Outflow
Area
Volume
Insert New Operation
Comment
New Variable
Get Sim Value
Set Operational Param
Branch (If/Else)
Math
Table
Set Operational Parameter (i.e. gate opening)
Structure.Total Flow (Fixed)
Structure.Total Flow (Desired)
Structure.Flow Additional
Structure.Flow Maximum
Structure.Flow Minimum
Structure.Total Gate Flow
Structure.Total Gate Flow Maximum
Structure.Total Gate Flow Minimum
=
Expression
Edit ...
10
Branching Operation (If/Else/ElseIf/Else/EndIf)
Branching Line Type:
If ( ) Then
If ( ) And/Or ( ) Then
ElseIf ( ) Then
ElseIf ( ) And/Or ( ) Then
Else
End If
Expression
Edit ...
'SAwse'
<
Expression
Edit ...
5

Get Simulation Value



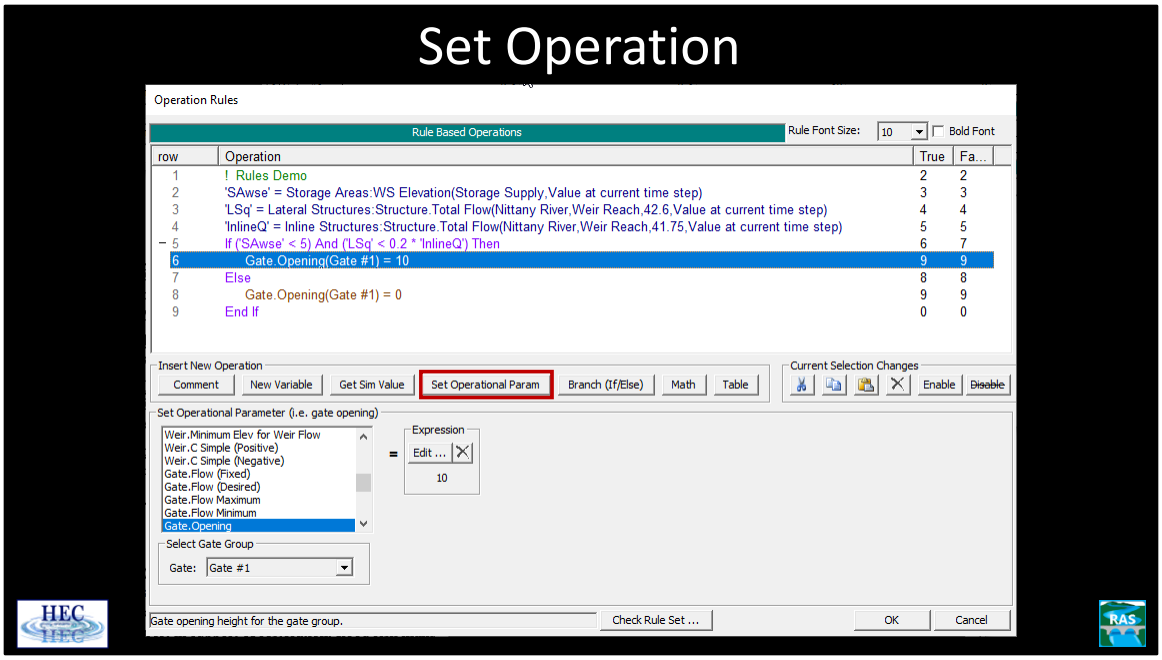
A group of rules for one hydraulic structure is referred to as a rule set. At the start of each time step, each rule set is evaluated to check for changes to the operation of the given hydraulic structure. Rule operations are performed from the first (top) rule to the last (bottom) rule. By default, each rule operation is evaluated once. However, branching operations (If/Then/Else, etc) can cause some rule operations to be skipped. No looping or jumping to prior rule operations is allowed. That is (during a given time step), a rule operation may not be performed more than once.

Note: A rule set is only called once during a time step, even if the program iterates during that given time step. (Whatever rules are “in force” at the start of the time step will apply during all of the iterations).

The Get Simulation Value operation provides information about the current state of the model. In the above example, the wsel at a cross section just upstream of the dam is being retrieved and stored in a variable named

“WSEL at dam.”
There are currently seven categories of simulation variables. These are Time, Solution, Cross Section, Inline Structure, Lateral Structure, Storage Areas, and Storage Area Connectors. Clicking on the “+” will expand the list for that category. Continued on next slide…

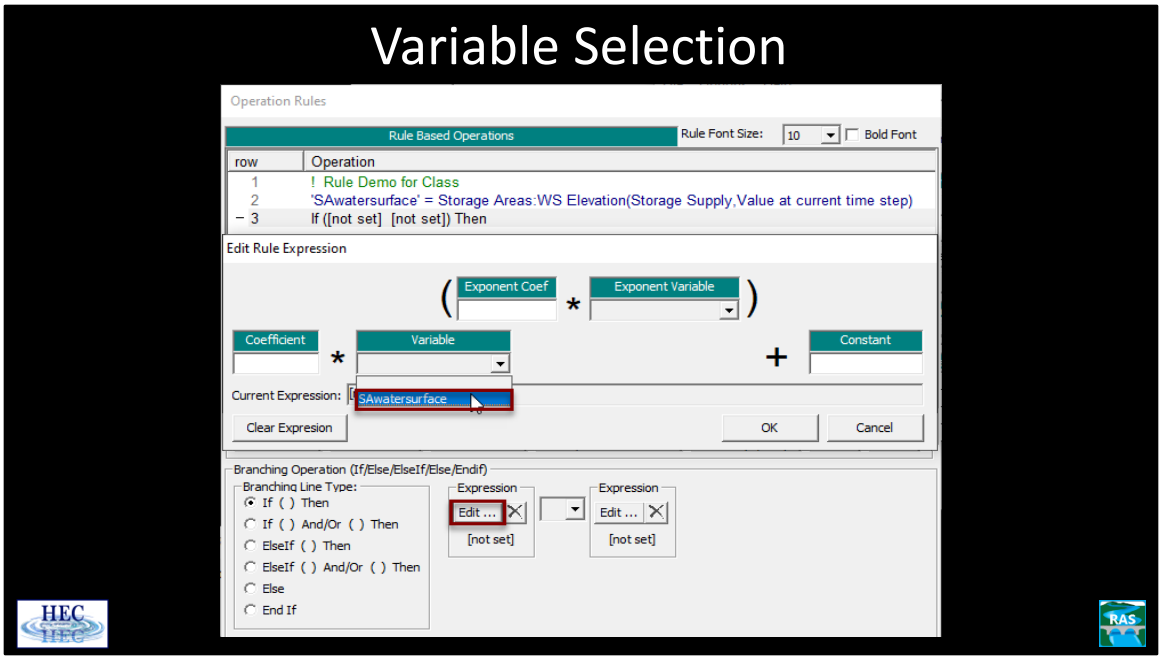
Set Operation



To control a given aspect of he hydraulic structure, a Set Operational Param rule operation is used. In the example above, rule 63 is setting the “gate flow desired” to the [previously calculated] value of “Flow New.” This will cause the RAS program to adjust the gate settings in order to get the desired flow. (The actual computed flow may be slightly different due to convergence tolerances and changing water surface elevations.) There are a number of different operational parameters that can be set. In addition to setting the gate opening height or having RAS compute the height to get a desired flow, the user can: set a maximum flow, set a minimum

flow, fix a given flow, etc.

Variable Selection



In order to use a variable in an expression, or store the result into an existing variable, the user selects the variable with a pull down menu, as shown.

In row 129, there is a two part If/Then. In the first part, the rule operation is checking to see if “Canal Dam Vol since midnight” is greater than or equal to “Canal Dam Vol Diversion.” In the second part, it is checking to see if “Green Dam 4 Hour Ave Flow” is less than 10. Since the two different parts are connected with an “Or,” if either part is true, the expression will be true and rules 134, 135, and 136 will be executed. In more understandable terms, there is a check to see if the maximum amount of water has been diverted, or if the four hour running average flow at Green dam is below 10 cfs. If either is true,

then all of the gates will be fully shut (and no more flow will be diverted for the rest of the day).

Rules

```
2     'Pool Stage' = Cross Sections:WS Elevation(Missouri River,Missouri,811.076
3     'RunTime' = Time:Hour of Simulation(Beginning of time step)
4     !
5     !
6     Structure.Total Flow (Desired) = 60000
7     !
8     ! Start to fill after 11 total days of run time
9     If ('RunTime' > 246) And ('Pool Stage' < 1205) Then
10        Structure.Total Flow (Desired) = 5000
11    ElseIf ('RunTime' > 246) And ('Pool Stage' >= 1205) Then
12        Structure.Total Flow (Desired) = 30000
13    End If
```

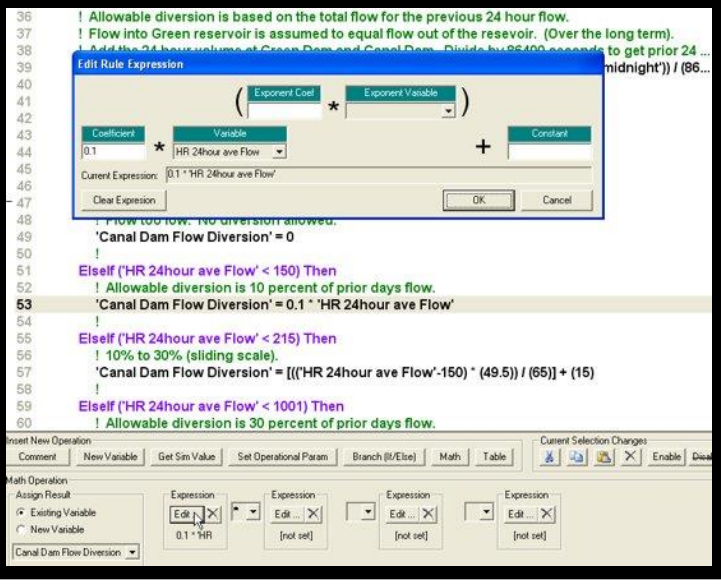
Get Sim Value

Set Operational Param

Comment

Branch (If/Else)

Rule Expression



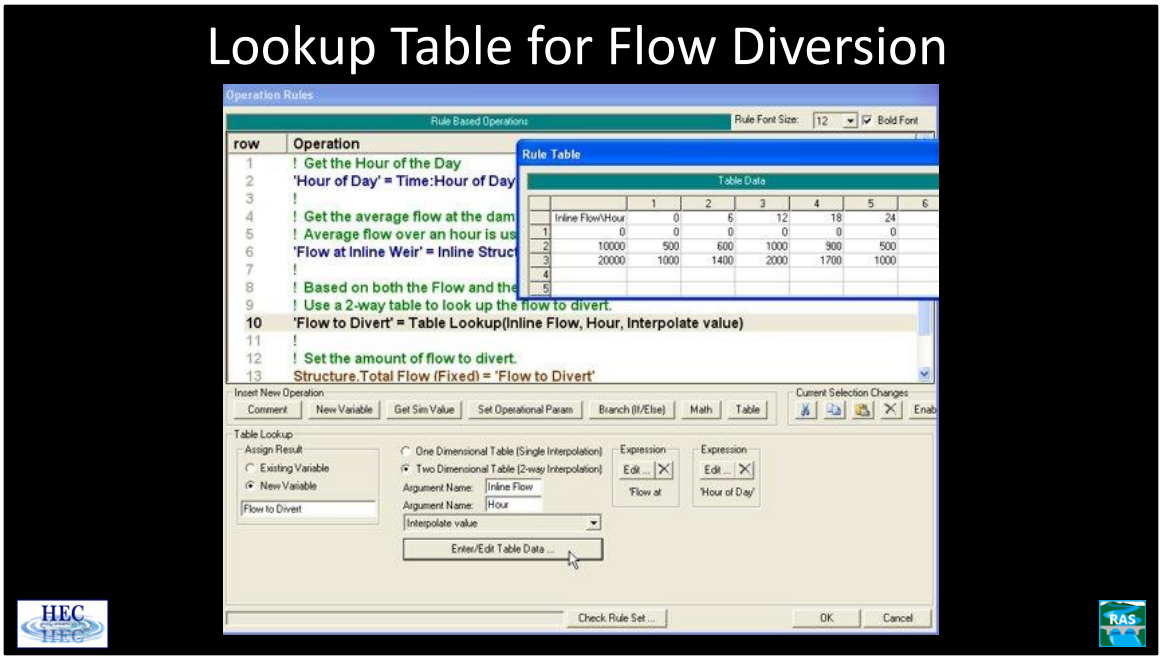
…continued from previous slide:
For all the variables under Time, the user can select to use the time at the beginning of the time step (default), the end of the time step, or the previous time step.
For the remaining [non-time] variables, the user can select the current value, the value from the previous time, or a "look back" value.

Clicking the **Math** operation button creates a math operation as shown. The result of the math operation can be assigned to either a new variable or an existing variable.

The math operation itself is composed of up to four different "expressions." Each expression that is defined will return a real number. Expressions should be defined from left to right. So if a math operation is composed of two expressions, the left two expressions should be defined and the right two expressions should be left as "[not set]" (i.e. they should be left blank). If more than one expression is defined,

then the user must choose an algebraic connector from the drop down menu between them. The choices are: addition, subtraction, multiplication, and division.

Lookup Table for Flow Diversion



In this simple example, a rule set that is attached to a lateral structure is being used to divert flow from the main river. The diversion is based both on the amount of flow going through a downstream dam and the time of day.

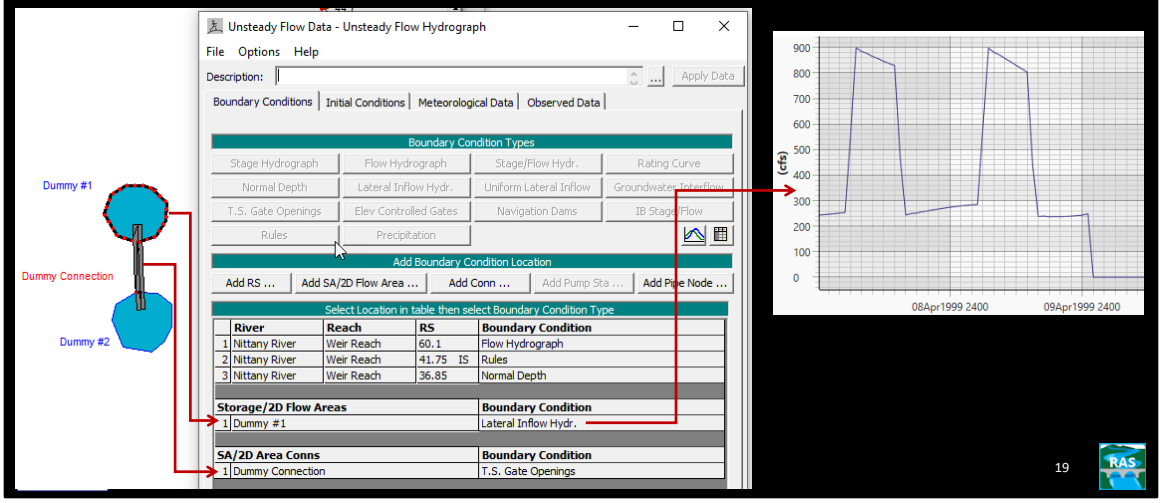
After getting the time of day and the flow at the inline structure, the actual diversion is determined from a lookup table as shown above. So, for instance, if the time is 12 (i.e. 1200) and the flow through the dam is 10,000 cfs, then 1000 cfs will be diverted. In this example, the user has selected to interpolate. So if, for example, the flow was 11000 at 12 hours, then the flow diverted would be 1100 cfs. Instead, the user could have selected "nearest index value" which would have resulted in 1000 cfs being diverted for a main river flow of 11000. This option could be useful, for instance, if the lookup table was being used to set gate openings that can only be opened in discrete amounts.

Note that in row 13, the flow diversion ('Flow to Divert') has been set as a "Total Flow (Fixed)". This means that the flow being diverted by this lateral structure is being

entirely controlled by the rules (and the value from the lookup table). There are no gates and no hydraulic computations (e.g. computed flow over a weir).

Rule Hacks

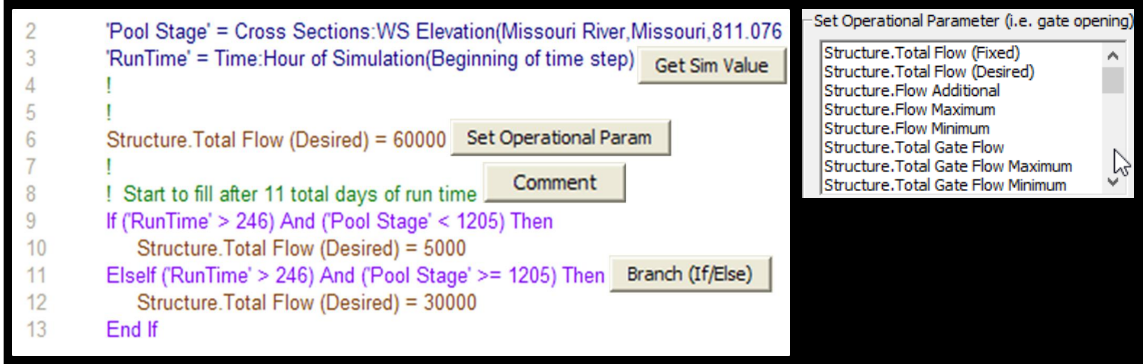
"Dummy" SA and/or Structure



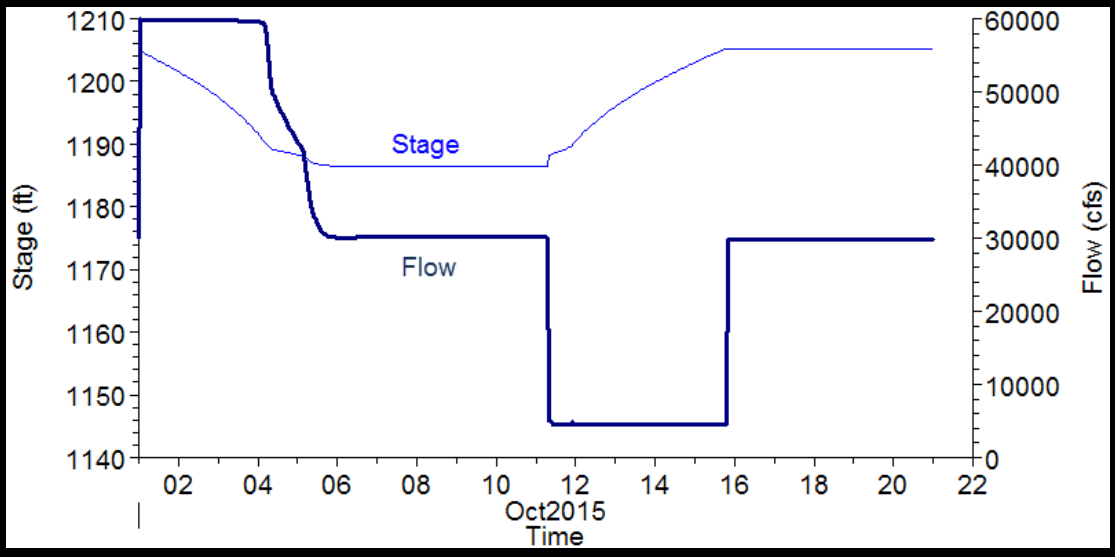
If you want to write rues against observed or synthetic flow or gate or stage operations that are external to the simulation, you can create a dummy "barbell" – 2 storage areas and a connection that are a closed system outside the model. Then you can bring flows (e.g historical, measured releases) into the storage area and any distance time series (e.g. historical or specified reservoir stage) in as (unusually large) gate openings.

Rule Hacks

Structure.Total Flow.(Desired)



"Desired" flow will aspire to deliver the specified flow, but will not dry out the model to get it.



-The relatively simple rule set in the previous slide generated this draining/flushing/refilling hydrograph.

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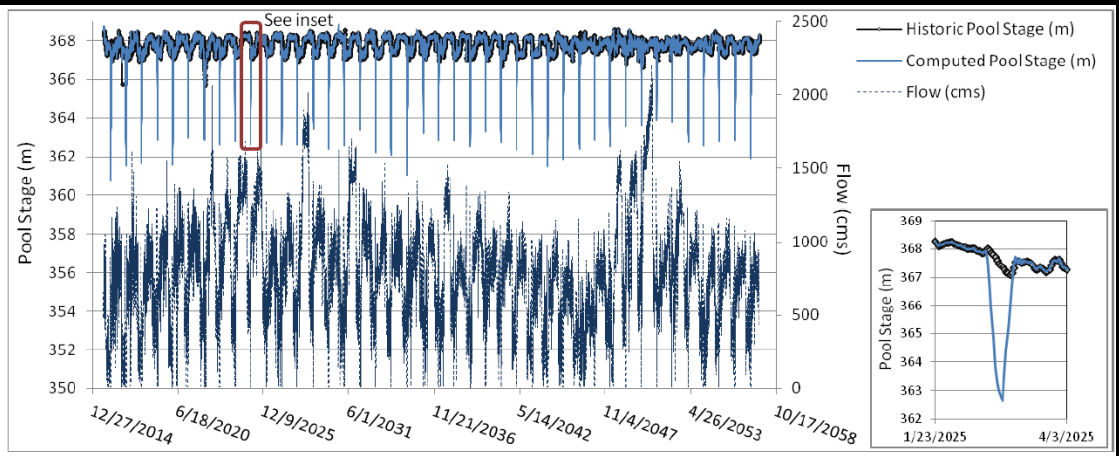
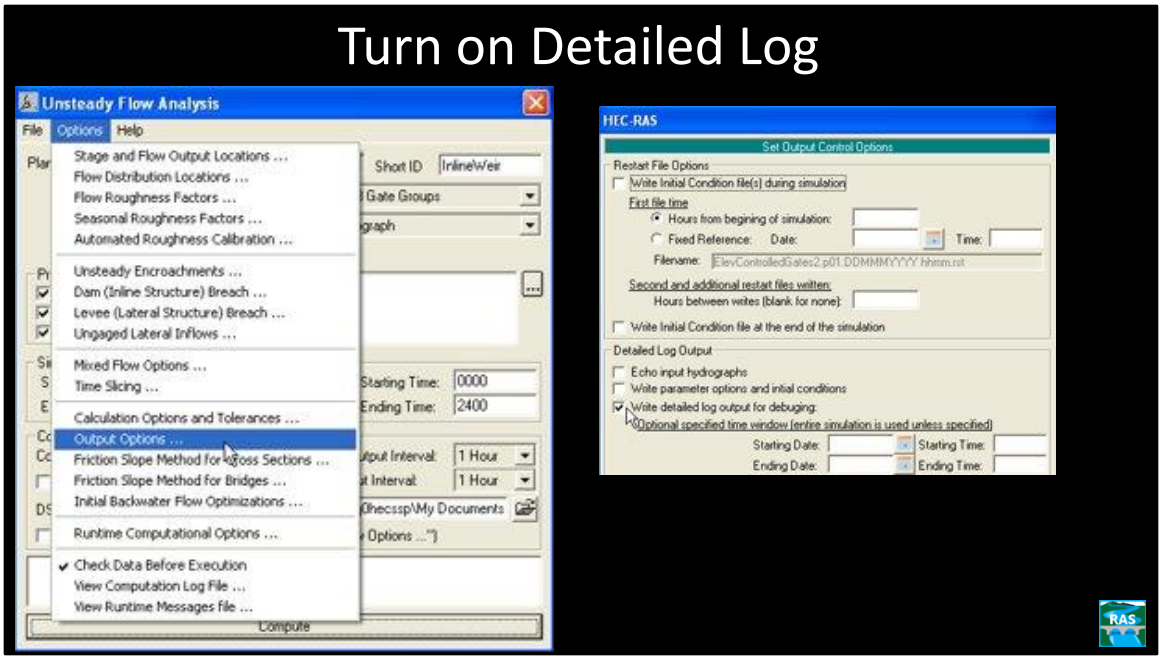


Figure 5: Fifty-Seven year period of record simulation starting with the 2011 geometry, which uses operational rules to maintain the historic water surface elevation coupled with the historic flows, but introduces an 850 cms flushing event every spring based on calendar and physical constraints.

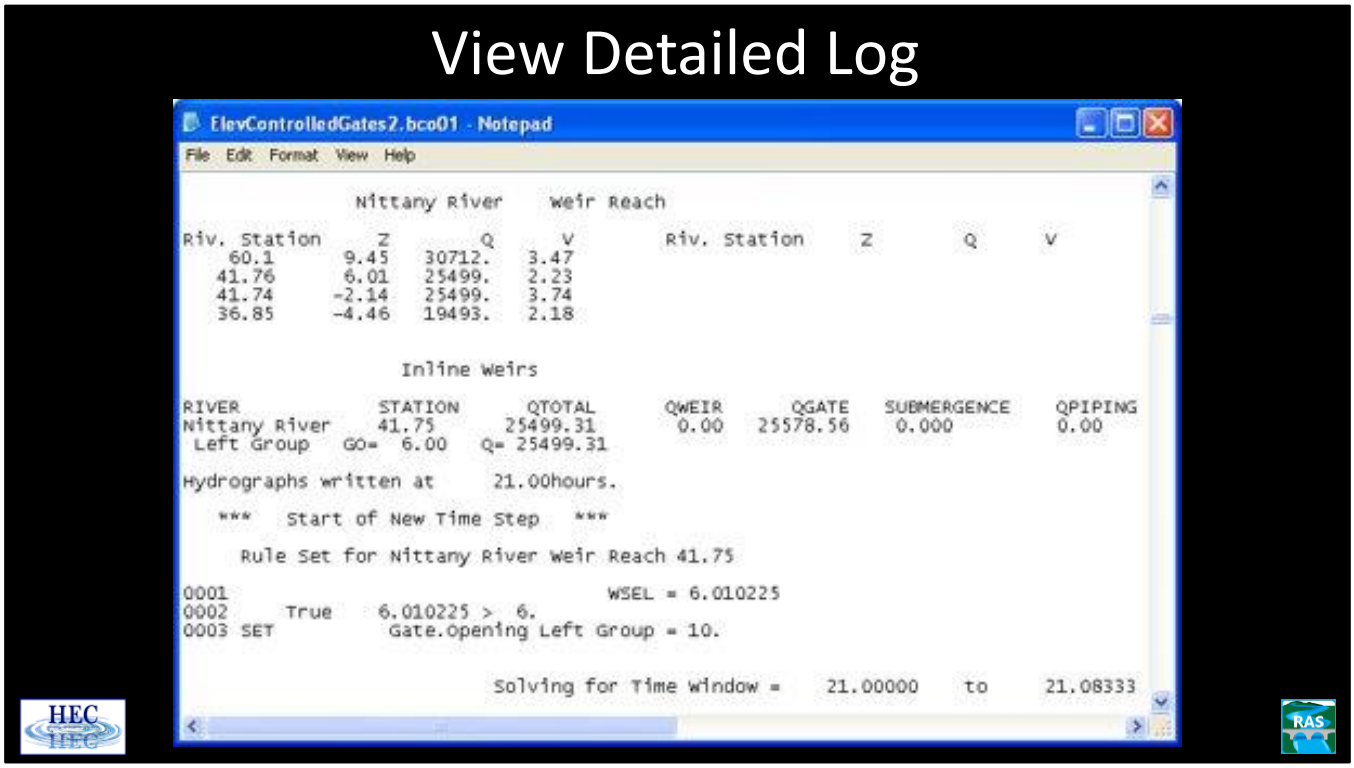
Gibson, S. and Boyd, P. (2014) "Modeling Long Term Alternatives for Sustainable Sediment Management Using Operational Sediment Transport Rules," *Reservoir Sedimentation* –Scheiss et al. (eds), 229-236.

Turn on Detailed Log



Deciphering (aka debugging) what a complicated rule set is actually doing can be tricky. RAS has a text based output file referred to as the Detailed Log. The operation of each rule in a rule set can be examined on a timestep by timestep basis from this log.
The log output is turned on as shown above.

View Detailed Log



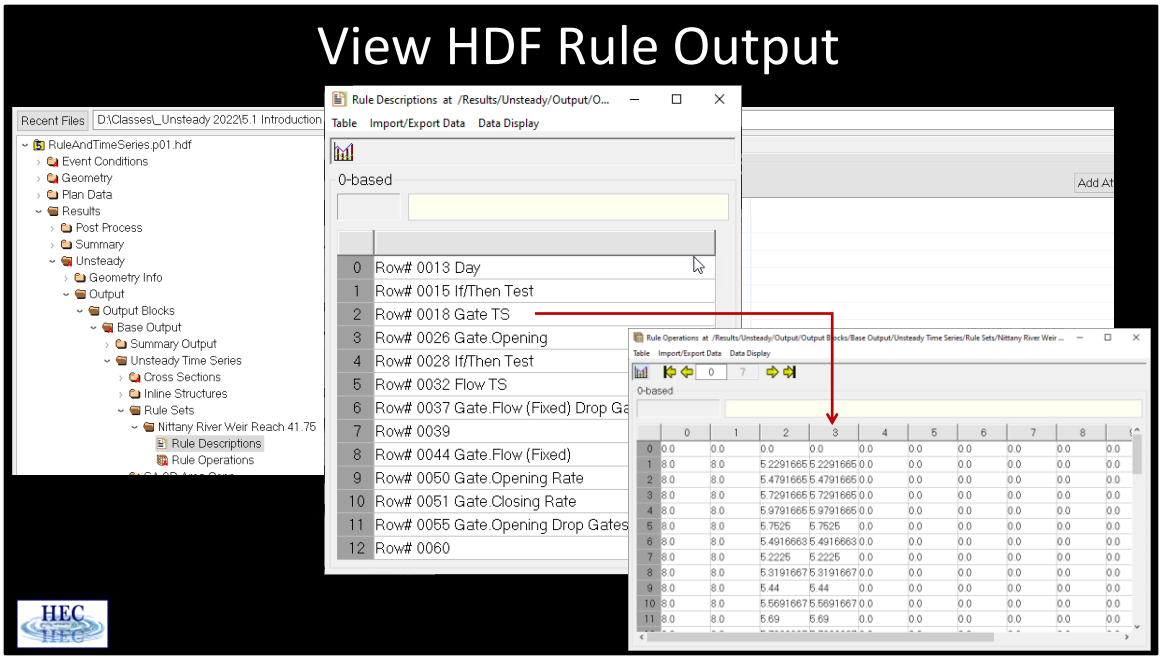
Every rule that is executed will be shown—as will the result of that rule. The output shown above is taken from the previous rule data set that opens the gate when the WSEL is greater than 6.0 feet.
Rule 1 is executed and the variable WSEL is set to the current water surface which is around 6.01 feet.

Rule 2 is executed and this rule is True because the value of the first expression (~6.01) is greater than the second expression (6.0).
Rule 3 is executed and the gate opening for the Left Group is set to 10 feet.

No other rules are executed for this rule data set (for this time step). Use the find function to locate when things happen. For instance, the string “0002 True” was searched on to find this location in the log file.

Note: having detailed (debug level) output for the rule data set directly available within the GUI is already on the RAS “wish list”.

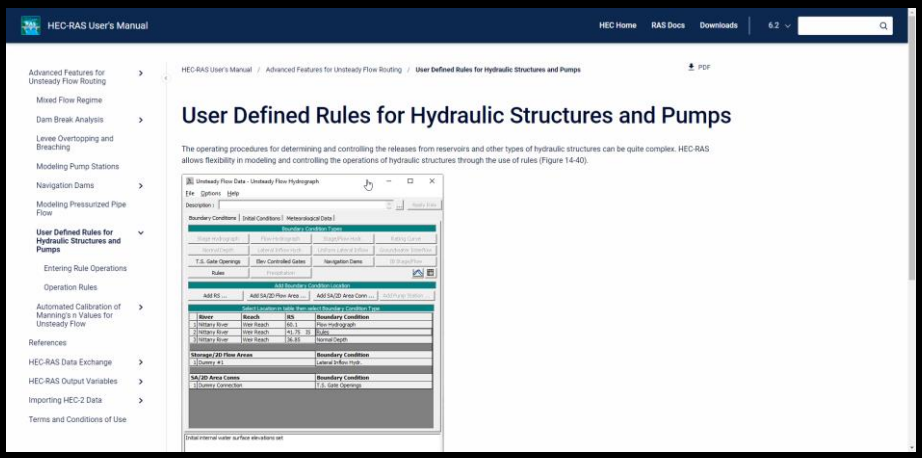
View HDF Rule Output



Results from rules is also sent to the HDF output file which can be opened with HDFView. The output for rules in the HDF file is more cryptic than the text based log file. However, the log file contains a lot of output for each time step that is not related to rules and it can be tedious to find how the rule set is operating over time. The HDF file concentrates all of the output for a given rule set into a single HDF data set.

Rule Hacks

Read the Manual !!!



https://www.hec.usace.army.mil/confluence/rasdocs/rasum/latest/advanced-features-for-unsteady-flow-routing/user-defined-rules-for-hydraulic-structures-and-pumps

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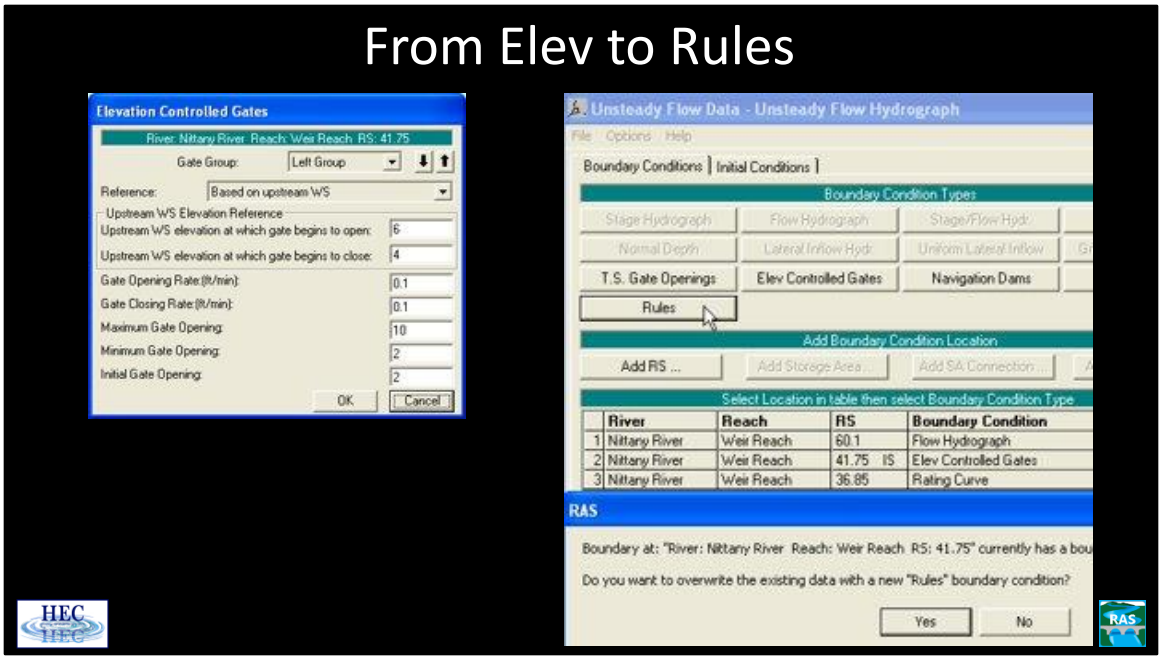
"Desired" flow will aspire to deliver the specified flow, but will not dry out the model to get it.

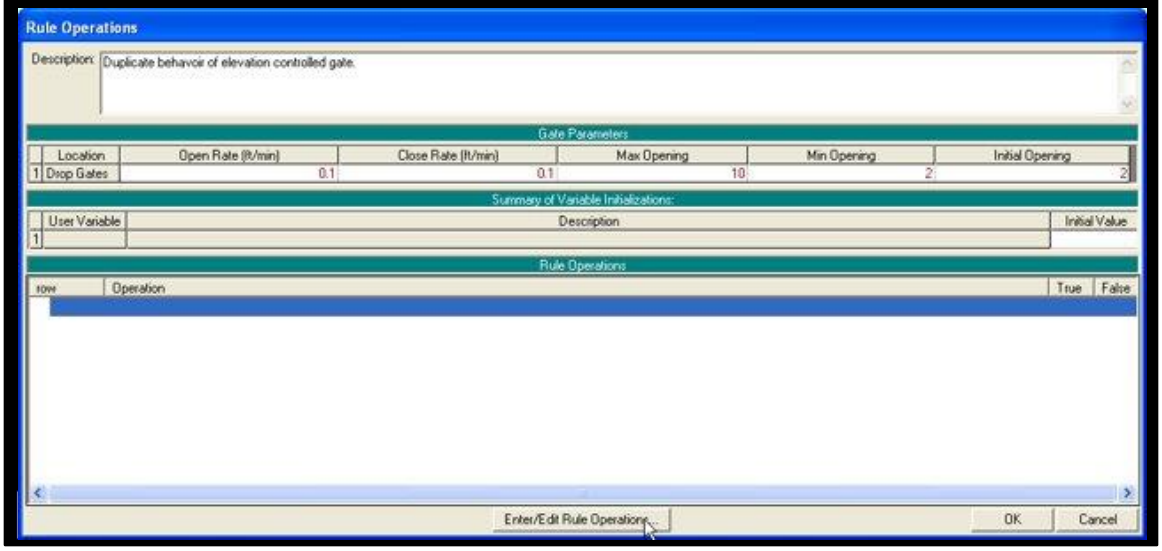
Examples

From Elev to Rules



In this, and following, slides, the gate control will be switched from elevation control to a rule set that has the same basic functionality.

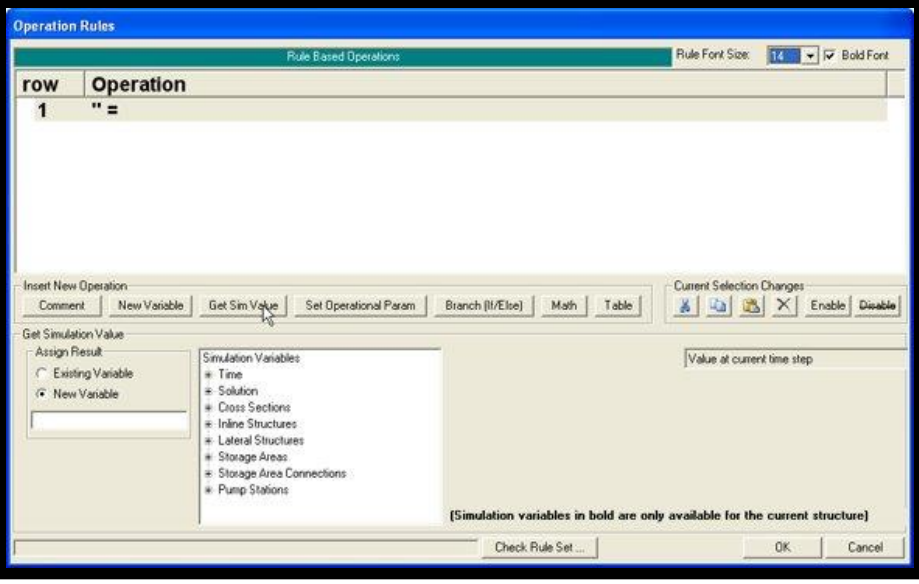
Gate Parameters



The gate opening rates, maximum, minimum and initial gate opening are entered.

Next, the **Enter /Edit Rule Operation** button is clicked.

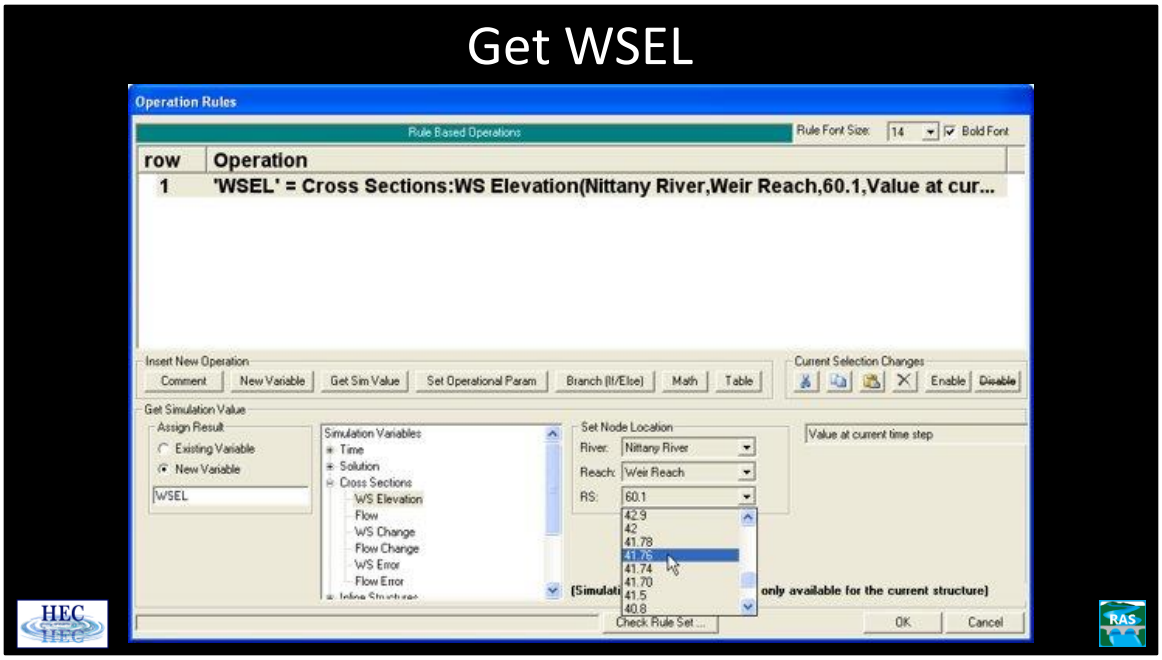
Get Simulation Value



The first rule that is needed is the water surface elevation immediately upstream of the inline structure.

Clicking the **Get Sim Value** button, as shown, will start the creation of the first rule.

Get WSEL



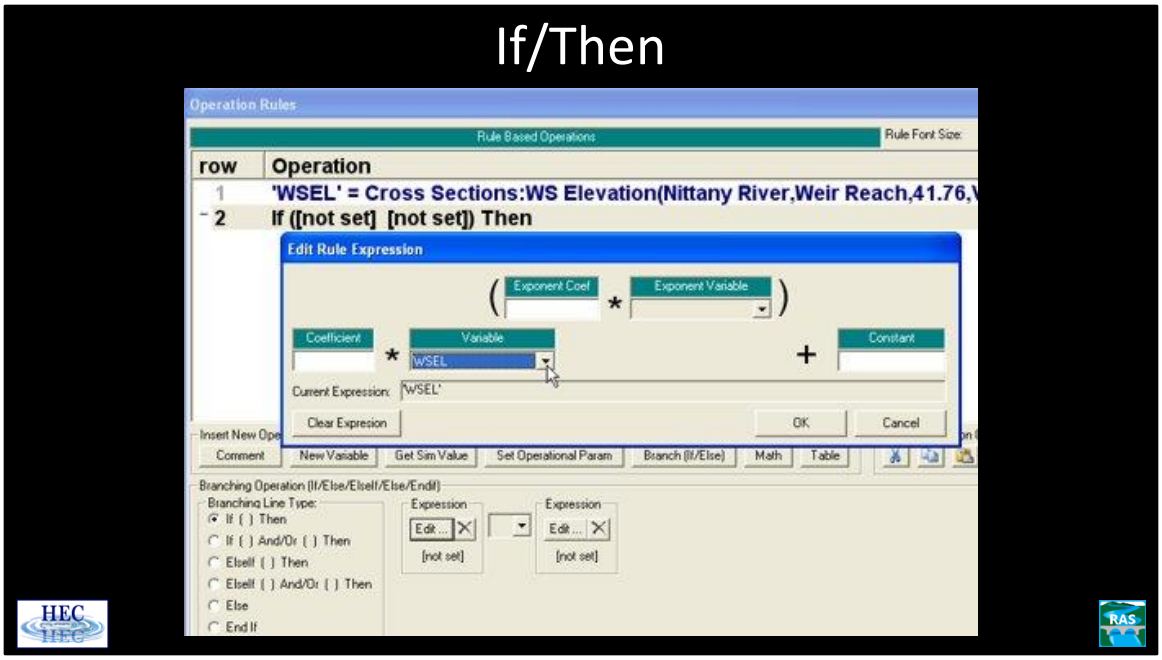
On the left, beneath where it says “Assign Result”, a descriptive variable name should be entered (in this case, WSEL).

Under Simulation Value, the Cross Section tab should be expanded and WS Elevation choosen.

Next, the river station just upstream of the inline structure is selected from the pull down menu.

On the right, the default “Value at current time step” should be left as-is. This gets the water surface at the start of the timestep. Other choices would get a previous water surface or a lookback/time-averaged water surface.

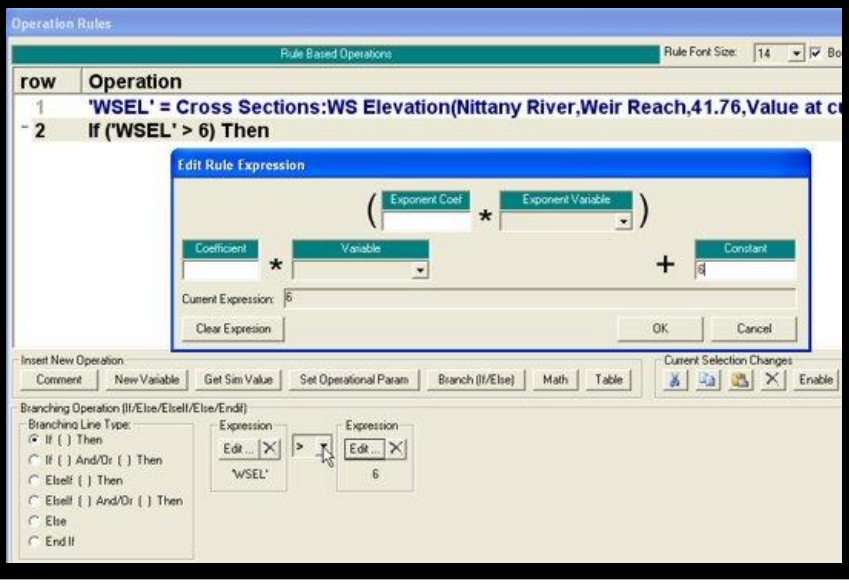
If/Then



The next step is to add a rule that checks to see if the water surface is high enough that the gates need opening. Clicking on the **Branch (If/Else)** button, will start the second rule. The If test compares the value of two different "Expressions". Clicking on **Edit** underneath the Expression on the left will bring up the Edit Rule Expression editor as shown. Clicking on the **Variable** pull down menu will show all of the variables in the rule data set. In this case there is only one. Selecting the variable WSEL (which is created by rule 1), allows the value of the water surface to be compared to the second expression. Since the water

surface is the desired item, the rest of the fields are left blank. (If it was desired, the Variable could be multiplied by a Coefficient, raised to an Exponent, and/or a Constant added.

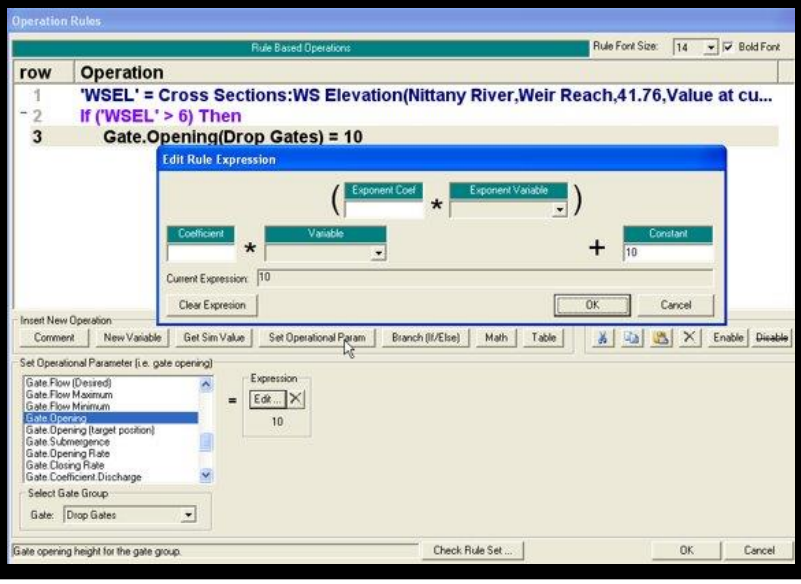
Setting Expression



For this If test, the check is to see if the water surface is greater than 6.0 feet. Between the two Expression buttons, there is a pull down menu that is used to select the “>” (greater than) operator.

The right **Edit** Expression is clicked and the number 6 is entered in the Constant field.

Set Gate Opening



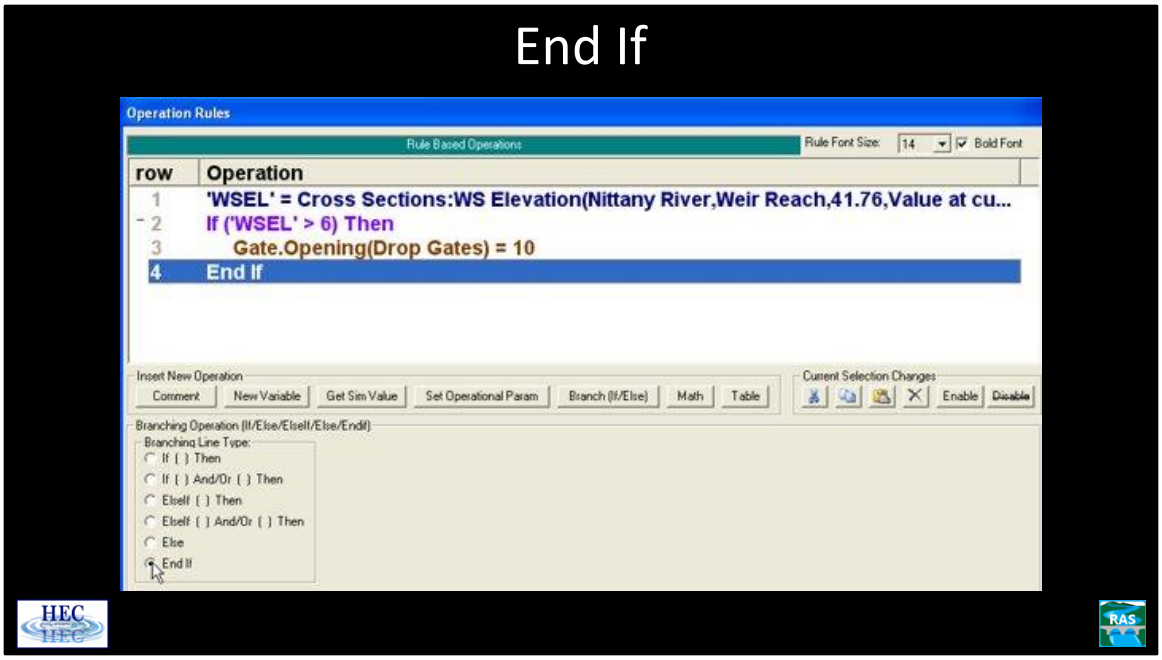
The next rule is to set the gate opening height when the water surface is above 6.0 feet.

Clicking the **Set Operational Param** button will display the menu on the lower left and

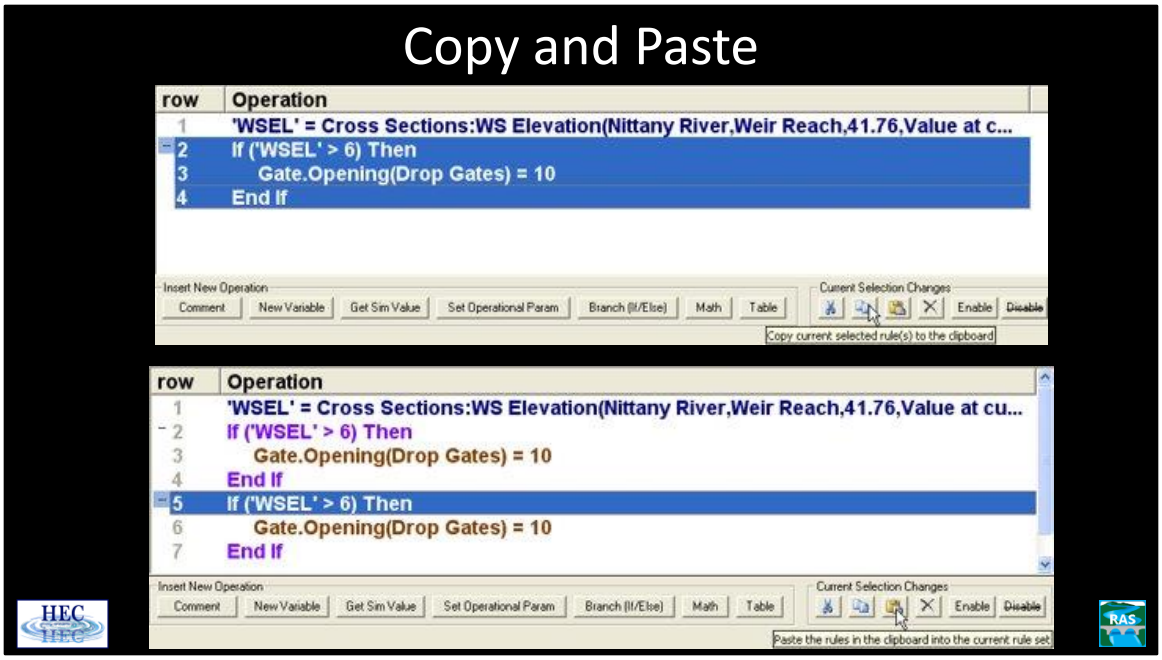
the Gate.Opening operation is selected. If there is more than one gate group, the proper gate group can be chosen by the drop down menu under the Select Gate Group.

The gate opening is set to 10.0 feet using the expression editor.

End If



Every If rule must have a corresponding End If. Click the **Branch** button, which initially creates an If rule. Change this rule to an End If by the selecting the End If radial button as shown.

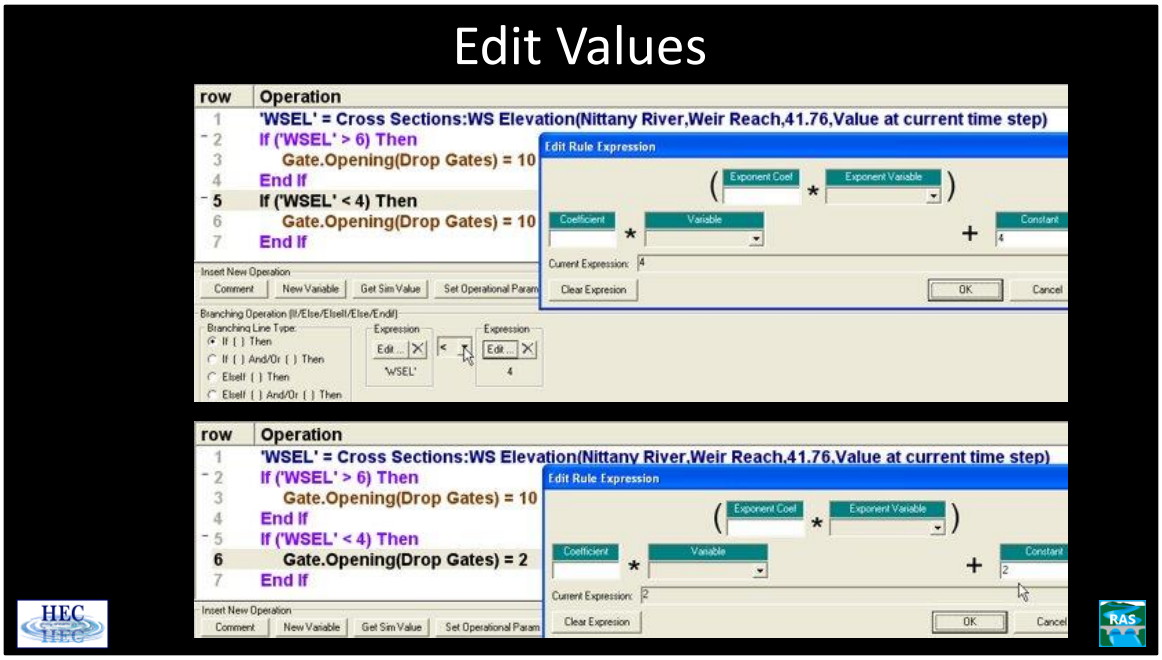


Another conditional must be created to close the gates when the water surface gets low enough.
The quickest and easiest way to do this is by making a copy of the existing rules (that open the gates), and then editing the copy.
Highlight rules 2 through 4 by clicking on rule 2 and then pressing the down arrow while holding the shift key (shift + down arrow).
Next, click on the **Copy** button, then move the cursor below row 4 (as if a new rule was to be made using one of the standard Insert New Operation) and then click on the **Paste** button.

The keyboard shortcuts Ctrl+X and Ctrl+V, can be used instead of clicking on the copy and paste keys.

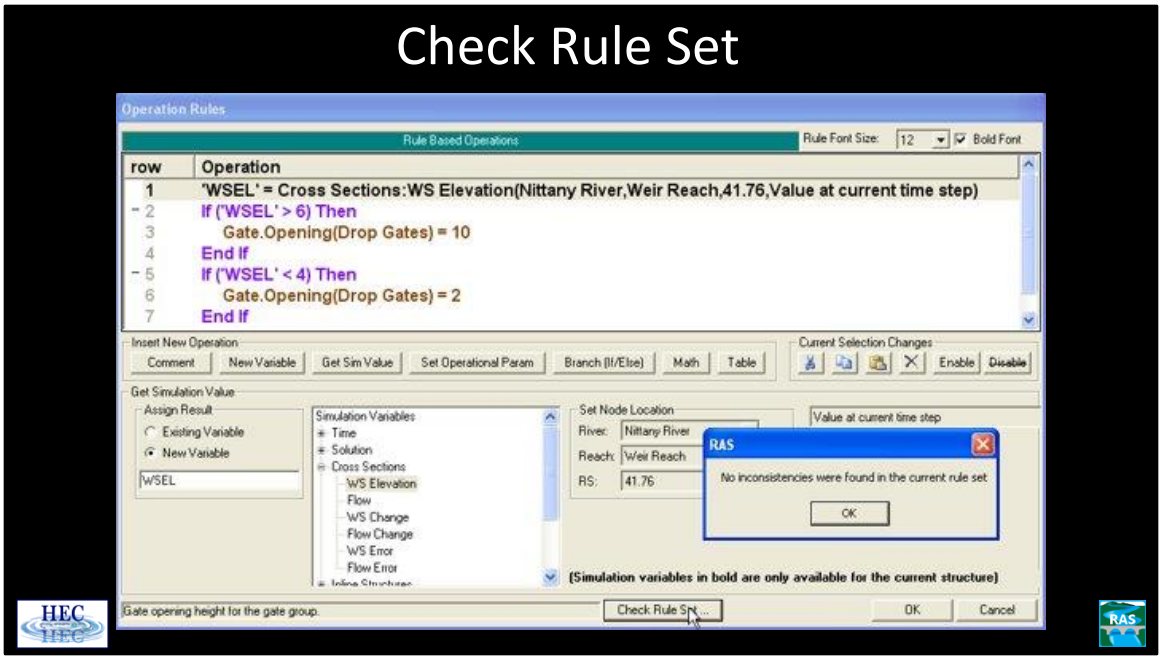
Copying existing rules using the Ctrl+X and Ctrl+V shortcuts (and then editing the copy) can save a lot of time and effort.

Edit Values



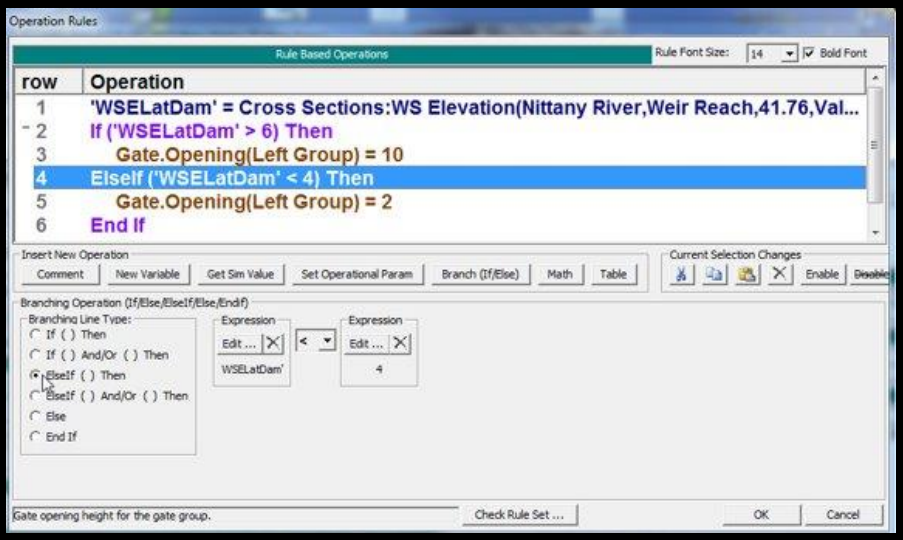
The next step is to edit the just copied rules.
The 6 needs to be changed to a 4 (in the If rule), the operand needs to be changed from a greater than to a lesser than, and the gate opening value needs to be changed from 10 to 2.

Check Rule Set

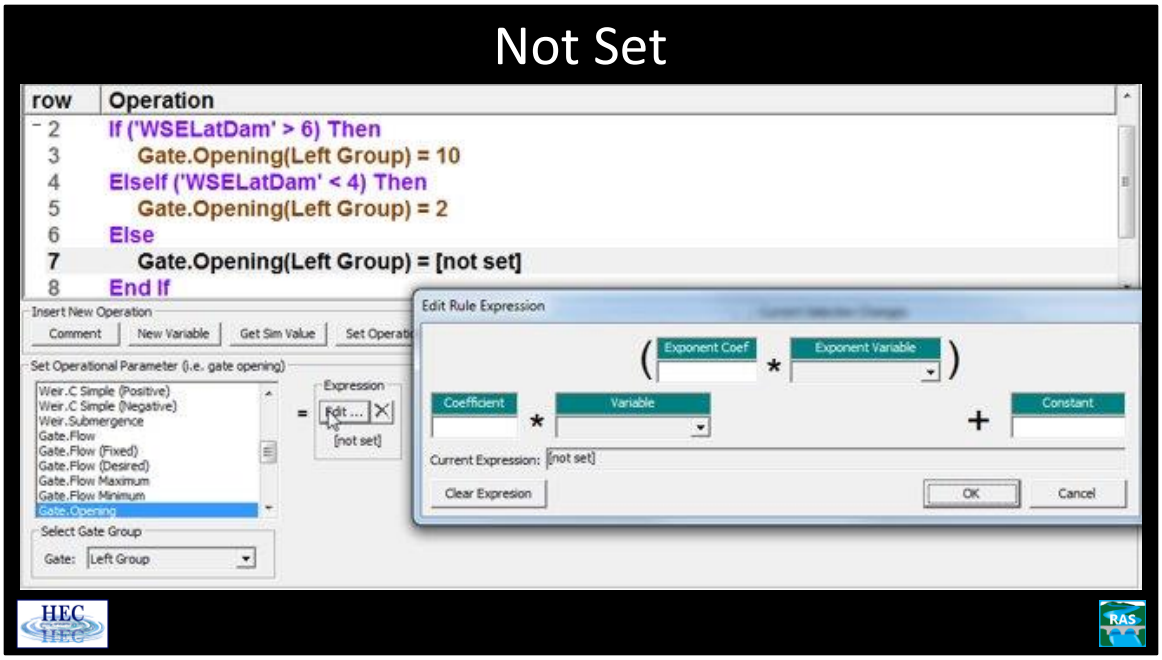


Finally, it is a good idea to click on the **Check Rule Set** button. RAS will check for any basic errors in the rule data set. (For instance, if there is a If rule that does not have a corresponding End If.) If the Check Rule is not performed at this stage, RAS will still perform the check at run time. Errors will generate a message for the user about the problem. The Check Rule button is a short cut that allows the user to identify problems while the Operation Rule editor is still open.

Switch to “ ElseIf ”



In addition to If/Then, the rules also allow for If/Then/Else and If/Then/ElseIf/Else type constructions (as well as nested If/Then statements).



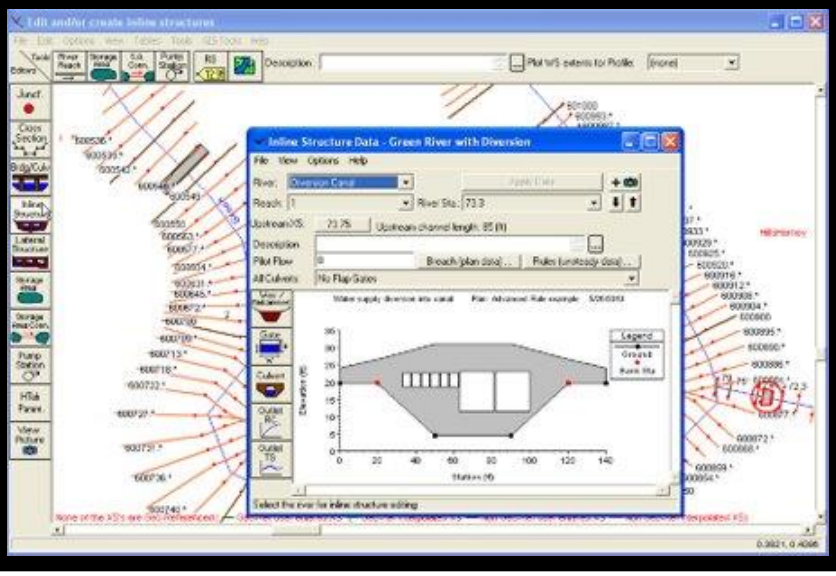
If the user has entered an Open Rate (or Close Rate), then this rate will restrict how quickly the gate is allowed to open. For instance, if the gate is currently opened to 4 and the WSEL has just gotten above 6, then the gate opening will be set to 10, but it may take several time steps for the gate to reach this value, which is referred to as the gate opening target position.

Once a gate opening target position has been selected, it will, by default, continue to that target position.

Continuing with the example, after several time steps the gate might be open to 5 and the WSEL may have dropped to 5.9. However, the gate will continue to open to 10 unless some other operation overrides the target position. Setting the gate opening to "not set" (by leaving the Expression editor blank) will "turn off" the gate opening. So if the WSEL has just dropped below 6, then row 7 will turn the gate opening off and the gate

will remain at its current opening of 5 until the WSEL is again greater than 6 or less than 4.

Canal Data set Example



The canal data set (which is included as one of the sample data sets when RAS is installed) provides a good example of the sophisticated operations that are possible with the advanced rule capability.

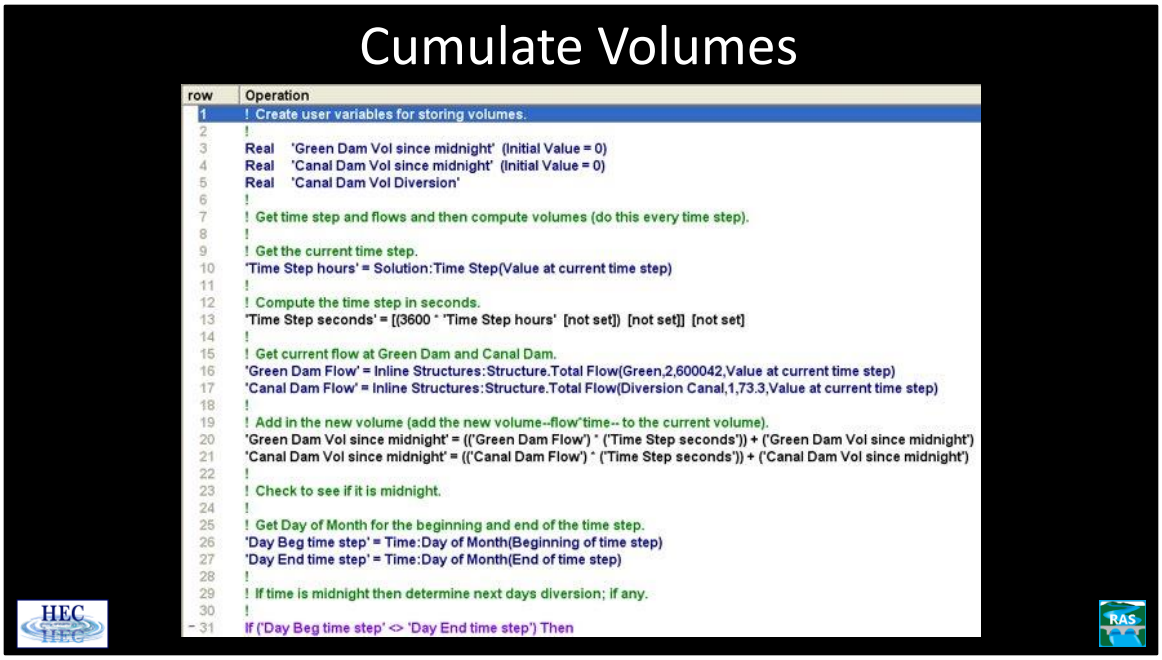
In this data set, the rules are being used to allow RAS to model a reservoir and a water supply canal in Florida. The Florida water district has a complicated operating agreement that it must conform with.

A reservoir has been modeled as a series of cross sections. A water supply canal leaves the side of the reservoir. This has been modeled with a junction and an inline structure (shown above and red circle) on the diversion canal. The main dam on the reservoir is further downstream (and is not shown on the above graphic).

The flat terrain (river gages suffer backwater effects far upstream of the dam) and the large groundwater flows make measuring inflows to the reservoir difficult. Instead, the inflow to the reservoir is assumed to be equal to the outflow (the outflow from the main dam plus the outflow through the water diversion canal).

The water district's allowable diversion is based on the previous day's outflow (midnight to midnight). Additionally, the water district is not allowed to divert water when the outflow from the main dam is too low. (The flow at the main dam is reduced when the reservoir drops too low—so, the water district is, indirectly, prevented from making diversions when the reservoir water surface is low.)

Cumulate Volumes



row	Operation
1	! Create user variables for storing volumes.
2	!
3	Real 'Green Dam Vol since midnight' (Initial Value = 0)
4	Real 'Canal Dam Vol since midnight' (Initial Value = 0)
5	Real 'Canal Dam Vol Diversion'
6	!
7	! Get time step and flows and then compute volumes (do this every time step).
8	!
9	! Get the current time step.
10	'Time Step hours' = Solution:Time Step(Value at current time step)
11	!
12	! Compute the time step in seconds.
13	'Time Step seconds' = [(3600 * 'Time Step hours' [not set]) [not set]] [not set]
14	!
15	! Get current flow at Green Dam and Canal Dam.
16	'Green Dam Flow' = Inline Structures:Structure.Total Flow(Green,2,600042,Value at current time step)
17	'Canal Dam Flow' = Inline Structures:Structure.Total Flow(Diversion Canal,1,73.3,Value at current time step)
18	!
19	! Add in the new volume (add the new volume--flow*time-- to the current volume).
20	'Green Dam Vol since midnight' = (('Green Dam Flow') * ('Time Step seconds')) + ('Green Dam Vol since midnight')
21	'Canal Dam Vol since midnight' = (('Canal Dam Flow') * ('Time Step seconds')) + ('Canal Dam Vol since midnight')
22	!
23	! Check to see if it is midnight.
24	!
25	! Get Day of Month for the beginning and end of the time step.
26	'Day Beg time step' = Time:Day of Month(Beginning of time step)
27	'Day End time step' = Time:Day of Month(End of time step)
28	!
29	! If time is midnight then determine next days diversion; if any.
30	!
31	If ('Day Beg time step' <> 'Day End time step') Then

Rules 3 through 5 create three variables. New variables are most often created with a Math or Get Sim Value operation. However, it is sometimes convinent to have the variable creation be its own rule. Note: the Initial Value = 0 sets the variable equal to 0.0 at the very start of the simulation (the very first time the rule set is called for the first timestep). Afterwards, the variable will keep its value between time steps (e.g., if it equal "5" at the end of the first time the rules set is called, it will equal "5" at the start of the next time). To set it equal to 0.0 at the start of each time step, a Math operation should be used.

Rule 10 gets the length of the time step with a Get Simulation rule. A math operation is then used to compute the length of the time step in seconds.

Rules 16 and 17 get the outflow from the main dam and the diversion canal.

Rules 20 and 21 add the volume of outflow (for this time step) to the current volume. The "current volume" is the volume of outflow since midnight.

Rules 26 and 27 get the day of the month at the beginning of the time step and the end of the timestep. If the data set is using 15 minute time steps, at some point the beginning of the timestep will be at 11:45pm and the end of the timestep will be at 12:00am. When that happens, the beginning day of month will not equal the end. Beginning might be 5 and ending 6, or beginning could be 31 (or 30 or 28) and the end will be 1 (the first of next month).

Note: The rules use a 24 hour clock, so in the above example, the timestep would actually be at 23:45 and 00:00.

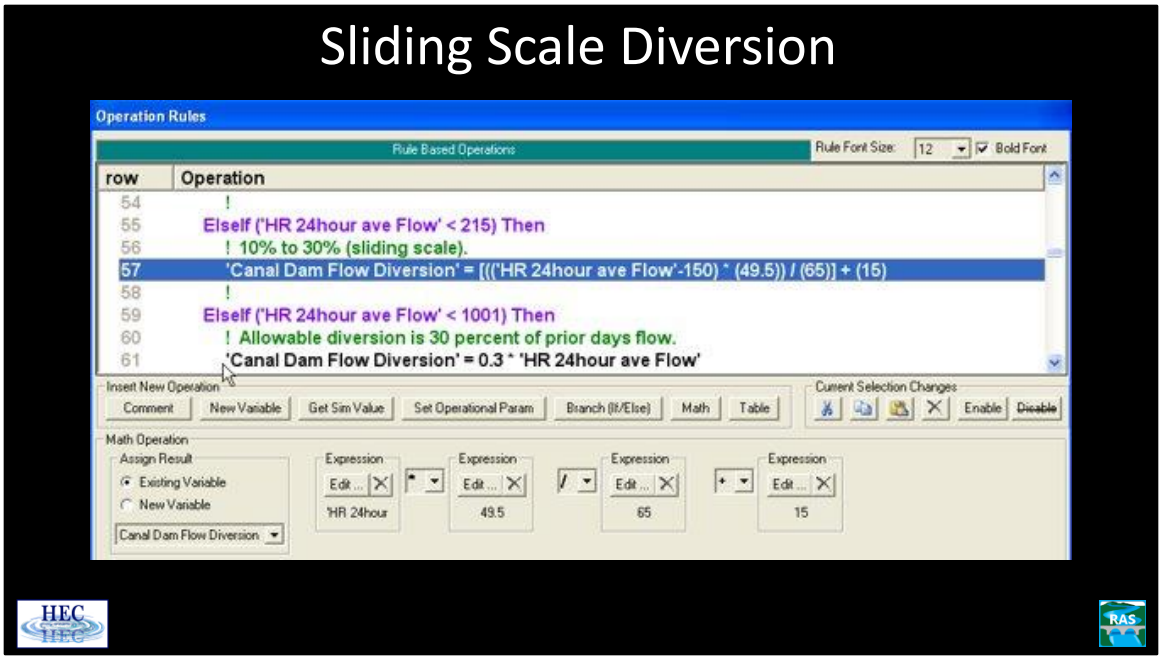
Compute Volume at Midnight

```
31    If ('Day Beg time step' <> 'Day End time step') Then
32       !
33       ! Time is midnight.  Following operations are only performed once a day.
34       ! Compute allowable flow through Canal Dam and set gate openings.
35       !
36       ! Allowable diversion is based on the total flow for the previous 24 hour flow.
37       ! Flow into Green reservoir is assumed to equal flow out of the resevoir.  (Over the long term).
38       ! Add the 24 hour volume at Green Dam and Canal Dam.  Divide by 86400 seconds to get prior 24 hour flow (in cfs).
39       'HR 24hour ave Flow' = (('Green Dam Vol since midnight') + ('Canal Dam Vol since midnight')) / (86400)
40       !
41       ! Reset the volumes to zero (for the next days accounting).
42       'Green Dam Vol since midnight' = 0
43       'Canal Dam Vol since midnight' = 0
44       !
45       ! Determine allowable diversion based on prior days average flow.
46       !
47       If ('HR 24hour ave Flow' < 100) Then
48          ! Flow too low.  No diversion allowed.
49          'Canal Dam Flow Diversion' = 0
50          !
51       ElseIf ('HR 24hour ave Flow' < 150) Then
52          ! Allowable diversion is 10 percent of prior days flow.
53          'Canal Dam Flow Diversion' = 0.1 * 'HR 24hour ave Flow'
54          !
55       ElseIf ('HR 24hour ave Flow' < 215) Then
56          ! 10% to 30% (sliding scale).
57          'Canal Dam Flow Diversion' = [(('HR 24hour ave Flow'-150) * (49.5)) / (65)] + (15)
58          !
59       ElseIf ('HR 24hour ave Flow' < 1001) Then
60          ! Allowable diversion is 30 percent of prior days flow.
61          'Canal Dam Flow Diversion' = 0.3 * 'HR 24hour ave Flow'
```

Rule 31 checks to see if it is midnight. When the timestep starts and ends on different days, it is midnight.
Rule 39 computes the total average outflow for the previous 24 hours (in cfs).
Rules 42 and 43 zero out the volume variables for use for the next day.
The methodology for determining the allowable diversion is based on the amount of outflow. No diversion when the flow is less than 100 cfs (rule 47). 10% of the previous days flow when the flow is between 100 and 150. A sliding scale (from 10% to 30%) when the flow is between 150 and 215. 30% for flows between 215 and

1000 and a maximum of 300 cfs (for flows over 1000).

Sliding Scale Diversion



Up to four separate expressions can be combined into a single Math operation.

Determine Diversion

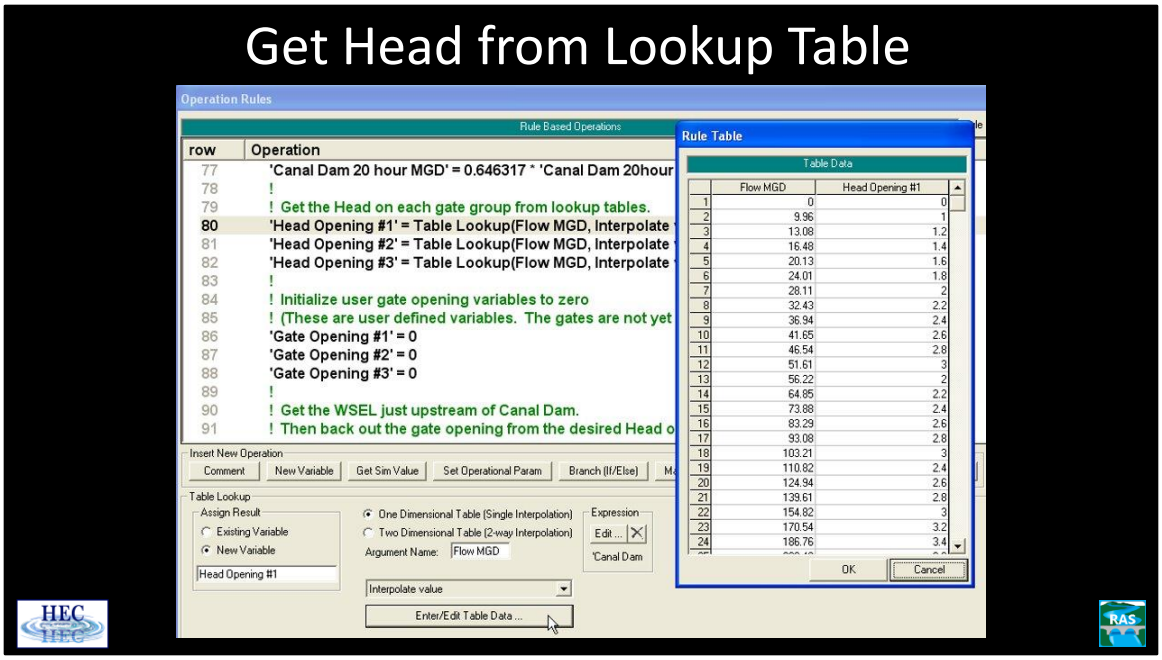
```
63      Else
64         ! Diversion capped at 300cfs.
65         'Canal Dam Flow Diversion' = 300
66      End If
67      !
68      ! Allowable volume diversion is allowable flow in cfs times 86400 seconds in a day.
69      'Canal Dam Vol Diversion' = ('Canal Dam Flow Diversion') * (86400)
70      !
71      ! The Gates are only adjusted once.  In order to make sure the full-allowable-amount is diverted;
72      ! The Volume is to be diverted in ~20 hours and then the gates will be closed.
73      ! So 24 hour flow is multiplied by 1.2 to get 20 hour flow.
74      'Canal Dam 20hour flow' = ('Canal Dam Flow Diversion') * (1.2)
75      !
76      ! Convert 20 hour cfs flow  to 20 hour MGD flow.
77      'Canal Dam 20 hour MGD' = 0.646317 * 'Canal Dam 20hour flow'
78      !
79      ! Get the Head on each gate group from lookup tables.
80      'Head Opening #1' = Table Lookup(Flow MGD, Interpolate value)
81      'Head Opening #2' = Table Lookup(Flow MGD, Interpolate value)
82      'Head Opening #3' = Table Lookup(Flow MGD, Interpolate value)
83      !
84      ! Initialize user gate opening variables to zero
85      ! (These are user defined variables.  The gates are not yet being set)
86      'Gate Opening #1' = 0
87      'Gate Opening #2' = 0
88      'Gate Opening #3' = 0
89      !
90      ! Get the WSEL just upstream of Canal Dam.
91      ! Then back out the gate opening from the desired Head on each gate.
92      !
93      'Wsel Upstream' = Cross Sections:WS Elevation(Diversion Canal,1,73.75,Value at current time step)
94      !
95      If ('Head Opening #1' > 0) Then
```

Rule 69 converts the allowable diversion from cfs to a daily volume.

The gates are adjusted at midnight and are left in place until the allowable diversion has taken place. The gate flows are computed so that the diversion will take approximately 20 hours. (If the flow was based on a 24 hour diversion and the gate flow was slightly less than assumed, then the gates would either have to be adjusted on the fly or the full, allowable diversion would not take place).

Rule 77 computes the 20 hour flow on a MGD basis.

Get Head from Lookup Table



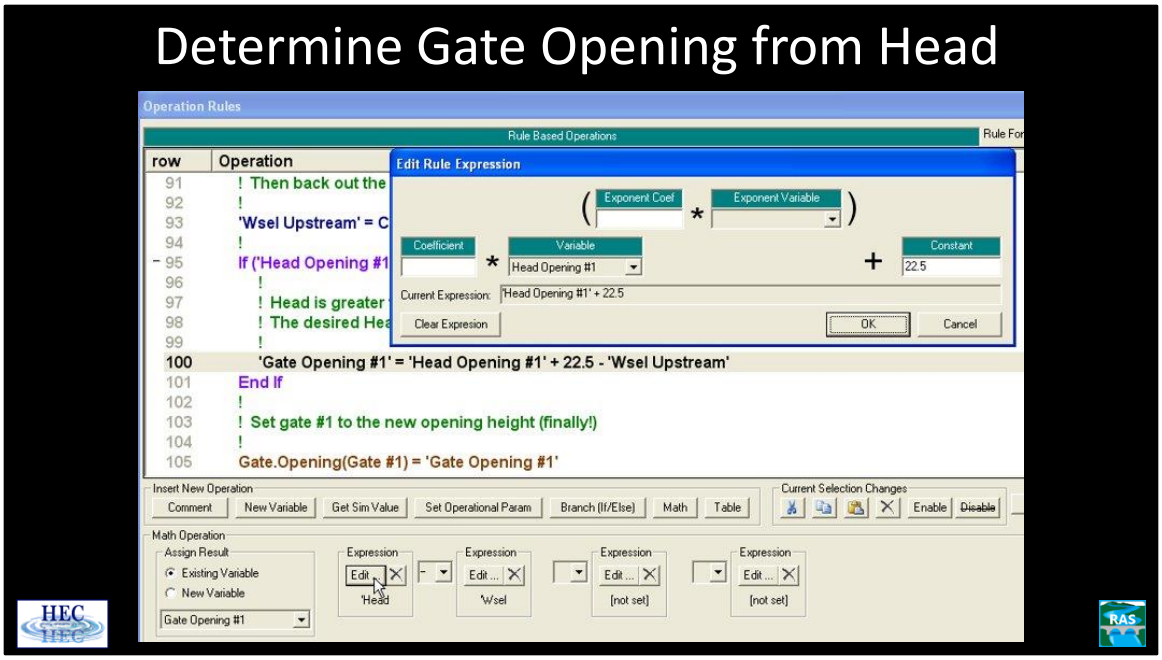
The inline structure has three different gate groups (that are used in normal operations). The gates are overflow (drop) gates.

For each gate group, the water district has a table that shows the amount of head that should be on that gate group for a given flow.

Rule 80 computes the amount of head needed on gate group #1 using the lookup table (shown above). The value that goes into the lookup table (input) is determined by the expression editor. In this case it is the "Canal Dam 20 hour MGD" variable (which the first part of the name can just be seen left of the lookup table). The result

of the lookup (output) is stored in a new variable, “Head Opening #1”.

Determine Gate Opening from Head



The head on the drop gate is the upstream water surface minus the gate opening height minus the invert elevation of the gate. Rearranging, gives the gate opening to be equal to the head plus the invert minus the upstream water surface as computed in rule 100.

Rule 100 computes the desired gate opening.

Rule 105 actually sets the gate opening to the value that was computed by rule 100.

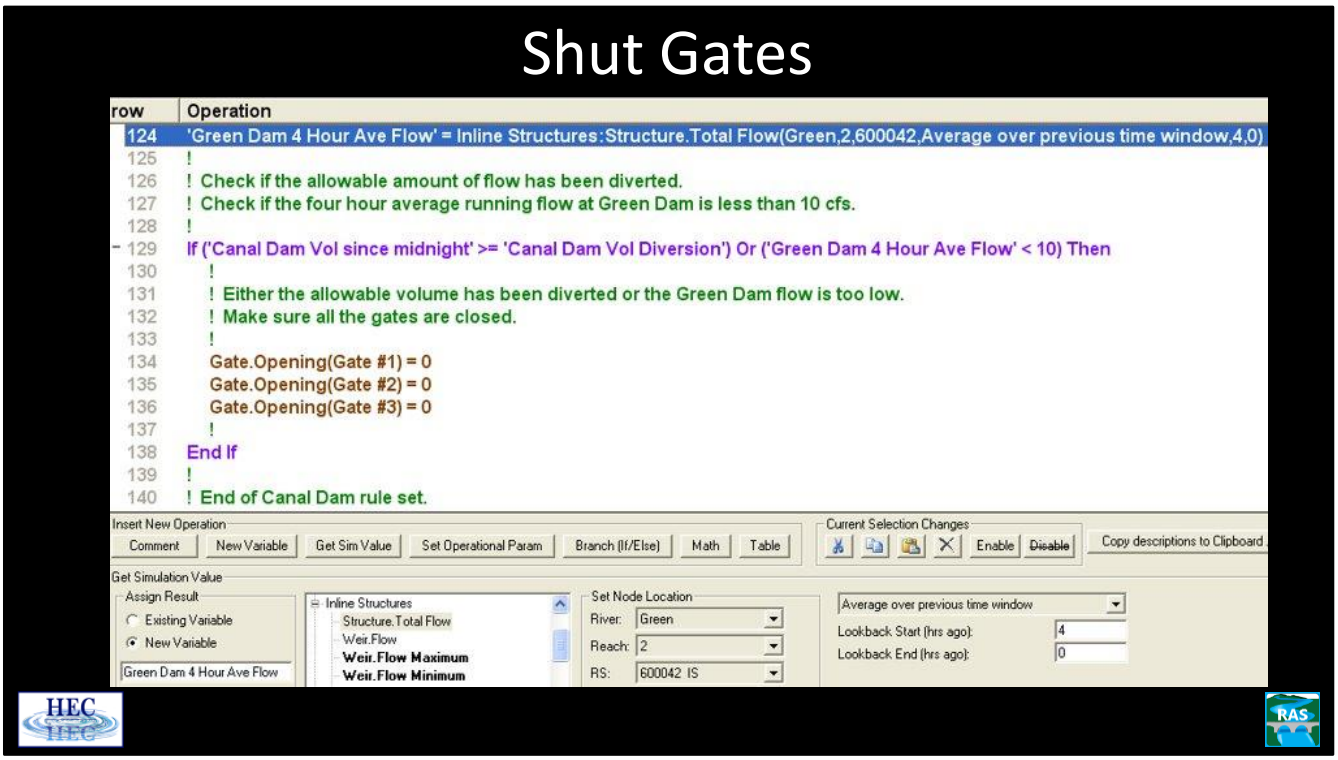
The computation for the gate opening involves two different variables (Head and WSEL), which meant that two different “Expressions” had to be used. The Set Gate Opening command can only use a single Expression. So

a Math operation was used (which can have up to 4 different variables/expression) in rule 100 to compute the value that was used by rule 105.

Set Gate Opening

```
93      'Wsel Upstream' = Cross Sections:WS Elevation(Diversion Canal,1,73.75,Value at current time step)
94      !
95      If ('Head Opening #1' > 0) Then
96         !
97         ! Head is greater than zero.  Determined gate opening for this gate.
98         ! The desired Head plus 22.5 minus the upstream water surface will give the drop gate opening.
99         !
100        'Gate Opening #1' = 'Head Opening #1' + 22.5 - 'Wsel Upstream'
101     End If
102     !
103     ! Set gate #1 to the new opening height (finally!)
104     !
105     Gate.Opening(Gate #1) = 'Gate Opening #1'
106     !
107     ! Repeat for gate #2 and #3.
108     !
109     If ('Head Opening #2' > 0) Then
110        'Gate Opening #2' = 'Head Opening #2' + 22.5 - 'Wsel Upstream'
111     End If
112     Gate.Opening(Gate #2) = 'Gate Opening #2'
113     !
114     If ('Head Opening #3' > 0) Then
115        'Gate Opening #3' = 'Head Opening #3' + 22.5 - 'Wsel Upstream'
116     End If
117     Gate.Opening(Gate #3) = 'Gate Opening #3'
118     !
119     ! This is the end of the midnight (once-a-day) operations
120     !
121  End If
122  !
123  ! Get the four hour running average flow at Green Dam.
```

Shut Gates



There are two different triggers for shutting the gates:

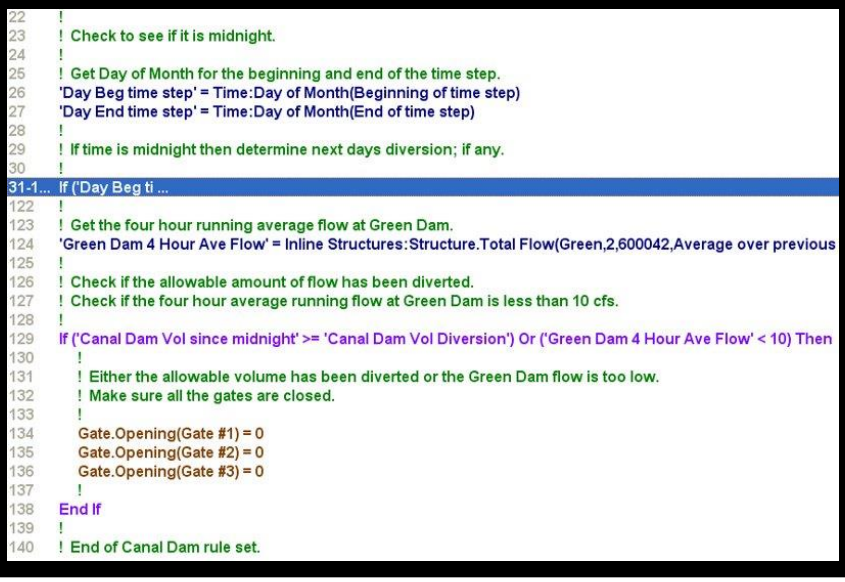
One trigger is the first part of rule 129. It checks to see if the allowable volume of water has been diverted. If it has, then rules 134-136 make sure all the gates are closed.

The other trigger is based on the outflow from Green dam. When the flow at Green dam is below 10 cfs, the water district must stop diverting water. (This only happens at low reservoir levels.) However, it is possible for the reported flow at Green dam to briefly drop below 10 cfs, either because of a switch in gate operations or because of a "missing value" from the remote data operation. To accommodate this, the water district does not have to stop the diversion until the average flow over 4 hours has dropped below 10 cfs.

Rule 124 computes a running, 4 hour average of the flow from Green

dam. Looking at the lower right of the above screen shot, the Lookback period is from 4 hours ago to the current time step (0 hours ago).
The second part of rule 129 checks if this 4 hour average is below 10 cfs. If it is, all of the gates are closed.

Collapsed View



The rules between an If/Then and it corresponding End If can be collapsed and/or expanded. This is done by clicking on the "+/-" to the left of the row number. This option can make viewing complicated data sets easier. (The rules are still active.) All of the rules that are involved in the once daily computations (at midnight) have been collapsed, above.