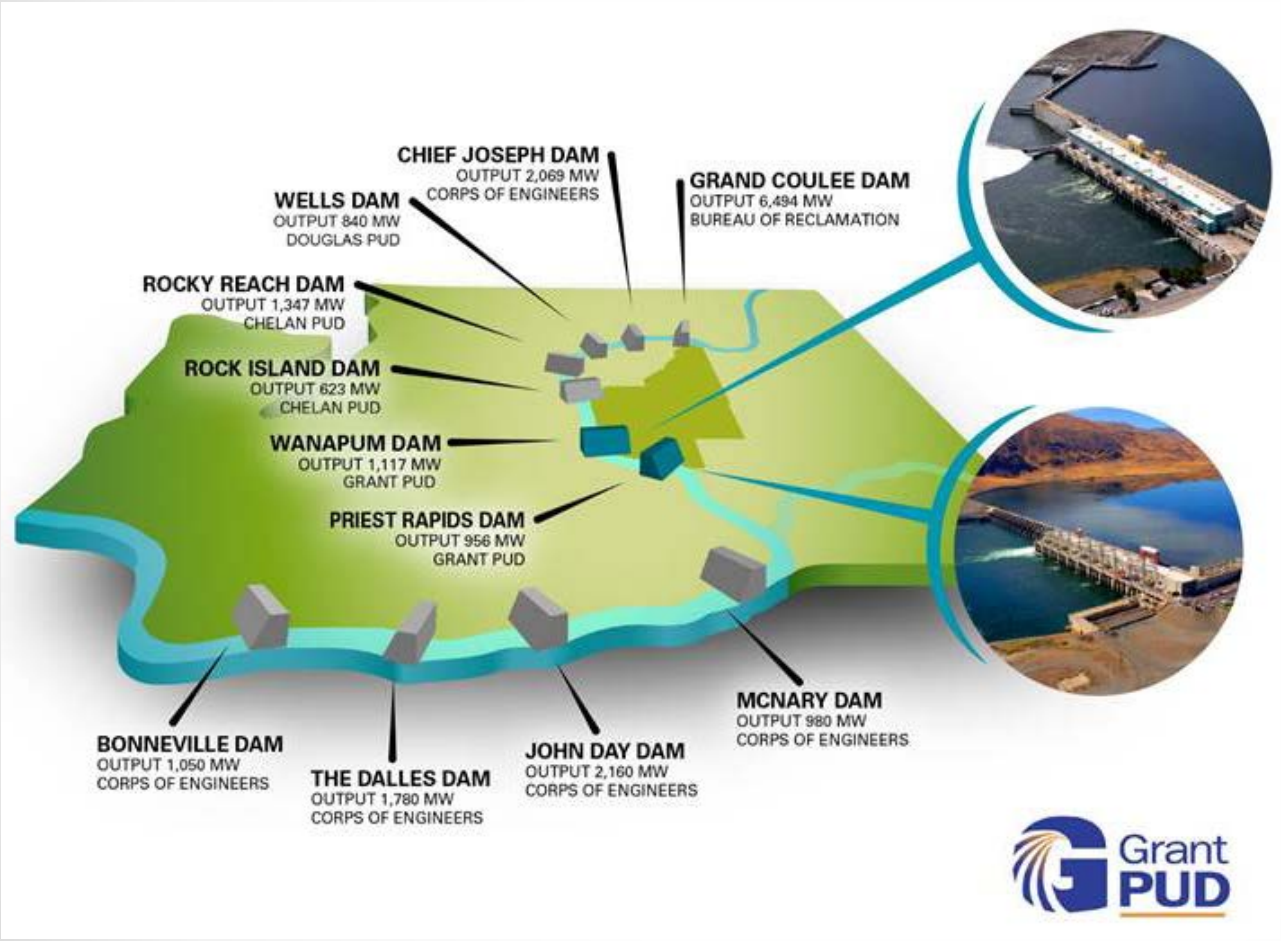
Combining Optimization and Rulebased Simulation to Guide Grant County PUD Hydropower Operations

Mike Frantz – Grant County PUD
Mitch Clement, Tim Magee – CADSWES

RiverWare Use Group Meeting
August 29, 2019

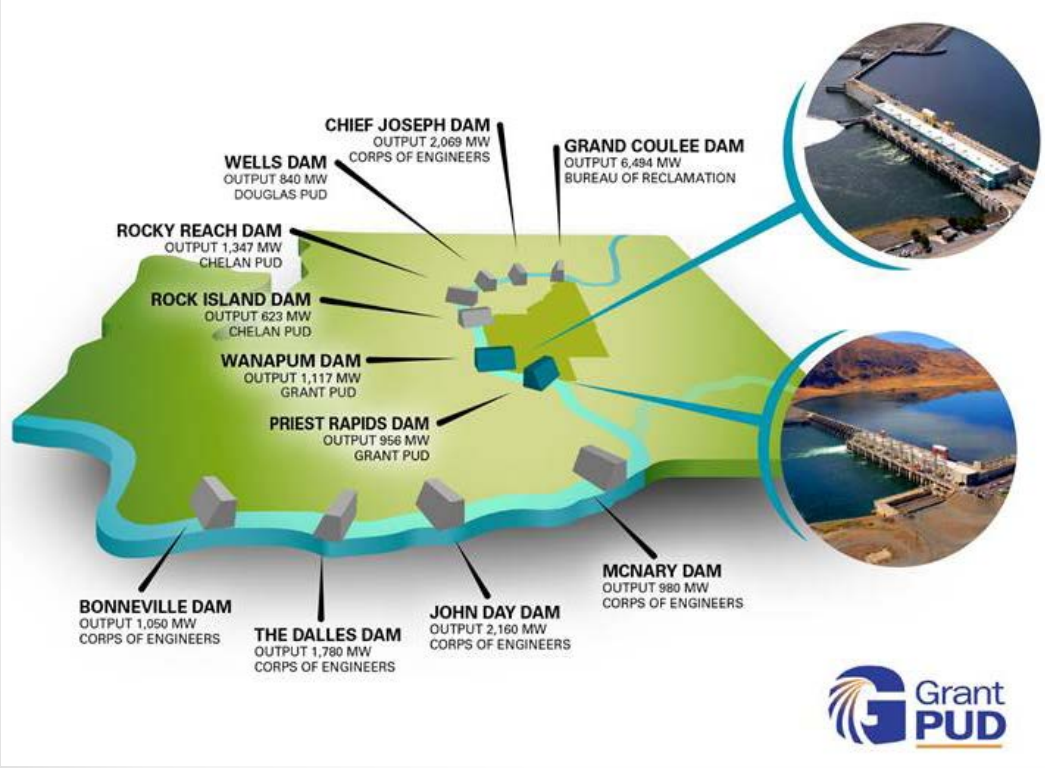
Mid-Columbia Hydro System



7 Projects on Columbia River

- 2 Federal
  - Grand Coulee
  - Chief Joseph
- 5 Mid-C PUD's
  - Wells – Douglas PUD
  - Rocky Reach and Rock Island – Chelan PUD
  - Wanapum and Priest Rapids – Grant PUD

Mid-Columbia Operations



Mid-C Hourly Coordination Agreement

- Non-Fed Generation Requests aggregated and dispatched to projects by Central
- Formally ended in 2017
- Series of bridge agreements and extensions 2017-2019
- Currently only Chelan PUD and Grant PUD coordinating (4 Dams)
- Grant and Chelan scheduled to cutover to independent operations 11/19

Grant Independent (Two Dam) Operation

- ~15 Participants with slice ownership
- Each Participant sending a single generation request (every 4 seconds)
- Multiple downstream flow requirements
  - Minimums
  - Maximums
  - Flow Bands
- Changing value proposition for many Participants
  - Flexibility
- Each Participant is responding to different value propositions

Grant Independent Operation – Request/Return

1. Participants send a single Grant Request (not to each Project)
2. All Participant Requests are aggregated into a Total Request
3. Total Request is allocated to the two Projects
4. Each Participant is assigned a Total Return

Grant Independent Operation - Priorities

1. Meet Grant Constraints
2. Meet Participant 4-second Requests
3. Inform Participants of Resource
   - Maximums and Minimums
4. Inform Participants of Obligations
   - Planned
   - Emergent
5. Preserve Participant Resources
   - Maintain Flexibility
6. Isolate Participants to the extent possible

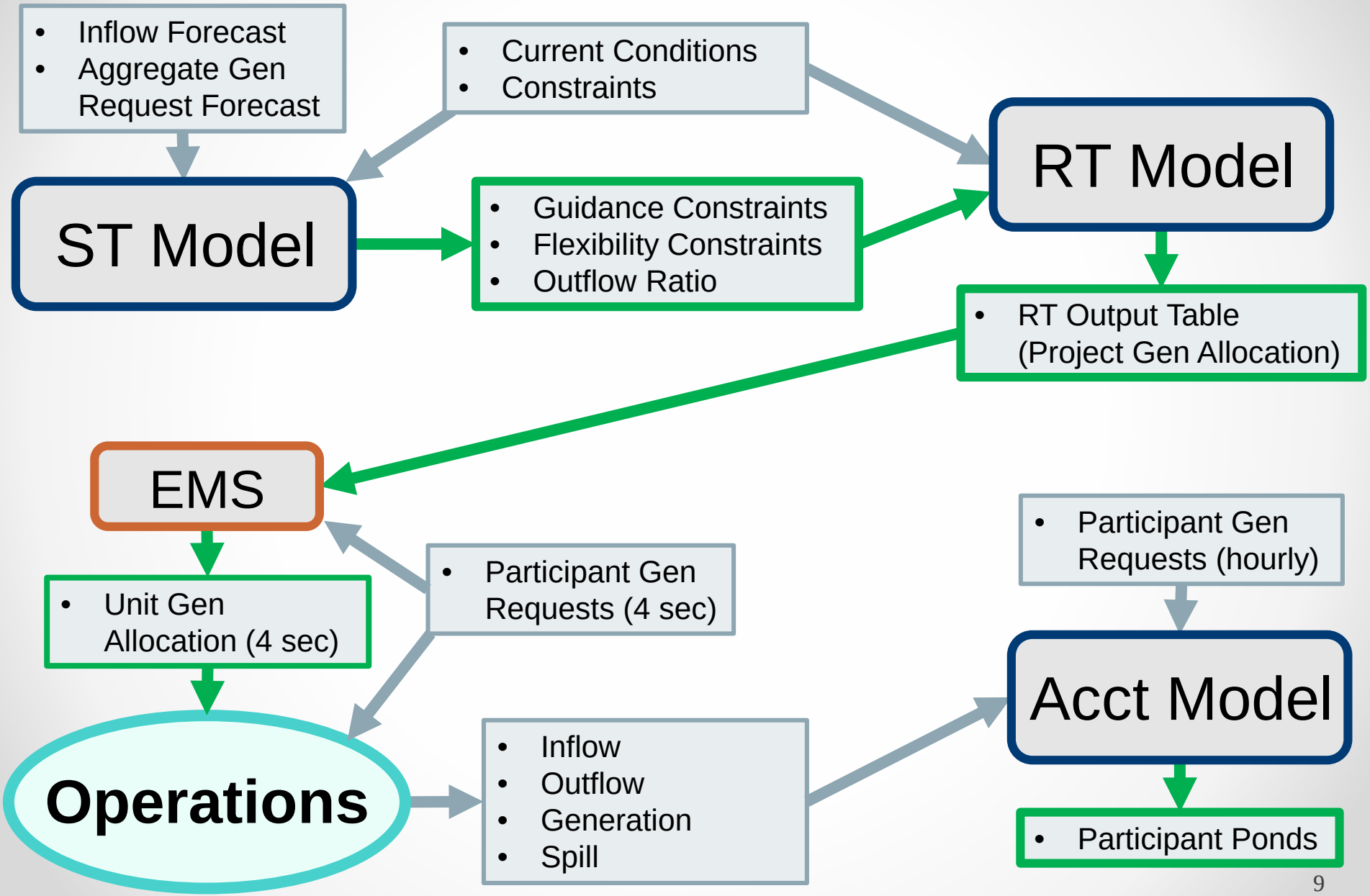
Grant Independent Operation – Operational "Tools"

1. Determine the split of Generation between Projects
2. Establishing Limits for Participants
3. Instigating Spill
4. Cutting Capacities to Participants

Grant RiverWare Models

- **Short Term Model**: Optimizaton
  - 1 Hour timestep
  - 3-5 days
  - Run 2x per hour
- **Real Time Model**: RBS – Iterative MRM
  - Single 1 Hour timestep
  - Run 1x per minute
- **Accounting Model**: Inline RBS and Accounting
  - 1 Hour timestep
  - ~ 1 month, last timestep is the previous hour
  - Run several times per day
  - After the fact accounting

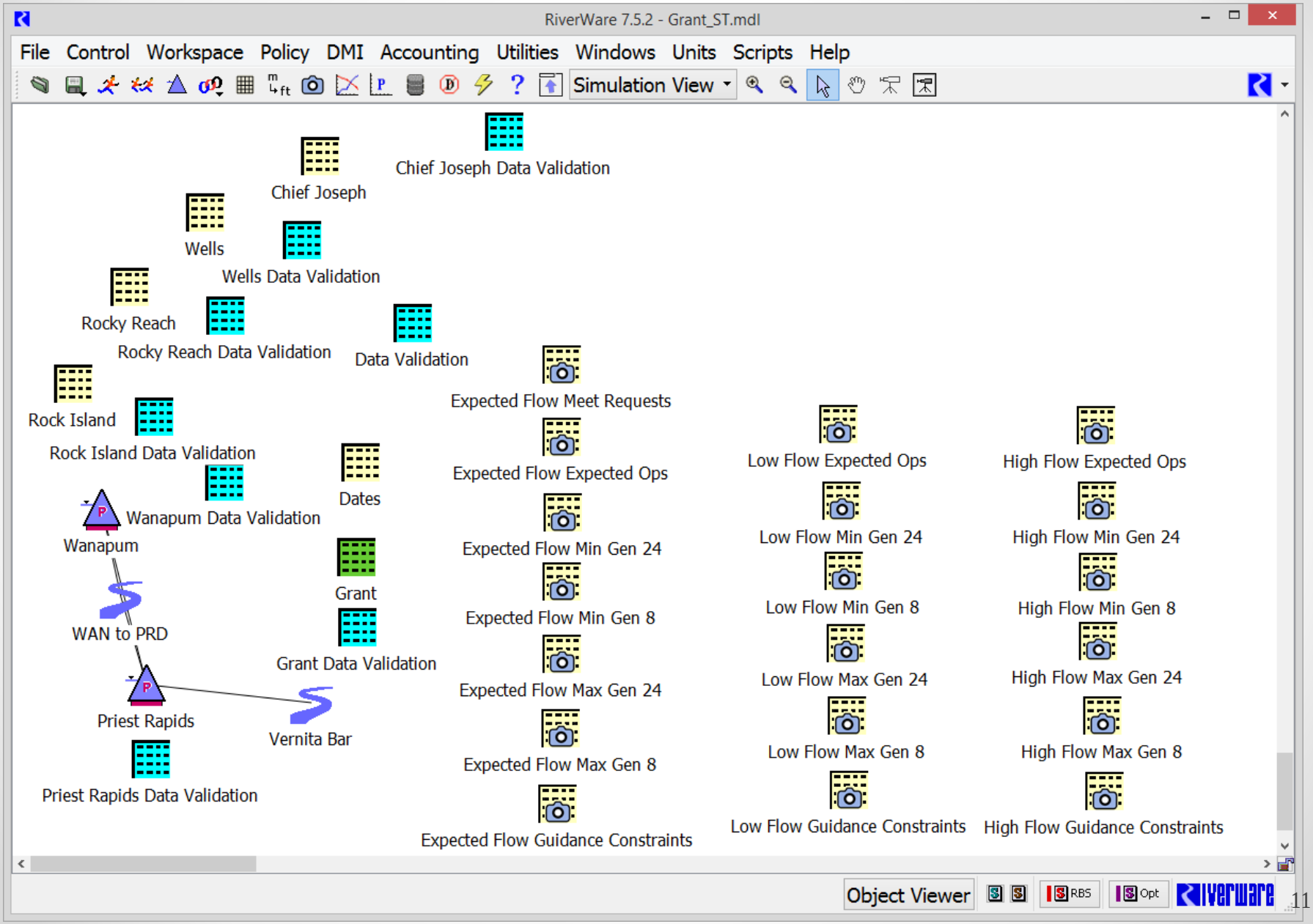
RiverWare in Grant's Process



Short Term Model Purposes

- Calculate Constraints
  - Guidance Constraints – ensure formal constraints can be met in the future
  - Flexibility Constraints – maintain full up/down generating capacity for *N* hours
- Real Time Model Guidance
  - Guidance Constraints & Flexibility Constraints
  - Preferred Outflow Ratio (first timestep)
- Information to Participants
  - Maximum generating capability
  - Minimum generation requirements
- Expected Operations (secondary purpose)

ST Model


RiverWare 7.5.2 - Grant_ST.mdl
File Control Workspace Policy DMI Accounting Utilities Windows Units Scripts Help
Simulation View
Chief Joseph
Chief Joseph Data Validation
Wells
Wells Data Validation
Rocky Reach
Rocky Reach Data Validation
Data Validation
Rock Island
Rock Island Data Validation
Wanapum Data Validation
Wanapum
Dates
Grant
WAN to PRD
Grant Data Validation
Priest Rapids
Vernita Bar
Priest Rapids Data Validation
Expected Flow Meet Requests
Expected Flow Expected Ops
Expected Flow Min Gen 24
Expected Flow Min Gen 8
Expected Flow Max Gen 24
Expected Flow Max Gen 8
Expected Flow Guidance Constraints
Low Flow Expected Ops
Low Flow Min Gen 24
Low Flow Min Gen 8
Low Flow Max Gen 24
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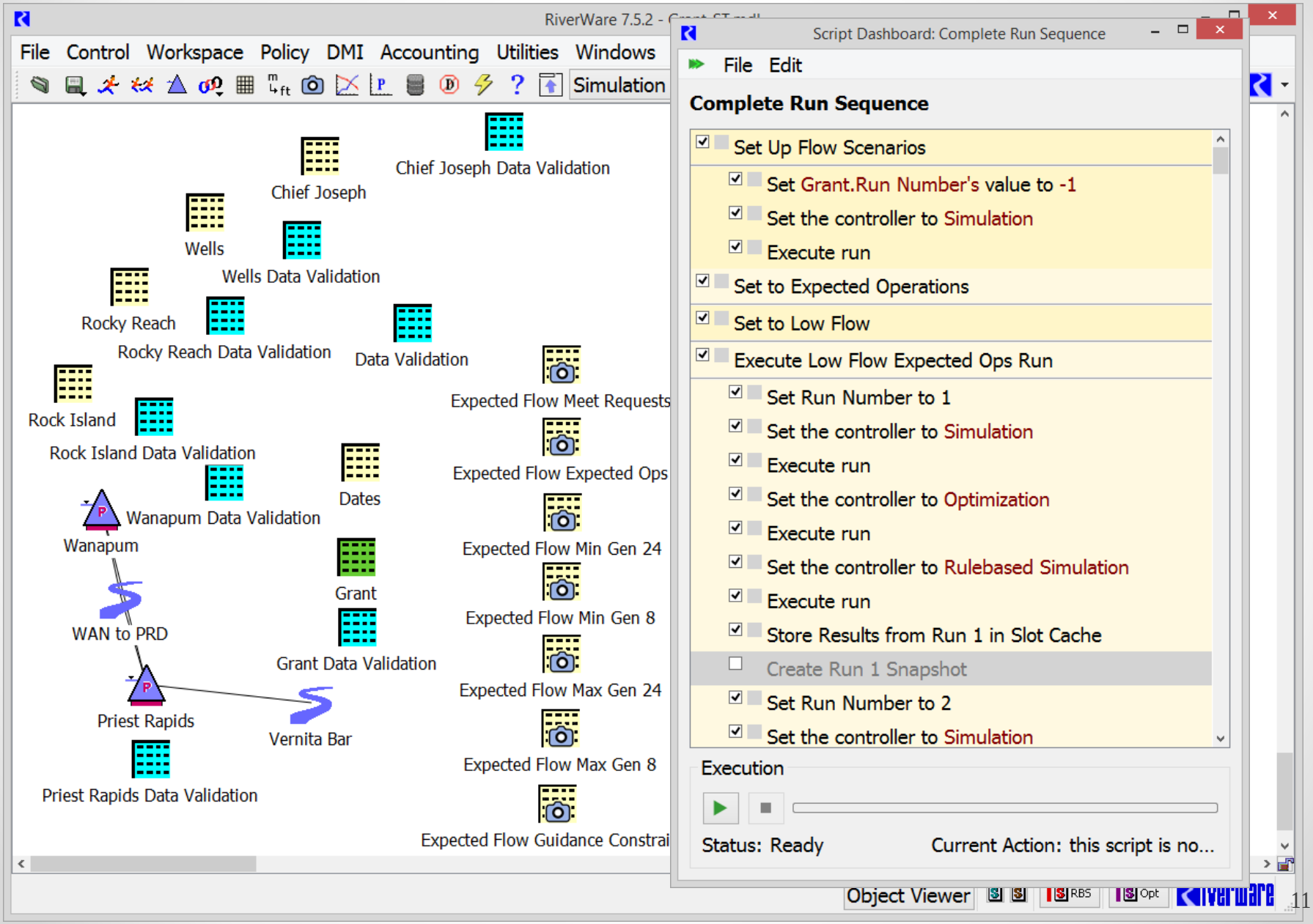
High Flow Min Gen 24
High Flow Min Gen 8
High Flow Max Gen 24
High Flow Max Gen 8
High Flow Guidance Constraints
Object Viewer
RBS
Opt
Riverware

ST Model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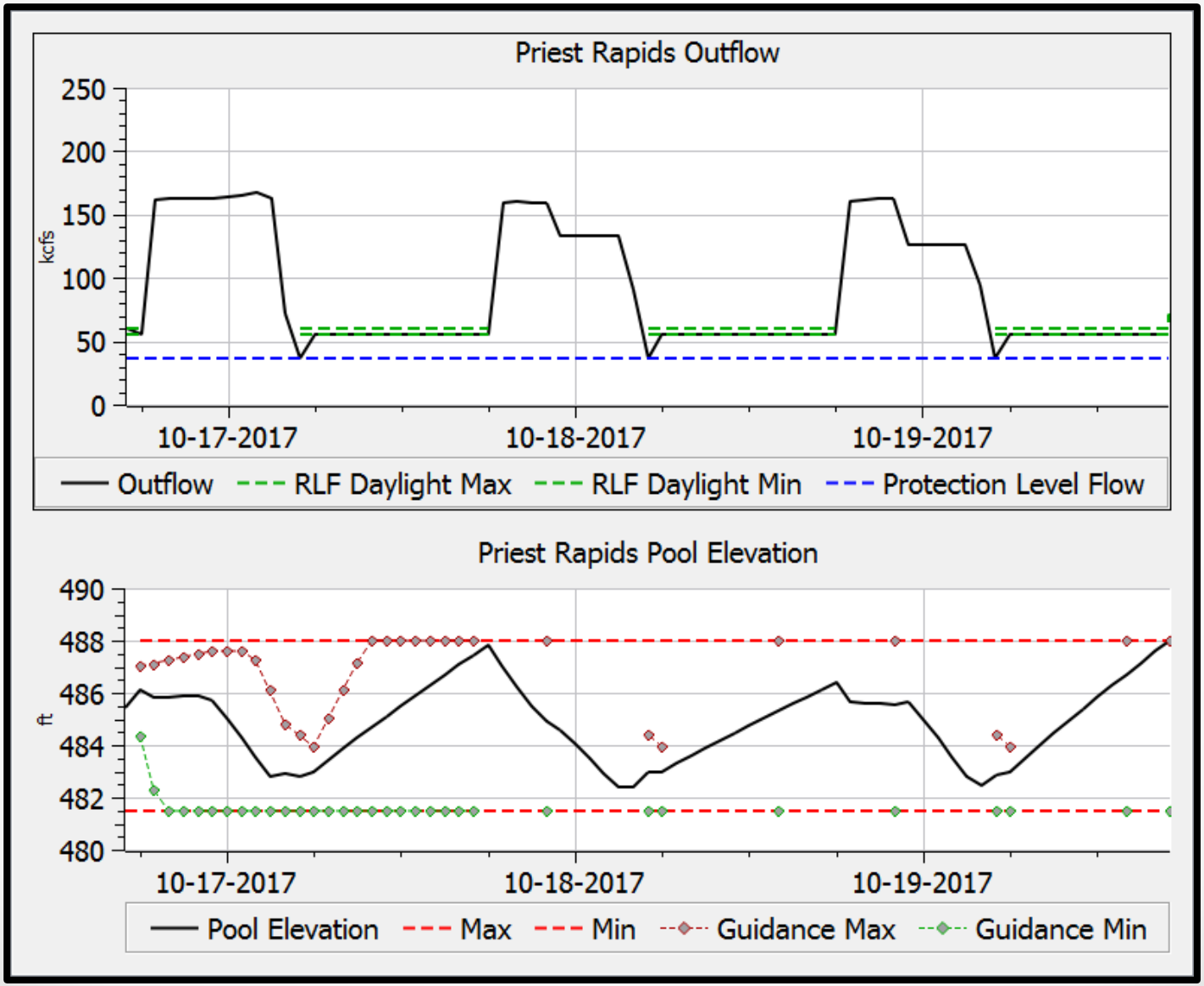
Expected Flow Meet Requests
Expected Flow Expected Ops
Expected Flow Min Gen 24
Expected Flow Min Gen 8
Expected Flow Max Gen 24
Expected Flow Max Gen 8
Expected Flow Guidance Constrai
Script Dashboard: Complete Run Sequence
File Edit
Complete Run Sequence
Set Up Flow Scenarios
Set Grant.Run Number's value to -1
Set the controller to Simulation
Execute run
Set to Expected Operations
Set to Low Flow
Execute Low Flow Expected Ops Run
Set Run Number to 1
Set the controller to Simulation
Execute run
Set the controller to Optimization
Execute run
Set the controller to Rulebased Simulation
Execute run
Store Results from Run 1 in Slot Cache
Create Run 1 Snapshot
Set Run Number to 2
Set the controller to Simulation
Execution
Status: Ready
Current Action: this script is no...
Object Viewer
RBS
Opt

Short Term Guidance Constraints

1. Low Flow Run: Storage Guidance Min
   - Meet high priority (formal) constraints
   - Trial objectives (no Freeze)
     - Minimize Storage at t_1
     - Minimize Storage at t_2…
2. High Flow Run: Storage Guidance Max
   - Similar but Maximize Storage
3. Expected Flow Run
   - Meet high priority (formal) constraints
   - Apply Storage Guidance Min/Max Constraints
   - Evaluate additional Guidance Constraints
     - Energy
     - Outflow

Guidance Constraints Example

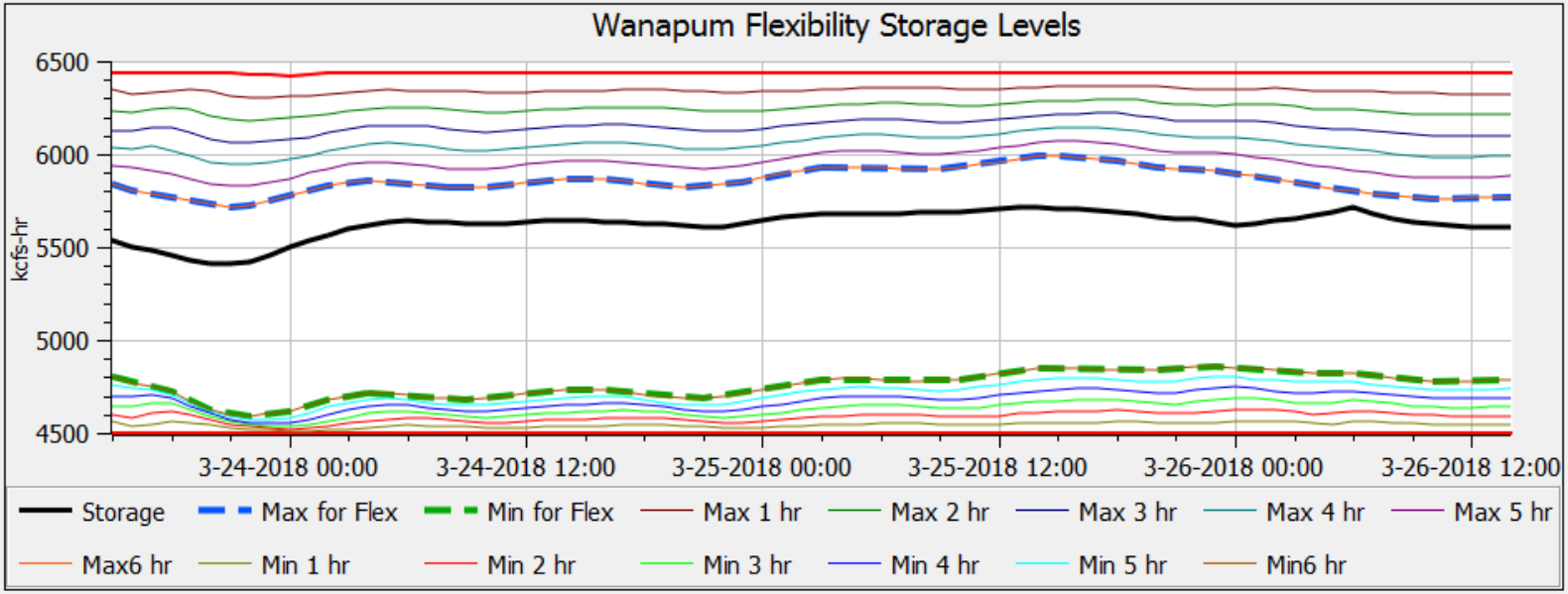
Spawning Season – Limited Priest Rapids daytime Outflow

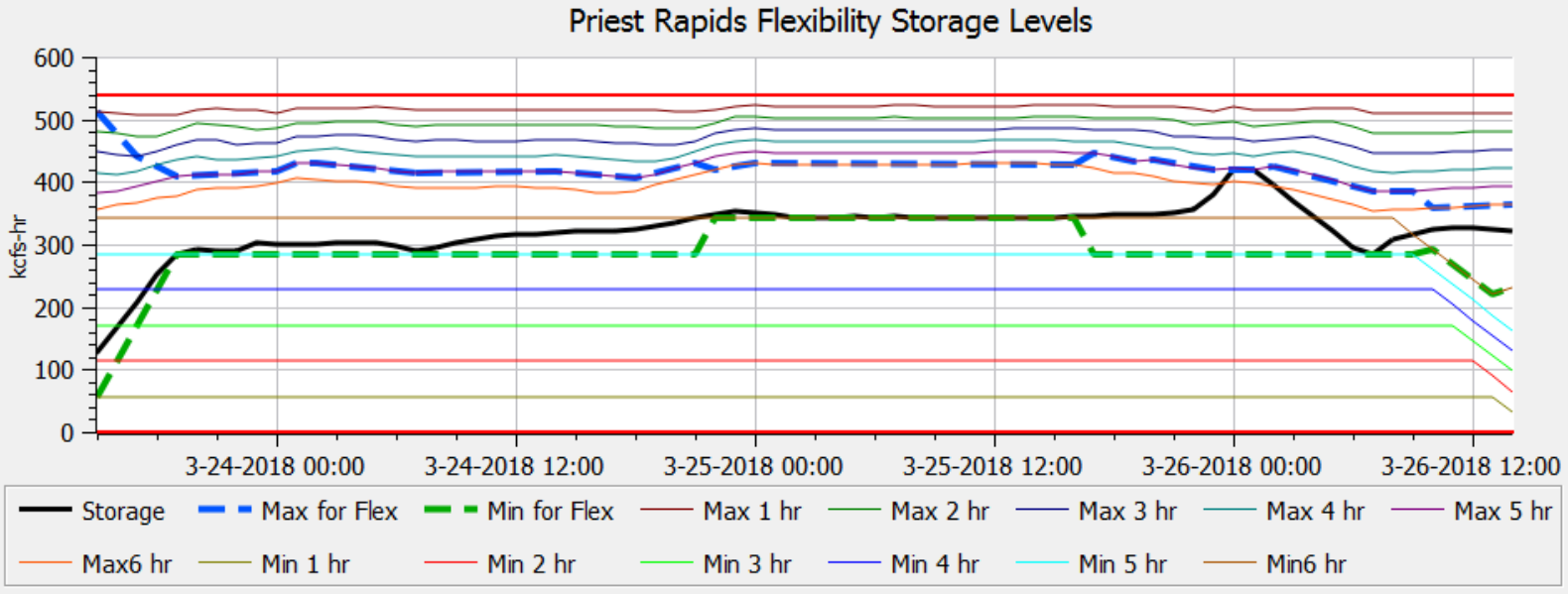


Flexibility Constraints

- One metric for flexibility: Number of hours with full upward and downward capacity
- Corollary:
  - Min Storage to generate at max for *N* hours before reaching formal min
  - Max Storage that allows min generation for *N* hours before forcing spill
- Model:
  - Calculate Min/Max Storage corresponding to *N* hours
  - Add constraints: $Min_N \leq Storage \leq Max_N$

Flexibility Constraints Example





Flexibility Constraints Implementation

- Initialization Rules: Calculate Storage Min/Max for *N* hours
- Optimization:
  - Trial objective (no Freeze): $\text{Min}_{N,t} \leq \text{Storage}_t \leq \text{Max}_{N,t}$
  - For each *t*
    - IF trial constraint was satisfied

      Apply $\text{Min}_{N,t}$, $\text{Max}_{N,t}$ with a Freeze
    - ELSE

      Omit the constraint
  - Repeat for *N* + 1
- Post-opt Rules: Report highest level satisfied

RT Model Purpose

- Guidance to EMS – how to allocate generation in real time
- RT Output Table

  Populated with Iterative MRM
- EMS interpolates using real-time (4 sec) generation request

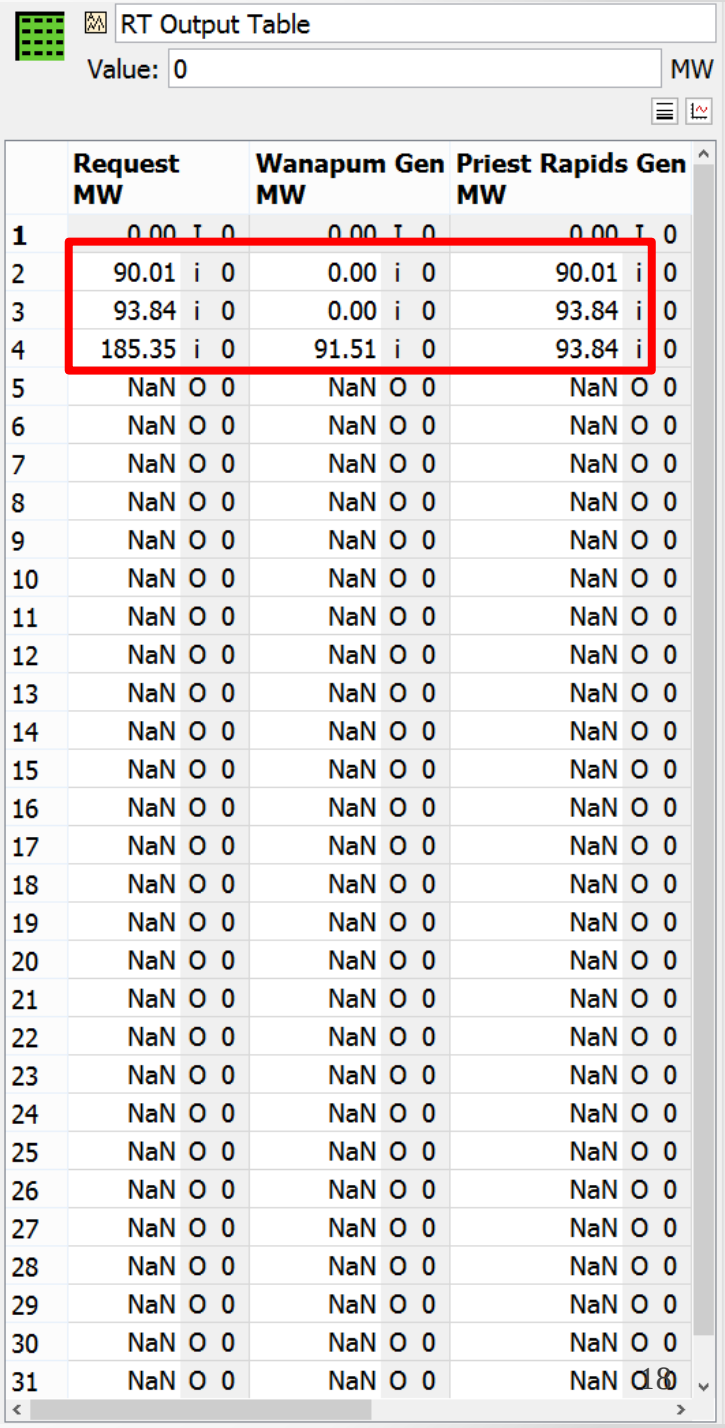
RT Output Table

Value: 0 MW

	Request MW	Wanapum Gen MW	Priest Rapids Gen MW
1	0.00 I 0	0.00 I 0	0.00 I 0
2	90.01 i 0	0.00 i 0	90.01 i 0
3	93.84 i 0	0.00 i 0	93.84 i 0
4	185.35 i 0	91.51 i 0	93.84 i 0
5	275.87 i 0	182.03 i 0	93.84 i 0
6	364.97 i 0	271.14 i 0	93.84 i 0
7	445.09 i 0	271.44 i 0	173.65 i 0
8	532.11 i 0	358.46 i 0	173.65 i 0
9	617.64 i 0	358.91 i 0	258.74 i 0
10	701.76 i 0	443.03 i 0	258.74 i 0
11	784.53 i 0	443.44 i 0	341.09 i 0
12	866.30 i 0	525.21 i 0	341.09 i 0
13	945.17 i 0	525.51 i 0	419.65 i 0
14	1,021.24 i 0	601.59 i 0	419.65 i 0
15	1,097.46 i 0	601.92 i 0	495.53 i 0
16	1,163.41 i 0	667.88 i 0	495.53 i 0
17	1,176.32 i 0	680.79 i 0	495.53 i 0
18	1,187.40 i 0	655.90 i 0	531.50 i 0
19	1,189.14 i 0	693.60 i 0	495.53 i 0
20	1,201.86 i 0	706.32 i 0	495.53 i 0
21	1,274.10 i 0	706.67 i 0	567.43 i 0
22	1,287.41 i 0	706.74 i 0	580.67 i 0
23	1,300.51 i 0	706.81 i 0	593.70 i 0
24	1,313.48 i 0	706.88 i 0	606.60 i 0
25	1,326.35 i 0	706.95 i 0	619.40 i 0
26	1,339.13 i 0	707.02 i 0	632.11 i 0
27	1,351.81 i 0	707.09 i 0	644.73 i 0
28	1,364.40 i 0	707.15 i 0	657.25 i 0
29	1,390.87 i 0	715.72 i 0	675.15 i 0
30	1,435.08 i 0	725.05 i 0	710.03 i 0
31	1,742.40 i 0	893.25 i 0	849.15 i 0

RT Iterative MRM

- For each run:
  - Operate to target Turbine Rel.
  - Rules check higher priorities
  - Calculate resulting Power
- Runs 1-3
  - Formal minimums
  - ST Guidance Constraint Mins
  - Flexibility Minimums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- Runs 1-3
  - Formal minimums
  - ST Guidance Constraint Mins
  - Flexibility Minimums
- Runs 4-6
  - Similar for Max

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	Request MW	Wanapum Gen MW	Priest Rapids Gen MW
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4	185.35 i 0	91.51 i 0	93.84 i 0
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RT Iterative MRM

Discretionary Range

(within flexibility constraints)

- Execute 2 “trial” runs
  1. Increase Wanapum Turbine Release by 1 unit

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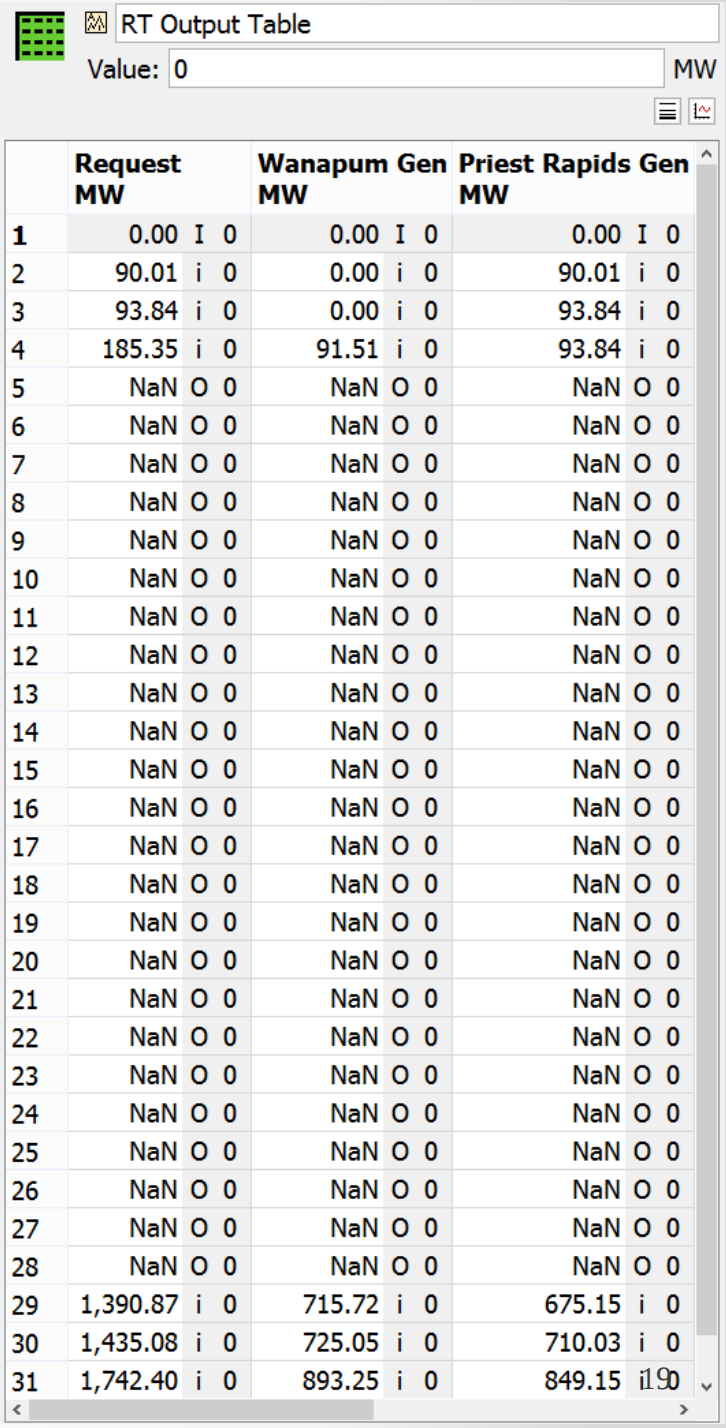
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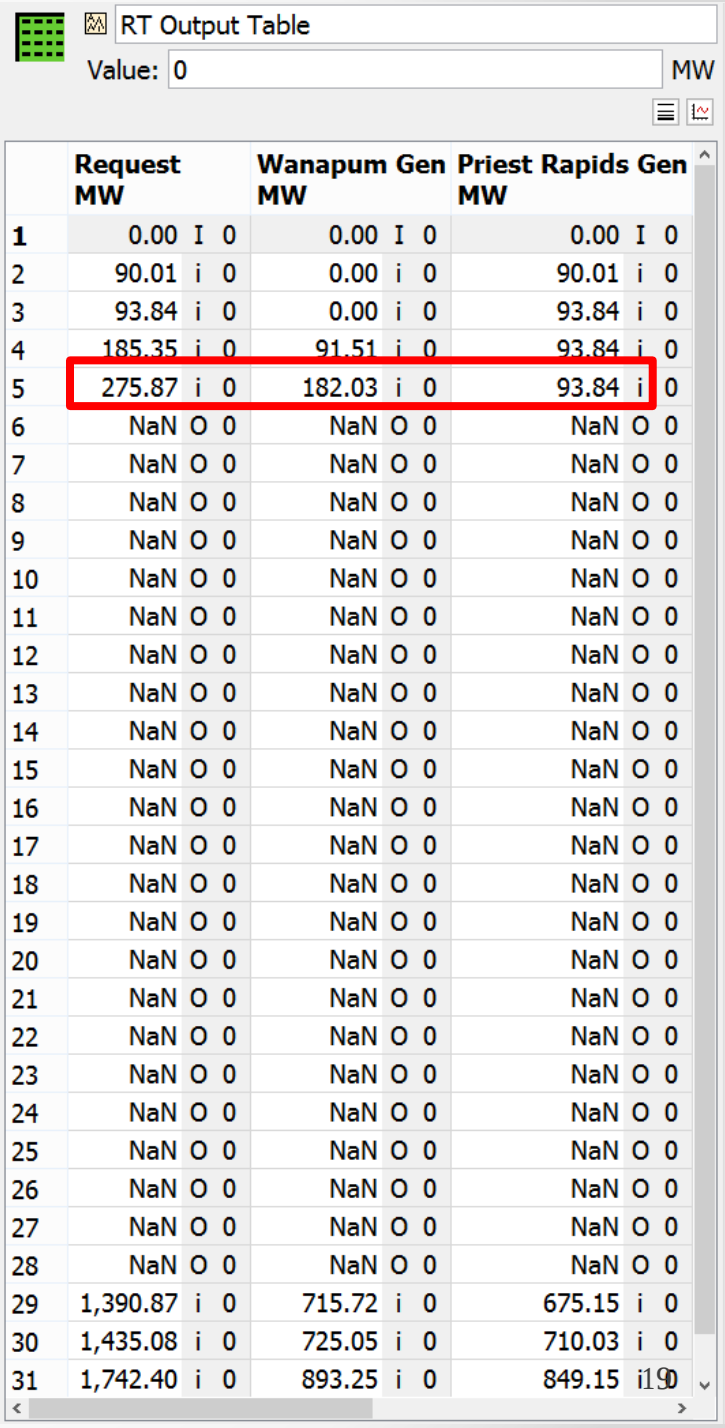

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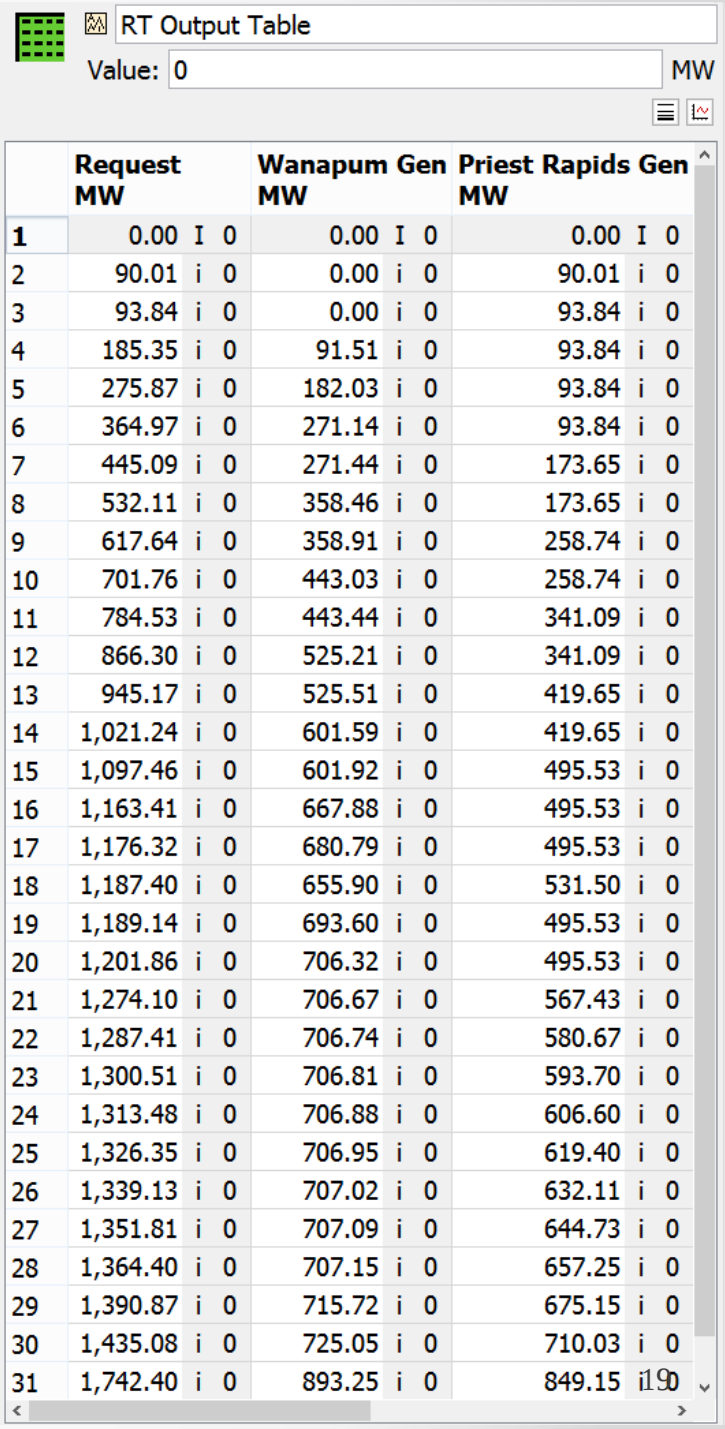
17	NaN O 0	NaN O 0	NaN O 0
18	NaN O 0	NaN O 0	NaN O 0
19	NaN O 0	NaN O 0	NaN O 0
20	NaN O 0	NaN O 0	NaN O 0
21	NaN O 0	NaN O 0	NaN O 0
22	NaN O 0	NaN O 0	NaN O 0
23	NaN O 0	NaN O 0	NaN O 0
24	NaN O 0	NaN O 0	NaN O 0
25	NaN O 0	NaN O 0	NaN O 0
26	NaN O 0	NaN O 0	NaN O 0
27	NaN O 0	NaN O 0	NaN O 0
28	NaN O 0	NaN O 0	NaN O 0
29	1,390.87 i 0	715.72 i 0	675.15 i 0
30	1,435.08 i 0	725.05 i 0	710.03 i 0
31	1,742.40 i 0	893.25 i 0	849.15 i 0

RT Iterative MRM

Discretionary Range

(within flexibility constraints)

- Execute 2 “trial” runs
  1. Increase Wanapum Turbine Release by 1 unit
  2. Increase Priest Rapids Turbine Release by 1 unit
- Iterative MRM rules select result closest to ST Outflow Ratio
- Repeat


RT Output Table

Value: 0 MW

	Request MW	Wanapum Gen MW	Priest Rapids Gen MW
1	0.00 I 0	0.00 I 0	0.00 I 0
2	90.01 i 0	0.00 i 0	90.01 i 0
3	93.84 i 0	0.00 i 0	93.84 i 0
4	185.35 i 0	91.51 i 0	93.84 i 0
5	275.87 i 0	182.03 i 0	93.84 i 0
6	364.97 i 0	271.14 i 0	93.84 i 0
7	445.09 i 0	271.44 i 0	173.65 i 0
8	532.11 i 0	358.46 i 0	173.65 i 0
9	617.64 i 0	358.91 i 0	258.74 i 0
10	701.76 i 0	443.03 i 0	258.74 i 0
11	784.53 i 0	443.44 i 0	341.09 i 0
12	866.30 i 0	525.21 i 0	341.09 i 0
13	945.17 i 0	525.51 i 0	419.65 i 0
14	1,021.24 i 0	601.59 i 0	419.65 i 0
15	1,097.46 i 0	601.92 i 0	495.53 i 0
16	1,163.41 i 0	667.88 i 0	495.53 i 0
17	1,176.32 i 0	680.79 i 0	495.53 i 0
18	1,187.40 i 0	655.90 i 0	531.50 i 0
19	1,189.14 i 0	693.60 i 0	495.53 i 0
20	1,201.86 i 0	706.32 i 0	495.53 i 0
21	1,274.10 i 0	706.67 i 0	567.43 i 0
22	1,287.41 i 0	706.74 i 0	580.67 i 0
23	1,300.51 i 0	706.81 i 0	593.70 i 0
24	1,313.48 i 0	706.88 i 0	606.60 i 0
25	1,326.35 i 0	706.95 i 0	619.40 i 0
26	1,339.13 i 0	707.02 i 0	632.11 i 0
27	1,351.81 i 0	707.09 i 0	644.73 i 0
28	1,364.40 i 0	707.15 i 0	657.25 i 0
29	1,390.87 i 0	715.72 i 0	675.15 i 0
30	1,435.08 i 0	725.05 i 0	710.03 i 0
31	1,742.40 i 0	893.25 i 0	849.15 i 0

Current Work

- ST Model:

  Special logic to prepare for a capacity imbalance – maintain a percentage of full capacity

- RT Model:

  Cases to use criteria other than ST Outflow Ratio

  Possibly convert to 5 Minute timestep

- Cutover to Independent Operations:

  November 2019