

### First Steps Towards a Multi-Objective Reservoir Optimization

#### RiverWare User Group Meeting February, 1 2018

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## 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



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

Approach

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

### **KINGLMALE**

- 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	<ul> <li>Optimization objective</li> <li>Wrote custom rule to ensure demand is met using <b>only</b> the upstream reservoir</li> <li>Developed conditional average demand for POR</li> </ul>
Power Pool	Release <b>additional</b> water to meet specified power load requirement	Reservoir operates using zones and required generation hours in coordination with the public power utility	<ul> <li>Optimization objective and decisions</li> <li>Power load requirements are designated periodic table slots (guide curves with generation times)</li> </ul>

### 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



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# How do we formulate the problem?

### Hypothetical Objective Functions

Minimize:  $f_{shortage vol.}(\mathbf{x}) = \sum_{t=1}^{t} Vol_{Demand Control Point Q < Demand}$ Maximize:  $f_{energy gen.}(\mathbf{x}) = \sum_{k=1}^{n} Reservoir Energy$ File Edit View Expression Adjust File View Expression WaterSupplyShortage WaterSupplyShortageObj Value: cfs View Expression File Evaluation Time: End of run Evaluation Range: Run start to run finish (Step: 1 DAY) Evaluation Time: End of run 🕺 HydropowerObi ----Max SumFlowsToVolume - / Demand Control Point .Outflow [] ), ObjectiveFunctions.WaterSupplyShort - DemandScenarioSlot () Evaluation Time: End of run @"Start Timestep", 0.00000000 "cfs" - SumSlot Reservoir. Energy, @"Finish Timestep" ٠ э @"Start Timestep" . Show: Comments @"Finish Timestep" **I** - F 🚱 Dec 31, 1928 cfs 01-01-1929 Tue NaN O Show: Comments < > Value: NaN Show: Comments Show: Description Show: Description Value: NaN acre-ft ObjectiveFunctions.WaterSupplyShortage [@ 24:00 Ja Show: Description 0 values:

KWH

### Hypothetical Decision Space



### Hypothetical Decision Variables

	Operating Level 4 (ft)	<b>Operating Level 5 (ft)</b>	<b>Operating Level 6 (ft)</b>
Date		Load fraction = 0.1	Load fraction = 0.2
		Approx. 75 hrs/mo	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

### Hypothetical Decision Variables

	Oper	ating Level 4 (ft)	<b>Operating Level 5 (ft)</b>	<b>Operating Level 6</b>	6 (ft)
Date			Load fraction = 0.1	Load fraction = C	).2
			Approx. 75 hrs/mo	Approx. 150 hrs/r	no
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	
			▲		

Constraint Boundaries

### Hypothetical Decision Variables

P Operating Level Table																
Value: 80 ft																
	1.00 NONE	2.00 NONE	3.00 NONE	4.00 NONE	5.00 NONE	6.00 NONE	7.00 NONE	8.00 NONE	9.00 NONE	10.00 NONE	11.00 NONE	12.00 NONE	13.00 NONE	14.00 NONE	15.00 NONE	16.00 NONE
0:00 ]an 1	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π	π
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0:00 Mar 22																
0:00 Apr 1																
0:00 May 1																
0:00 Jun 15																
0:00 Aug 1																
0:00 Aug 2																
0:00 Aug 15																
0:00 Sep 1																
0:00 Oct 1																
0:00 Nov 15																
0:00 Dec 31							-									

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

### Simulation-Optimization Framework Setup

New Decision Variable Values to Initiate and Run a New Population



**Generation Loop** 

### 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

energy gen. fenergy gen. fenergy gen. fenergy gen. fenergy gen. fenergy gen. fenergy gen.

#### **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?



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# **Proof of Concept**

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

Iocalhost:5006/BokehResults						
Reservoir Interactive Visualization Tool						
This tool provides interactive plots to visualize the Pareto-approx	imate (referred to as 'Pareto') solution set. Ea	ch Pareto se	plution is comp	osed of decisions (i.e., varia	ables controlled by the reservoir operator) and	
objective function (i.e., functions that measure solution optimality	) values. For Reservoir, the dec	cisions are tl	ne conservation	pool operating curves (i.e.	., guide curve inflection points consisting of	
dates and pool elevations) and associated hydropower load fract	ions (i.e., used to designate turbine run time).					
Parata Calutian Cate Desiring and Objectives						
Pareto Solution Set: Decisions and Objectives						
Use the selection and lasso tools to select Pareto solutions from the Non-Dor to visualize decision lever values in the Operating Level Results plot and the	ninated Tradeoffs plot. The Pareto Solution ID dropd	lown box is au	tomatically popula	ted with the user-selected Pareto	o Solution IDs. Use the Pareto Solution ID dropdown box	
······································	,					
Non-Dominated Tradeoffs	Operating Level Results	H	/dropower Load	Fractions		
	Pareto Solution ID	#	Op. Level	Load Fraction [Hrs/Wk]		
10545000	9	•	0 0	0.0		
	Ģ					
,0 <sup>0000</sup> =						
e 105500 -	-				- Op. Lev. 5	
	0.5				Op. Lev. 6	
C VOORON C	E -				Base Op. Lev. 4	
	stion -				Base. Lev. 5	
068500					Dase. Lev. b	
	00					
1057000						
- on-						
1057500						
1	-1					
100000 000000 0000000 000000 00	Jan00 Mar00	May00	Jul00 Date	Sep00 Nov00		
Water Supply Objective [m^3]			Duto			
Period of Record Performance: Water Supply				Period of Record Pe	erformance: Hydronower	

#### Period of Record Performance: Water Supply

The plotted black lines represents the baseline performance. Use the hover tool to associate Pareto Solution IDs with performance lines.

Frequency metrics are representative of the entire period of record (both wet and dry years).

The plotted black line represents the baseline performance. Use the hover tool to associate Pareto Solution IDS with performace bars.

Wet Years: Median |Demand Control Pt vs. Conditional Avg Demand (blue line) Water Supply Shortage Frequency Metrics

	12	#	Pareto Sol.	I # of Shortages	Total Vol. Shorted [AF]	P(Shortage) [%]
0.5	02	0	0	0	0.0	0.000
0.5	0					

Average Monthly Hydropower

Iced [MWH]



• Develop constraints for **realistic** guide curves



#### Hydropower Load Fractions

Pareto Solution ID	#	Op. Level	Load Fraction [Hrs/Wk]
30200_45701 🔹	0	Op. Lev. 5	25.2
	1	Op. Lev. 6	41.8





#### 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





### 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

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