



Hourly RiverWare Model Update Challenges and Opportunities

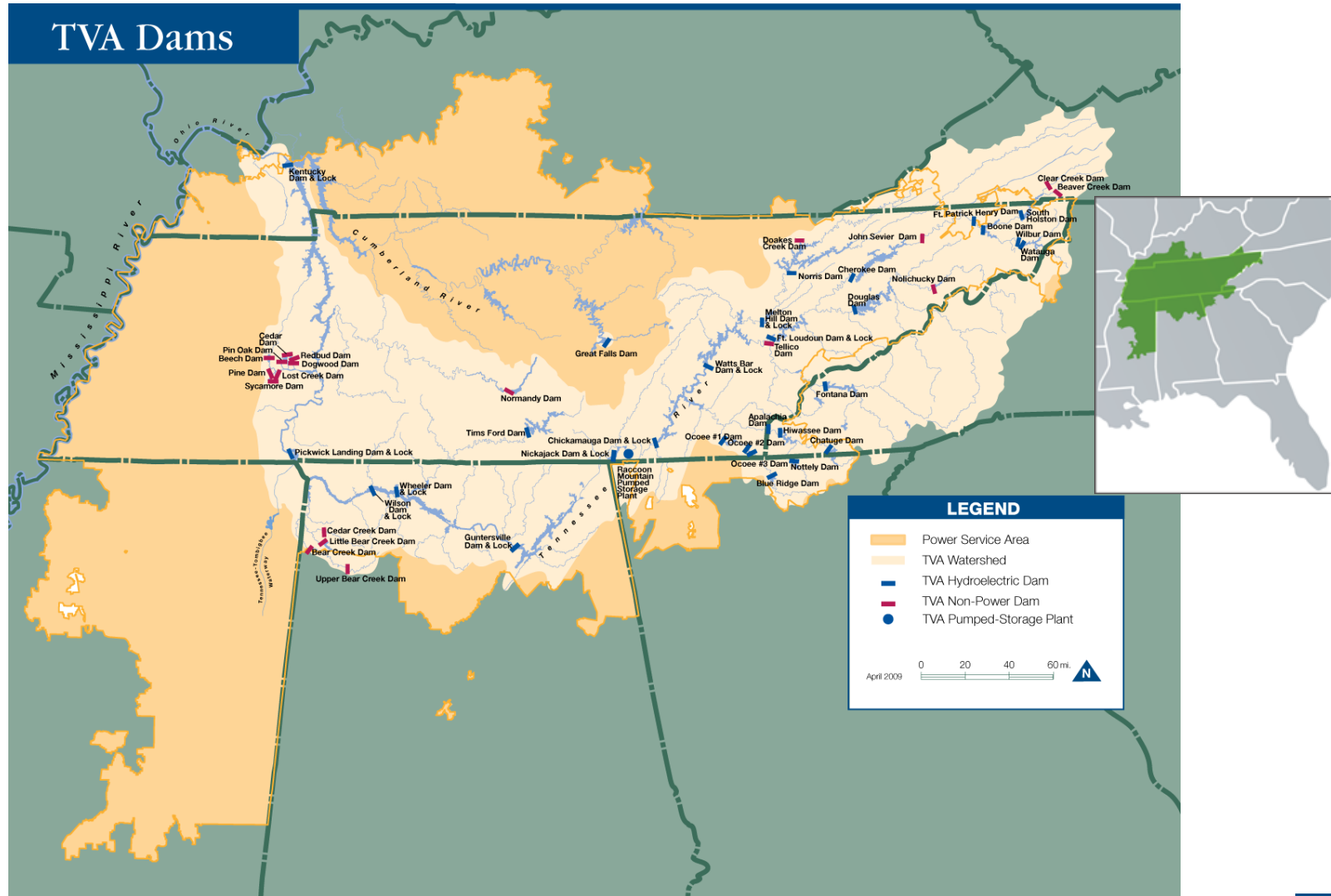
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Overview

- **TVA and Tennessee Valley**
- **Optimization at TVA**
- **Hourly Model Changes**
 - Why?
 - What?
 - How?
- **What's Next?**



Tennessee River System



Reservoir System Benefits

- **Flood Control**
- **Navigation**
- **Power**
- **Recreation**
- **Water Quality**
- **Water Supply**



Goal of Optimization

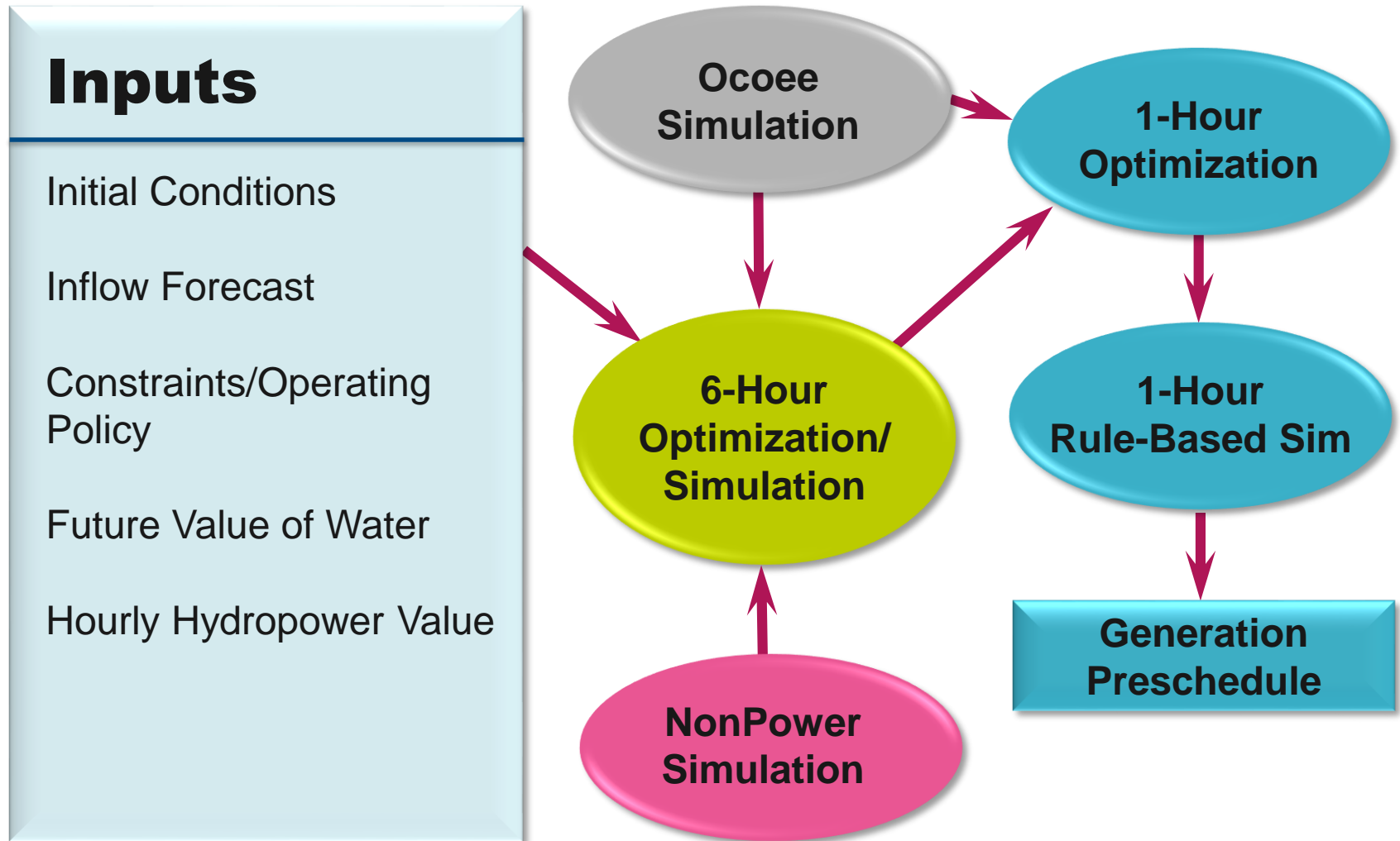
Balance System Benefits

Minimize Total Cost of Generation

- ~10% of TVA's Portfolio
- Low O&M Costs
- Rapid Dispatch
- Flexibility



TVA Optimization Process



Why Change the Hourly Model?

Some Constraints Not Fully Modeled

- Unit Start/Stops
- Unit Ramping
- System Ramping
- Partial-Unit Use
- Pulses
- Special Operations
- Hydrothermal Needs
- Recreation

Timestep	Day	FtLoudoun MWH [Sum]	FtLoudoun MWH [Sum]	WattsBar MWH [Sum]	Chickamauga MWH [Sum]	Nickajack MWH [Sum]	Guntersville MWH [Sum]	Wheeler MWH [Sum]
3/23 24:00	Wed	55	NaN	0	32	0	0	31
3/23 24:00	Wed	55		0	32	0	0	31
Total	Wed	55	NaN	0	32	0	0	31
FS Tot	Wed							
Diff	Wed							
MEL	Wed							
MSL	Wed							
3/24 24:00	Thu	1,262	NaN	1,424	1,330	685	1,583	1,631
3/24 1:00	Thu	0		0	0	0	0	0
3/24 2:00	Thu	0		0	0	0	0	0
3/24 3:00	Thu	0		0	0	0	0	0
3/24 4:00	Thu	0		0	0	0	0	0
3/24 5:00	Thu	0		0	0	0	0	0
3/24 6:00	Thu	0		0	0	0	0	0
3/24 7:00	Thu	51		0	57	0	42	208
3/24 8:00	Thu	111		140	93	0	130	0
3/24 9:00	Thu	111		140	93	90	129	0
3/24 10:00	Thu	0		140	93	100	0	0
3/24 11:00	Thu	0		140	42	0	129	70
3/24 12:00	Thu	111		0	93	100	129	0
3/24 13:00	Thu	106		140	93	0	129	199
3/24 14:00	Thu	111		140	92	14	128	0
3/24 15:00	Thu	111		23	92	90	0	250
3/24 16:00	Thu	104		140	92	100	128	0
3/24 17:00	Thu	0		0	92	0	128	0
3/24 18:00	Thu	111		140	31	0	0	173
3/24 19:00	Thu	111		140	92	0	128	0
3/24 20:00	Thu	111		0	92	100	128	0

Why Change the Hourly Model?

Fortran-Based “Clean-Up”

- Smooth Generation/Eliminate “Holes”
- Meet Unit Ramping
- Meet Minimum Flows/Pulses

“Clean-Up” Could Undo Optimization

- System Ramping
- Special Operations
- Hydrothermal Needs
- Recreation

Migration to Delft-FEWS

Pros:

- Centralized Data Warehouse
- Faster
- Excels at Storing and Manipulating Time-Series

Challenges:

- Requires Initialization Rules
- Improved LP Parameter Estimation (Approximation Points)
- Easier to Modify Policy

▲ P	Hourly and 6 Hour Model Initialization Rules			
R	Set Day 1 outflows for plants with MSL or greater1	17	Z	0
R	Set and Compute Requested Discharges (FLH, KYH, BYH)	18	Z	0
R	Set Day 1 Tellico Outflow to 0	19	Z	0
R	Auto-Fill Appropriate slots	20	R	IR
R	Set headwaters across Model Period	21	Z	0
R	Set Tailwater Elevation LP Parameters	22	Z	0
R	Set Backwater Lambda LP Parameters	23	Z	0
R	Set Ending Targets	24	Z	0
R	Set Minimum Daily Flows at plants with Pulses	25	Z	0
R	Hourly Set Upper Bound LP Param, Spill/Bypass LP Param, and U...	26	Z	0
R	Set Lower Bound LP Parameters	27	Z	0
R	Set Power LP Param	28	Z	0
R	Set Pool Elevation LP Param	29	Z	0
R	Set Energy-In-Storage LP Param	30	Z	0
R	Compute Tributary System Storage	31	Z	0
R	Set Observed Storage	32	Z	0
R	Set Observed Power Coefficient - Day 0	33	Z	0
R	Compute Ocoee 3 Spill	34	Z	0
R	Compute Operating Head	35	Z	0
R	Data Checks	36	R	IR
R	Set Ocoee 2 HW for VPS model	37	Z	0
R	Summer Balancing & FG	38	Z	0

Considerations

Reduce Need for User Input!

- Run Time
- Allow for User Input/Overrides
- Meet Minimum Flows/Pulses
- Meet Daily Volumes
- Special Operations
- Eliminate “Holes”/“Peaks”
- Minimize Spill
- Meet Unit/System Ramping

```
Lower and upper bounds
Arguments: OBJECT res, DATETIME t, NUMERIC offset, LIST SetPoints Return Type: LIST

WITH NUMERIC minQ = IF (offset == 0.00000000 "hr") THEN DO
    MaxItem (
        Minimum flow from constraints (res, t, offset, SetPoints),
        Hole Prevention Minimum (res, t, SetPoints)
    )
ELSE
    Minimum flow from constraints (res, t, offset, SetPoints)
END IF

WITH NUMERIC maxQ = IF (offset == 0.00000000 "hr") THEN DO
    MinItem (
        MinItem (
            Maximum flow from constraints (res, t, offset, SetPoints),
            Hole Prevention Maximum (res, t)
        ),
        minQ
    )
ELSE
    Max (
        minQ,
        Maximum flow from constraints (res, t, offset, SetPoints)
    )
END IF

WITH NUMERIC adjQ = Min (maxQ, minQ) DO
    WITH NUMERIC LowerSetpoint = Round Down To Setpoint (adjQ, SetPoints) DO
        WITH NUMERIC UpperSetpoint = Round Up To Setpoint (adjQ, SetPoints) DO
            WITH NUMERIC LowerBound = Max (LowerSetpoint, minQ) DO
                WITH NUMERIC UpperBound = IF (maxQ < UpperSetpoint) THEN DO
                    LowerBound
                ELSE
                    UpperSetpoint
                END IF
            END IF
        END IF
    END IF
    { LowerBound, UpperBound }
```

Model Innovations

Optimization Goals:

- Basics remain
- Added complexity where needed
 - Minimum flows
 - Merged Hydro Ramp Rates
 - Minimize Spill

Optimization Goal Set (from model file) RPL Set Loaded

Policy & Utility Groups Report Groups

Name	Priority	On	Type
▶ Minimum Flow	7-10	✓	Policy Group
▶ Daily Volume	11-13	✓	Policy Group
▶ Daily Volume for Canal Projects	14-16	✗	Policy Group
▶ Tims Ford	17-17	✓	Policy Group
▶ Special Operations	18-19	✓	Policy Group
▶ Tandem Plants	20-20	✓	Policy Group
▶ Top_Botton Oper Zone (Tribes)	21-21	✗	Policy Group
▶ Top+Bottom of Operating Zone (Main River)	22-22	✗	Policy Group
▶ Top+Bottom of Operating Zone (Cumberland)	23-23	✗	Policy Group
▶ Top+Bottom of Operating Zone	24-26	✗	Policy Group
▶ One unit off on	27-27	✓	Policy Group
▶ Minimum Power Elevation	28-28	✗	Policy Group
▶ Modified Load	29-29	✗	Policy Group
▶ SEPA Energy Declaration	30-30	✓	Policy Group
▲ Minimize Spill		✓	Policy Group
New 'No Spill'	31	✓	Goal
▲ Ramp rates		✓	Policy Group
Maximum Daily Flow Change	32	✓	Goal
Unit Ramp rates	33	✓	Goal
Minimum Plant Hydro on Daily Minimum	34	✗	Goal
Minimum Total Hydro on Daily Minimum	35	✗	Goal
Peak Plant Hydro on Peak	36	✗	Goal
Peak Total Hydro on Peak	37	✗	Goal
Increasing/Decreasing project generati...	38	✓	Goal
Hydro Ramp Rate	39	✗	Goal
Merged Hydro Ramp Rates	40	✓	Goal
▶ Maximize Avoided Operating Cost	41-41	✓	Policy Group
▶ Boneyard	42-42	✗	Policy Group

Model Innovations

“RunMSL” Function:

- Why force optimization to find a value if you already know the answer?
- Sets outflow via an initialization rule if to outflow exceeds turbine capacity.

```

WITH DATETIME lastT = Round Date Up ( t , hours * 1.00000000 "hour" ) DO
  # Average MSL = MSL in LP Param table * average ppcf
  WITH NUMERIC AvgMSL = OptMSL * SlotAvg ( res . "Power Plant Cap Fraction" , lastT , hours ) DO
    IF ( hours == 24.00000000 ) THEN
      # Use the daily volume calculated by the 6 Hour model
      WITH NUMERIC outflow = SlotValueFromDataObject ( res , "Volume" , lastT ) DO
        hours
        # True if outflow > average MSL * capacity factor (e.g. 0.95)
        # Calculate spill without capacity factor and require it to be non-negative
        { outflow > AvgMSL * capacityratio , Max ( outflow - AvgMSL , 0.00000000 "cfs" ) }
      END WITH
    ELSE WITH
      IF ( hours == 6.00000000 ) THEN
        WITH NUMERIC outflow = SlotValueFromDataObject ( res , "Flowsheet Outflow_6hr" , lastT ) DO
          # True if outflow > average MSL * capacity factor (e.g. 0.95)
          # Calculate spill without capacity factor and require it to be non-negative
          { outflow > AvgMSL * capacityratio , Max ( outflow - AvgMSL , 0.00000000 "cfs" ) }
        END WITH
      ELSE
        IF ( hours == 1.00000000 ) THEN
          WITH LIST DailyMSL = RunMSL ( res , t , 24.00000000 , capacityratio , OptMSL ) DO
            IF ( res IN ( AllReservoirs-TVA ( ) UNION Reservoirs_Brookfield_All ( ) ) ) THEN
              # For TVA or Brookfield Reservoirs (Except O2H and RMPS)
              WITH LIST Hour6MSL = RunMSL ( res , t , 6.00000000 , capacityratio , OptMSL ) DO
                # Run MSL if required for both Daily and 6-Hour.
                # Return 6Hour average spill for hourly spill.
                { ( DailyMSL < 0 > ) AND Hour6MSL < 0 > , Hour6MSL < 1 > }
              END WITH
            ELSE
              # Cumberland
              # Run MSL if required for both Daily.
              # Return Daily average spill for hourly spill.
              { DailyMSL < 0 > , DailyMSL < 1 > }
            END IF
          END WITH
        ELSE
          STOP_RUN "Global function RunMSL expects the hours argument to be 1, 6, or 24, and instead w
        END IF
      END IF
    END IF
  END WITH

```

New Opt/RBS vs Final Preschedule

Timestep	Day	SoHolston MWH [Su]	Watauga MWH [Su]	Wilbur MWH [Su]	Boone MWH [Su]	FtPatH MWH [Su]	Cherokee MWH [Su]	Douglas MWH [Su]	SoHolston	Watauga	Wilbur	Boone	FtPatH	Cherokee	Douglas	Fontana
8/15 24:00	Mon	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0	0	0	0	0	0	0	0
8/16 24:00	Tue	450	272	0	243	231	1,192	1,471	0	0	0	0	13	0	0	0
8/17 24:00	Wed	440	212	44	371	221	1,165	1,414	0	0	0	22	0	0	0	0
8/17 1:00	Wed	0	0	0	0	0	0	0	0	0	0	22	13	20	0	0
8/17 2:00	Wed	0	0	0	0	13	0	0	23	0	0	22	0	0	0	0
8/17 3:00	Wed	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0
8/17 4:00	Wed	0	0	0	0	0	0	0	0	0	0	22	0	0	17	0
8/17 5:00	Wed	0	0	0	0	12	19	0	0	0	0	0	17	0	0	0
8/17 6:00	Wed	20	0	0	0	0	0	0	0	0	0	0	17	0	0	0
8/17 7:00	Wed	0	0	0	0	0	0	19	0	0	0	0	17	0	0	0
8/17 8:00	Wed	0	0	0	0	12	0	0	0	0	0	0	17	0	0	0
8/17 9:00	Wed	0	0	0	0	0	0	0	42	30	0	0	17	37	76	87
8/17 10:00	Wed	0	0	0	0	0	0	0	0	0	0	0	17	74	111	174
8/17 11:00	Wed	0	0	0	0	13	73	72	42	30	7	0	17	114	148	261
8/17 12:00	Wed	42	0	0	0	13	74	107	40	30	7	22	0	114	148	261
8/17 13:00	Wed	42	30	6	47	13	110	142	40	30	7	22	0	114	148	261
8/17 14:00	Wed	42	30	6	52	13	111	142	40	30	7	22	17	114	148	261
8/17 15:00	Wed	42	30	6	52	26	111	142	40	30	7	22	17	114	148	261
8/17 16:00	Wed	42	30	6	52	26	135	142	40	30	7	22	17	114	148	261
8/17 17:00	Wed	42	62	8	51	26	136	167	40	30	7	22	17	114	148	261
8/17 18:00	Wed	42	30	6	23	14	136	141	42	0	0	22	17	114	111	174
8/17 19:00	Wed	42	0	0	23	14	75	107	42	0	0	22	17	114	76	174
8/17 20:00	Wed	42	0	0	23	14	74	71	42	0	0	22	0	74	76	174
8/17 21:00	Wed	42	0	0	23	0	38	71	0	0	0	22	0	37	38	87
8/17 22:00	Wed	0	0	0	23	0	37	71	0	0	0	22	13	37	0	87
8/17 23:00	Wed	0	0	0	0	13	37	0	0	0	0	22	0	0	0	87
8/17 24:00	Wed	0	0	0	0	0	0	0	0	0	0	22	0	0	0	87

Next Steps

- **Refine the model**
 - Special Operations
 - AGC Plant Scheduling
- **Scheduling in the model**
- **Unit-level Scheduling**
 - Day-by-day vs timestep-by-timestep
- **10-day run?**
 - Days 1-3 at unit/plant level?
 - Days 4-10 at the system level?

Summary

So... Why Change the Hourly Model?

- Original Solution Required Much User Clean-Up
- Normal Operation Constraints Were Only Partially Implemented in the Original Optimization Solution
- RiverWare and Computers have evolved greatly



Questions?

