First Steps Towards a Multi-Objective Reservoir Optimization

RiverWare User Group Meeting February, 1 2018

Abby Watson[1], Noah Friesen[1], Paul Micheletty[1], Jon Quebbeman[1], Jay Day[1] & Allen Avance[2]
[1]RTI International, [2]U.S. Army Corps of Engineers, Fort Worth District


Hypothetical Reservoir
Project Goals
Approach
Proof of Concept
Summary
RTI
INTERNATIONAL

Hypothetical Reservoir

Hypothetical Reservoir

- Operational objectives:
  - Flood risk management
  - Hydropower generation
  - Water conservation and supply

- Operational challenges:
  - Coordinated operations with a smaller reservoir downstream
  - Formal operation manual not formally updated since new permanent river structures built downstream
  - Multiple stakeholders involved and control points to consider

Project Goals

Project Goals

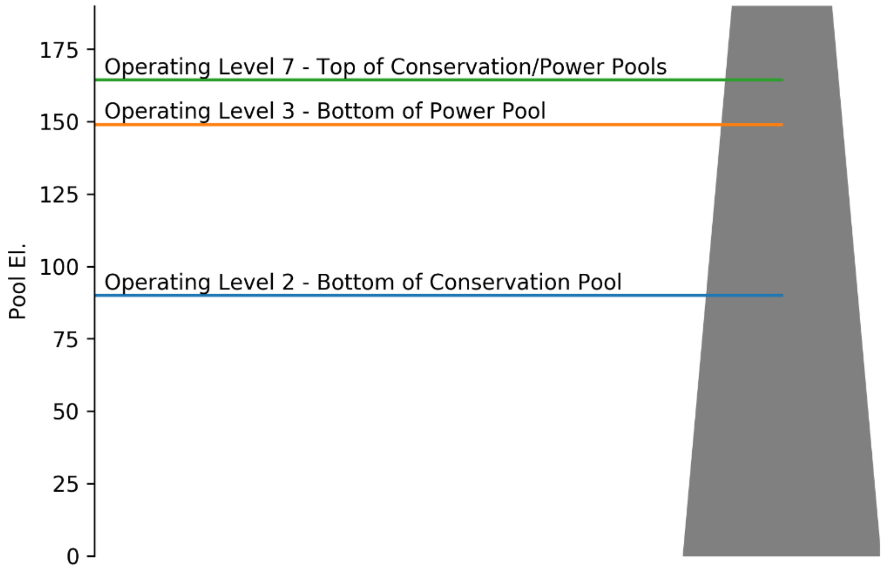
1. Develop conservation pool operational guidelines that

Maximize Hydropower Production

Conservation releases are made in accordance with request by the public power utility

Minimize Risk of Water Supply Shortages

Local irrigation district subject to water rights of **up to** 2,000 cfs/day



2. Develop a decision support tool for exploring operational guideline alternatives

Approach

What are the available tools to **simulate** and **optimize** reservoir operations?

Tools for **Simulating** Reservoir Operations

- RiverWare rulebased simulation model provided
- Custom operational rules written in RPL
- Model used for long-term planning and evaluating proposed operational changes
- Minimal updates required

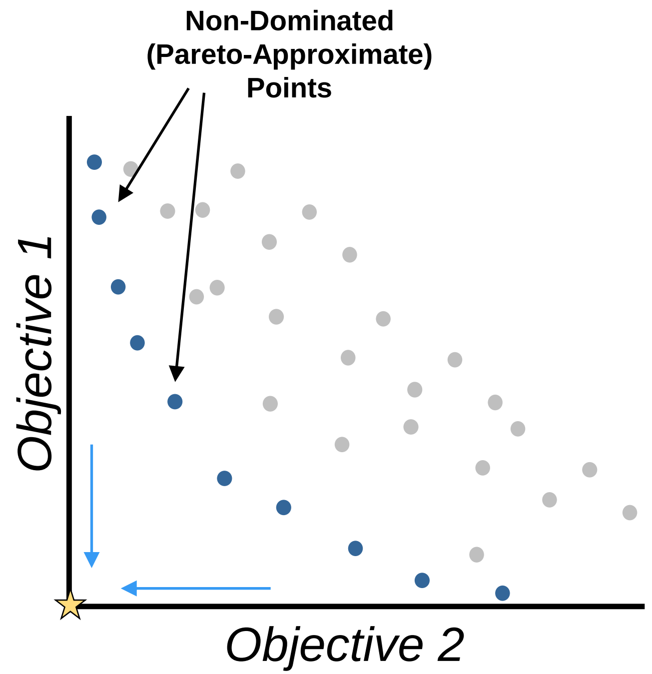
Relevant Operations

	Operation	Application	Project Implications
Conservation Pool	Downstream demand / low flow requirement releases	Releases must satisfy downstream demand request (up to 2,000 cfs per day) ~120 mi d/s, ~140 hr travel time	- Optimization objective - Wrote custom rule to ensure demand is met using **only** the upstream reservoir - Developed conditional average demand for POR
Power Pool	Release **additional** water to meet specified power load requirement	Reservoir operates using zones and required generation hours in coordination with the public power utility	- Optimization objective and decisions - Power load requirements are designated periodic table slots (guide curves with generation times)

Tools for **Optimizing** Reservoir Operations

Multi-objective optimization using the NSGA-II algorithm *[4]*

- Simulation model available – let's use it!
- No aggregation to a single objective function
- Readily-available parallelized NSGA-II code with a local Windows-based computing 'cluster'
- Smith et al. (2015) *[5]* successfully integrated RiverWare simulation model with Borg MOEA



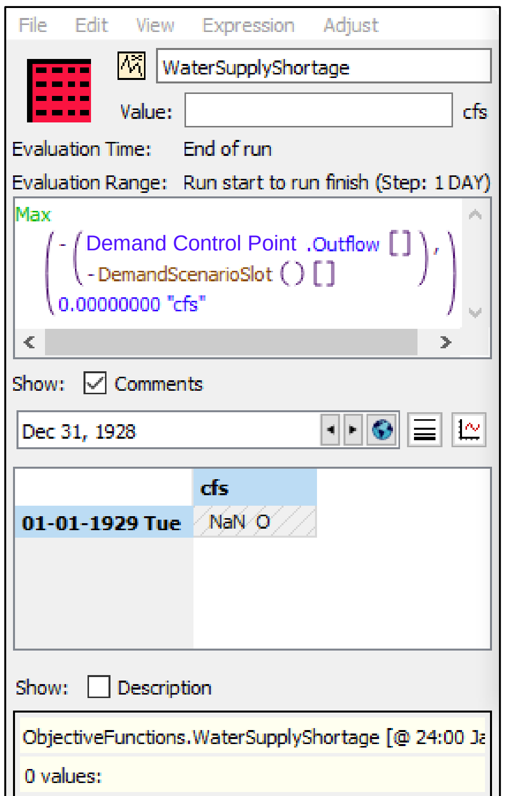
[4] Deb, K.; Pratap, A.; Agarwal, S. & Meyarivan, T. A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II IEEE Transactions on Evolutionary Computation, 2002, 6, 182-197
[5] Smith, R., et al. (2010) "Many-Objective Analysis to Optimize Pumping and Releases in Multireservoir Water Supply Network", Journal of Water Resources Planning and Management 142(2) .

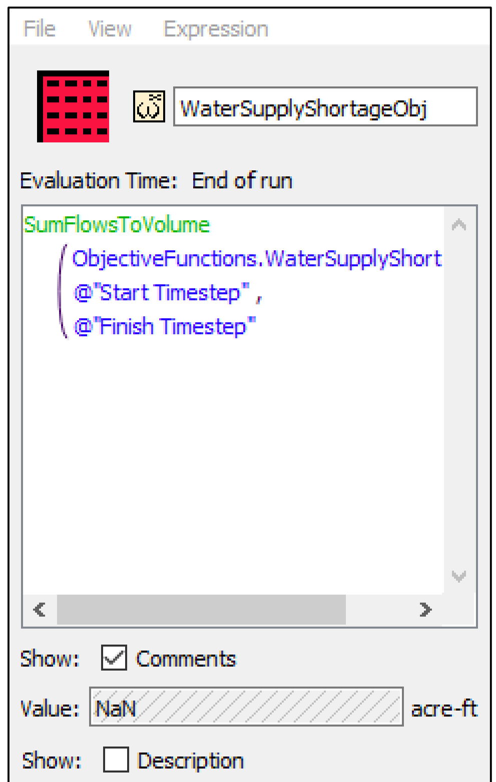
How do we formulate the problem?

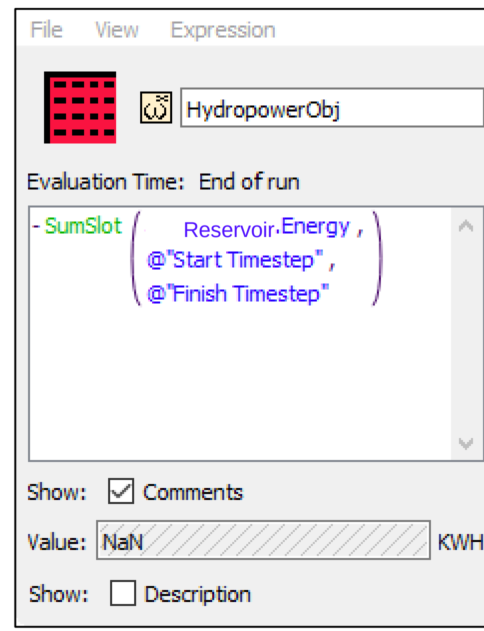
Hypothetical Objective Functions

$$\text{Minimize: } f_{shortage\ vol.}(\text{x}) = \sum_{t=1}^{T} Vol_{\ Demand\ Control\ Point\ Q\ <\ Demand}$$

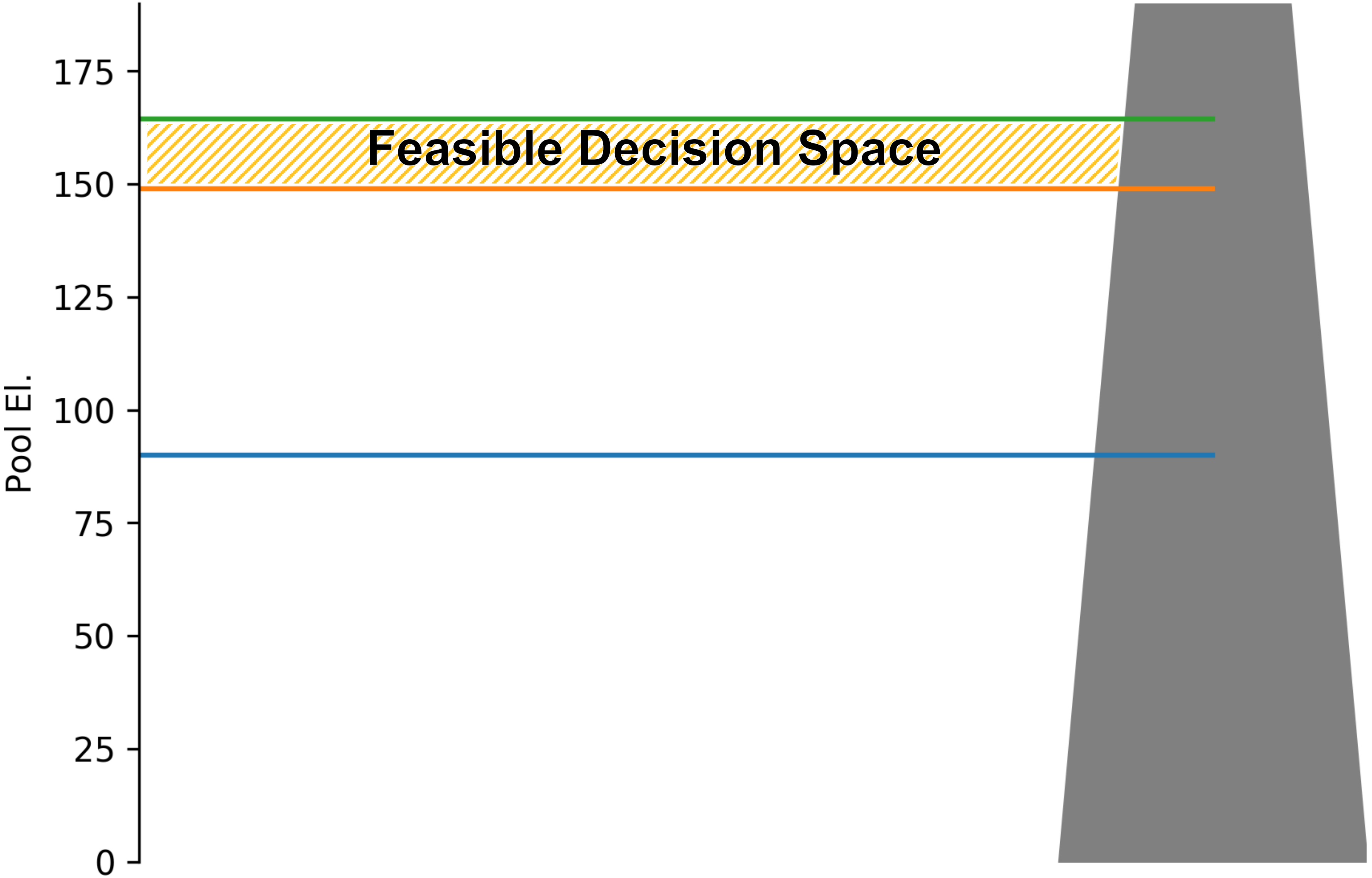
$$\text{Maximize: } f_{energy\ gen.}(\text{x}) = \sum_{t=1}^{T} Reservoir\ Energy$$







Hypothetical Decision Space



Hypothetical Decision Variables

Date	Operating Level 4 (ft)	Operating Level 5 (ft)	Operating Level 6 (ft)
		Load fraction = 0.1 Approx. 75 hrs/mo	Load fraction = 0.2 Approx. 150 hrs/mo
1-Jan	148	153	158
2-Feb	148	156	158
15-Mar	147	152	158
21-Mar	146	152	158
22-Mar	146	152	158
1-Apr	146	153	158
1-May	146	155	159
15-Jun	146	158	159
1-Aug	149	155	159
2-Aug	149	155	159
15-Aug	150	154	159
1-Sep	150	153	159
1-Oct	148	151	158
15-Nov	146	148	158
31-Dec	148	153	158

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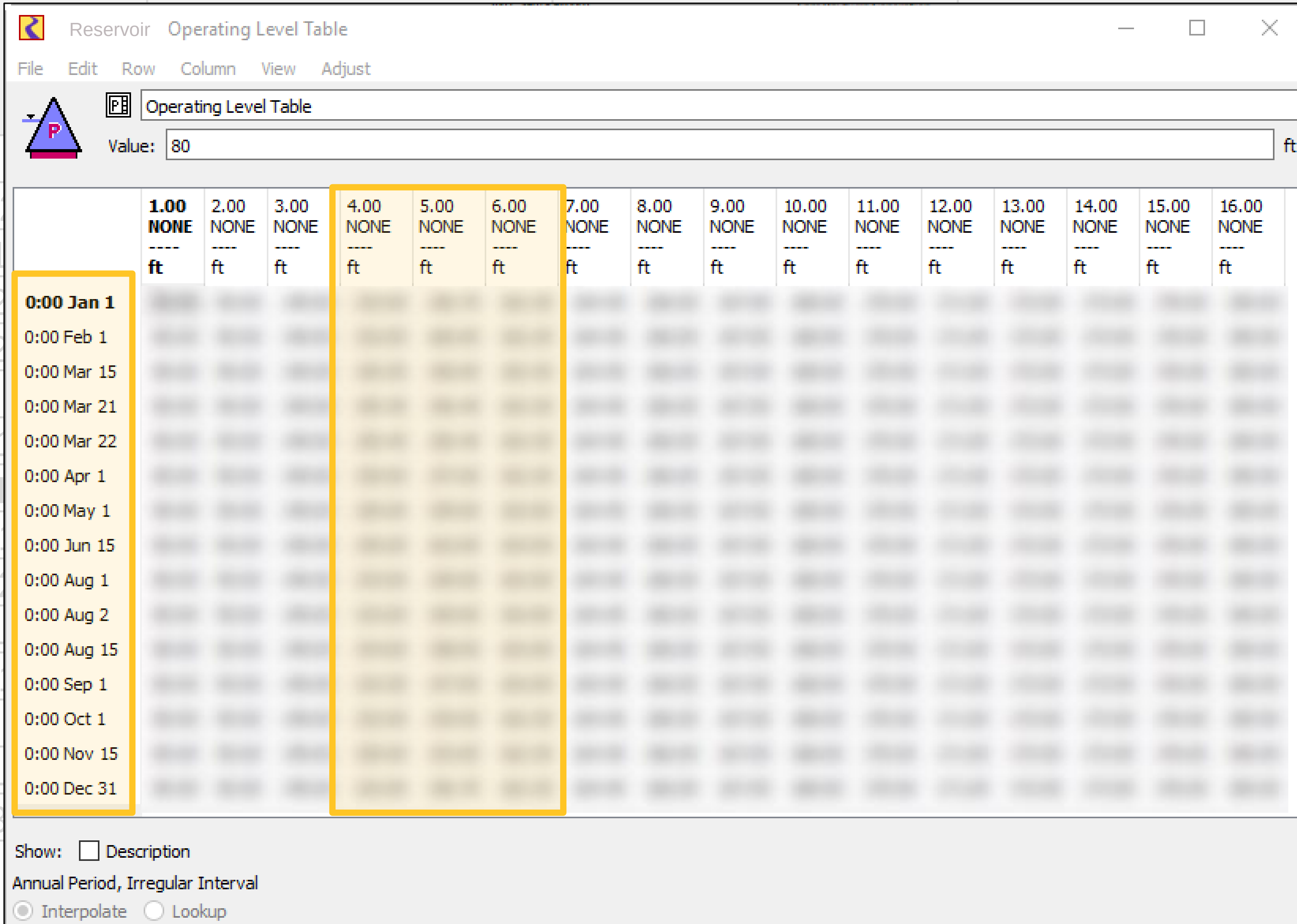
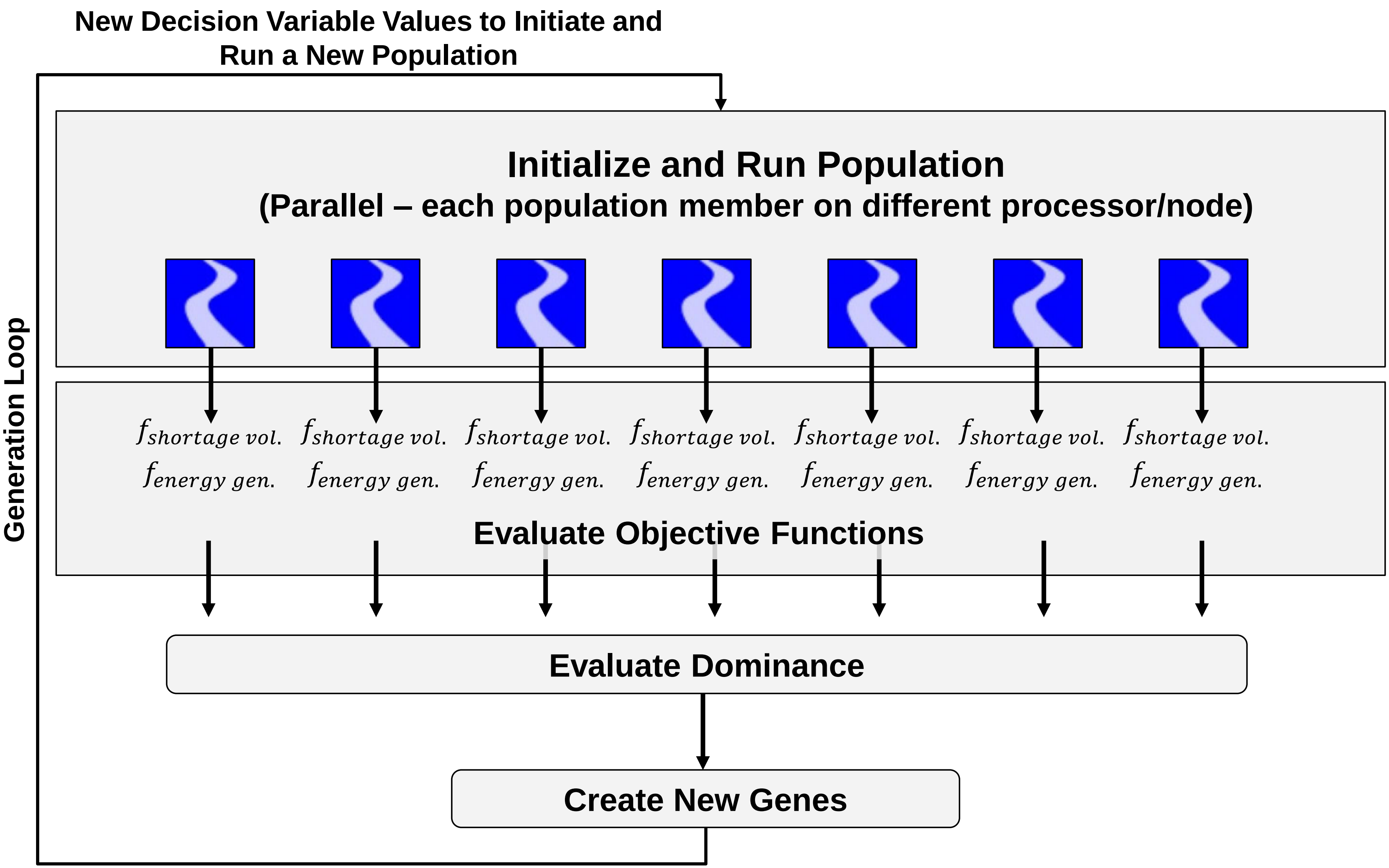
Constraint Boundaries

Hypothetical Decision Variables



How do we connect
RiverWare and **NSGA-II**?

Simulation-Optimization Framework Setup



Simulation-Optimization Framework Setup

New Decision Variable Values to Initiate and Run a New Population

Conditions of Optimization (for framework testing):

- Optimizing given historical hydrology and conditional average demand over a 10-yr period
  - Individual Simulation Run Time ~2.5 minutes
- Two objectives:
  1. Min. water supply shortage
  2. Max. hydropower production

NSGA-II Parameters (for framework testing):

Population Size = 96
Number of Generations = 100
Total Number of Model Calls = 9,600
Probability of mutation = set to 1/L, where L = # of Decision Variables

Create New Genes

How can we explore, understand, and select alternatives?

Decision Support Challenges

Problem Formulation

- Critical for implementable and acceptable operational guidelines
- Prefer to capitalize on the strengths of USACE and RTI

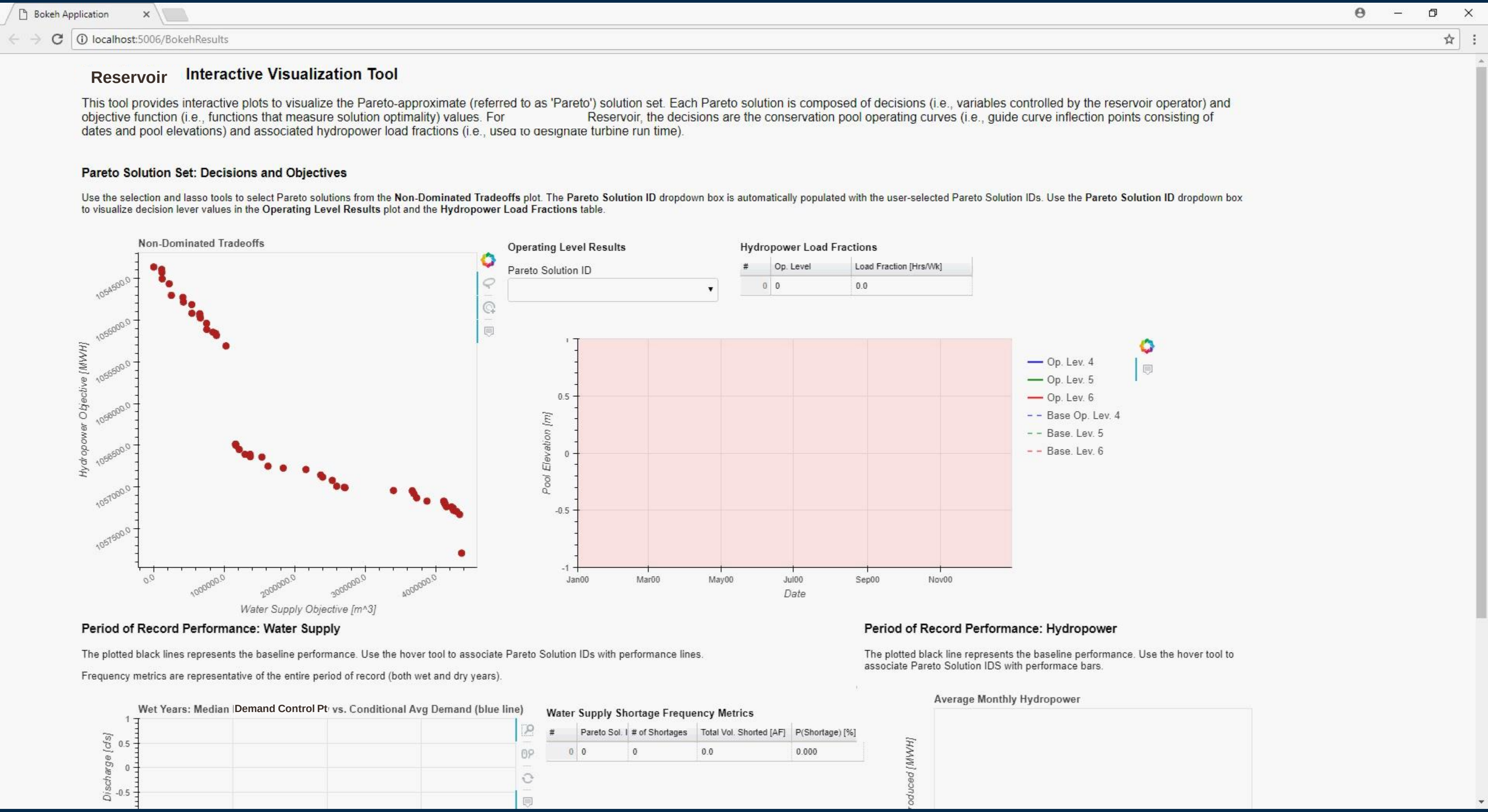
Interactive Visualization Tool

Decision-Making

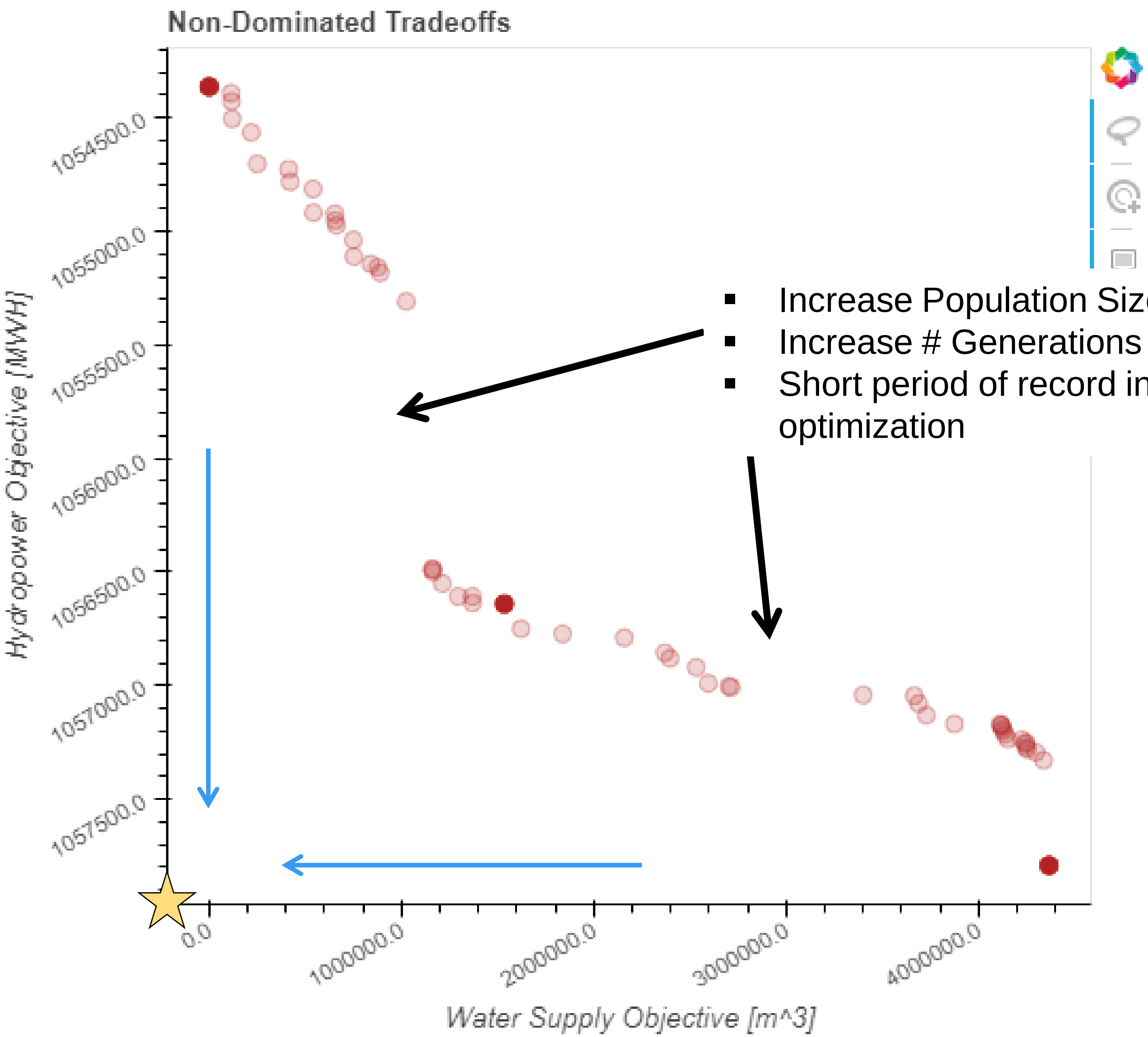
- Methodology for exploring and understanding the alternative Pareto-approximate set of solutions

Proof of Concept

Interactive tool developed using bokeh (video unable to play in pdf presentation)



Hypothetical Problem Formulation Takeaways



- Increase Population Size
- Increase # Generations
- Short period of record in optimization

Hypothetical Problem Formulation Takeaways

- Develop constraints for **realistic** guide curves

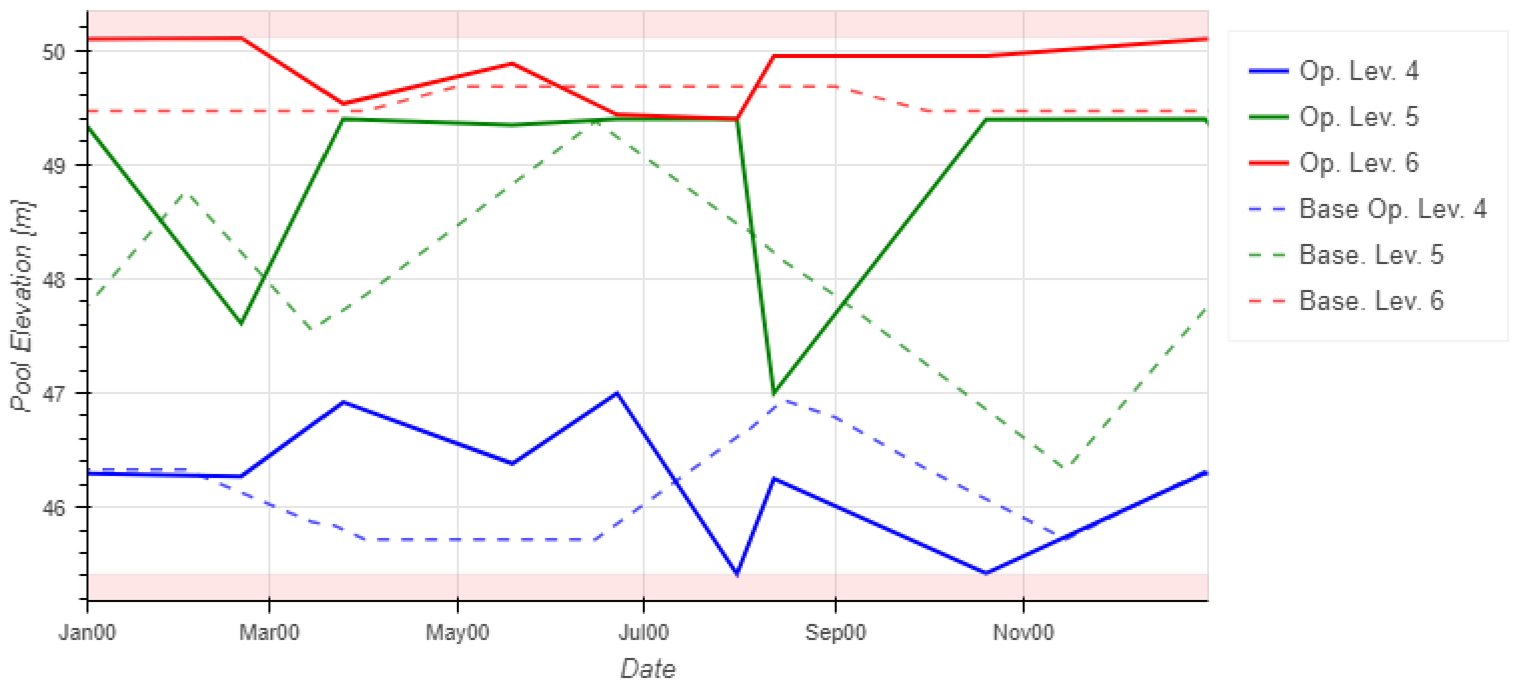
Operating Level Results

Pareto Solution ID

30200_45701 ▾

Hydropower Load Fractions

#	Op. Level	Load Fraction [Hrs/Wk]
0	Op. Lev. 5	25.2
1	Op. Lev. 6	41.8



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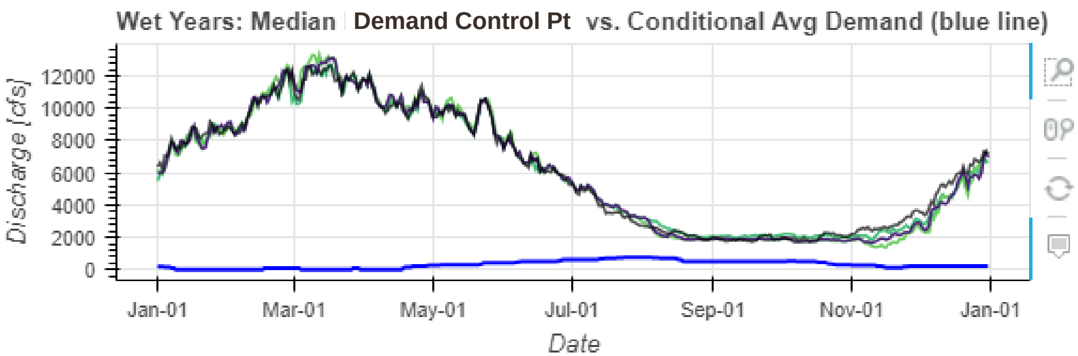
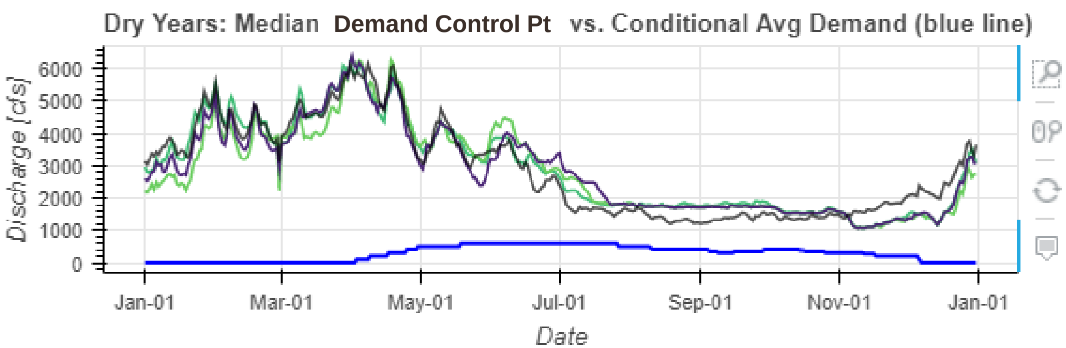


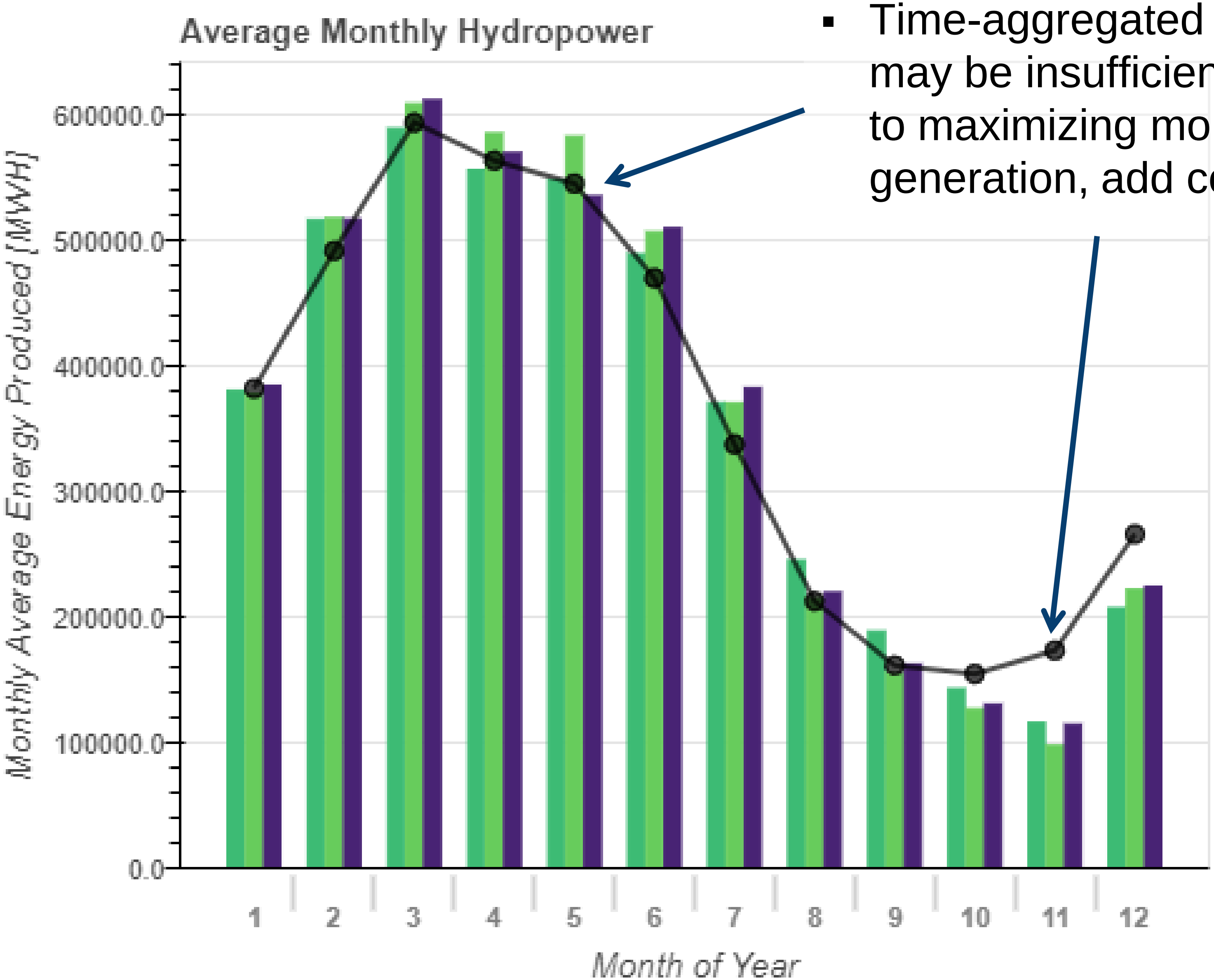


Water Supply Shortage Frequency Metrics

#	Pareto Sol. I	# of Shortages	Total Vol. Shorted [AF]	P(Shortage) [%]
0	45701	21	8310.0	0.065
1	86542	17	5455.0	0.053
2	08979	23	11449.7	0.072

- Custom water supply rule may be too conservative
- Presently not minimizing water supply risk
- Integrate a water supply decision variable to indicate conditions when water supply **cannot** be met

Hypothetical Problem Formulation Takeaways



- Time-aggregated objectives may be insufficient (i.e., move to maximizing monthly power generation, add constraints)

Summary

Summary

Achievements:

- Identified broad objectives and preliminary decision variables
- Developed simulation-optimization framework
- Developed interactive decision-support tool
- Utilized decision-support tool to learn about the system

Next Steps:

- Work with the USACE to re-formulate the objectives, decision variables, and constraints
- Tune the optimization parameters
- Implement *a posteri* robustness analysis to assess Pareto solution set under variable conditions

Thank You

Abby Watson
Water Resources Engineer
970.498.1817
aawatson@rti.org

Noah Friesen
Sr. Water Resources Engineer
970.498.1855
nfriesen@rti.org