A Side-By-Side Comparison of RiverWare's and StateMod's Water Right Solvers

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Precision Water Resources Engineering

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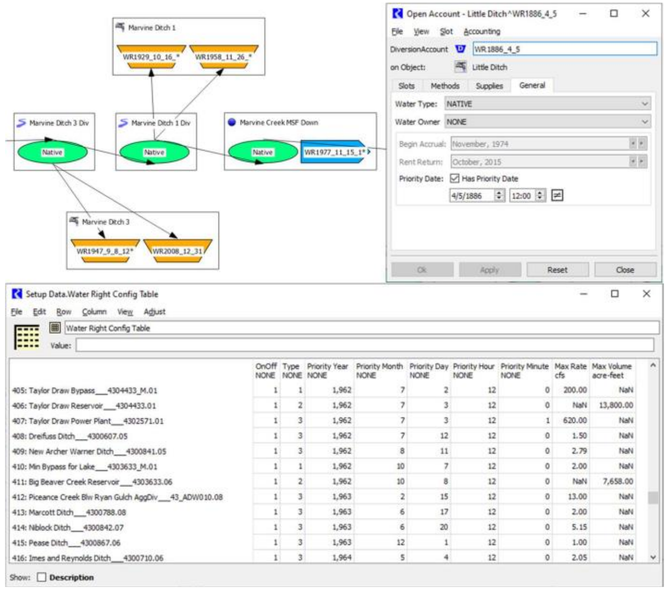

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Study Purpose and Objectives

- Accurately simulating water rights is of utmost importance in water resource system models of Colorado's basins.
- However, the complexity of the water right system presents challenges for many modeling platforms.
- A primary strength of the Colorado Decision Support System's (CDSS) surface water model, StateMod, lies in its ability to simulate the water rights systems
- RiverWare excels in many of the areas where StateMod is limited (transparency, flexibility, user-support, etc.)
- However, RiverWare's ability to simulate water rights remain largely untested in Colorado water rights systems.

- **Primary Objective:** Evaluate RiverWare's ability to simulate components of Colorado's complex water right systems.
- Achieve this by developing a RiverWare model of a Colorado basin's water right system, and by analyzing and comparing its simulation process and results against an existing StateMod model of the same basin.

- Study funded by CWCB Severance Tax Operational Fund Grant (2019-2020)
- Past presentation: 2016 RWUGM – "A Comparison of RiverWare and StateMod as Water Allocation Model Platforms" – Brian Macpherson (now at CWCB) – Great qualitative overview and comparison

StateMod Overview

- Surface water model component of the CWCB's Colorado Decision Support System (CDSS)
- Generalized hydrologic modeling tool that can be applied to any river basin (but mostly Colorado)
- Monthly and/or daily timestep
- Primary strength is simulating water right allocation
- Integration in CDSS allows for relatively efficient model development, data management, and joint utilization with CDSS's other components such as StateCU and HydroBase.
- Trusted by Colorado's water managers due to decades of use and relatively standardized implementation across CO's river basins.
- StateMod models have been developed and implemented in the CDSS framework (or are nearing completion) for all of Colorado's major river basins.
- StateMod has strict data preparation requirements and formats (text file based)
- StateMod relies heavily upon the use of standardized modeling methods and procedures within the platform.
- Despite limited ability for customization outside of standard methods, StateMod's methods have been developed alongside and to be consistent and effective within the CDSS framework and are accepted by Colorado's water resource community.
- Software is free and publicly available (limited support)
- More info: cdss.colorado.gov/software/statemod
- StateMod models are generally used for planning-type modeling. Not aware of any "operational" or "administration" uses of StateMod models.

RiverWare Overview

- State-of-the-art and widely used generalized water resource system modeling platform
- Funded largely by Bureau of Reclamation, Army Corps of Engineers, and Tennessee Valley Authority
- Developed and actively maintained and supported by CADSWES at University of Colorado, Boulder
- RiverWare models are utilized by water professionals in many river basins across the United States and the world. Models range in size from large-scale federal projects to local municipal systems.
- Uses range from near-future hourly timestep hydropower optimization to short-term operational forecasting and scheduling to long-term planning, policy development, and water supply evaluations.
- Very active and involved user group and developers
- Use of software requires paid license
- More info: riverware.org

- Core features include:
  - User-friendly workspace GUI to represent the physical layout of a basin's water resource system by linking objects in an intuitive visual network.
  - Extensive library of built-in methods used to simulate many processes on objects throughout the network.
  - User-constructed and customizable rulesets to simulate river basin policy, basin operations and decision-making processes.
  - Water accounting infrastructure to perform complex water accounting.
- Strengths include flexibility, transparency, and ability to model complex reservoir operations and accounting.
- Highly transparent - Results can be traced to the specific and step-by-step calculations used to simulate the decisions and processes that drive system operations.

White River Basin StateMod Model Overview

The White River basin in NW Colorado was selected as an effective basis for comparison for this study for several key reasons:

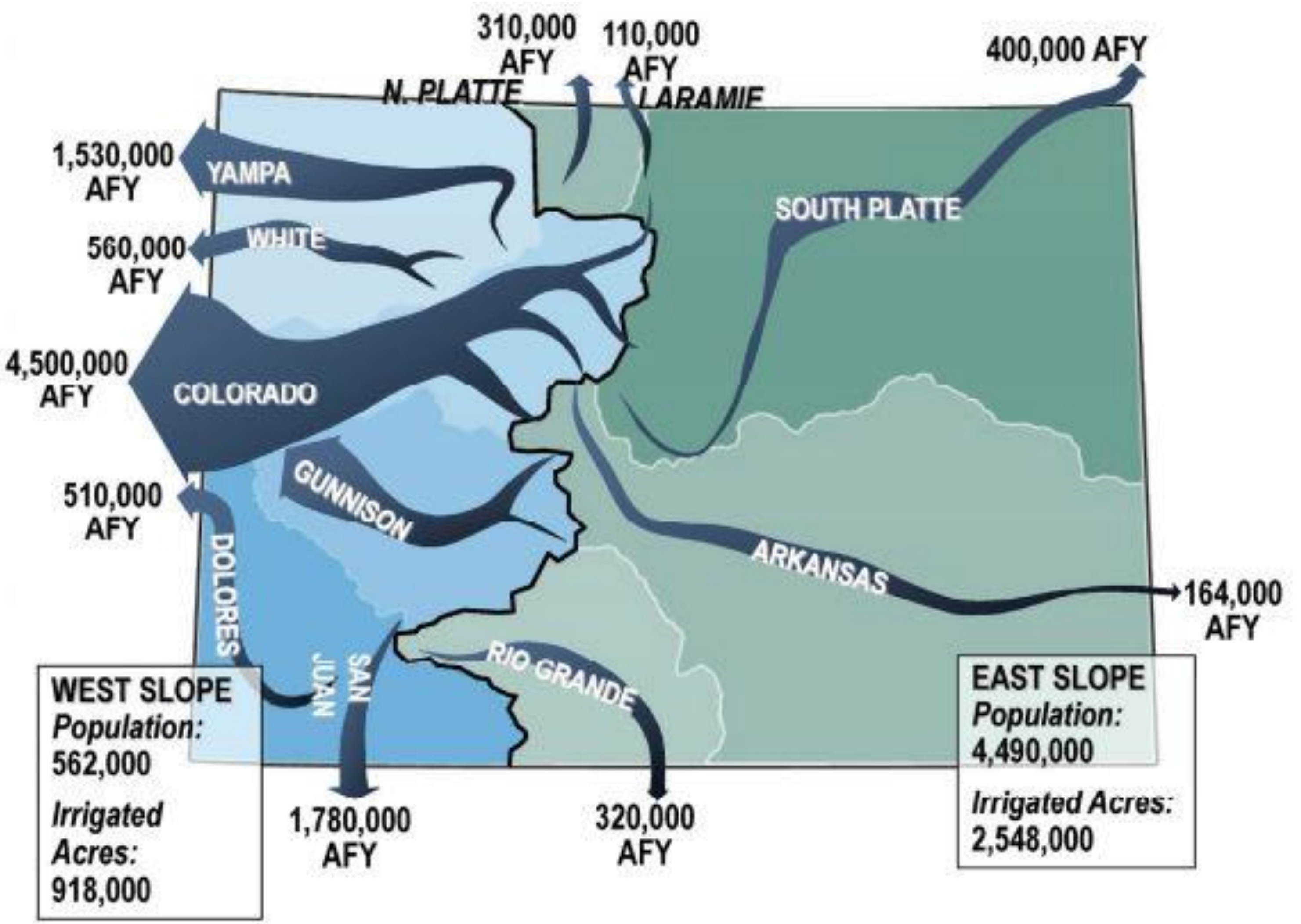
1. The White Basin StateMod model is complete and straightforward.
2. The White Basin does not contain as complex operations and accounting found in other basins, which would make it more difficult to isolate and compare how water right allocation and related operations are simulated.
3. It is trusted and has been used successfully by basin stakeholders.

Source: Wikipedia

- CWCB & Wilson Water Group (WWG) provided a version of the existing White Basin StateMod model
  - Several modifications from base model were made to facilitate comparison of specific types of water rights and operations
- Monthly timestep, 10/1974 – 9/2015, 41 WY
- 203 total StateMod nodes
  - 3 reservoirs (1 is offstream/future) + minor agg's
  - 146 demands/water users
- Water Rights
  - Direct flow rights x 504
  - Storage rights x 14
  - Instream flow rights x 16

White Basin Facts

- Basin size (in CO) ~3,750 mi^2
- Avg annual flow at border ~560,000 af
- Avg annual divs & depls ~300,000 af, ~50,000 af
- Largest Existing Reservoir is Taylor Draw, ~13,800 af
- Population ~6,500
- Primarily Ag water uses, ~26,000 acres (90% grass, 10% alfalfa)
- Perhaps the only major CO basin without exports/imports

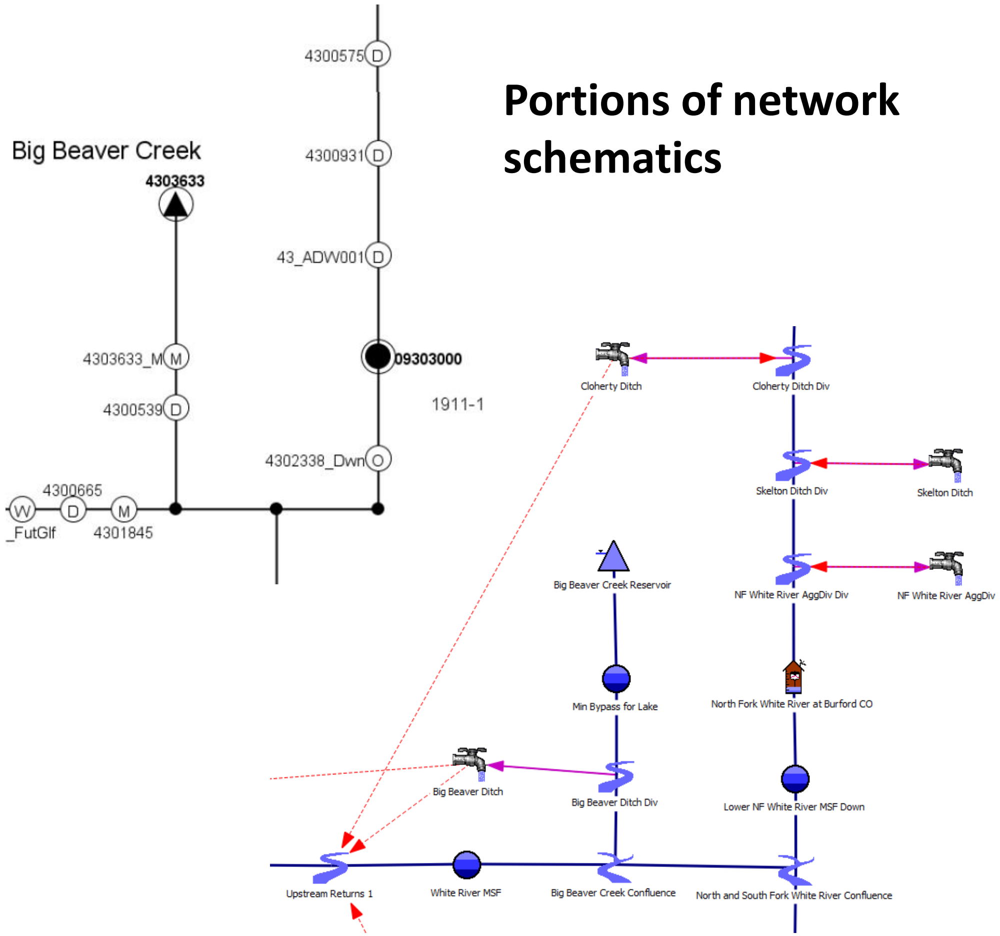


Colorado population, irrigated acres & flows. CWCB (2011)

White River Basin RiverWare Model Development

- Main Model Objectives:
  - Be able to compare simulation processes apples-to-apples
  - Be able to isolate specific types of water rights and associated operations for comparison of results
- Monthly Timestep to match StateMod
- StateMod's network was translated to RiverWare
- Attempted to develop the RiverWare model to use the same simulation process, data, and methods used by StateMod as much as possible
  - E.g., reservoir methods had to be dumbed down
- Important Note: Due to these reasons, the way the model was developed and end model itself is quite different than if developed as a "traditional" RiverWare model (whatever that is)
- Credit where it's due, StateMod's uniformity and ability/need to standardize models across varying basins is a big strength (for its intended uses at least)

Portions of network schematics



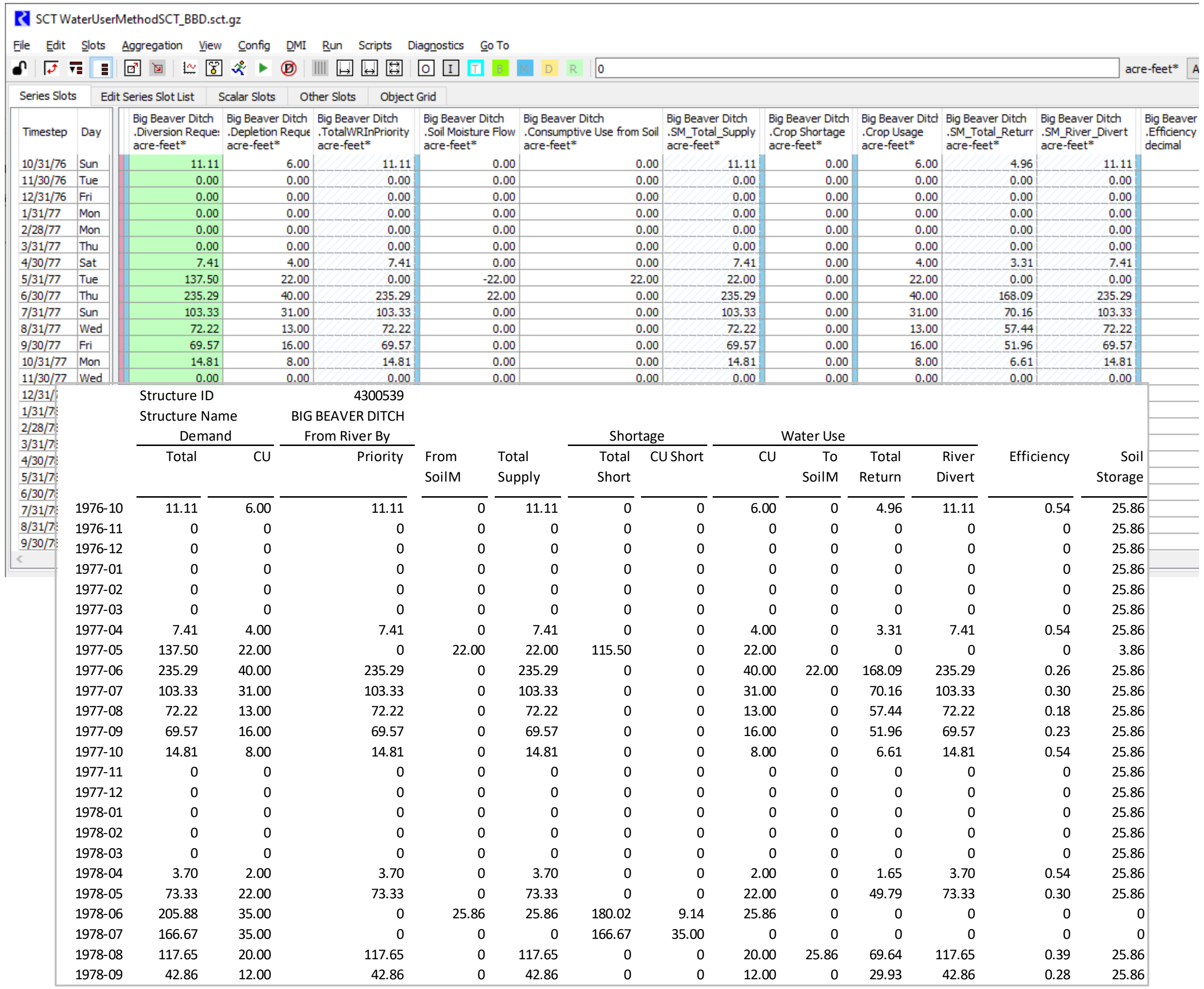
Model Network - StateMod Nodes vs RiverWare Objects

StateMod Node Type	RiverWare Object(s)	RiverWare Representation Description
Diversion	Reach object with a linked Water User object	These Reach objects do not have Local Inflows (“gains”), and thus the object methods use "No Local Inflow, Solve Outflow" and "Available Flow Based Diversion". Water User object methods differ depending on the type of use. The Water User’s “Incoming Available Water”, “Diversion”, and “Return Flow” slots are linked to the appropriate reaches (note that the specific RF slot linked varies by RF splitting/routing method).
Diversion/Natural Flow	Reach object with a linked Water User object	These Reach objects have Local Inflows (“gains”), and thus the object methods use "Specify Local Inflow, Solve Outflow", which allows them to be set by Initialization Rule (IR), and "Available Flow Based Diversion". Water User object methods differ depending on type of use.
Well	Water User object	Water User objects do not have a built-in method to lag the surface water depletions associated with well pumping, and thus the Water User object’s diversion slots were not directly linked to a reach but instead set directly to the appropriate nodes via a rule. The return flow slots are linked in the same manner as a surface water user.
Instream (Minimum Flow)	Control Point object	Control Point objects must be used in RiverWare here to allow for Instream Flow water rights accounts.
Instream / Natural Flow	Control Point object	Control Point objects must be used in RiverWare here to allow for Instream Flow water rights accounts. These are generally upstream ends of reach sections that include “Boundary Inflows” set by IR at the start of run.
Other	Reach/Stream Gage object as appropriate	The reach object methods include "No Routing" and "No Local Inflow, Solve Outflow". “Other” nodes are generally used to define downstream ends of instream flow reaches in StateMod.
Plan	Data object or slots on associated network objects	This type of node is modeled in RiverWare using rules that set slot values to Data objects or custom slots on the associated network objects.
Reservoir	Reservoir object	The Reservoir Object methods include "Input Evaporation” which allows evaporation to be calculated and set by rule using the same calculation as StateMod.
Reservoir / Natural Flow	Reservoir object	If the reservoir is the upstream end of a river section, “Boundary Inflows” are set by Initialization Rules. If the reservoir is within a river reach, the "Input Hydrologic Inflow" method is used so the “Local Inflows” can be set by IR.
Streamflow Gage	Stream Gage object	No methods needed.
Streamflow Gage / Natural Flow	Stream Gage object	These have “Boundary Inflows” that are set by IR.
n/a	Confluence object	RiverWare can use a Confluence objects to represent the confluence of two rivers/streams. StateMod does not use a distinct node type for this purpose. Rather, two upstream nodes will be defined to have the same downstream node, and this will combine the upstream flows.

Water User Methods

- Key Feature of StateMod, "Variable Efficiency and Soil Moisture Accounting" was able to be replicated in RW (with nearly identical results)
- RW has equivalent Return Flow split and lag methods

	Irrigation Nodes	Non-Irrigation Nodes
Method Category	RiverWare Method Name	
Diversion and Depletion Request	Irrigation Requests with Soil Moisture	Input Requests
Irrigation Acreage and Evapotranspiration Rates	Input Acreage and Rates	N/A
Return Flow	Variable Efficiency with Soil Moisture	Variable Efficiency
Return Flow Split	Nodes with multiple return flow locations (21 total) use the "Multi Return Fractional Split" Method, otherwise no method was used.	
Return Flow Routing	Nodes with multiple return flow locations (21 total) use the "Multi Split Impulse Response" method. All other nodes use the "Impulse Response" method.	



SCT WaterUserMethodSCT_BBD.sct.gz

Timestep	Day	Big Beaver Ditch .Diversion Reque: acre-feet*	Big Beaver Ditch .Depletion Reque acre-feet*	Big Beaver Ditch .TotalWRInPriority acre-feet*	Big Beaver Ditch .Soil Moisture Flow acre-feet*	Big Beaver Ditch .Consumptive Use from Soil acre-feet*	Big Beaver Ditch .SM_Total_Supply acre-feet*	Big Beaver Ditch .Crop Shortage acre-feet*	Big Beaver Ditcl .Crop Usage acre-feet*	Big Beaver Ditch .SM_Total_Returr acre-feet*	Big Beaver Ditch .SM_River_Divert acre-feet*	Big Beaver .Efficiency decimal
10/31/76	Sun	11.11	6.00	11.11	0.00	0.00	11.11	0.00	6.00	4.96	11.11	
11/30/76	Tue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
12/31/76	Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
1/31/77	Mon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2/28/77	Mon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
3/31/77	Thu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
4/30/77	Sat	7.41	4.00	7.41	0.00	0.00	7.41	0.00	4.00	3.31	7.41	
5/31/77	Tue	137.50	22.00	0.00	-22.00	22.00	22.00	0.00	22.00	0.00	0.00	
6/30/77	Thu	235.29	40.00	235.29	22.00	0.00	235.29	0.00	40.00	168.09	235.29	
7/31/77	Sun	103.33	31.00	103.33	0.00	0.00	103.33	0.00	31.00	70.16	103.33	
8/31/77	Wed	72.22	13.00	72.22	0.00	0.00	72.22	0.00	13.00	57.44	72.22	
9/30/77	Fri	69.57	16.00	69.57	0.00	0.00	69.57	0.00	16.00	51.96	69.57	
10/31/77	Mon	14.81	8.00	14.81	0.00	0.00	14.81	0.00	8.00	6.61	14.81	
11/30/77	Wed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

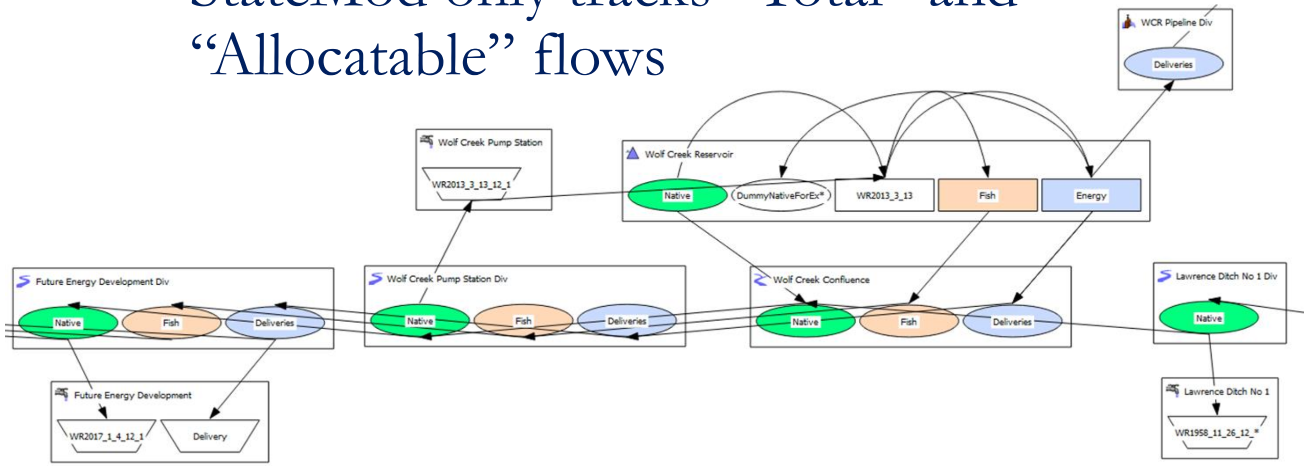
Structure ID 4300539
Structure Name BIG BEAVER DITCH

	Demand Total	Demand CU	From River By Priority	From SoilM	Total Supply	Shortage Total Short	Shortage CU Short	Water Use CU	Water Use To SoilM	Water Use Total Return	Water Use River Divert	Efficiency	Soil Storage
1976-10	11.11	6.00	11.11	0	11.11	0	0	6.00	0	4.96	11.11	0.54	25.86
1976-11	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1976-12	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1977-01	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1977-02	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1977-03	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1977-04	7.41	4.00	7.41	0	7.41	0	0	4.00	0	3.31	7.41	0.54	25.86
1977-05	137.50	22.00	0	22.00	22.00	115.50	0	22.00	0	0	0	0	3.86
1977-06	235.29	40.00	235.29	0	235.29	0	0	40.00	22.00	168.09	235.29	0.26	25.86
1977-07	103.33	31.00	103.33	0	103.33	0	0	31.00	0	70.16	103.33	0.30	25.86
1977-08	72.22	13.00	72.22	0	72.22	0	0	13.00	0	57.44	72.22	0.18	25.86
1977-09	69.57	16.00	69.57	0	69.57	0	0	16.00	0	51.96	69.57	0.23	25.86
1977-10	14.81	8.00	14.81	0	14.81	0	0	8.00	0	6.61	14.81	0.54	25.86
1977-11	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1977-12	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1978-01	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1978-02	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1978-03	0	0	0	0	0	0	0	0	0	0	0	0	25.86
1978-04	3.70	2.00	3.70	0	3.70	0	0	2.00	0	1.65	3.70	0.54	25.86
1978-05	73.33	22.00	73.33	0	73.33	0	0	22.00	0	49.79	73.33	0.30	25.86
1978-06	205.88	35.00	0	25.86	25.86	180.02	9.14	25.86	0	0	0	0	0
1978-07	166.67	35.00	0	0	0	166.67	35.00	0	0	0	0	0	0
1978-08	117.65	20.00	117.65	0	117.65	0	0	20.00	25.86	69.64	117.65	0.39	25.86
1978-09	42.86	12.00	42.86	0	42.86	0	0	12.00	0	29.93	42.86	0.28	25.86

RiverWare Accounting

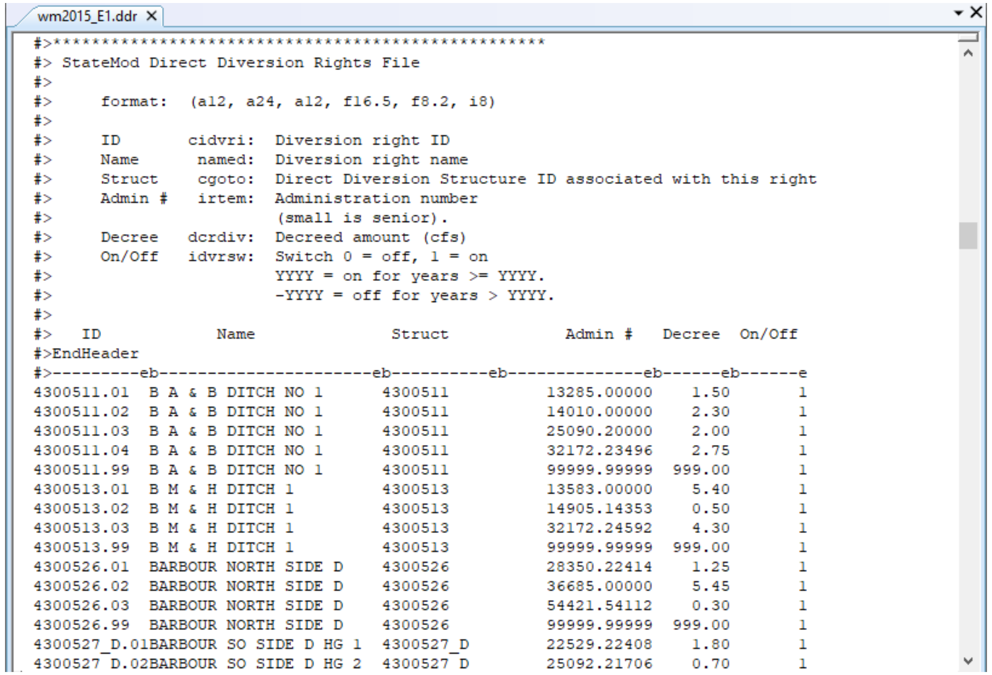
- For RW to simulate accounting and water right allocation, need to add the accounting network/layer to physical network
  - StateMod models innately have and utilize water rights
- Types of RW Accounts
  - Passthrough accounts, e.g., “Native”
  - Storage accounts (can have WRs)
  - Diversion accounts (can have WRs)
  - Instream Flow accounts (can have WRs)

- Flow Accounting Chains
  - “Allocatable” flow (e.g., “Native”) vs. “Non-allocatable” flow (other water types, e.g., “Project”, “imported”, etc.)
  - RW’s accounting allows multiple, explicitly represented flow chains
  - StateMod only tracks “Total” and “Allocatable” flows



Model Configuration of Water Rights

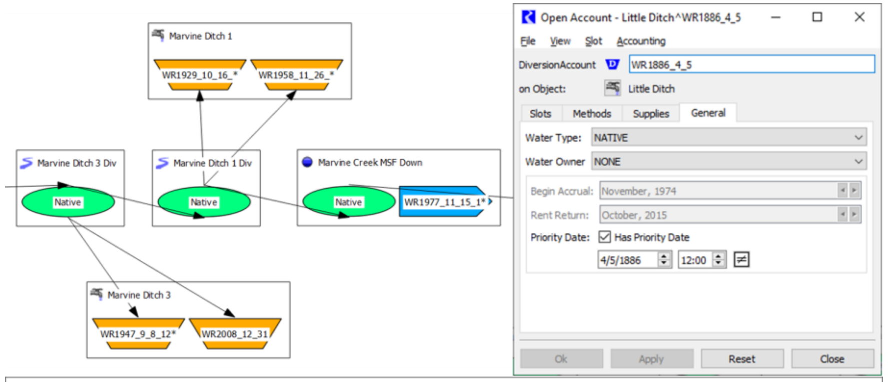
- StateMod:
  - Defined in text files (.ddr, .rer, .ifr)
  - Not very user-friendly, but allows for efficient model development and configuration



wm2015_E1.ddr

```
#>*****************************************************
#> StateMod Direct Diversion Rights File
#>
#>    format:  (a12, a24, a12, f16.5, f8.2, i8)
#>
#>    ID        cidvri:  Diversion right ID
#>    Name       named:  Diversion right name
#>    Struct     cgoto:  Direct Diversion Structure ID associated with this right
#>    Admin #    irtem:  Administration number
#>                        (small is senior).
#>    Decree    dcrdiv:  Decreed amount (cfs)
#>    On/Off    idvrsw:  Switch 0 = off, 1 = on
#>                        YYYY = on for years >= YYYY.
#>                        -YYYY = off for years > YYYY.
#>
#>   ID            Name              Struct           Admin #    Decree  On/Off
#>EndHeader
#>---------eb----------------------eb----------eb--------------eb------eb------e
4300511.01  B A & B DITCH NO 1      4300511         13285.00000    1.50       1
4300511.02  B A & B DITCH NO 1      4300511         14010.00000    2.30       1
4300511.03  B A & B DITCH NO 1      4300511         25090.20000    2.00       1
4300511.04  B A & B DITCH NO 1      4300511         32172.23496    2.75       1
4300511.99  B A & B DITCH NO 1      4300511         99999.99999  999.00       1
4300513.01  B M & H DITCH 1         4300513         13583.00000    5.40       1
4300513.02  B M & H DITCH 1         4300513         14905.14353    0.50       1
4300513.03  B M & H DITCH 1         4300513         32172.24592    4.30       1
4300513.99  B M & H DITCH 1         4300513         99999.99999  999.00       1
4300526.01  BARBOUR NORTH SIDE D    4300526         28350.22414    1.25       1
4300526.02  BARBOUR NORTH SIDE D    4300526         36685.00000    5.45       1
4300526.03  BARBOUR NORTH SIDE D    4300526         54421.54112    0.30       1
4300526.99  BARBOUR NORTH SIDE D    4300526         99999.99999  999.00       1
4300527_D.01BARBOUR SO SIDE D HG 1  4300527_D       22529.22408    1.80       1
4300527_D.02BARBOUR SO SIDE D HG 2  4300527_D       25092.21706    0.70       1
```

- RiverWare:
  - Defined on accounts on objects (1 WR per acct)
  - Limited ability to automate configuration



Setup Data.Water Right Config Table

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Water Right Config Table

Value:

	OnOff NONE	Type NONE	Priority Year NONE	Priority Month NONE	Priority Day NONE	Priority Hour NONE	Priority Minute NONE	Max Rate cfs	Max Volume acre-feet
405: Taylor Draw Bypass___4304433_M.01	1	1	1,962	7	2	12	0	200.00	NaN
406: Taylor Draw Reservoir___4304433.01	1	2	1,962	7	3	12	0	NaN	13,800.00
407: Taylor Draw Power Plant___4302571.01	1	3	1,962	7	3	12	1	620.00	NaN
408: Dreifuss Ditch___4300607.05	1	3	1,962	7	12	12	0	1.50	NaN
409: New Archer Warner Ditch___4300841.05	1	3	1,962	8	11	12	0	2.79	NaN
410: Min Bypass for Lake___4303633_M.01	1	1	1,962	10	7	12	0	2.00	NaN
411: Big Beaver Creek Reservoir___4303633.06	1	2	1,962	10	8	12	0	NaN	7,658.00
412: Piceance Creek Blw Ryan Gulch AggDiv___43_ADW010.08	1	3	1,963	2	15	12	0	13.00	NaN
413: Marcott Ditch___4300788.08	1	3	1,963	6	17	12	0	2.00	NaN
414: Niblock Ditch___4300842.07	1	3	1,963	6	20	12	0	5.15	NaN
415: Pease Ditch___4300867.06	1	3	1,963	12	1	12	0	1.00	NaN
416: Imes and Reynolds Ditch___4300710.06	1	3	1,964	5	4	12	0	2.05	NaN

Show: Description

Water Right Solver Algorithms

StateMod's "Modified Direct Solution Algorithm" or MDSA:
(summarized, see StateMod documentation for more)

1. Water availability is determined at each river node to include both native inflows and return flows accruing from a prior time step.
2. The most senior direct, instream, storage, well or operational water right is identified.
3. Diversions are estimated to be the minimum of the decreed water right, structure capacity, demand, and available flow in the river.
4. Downstream flows are adjusted to reflect the senior diversion and its return flows.
5. Return flows for future time periods are determined and stored.
6. Well depletions for future time periods are determined and stored.
7. The process is repeated by priority for each successive direct, instream, storage, well and operational water right.
8. If new water is introduced to the system from a reservoir's operation or return flows accrue to a non-downstream node, the model reoperates the current time step and the process is repeated beginning with the most senior direct, instream, storage or operational right.
9. The process is repeated for each month or day of the study period.

RiverWare's algorithm exists as function "SolveWaterRights", called by a rule at some point in the ruleset. SolveWaterRights works like this:

1. Determine local timestep of the accounts representing the rights. (Only when simulating networks with lags)
2. Clone the accounting network. The solver works on this cloned system to solve the problem.
3. Clear values on supplies that represent allocations from the allocatable flow supply chain.

Then, for each water right in priority order:

4. Compute the appropriation request.
5. Compute allocation that meets the request, constrained by not violating senior rights.
6. Create a list of {slot name, value} pairs or a list of {slot name, date-time, value} triplets of allocations that are returned by rule function.

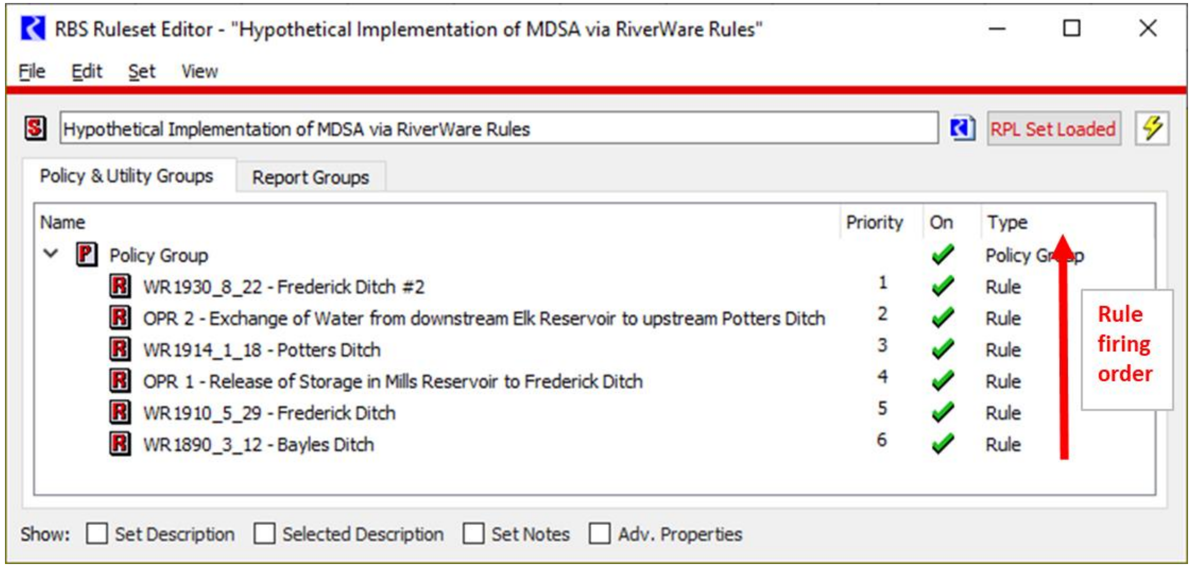
- After WRS function returns, rule makes the assignments to the accting network.
- Then RW moves to next rule in ruleset in Rulebased Simulation manner.
- In this manner, water right simulation can be "layered" on to other processes the model is simulating, or more often, other operations are layered on to the WR solution (e.g., non-allocatable/"project" flow ops).
- The WRS rule can be called multiple times per timestep (and sometimes must be, e.g., for Instream Flow Rights), but it's good practice to limit the # of times

Water Right Solver Algorithms

- On the surface the algorithms may seem quite different, but this is really only due to two things:
  - Each platform handles its object network and allocatable flow chain differently
  - The RW water rights solver is implemented within traditional Rulebased Simulation
- Otherwise, the water right allocation algorithms are actually very similar.
- At a base level, they simply step through the water rights in priority order, allocate the available flow to them, correspondingly update the available allocatable flow through the network, and repeat.

Hypothetical Implementation of StateMod Solution Process in RiverWare Rules

- Fundamentally, StateMod's solution algorithm is like a RW ruleset consisting of 1 rule per WR, firing in senior to junior priority order, where each rule solves and sets its WR's allocation.
- After each rule fired, the associated objects would then solve and the results would propagate through the network.
- Then, changes to the dependencies of the previous rules (e.g., increased allocatable flow available to previously fired, more-senior water rights) would trigger those rules to re-fire.
- If a RiverWare ruleset were created in this manner, then it might make sense to place the various other operating rules (i.e., non-water right rules) within the water right priority system.
- Not feasible to implement this way in RW (>500 rules)
- But this conceptualization may help users who are familiar with either platform understand how the other works.



Strengths and Limitations of RW's Water Right Solver

- Major Strength = Transparency

Future Oil Shale Development^WR1975_1_1

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Future Oil Shale Development^WR1975_1_1

Value: acre-feet Alt Units Sep 1974

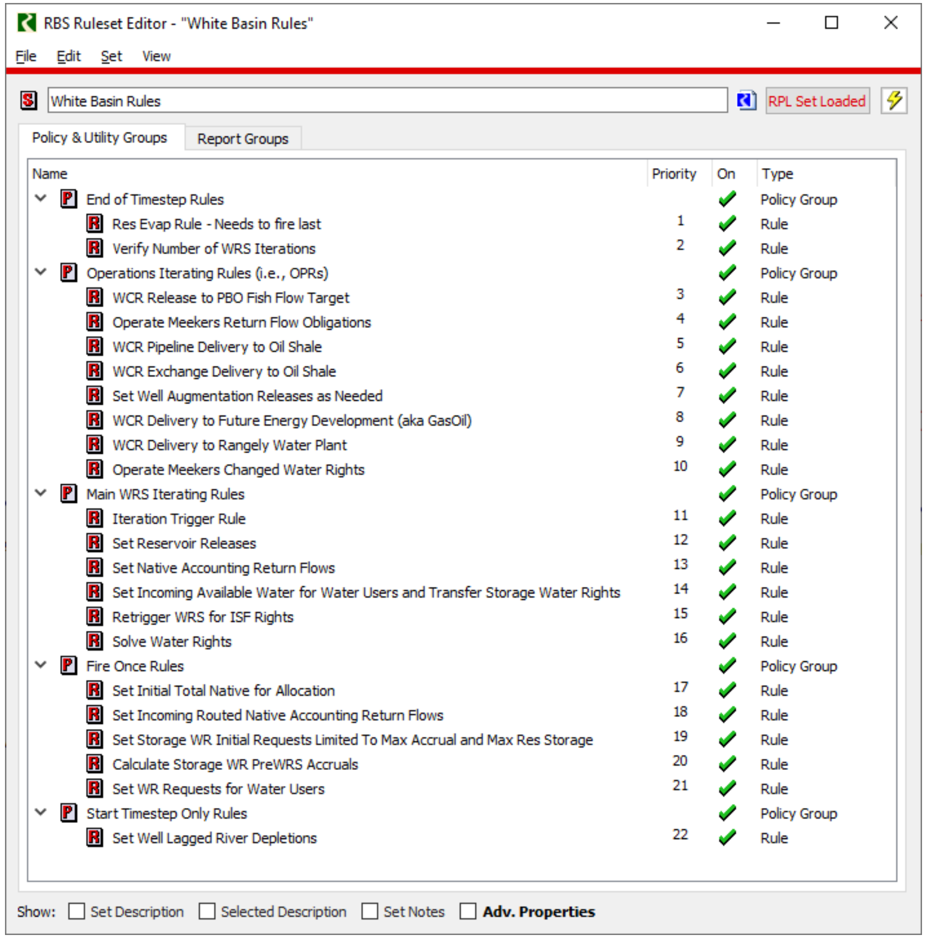
	Diversion Total acre-feet*	Depletion acre-feet*	Accrual acre-feet	Shortage acre-feet*	Appropriation Request acre-feet*	Initial Request acre-feet*	Maximum Request acre-feet*	Temp Reaso NONE
06-1976	833.00 R	833.00 A	6,664.00 A	0.00 A	833.00 R	833.00 R	119,008.26 R	1.00
07-1976	804.80 R	804.80 A	7,468.80 A	28.20 A	833.00 R	833.00 R	122,975.21 R	18,401.00
08-1976	833.00 R	833.00 A	8,301.80 A	0.00 A	833.00 R	833.00 R	122,975.21 R	1.00
09-1976	576.12 R	576.12 A	8,877.92 A	256.88 A	833.00 R	833.00 R	119,008.26 R	17,401.00
10-1976	833.00 R	833.00 A	9,710.92 A	0.00 A	833.00 R	833.00 R	122,975.21 R	1.00
11-1976	833.00 R	833.00 A	833.00 A	0.00 A	833.00 R	833.00 R	119,008.26 R	1.00
12-1976	398.12 R	398.12 A	1,231.12 A	434.88 A	833.00 R	833.00 R	122,975.21 R	401.00
01-1977	799.74 R	799.74 A	2,030.86 A	33.26 A	833.00 R	833.00 R	122,975.21 R	401.00
02-1977	833.00 R	833.00 A	2,863.86 A	0.00 A	833.00 R	833.00 R	111,074.38 R	1.00
03-1977	833.00 R	833.00 A	3,696.86 A	0.00 A	833.00 R	833.00 R	122,975.21 R	1.00
04-1977	833.00 R	833.00 A	4,529.86 A	0.00 A	833.00 R	833.00 R	119,008.26 R	1.00
05-1977	124.44 R	124.44 A	4,654.30 A	708.56 A	833.00 R	833.00 R	122,975.21 R	17,401.00
06-1977	0.00 R	0.00 A	4,654.30 A	833.00 A	833.00 R	833.00 R	119,008.26 R	18,401.00
07-1977	106.30 R	106.30 A	4,760.61 A	726.70 A	833.00 R	833.00 R	122,975.21 R	18,401.00
08-1977	277.72 R	277.72 A	5,038.33 A	555.28 A	833.00 R	833.00 R	122,975.21 R	18,401.00
09-1977	240.47 R	240.47 A	5,278.79 A	592.53 A	833.00 R	833.00 R	119,008.26 R	17,401.00

- Operations and other rules outside of WR priority ordering and are flexible and customizable

- Notable Limitations:
  - Same-timestep return flows
    - RW WRS does not internally account for RFs generated by WR allocations accruing back to system the same timestep.
    - Not an issue in daily timestep models
    - For monthly, workaround is to "iterate" the WRS rule, worked for this study but not very efficient
  - Instream Flow Water Rights
    - RiverWare only allows instream flow rights to be implemented as points
    - StateMod allows instream flow rights to be defined for stretches of river designated by an upstream and a downstream node
    - Further, RW requires multiple WRS calls per timestep, 1 initial + 1 for each ISF right
    - These multiple calls become a significant burden and limit available workarounds

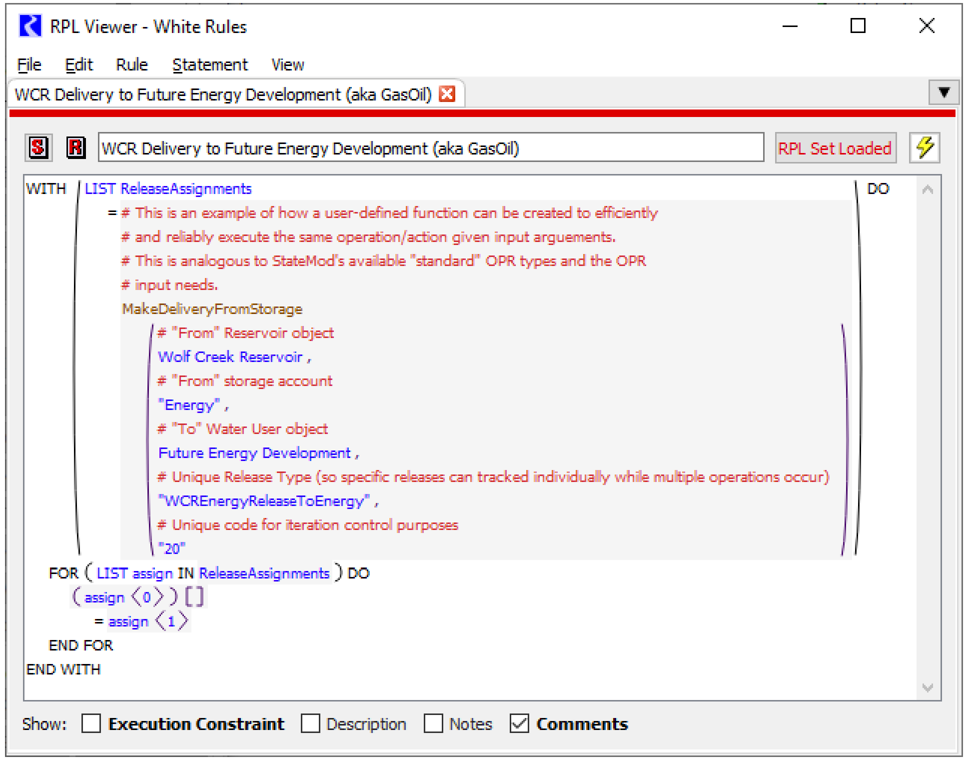
RW Ruleset and Solution Order

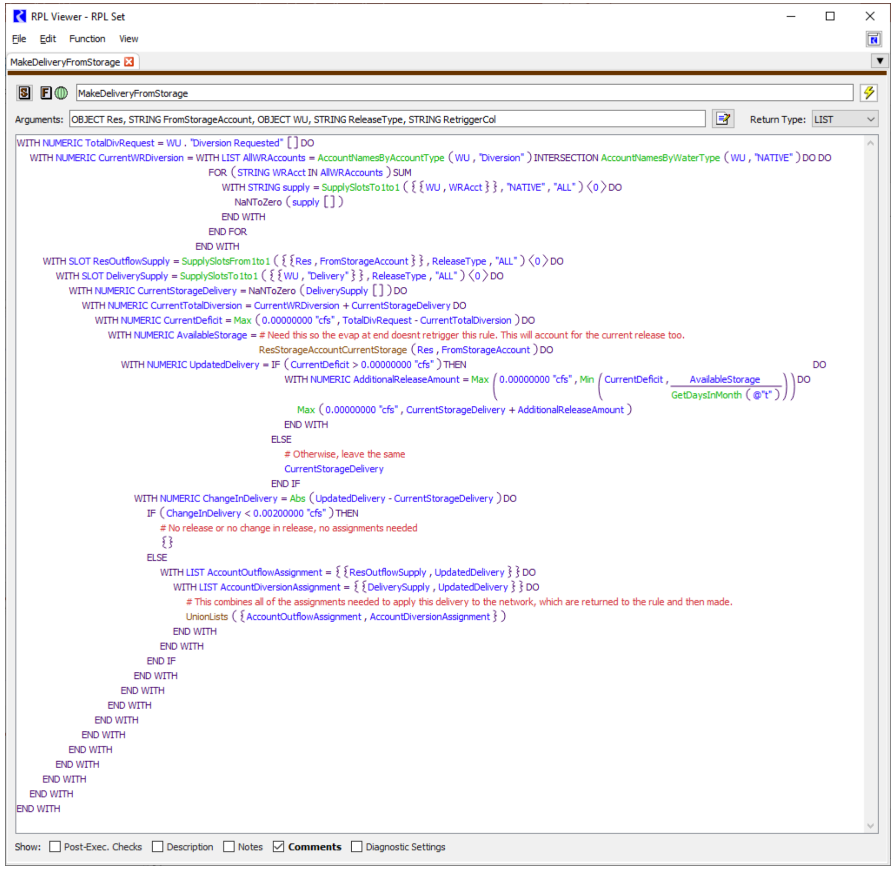
- Remember that this ruleset was developed specifically to mimic the StateMod solution order. Otherwise, it would be quite different.
- Uses execution constraints and rule refiring triggers to control the solution order.
- Policy Groups in Firing Order:
    1. Start Timestep Only Rules
    2. Fire Once Rules
    3. Main WRS Iterating Rules
    4. Operations Iterating Rules
    5. End of Timestep Rules



Generalized RW Rules/Functions

- Example of how StateMod's standard "OPR" types may be implemented in RW models via generalized rules/functions





Water Rights Types and Operations Compared

The RW and StateMod models were configured in separate runs to isolate the specific processes below so that their simulation and results could be compared apples-to-apples.

- Diversion/Direct Flow Water Rights
- Storage Water Rights
- Instream Flow Water Rights
- Well Water Rights and Well Augmentation
- Offstream Reservoir Storage and Various Associated Operations
- Changed Water Rights and Various Associated Operations

Results - Diversion and Storage Water Rights

Run Description:

- Only Diversion and Storage water rights turned on, no other rights/operations
- This was the "Comparison Base" run and these water rights were on in all other runs as well

Comparison Results:

- Simulated allocations to direct flow diversion water rights and storage water rights were **IDENTICAL** to StateMod results
- This is a significant finding and shows that the RiverWare and StateMod water right allocation simulation algorithms found the exact same results for all allocations to all water rights (>500 of them) throughout the whole model network.

Notable limitations:

- Incorporation of same timestep return flows was implemented by iterating the RW WRS rule as a workaround
  - Enhancements to RW could potentially eliminate the need for this workaround
  - But again, not going to be an issue for daily timestep models

Results - Instream Flow Water Rights

Run Description:

- Instream Flow Rights turned on
- Represented as points in both RW and StateMod models

Comparison Results:

- Although limited in applicability, the RW model and WRS did produce the exact same results as the modified StateMod model.
- Overall, the fact that RiverWare is not currently able to simulate instream flow water rights as reaches is a considerable limitation relative to StateMod.

Notable limitations/differences:

- RiverWare only allows instream flow rights to be implemented as points.
- StateMod allows instream flow rights to be defined for stretches of river by an upstream and a downstream node.
- RW's need for multiple calls of WRS is cumbersome and inefficient (but is necessary to account for non-WR ops).

Results - Well Water Rights and Augmentation

Run Description:

- Water user representing well pumping surface water depletion and well water right with "augmentation plan" operation.
- "You can't stop the wells", which means that they are simulated as pumping and depleting the river before their in-priority status is determined (since their surface water depletions are lagged)
- The Augmentation Plan releases water from a storage source when depletions are found to be out-of-priority.

Comparison Results:

- Nearly identical results, only minor differences in two months were due to a StateMod nuance to handle negative available flow (RW handles better)

Notable limitations/differences:

- RW doesn't have a built-in method for representing lagged river depletions due to well pumping
  - WU method could potentially be added
- However, by using an "unlinked" water user object and a couple rules the StateMod representation was replicated in RW
- Determination of whether "unlinked" well water right was in-priority also required a custom rule.

Results - Offstream Reservoir Storage and Operations

Run Description:

- 4 runs to isolate five individual operations:
  1. Pump to offstream reservoir when WRs are in-priority.
  2. River release/delivery to downstream demand when it's out-of-priority
  3. Pipeline delivery to upstream demand when it's out-of-priority.
  4. River release for "delivery exchange" to upstream demand when it's out-of-priority.
  5. River release to downstream Fish Flow Target when its ISF is out-of-priority and target is not otherwise met.

Comparison Results:

- Full model results matched exactly between RW and StateMod across the different configurations.
- Notable that results were identical even considering that StateMod simulates these operations within the water right priority system, while the RW rules are executed outside of the water rights solver.
- To replicate the StateMod operations, the 5 individual operational rules simply had to be ordered to fire in the same relative order as in StateMod.

Notable limitations/differences:

- In StateMod, five "standard"/"built-in" operational rights (OPRs) types are used to simulate these operations.
- Implemented in RW via rules with custom but generalized functions.
- RW WRS did need to be re-fired after each operational rule to incorporate it's impacts into the WR solution.

Results – Changed Water Rights

Run Description:

- Two model configurations (1-4 below, then +5) and runs were made to simulate the following changed water rights operations :
  1. A diversion water user with 7 DF WRs was modified to represent split ownership
     - Continue to supply Ag WU with its 95% portion of WR Yield
     - 5% share now owned by M&I water user with different delivery location
  2. Deliver M&I portion of yield as needed to its remaining demand not met by its other DF WRs.
  3. Calculate and track reusable return flows generated from the changed WR portion of the delivery.
  4. Calculate and track return flow requirements due to the changed use of the WR yield based on historical CU factors.
     - Meet RF requirements by (1) they are in-priority, and (2) reusable return flows.
  5. (Additionally) Attempt to exchange any excess yield from the M&I portion to an upstream reservoir.
     - (3) Release from that storage can now be used to meet RF requirements.

Comparison Results:

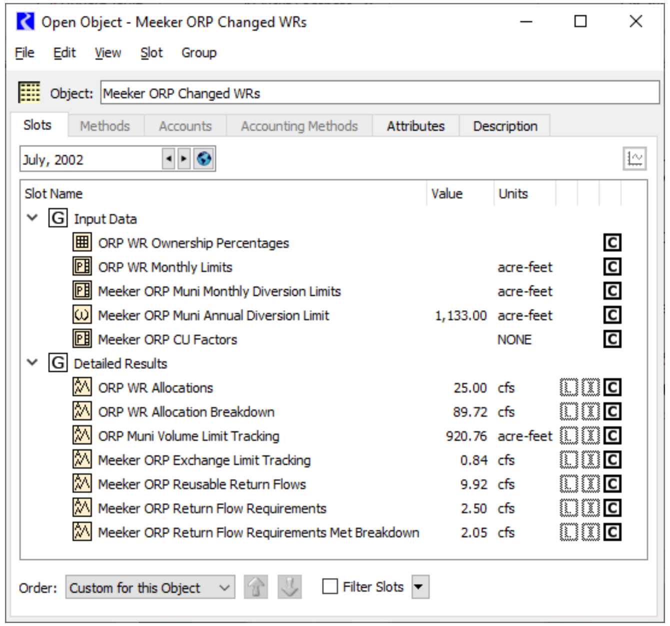
- Nearly identical results between RW and StateMod for first configuration.
- Very similar results for second config, (differences are negligible as far as impact on overall results)
- The minor differences were traced again to StateMod nuances that the RW implementation handles better:
  - StateMod "plan" operations will temporarily remove allocatable flow from system between its associated yield and use. Unused plan water does get "spilled" back to the system later in the timestep, but its temporary removal can cause different results for OPRs that do subsequently get re-evaluated.

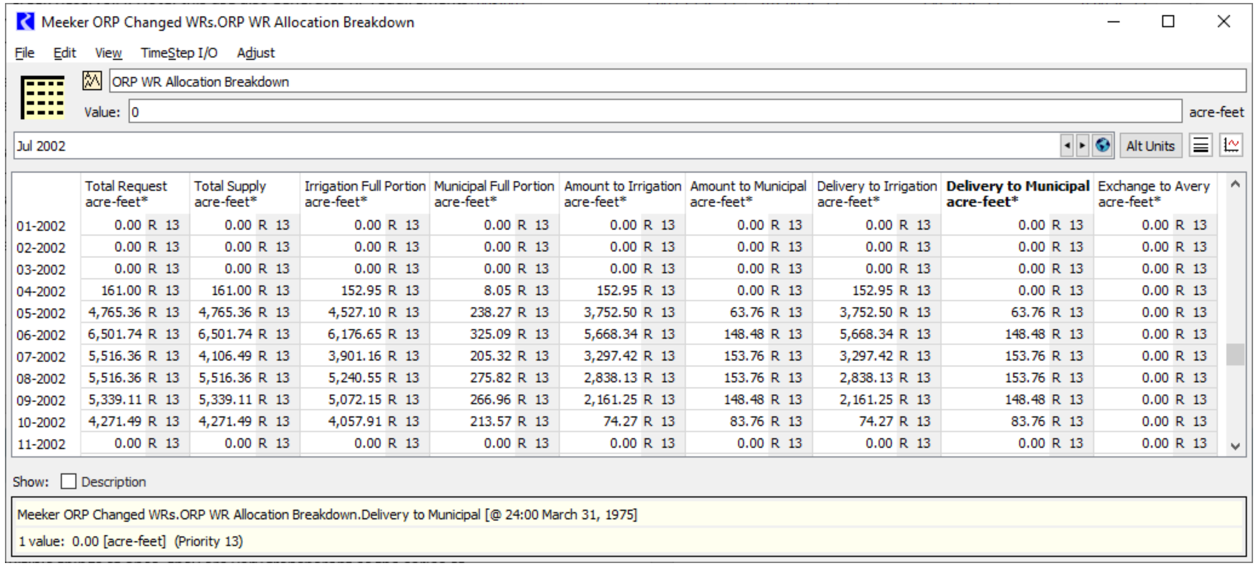
Notable limitations/differences:

- In StateMod, 20 different operational rights of 10 different OPR types are used to simulate these operations.
- In RiverWare, these operations were implemented in 2 rules. They are relatively advanced and do multiple things at once, but they are transparent and easy to follow. Assignments are also made to tracking slots to report process sub-results and calculations.

Results – Changed Water Rights

- Data object and example breakdown tracking slot used in RW simulation of changed WR operations.





	Total Request acre-feet*	Total Supply acre-feet*	Irrigation Full Portion acre-feet*	Municipal Full Portion acre-feet*	Amount to Irrigation acre-feet*	Amount to Municipal acre-feet*	Delivery to Irrigation acre-feet*	**Delivery to Municipal acre-feet***	Exchange to Avery acre-feet*
01-2002	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13
02-2002	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13
03-2002	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13
04-2002	161.00 R 13	161.00 R 13	152.95 R 13	8.05 R 13	152.95 R 13	0.00 R 13	152.95 R 13	0.00 R 13	0.00 R 13
05-2002	4,765.36 R 13	4,765.36 R 13	4,527.10 R 13	238.27 R 13	3,752.50 R 13	63.76 R 13	3,752.50 R 13	63.76 R 13	0.00 R 13
06-2002	6,501.74 R 13	6,501.74 R 13	6,176.65 R 13	325.09 R 13	5,668.34 R 13	148.48 R 13	5,668.34 R 13	148.48 R 13	0.00 R 13
07-2002	5,516.36 R 13	4,106.49 R 13	3,901.16 R 13	205.32 R 13	3,297.42 R 13	153.76 R 13	3,297.42 R 13	153.76 R 13	0.00 R 13
08-2002	5,516.36 R 13	5,516.36 R 13	5,240.55 R 13	275.82 R 13	2,838.13 R 13	153.76 R 13	2,838.13 R 13	153.76 R 13	0.00 R 13
09-2002	5,339.11 R 13	5,339.11 R 13	5,072.15 R 13	266.96 R 13	2,161.25 R 13	148.48 R 13	2,161.25 R 13	148.48 R 13	0.00 R 13
10-2002	4,271.49 R 13	4,271.49 R 13	4,057.91 R 13	213.57 R 13	74.27 R 13	83.76 R 13	74.27 R 13	83.76 R 13	0.00 R 13
11-2002	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13	0.00 R 13

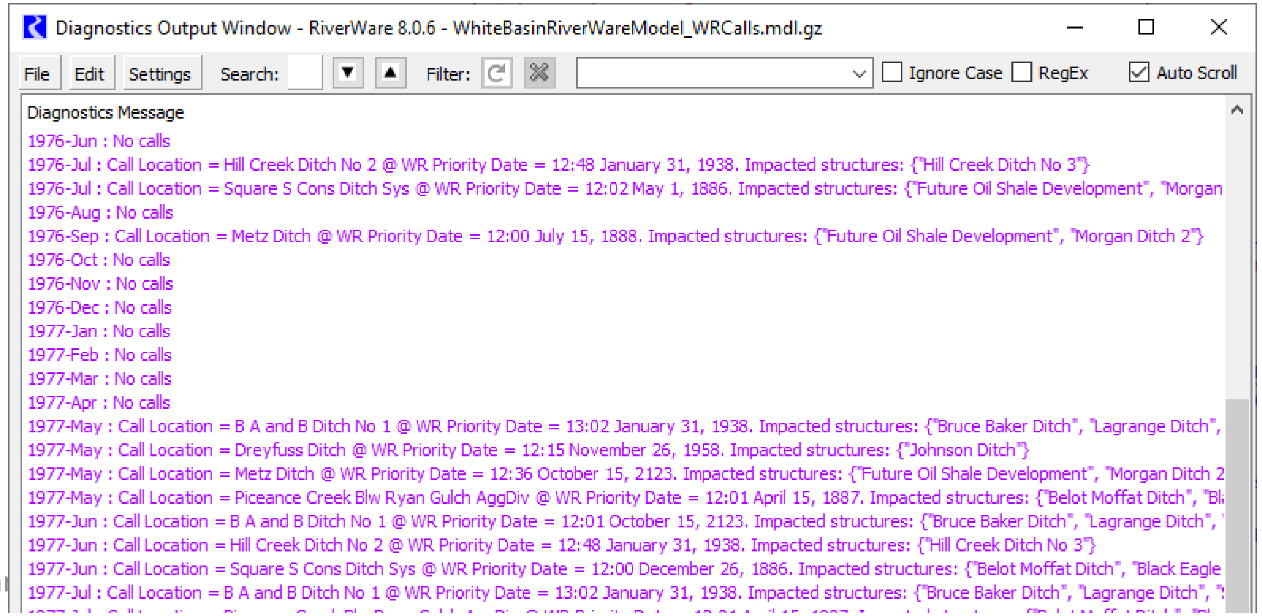
Main Takeaways

- Overall, RW simulated the allocation of available flow by water rights and other associated operations in a very similar, if not identical, manner to StateMod.
- RW's and StateMod's water right solution algorithms are nearly identical and were shown to produce identical results when simulating allocation to direct flow and storage WRs, instream flow rights at points, and several associated water right operations.
- RW's water right solver has two notable shortcomings relative to StateMod's capabilities:
  - It does not innately incorporate same-timestep return flows for subsequent allocation
  - Instream flow water rights can only be represented as points, rather than as reaches.
- RW can simulate offstream reservoir system operations, exchanges, and changed water rights including reusable return flows and return flow replacement obligations in a comparable (often equivalent) manner to StateMod. RW also provides considerable additional flexibility in representation of complex or specific operations.
- Well water rights and augmentation plans can be adequately implemented in RW, albeit in a less robust way that would make large scale inclusion difficult. Potential enhancements to RiverWare could improve well simulation.
- StateMod's direct integration within the CDSS system allows for efficient model and input dataset development, management, and updates, and is a key strength compared to RiverWare for CDSS applications.

Two More Considerations

- Simulation speed is a big strength of StateMod. Run times:
  - StateMod, full run, ~10 seconds
  - RiverWare, “Base Comparison” run, WRS iterating, ~7 minutes
    - Limited to single WRS call, ~3 minutes
- Reporting of Water Right “Calls”
  - Pertinent to real-world administration, but not really as imperative or clear cut from a model standpoint (neither model allocates by “calling out” upstream junior WRs)
  - Included in StateMod’s standard output
  - Implemented in RW via custom rule

OutCallR	Year	Mon	Day	Imcd	Call Location	Call Right	Call Location Name
OutCallR	1976	JUN	1	-1	NA	-1.0000	NA
OutCallR	1976	JUL	1	41	4300696	999.0000	HILL CREEK NO 2 DITC_DIV
OutCallR	1976	JUL	1	146	4300948	999.0000	SQUARE S CONS D SYS _DIV
OutCallR	1976	AUG	1	-1	NA	-1.0000	NA
OutCallR	1976	SEP	1	148	4300816	999.0000	METZ DITCH _DIV
OutCallR	1976	OCT	1	-1	NA	-1.0000	NA
OutCallR	1976	NOV	1	-1	NA	-1.0000	NA
OutCallR	1976	DEC	1	145	43_OilShl	2000.0000	Future Oil Shale Dev_DIV
OutCallR	1977	JAN	1	145	43_OilShl	2000.0000	Future Oil Shale Dev_DIV
OutCallR	1977	FEB	1	-1	NA	-1.0000	NA
OutCallR	1977	MAR	1	-1	NA	-1.0000	NA
OutCallR	1977	APR	1	-1	NA	-1.0000	NA
OutCallR	1977	MAY	1	65	4300608	999.0000	DREYFUSS DITCH _DIV
OutCallR	1977	MAY	1	87	4300511	999.0000	B A & B DITCH NO 1 _DIV
OutCallR	1977	MAY	1	143	43_ADW010	999.0000	PICE_ADW PicCrBlRyan_DIV
OutCallR	1977	MAY	1	148	4300816	999.0000	METZ DITCH _DIV
OutCallR	1977	JUN	1	41	4300696	999.0000	HILL CREEK NO 2 DITC_DIV



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Link to Full Report:

RiverWareStateModWaterRightSolverComparisonStudy_11.21.20_FINAL.pdf

https://precisionwater.sharepoint.com/:b:/s/570_CWCB/570001_STGrant19_RWSMWRSComp/Ef3kibkSXihAj1jENRxlMmkB3ft6XrOzmb5HnCl-G_sGWg?e=bvWkRS

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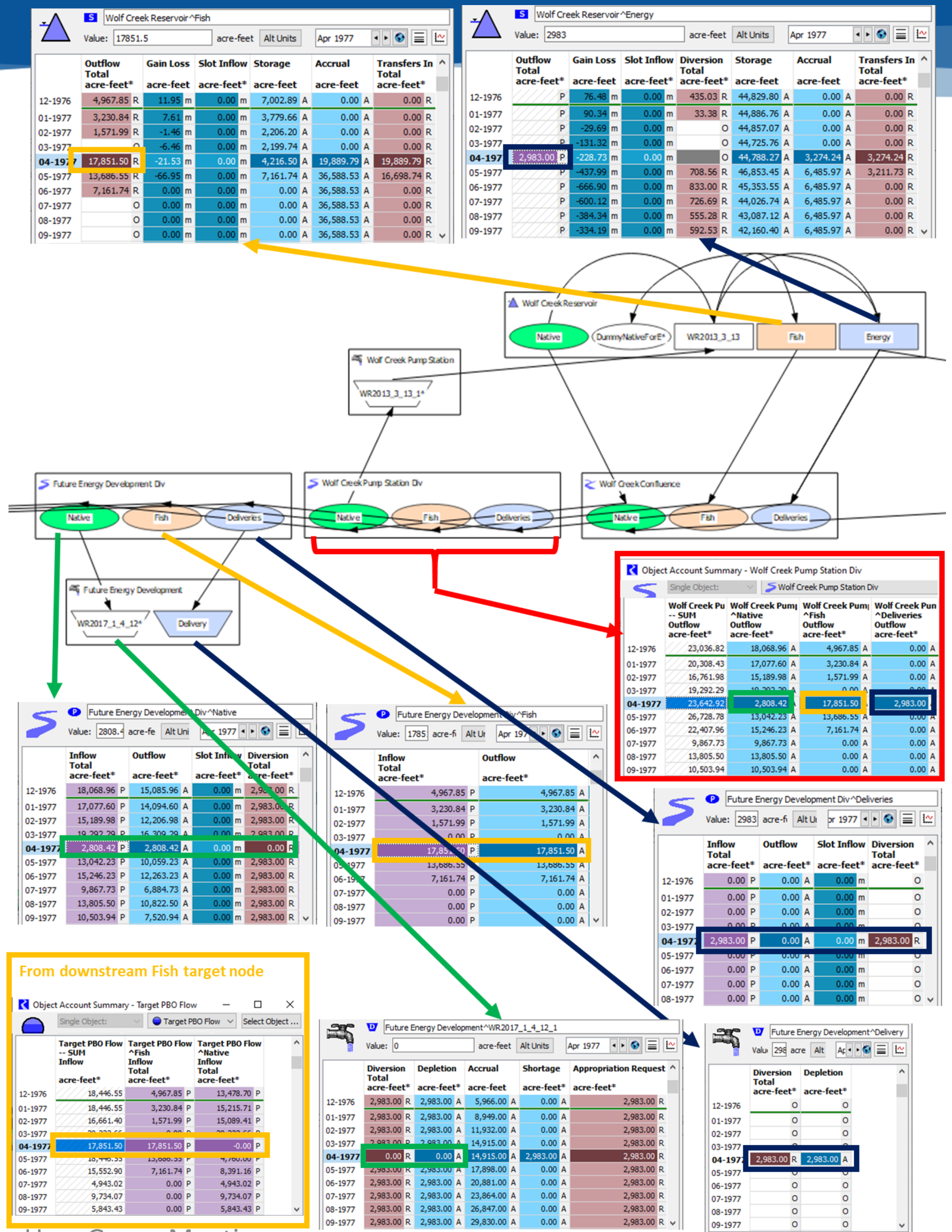
COLORADO Colorado Water Conservation Board Department of Natural Resources

wilsonwater group

Questions?


Wolf Creek Reservoir^Fish
Wolf Creek Reservoir^Energy
Wolf Creek Reservoir
Native
Fish
Energy
Wolf Creek Pump Station
Future Energy Development Div
Wolf Creek Pump Station Div
Wolf Creek Confluence
Deliveries
Future Energy Development
Delivery
Object Account Summary - Wolf Creek Pump Station Div
Future Energy Development Div^Native
Future Energy Development Div^Fish
Future Energy Development Div^Deliveries
From downstream Fish target node
Object Account Summary - Target PBO Flow
Future Energy Development^Delivery