Center for Advanced Decision Support for Water and Environmental Systems (CADSWES)

UNIVERSITY OF COLORADO **BOULDER**

Overview of RiverWare Optimization and Hydropower Modeling

2025 RiverWare User Group Meeting

Presenter: Tim Magee and Mitch Clement

Presentation Overview

- RiverWare Optimization Overview
- TVA Models
- RiverWare techniques to address real-world optimization challenges

Hydropower of RiverWare Optimization Users

Hydropower	Installed Capacity (MW)	Generation (GWh)
U.S. Total	102,867	322,390
RiverWare Opt Users	32,514	~113,530
Percent	32 %	35%

Optimization Overview

- Simultaneous solution of all reservoirs and all timesteps
  - Prioritized reduction of the solution space
- Many variables and many physical and policy constraints
  - Variables and constraints determined by method selections
  - Policy in RiverWare Policy Language (RPL)
- Multiple-use reservoirs lead to multiple objectives/constraints
- Goal programming: prioritized soft constraints
  - Many priority levels are possible
  - High priority: almost hard constraints (limits, min flows, etc.)
  - Medium priority: met except during extreme conditions
  - Low priority: met under “normal” conditions
  - Lowest priority: hydropower optimization

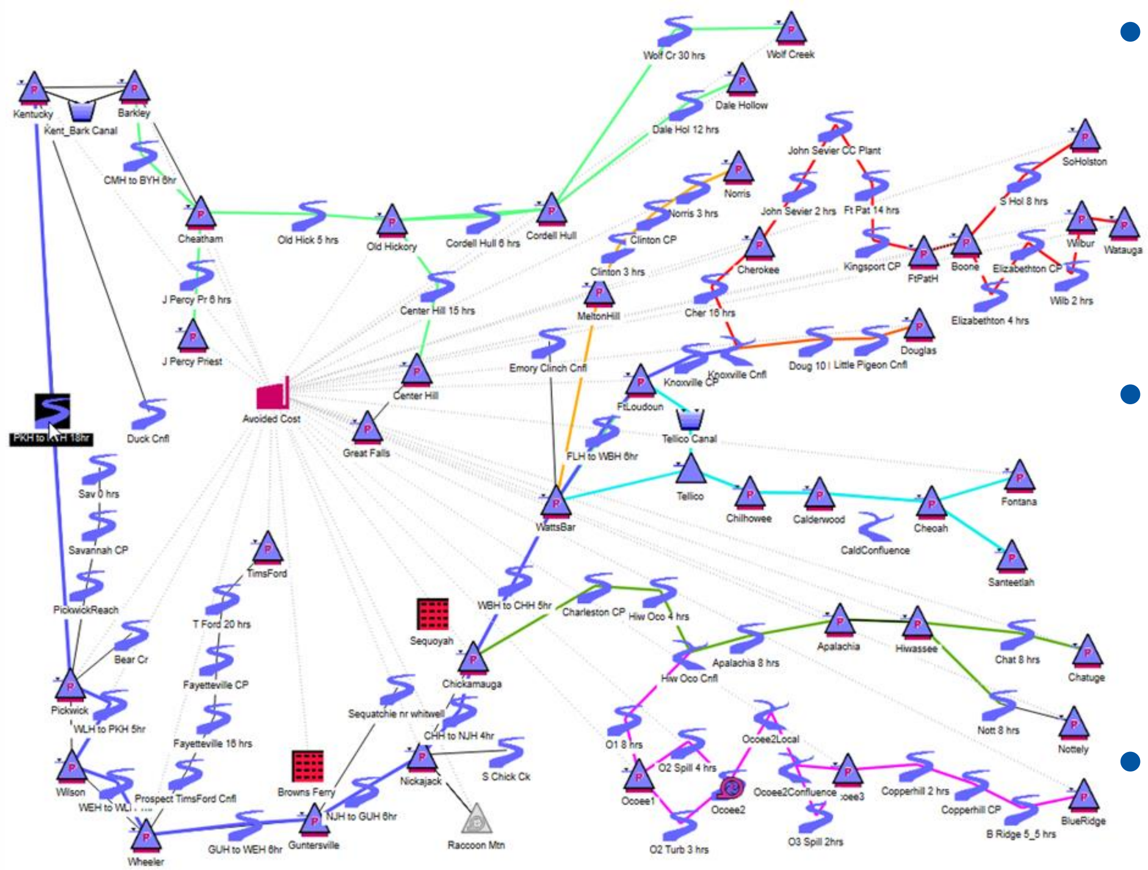
TVA Models


ILLINOIS
KENTUCKY
VIRGINIA
MISSOURI
ARKANSAS
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
MISSISSIPPI
ALABAMA
GEORGIA
Ohio River
Mississippi River
Cumberland River
Tombigbee Waterway
Paducah
Kentucky
Nashville
Knoxville
Chattanooga
Memphis
Huntsville
Decatur
Muscle Shoals
Guntersville
Pickwick
Wilson
Wheeler
Beech River Projects
Normandy
Tims Ford
Nickajack
Chickamauga
Watts Bar
Melton Hill
Fort Loudoun
Tellico
Norris
Cherokee
Douglas
Boone
Watauga
Great Falls
Cedar Creek
Little Bear Creek
Upper Bear Creek
Bear Creek
Raccoon Mountain Pumped Storage
Blue Ridge
Chatuge
* Tapoco
Tennessee River System and Watershed
Dam
Metropolitan Area

TVA Models

- Many models developed, enhanced, and used over many years
  - Models work together
- RMO project: concentrated effort 2019-2024
- Subbasin models: Non-power (sim), Ocoee River (sim)
- Short-term: hourly timestep, 3 days, power emphasis, (opt.)
- Mid-term: 1-hour and 6-hour timesteps, ~2 weeks,
  daily release emphasis, optimization and simulation
  - Testing and improving
- Portfolio Optimization: RiverWare and Production Cost Model
- Long-term: 1-week solutions with 6-hour timesteps
  combined to form multi-year solutions, (rules)

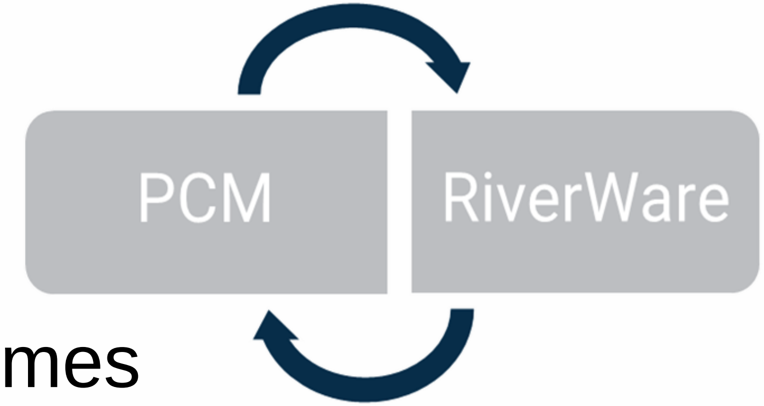
TVA Hourly Model (Short-Term Model)



- Used for creating power “preschedule”
  - Day 1 (today) – update for conditions
  - Day 2 – Main focus of decision making
  - Day 3 – Preliminary plan
- Optimization
  - Constrained by daily releases from MT
  - Focus: timing of hydropower
  - Some non-power constraints
  - Includes Cumberland River (USACE)
- Post-optimization rules
  - Unit considerations & Heuristics
- In use!

Portfolio Optimization

- Joint Optimization of TVA generation =
  - RiverWare model (Hydropower & non-power) +
  - Production Cost Model (all power sources)

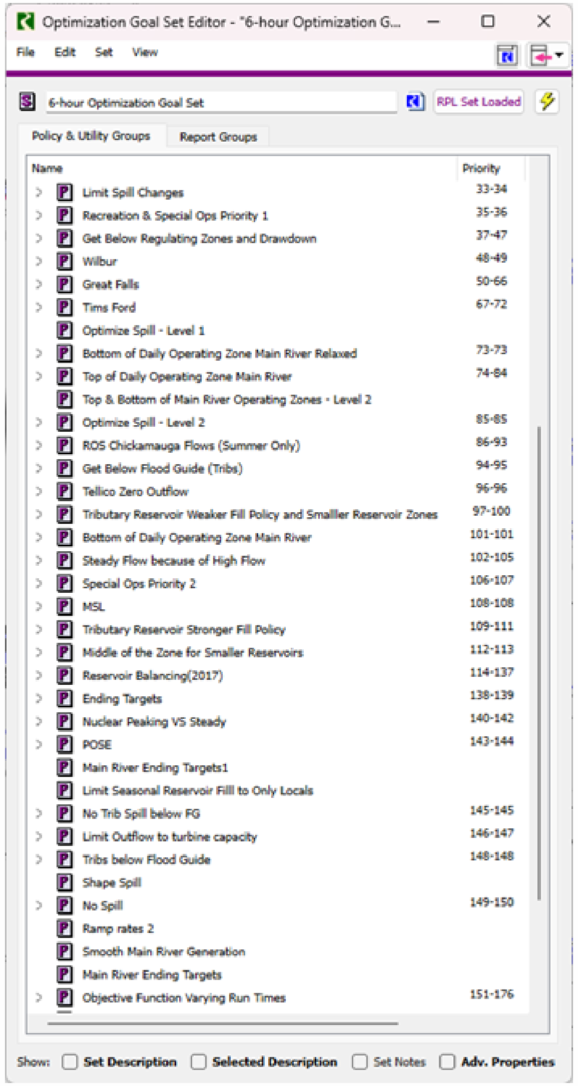


1. RW optimization: calculate hydropower extremes
2. PCM: optimal power and hydropower within extremes
3. RW optimization: As Close As Possible to PCM solution
4. PCM: schedule remaining power given hydropower

- In use!

Mid-Term Optimization Model

- Purpose: daily releases and power estimates
- Time: 1-hour and 6-hour timesteps for ~2 weeks
  - Needed to capture variations in power load and value
- Challenges
  - Sloped storage reservoirs
    - Nonlinear dynamic process with steady state modeling
    - Naïve elevation constraints create perverse incentives
  - Uncertainty, hedging and risk tolerance in practice
- Transition from Simulation to Optimization
  - Simulate early days and optimize later days
  - Ongoing user testing, feedback, and improvement



Hydropower Optimization – Real-world Challenges

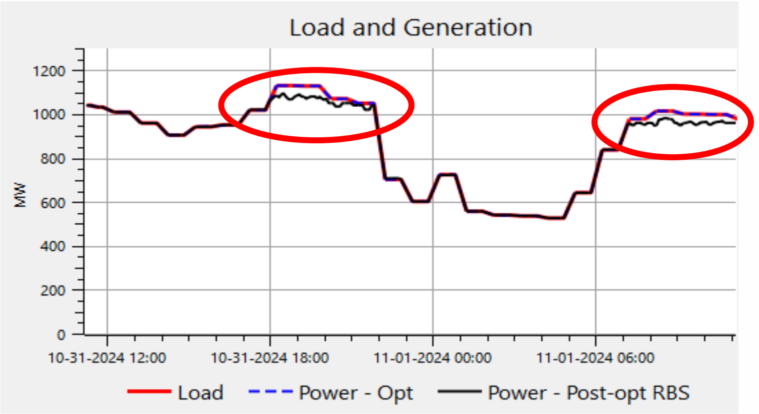
- Nonlinearity – Approximation error matters!
- Solution quality – "Real-world optimal"
- Forecast uncertainty – Don't over-optimize to uncertain future
- Discrete unit operations – Can be computationally intensive!
- User input operations – Allow overriding opt solution

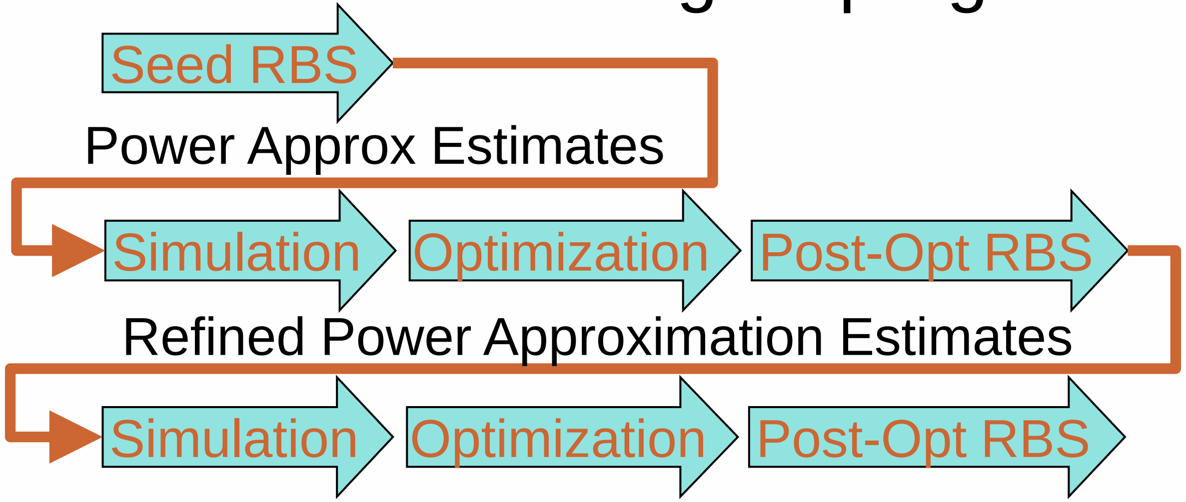
- **Solution time – Trade off accuracy vs. time**

RiverWare modeling techniques to address these challenges…

Nonlinearity and Approximation Error

- Approximation error matters!
  - Power
  - Sloped Storage
- Solutions:
  - Successive linear goal programming





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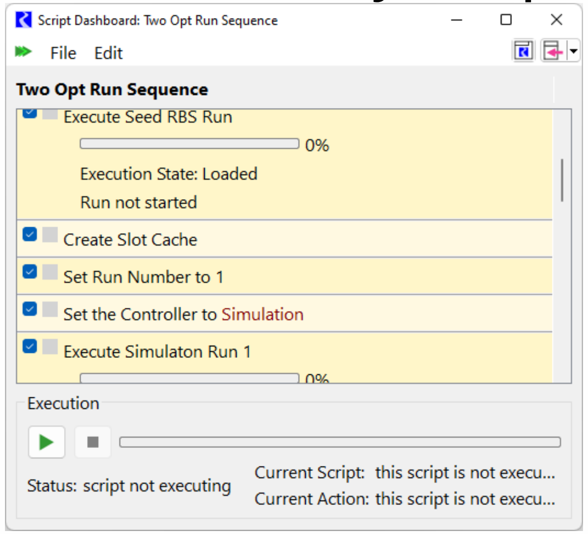
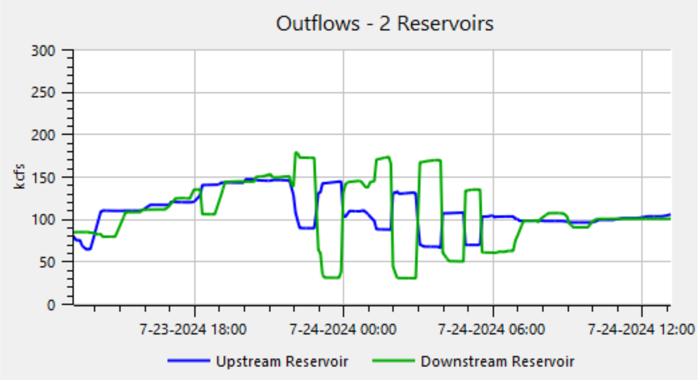


  - Add refined constraints based on intermediate solution

Solution Quality – Realistic Operations

- Numerically optimal may not be "real-world optimal"
  - "Spikey" flows, oscillations, and extreme ops
  - "We would never operate that way!"



- Can't just squeeze the balloon

- Solutions:
  - Trial objectives with relaxed constraints

IF (Trial object constraints are fully satisfied)

Apply standard constraints

ELSE

Apply relaxed constraints

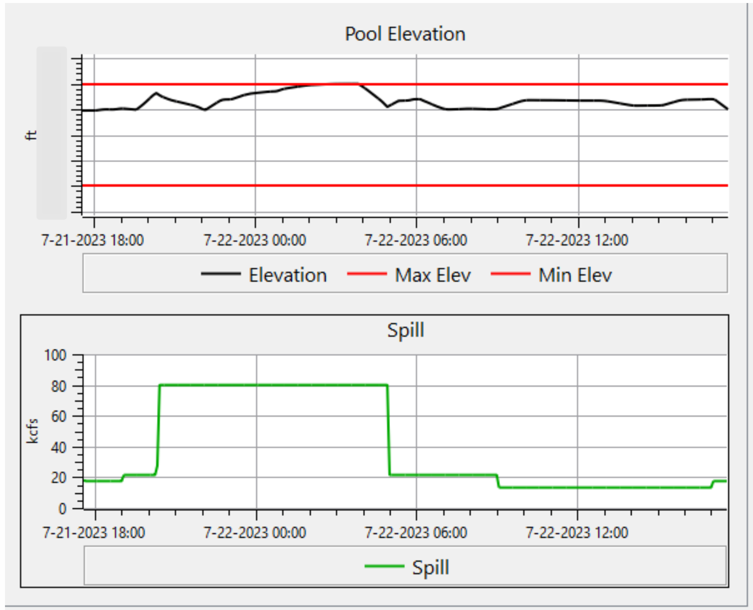
  - Weights – trade off objectives (constraints) at a single priority

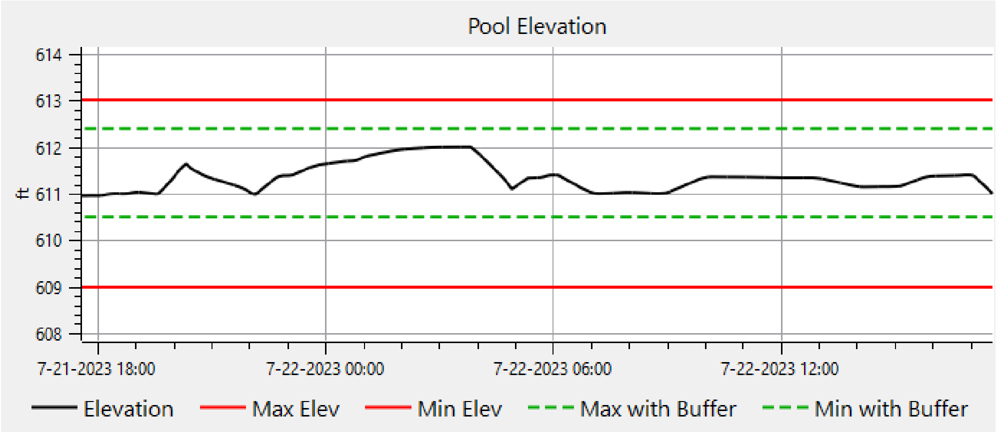
Especially for systems with limited degrees of freedom

Forecast Uncertainty

- Don’t over-optimize to an uncertain future
  - Preemptive spill
  - Early constraint violations
- Solutions:
  - Time-weighting – applied with RPL

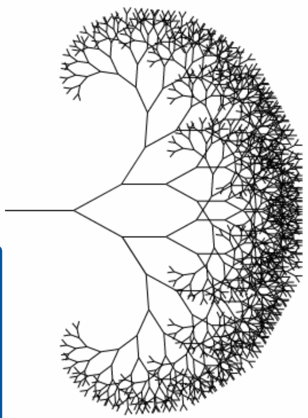
    Higher “penalty” on earlier violations
  - Buffers –reduce flexibility in solution to maintain flexibility for ops





Discreet Unit Operating Points

- Unit-level operations – Computationally intensive!
- Solution: Plant-level → Plant-level with unit heuristics → Unit-level
  - Unit heuristics in RPL
  - Successive linear goal programming



1. Simulation → Optimization (Plant-level) → Post-Opt RBS (Unit-level)
2. Simulation (Init rules: set up heuristics) → Optimization (Plant-level, unit heuristics) → Post-Opt RBS (Unit-level, refined)
3. Simulation (Init rules: set up heuristics) → Optimization (Unit-level constraints) → Post-Opt RBS (Unit-level, refined) → Unit Energy Schedule – integer values

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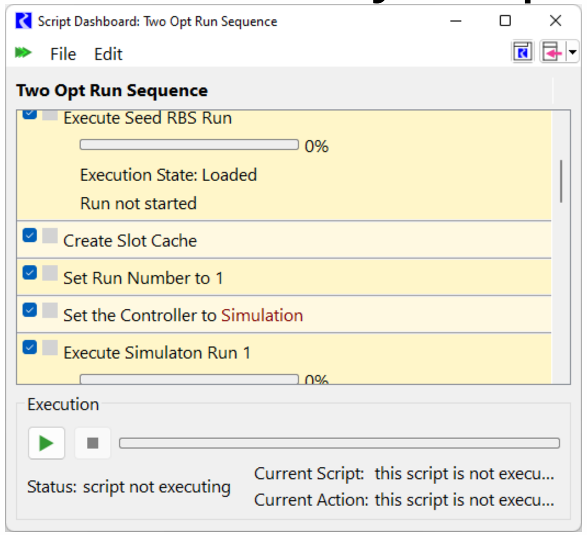

User Input Operations

- Override portions of the opt solution
  - Some portion already scheduled
  - Need to specify operations in some cases
- Solutions:
  - RiverWare automatic handling of inputs
    - Objects/timesteps solved in Sim removed from Opt
    - Inputs effectively highest priority constraints
  - RPL logic to omit constraints when ops are input

Timestep	Day	Unit 1 MWH	Unit 2 MWH	Unit 3 MWH	Unit 4 MWH	Unit 5 MWH	Energy MWH	Price $/MWh	Load MWH	Elevation ft	Outflow cfs
1/15 10:00	Mon	48	0	0	0	0	48	4.27	82	641.15	4,390
1/15 11:00	Mon	48	0	0	0	0	48	4.63	96	641.15	4,390
1/15 12:00	Mon	48	0	0	0	0	48	5.52	112	641.15	4,390
1/15 13:00	Mon	48	0	0	0	0	48	11.68	111	641.15	4,390
1/15 14:00	Mon	48	0	0	0	0	48	17.45	116	641.15	4,390
1/15 15:00	Mon	48	0	0	0	0	48	27.45	135	641.15	4,390
1/15 16:00	Mon	48	0	0	0	0	48	34.54	172	641.15	4,390
1/15 17:00	Mon	48	0	0	0	48	96	59.61	209	641.15	9,118
1/15 18:00	Mon	48	0	0	48	48	144	112.09	212	641.15	13,843
1/15 19:00	Mon	50	0	0	50	50	150	128.09	204	641.15	14,423
1/15 20:00	Mon	48	0	0	48	48	144	116.92	187	641.15	13,843
1/15 21:00	Mon	48	0	0	48	48	144	104.34	168	641.15	13,843
1/15 22:00	Mon	49	0	0	49	49	147	91.68	140	641.15	14,130
1/15 23:00	Mon	48	0	0	0	48	96	63.99	146	641.15	9,118
1/15 24:00	Mon	50	0	0	0	0	50	59.30	133	641.15	4,573

Opt override inputs

1 Max Pool Elevation   RPL Set Loaded

```
REPEATED MAXIMIN
  FOR ( OBJECT res IN AllReservoirs ( ) ) DO
    FOR ( DATETIME t IN @"Start Timestep" TO @"Finish Timestep" ) DO
      IF ( NOT IsInput ( res . "Outflow" , t ) ) THEN
        ADD CONSTRAINT res . "Pool Elevation" [ t ] <= res . "Pool Elevation Max" [ ]
      END IF
    END FOR
  END FOR
END MAXIMIN
```