A Multi-Reservoir Testbed in Borg-RiverWare to Aid Multi-Objective Simulation-Based Optimization

Joseph Kasprzyk, Edith Zagona, David Neumann, Patrick Lynn

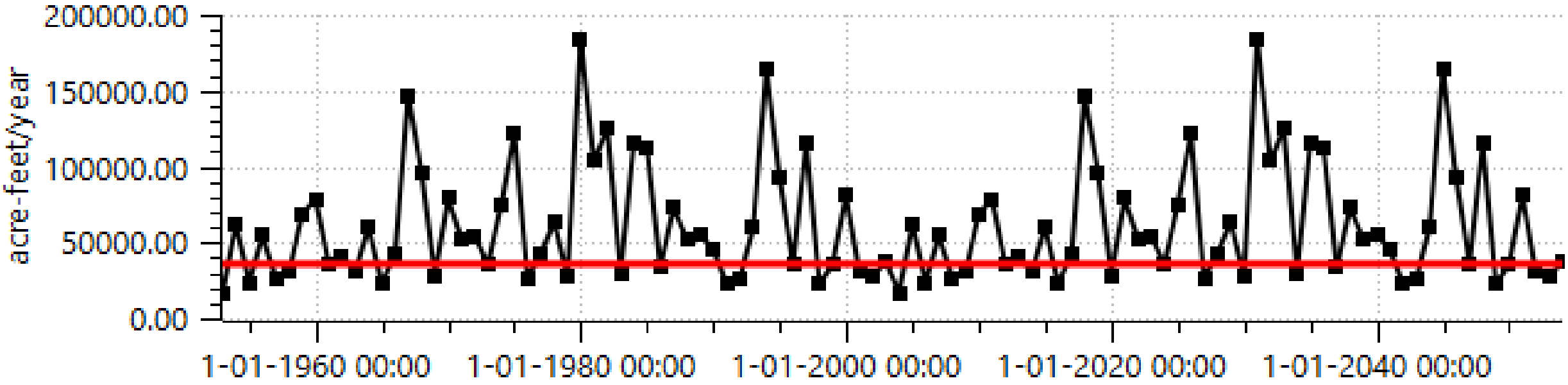
Presentation for the 2025 RiverWare User Group Meeting

Outline:

(1) **What can Borg-RiverWare be used for? A single reservoir example**

(2) A more complex multi-reservoir testbed

A **single** reservoir testbed



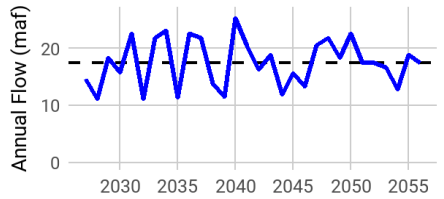
What **volumetric capacity** can meet **36,000 af/year** demand…

…but also maintain storage targets…

…and avoid multiple failure periods…

“Trial and Error”: modify system configuration and operating policy by changing values of slots referenced in RPL rules, creating performance metrics to judge performance.

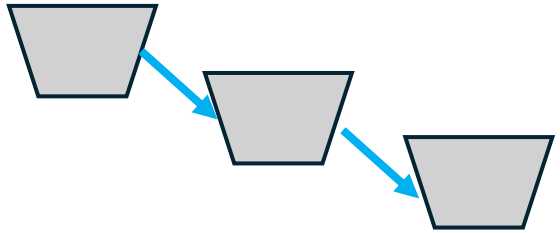
External Inputs



Hydrology (stochastic ensemble, historical record, forecast, etc.)

Water Demand

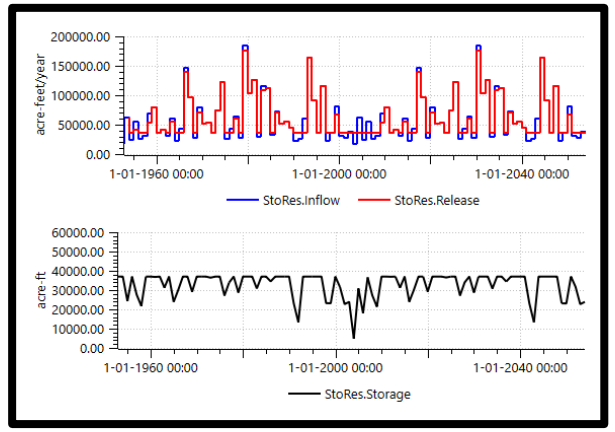
RiverWare



Outputs

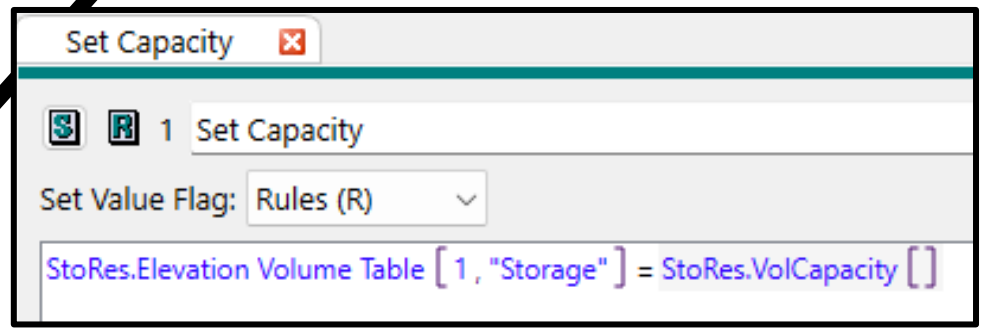
Timeseries of Storage, Water Deliveries, etc.

Performance Metrics



Use expression slots to analyze timeseries of delivery and storage

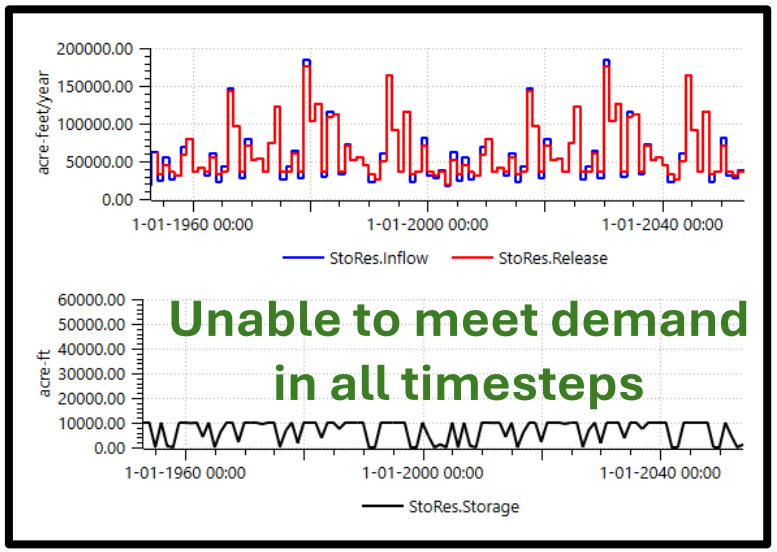
System Configuration and Operating Policy



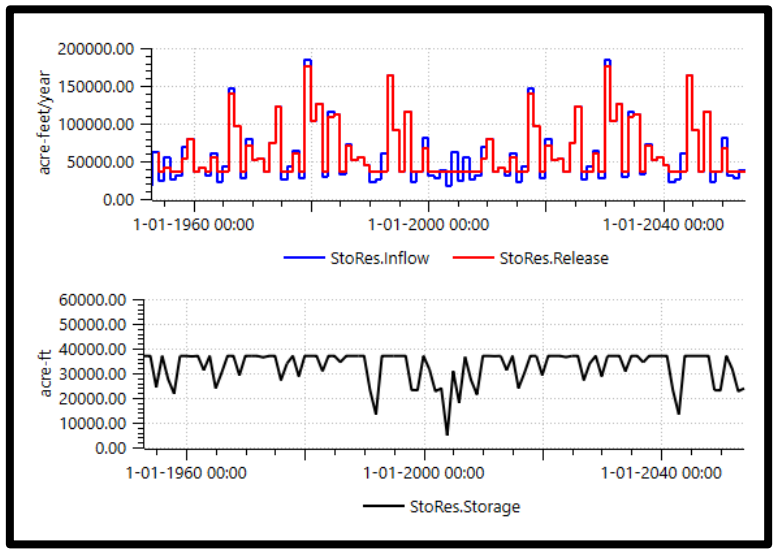
Set a volumetric capacity in an initialization rule

Three potential alternatives

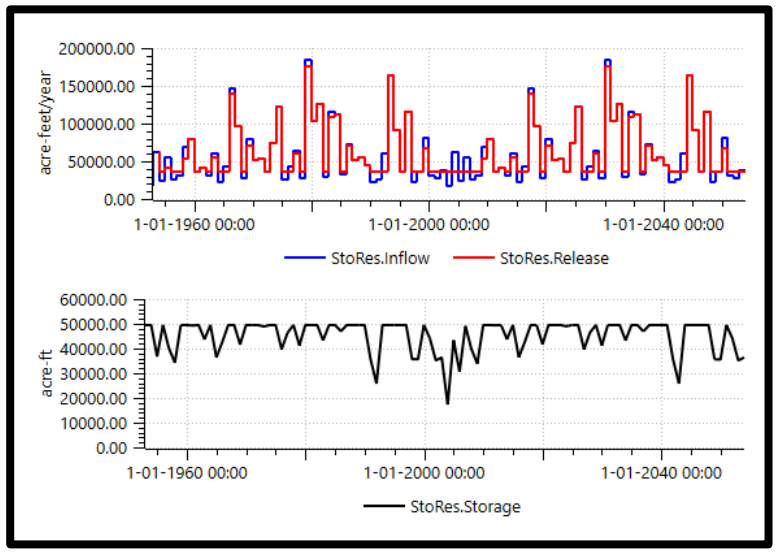
A: 10,000 af cap.



B: 37,000 af cap.



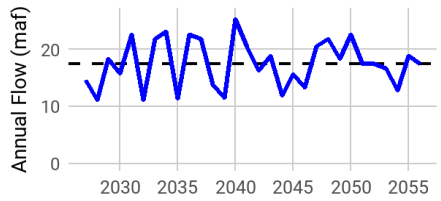
C: 49,500 af cap.



Different levels of excess capacity

Is there a better way to perform this analysis beyond trial and error?

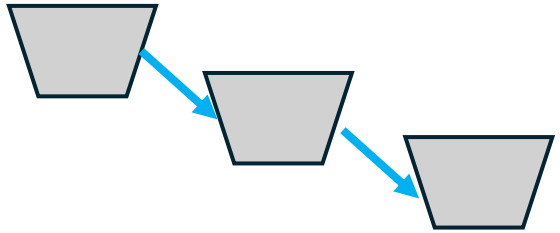
External Inputs



Hydrology (stochastic ensemble, historical record, forecast, etc.)

Water Demand

RiverWare



Outputs

Timeseries of Storage, Water Deliveries, etc.

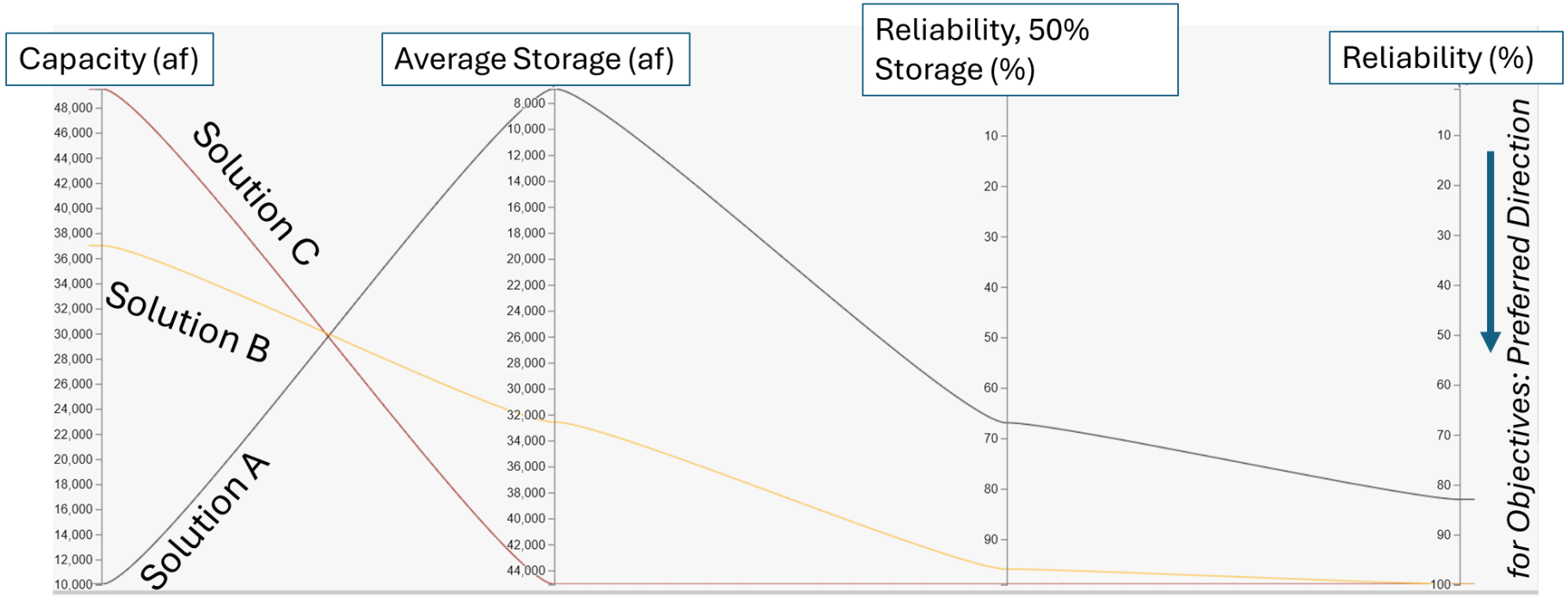
Performance Objectives

Config. and Op. Policy defined by Decision Variables

Borg MOEA

The Multi-Objective Evolutionary Algorithm (MOEA) mimics trial-and-error but *automatically* finds sets of **decision variable values** having the best compromises among **objectives**.

Variable	Equation (T = number of timesteps)	A	B	C
Decision Variable	Capacity [af]	10,000	37,000	49,500
Obj: Maximize Reliability	$100\% \times \left(\frac{\text{Num. timesteps with demand met}}{T}\right)$	83%	100%	100%
Obj: Maximize Reliability of 50% Storage	$100\% \times \left(\frac{\text{Num. timesteps with Storage } \geq 50\%}{T}\right)$	67%	96%	99%
Obj: Maximize Avg. Storage	$\frac{1}{T}\sum \text{Storage}$	6,905 af	32,599 af	45,099 af



Non-dominated solutions have performance at least as good as other members in the set and no worse in any objective.

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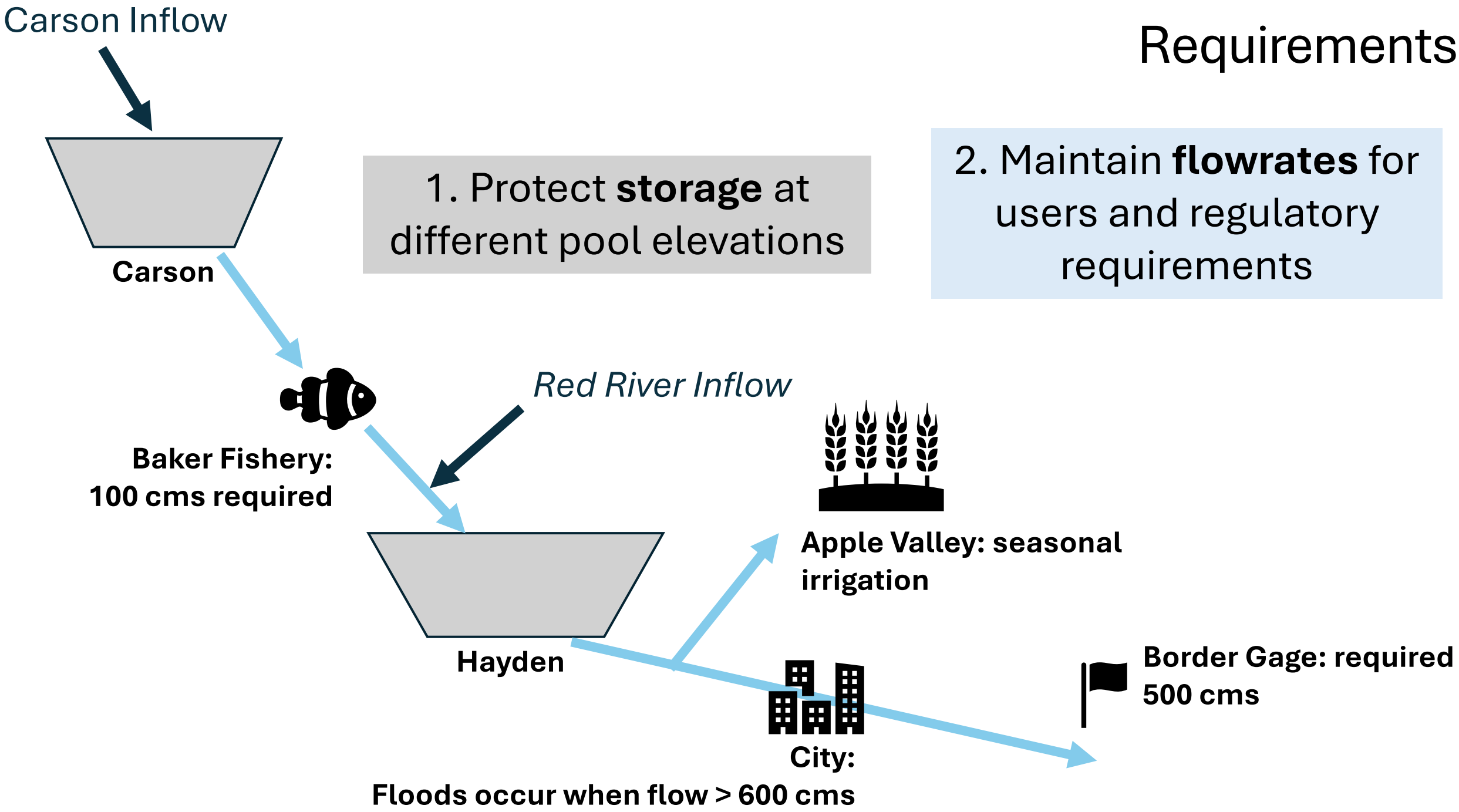
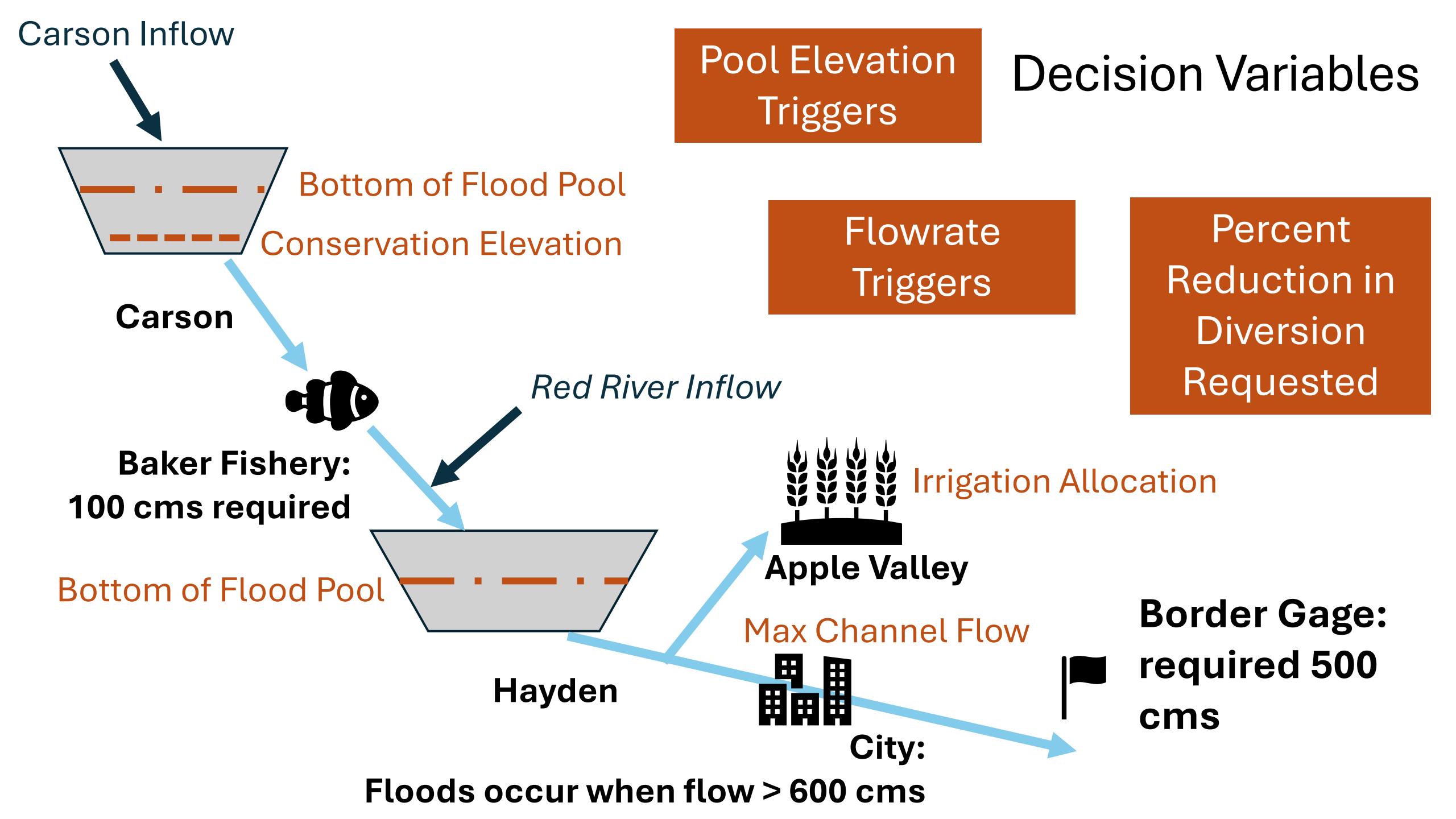
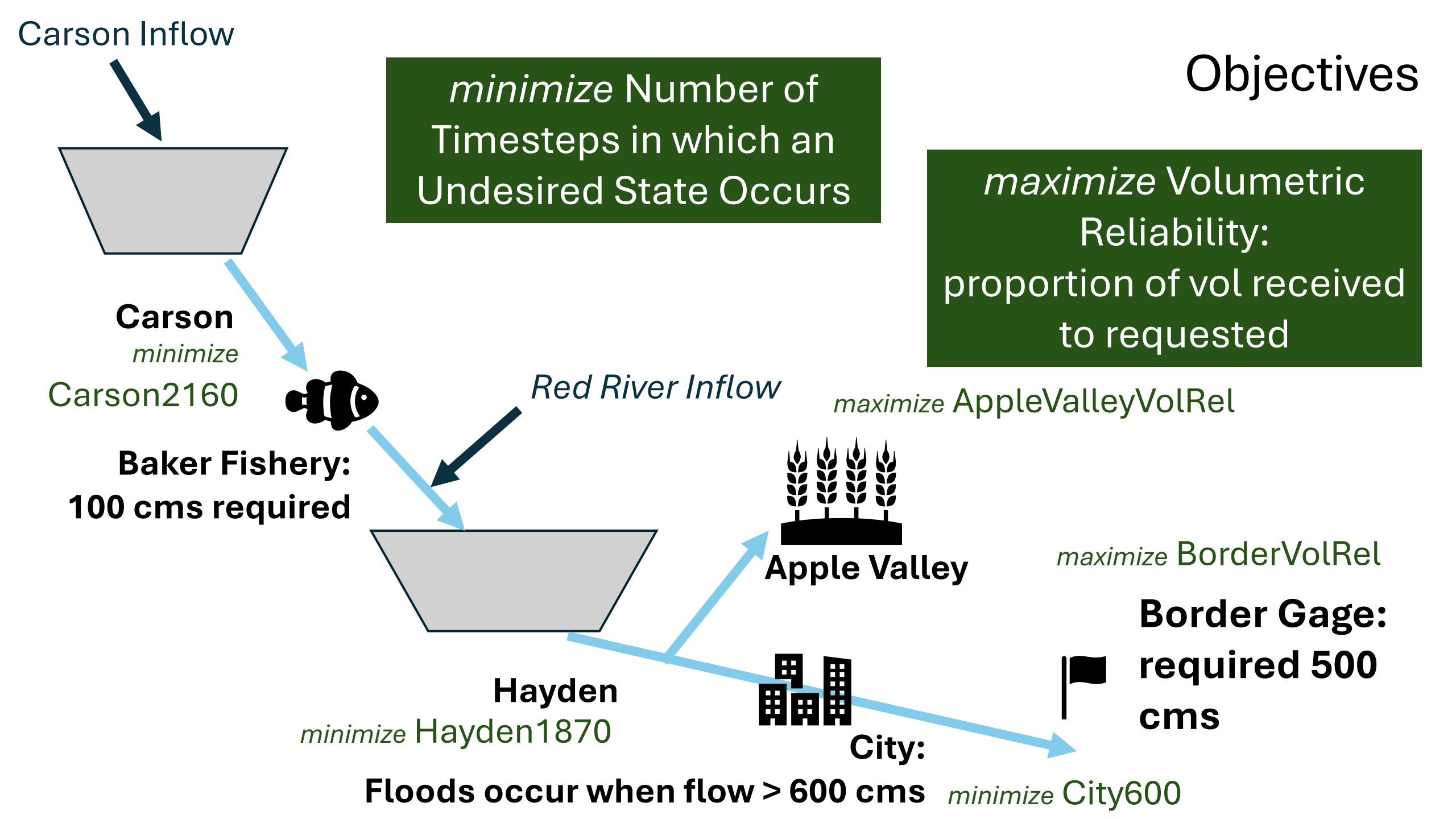
Requirements




Carson Inflow
Pool Elevation Triggers
Decision Variables
Bottom of Flood Pool
Conservation Elevation
Flowrate Triggers
Percent Reduction in Diversion Requested
Carson
Red River Inflow
Baker Fishery:
100 cms required
Irrigation Allocation
Apple Valley
Bottom of Flood Pool
Max Channel Flow
Border Gage:
required 500
cms
Hayden
City:
Floods occur when flow > 600 cms


Carson Inflow
Objectives
minimize Number of Timesteps in which an Undesired State Occurs
maximize Volumetric Reliability: proportion of vol received to requested
Carson
minimize
Carson2160
Red River Inflow
maximize AppleValleyVolRel
Baker Fishery:
100 cms required
Apple Valley
maximize BorderVolRel
Border Gage: required 500 cms
Hayden
minimize Hayden1870
City:
Floods occur when flow > 600 cms
minimize City600

```
Carson.Release [ ]
  = IF ( Border Gage.Gage Outflow [ ] < Border Gage.Interstate Flow Requirement [ ]
         AND Carson.Pool Elevation [ ] > Carson.Conservation Elevation [ ] ) THEN
    Min ( GetMaxReleaseGivenInflow ( Carson ,
                                     Carson.Inflow [ ] ,
                                     @"t" ) ,
          Max ( Carson.Release [ ]
                + ( Border Gage.Interstate Flow Requirement [ ]
                    - Border Gage.Gage Outflow [ ] ) ,
                SolveOutflow ( Carson ,
                               Carson.Inflow [ ] ,
                               ElevationToStorage ( Carson ,
                                                    Carson.Conservation Elevation [ ] ) ,
                               Carson.Storage [ @"t - 1" ] ,
                               @"t" ) ) )
  END IF
```

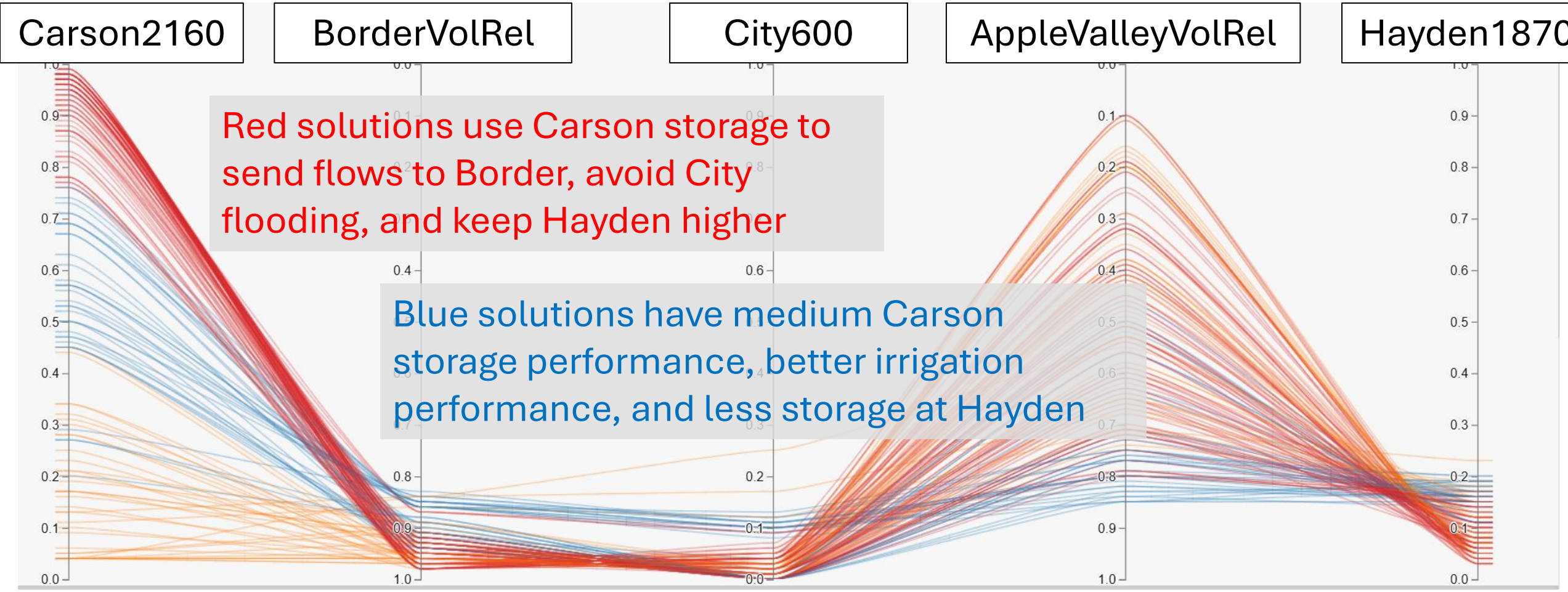
```
# (minimize) the fraction of time that Hayden is below 1870' (when it is below that
# elevation, it cannot release significant water)
FOR ( DATETIME date IN @"Start Timestep" TO @"Finish Timestep" ) WITH NUMERIC result = 0.00 DO
    result = result + IF ( Carson.Pool Elevation [ date ] <= 2,160.00 "m" ) THEN
                          1.00
                      ELSE
                          0.00
                      END IF
END FOR
                                  LENGTH @"Start Timestep" TO @"Finish Timestep"
```

The Borg MOEA creates a proposed value for **Carson.Conservation Elevation[]**

Results of an **expression slot** are sent back to the Borg MOEA and used to judge the performance of this solution

Config. and Op. Policy defined by Decision Variables

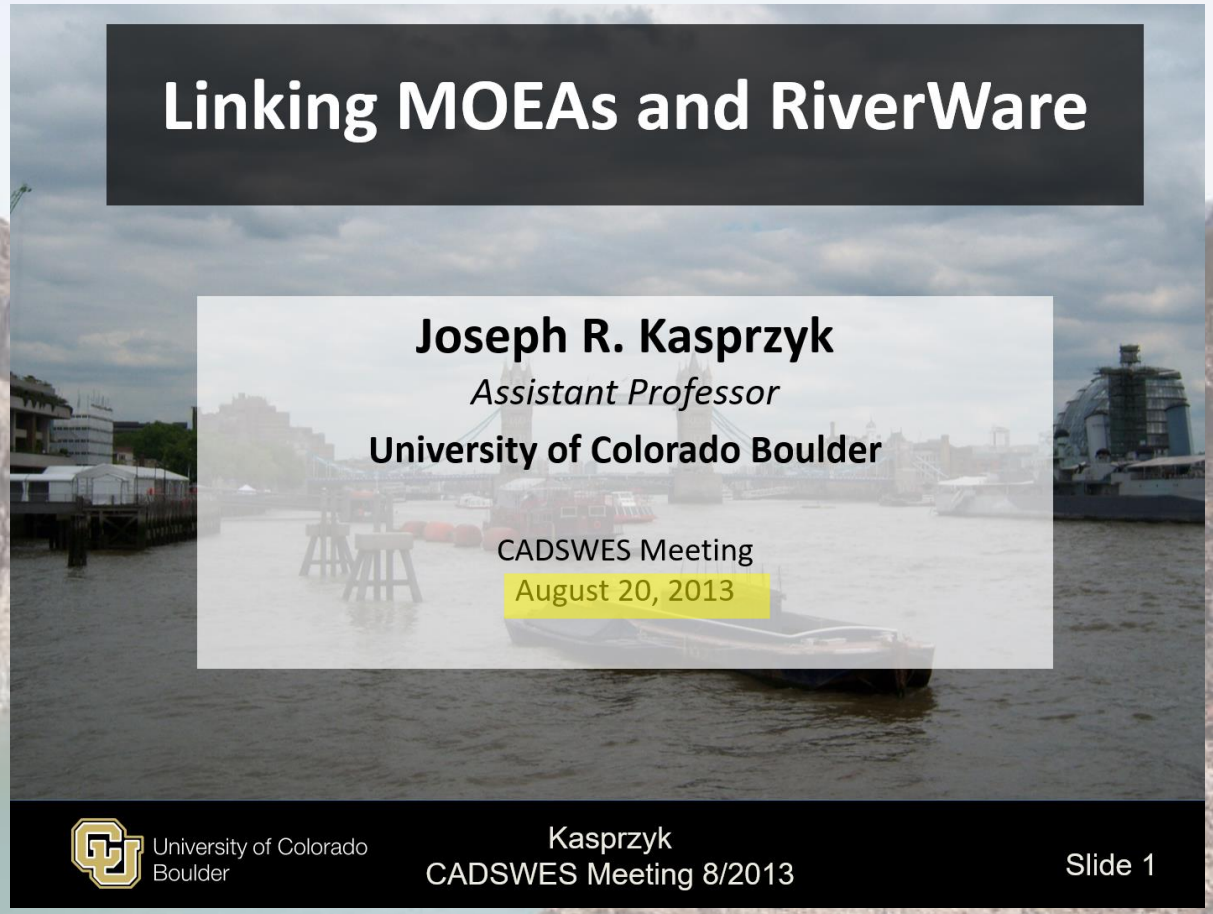
Borg MOEA


Carson2160
BorderVolRel
City600
AppleValleyVolRel
Hayden1870
Red solutions use Carson storage to send flows to Border, avoid City flooding, and keep Hayden higher
Blue solutions have medium Carson storage performance, better irrigation performance, and less storage at Hayden
Orange solutions protect Carson storage, limiting deliveries to Apple Valley irrigators

Acknowledgements

- Funded in part by the Bureau of Reclamation Lower Colorado Region and the U.S. Army Corps of Engineers Southwest Division
- Sincere thanks to the CADSWES team and Prof. Pat Reed for their continued support on the Borg-RiverWare project

A dream come true…



Thank you! Questions?

Joseph.Kasprzyk@colorado.edu

Figure: Chitose Suzuki