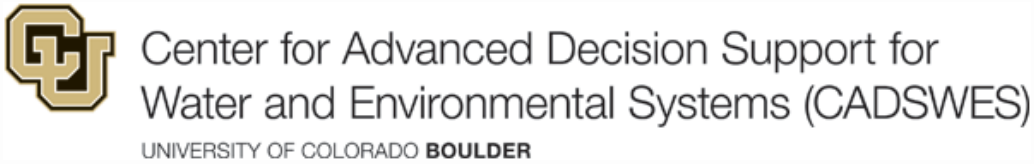


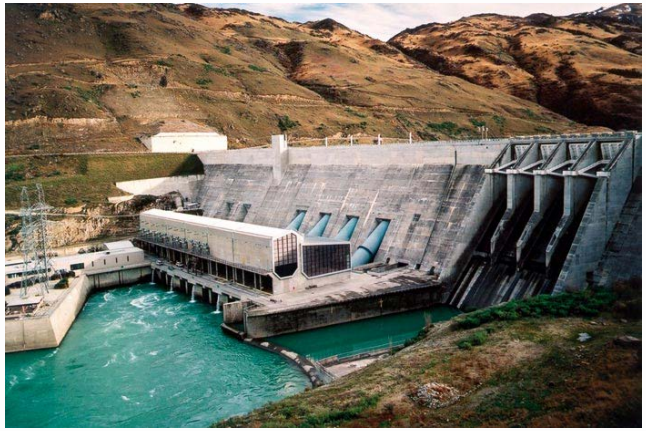
RiverWare Optimization

2019 RiverWare User Group Meeting

Tim Magee

RiverWare Optimization

- Primary motivation: Hydropower
  - Short term planning
  - Real time operations
- Can be useful for other objectives
  - Get the most you can out of the system
  - Hedge against uncertainty
  - Example: Balancing reservoirs



RiverWare Hydropower Optimization Users

Hydropower	Installed Capacity (MW)	Generation (GWh)
U.S. Total	102,867	322,390
RiverWare Opt Users	32,514	~113,530
Percent	32 %	35%

The Golden Age of Hydropower?

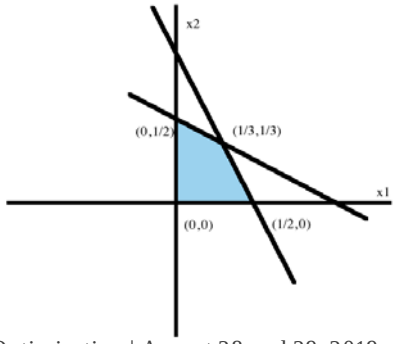
- 100% Renewable Portfolio Standards (RPS)
  - Coal is going away
  - Natural gas: “Bridge” to renewables
  - Solar: price is decreasing
  - Prediction: California’s issues will spread

- Hydropower is quietly being reclassified as “renewable” at the state level
- Past: “fuel” limited, peaking generation
- Future: “flexibility”, ramping, reserves, regulation
- Pumped Storage “battery”: req. market changes

Optimization vs. RBS 1

- **RBS**: Timestep by timestep, object by object
  - Execute all rules at a given timestep before advancing to next timestep
  - Objects dispatch one at a time
  - “Look ahead” must be written explicitly in rule logic

- **Optimization**: Global solution in time and space
  - Solves all timesteps and all objects simultaneously
  - “Look ahead” inherent in the solution



Optimization vs. RBS 2

- **RBS**: Evaluate a prescribed solution
  - Set decision variables (slot values) based on rule logic

    IF (state of system)

    THEN (set decision variable)

- **Optimization**: Find the “best” solution within constraints

  Maximize (objective)

  Subject to …

Optimization vs. RBS 3

Which is better?

Depends on use case

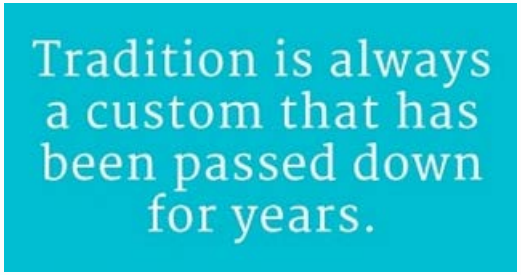
- **RBS**:
  - Long-term studies
  - Prescribed operating rules
- **Optimization**:
  - Short-term scheduling
  - Determining “best” operations
  - Need to consider system-wide effects
  - Need to look-ahead in time

Traditional Optimization Approach

- Maximize hydropower objective, e.g. $$

  Subject to: Policy constraints

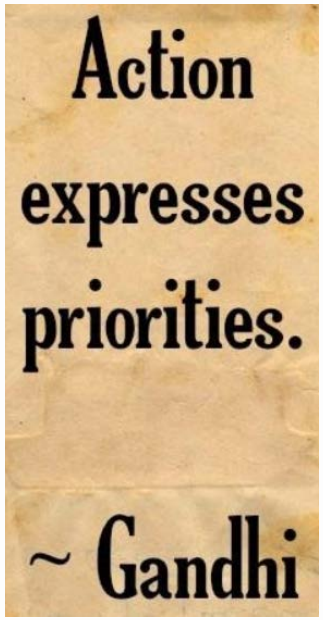
  - License elevation limits
  - Environmental flows
  - Special operations for maintenance …



- If constraints are feasible …
  - Works well
  - Hydropower value may be reduced by constraints
- If constraints are infeasible (conflict)? …

Preemptive Linear Goal Programming

- Linear Programming
  - Solution engine
  - Constraints + 1 objective
  - Linear and piecewise approximation
  - Similar results to convex nonlinear programming
- Goal Programming
  - Soft constraints
  - Includes traditional objective functions
- Preemptive
  - Priority levels
  - No sacrifice of high priorities for low priorities



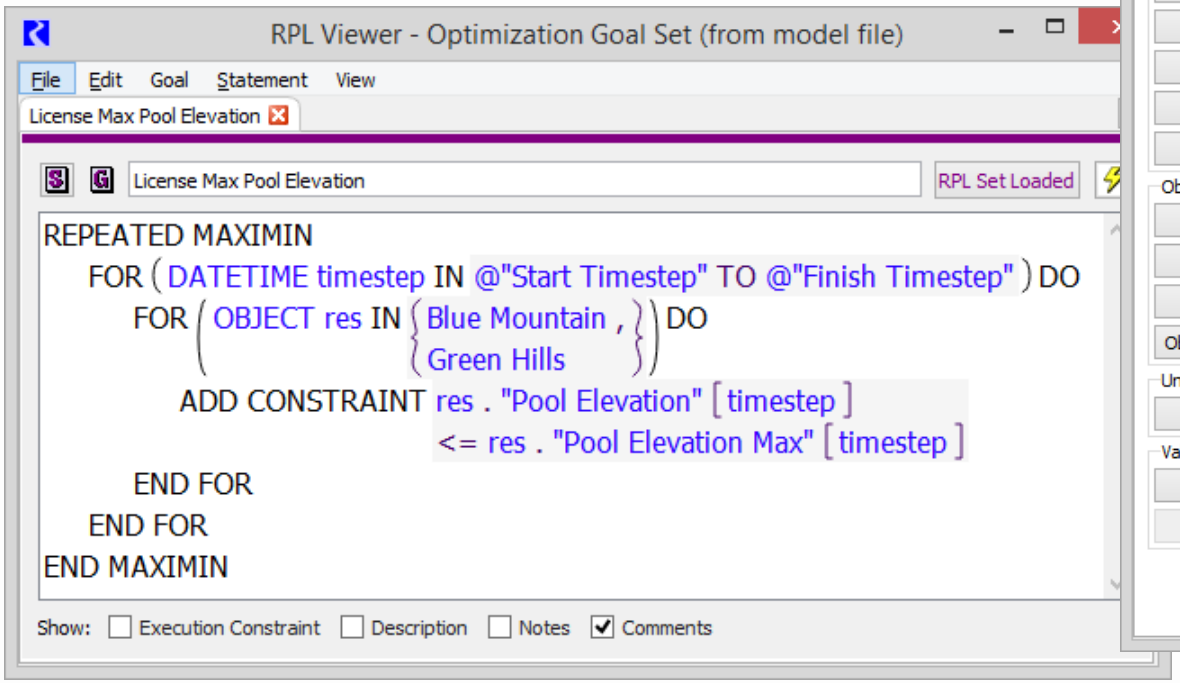
Preemptive Linear Goal Programming

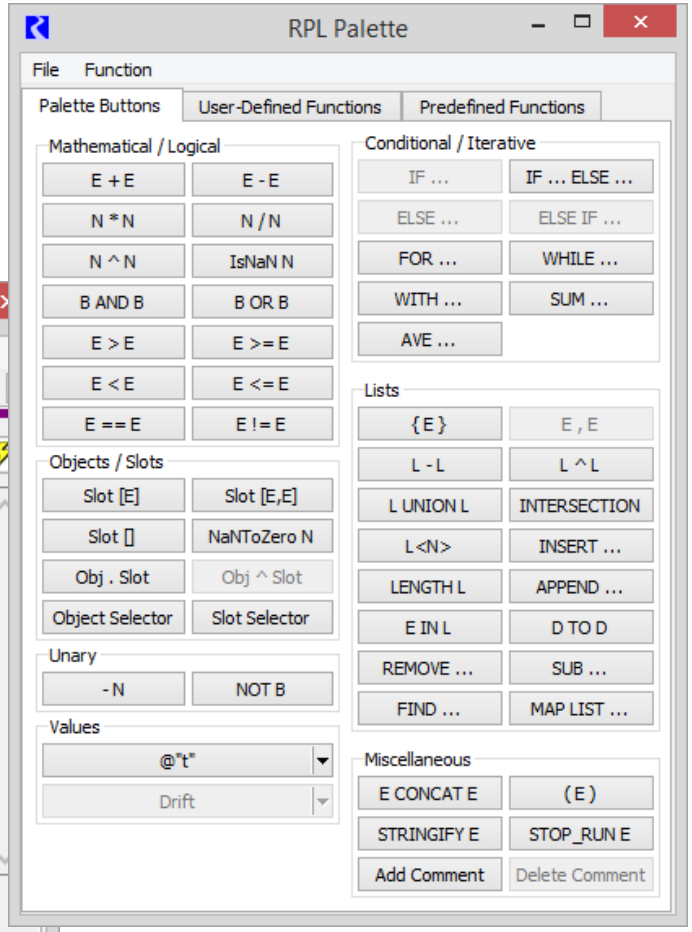
- Policies (goals) are prioritized
- Solves LP at each priority
- Soft constraints converted to objective → maximize satisfaction
- Freezes objective value – not degraded by lower priorities
- Minimized infeasibilities

Name	Priority
P License Pool Elevations	
G License Max Pool Elevation	1
G License Min Pool Elevation	2
P Minimum Flows	
G Minimum Flow Requirements	3
P Green River Daylight Flows	
G Green River Daylight Flow Restriction	4
P Target Operating Elevations	
G Target Forebay Operating Range	5
P Ending Elevation	
G Ending Elevation Target	6
P Economic Objective Function	
G Maximize Hydropower Revenue	7

RPL Goal Editor

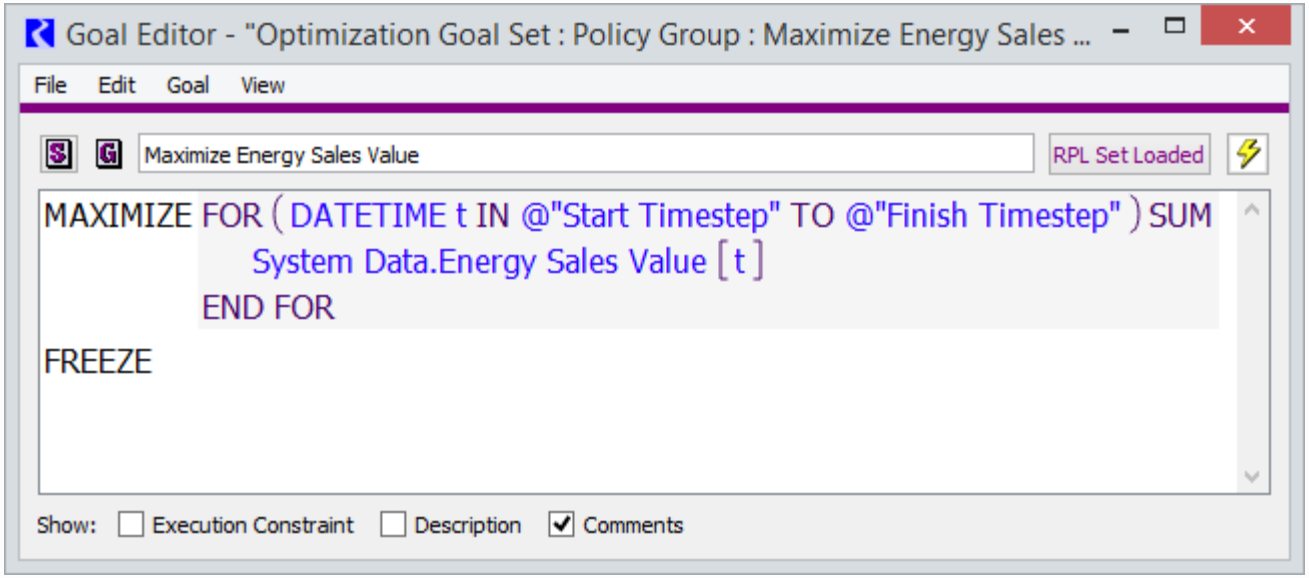
- RPL - Same language as rules
- Same palette as rules
- Most syntax same as rules





Maximize and Minimize Objectives

- User can formulate any linear objective



- Typically at lowest priority

Standard Controller Sequence

Complete Opt run — three separate runs

Clear outputs

Compute consequences of input values

Preemptive linear goal program – solve a series of LPs

Simulate using input values and selected opt values;

post-processing

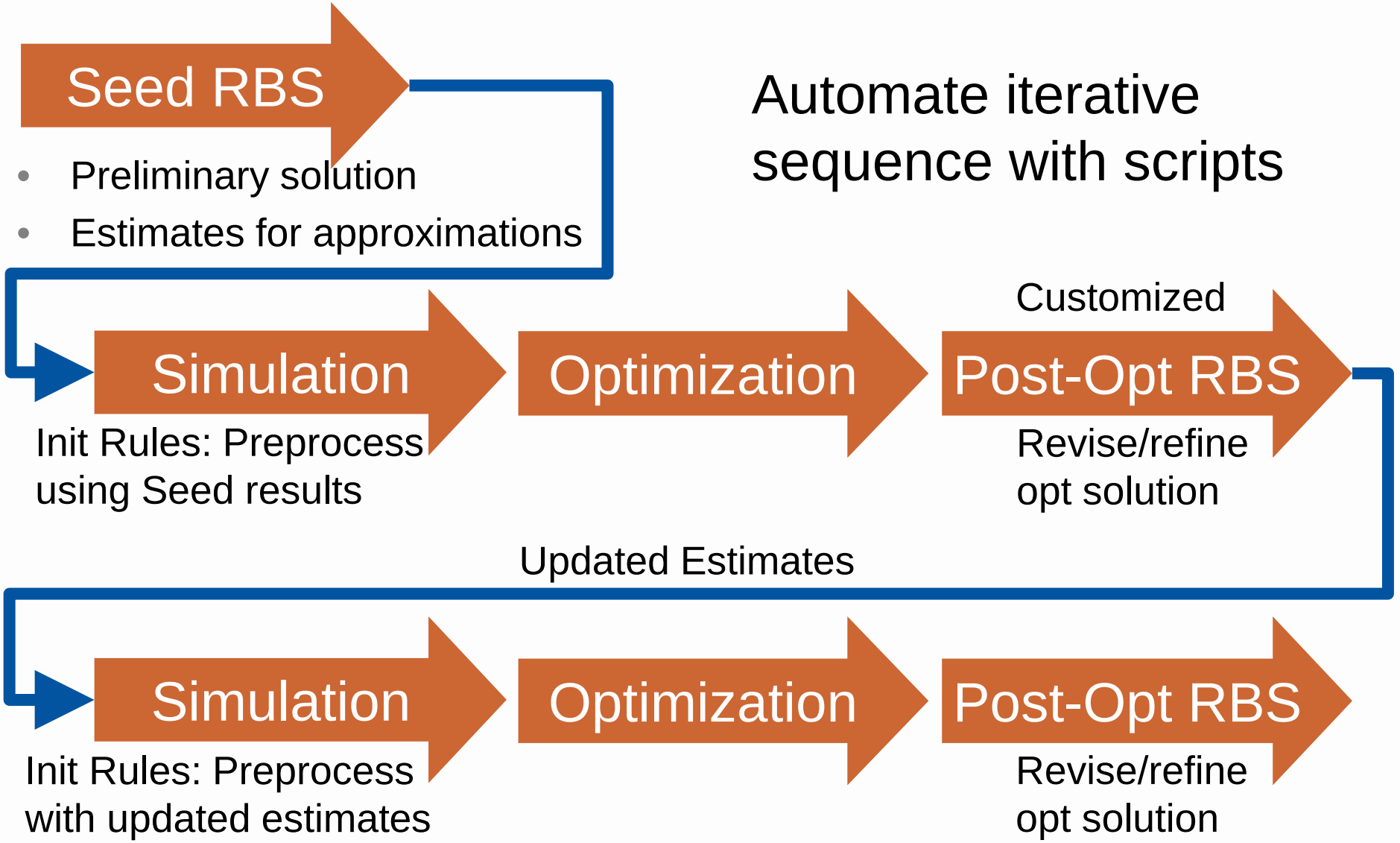
Post-optimization RBS

- Returns opt solution to the workspace
- Rules typically set Outflow

```
Res.Outflow[] = OptValue(Res.Outflow, @"t")
```

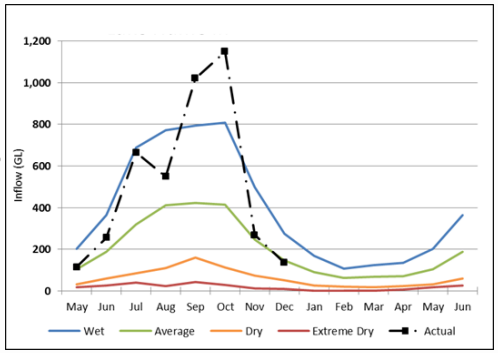
- Solve RBS using simulation methods - removes approximations

Extension of Optimization + RBS

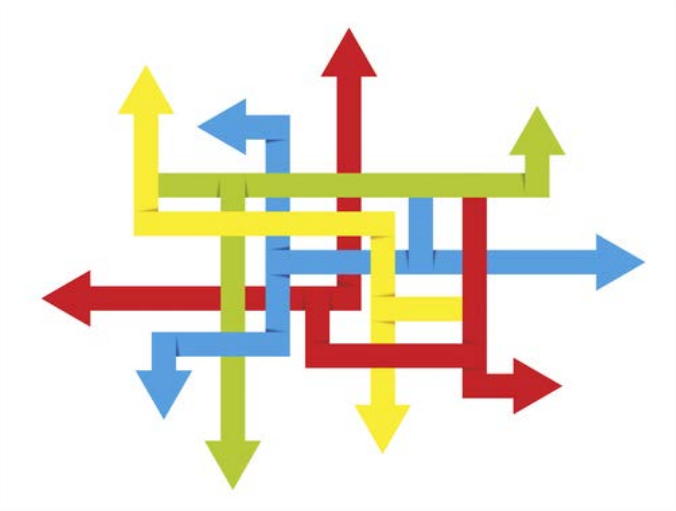


RBS-based Optimization

- Borg (MOEA) – Evaluations with RBS
- Stochastic Programming with Recourse
  - Normally, opt. with 1 objective
  - Using RBS with Multiple Objectives
    - Optimizing risk informed Stage 1 plan
    - Evaluate Stage 2 scenarios with RBS
    - Vary the Stage 1 decision, while evaluating Stage 2
    - Examine the outcomes for Stage 1 & Stage 2
    - Converge on an optimal Stage 1 decision



New Directions



- TVA IT Project:
  - Long Term Model
  - Improve Short Term Optimization
  - Block Cost Alternative: Perfect Dispatch
- Joint optimization of power resources
  - Asynchronous optimization
  - Time has arrived?
- Flexibility in hydropower
  - What is it? Measure it? Use it? Improve it? Cost?