# Hourly RiverWare Model Update Challenges and Opportunities

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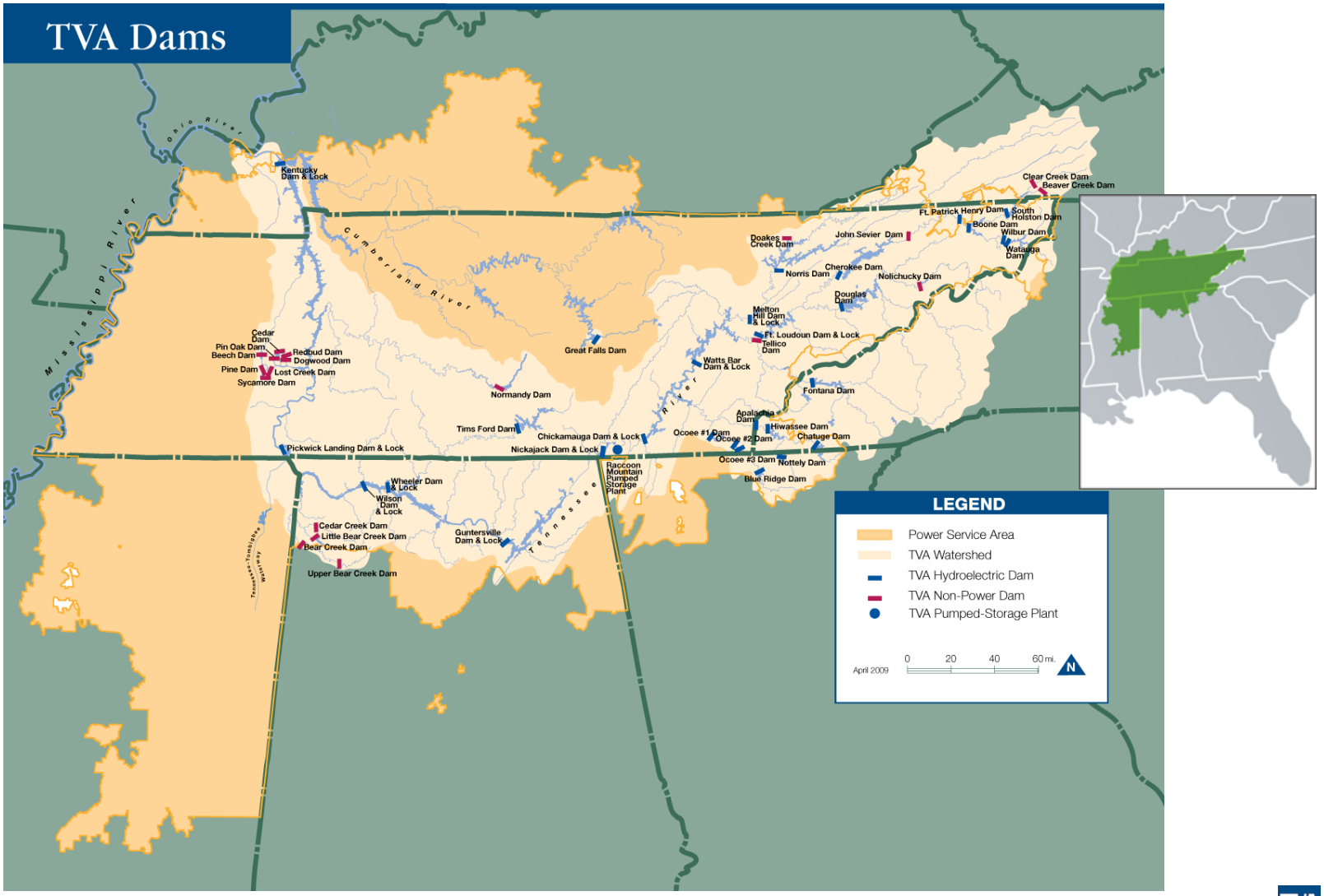
# Overview

- **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

## Inputs

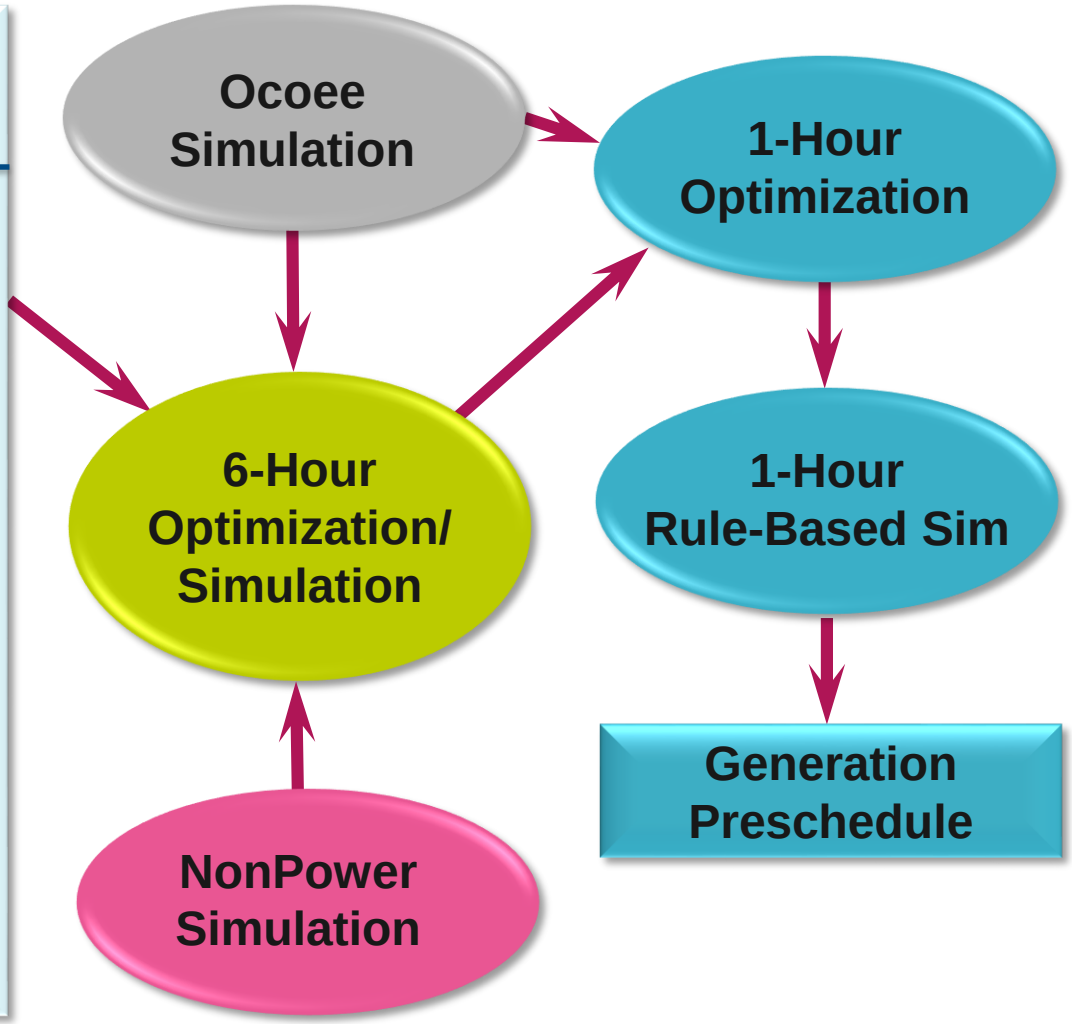
Initial Conditions

Inflow Forecast

Constraints/Operating Policy

Future Value of Water

Hourly Hydropower Value



# 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 | FtLoudo MWH [S | 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 |

# 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

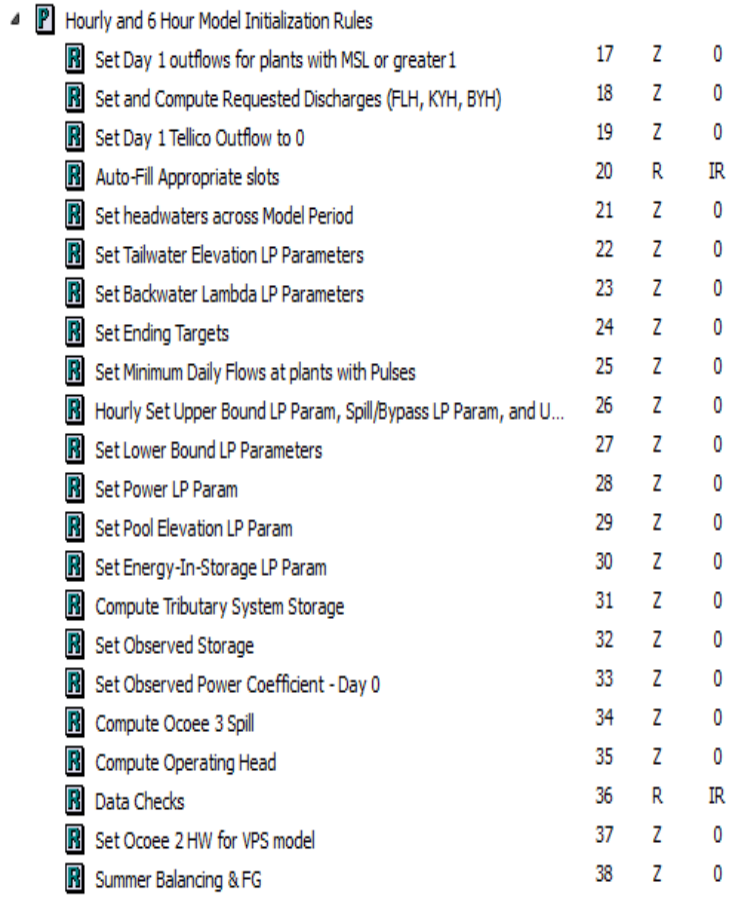
# Migration to Delft-FEWS

## Pros:

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

## Challenges:

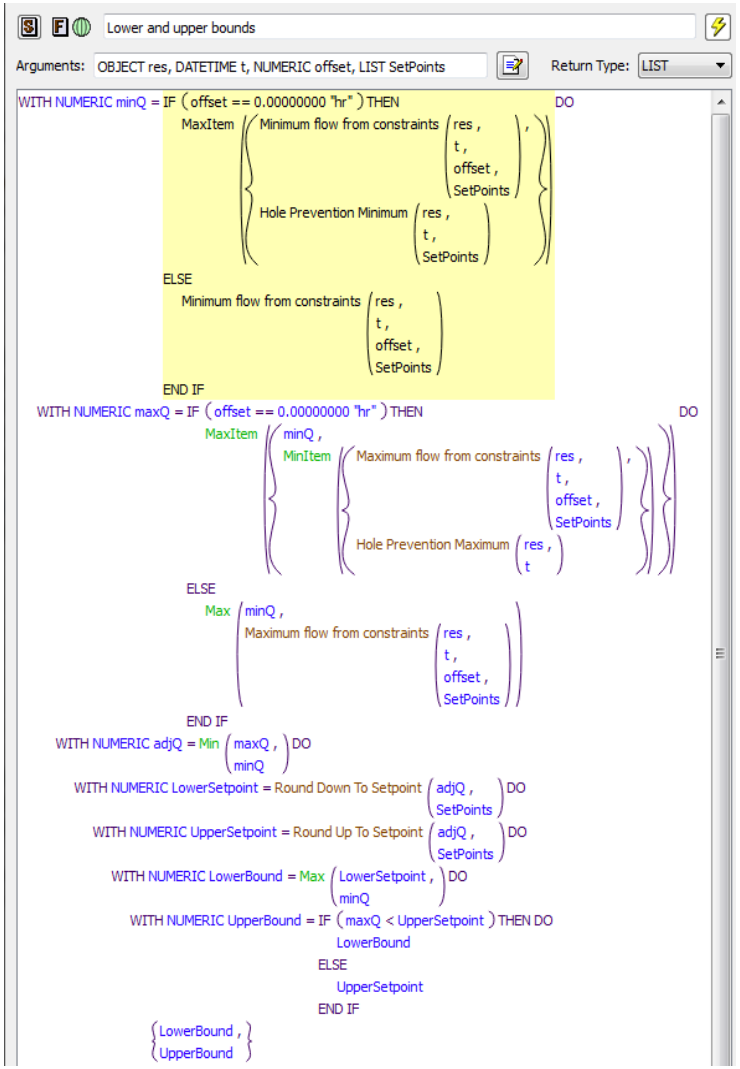
- Requires Initialization Rules
- Improved LP Parameter Estimation (Approximation Points)
- Easier to Modify Policy



# Considerations

## Reduce Need for User Input!

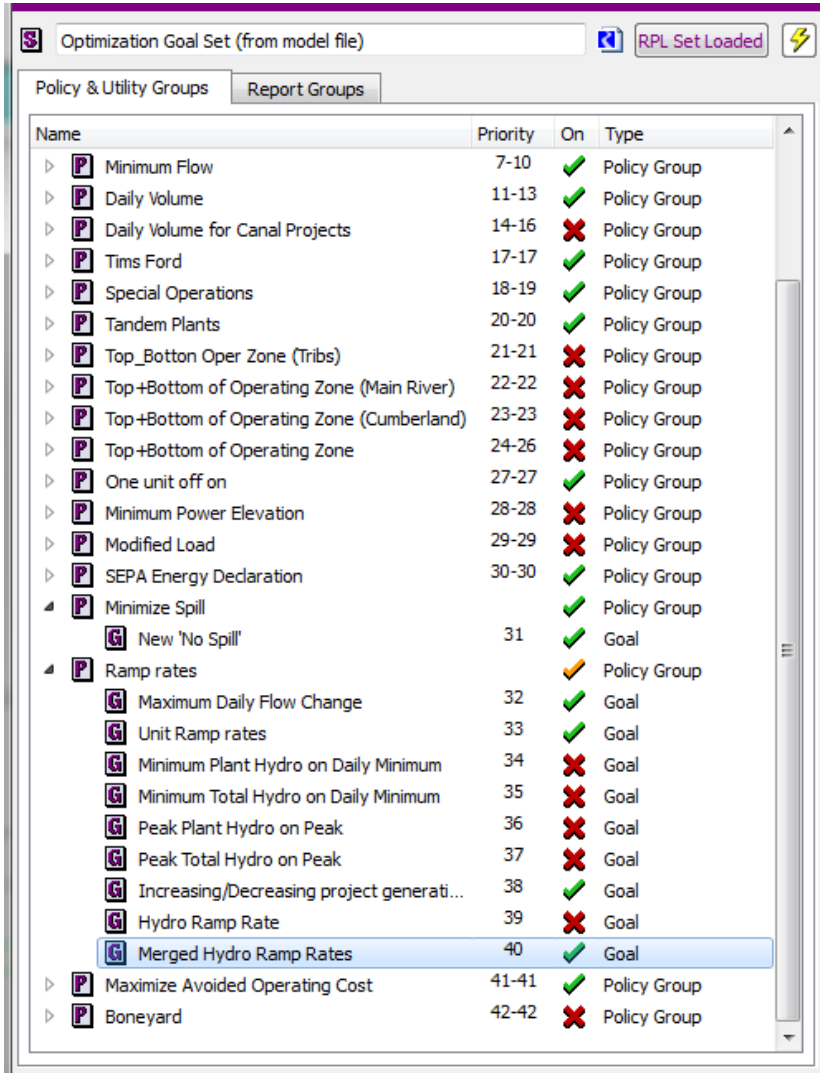
- Run Time
- Allow for User Input/Overrides
- Meet Minimum Flows/Pulses
- Meet Daily Volumes
- Special Operations
- Eliminate “Holes”/“Peaks”
- Minimize Spill
- Meet Unit/System Ramping



# Model Innovations

## Optimization Goals:

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



# 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
      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
```

# New Opt/RBS vs Final Preschedule

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

| SoHolston | Watauga | Wilbur | Boone | FtPatH | Cherokee | Douglas | Fontana |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 |
| 0 | 0 | 0 | 22 | 0 | 0 | 17 | 0 |
| 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 22 | 13 | 20 | 0 | 0 |
| 23 | 0 | 0 | 22 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 22 | 0 | 0 | 17 | 0 |
| 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 17 | 37 | 76 | 87 |
| 42 | 30 | 0 | 0 | 17 | 74 | 111 | 174 |
| 40 | 30 | 7 | 0 | 17 | 114 | 148 | 261 |
| 40 | 30 | 7 | 22 | 0 | 114 | 148 | 261 |
| 40 | 30 | 7 | 22 | 0 | 114 | 148 | 261 |
| 40 | 30 | 7 | 22 | 17 | 114 | 148 | 261 |
| 40 | 30 | 7 | 22 | 17 | 114 | 148 | 261 |
| 40 | 30 | 7 | 22 | 17 | 114 | 148 | 261 |
| 42 | 0 | 0 | 22 | 17 | 114 | 111 | 174 |
| 42 | 0 | 0 | 22 | 17 | 114 | 76 | 174 |
| 42 | 0 | 0 | 22 | 0 | 74 | 76 | 174 |
| 0 | 0 | 0 | 22 | 0 | 37 | 38 | 87 |
| 0 | 0 | 0 | 22 | 13 | 37 | 0 | 87 |
| 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?