

Arkansas Basin RiverWare Model – Putting RiverWare's Flexibility to the Test & Pueblo Water's Water Rights Change Case

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&

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2019 RiverWare User Group Meeting

August 28, 2019



Pueblo Dam and Reservoir

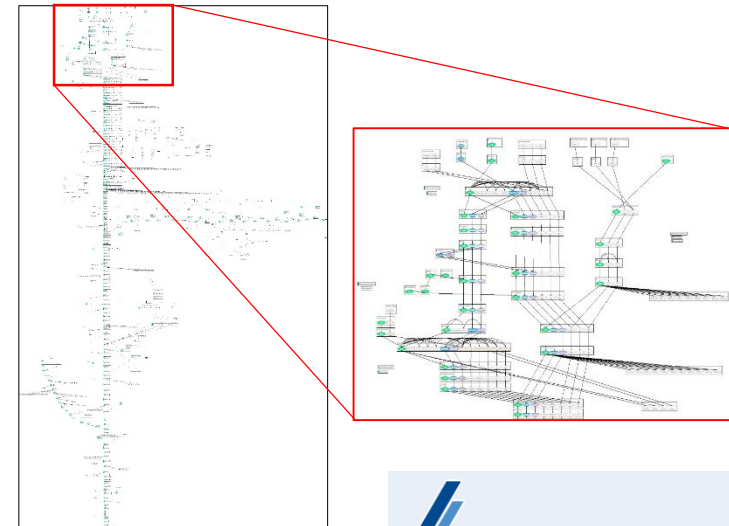
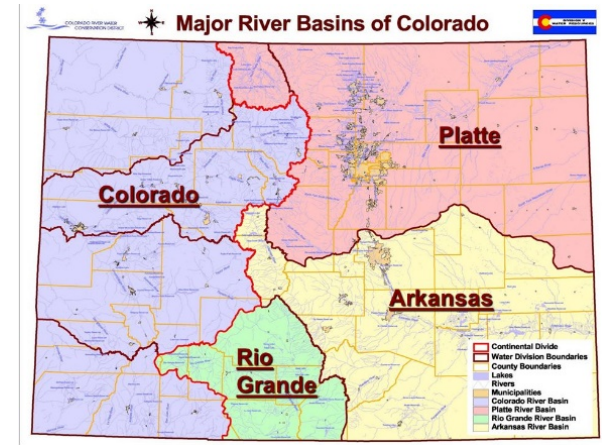


PRECISION
WATER RESOURCES ENGINEERING



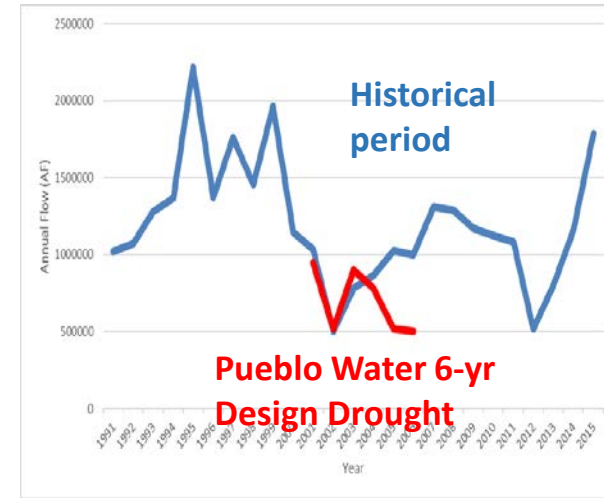
Quick Model Overview

- Extent: Arkansas River headwaters near Leadville to CO-KS border, ~330 mainstem river miles
- Daily-timestep
- Flexible model period
- Heavy Accounting and Water Rights simulation
- 11+ reservoirs (incl. Turquoise Lake and Twin Lakes, Pueblo Res, John Martin Res)
- 90+ water user objects, 200+ flow nodes



Hydrology Construction Workbook

- Base, “naturalized” model input hydrology (25 years, 1991-2015) for 51 inflow nodes
- Workbook facilitates sampling, re-sequencing, adjusting to create novel hydrology sequences
- Automates generation of hydrology data for all input nodes and sets up for DMI



Model Year	Historic Hydrology Year	Hydrology Scale Factor (.5 to 2)	Historic Import Year	Desired Historic Year	Notes/Comments
1991	2008	1	1979	1979	
1992	2008	0.97	1976	1976	
1993	2008	1	2008	2008	
1994	2012	0.94	2012	2012	
1995	2002	1	2002	2002	
1996	2012	1	1972	1972	
1997	2002	1.05	1965	1965	
1998	2012	1	1983	1983	
1999	1999	0.98	1987	1987	
2000	2000	1	1973	1973	
2001	2001	1	1977	1977	
2002	2015	1	1995	1995	
2003	2002	1.3	1999	1999	
2004	2004	1	1985	1985	
2005	2005	1	1989	1989	
2006	2005	1	2007	2007	
2007	2007	0.86	2011	2011	
2008	2008	1	1997	1997	
2009	2009	1.02	1998	1998	
2010	2010	1	2010	2010	
2011	2011	1	2011	2011	
2012	2012	1	2012	2012	
2013	2013	1	2013	2013	
2014	2014	1	2014	2014	
2015	2015	1	2015	2015	

Instructions

Under "Run Parameters," specify number of years in run (up to 25) as well as the first year of simulation. Enter the desired historical year beside each simulated year in the column labeled "Hydrology Historical Year." In the "Hydrology Scale Factor" column, enter the desired factor for scaling historical data. If no scaling is desired, the default is 1. Additional information regarding the use of the workbook can be found in the "Help" tab.

Build Hydrology

Local Inflows: Abv Salida Local

Year	NRCS Salida page natural flow forecast, Apr-Sep volume, TAF	NRCS Pueblo base-year natural inflow forecast, Apr-Sep volume, TAF	"Tree Flow" Natural WY Flow Volume at Canon City, TAF	"Tree Flow" Natural WY Flow Volume at Salida, TAF
1947	425		505	588
1948	450		483	617
1949	300	Todd Vanover, Denver (Apr-Sep)	505	602
1950	300		393	351
1951	450		471	411
1952	500		572	565
1953	250		417	252
1954	225	250	276	203
1955	250		305	289
1956	325		315	361
1957	413		450	818
1958	425		450	489
1959	290		315	273
1960	330		340	409
1961	300		308	365
1962	490		496	575
1963	158		147	357
1964	235		235	326
1965	490		438	600
1966	360		358	389
1967	225		194	368
1968	310		291	401
1969	275		255	404
1970	400		440	557
1971	300		275	440

Historical Hydrology Selection Assistance

This tool may be used to find a year in the developed model input hydrology dataset that is similar to a desired year not found in the developed data set. Additionally, this tool will suggest scale factors based on the given metrics. Each row suggests a year based on the appropriate metric.

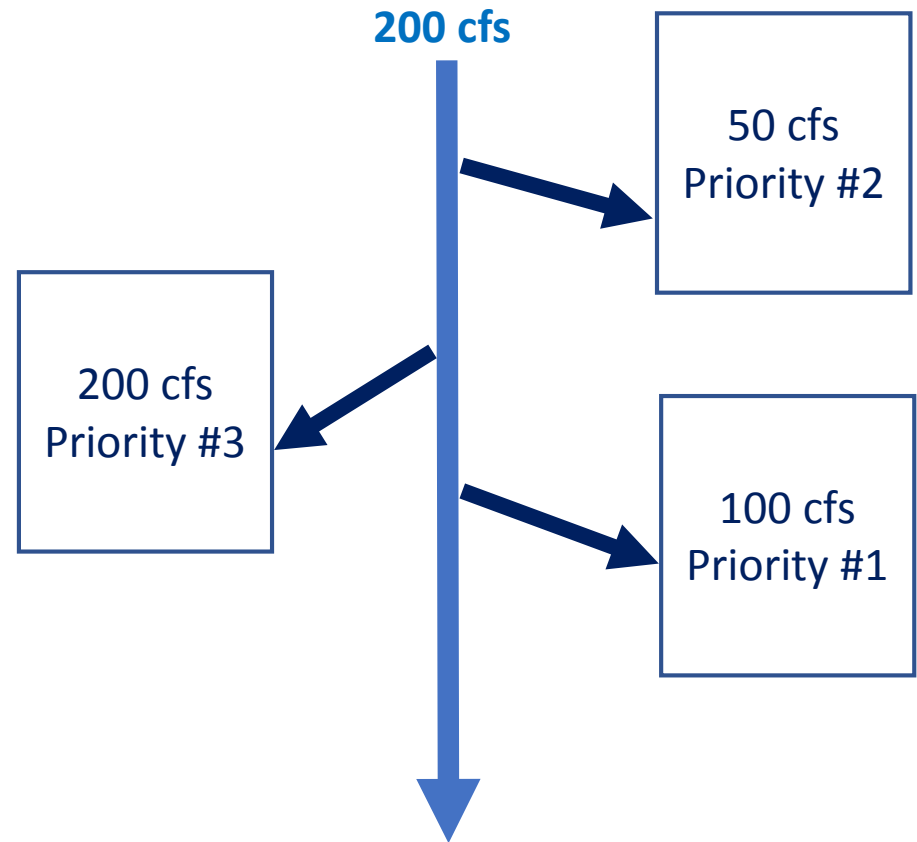
Desired Year	Metric	Desired Fr Volume	Suggested Year	Salida Forecast Volume for Suggested Years	Pueblo Forecast Volume for Suggested Years	Suggested Scale Notes
2002	Salida Forecast	350	2012	350	240	1.34x by Salida forecast volume
2002	Pueblo Res Forecast	350	2002	77	85	1.11x by Pueblo forecast volume
2002	Forecast Combination	350	2002	77	85	1.11x by Pueblo forecast volume

NRCS Natural Flow Forecast Metrics

Tree Flow Natural Flow Metrics

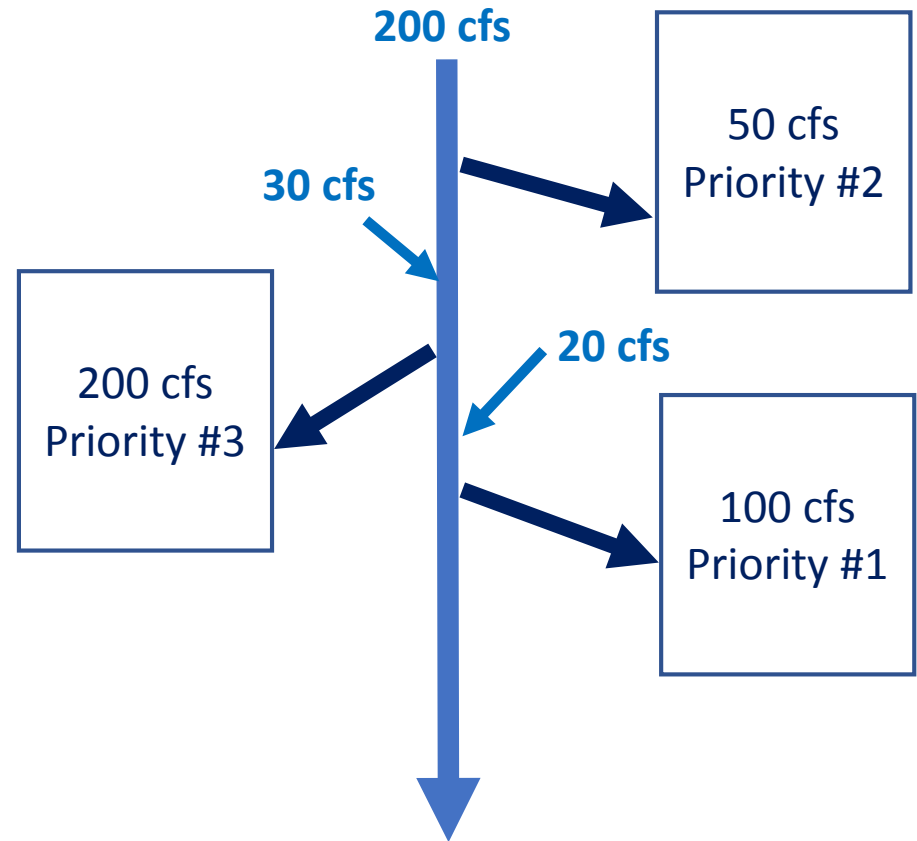
Complex Water Rights System

- Over 300 unique water rights
 - Direct flow and storage
- Multi-part, “piecemeal” water rights



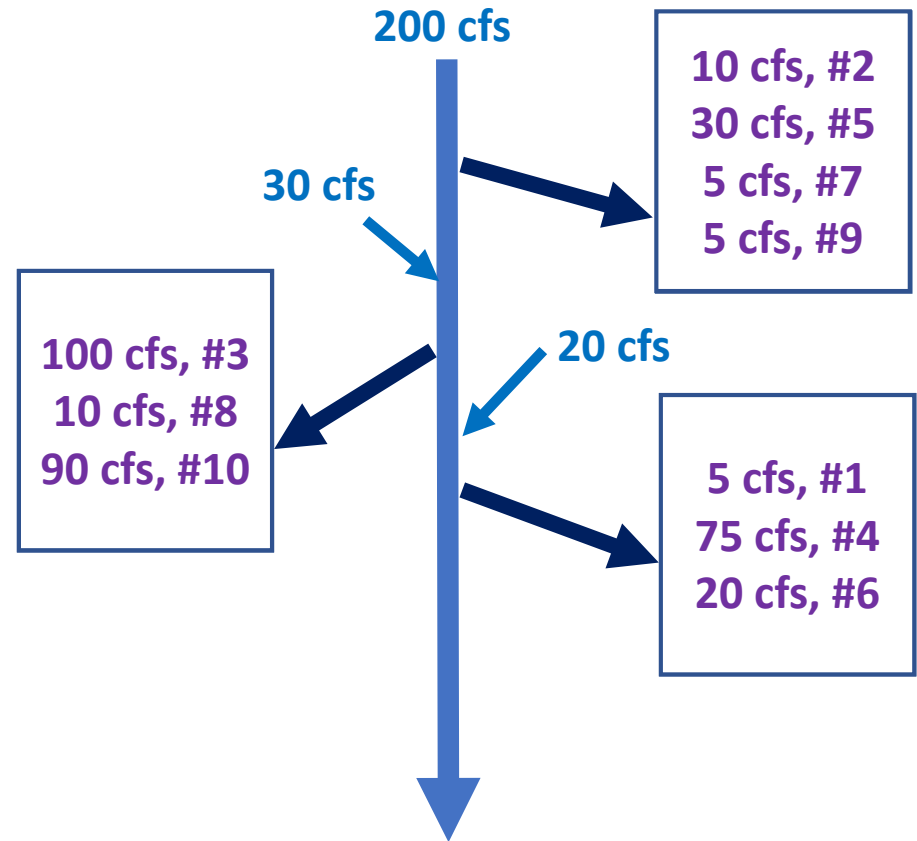
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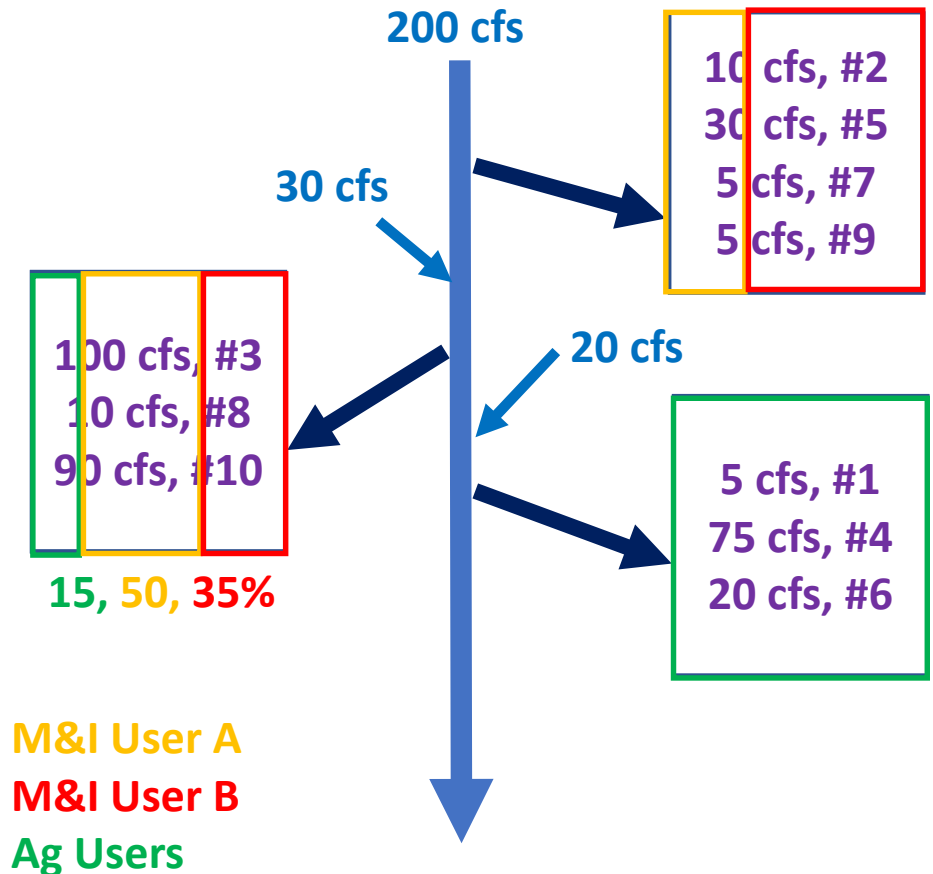
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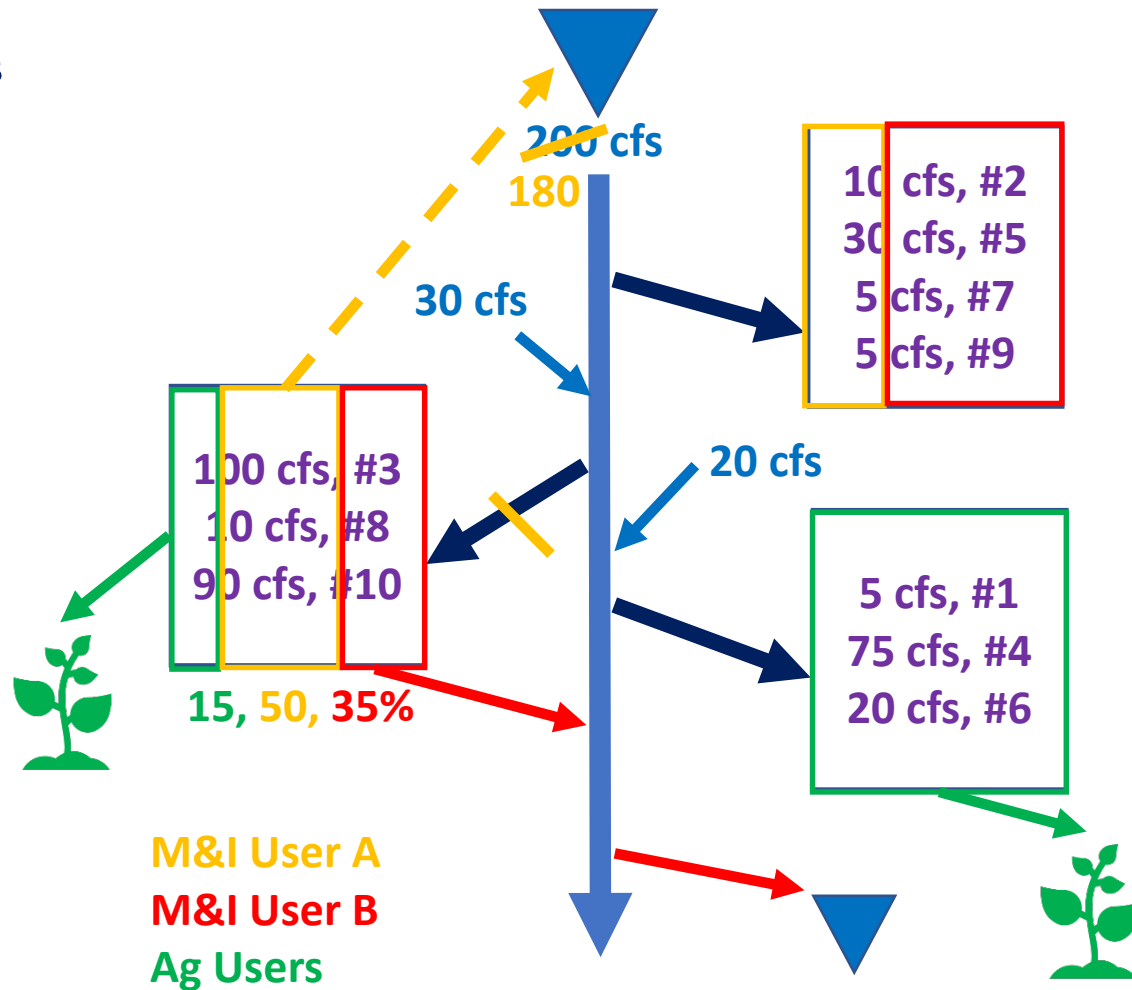
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- Over 300 unique water rights
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- Multi-part, “piecemeal” water rights
- Ditch ownership often divided by shares
- WR allocations prorated by ownership %’s

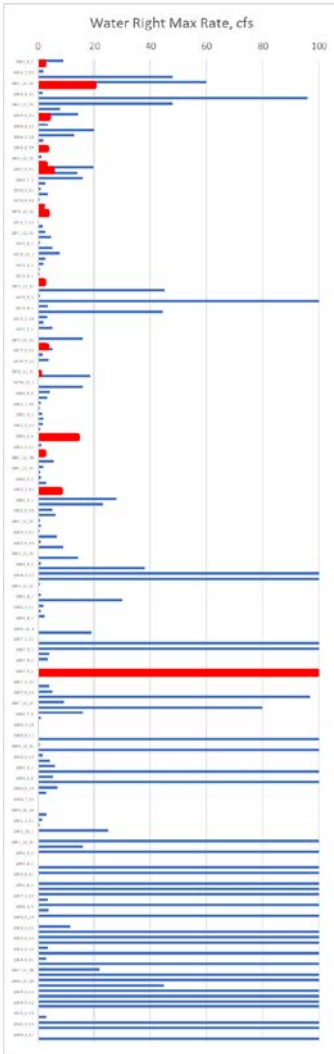


Complex Water Rights System

- Over 300 unique water rights
 - Direct flow and storage
- Multi-part, “piecemeal” water rights
- Ditch ownership often divided by shares
- WR allocations prorated by ownership %’s
- Different owners can do different things with their portion of allocation

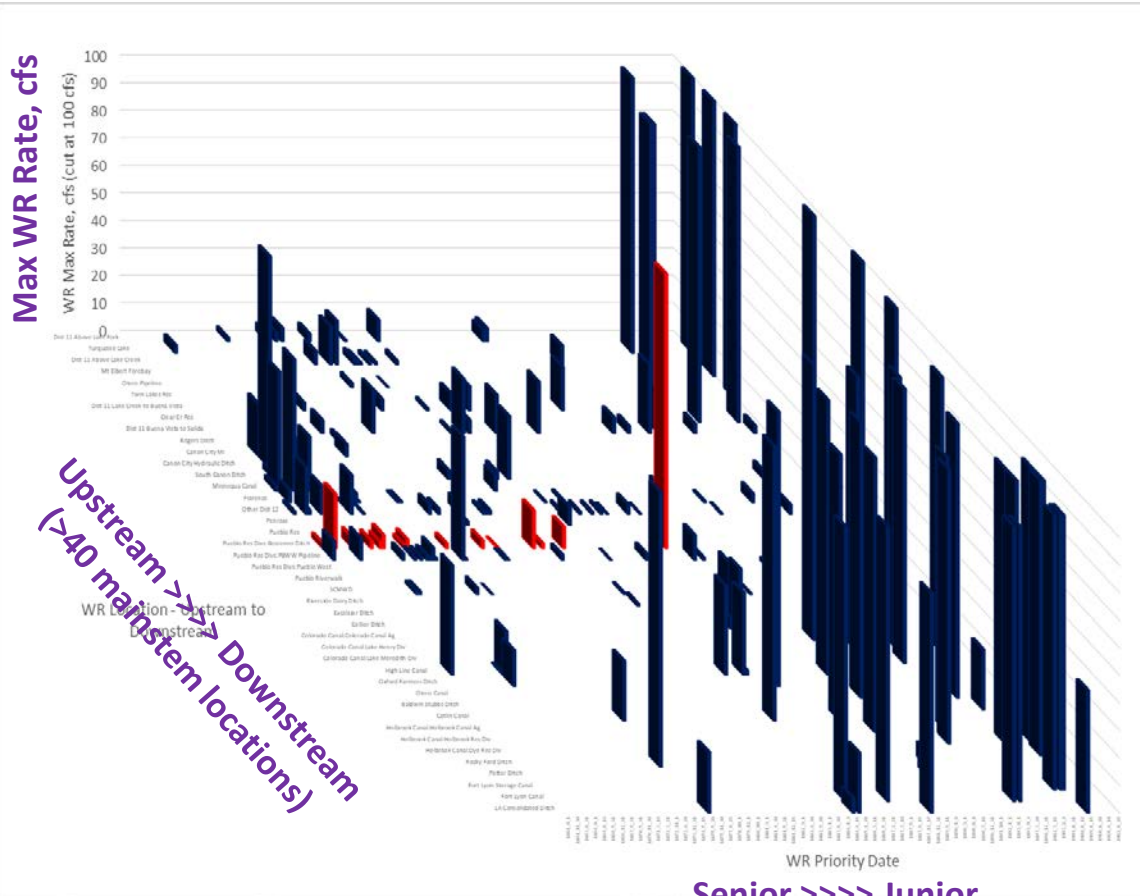


Max WR Rate, cfs (cut at 100 cfs)



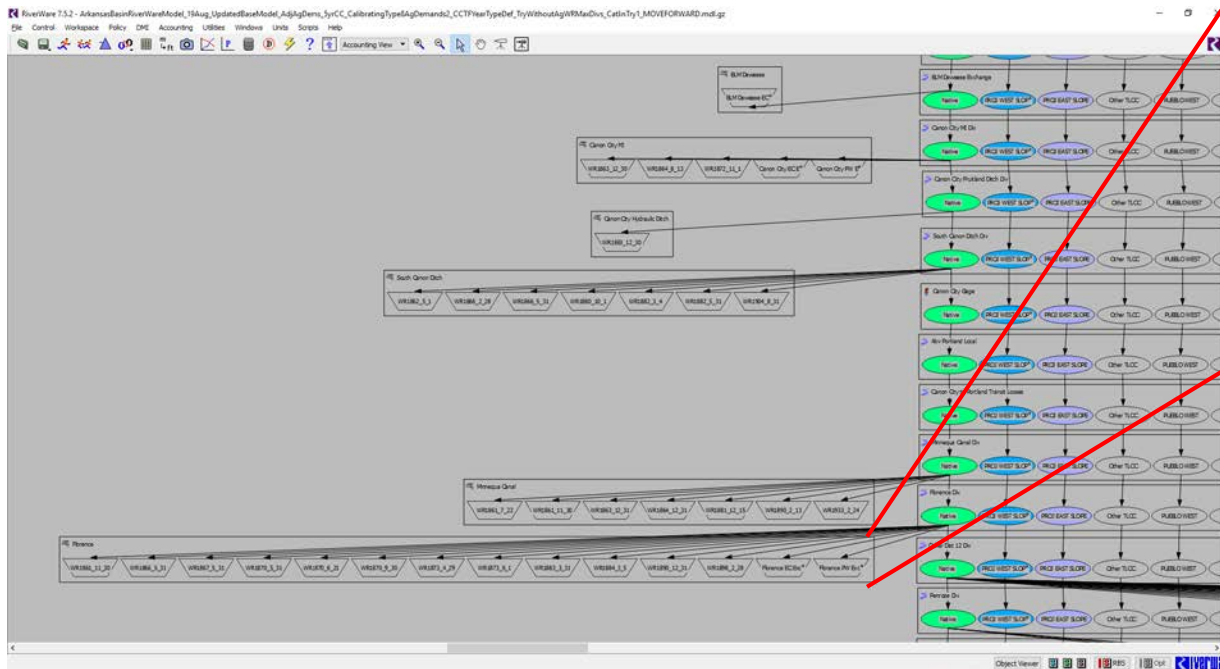
Senior >>>> Junior (>180 priority dates)

**Bessemer
Ditch Water
Rights (14
different
priority dates,
ranging from
<1 to 322 cfs)**



Senior >>>> Junior
(>180 priority dates)

Implementation in RiverWare



Object Viewer

High Line Canal | Florence

Object: Florence

Account Name	Type	Water Type	Water Owner
WR1861_11_30	Diversion	NATIVE	NONE
WR1866_5_31	Diversion	NATIVE	NONE
WR1867_5_31	Diversion	NATIVE	NONE
WR1870_5_31	Diversion	NATIVE	NONE
WR1870_6_21	Diversion	NATIVE	NONE
WR1870_9_30	Diversion	NATIVE	NONE
WR1873_4_29	Diversion	NATIVE	NONE
WR1873_6_1	Diversion	NATIVE	NONE
WR1883_3_31	Diversion	NATIVE	NONE
WR1884_3_5	Diversion	NATIVE	NONE
WR1890_12_31	Diversion	NATIVE	NONE
WR1898_2_28	Diversion	NATIVE	NONE

Open Account - Florence^WR1870_9_30

File View Slot Accounting

DiversionAccount | WR1870_9_30

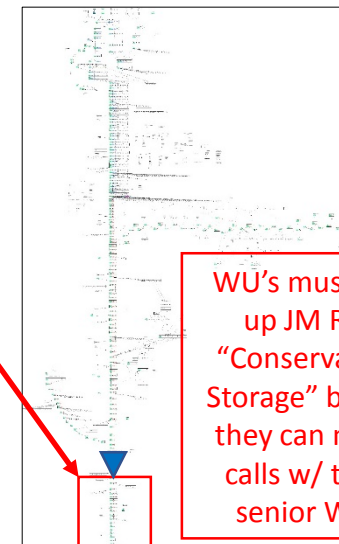
on Object: Florence

Slot Name	Value	Units
Accrual	0.00	acre-feet
Appropriation Request	NaN	cfs
Depletion	NaN	cfs
Diversion	NaN	cfs
Fraction of Diversion	0.00	NONE
Initial Request	0.50	cfs
Maximum Accrual	NaN	acre-feet
Maximum Request	NaN	cfs
Priority	38.00	NONE
Return Flow Lag	NaN	NONE
returnFlow	NaN	cfs
Shortage	NaN	cfs
Temp Available For Shared Priority	NaN	cfs
Temp Reason	NaN	NONE

Complex Water Rights, cont.

- Detailed WR limits (w/ more exceptions than rules)
 - Max flow rates, often annual volumes
 - Monthly/other period rates & volumes limits
 - Variable limits based on type of use, demands, etc.
- Other complexities, e.g. alternative points of diversion, “fixed call” dates, storage availability constraints
- **RiverWare’s flexibility has been crucial for implementation of complex WRs**
- **Water Rights Solver has handled everything thrown at it**
- Currently doing a Water Right Simulation Comparison Study between RiverWare and StateMod with the Colorado Water Conservation Board using White basin

Comanche Annual Demand acre-feet	June July Aug Max Rate cfs	Other Months Max Rate cfs
0	0.00	18.00
1	2,500.00	17.50
2	5,100.00	17.00
3	6,600.00	16.40
4	7,300.00	16.10
5	7,600.00	16.00
6	7,900.00	15.80
7	8,600.00	15.60
8	9,600.00	15.20
9	10,200.00	15.00
10	99,999.00	15.00

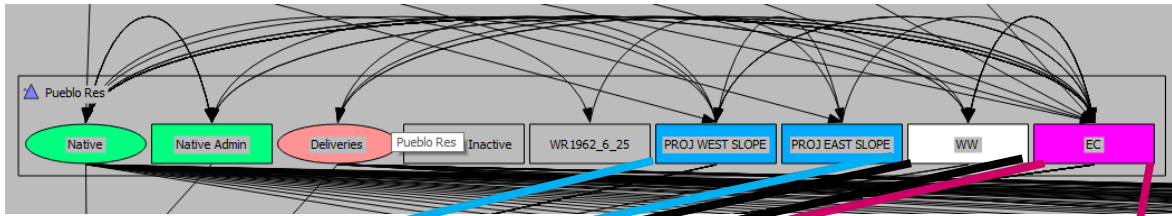


WU's must use up JM Res "Conservation Storage" before they can make calls w/ their senior WRs

Flexible Storage Accounting Framework

- Real-world administration necessitates very detailed accounting
- In Pueblo Reservoir, Reclamation tracks over 150 individual accounts
 - After lumping... ONLY ~70 accounts are modeled in Pueblo
- Flexible framework was developed to allow variable levels of detail
- “Traditional” RW storage accounts can be divided into subaccounts,
 - Subaccounts can be further subdivided, and so on
- Allows model development & enhancements to be tailored to specific needs, without the need for highest level of detail everywhere

“Proxy” Accounts



Open Object - PBWW LT EC

Object: PBWW LT EC

Slots Methods Accounts Accounting Methods

August 30, 1995

Slot Name	Value	Units
Max Content	9,000.00	acre-feet
Storage	4,359.28	acre-feet
Inflow	1.11	cfs
Outflow	23.69	cfs
Evap	1.41	acre-feet
Exchange	-1.40	cfs
SourceAccounts		
Summary Slots		

Order: Custom for this Object

EC Totals

Excess Capacity Account Setup Data

MASTER CONTRACT EC ACCOUNTS

PROJECT WATER ACCOUNTS	WINTER WATER ACCOUNTS	LONG TERM EC ACCOUNTS	ANNUAL EC ACCOUNTS	Upstream of Pueblo Accounts	PVC and SDS User Accounts	AIC User Accounts	Other MC Accounts
Unallocated PW	Unallocated WW	Aurora LT EC	AGUA EC	Canon City EC	Fourtan EC	96 Pipeline Co EC	UAWCD EC
Agriculture PW	Bessemer WW	CSU LT EC	ARFG EC	Florence EC	Pueblo WW	Crowley County EC	UAWCD EC
West of Pueblo PW	Riverdale Dairy WW	Fourtan LT EC	BLM EC	...	Security EC	Kado EC	Other Master Contract EC
East of Pueblo PW	CO Canal WW	PBWW LT EC	...	...	Stratmoor EC	Powder EC	Flex Annual EC Accounts
Fountain Valley Pipeline PW	High Line WW	Pueblo West LT EC	...	...	Wilderfield EC	Las Animas EC	Flex Annual EC_Upper Ark ME
Pueblo PW	Clifford WW	Donata LT EC	...	...	...	Marionville EC	Flex Annual EC_Lower Ark ME
Other PW	Calin WW		...	...	...	May Valley EC	Flex Annual EC_Lower Ark Ag
	Hobbrook WW		...	...	...	Orinay EC	
	Fort Lyon WW		...	...	...	Rocky Ford EC	
	LA Consolidated WW		...	...	...	Schwid EC	
	Amity WW		...	...	...

Slot Viewer

Selected Slot: PBWW LT EC.Storage

Value: 3523.6562965502

	PBWW LT EC Storage	PBWW LT EC Inflow	PBWW LT EC Outflow	PBWW LT EC Evap	PBWW LT EC Exchange
	acre-feet	cfs	cfs	acre-feet	cfs
09-28-1995 Thu	3,125.80 R 9	0.00 R 9	18.78 R 65	0.83 R 12	-0.96 R 135
09-29-1995 Fri	3,087.74 R 9	0.00 R 9	18.78 R 65	0.81 R 12	NaN O
09-30-1995 Sat	3,052.30 R 9	1.31 R 9	18.78 R 65	0.79 R 12	NaN O
10-01-1995 Sun	3,051.10 R 9	0.00 R 9	0.21 R 133	0.78 R 12	NaN O
10-02-1995 Mon	3,049.91 R 9	0.00 R 9	0.21 R 133	0.77 R 12	NaN O
10-03-1995 Tue	3,048.73 R 9	0.00 R 9	0.21 R 133	0.76 R 12	NaN O
10-04-1995 Wed	3,047.56 R 9	0.00 R 9	0.21 R 133	0.75 R 12	NaN O
10-05-1995 Thu	3,046.39 R 9	0.00 R 9	0.21 R 133	0.74 R 12	NaN O
10-06-1995 Fri	3,045.24 R 9	0.00 R 9	0.21 R 133	0.73 R 12	NaN O

Show: Description

PBWW LT EC.Storage [at 24:00 September 4, 1995]

1 value: 3,523.66 [acre-feet] (Priority 9)

- Semi-standardized data objects represent subaccounts
- Mapped to main accounts by object attributes
- Rules set up to manage aggregation, reconcile, etc.

Further Subaccounting

- Some accounts must be further sub-accounted by different “water types”
- Each with unique rules/limits/criteria (which are often limiting factors)
 - E.g., PBWW’s “West Pueblo Ditch” water can’t be used at Comanche Power Plant
- Similar to how main accounts are subdivided into Proxy Accounts, Proxy Accounts can be further subdivided by water types
- AggSeries slots have really helped keep this manageable!

Single Proxy Account

Slot Name	Value	Units
Max Content	9,000.00	acre-feet
Storage	4,359.28	acre-feet
Inflow	1.11	cfs
Outflow	23.69	cfs
Evap	1.41	acre-feet
Exchange	-1.40	cfs
SourceAccounts		
Summary Slots		

Breakdown into Water Type Accounts
(held on single data object)

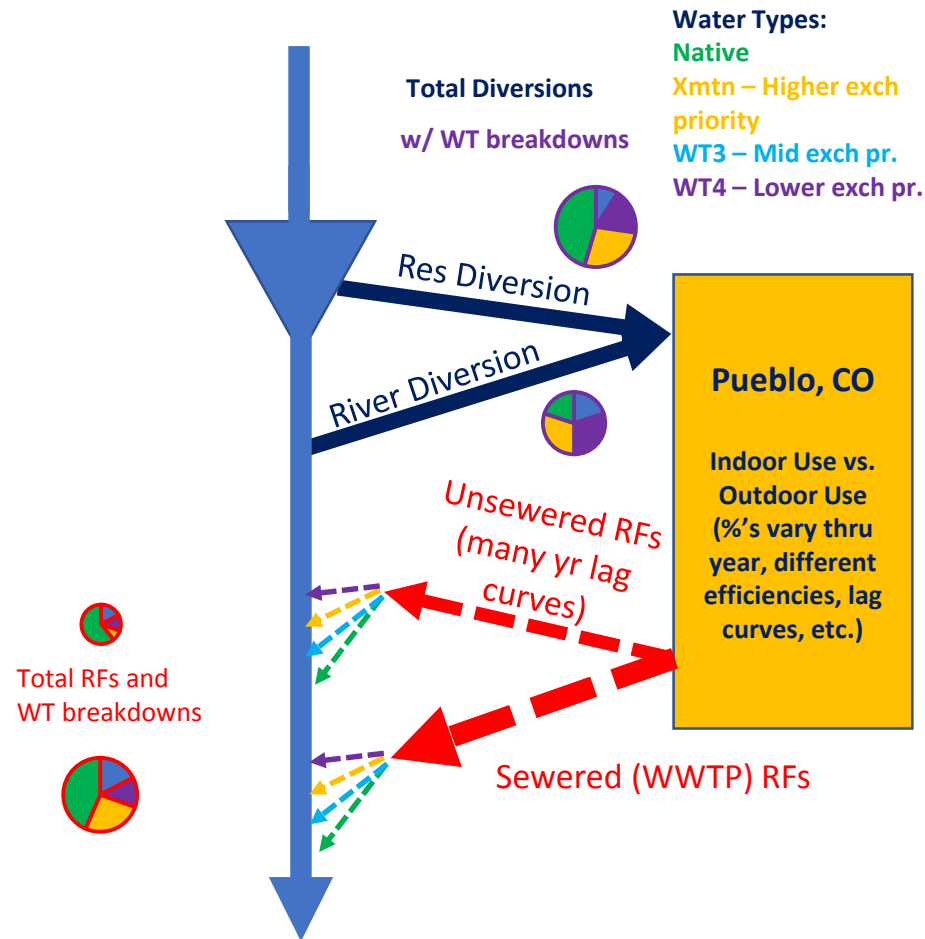
Slot Name	Value	Units
Breakdown Configuration		
Breakdown Initialization		
Expression Slots		
Total Storage	14,446.19	acre-feet
Water Types		
Native	3,816.23	acre-feet
Transmountain	9,430.71	acre-feet
FryArk RF	0.00	acre-feet
West Pueblo Ditch	1,199.24	acre-feet
Water Type X	0.00	acre-feet
Water Type Y	0.00	acre-feet
Water Type Z	0.00	acre-feet
Reconcile Checks		
For Plots		

Each Water Type Account

Date	Storage acre-feet	Inflow cfs	Outflow cfs	Diversion cfs	Transfers In cfs	Transfers Out cfs	Evap acre-feet
06-30-1992 Tue	9,495.63 R 7	6.13 R 39	NaN O	23.65 R 62		NaN O	4.28 R 8
07-01-1992 Wed	9,440.25 R 7	0.92 R 71	NaN O	26.70 R 64		NaN O	4.24 R 8
07-02-1992 Thu	9,437.67 R 7	0.83 R 71	NaN O	NaN O		NaN O	4.23 R 8
07-03-1992 Fri	9,434.92 R 7	0.74 R 71	NaN O	NaN O		NaN O	4.22 R 8
07-04-1992 Sat	9,430.71 R 7	NaN O	NaN O	NaN O		NaN O	4.21 R 8
07-05-1992 Sun	9,426.51 R 7	NaN O	NaN O	NaN O		NaN O	4.20 R 8
07-06-1992 Mon	9,369.77 R 7	NaN O	NaN O	26.51 R 64		NaN O	4.17 R 8
07-07-1992 Tue	9,325.52 R 7	6.28 R 39	NaN O	26.51 R 64		NaN O	4.13 R 8
07-08-1992 Wed	9,268.92 R 7	NaN O	NaN O	26.47 R 64		NaN O	4.10 R 8
07-09-1992 Thu	9,226.71 R 7	7.28 R 39	NaN O	26.51 R 64		NaN O	4.07 R 8

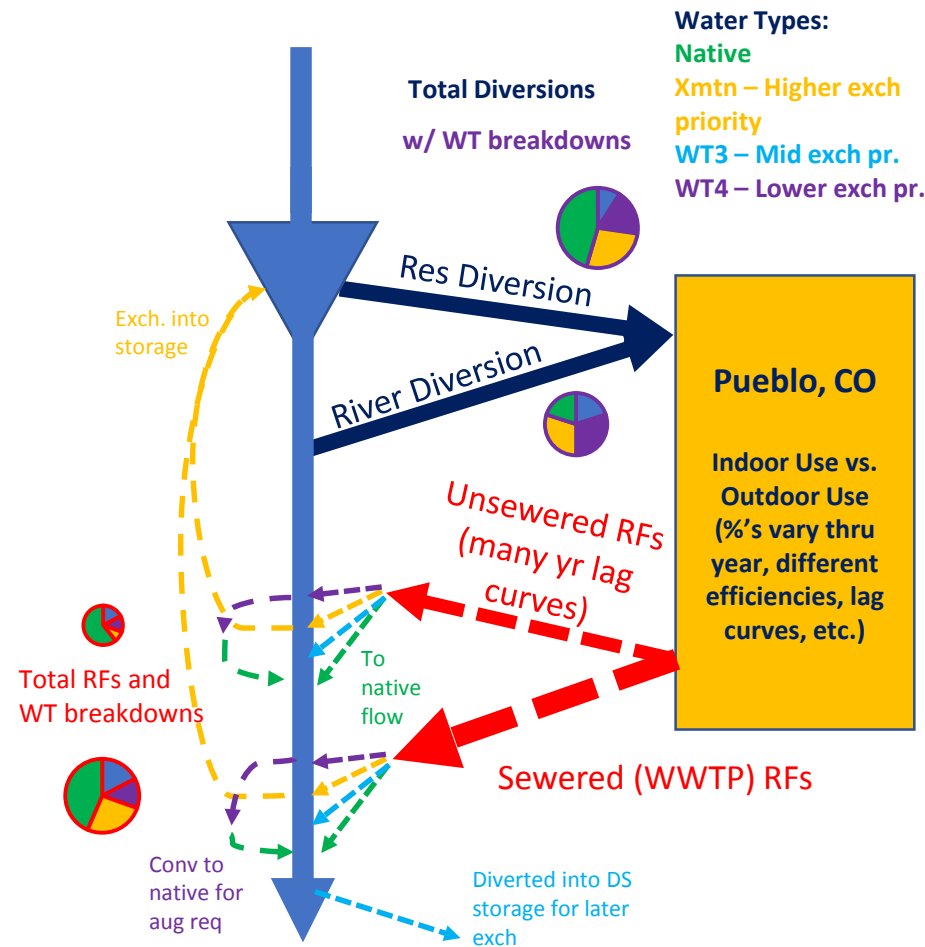
Detailed Return Flow Accounting

- Many water types are “reusable” or “fully consumable” (e.g., xmtn, Δ WRs)
- These can be significant supply sources and important to operations
- Thus, need to simulate detailed RF processes and accounting

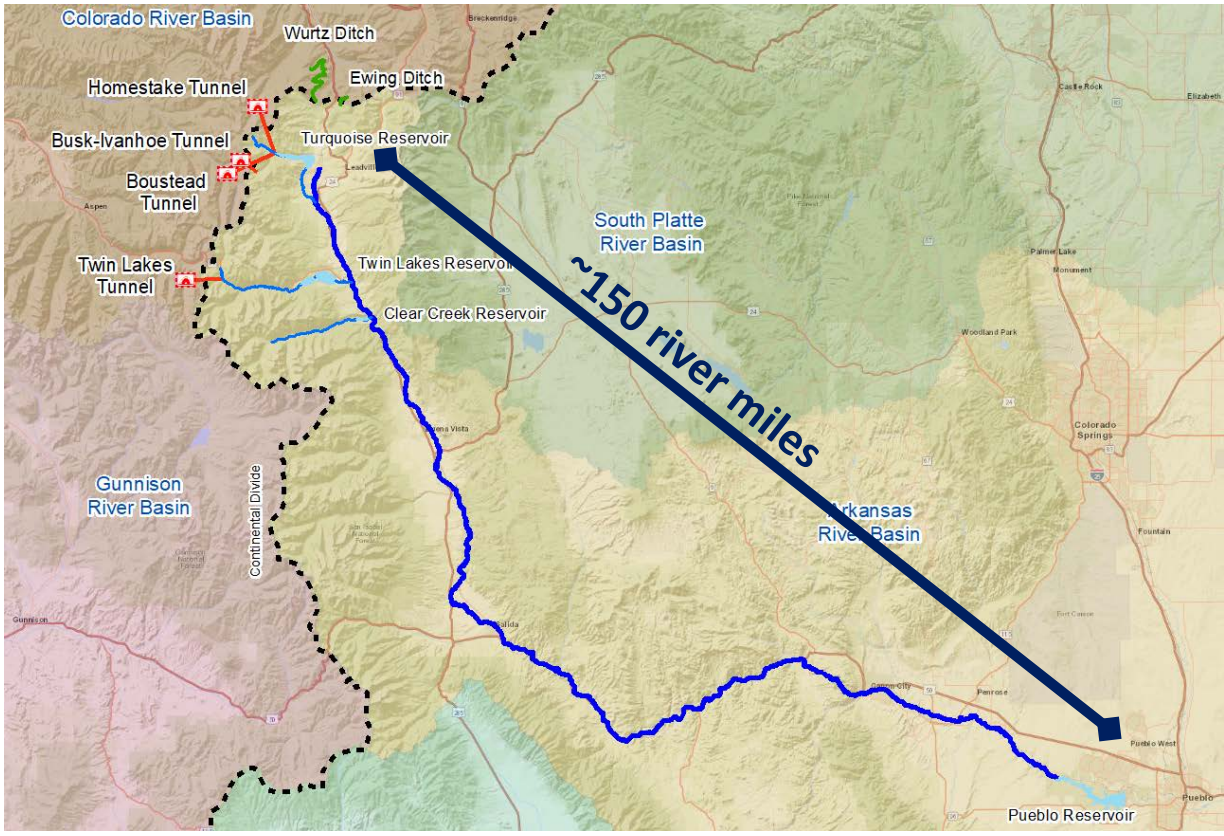


Detailed Return Flow Accounting

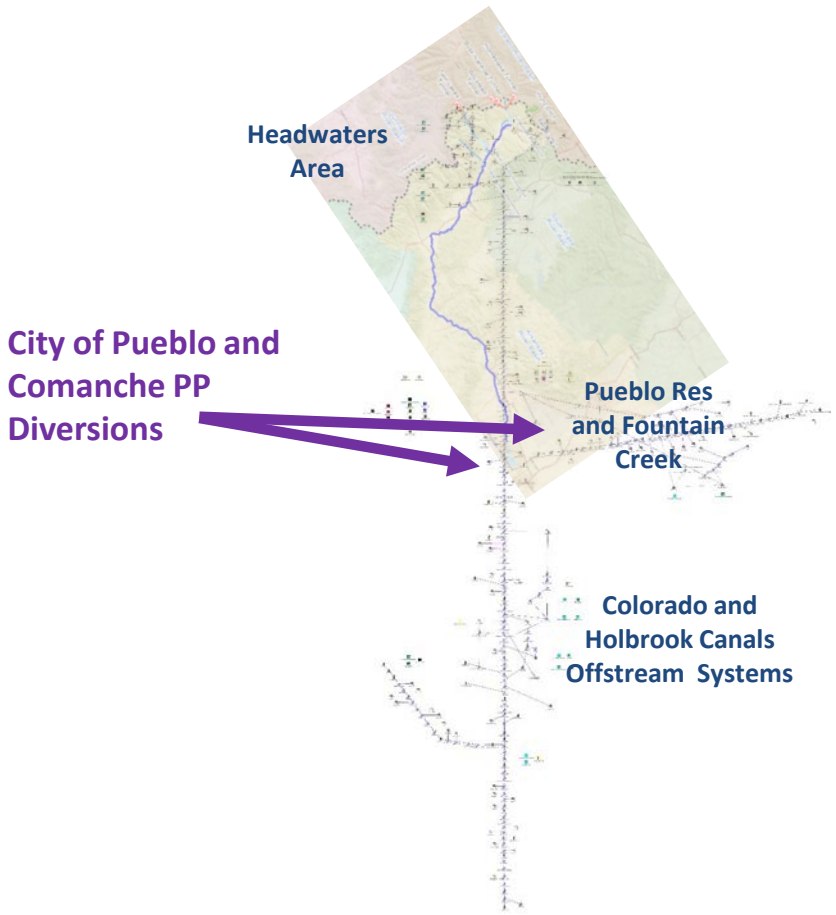
- Many water types are “reusable” or “fully consumable” (e.g., xmtn, ΔWRs)
- These can be significant supply sources and important to operations
- Thus, need to simulate detailed RF processes and accounting
- As reusable RFs return to river, different WTs can be used in different ways



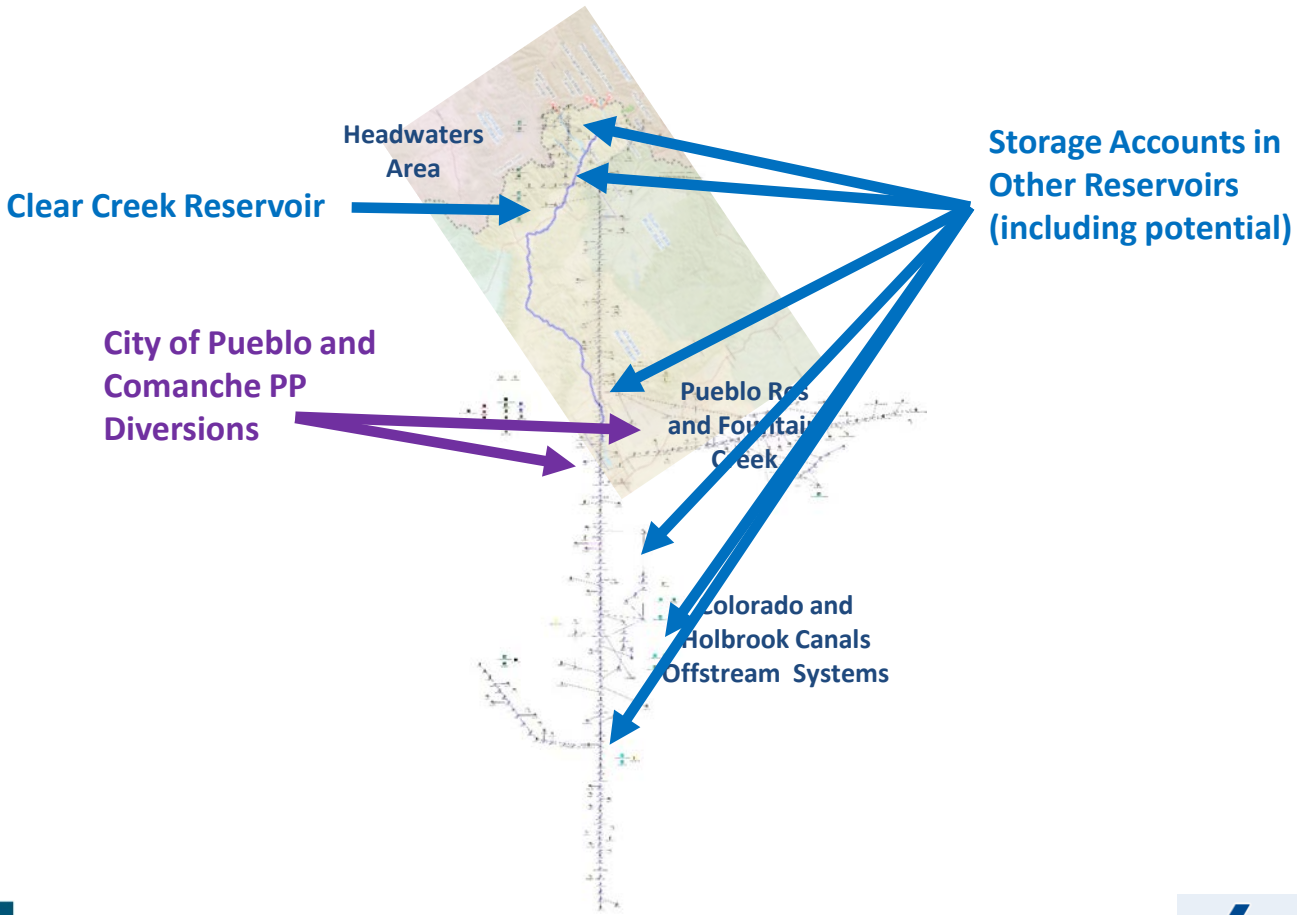
Overview of Pueblo Water's System



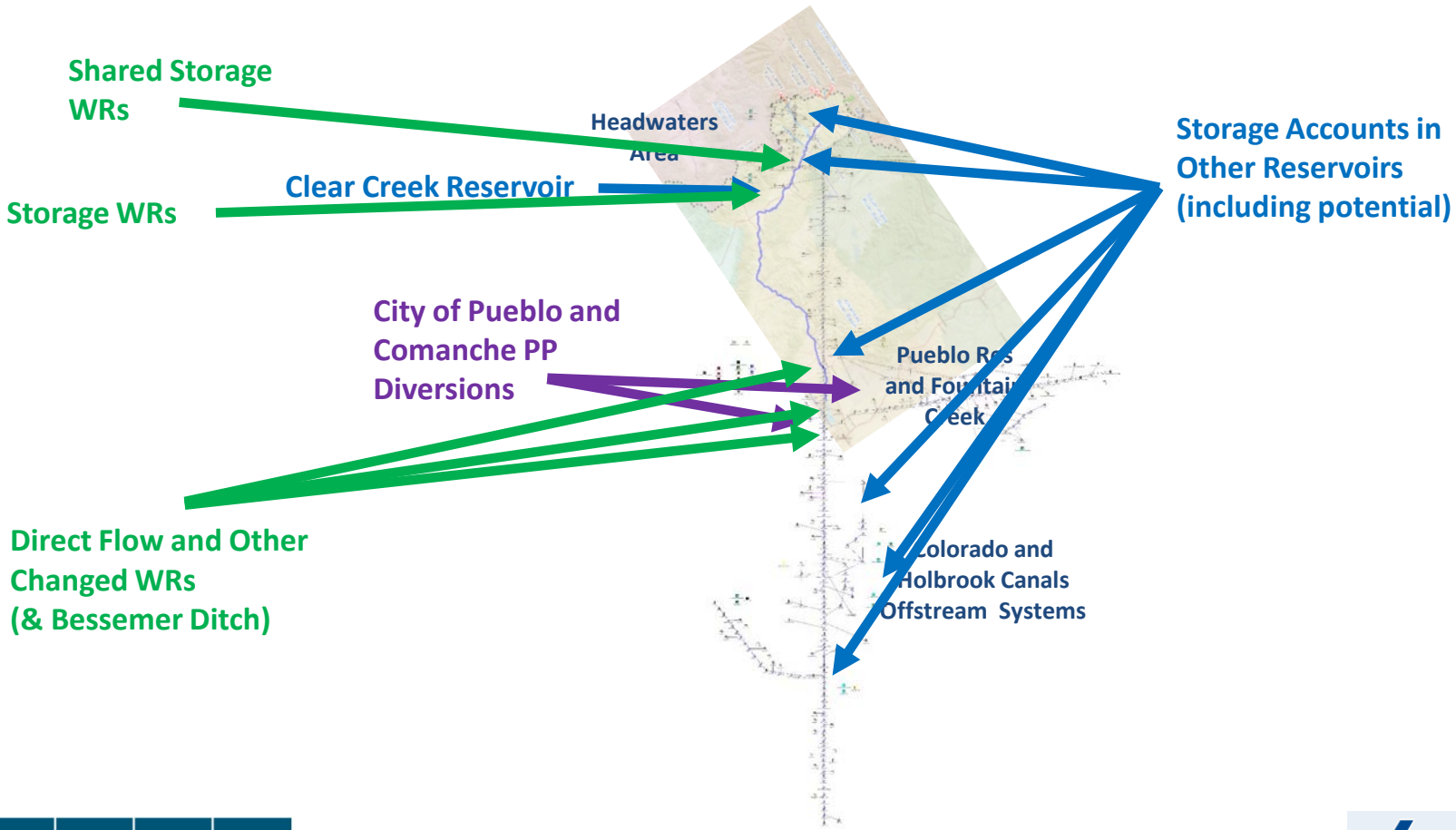
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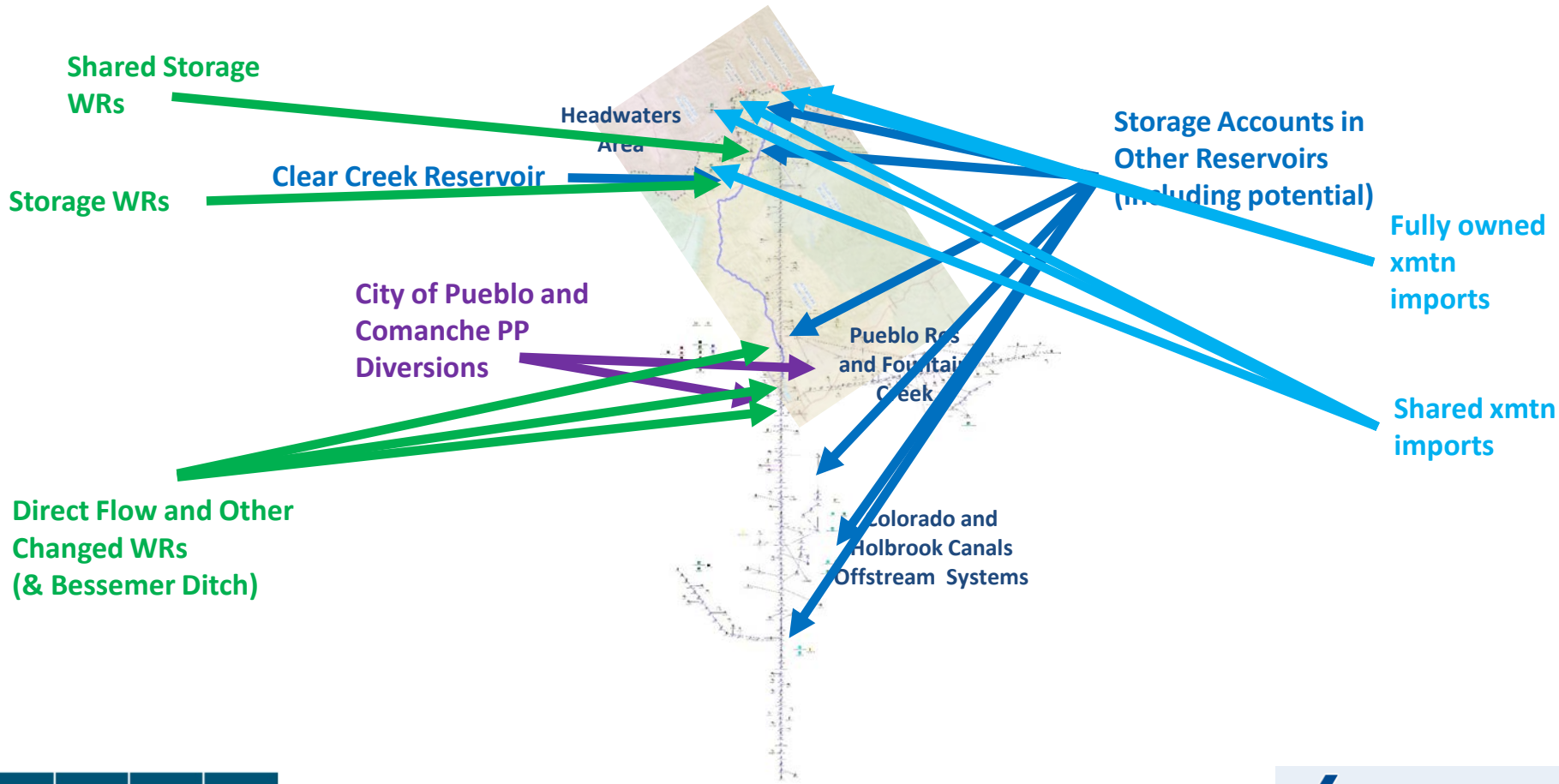
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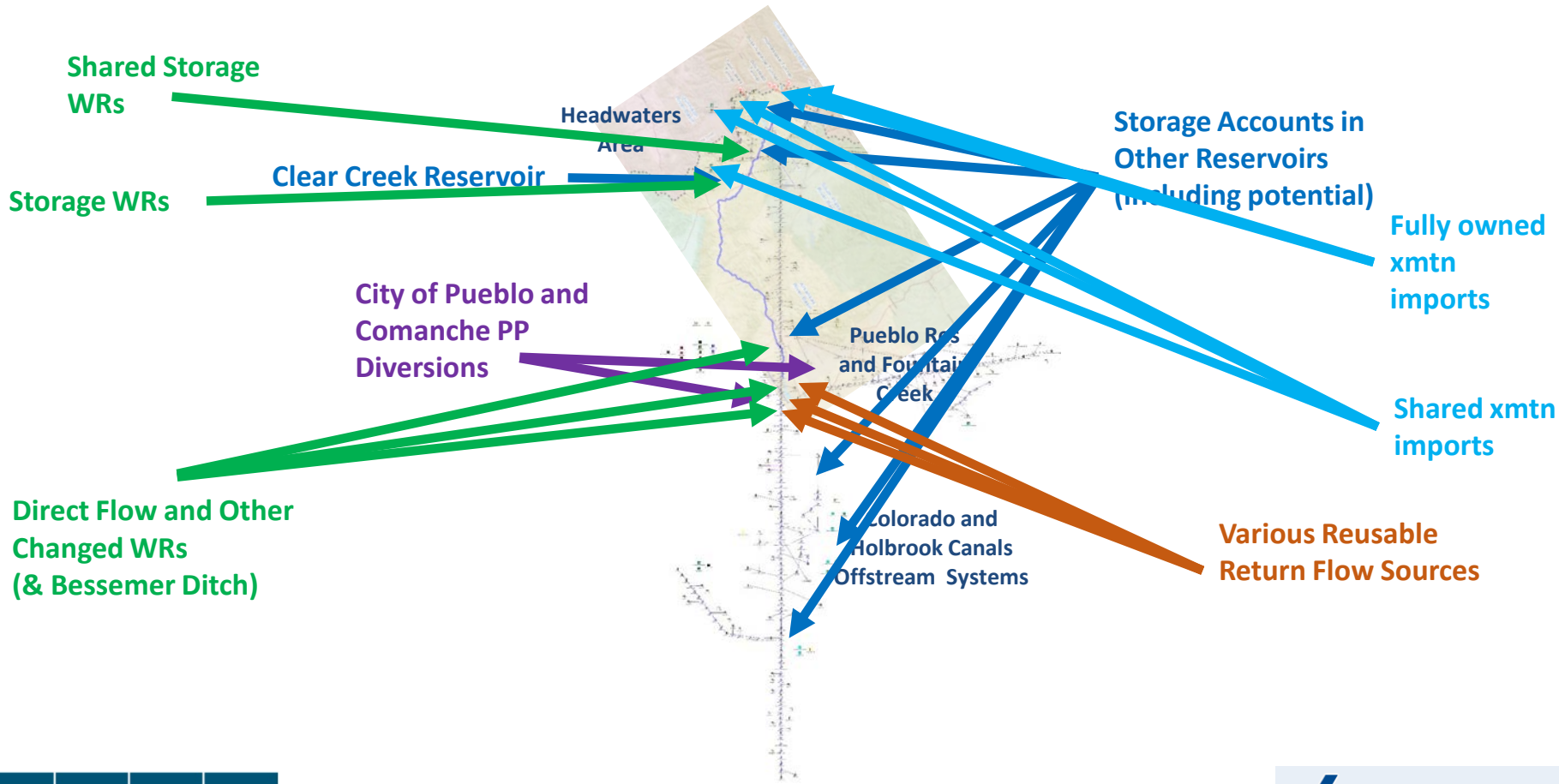
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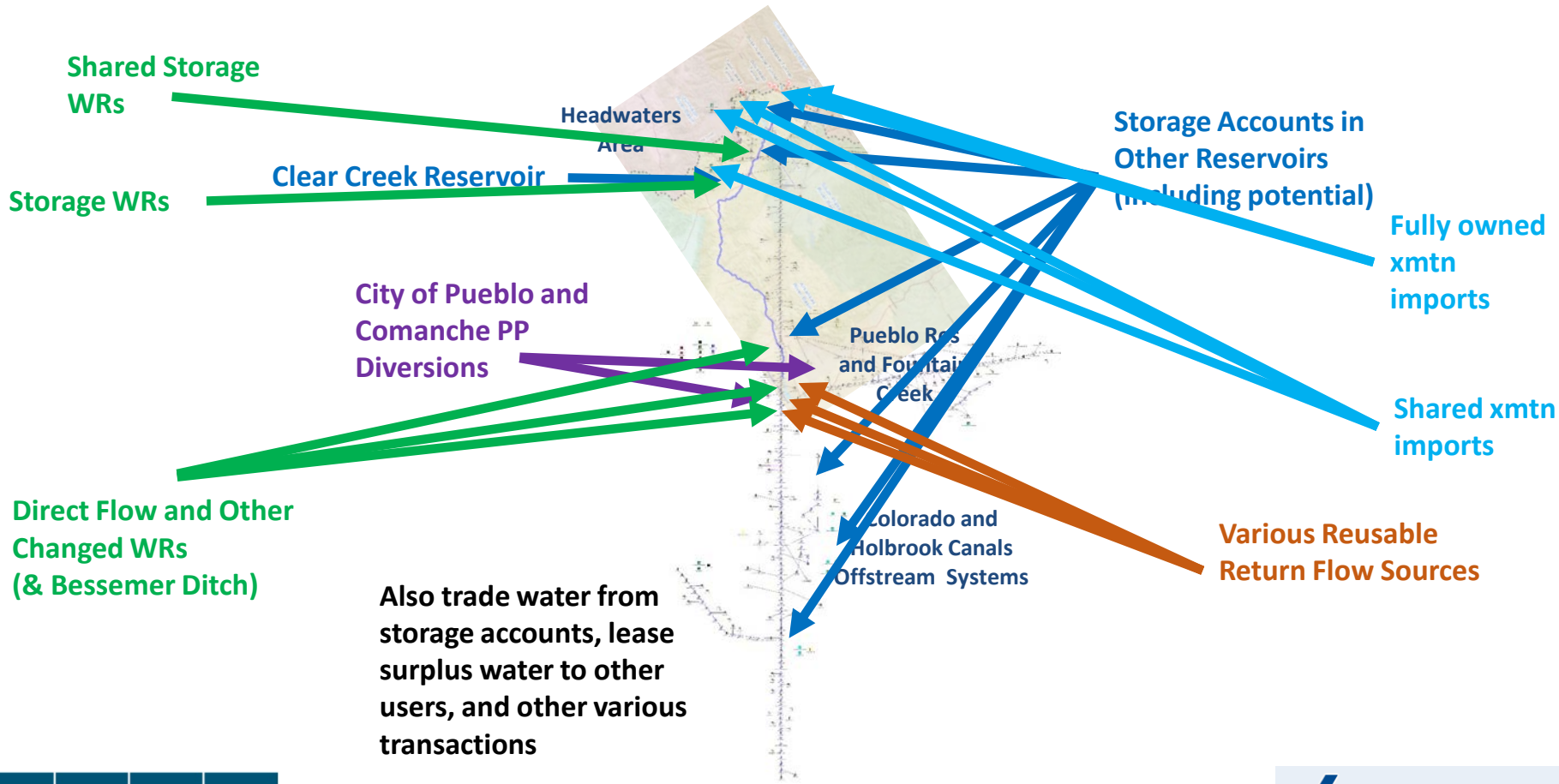
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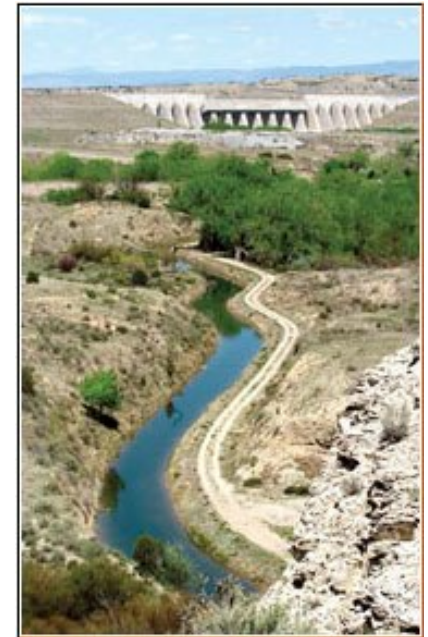
Pueblo Water's Water Rights Change Case

Emily Logan, Pueblo Water



Background

- Pueblo Water purchased ~28% of Bessemer Ditch in 2009
 - ~5488.36 shares at >\$10,000/share = >\$55,000,000
 - Annual yield ~ 7,500 AF/year
- Bessemer Ditch Water Rights:
 - 322 cfs with May 1887 priority date
 - 70.65 cfs of 1882 and earlier priority date
 - Winter Water – annual average diversion of about 63,000 AF
- Water Rights currently only allow for agricultural uses
 - Yields are leased back to farmers
 - Plan is to gradually convert shares to municipal use as need grows
- Need to go through Colorado Water Courts to change them to allow for municipal, storage, and other uses



Pueblo Water's Team of Experts

- Water Rights & Engineering - Deere and Ault Consultants
- System Modeling - Precision Water Resources Engineering
- Population Growth – Summit Economics, State Demography Office
- Demand Projections – Pueblo Water
- Climate Change – Abt Associates, Corona Environmental Consulting
- Colorado Compact/Transbasin Imports – Anne Castle
- Water Quality - Timothy Gates, CSU

Main Study Objectives

- Colorado's Anti-Speculation Water Doctrine
 - Essentially, to get water rights changed to allow for municipal uses and storage, need to show an actual need for the water
 - Pagosa Springs v. Trout Unlimited Supreme Court case
- Pueblo Water's Planning Objective:
 - 50-year Planning Horizon – Year 2070
 - Have sufficient water supplies to meet projected future demands
- Develop a range of potential scenarios and alternatives
- Two Failure Conditions:
 - “Minimum Storage Reserve” and/or “Delivery Shortage” failures

Model Scenarios and Alternatives

- 20 total scenarios developed to envelope potential future conditions

Hydrology Alternatives (3 total)	6-Year “Base” Design Drought
	6-Year Design Drought Adjusted -4% for Climate Change and Curtailed Imports in last 3 years
	6-Year Design Drought Adjusted -10% for Climate Change and Curtailed Imports in last 3 years
Demand Alternatives (6 total)	Future-Mid Growth
	Future-High Growth
	Future-Mid + 6%
	Future-High + 6%
	Future-Mid + 6% with Reduced Comanche PP
	Future-High + 6% with Reduced Comanche PP
Bessemer Ditch Yield Usage Alternatives (2 total)	No Bessemer Usage
	With Bessemer Usage

Hydrology Alternatives

- Base Design Drought, existing from previous studies
 - 6-year long, ~100 year return period
 - Model inputs not available for all years, analog years used

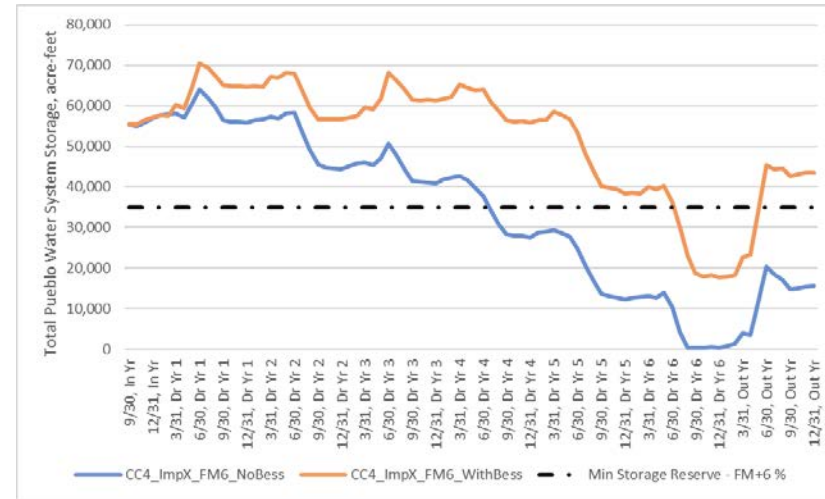
Climate Change and Import Curtailment Scenarios

- -4% Naturalized Hydrology Inputs
- -10% Naturalized Hydrology Inputs
- In both, last 3 years of drought have curtailed imports (those junior to Colorado Compact)
- ABRW Model “Hydrology Construction Workbook” used to very efficiently develop alternative inputs

Pueblo Water 6-yr Design Drought Sequence Historical Year	Analog Model Input Hydrology Year Used	Historical Import Year Used
1976	2001	1976
1977	2012	1977
1988	1992	1988
1990	1991	1990
1981	2012	1981
2002	2002	2002

Summary of Modeling Results

- Clear need for Bessemer water under all but the least severe scenario
- Many scenarios show additional need even with Bessemer yields



Shorthand Model Scenario Name	Water Supply Performance	Minimum Storage Reserve (AF)	Simulated Minimum Total Pueblo Water System Storage, AF	Simulated Total Delivery Shortages, AF
DD_FM_NoBess	No failures	45,270	34,388 (in 6 th yr)	0
DD_FH_NoBess	Minimum Storage Reserve failure	48,440	25,850 (in 6 th yr)	0
DD-4%+ImpX_FM+6%_NoBess	Minimum Storage Reserve and Delivery Shortage failures	47,990	Empty (in 6 th yr)	8,686 (in 6 th yr)
DD-4%+ImpX_FH+6%_NoBess	Minimum Storage Reserve and Delivery Shortage failures	51,350	Empty (in 6 th yr)	19,206 (in 6 th yr)
DD-10%+ImpX_FM+6%_NoBess	Minimum Storage Reserve and Delivery Shortage failures	47,990	Empty (in 6 th yr)	15,500 (in 6 th yr)
DD-10%+ImpX_FH+6%_NoBess	Minimum Storage Reserve and Delivery Shortage failures	51,350	Empty (in 5 th and 6 th yrs)	25,869 (in 5 th and 6 th yrs)

Shorthand Model Scenario Name	Water Supply Performance	Minimum Storage Reserve (AF)	Simulated Minimum Total Pueblo Water System Storage, AF	Simulated Total Delivery Shortages, AF
DD_FM_WithBess	No failures	45,270	51,706 (in 6 th yr)	0
DD_FH_WithBess	No failures	48,440	47,959 (in 6 th yr)	0
DD-4%+ImpX_FM+6%_WithBess	Minimum Storage Reserve failure	47,990	17,546 (in 6 th yr)	0
DD-4%+ImpX_FH+6%_WithBess	Minimum Storage Reserve failure	51,350	10,054 (in 6 th yr)	0
DD-10%+ImpX_FM+6%_WithBess	Minimum Storage Reserve failure	47,990	10,623 (in 6 th yr)	0
DD-10%+ImpX_FH+6%_WithBess	Minimum Storage Reserve failure	51,350	631 (in 6 th yr)	0 (narrowly)

Proposed Bessemer Ditch Ops

- Implement procedures following mutual ditch operations
 - Prorated amount of water delivered based on share quantity
- Portion of our shares will be delivered to Pueblo Reservoir
 - This will result in an incremental reduction of canal loss by volume; therefore, 4.25% of its lateral headgate deliveries will be returned to the river to mitigate the possible increased consumptive use
- 10% of our shares will be delivered down the ditch to replicate surface return flows
- Lagged return flows will be delivered based on timing function at appropriate band

Ditch Loss Percent	0.124
Total WR Allocation	150
PBWW Shares	0.278
PBWW Portion	41.7
PBWW Ditch Loss	5.17
PBWW Total Equiv Lat HG Div	36.52
PBWW Transfer to Storage	32.87
PBWW Deliver through Ditch	3.65

Ditch operators guess based on flows (historical records indicate an average ditch loss from 11.5% - 16% based on diversion)

Direct Flow Rights in priority

PBWW portion based on 27.8% shares

Theoretical amount going to "head gate"

PBWW agreed to deliver 10% through the ditch and keep 90% in storage

Outcome

- RiverWare modeling and results were well accepted and not challenged by opposing parties
- While we don't have a final decree yet because we are waiting on settlement in our exchange case, we were successful in reaching agreements with opposers and proving our need

Future Uses:

- Expansion of reservoir storage
- Operational decision model for short term planning
- More accurate determination for leases
- Primary tool for Integrated Water Resources Plan

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