IMPROVING HYDRO STAKEHOLDER VALUE

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February 1, 2018

OVERVIEW

- River Forecast Center
- Six-Hour Model Value
  - Hourly Sub-Timestep Embedded within 6-Hour Timestep Model
- Hydro Value Analysis
  - Evaluate Special Operations
- Lessons Learned

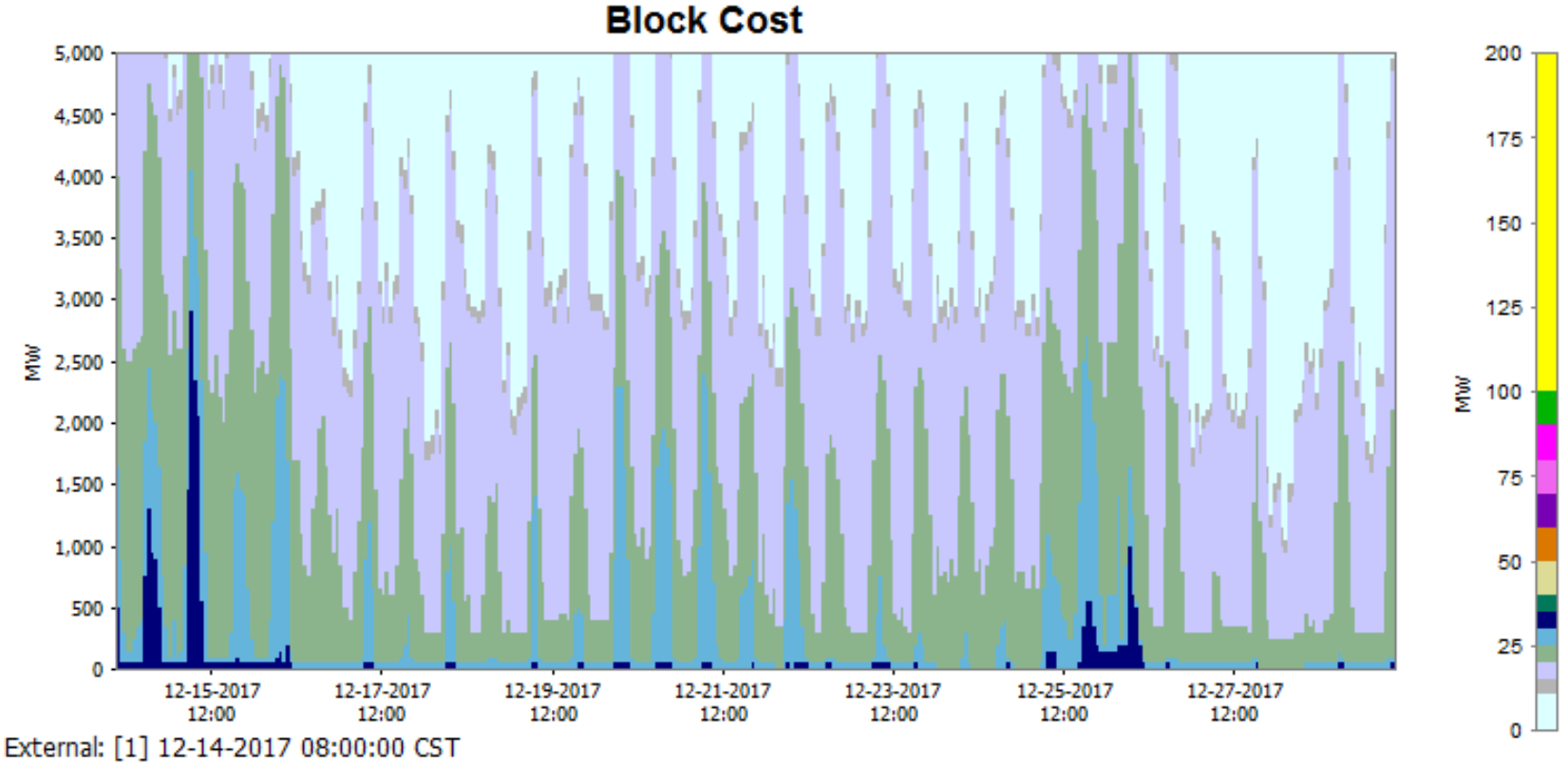
RIVER FORECAST CENTER

- Meet System Benefits
  - Flood Control
  - Navigation
  - Power
  - Recreation
  - Water Quality
  - Water Supply
- Create Value for TVA and Stakeholders
  - Displace More Expensive Power

SIX-HOUR MODEL

- Purpose:
  - Meet Policy/River System Benefits
  - Allocate Excess Water Based on Economics
- Model:
  - Daily Discharge Forecast
  - 15 Days
  - 6-Hour Timestep
  - Coarser Timestep = Faster

BLOCK COSTS


Block Cost
MW
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
12-15-2017 12:00
12-17-2017 12:00
12-19-2017 12:00
12-21-2017 12:00
12-23-2017 12:00
12-25-2017 12:00
12-27-2017 12:00
MW
200
175
150
125
100
75
50
25
0
External: [1] 12-14-2017 08:00:00 CST

AGGREGATION OF BLOCK COSTS

	Blk 1 $/MWh	Blk 2 $/MWh	Blk 3 $/MWh	Blk 4 $/MWh	Blk 5 $/MWh	Blk 6 $/MWh
12-11-2017 Mon 24:00	NaN O	NaN O	NaN O	NaN O	NaN O	NaN O
12-12-2017 Tue 01:00	34.01 I 0	30.22 I 0	26.80 I 0	26.68 I 0	26.04 I 0	25.66 I 0
12-12-2017 Tue 02:00	34.01 I 0	30.23 I 0	26.80 I 0	26.67 I 0	26.01 I 0	25.63 I 0
12-12-2017 Tue 03:00	34.01 I 0	30.40 I 0	26.71 I 0	26.45 I 0	25.95 I 0	25.30 I 0
12-12-2017 Tue 04:00	34.01 I 0	30.19 I 0	26.71 I 0	26.41 I 0	25.95 I 0	25.24 I 0
12-12-2017 Tue 05:00	31.17 I 0	26.45 I 0	25.95 I 0	25.41 I 0	24.48 I 0	24.22 I 0
12-12-2017 Tue 06:00	31.17 I 0	26.45 I 0	25.95 I 0	25.61 I 0	25.28 I 0	25.18 I 0
12-12-2017 Tue 07:00	34.00 I 0	33.86 I 0	33.74 I 0	33.64 I 0	33.64 I 0	33.64 I 0
12-12-2017 Tue 08:00	39.05 I 0	33.91 I 0				
12-12-2017 Tue 09:00	38.61 I 0	32.06 I 0				
12-12-2017 Tue 10:00	38.61 I 0	31.04 I 0				
12-12-2017 Tue 11:00	37.72 I 0	29.63 I 0				
12-12-2017 Tue 12:00	37.72 I 0	29.63 I 0				
12-12-2017 Tue 13:00	37.58 I 0	28.54 I 0				
12-12-2017 Tue 14:00	37.58 I 0	28.55 I 0				
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12-12-2017 Tue 16:00	30.85 I 0	29.63 I 0				
12-12-2017 Tue 17:00	33.64 I 0	33.53 I 0				
12-12-2017 Tue 18:00	34.01 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 19:00	34.01 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 20:00	34.01 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 21:00	34.09 I 0	34.03 I 0	33.99 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 22:00	34.01 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 23:00	33.68 I 0	33.12 I 0	32.98 I 0	32.98 I 0	32.98 I 0	32.86 I 0
12-12-2017 Tue 24:00	30.61 I 0	29.98 I 0	29.91 I 0	29.63 I 0	29.63 I 0	29.63 I 0

	Blk 1 $/MWh	Blk 2 $/MWh	Blk 3 $/MWh	Blk 4 $/MWh	Blk 5 $/MWh	Blk 6 $/MWh
12-11-2017 Mon 24:00	NaN O	NaN O	NaN O	NaN O	NaN O	NaN O
12-12-2017 Tue 06:00	33.06 I 0	28.99 I 0	26.49 I 0	26.20 I 0	25.62 I 0	25.20 I 0
12-12-2017 Tue 12:00	37.62 I 0	31.69 I 0	31.46 I 0	31.30 I 0	30.85 I 0	30.59 I 0
12-12-2017 Tue 18:00	33.99 I 0	30.35 I 0	30.08 I 0	29.82 I 0	29.70 I 0	29.39 I 0
12-12-2017 Tue 24:00	33.40 I 0	33.16 I 0	33.12 I 0	33.06 I 0	33.06 I 0	33.04 I 0

- Decisions Made at Hourly Level

What's the Problem?

- 6-Hour Block Costs.....
  - All-or-Nothing Approach
  - Example
    - > 1-unit plant
    - > 12 hours of generation
    - > Avg 6-hr value = $31.95/MW
    - > Avg 1-hr value = $32.79/MW
- Takeaway -

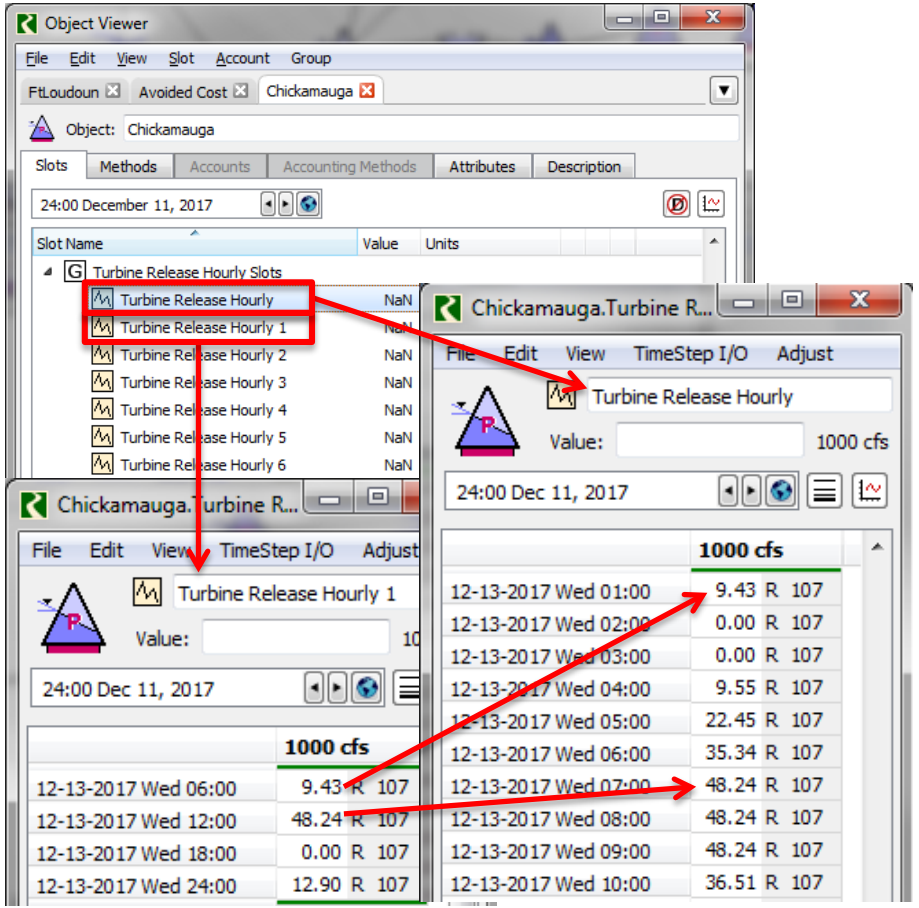
  Data Smoothing Can Lead to Less-than-Ideal Answer

	Blk 1 $/MWh	Blk 2 $/MWh	Blk 3 $/MWh	Blk 4 $/MWh	Blk 5 $/MWh	Blk 6 $/MWh
12-11-2017 Mon 24:00	NaN O	NaN O	NaN O	NaN O	NaN O	NaN O
12-12-2017 Tue 01:00	34.01 I 0	30.22 I 0	26.80 I 0	26.68 I 0	26.04 I 0	25.66 I 0
12-12-2017 Tue 02:00	34.01 I 0	30.23 I 0	26.80 I 0	26.67 I 0	26.01 I 0	25.63 I 0
12-12-2017 Tue 03:00	34.01 I 0	30.40 I 0	26.71 I 0	26.45 I 0	25.95 I 0	25.30 I 0
12-12-2017 Tue 04:00	34.01 I 0	30.19 I 0	26.71 I 0	26.41 I 0	25.95 I 0	25.24 I 0
12-12-2017 Tue 05:00	31.17 I 0	26.45 I 0	25.95 I 0	25.41 I 0	24.48 I 0	24.22 I 0
12-12-2017 Tue 06:00	31.17 I 0	26.45 I 0	25.95 I 0	25.61 I 0	25.28 I 0	25.18 I 0
12-12-2017 Tue 07:00	34.00 I 0	33.86 I 0	33.74 I 0	33.64 I 0	33.64 I 0	33.64 I 0
12-12-2017 Tue 08:00	39.05 I 0	33.91 I 0	33.72 I 0	33.64 I 0	33.64 I 0	33.64 I 0
12-12-2017 Tue 09:00	38.61 I 0	32.06 I 0	32.06 I 0	32.04 I 0	30.82 I 0	29.98 I 0
12-12-2017 Tue 10:00	38.61 I 0	31.04 I 0	29.98 I 0	29.98 I 0	29.68 I 0	29.63 I 0
12-12-2017 Tue 11:00	37.72 I 0	29.63 I 0	29.63 I 0	29.63 I 0	29.63 I 0	29.47 I 0
12-12-2017 Tue 12:00	37.72 I 0	29.63 I 0	29.63 I 0	28.89 I 0	27.67 I 0	27.16 I 0
12-12-2017 Tue 13:00	37.58 I 0	28.54 I 0	27.96 I 0	27.56 I 0	27.32 I 0	27.02 I 0
12-12-2017 Tue 14:00	37.58 I 0	28.55 I 0	27.98 I 0	27.56 I 0	27.34 I 0	27.02 I 0
12-12-2017 Tue 15:00	30.31 I 0	27.91 I 0	27.54 I 0	27.21 I 0	27.02 I 0	27.02 I 0
12-12-2017 Tue 16:00	30.85 I 0	29.63 I 0	29.53 I 0	29.13 I 0	29.11 I 0	28.70 I 0
12-12-2017 Tue 17:00	33.64 I 0	33.53 I 0	33.53 I 0	33.53 I 0	33.48 I 0	32.64 I 0
12-12-2017 Tue 18:00	34.01 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 19:00	34.01 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 20:00	34.01 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 21:00	34.09 I 0	34.03 I 0	33.99 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 22:00	34.01 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0	33.94 I 0
12-12-2017 Tue 23:00	33.68 I 0	33.12 I 0	32.98 I 0	32.98 I 0	32.98 I 0	32.86 I 0
12-12-2017 Tue 24:00	30.61 I 0	29.98 I 0	29.91 I 0	29.63 I 0	29.63 I 0	29.63 I 0

	Blk 1 $/MWh	Blk 2 $/MWh	Blk 3 $/MWh	Blk 4 $/MWh	Blk 5 $/MWh	B
12-11-2017 Mon 24:00	NaN O	NaN O	NaN O	NaN O	NaN O	
12-12-2017 Tue 06:00	33.06 I 0	28.99 I 0	26.49 I 0	26.20 I 0	25.62 I 0	
12-12-2017 Tue 12:00	37.62 I 0	31.69 I 0	31.46 I 0	31.30 I 0	30.85 I	
12-12-2017 Tue 18:00	33.99 I 0	30.35 I 0	30.08 I 0	29.82 I 0	29.70 I 0	
12-12-2017 Tue 24:00	33.40 I 0	33.16 I 0	33.12 I 0	33.06 I 0	33.06 I	33.04 I 0

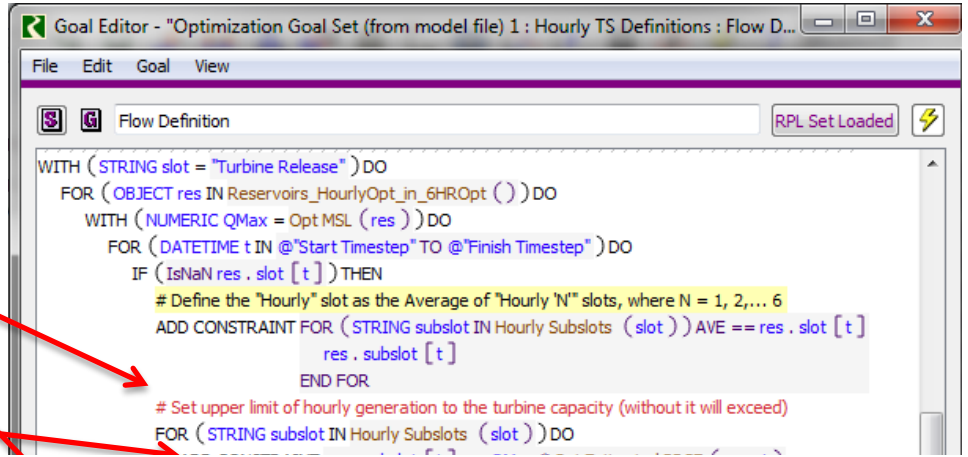
The Solution?

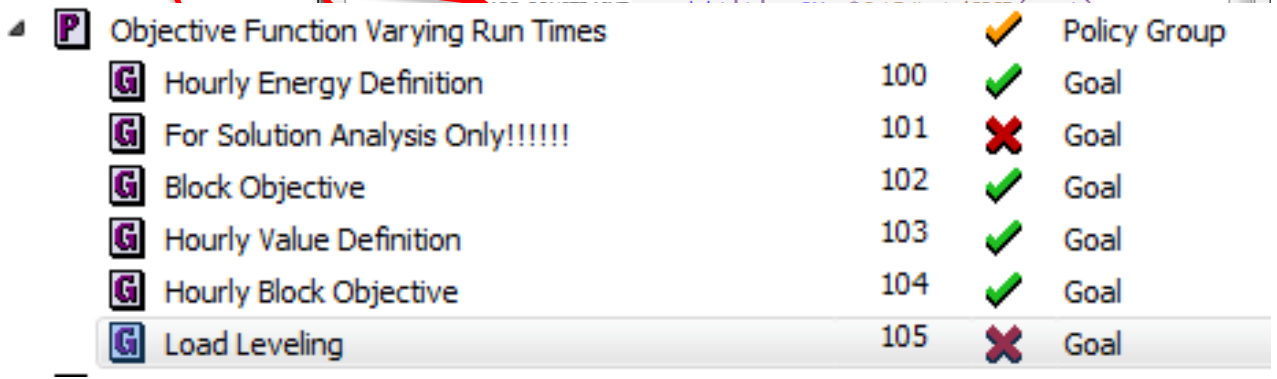
- Use (Pseudo)Hourly Timestep in the 6-Hour Model
- User-Defined Optimization Variables
  - "Turbine Release" for Ramping Restrictions
  - "Energy" for Maximizing Value



The Solution?

- Define Hourly Variables
- Relate Variables to Model Timestep
- Add Sub-Timestep Restrictions



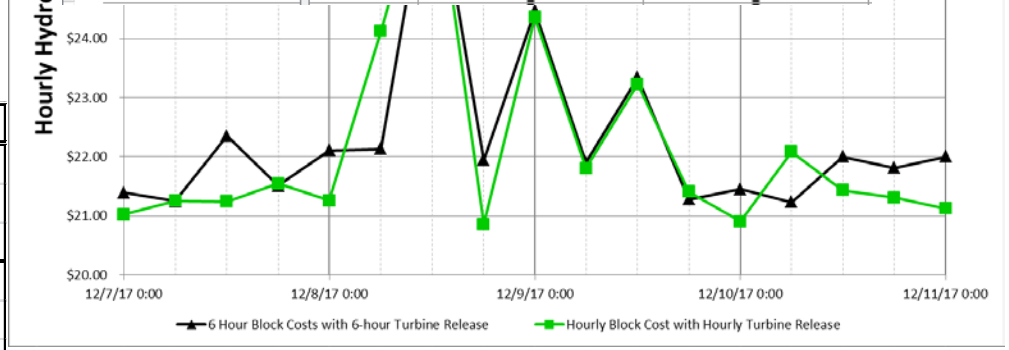


Results

- Realistic Generation at 1-Unit Plants
- More Accurate Marginal Costs
- Energy Shifted to More Valuable Days

		15-Day Run
6-Hour Block Cost	Value ($)	11,463,000
	Generation (MWH)	517,900
	Average Value ($/MWH)	22.13
Hourly Block Cost	Value ($)	10,978,000
	Generation (MWH)	500,300
	Average Value ($/MWH)	21.94

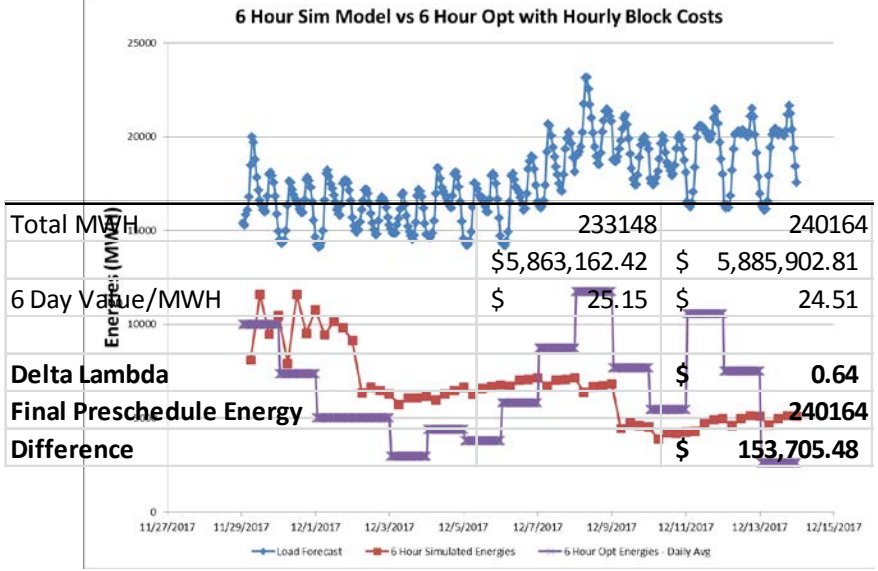
Slot Label	12/7 Thu	12/8 Fri	12/9 Sat	12/10 Sun	12/11 Mon
▸ CHATUGE					
▸ Adjustment	0.00	0.00	0.00	0.00	0.00
▸ Total local	0.15	0.15	0.15	0.14	0.14
▸ Total inflow	0.15	0.15	0.15	0.14	0.14
▸ Storage	89.23	88.64	88.31	88.40	87.80
▸ Elevation	1,917.83	1,917.62	1,917.50	1,917.53	1,917.31
▸ Hydro capacity	13.23	13.23	13.23	13.23	13.21
▾ Energy	126	140	89	11	139
6:00	14	14	14	0	0
12:00	42	56	69	6	69
18:00	14	14	0	0	42
24:00	56	56	6	6	28



Results

- Buy-In Important
  - Reran Opt Model with Approx. Total Energy
  - Compared to Sim Model
  - No Rain in Forecast
  - Total Cost = $140,000
- For good measure
  - Compared Estimated Hourly Energy in 6-Hour Model to Final Preschedule
  - Cost > $150,000 for 6 Days

Simulation	Total Value	$ 8,833,117	
	Total Energy	**395183**	**MWH**
	Average Value	**$ 22.35**	**$/MWH**
6 Hour Opt; Match MWH	Total Value	$ 8,950,107	
	Total Energy	**394340**	**MWH**
	Average Value	**$ 22.70**	**$/MWH**



Total MWH	233148	240164
	$5,863,162.42	$ 5,885,902.81
6 Day Value/MWH	$ 25.15	$ 24.51
Delta Lambda		**$ 0.64**
Final Preschedule Energy		**240164**
Difference		**$ 153,705.48**

Hydro Value Analysis (Post Operation)

- Valuation of “Special Operations”
- Currently Fortran Exe
- Migrating to RiverWare
  - Base Model is Hourly (Preschedule) Model
  - Currently Prototyping

Select a reservoir: Chickamauga

View Details

Export Details

Hour	Price	Actual	Optimal	Ramp/Pulse	Recreation	Outage	Special Ops	Hydro Thermal	Unforced Spill
01	32.77	42.92	80.37	80.37	80.37	0.00	42.00	42.00	42.00
02	33.78	42.26	80.37	80.37	80.37	0.00	42.00	42.00	42.00
03	31.71	42.38	80.37	80.37	80.37	0.00	42.00	42.00	42.00
04	31.29	42.37	80.37	80.37	80.37	0.00	42.00	42.00	42.00
05	34.04	42.26	80.37	80.37	80.37	0.00	42.00	42.00	42.00
06	42.55	42.24	125.47	125.47	125.47	0.00	42.00	42.00	42.00
07	45.00	42.31	125.47	125.47	125.47	0.00	42.00	42.00	42.00
08	43.19	42.61	125.47	125.47	125.47	0.00	125.47	125.47	125.47
09	37.28	81.77	80.37	80.37	80.37	0.00	125.47	125.47	125.47
10	32.55	82.89	80.37	80.37	80.37	0.00	80.37	80.37	80.37
11	32.73	83.02	80.37	80.37	80.37	0.00	80.37	80.37	80.37
12	29.41	82.64	80.37	80.37	80.37	0.00	80.37	80.37	80.37
13	26.10	82.87	0.00	0.00	0.00	0.00	80.37	80.37	80.37
14	25.01	82.81	0.00	0.00	0.00	0.00	69.69	69.69	69.69
15	24.99	83.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	26.09	82.97	0.00	0.00	0.00	0.00	80.37	80.37	80.37
17	30.66	83.07	80.37	80.37	80.37	0.00	80.37	80.37	80.37
18	34.57	83.08	80.37	80.37	80.37	0.00	80.37	80.37	80.37
19	32.51	82.92	80.37	80.37	80.37	0.00	80.37	80.37	80.37
20	32.16	83.14	80.37	80.37	80.37	0.00	80.37	80.37	80.37
21	31.57	82.58	80.37	80.37	80.37	0.00	80.37	80.37	80.37
22	28.60	82.54	55.65	55.65	55.65	0.00	80.37	80.37	80.37
23	25.10	64.24	0.00	0.00	0.00	0.00	80.37	80.37	80.37
24	24.95	43.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	768.61	1606.16	1557.24	1557.24	1557.24	0.00	1579.07	1579.07	1579.07

Hydro Value Analysis Implementation

- Iterative process
  - Likely to Use MRM Runs
  - Alternative Options
    - > Scripting and Lists (Looping)
    - > Batch Script
- Output = Energies
- Post-Opt Processing
  - Computation of Cost/Value

Select a reservoir: Chickamauga

View Details

Export Details

Hour	Price	Actual	Optimal	Ramp/Pulse	Recreation	Outage	Special Ops	Hydro Thermal	Unforced Spill
01	32.77	42.92	80.37	80.37	80.37	0.00	42.00	42.00	42.00
02	33.78	42.26	80.37	80.37	80.37	0.00	42.00	42.00	42.00
03	31.71	42.38	80.37	80.37	80.37	0.00	42.00	42.00	42.00
04	31.29	42.37	80.37	80.37	80.37	0.00	42.00	42.00	42.00
05	34.04	42.26	80.37	80.37	80.37	0.00	42.00	42.00	42.00
06	42.55	42.24	125.47	125.47	125.47	0.00	42.00	42.00	42.00
07	45.00	42.31	125.47	125.47	125.47	0.00	42.00	42.00	42.00
08	43.19	42.61	125.47	125.47	125.47	0.00	125.47	125.47	125.47
09	37.28	81.77	80.37	80.37	80.37	0.00	125.47	125.47	125.47
10	32.55	82.89	80.37	80.37	80.37	0.00	80.37	80.37	80.37
11	32.73	83.02	80.37	80.37	80.37	0.00	80.37	80.37	80.37
12	29.41	82.64	80.37	80.37	80.37	0.00	80.37	80.37	80.37
13	26.10	82.87	0.00	0.00	0.00	0.00	80.37	80.37	80.37
14	25.01	82.81	0.00	0.00	0.00	0.00	69.69	69.69	69.69
15	24.99	83.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	26.09	82.97	0.00	0.00	0.00	0.00	80.37	80.37	80.37
17	30.66	83.07	80.37	80.37	80.37	0.00	80.37	80.37	80.37
18	34.57	83.08	80.37	80.37	80.37	0.00	80.37	80.37	80.37
19	32.51	82.92	80.37	80.37	80.37	0.00	80.37	80.37	80.37
20	32.16	83.14	80.37	80.37	80.37	0.00	80.37	80.37	80.37
21	31.57	82.58	80.37	80.37	80.37	0.00	80.37	80.37	80.37
22	28.60	82.54	55.65	55.65	55.65	0.00	80.37	80.37	80.37
23	25.10	64.24	0.00	0.00	0.00	0.00	80.37	80.37	80.37
24	24.95	43.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	768.61	1606.16	1557.24	1557.24	1557.24	0.00	1579.07	1579.07	1579.07

Future Uses of Hydro Value Analysis

- Pre-Operation Analyses
  - Evaluate Alternative Start Times for Special Operations
    - > Adds Stakeholder value
  - Weigh Cost of Lost Generation
- Pre-Operations Evaluation of Cost for Maintenance Outages

Select a reservoir: Chickamauga

View Details

Export Details

Hour	Price	Actual	Optimal	Ramp/Pulse	Recreation	Outage	Special Ops	Hydro Thermal	Unforced Spill
01	32.77	42.92	80.37	80.37	80.37	0.00	42.00	42.00	42.00
02	33.78	42.26	80.37	80.37	80.37	0.00	42.00	42.00	42.00
03	31.71	42.38	80.37	80.37	80.37	0.00	42.00	42.00	42.00
04	31.29	42.37	80.37	80.37	80.37	0.00	42.00	42.00	42.00
05	34.04	42.26	80.37	80.37	80.37	0.00	42.00	42.00	42.00
06	42.55	42.24	125.47	125.47	125.47	0.00	42.00	42.00	42.00
07	45.00	42.31	125.47	125.47	125.47	0.00	42.00	42.00	42.00
08	43.19	42.61	125.47	125.47	125.47	0.00	125.47	125.47	125.47
09	37.28	81.77	80.37	80.37	80.37	0.00	125.47	125.47	125.47
10	32.55	82.89	80.37	80.37	80.37	0.00	80.37	80.37	80.37
11	32.73	83.02	80.37	80.37	80.37	0.00	80.37	80.37	80.37
12	29.41	82.64	80.37	80.37	80.37	0.00	80.37	80.37	80.37
13	26.10	82.87	0.00	0.00	0.00	0.00	80.37	80.37	80.37
14	25.01	82.81	0.00	0.00	0.00	0.00	69.69	69.69	69.69
15	24.99	83.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	26.09	82.97	0.00	0.00	0.00	0.00	80.37	80.37	80.37
17	30.66	83.07	80.37	80.37	80.37	0.00	80.37	80.37	80.37
18	34.57	83.08	80.37	80.37	80.37	0.00	80.37	80.37	80.37
19	32.51	82.92	80.37	80.37	80.37	0.00	80.37	80.37	80.37
20	32.16	83.14	80.37	80.37	80.37	0.00	80.37	80.37	80.37
21	31.57	82.58	80.37	80.37	80.37	0.00	80.37	80.37	80.37
22	28.60	82.54	55.65	55.65	55.65	0.00	80.37	80.37	80.37
23	25.10	64.24	0.00	0.00	0.00	0.00	80.37	80.37	80.37
24	24.95	43.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	768.61	1606.16	1557.24	1557.24	1557.24	0.00	1579.07	1579.07	1579.07

Lessons Learned in This Process

- Aggregating data can result in a bad solution if the effect spans the time frame of interest
- Sub-timestep computation can greatly improve the solution while adding little computation time
- Review RPL Analysis data
  - Computed operating head multiple times for each timestep
    - > Now computed once and passed to other functions
    - > (saved ~10 seconds on RBS)
- Predefined functions are often more efficient
  - Switching to the internal “GetSelectedUserMethod” shaved 20+ seconds off RBS


TVA