RECLAMATION
Managing Water in the West

Using Multi-Objective Optimization to Explore Reservoir Operating Policies in the Colorado River Basin

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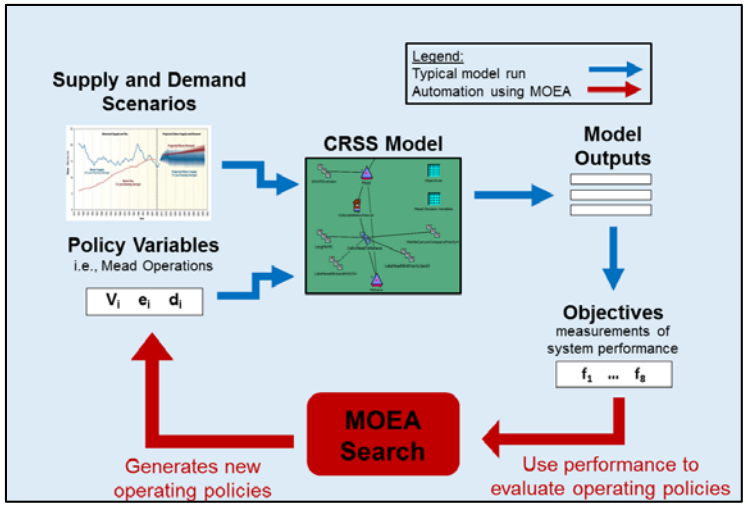
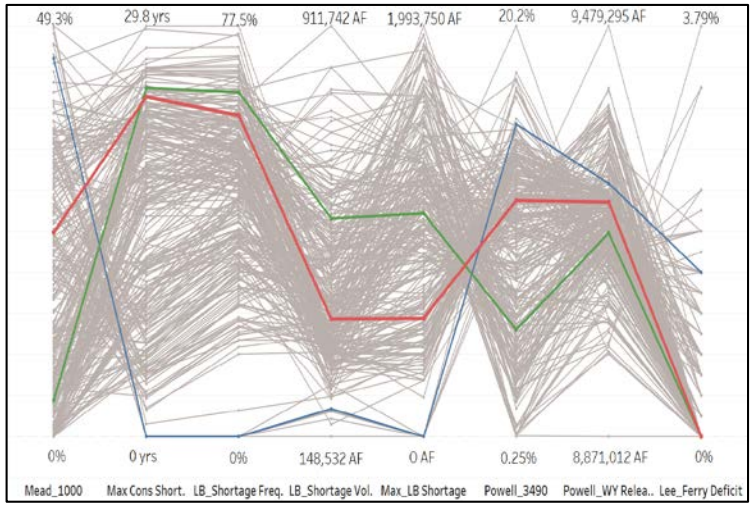
Agenda

Colorado River Policy



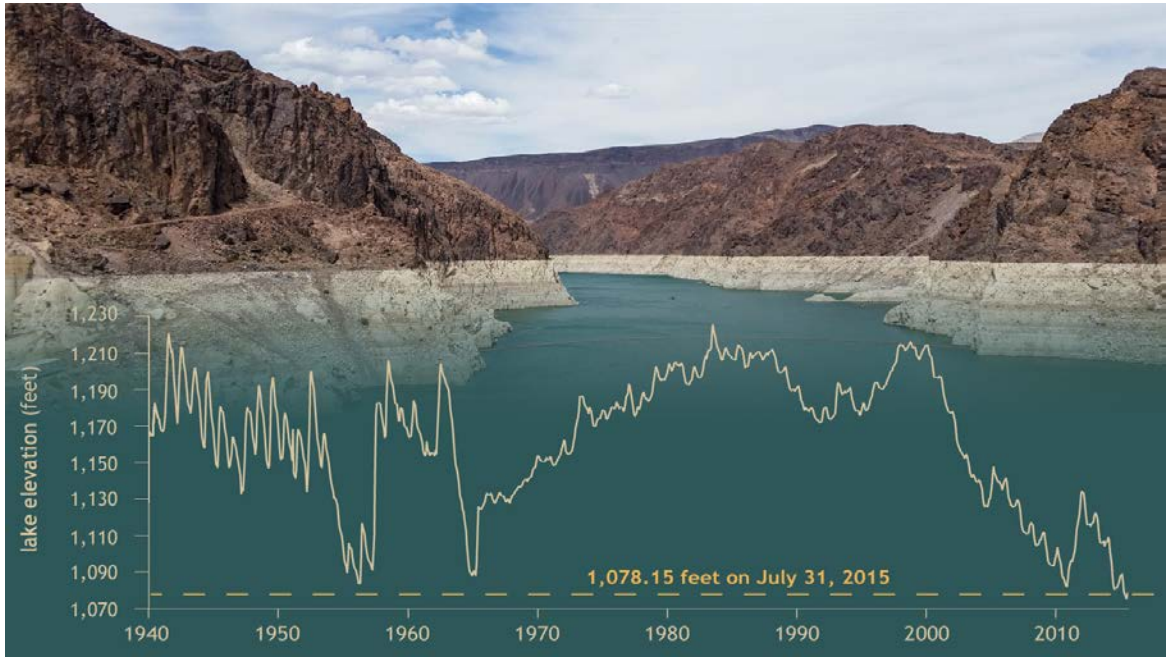
Methods



Preliminary Results

2007 Interim Guidelines Proposed Federal Actions

- **The interim guidelines would be used by the Secretary to:**
  - **Determine explicit guidelines for shortage operation in Lake Mead (Shortage Guidelines).**



THE SECRETARY OF THE INTERIOR
WASHINGTON

Record of Decision

Colorado River Interim Guidelines for Lower Basin Shortages and the

Coordinated Operations for Lake Powell and Lake Mead

December 2007

Recommending Official:

ROBERT JOHNSON — Date
Commissioner, Bureau of Reclamation

Approved:

DIRK KEMPTHORNE — Date
Secretary of the Department of the Interior

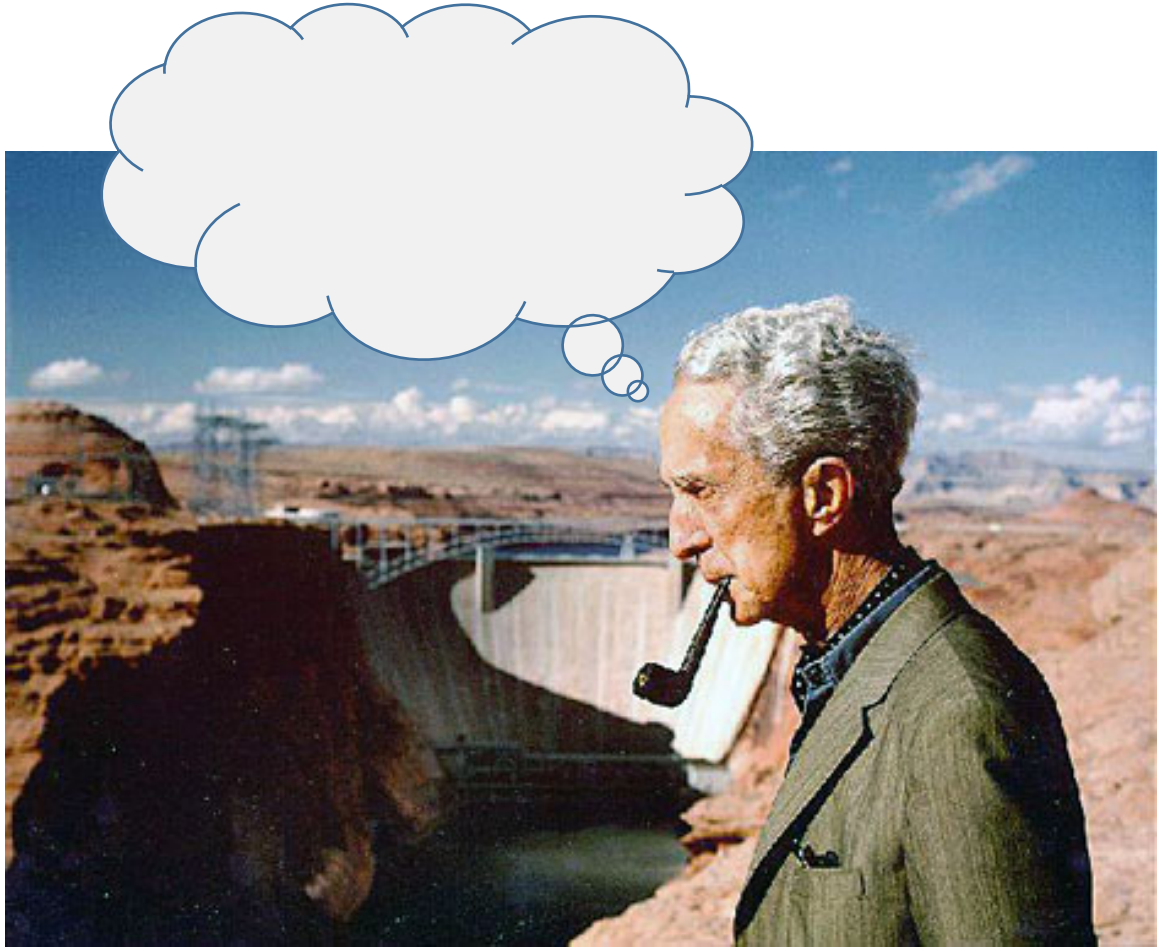
2007 Interim Guidelines Proposed Federal Actions

Lake Mead Elevation (feet msl)	No Action Alternative	Basin States Alternative	Conservation Before Shortage Alternative	Water Supply Alternative	Reservoir Storage Alternative	Preferred Alternative	Lake Mead Storage (maf)
1,220	Flood Control or 70R Surplus	Flood Control or 70R Surplus	Flood Control or 70R Surplus	Flood Control or 70R Surplus	Flood Control or 70R Surplus	Flood Control or 70R Surplus	25.9
1,200	Full Domestic Surplus (through 2016)	Domestic Surplus	Domestic Surplus	Full Domestic Surplus	Normal Operations	Domestic Surplus	22.9
1,145	Partial Domestic Surplus (through 2016)	Normal Operations	Normal Operations	Partial Domestic Surplus		Normal Operations	15.9
1,125	Normal Operations			Normal Operations			13.9
1,100					Shortage 500[1] kaf		11.5
1,075	Shortage 80 percent Protection of elevation 1,050 feet msl	Shortage 333 kaf[1]	Voluntary Conservation		Shortage 667[1] kaf	Shortage 333 kaf[1]	9.4
1,050		Shortage 417 kaf[1]			Shortage 833[1] kaf	Shortage 417 kaf[1]	7.5
1,025		Shortage 500 kaf[1] and Consultation[2]			Shortage 1,000[1] kaf	Shortage 500 kaf[1] and Consultation[2]	5.8
1,000	Shortage Absolute Protection of elevation 1,000 feet msl		Shortage Absolute Protection of elevation 1,000 feet msl				4.3
895							0

[1] These are amounts of shortage (i.e., reduced deliveries in the United States). As in the Draft EIS, the Final EIS includes modeling assumptions that identify water deliveries to Mexico pursuant to the 1944 Treaty.
[2] If Lake Mead falls below elevation 1,025, the Department will initiate efforts to develop additional guidelines for shortages at lower Lake Mead elevations.

Research Question

How can we inform the policy making process through searching a wide range of operating policies and quantify multiple basin resource performance metrics in an integrated framework?



Multi-Objective Evolutionary Algorithm (MOEA)

- **Multi-objective:** Solves multiple objectives simultaneously
- **Evolutionary:** Uses a process similar to natural selection to ‘evolve’ new solutions (see fig.)
- **Borg-MOEA:** Tested on many problems in civil engineering
- **Borg-RW:** RiverWare is embedded within the Borg search loop via a “wrapper”

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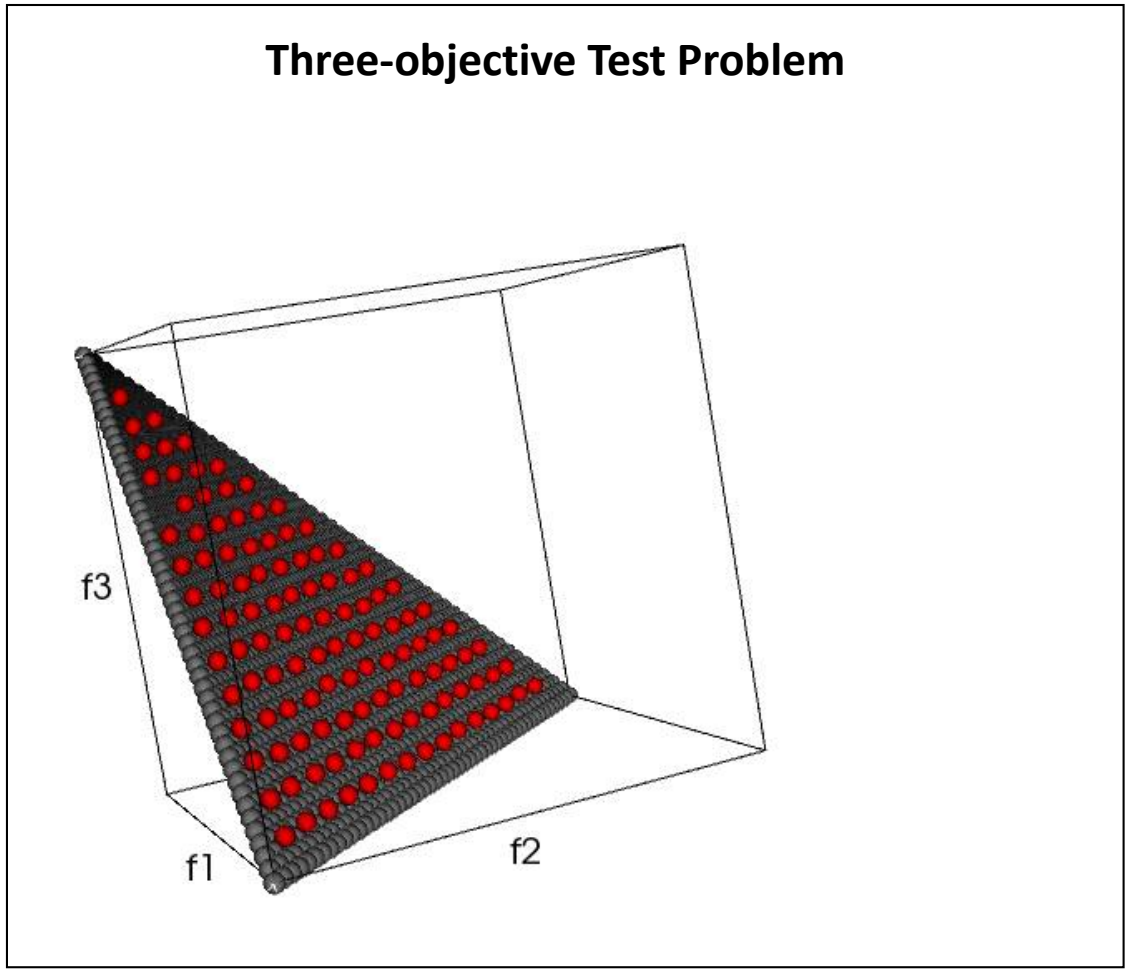
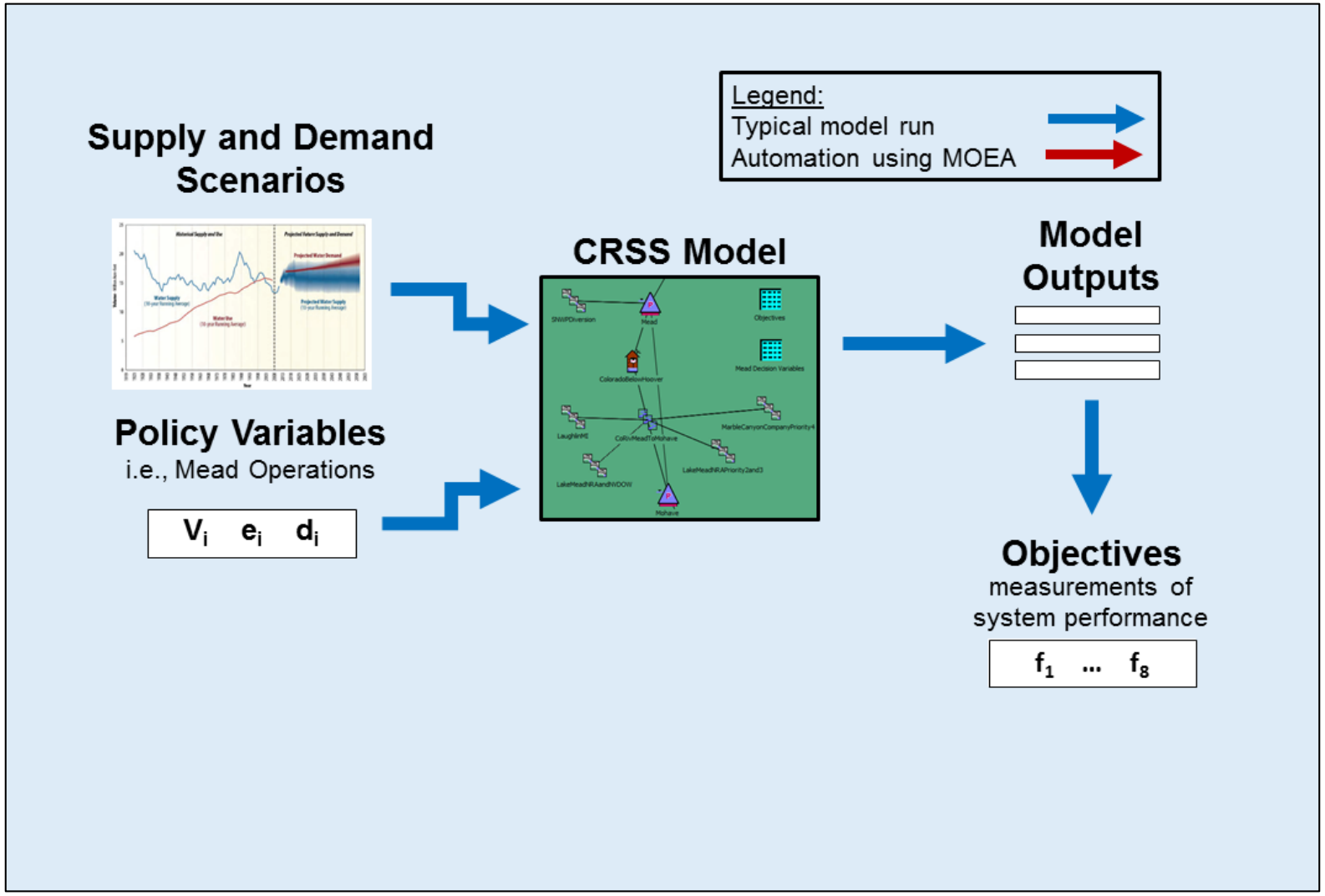
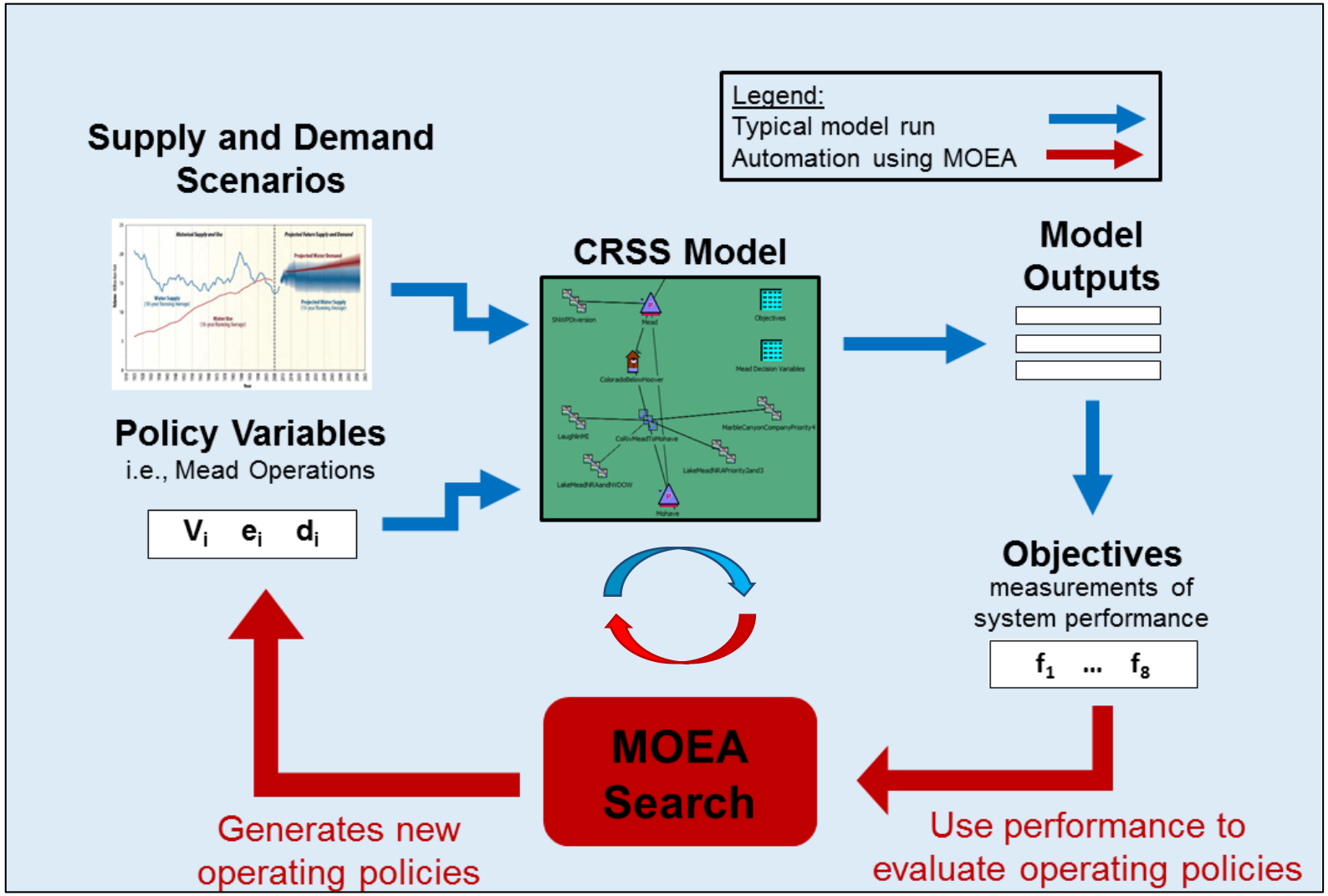


[Kasprzyk et al. 2016]

Coupling Colorado River Simulation System (CRSS) with Borg-MOEA



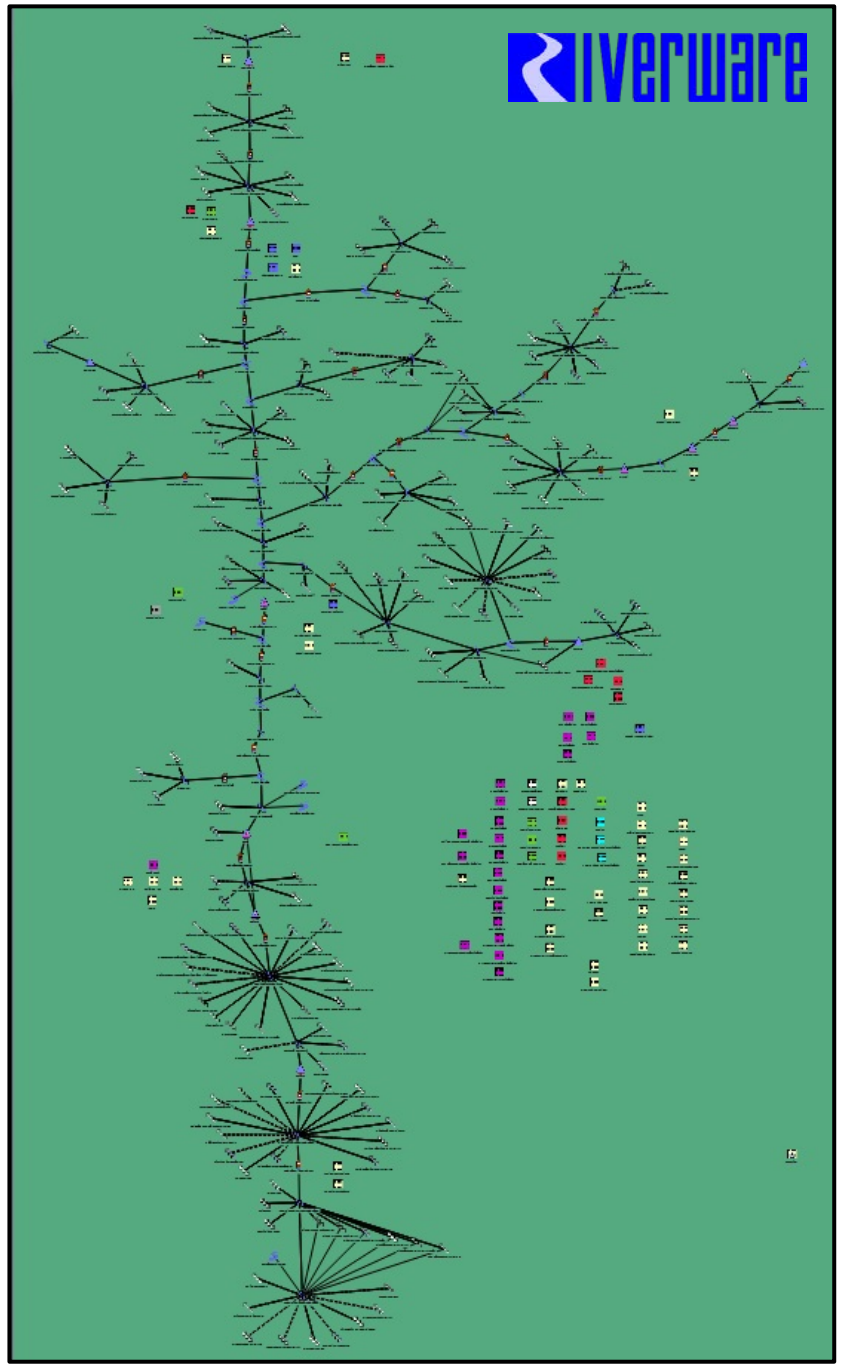
Coupling Colorado River Simulation System (CRSS) with Borg-MOEA



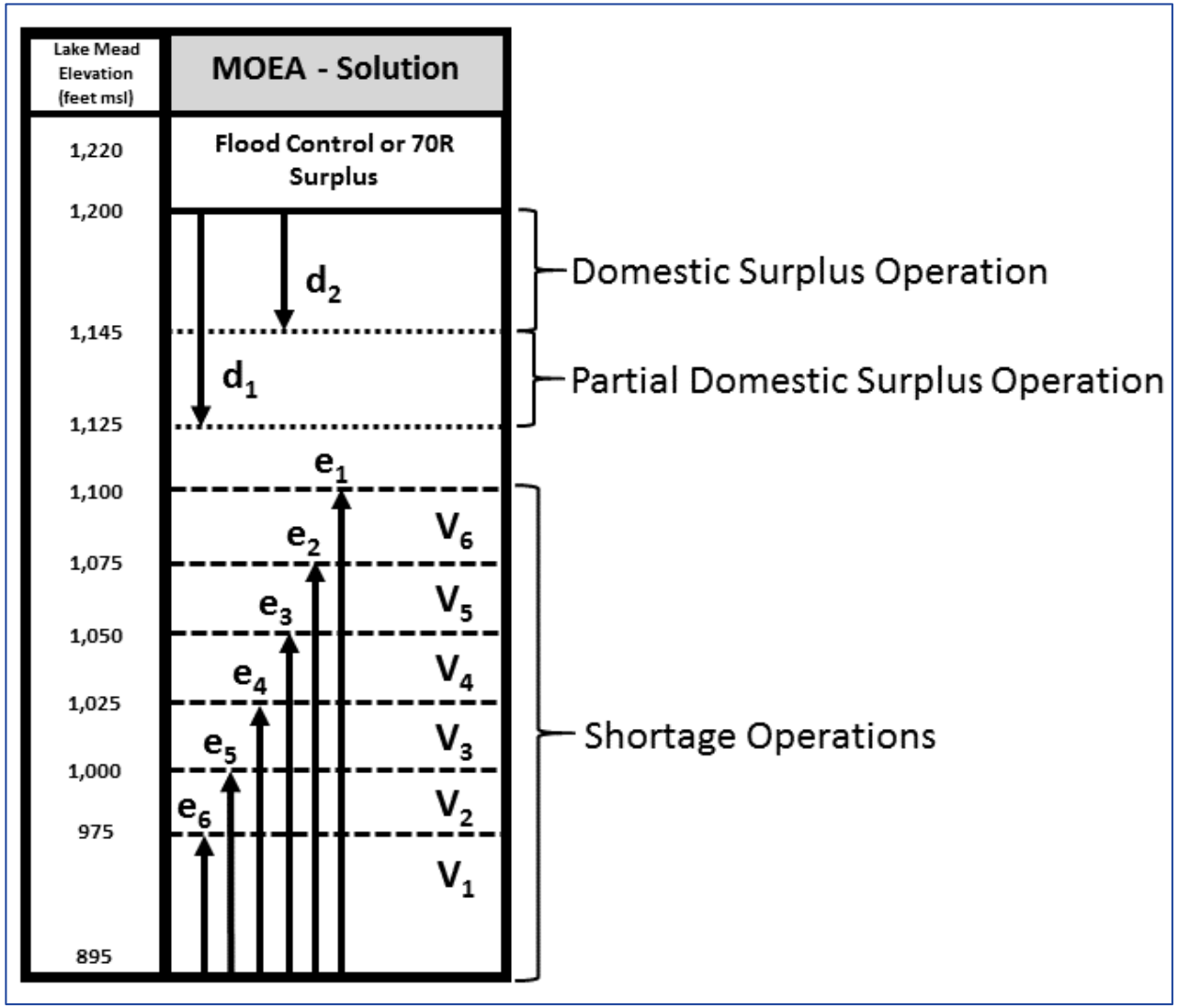
Colorado River Simulation System

Key Modeling Assumptions

- Simulation horizon is from 2017 to 2060.
- **Initial conditions** based on historical December, 2016 reservoir conditions
- **Input hydrology** is developed by resampling the observed natural flow record (1906-2012)
- **Upper Basin demands** are per the 2007 UCRC schedule
- **Lower Basin demands** are per the Interim Guidelines Final EIS
- **Lake Mead Operation:** is fixed throughout the simulation



New Operations: Policy Variables



Surplus Distance Variables: (d_{1-2})

- Sets Domestic and Partial Domestic surplus operation tiers for Lake Mead

Shortage Elevation Variables: (e_{1-6})

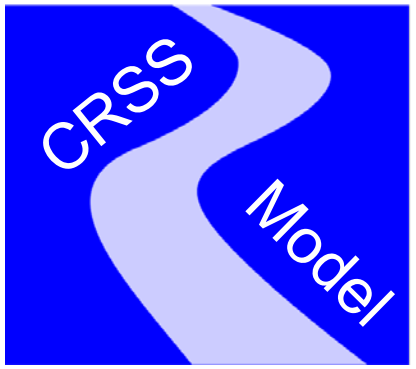
- Modifies the size and number of shortage operation tiers for Lake Mead;
- Set up to 6 discrete shortage tiers

Shortage Volume Variables: (V_{1-6})

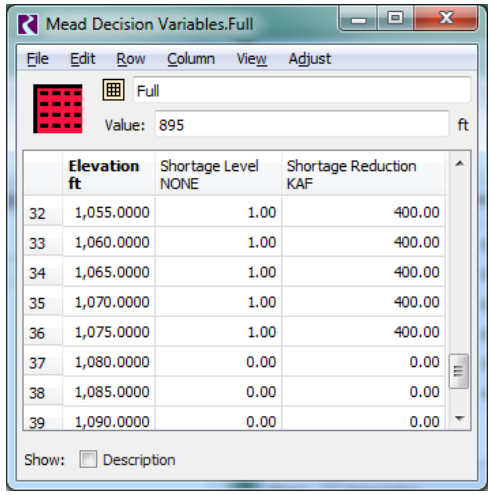
- Shortage reductions to US Lower Basin States and United Mexican States normal allocation;
- Volume ranges from 0 KAF to 2400 KAF

Policy Variables to Mead Operation

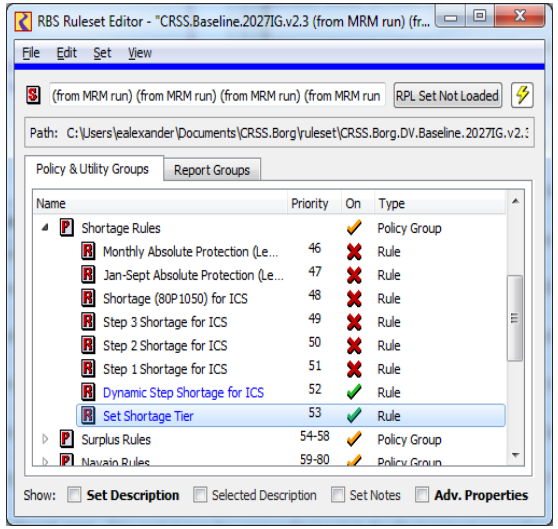
DMI



IR



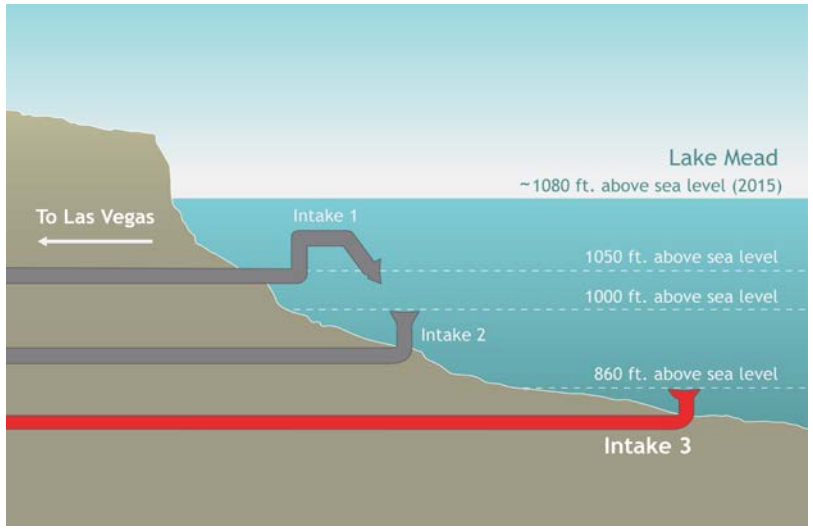
R

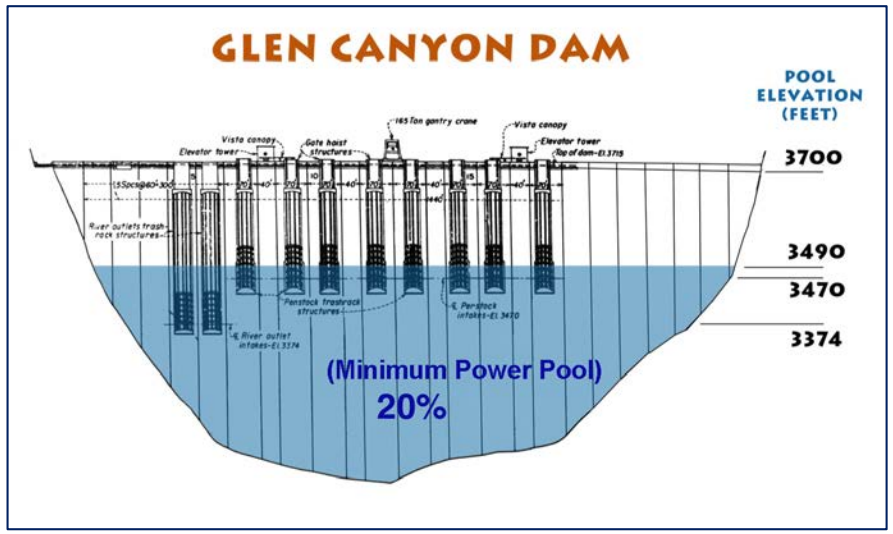


DMI = Data Management Interface
IR = Initialization Rule
R = Rules

Evaluating Operations: Objectives

Lower Basin Objectives		
Mead 1000	1	Minimize % of time that monthly Mead Pool Elevation is < 1,000'
LB Max Consecutive Shortage Duration	2	Minimize the maximum amount of consecutive years in a shortage condition
LB Shortage Frequency	3	Minimize % of time that the system is in an annual shortage condition
LB Shortage Volume	4	Minimize the cumulative average annual Lower Basin total shortage volume
Max Annual LB Shortage	5	Minimize the maximum annual Lower Basin policy shortage volume
Upper Basin Objectives		
Powell 3490	6	Minimize % of time that monthly Powell Pool Elevation is less than 3,490'
Powell WY Release	7	Minimize cumulative average annual Water Year release from Powell
Lee Ferry Deficit	8	Minimize % of time that annual 10 year compact volume falls below 75 maf





Evaluating Operations: Objectives

Lower Basin Objectives	
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LB Max Consecutive Shortage Duration	2
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LB Shortage Volume	4
Max Annual LB Shortage	5
Upper Basin Objectives	
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Powell WY Release	7
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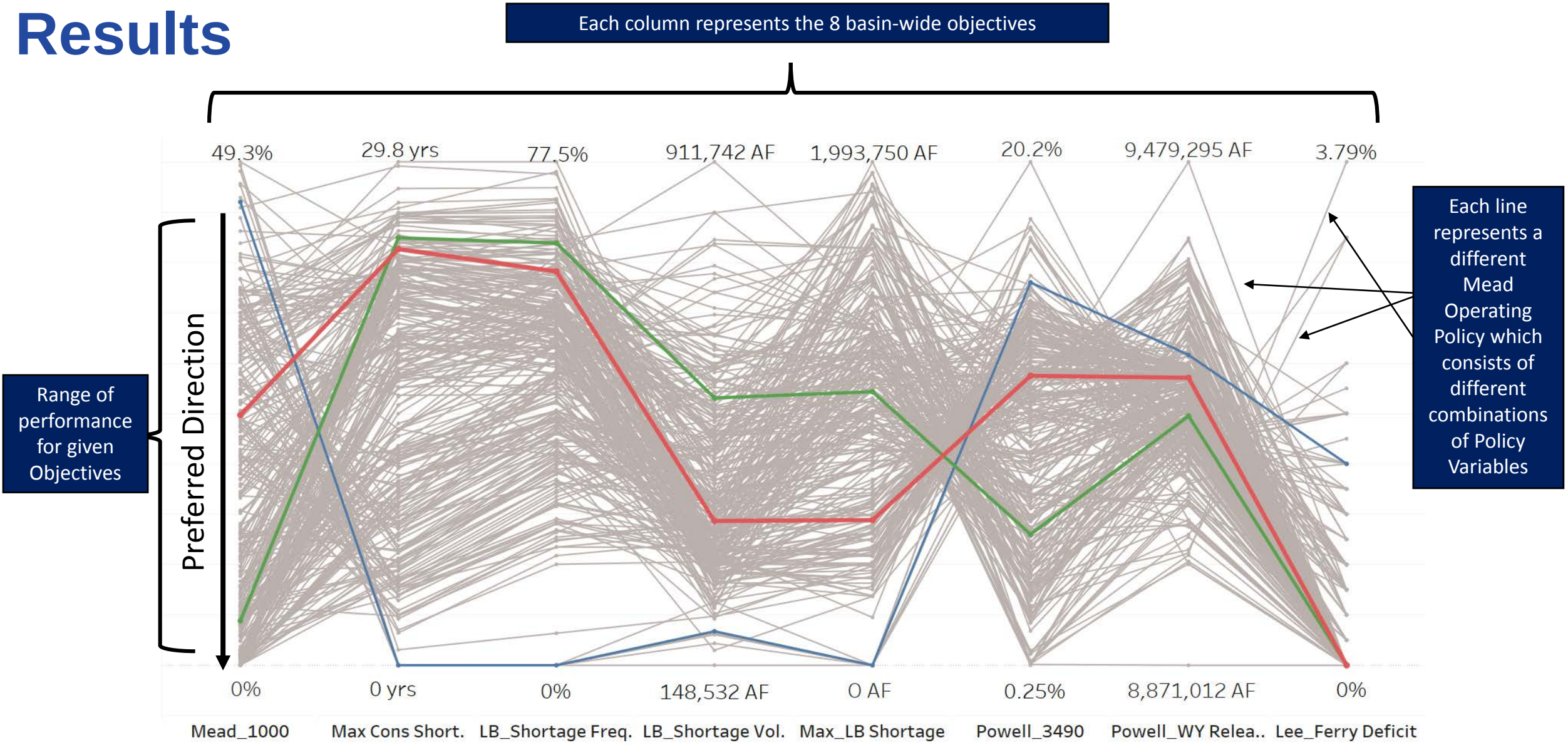
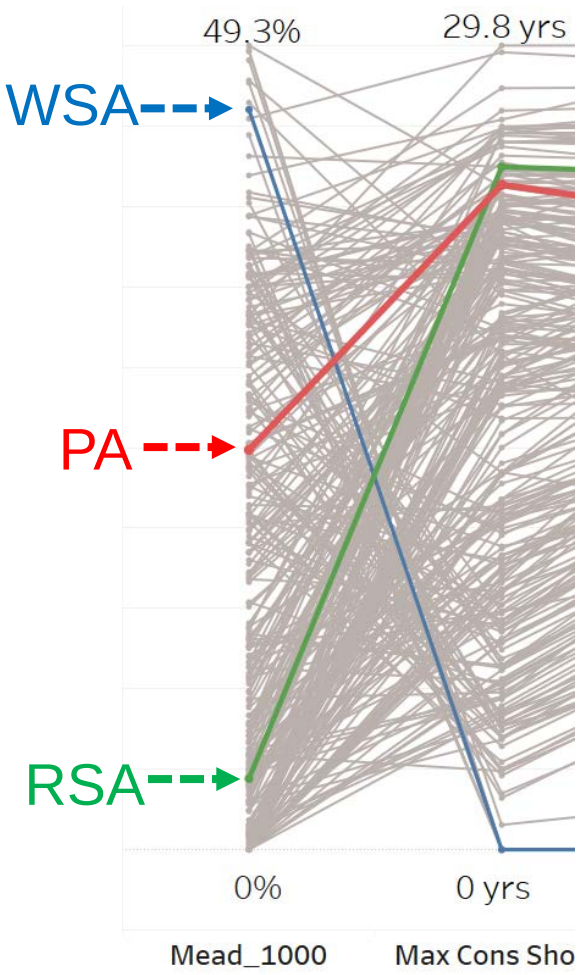
Results


Each column represents the 8 basin-wide objectives
49.3%
29.8 yrs
77.5%
911,742 AF
1,993,750 AF
20.2%
9,479,295 AF
3.79%
Preferred Direction
Range of performance for given Objectives
Each line represents a different Mead Operating Policy which consists of different combinations of Policy Variables
0%
0 yrs
0%
148,532 AF
0 AF
0.25%
8,871,012 AF
0%
Mead_1000
Max Cons Short.
LB_Shortage Freq.
LB_Shortage Vol.
Max_LB Shortage
Powell_3490
Powell_WY Relea..
Lee_Ferry Deficit

Results: 2007 Interim Guidelines

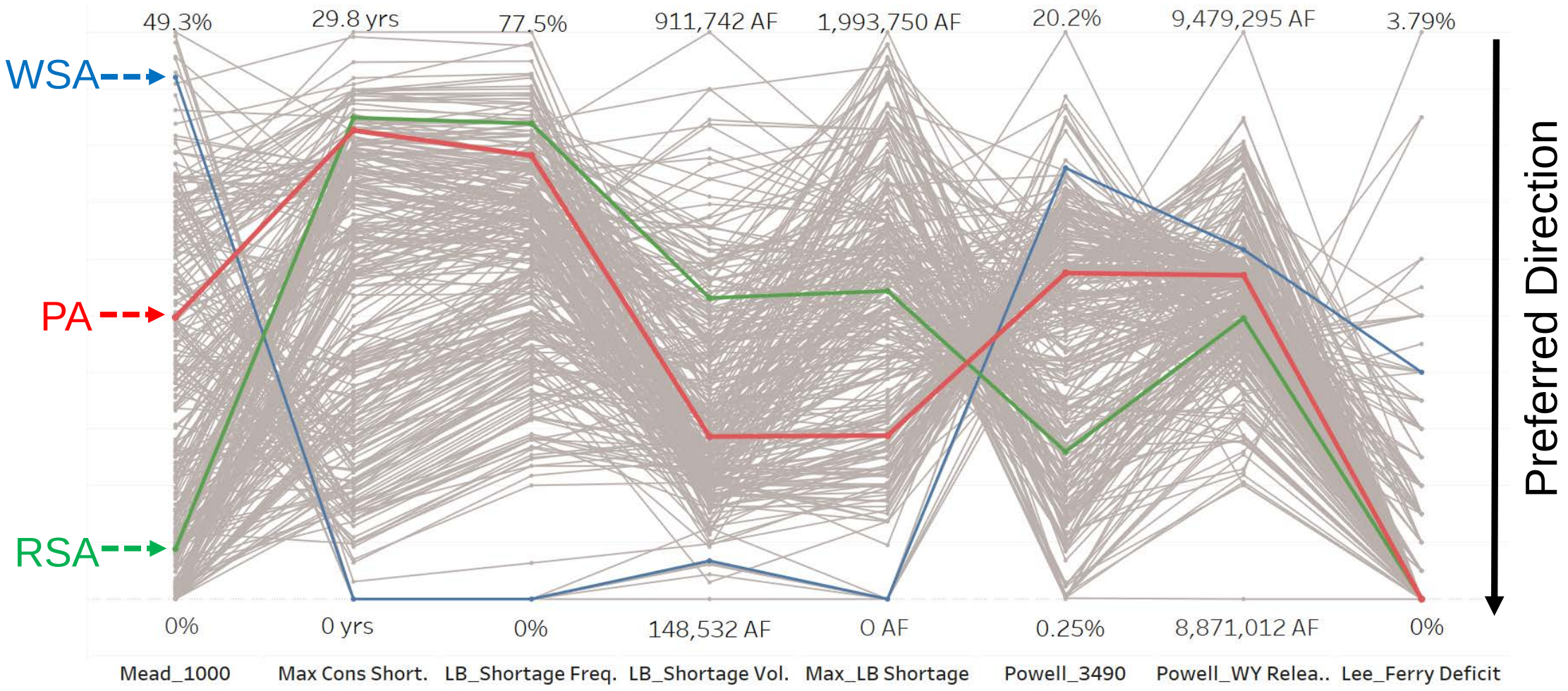


Water Supply Alternative (WSA) - policy that maximizes water deliveries at the expense of retaining water in storage in Mead and Powell

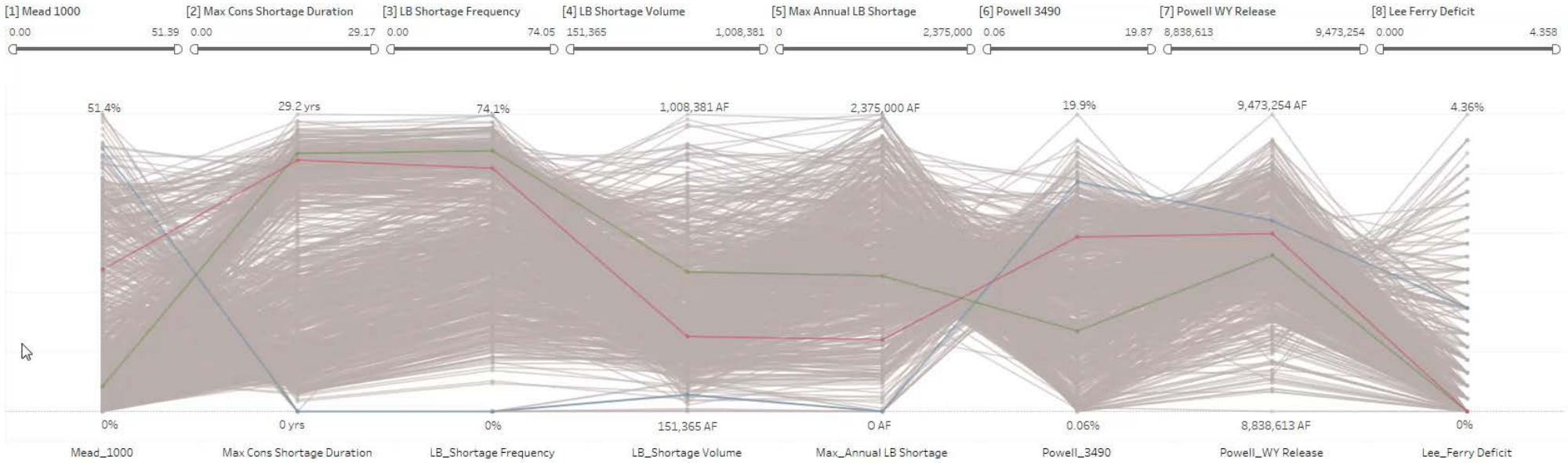
Preferred Alternative (PA) – recommended operating policy of Lake Mead and has less shortage reductions than RSA

Reservoir Storage Alternative (RSA) - policy that keeps more water in storage through increasing shortages volumes

Results: 2007 Interim Guidelines



Results: Interactive Visual Analytics



Conclusions

- Pairing a MOEA with CRSS is an effective tool to generate and evaluate operating policies.
- The MOEA-generated solutions explored a wider range of the solution space than the previously negotiated policies.
- Future work will evaluate the robustness of the MOEA-generated solutions through incorporating deep uncertainty with respect to a changing climate.

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U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Citations

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