The Fryingpan-Arkansas Project RiverWare Model

Water Rights, Proxy Accounts, Release Components, and List-Assignments; Innovative Approaches for an Incredibly Complex, Accounting Driven System

RiverWare User Group Meeting
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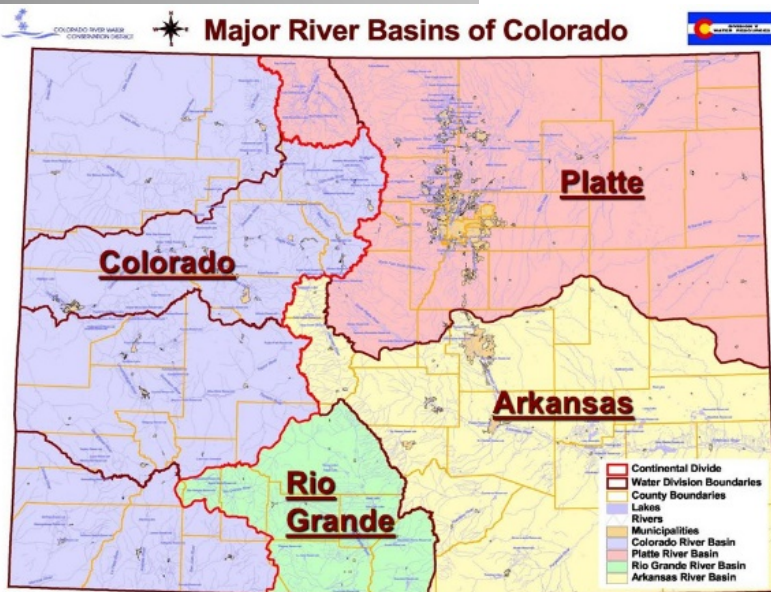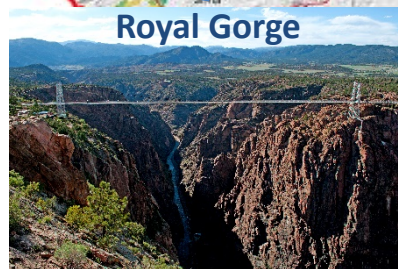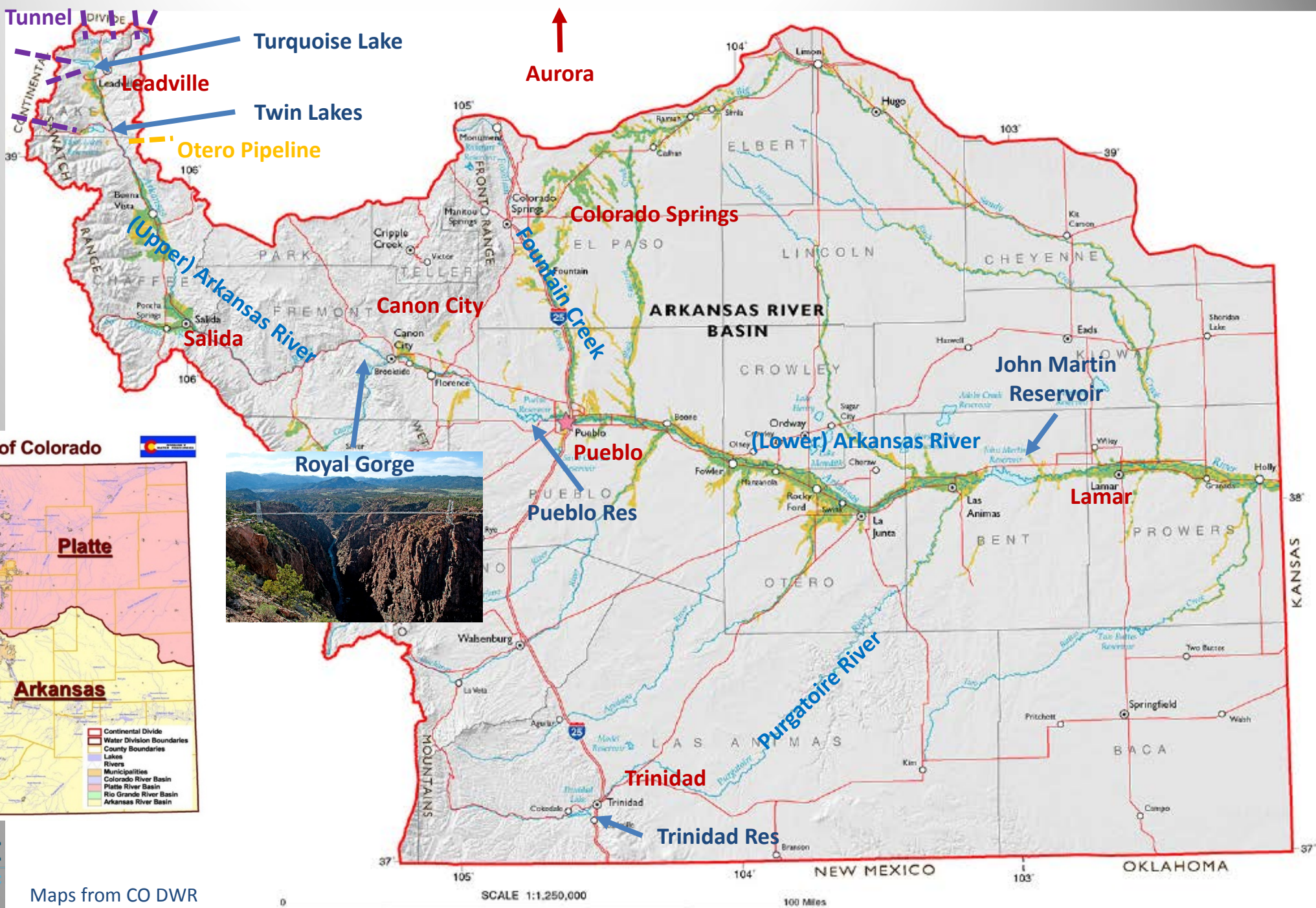Precision Water Resources Engineering
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Sugar Loaf Dam and Turquoise Lake

Pueblo Dam and Reservoir

Eastern Colorado Area Office
& Pueblo Field Office

Maps from CO DWR
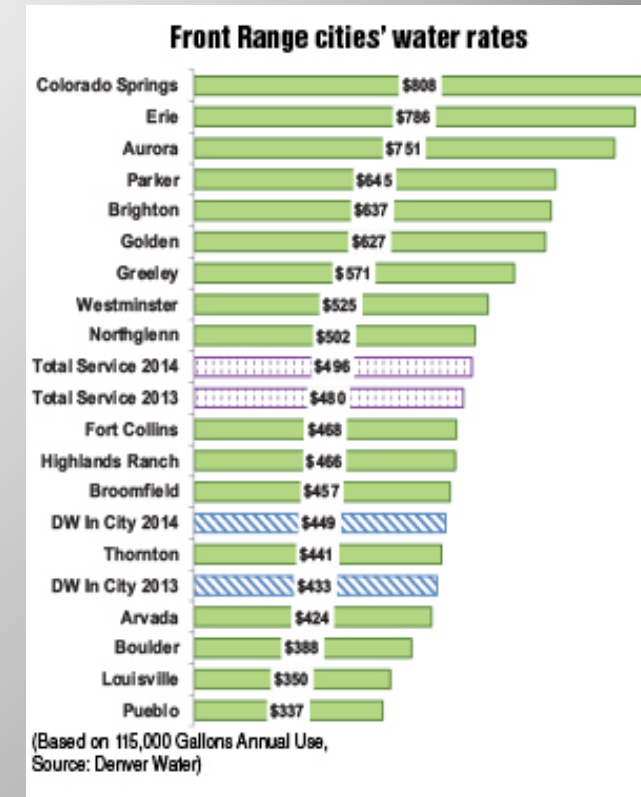
Arkansas River Basin Policy and Uses

- Colorado Water Law underlies everything
  - Decrees, decrees, decrees!
  - "More exceptions than rules"
- Fryingpan-Arkansas Project
- Other Transbasin Imports/Exports
- Colorado-Kansas Arkansas River Compact
- Many Cooperating AND Competing Entities
  - Agricultural Users, Ditch Companies, Conservancy Districts
  - Colorado Springs Utilities, Pueblo Water, Aurora Water, etc

Front Range cities' water rates

City	Rate
Colorado Springs	$808
Erie	$786
Aurora	$751
Parker	$645
Brighton	$637
Golden	$627
Greeley	$571
Westminster	$525
Northglenn	$502
Total Service 2014	$496
Total Service 2013	$480
Fort Collins	$468
Highlands Ranch	$466
Broomfield	$457
DW In City 2014	$449
Thornton	$441
DW In City 2013	$433
Arvada	$424
Boulder	$388
Louisville	$350
Pueblo	$337

(Based on 115,000 Gallons Annual Use, Source: Denver Water)

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Fryingpan-Arkansas Project Overview

- Transbasin water diversion and delivery project (const. 1964-1981)
- Imports an average of ~65 TAF/yr from the Fryingpan River in the Upper Colorado River Basin through the Boustead Tunnel into Turquoise Lake (2007-2016, ranging from 13 to 99 TAF)
- "Project Water" stored in Turquoise, Twin Lakes, and Pueblo Res
- ~45% allocated to Agriculture, 55% to Municipal
- Necessitates detailed accounting of Project Water through the system, including "Reusable Return Flows"
- "Excess Capacity" Accounts in Pueblo Reservoir
  - Reclamation lease's out the "excess" (empty) storage space in Pueblo Reservoir to various entities who want to store their own water supplies from other sources. Each account is essentially it's own pseudo-reservoir.

Anticipated Model Uses and Objectives

- Developed as a long-term planning model
  - First Application (ongoing): NEPA analysis of Pueblo Reservoir "Excess Capacity" Accounts
  - Long-term policy planning, evaluation, water supply, climate change studies, etc
- Also desired for use in Short-Term Operations and Accounting with minimal adaptation

- Appropriate representation of the highly complex, accounting-driven operations made necessary with Colorado water law and transbasin import projects
- Flexibility and adaptability
- Transparency (how and why were decisions made?)
- Limit "implicit" dependence on historic operations/decisions/conditions
  - Highly changing procedures, policy, water uses, etc are constantly changing
  - Rules to operate the system under current procedures

Model Basics

- Model Extent: Arkansas River from headwaters near Leadville to the CO-KS stateline (~330 river miles). Limited representation of Fountain Creek from Colo Springs to Ark. Purgatoire River from Trinidad Reservoir to Ark
- Daily timestep, 25 year model runs (data limited)
- Inline Rulebased Simulation and Accounting
- 11 reservoirs (+2 proposed), 90 water user objects, 164 reach objects
- Water Rights Solver, Heavy Accounting
- Many different types of exchanges and other accounting transactions:
  - Diversion to Reservoir, Reservoir to Diversion ("Delivery Exchange"), Reservoir to Reservoir, Return Flow to Reservoir, Import to Reservoir, Contract Exchanges, Trades, Leases, etc.
- Basic, Dynamic Transit Losses, % of flow, prorated through accounts. Allows for representation of transit losses while maintaining physical/accounting reconcile. Works well within WRS. Allows transit losses to be charged on deliveries, e.g. release 55 to divert 50 cfs.
- 4 day Time Lag from top to bottom (whole days for WRS)

Reservoir	Capacity, af
Turquoise	129,398 AF
Twin Lakes	140,855 AF
Clear Creek	9,214 AF
Pueblo Res	330,654 AF
Lake Henry	8,906 AF
Lake Meredith	42,355 AF
Holbrook	6,300 AF
John Martin	340,771 AF (603,465 AF)
Trinidad	68,578 AF

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Model Schematics

Simulation View
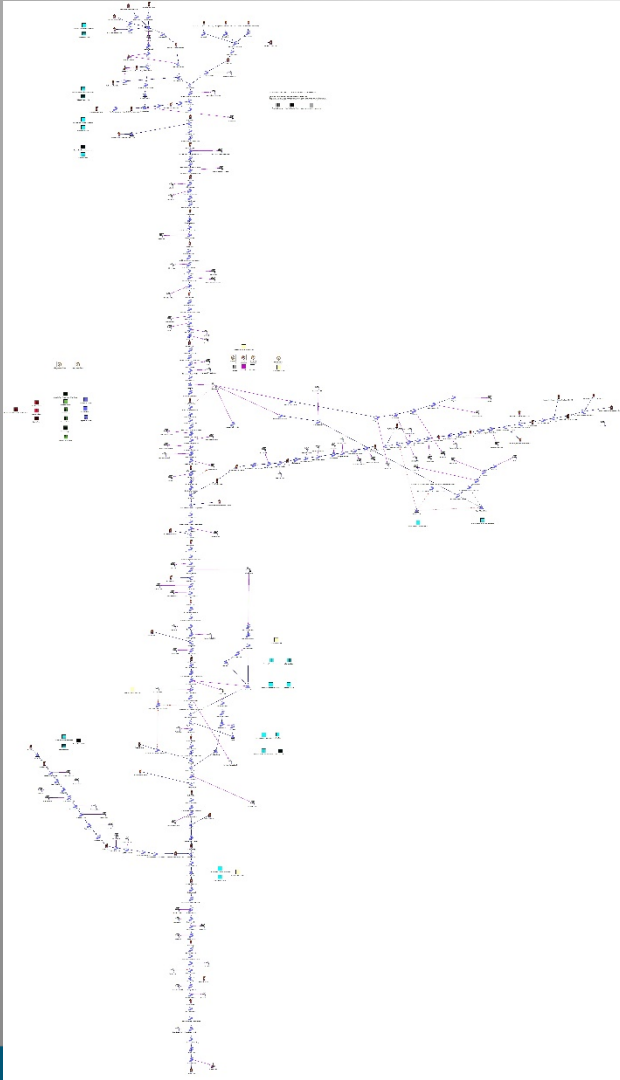
Accounting View
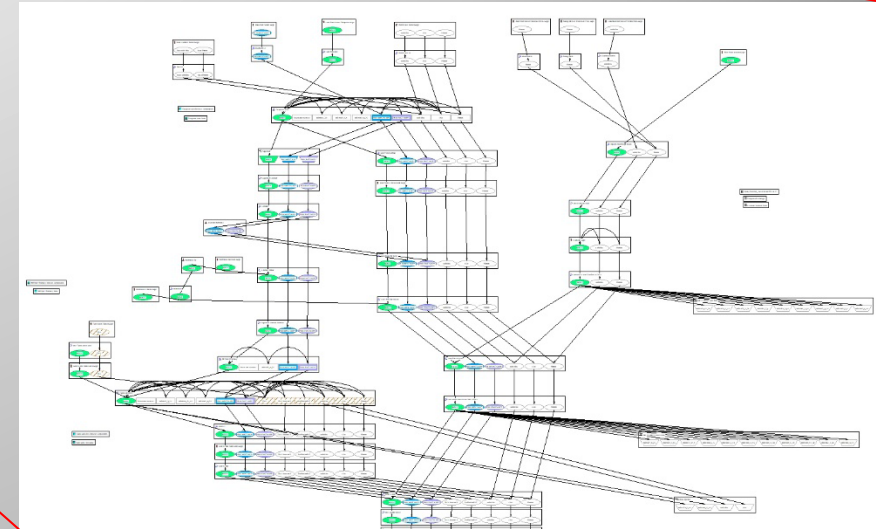
Modeling Issues and Challenges

- Very large system, modeled (& operated!) at a very detailed level
  - Excess Capacity accounts with storages in the 10s, 100s, 1000s, 10000s AFs
- Colorado's complex water rights/water law system
- "More exceptions than rules", makes it difficult to standardize logic, variable/dynamic limits, triggering criteria, etc
- Variable relationships: 1 to Many, Many to 1, Many to Many
  - e.g., Groups of WRs, ownership splits, multiple source deliveries
- Managing the large number of potential transactions, varying types of exchanges, etc
- Appropriately ordering rules to represent real world operations
- Computationally heavy, long run times, efficiency VERY important

Use of the Water Rights Solver

- Almost 300 total diversion and storage water rights
- Initial set up of water rights for the entire run period is done with Initialization Rules
- But still, many WR requests must be set/adjusted with Rules each timestep prior to WRS.
  - Standard naming convention of the Water Right diversion/storage accounts
  - By defining max rates/volumes/dates/etc. in Tables, many limits are set with few rules.
- Water Rights Solver called near the beginning of each timestep to allocate native flow; provides the initial, base solution. Later operations are then "layered" onto base solution
  - Storage deliveries to "fill" the incompletely allocated diversions to a full demand.
  - Exchange of allocated diversion WRs to a reservoir storage account (if decreed...)

- Full Model Run Time = **Just over 2 hours**, Water Rights Solver time = **24 minutes**

Many-Part Water Rights are Common in the Arkansas Basin, + Split Ownership
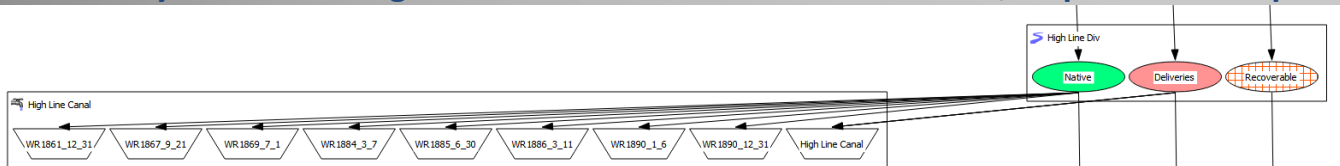
Ownership of Storage Water Right's is split between Water Right "Bounce Through's"
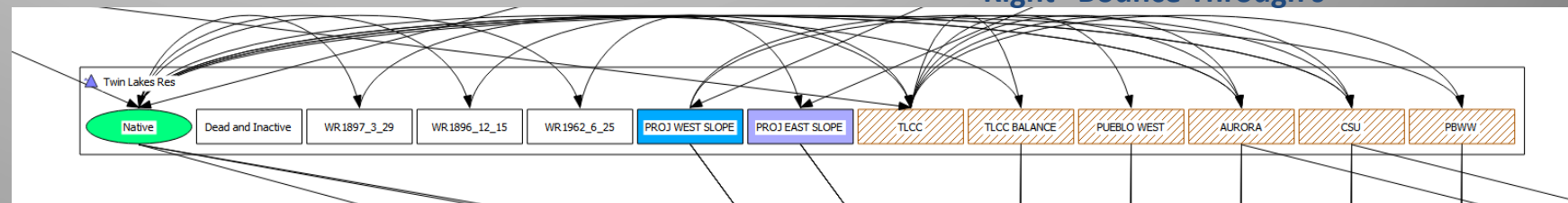
Incredibly Detailed Accounting in Pueblo Reservoir

- Reclamation tracks over 150 individual accounts!

  – Many of those accounts are further sub divided by their owners by sources, water type,

- After lumping… ONLY 64 accounts are modeled

- Infeasible to represent with "normal" RiverWare Accounting

- Each account is unique: maximum capacities, unique sources and demands, different rules for different water types/sources

"Proxy" Accounts

- Credit for the concept to **Terry Dawson**, Reclamation-Pueblo,
- "Proxy Accounts" are simply sets of ~standardized data objects that represent a breakdown of an account on a reservoir object
- Defined with Object Attributes, easily accessible by Rules
- Facilitates each account operating individually, essentially as it's own pseudo-reservoir within a broad account type
- End-of-timestep rules simply do the mass-balances within each Proxy Account and sum across all of the Proxy Accounts of the same types.
- When you set something with a Rule, just add one more assignment.
  - E.g., Setting a delivery from a Proxy Account. You're already setting a Physical Release slot and an Accounting Outflow slot, now just set a Proxy Account Outflow slot too.
- Makes adding and removing accounts simple
- Utilize Generalized Rules/Functions to operate the accounts as much as possible
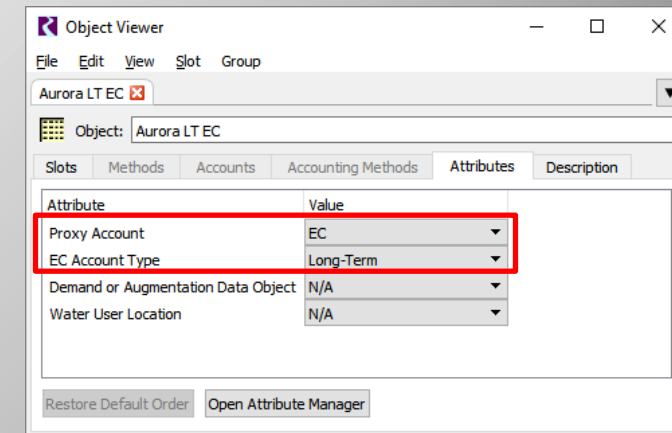
"Proxy" Accounts

- SourceAccounts Table: Generalized rules can establish storage for standard water supply sources, basic exchanges, inflow from upstream, etc.

- Custom sources can be mapped

- Sum(SourceYields) = Inflow

"Proxy" Accounts

Adding Another Dimension to Proxy Accounts

- Track Total's Through Various Locations
- Keep Track of Different Water Types Within an Account
- etc

Release Components

- As a timestep solves, many rules may alter releases for various reasons.
- Traditionally, Rules would just keep making assignments to the Release slot. After the fact, figuring out how it got there can be very hard!
- We utilized and expanded upon the process that was developed in the Truckee models to aid in transparency and tracking of how and why a release was set.
- Each Reservoir has a "Release Components" Data Object with a standard naming convention, e.g. "**John Martin Res** Release Components"
- Within each Release Component object, series slots are used to track the various components of the total release. There can be a flexible number and different names of slots so that each reservoir can have it's own set.
- A REFIRING "Set Reservoir Releases" Rule will refire when a release components is set or changed, and will update the release.

Release Components

- Release = 733 cfs
- Set by Rule 84
- But that's just the last Rule that changed it!
- Breaking it down, debugging can be very tedious

Release Components

List-Assignments

…ok, first…

List-Processing in RPL Rules and Functions

- I know, it can be intimidating, confusing, scary even.

- And there is DEFINITELY a learning curve to it.

- It can make difficult things easy and impossible things possible.
  - Huge efficiency improvements
  - Large reduction of number of needed rules and functions
  - Passing variables between functions, reducing Arguments.
  - Improved Rule/Function "Readability"
  - Internal "simulation", e.g., keeping track of and manipulating a chain of reach outflows…
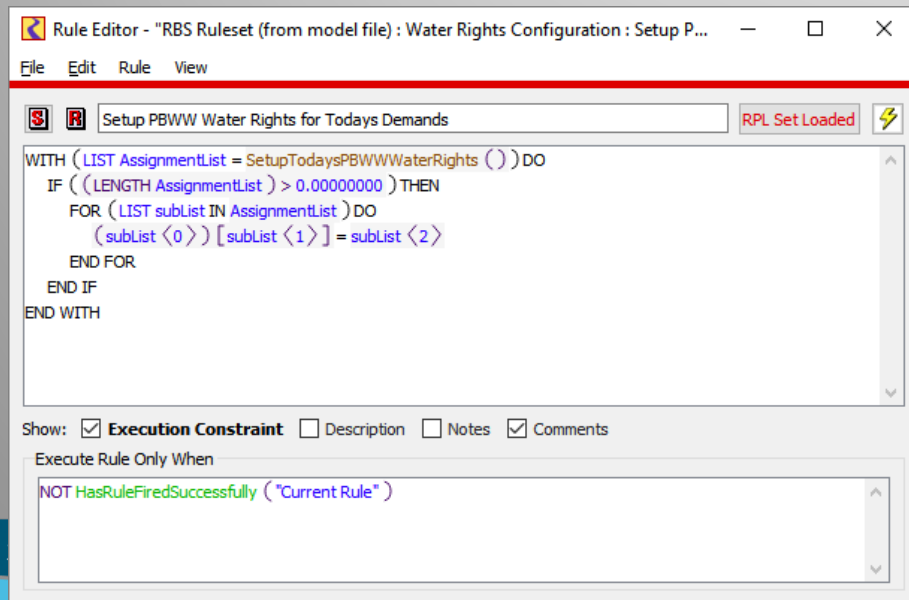
Basic List-Assignment Rule Formats

- Assignment in list form {Slot, date, value}

- Rule/Function Output in List-Assignment form:

{ {Slot, date, value}, {Slot2, date2, value2}, {Slot3, date3, value3} , etc }

assignment 1   assignment 2   assignment

Making a "Hard" assignments

Making a change to a value already there
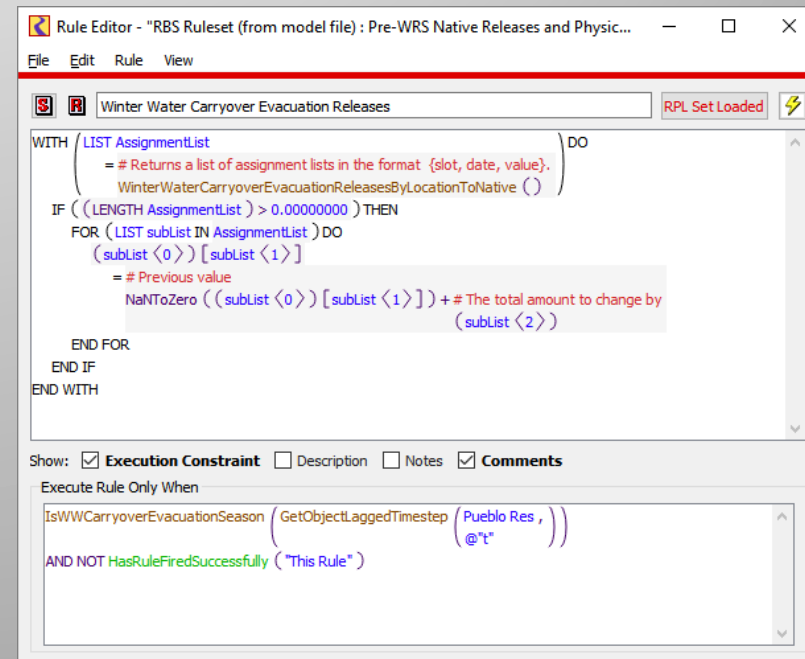
List-Assignments

- Demo

- Because of the way RiverWare makes assignments, you need to combine all assignments to the same slot.

- Be careful with list Unions because it will remove duplicates, rather than combining them.

Acknowledgements

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Questions?