Center for Advanced Decision Support for
Water and Environmental Systems (CADSWES)
UNIVERSITY OF COLORADO **BOULDER**

FIRO and Risk Informed Dynamic Seasonal Forecasting

2026 RiverWare User Group Meeting

Presenter: Mitch Clement

FIRO and Risk Informed Dynamic Seasonal Forecasting

Applications:

- Ruedi Reservoir – Colorado
  - Fill season release decision
  - One-year ensemble forecast
  - 10-day forecast
- Lake Chelan – Washington
  - Water year planning
  - Historical water years as traces
- USACE Flood Control Reservoir – Texas
  - Benefit/risk of modifying flood control elevations
  - Ensemble forecast (historical water years for testing)

How can ensemble **forecasts** be used to manage **risk** and **inform** operations considering the **seasonal** time scale as well as near-term?

Ruedi Reservoir

- USBR ECAO
- Frying Pan River –
  - Colorado Western Slope
  - Frying Pan – Arkansas Project
- ~100,000 ac-ft active storage

Fill Season Objectives (April-July)

- Try to be full at end of fill season (mid-July) – maximize water supply
- Do not exceed channel capacity downstream
- "Optimize" hydropower generation when possible
- Infrequent release changes – weekly

How much to fill, at what rate?

→ Decision variable: **Weekly Release Rate**

Risk-informed Decision Making:

How can ensemble **forecasts** be used to manage **risk** and **inform** release decisions?

Ruedi RIDM Pilot Operations Study

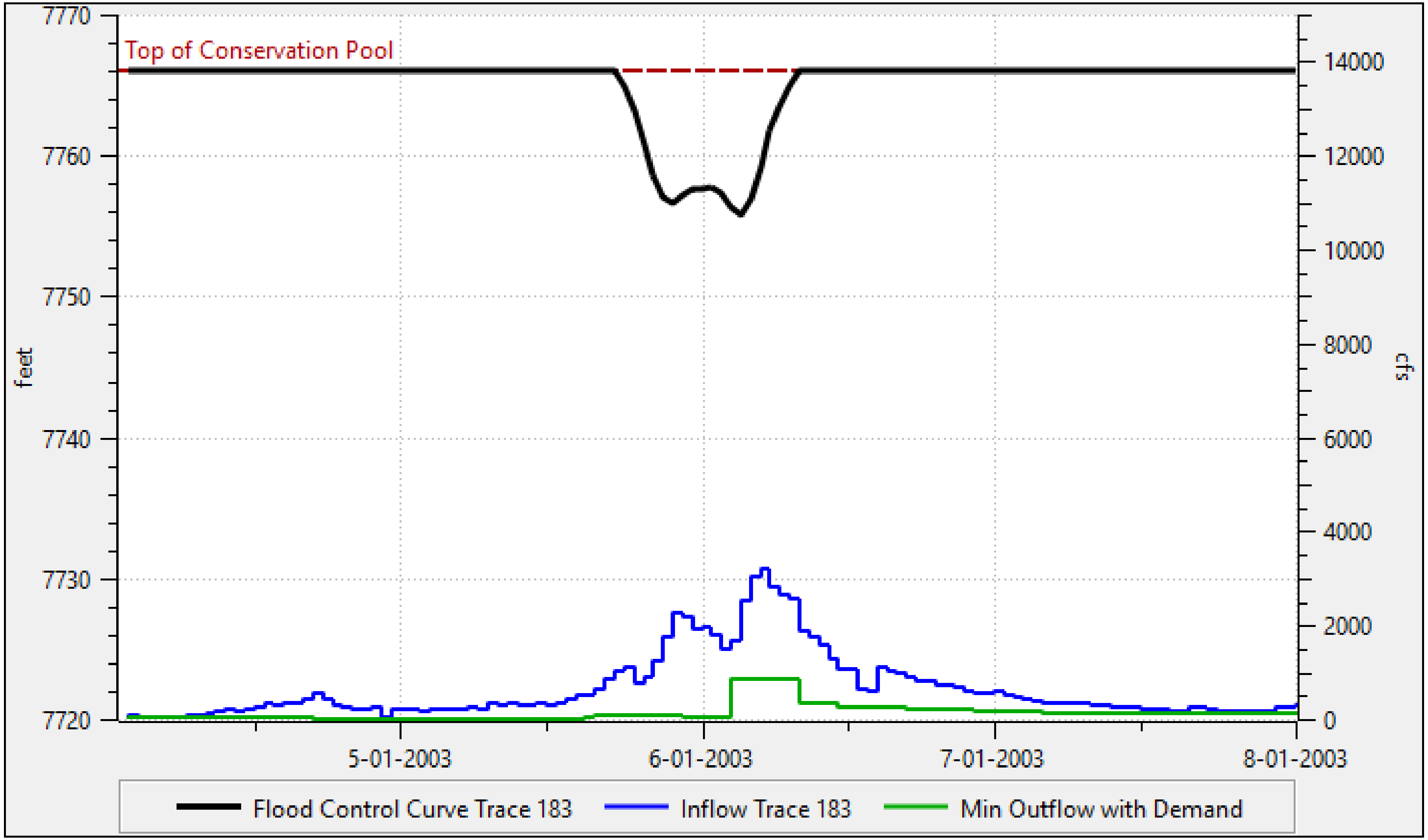
- Collaboration with USBR TSC
- Two Forecast Ensembles
  - 1-year, updated weekly
  - 10-day, updated daily
- RIDM Approach: 3 Phases
  - I: Dynamic Envelope Curves – min/max storage
  - II: Select preferred Week 1 Release
  - III: Use 10-day forecast to update envelope curves and release if necessary

Weekly,
1-year forecast

Phase I: Dynamic Envelope Curves

Flood Control Curve

- Work backward from "ideal fill date" at max elevation
- Max storage at end of previous day given max outflow and inflow forecast trace
- Move back one day and repeat



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Flood Control Curve

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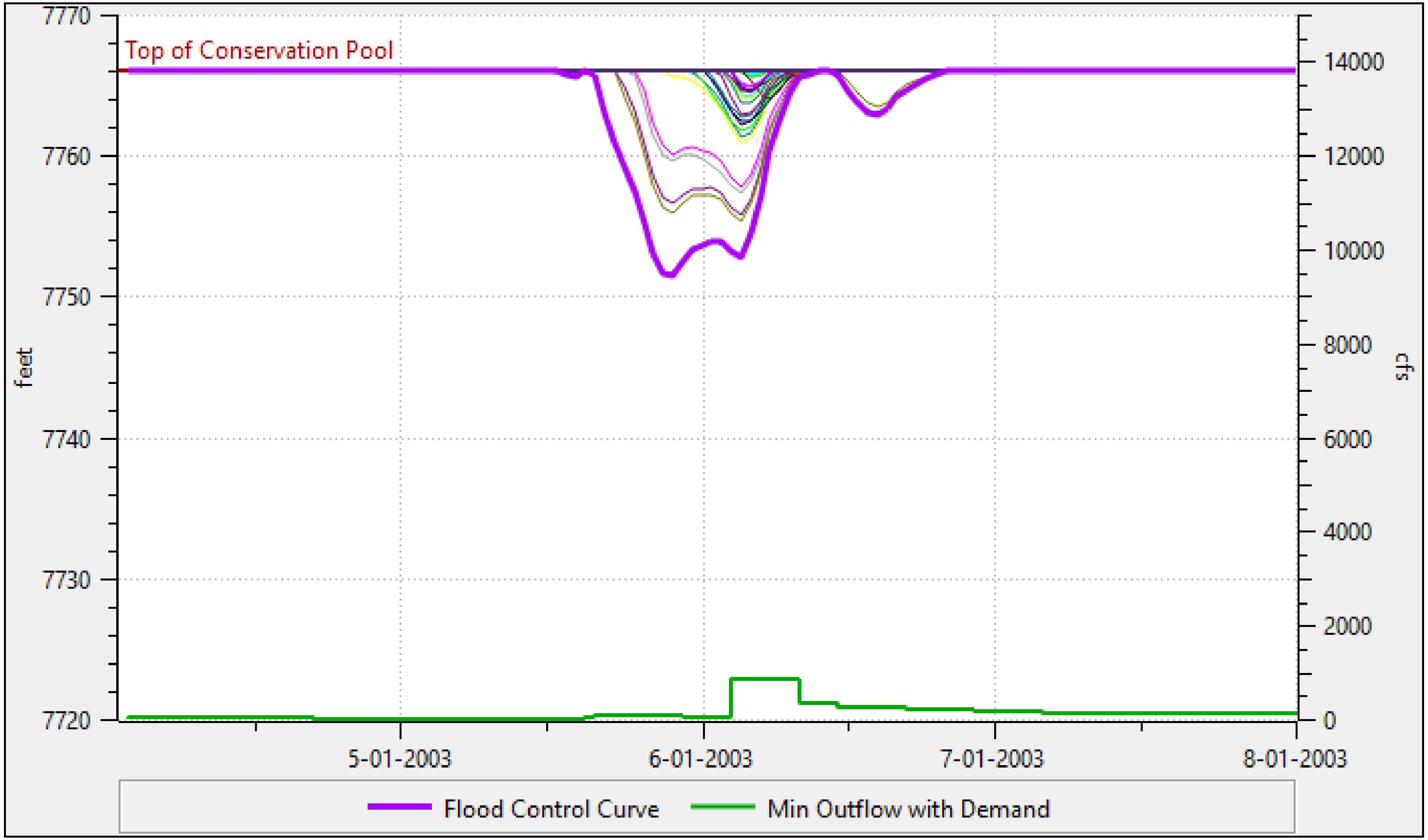
- Repeat for all traces
- Set final curve based on Reliability %



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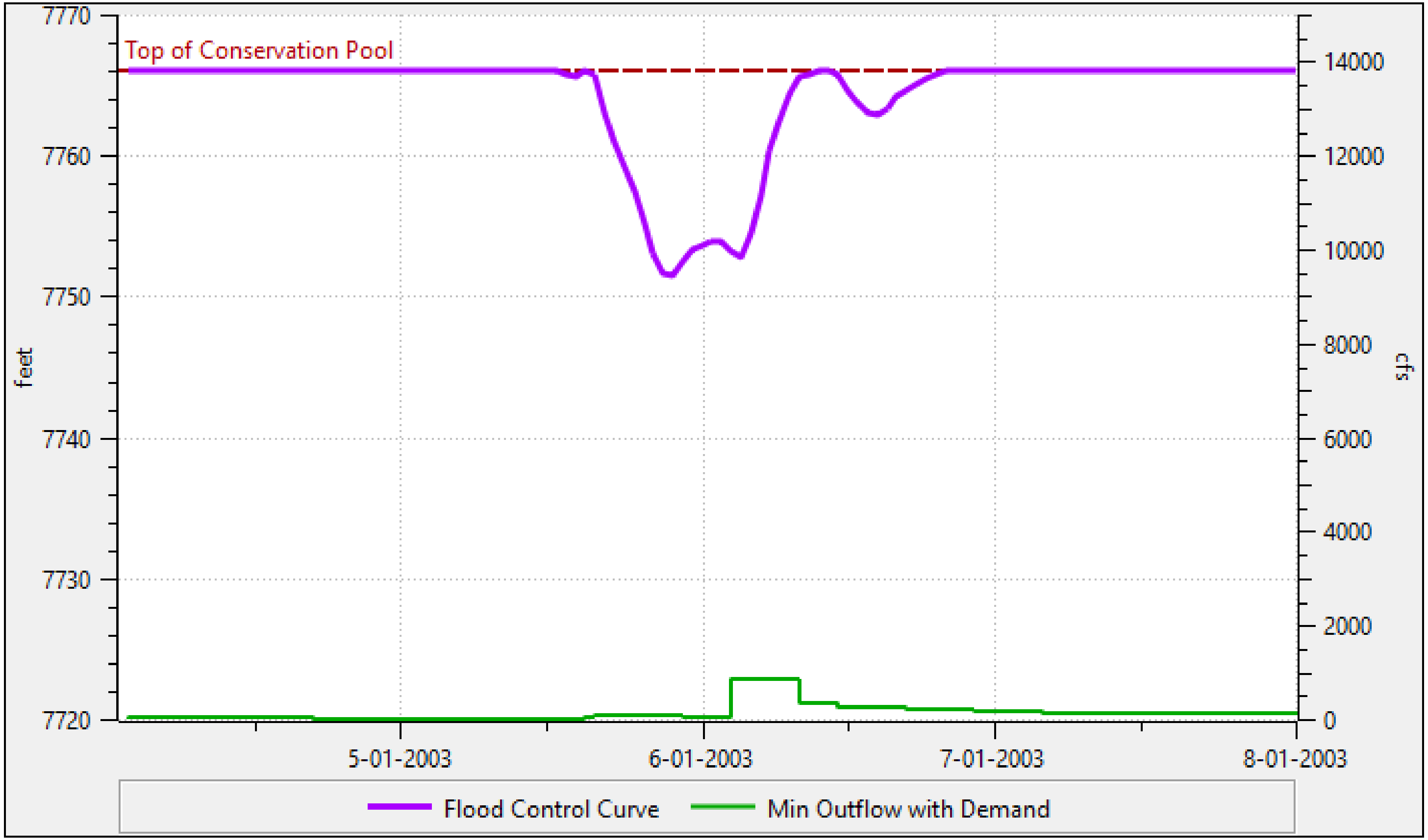

Phase I: Dynamic Envelope Curves

Water Supply Curve

- Work backward from "ideal fill date" at full elevation
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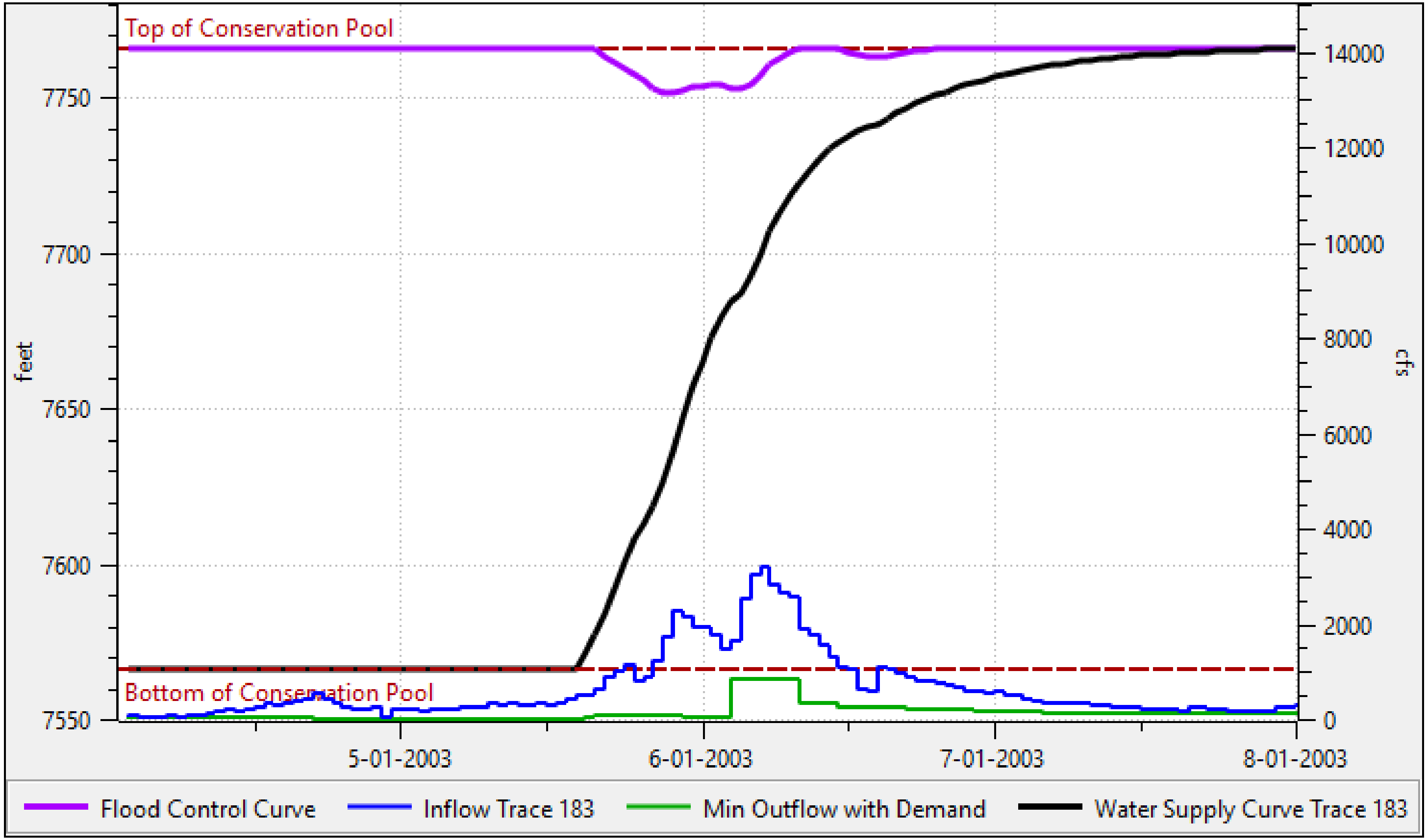

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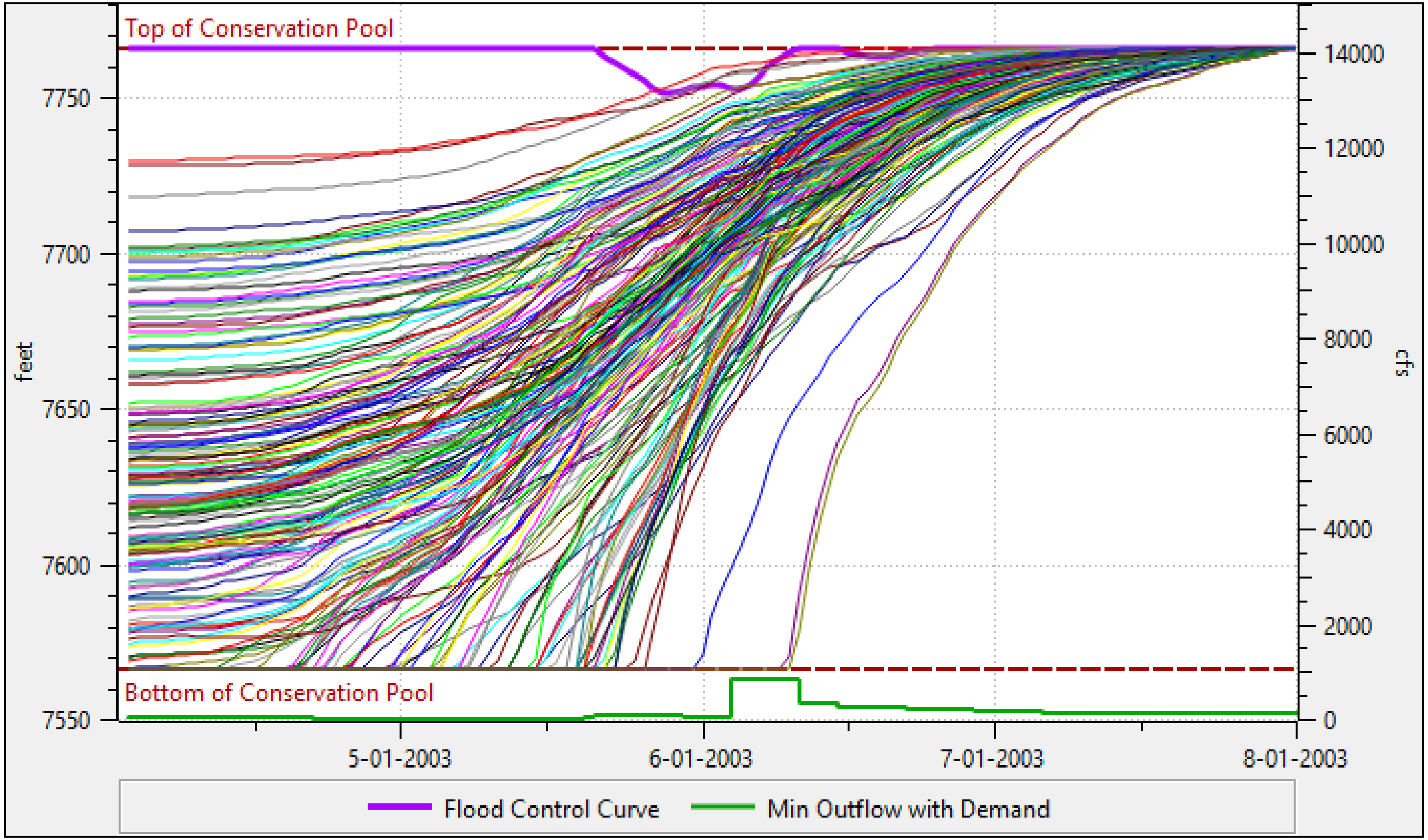

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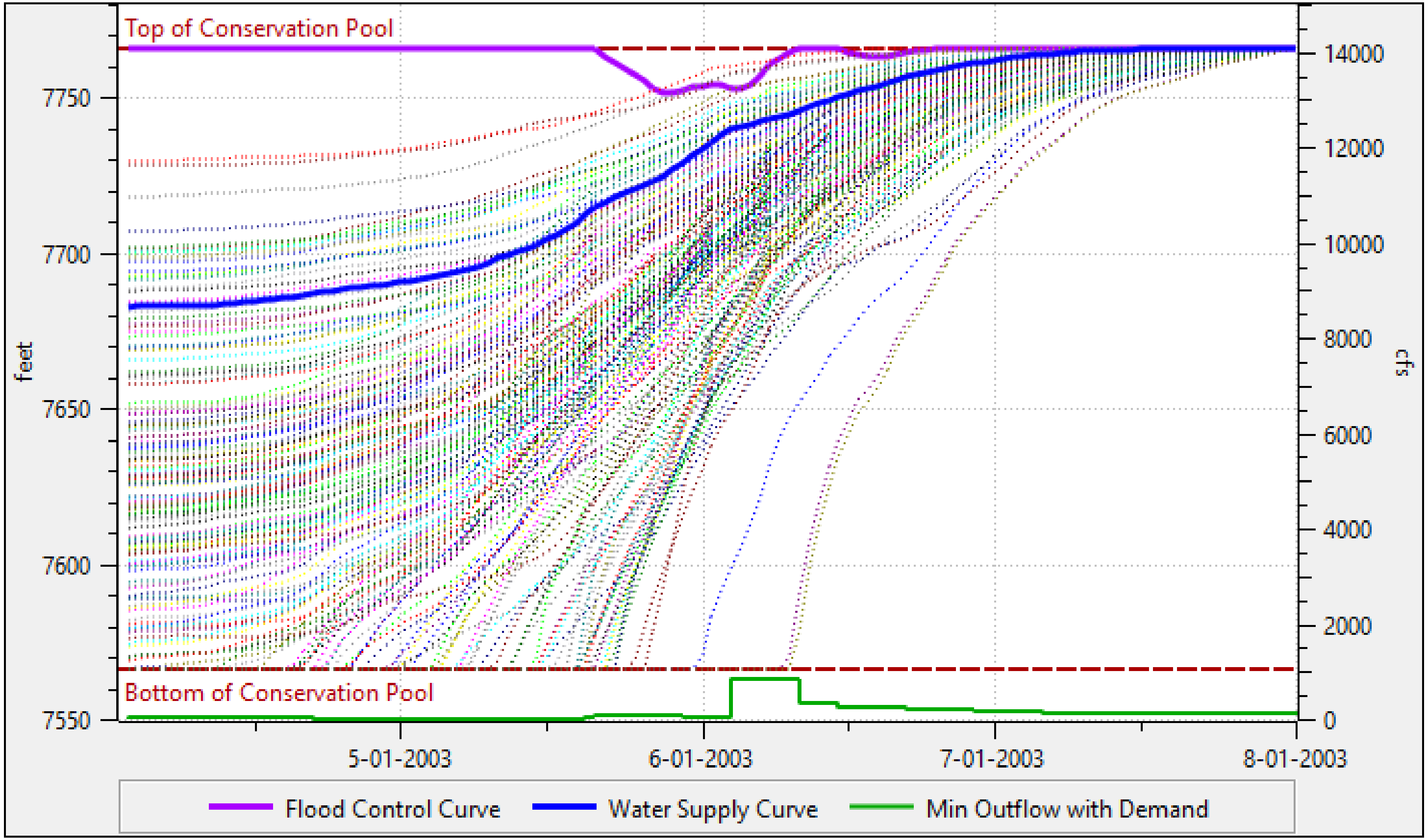

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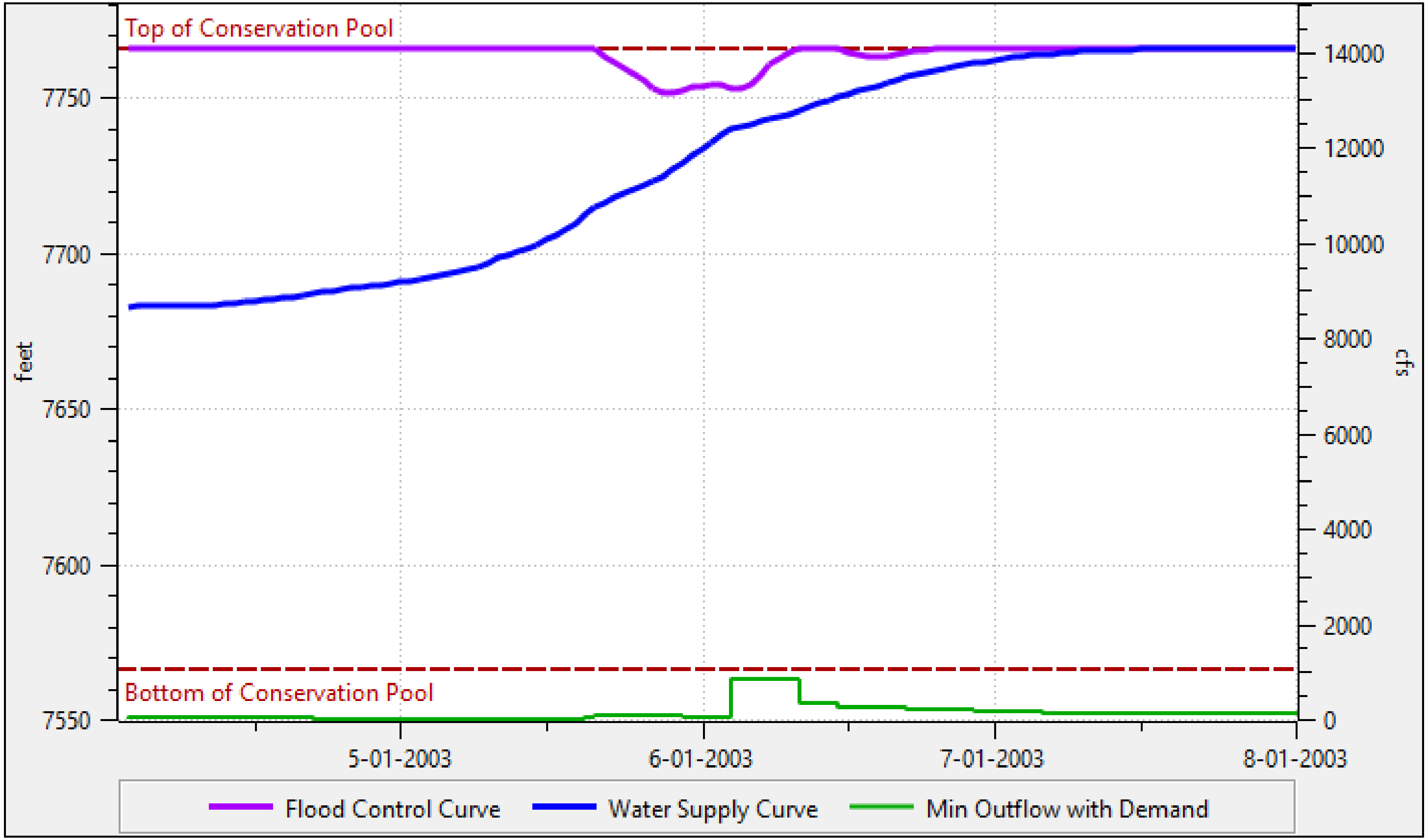


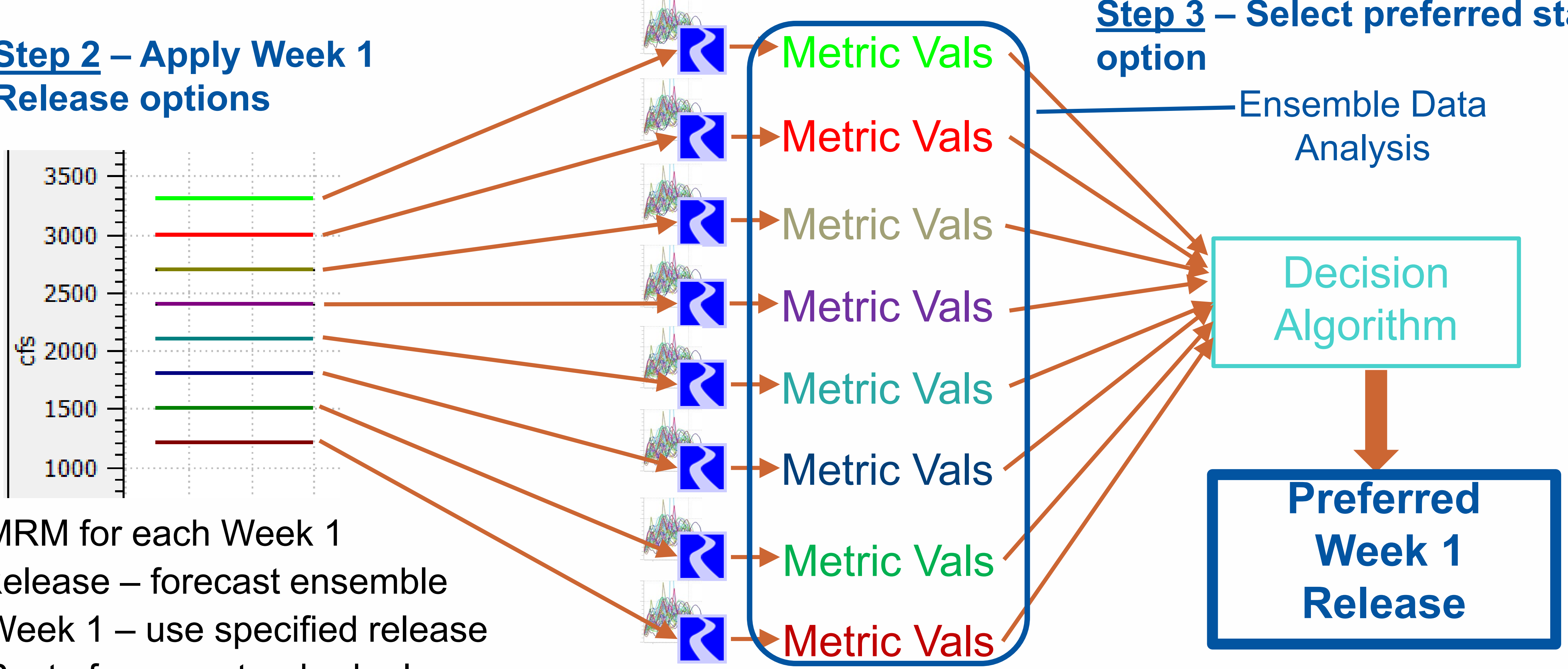
Phase II: Select Week 1 Release

Two-stage Stochastic Programming with Recourse

Step 1 – Determine Week 1 Release options

Step 2 – Apply Week 1 Release options

Step 3 – Select preferred stage 1 option



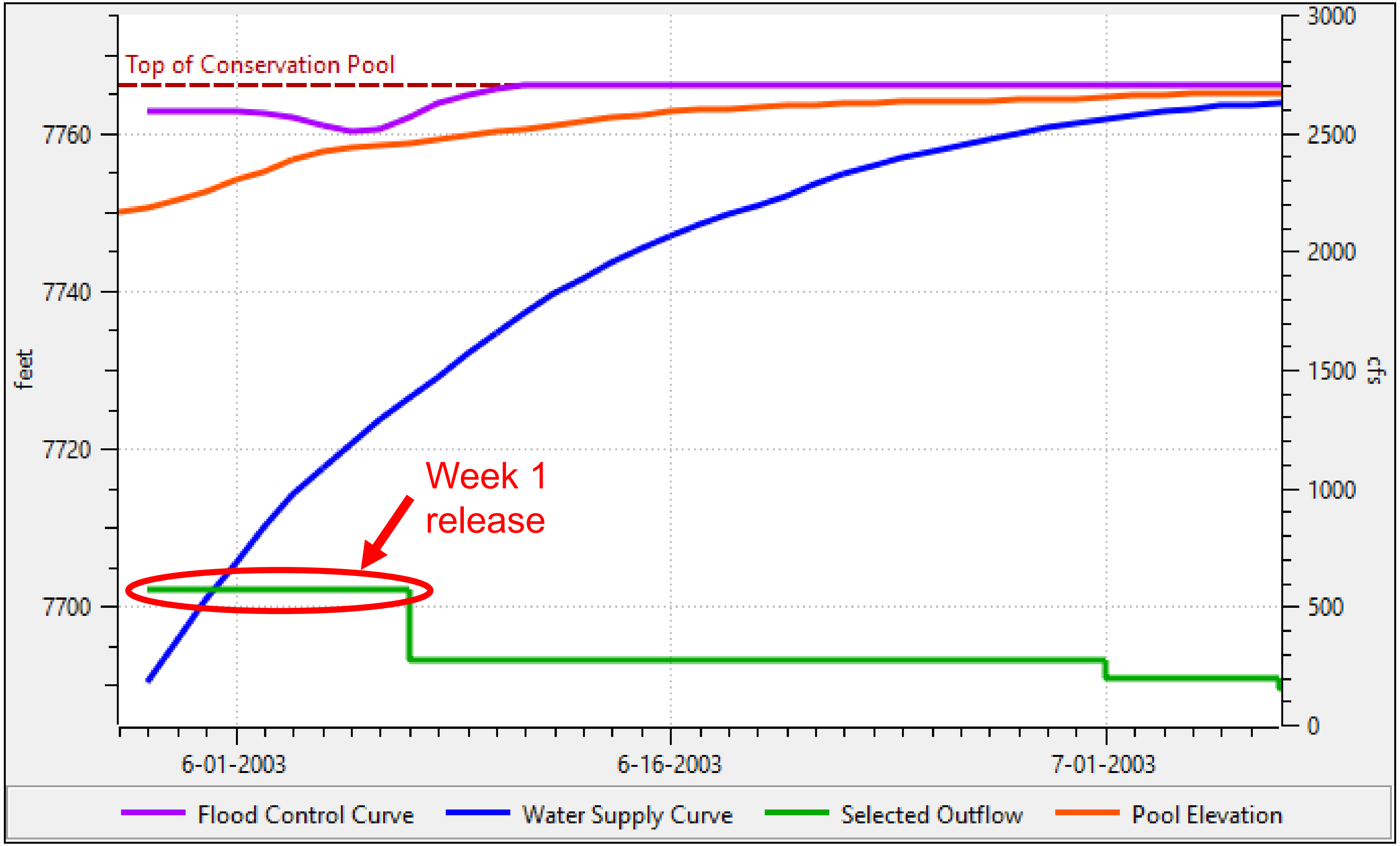
- MRM for each Week 1 Release – forecast ensemble
- Week 1 – use specified release
- Rest of year – standard rules

Evaluate metrics each trace

Phase II: Week 1 Release Decision

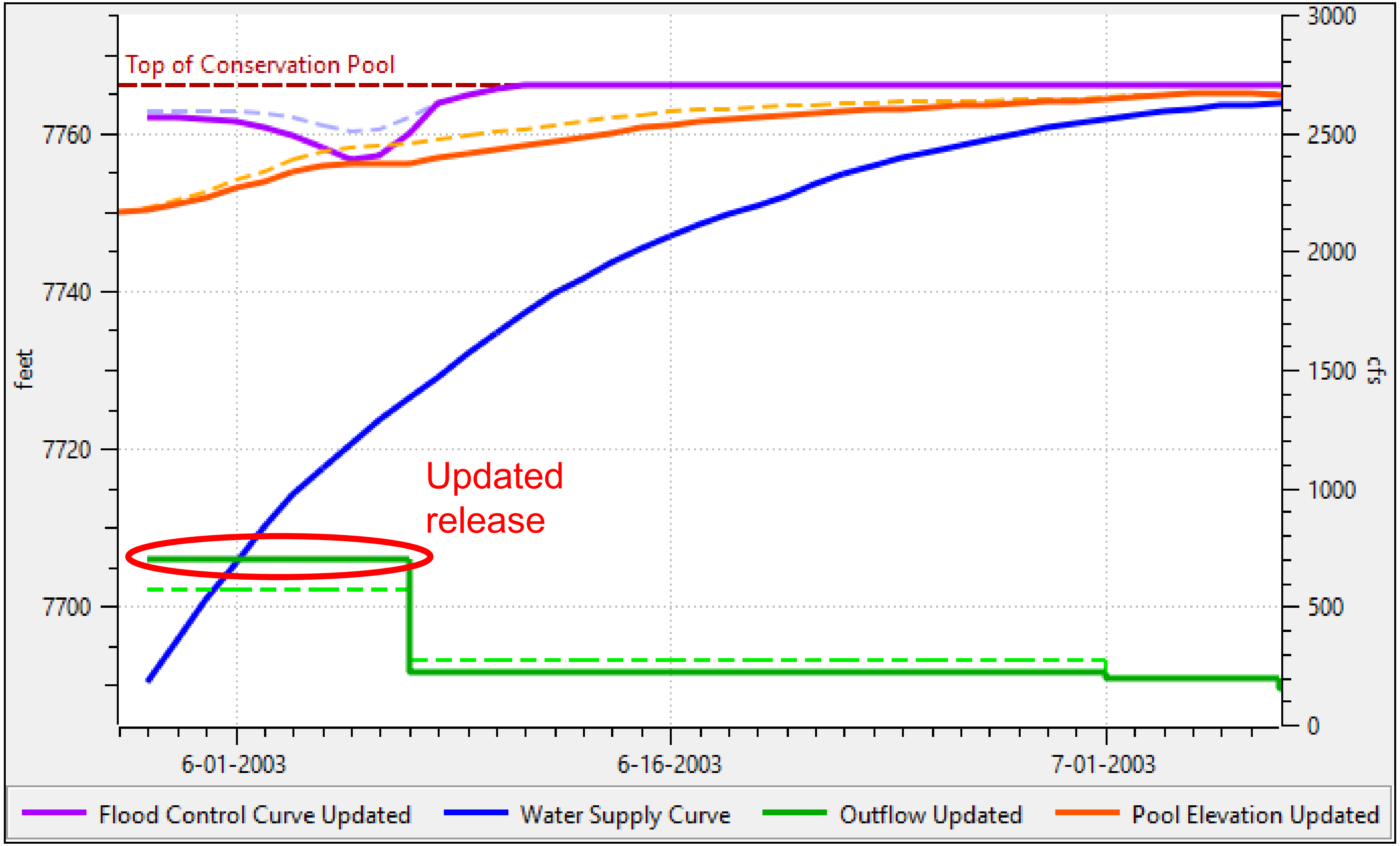
Select preferred release option

- Stay within the envelope curves – accounts for water objectives
- Best hydropower value – Stage 1 and Stage 2 combined



Phase III: Update with 10-Day Forecast

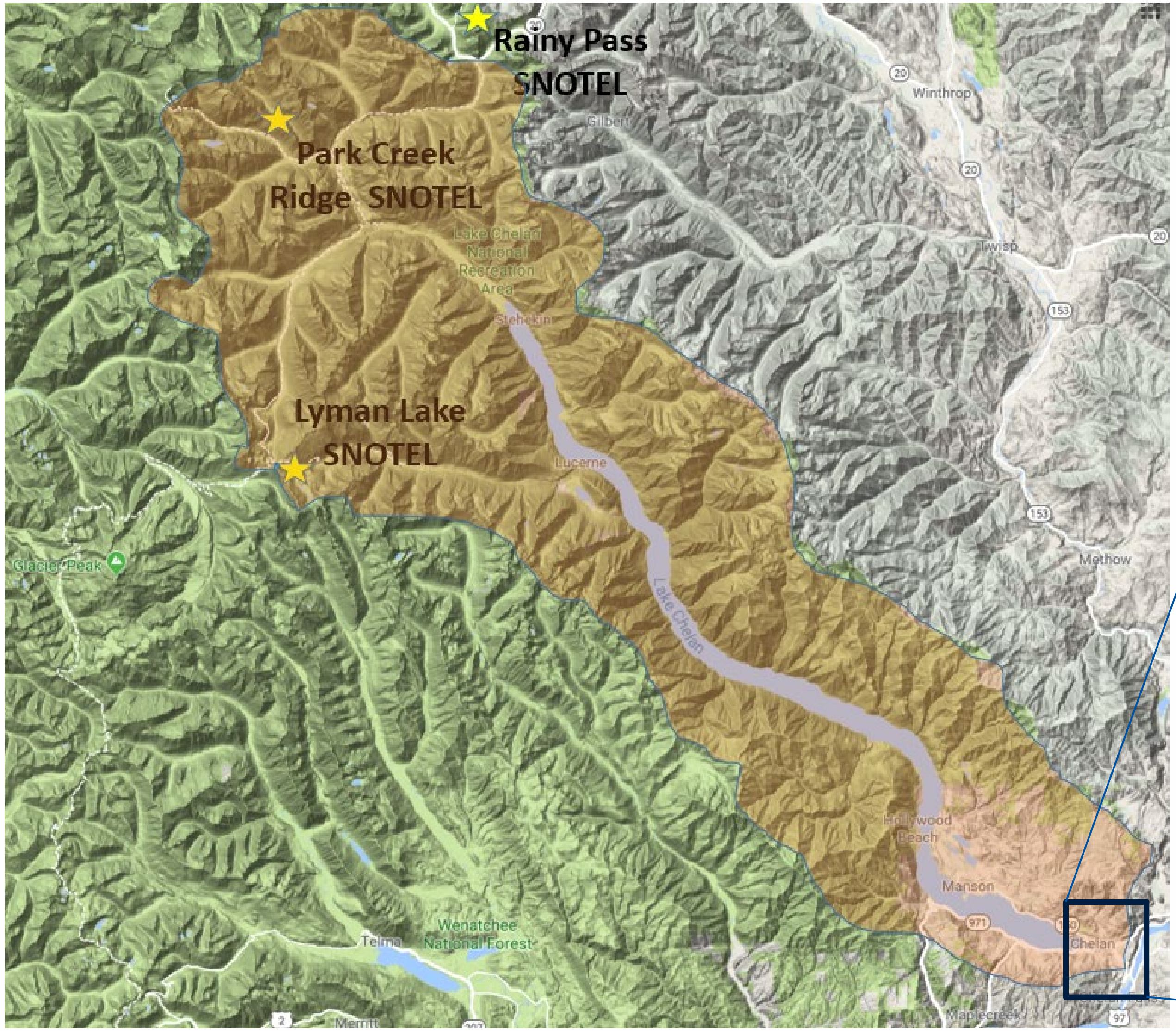
- Compute updated envelope with 10-day forecast
- Check if projected storage with updated inflows violates updated envelope
- Compute updated release to remain within envelope



Ruedi RIDM Pilot Operations Study

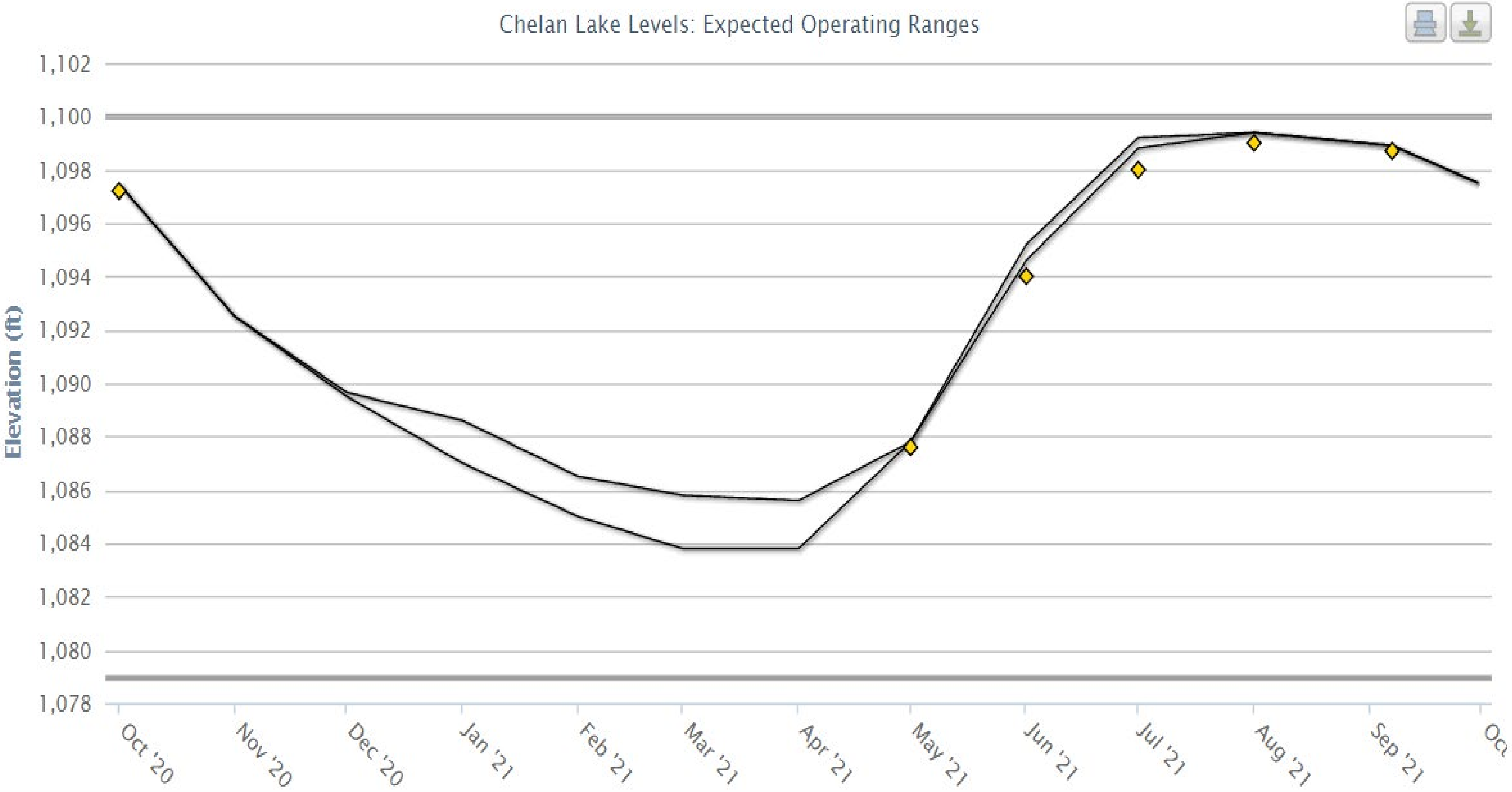
- Simulate multiple years applying RIDM for fill season
  - RiverWare Scripts automate Phase I, II, III sequence
  - Phase I Envelope Curves – Initialization Rules
  - Phase II Release Selection – MRM with Ensemble Data Analysis
  - Batch script automates overall study sequence
    - Execute Phases I-III to select preferred release using ensemble forecast
    - Simulate 1 week with selected release and actual inflow
    - Advance 1 week with updated forecast and repeat
- Status:
  - Preliminary testing of Phases I & II completed
  - Phase III logic implemented – waiting on forecasts to test
  - Finalizing model details with USBR TSC

Lake Chelan Overview



Current Target Curves

- FERC license minimum (target) elevations: May 1 – Oct 1
- Two static target curves
- Selection based on Apr 1-July 31 forecast volume
- Wet year: ≥ 118% avg
- Avg/Dry year: < 118% avg



Key Lake Chelan Policies

- Minimum and Maximum Elevation
- Minimum Flows
  - Tailrace – Turbine Release
  - Chelan River environmental objectives – Spill
  - Seasonal variation
- **Maximum Flow (spill)**
  - 6,000 cfs, prefer less if possible
  - To prevent stream bank erosion, habitat damage
- **FERC license minimum (target) elevations**
  - May 1, June 1, **July 1, Aug 1, Sept 7, Oct 1**

Risk tradeoff: Improving position for one increases the risk of violating the other

Questions to Answer With the Model

- Where to position the reservoir at the start of fill season?
  Best position to meet elevation targets and minimize spill
- Is preemptive spill necessary to avoid excess spill later?
  When to start and how much?
- Could you generate more if energy prices, demands are higher?
  Could you still expect to meet FERC license target min elevations later?
- What is the forecasted range of expected operations?
  5^{th}-95^{th} percentile – shown to the public
- How does the target operation change in the case of outages?
  Unique target curve for the specific season and system conditions

Framework: Min and Max Elevation Envelope Curves

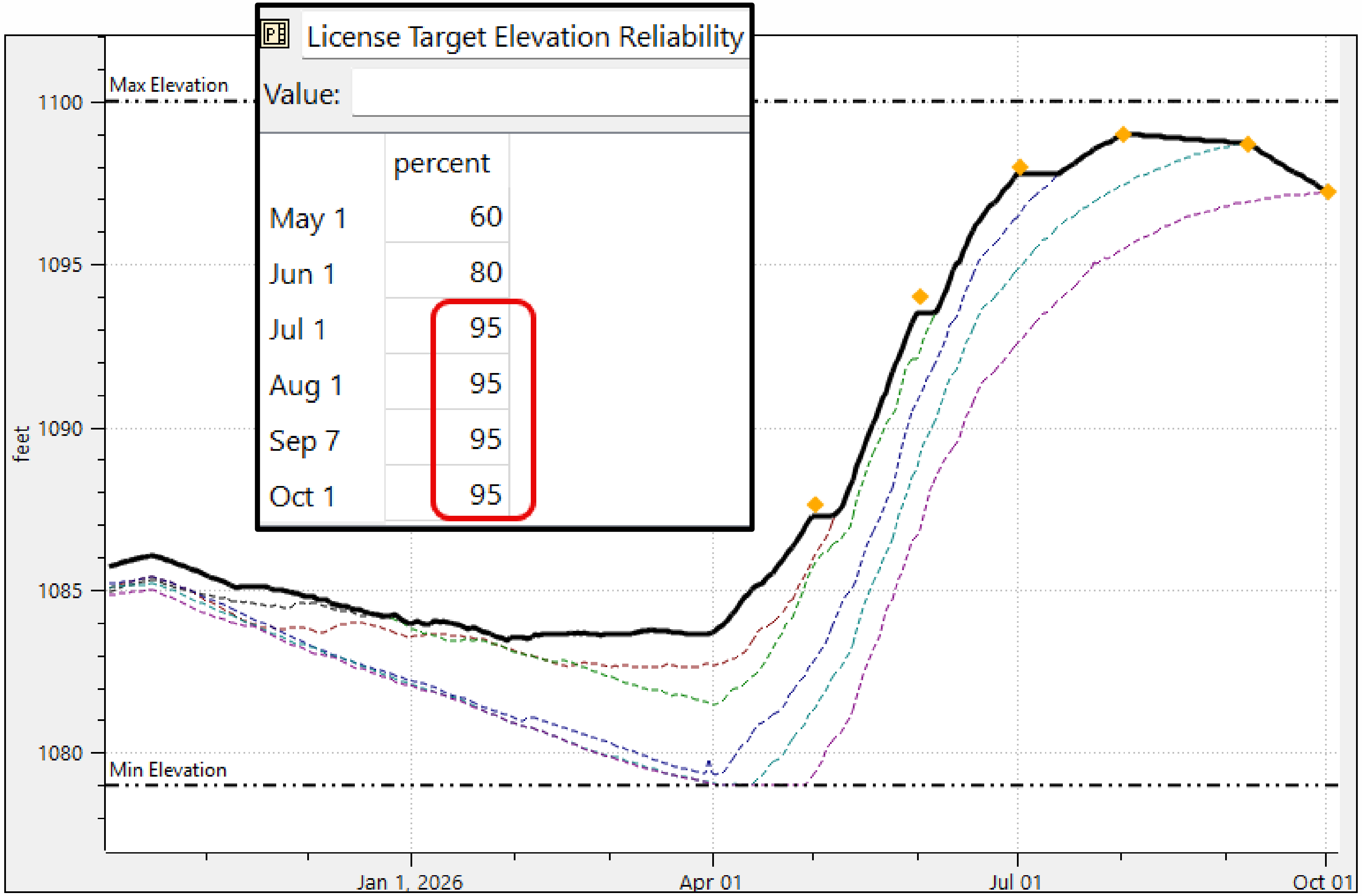
- Remainder of the water year – current day to October 1
- Historical inflows (water years) as ensemble traces
- Use all years at the beginning of water year; narrow the selection as snowpack information improves – years similar to current conditions
- Compute a Min Elevation Curve

  Meet FERC License Target Mins with specified reliability
- Compute a Max Elevation Curve

  Keep spill below specified limits at specified reliability

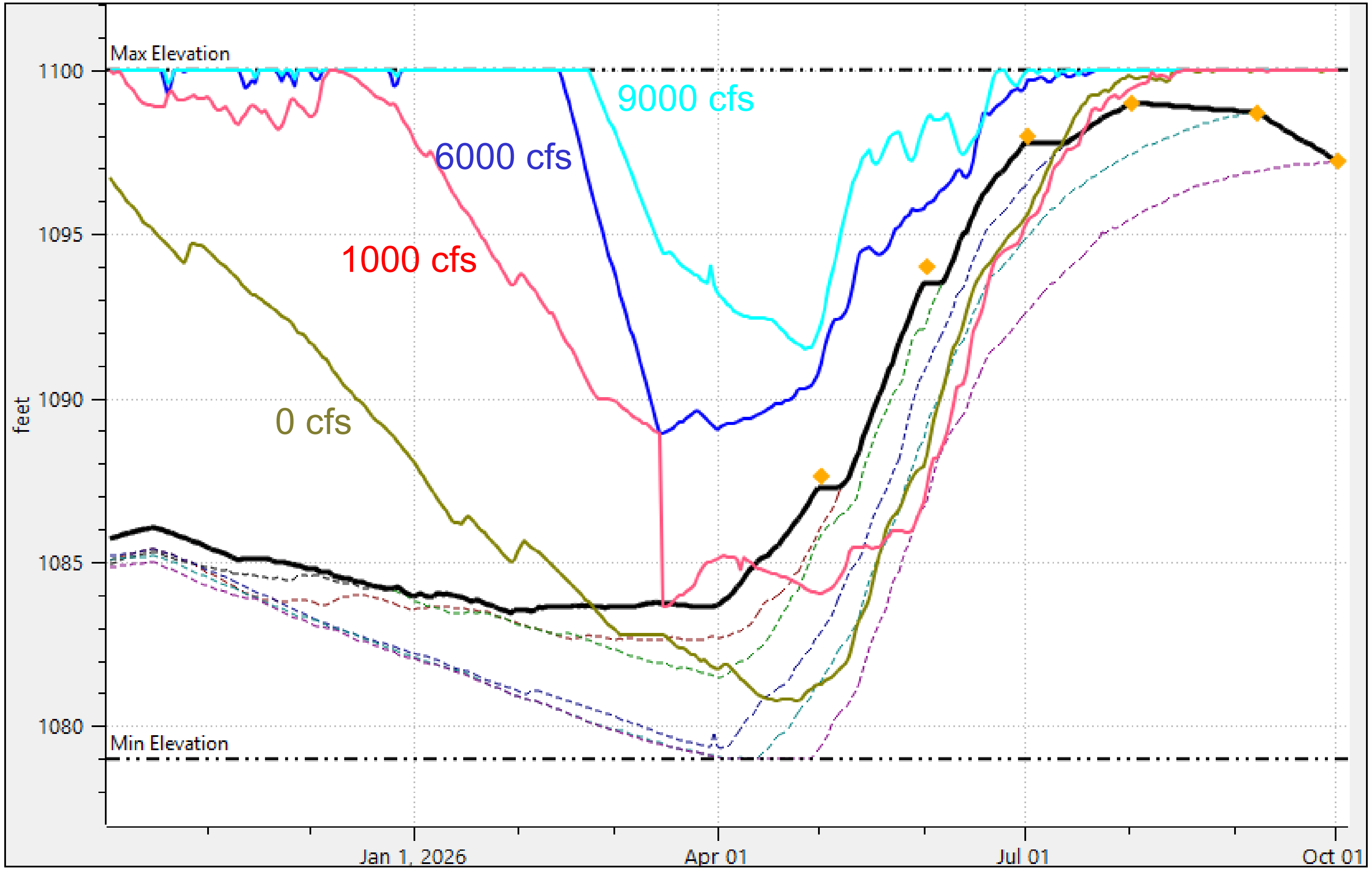
Min Elevation Envelope Curve

- Like Ruedi Water Supply Curve, but for multiple target dates/elevations
- For each Target Min Date
  - For each trace – work backward to compute min storage given inflow and min outflow
  - At each date take the elev corresponding to the reliability % - Reliability Curve for that target
- Repeat for all targets
- Take the highest Reliability Curve at each date as the Min Elev Curve



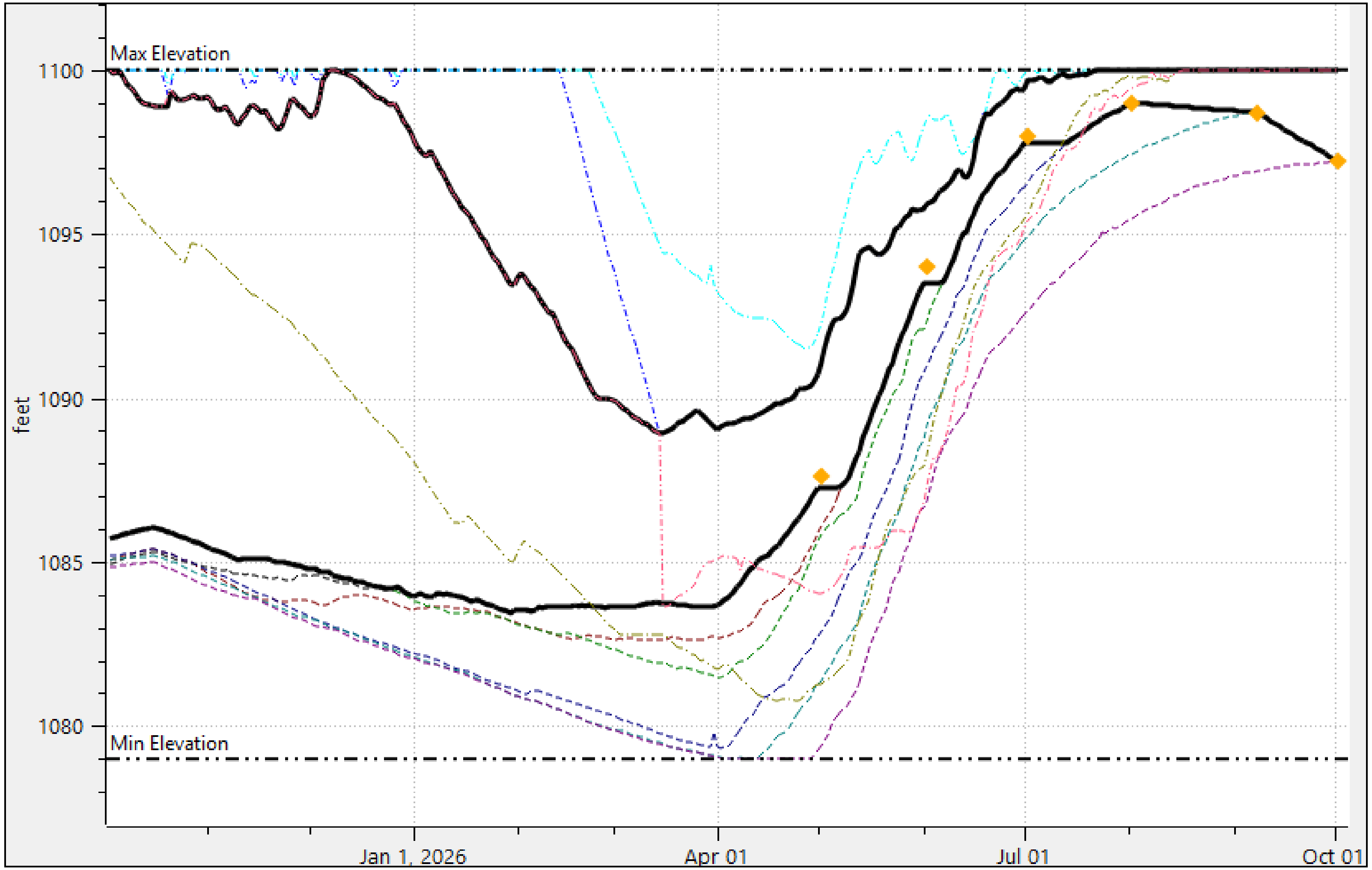
Max Elevation Envelope Curve

- Similar to Ruedi Flood Control Curve but for multiple spill limits
- Reliability Curve for each Spill Limit – based on Inflow and Max Outflow (reset at March 15 with different reliability %)



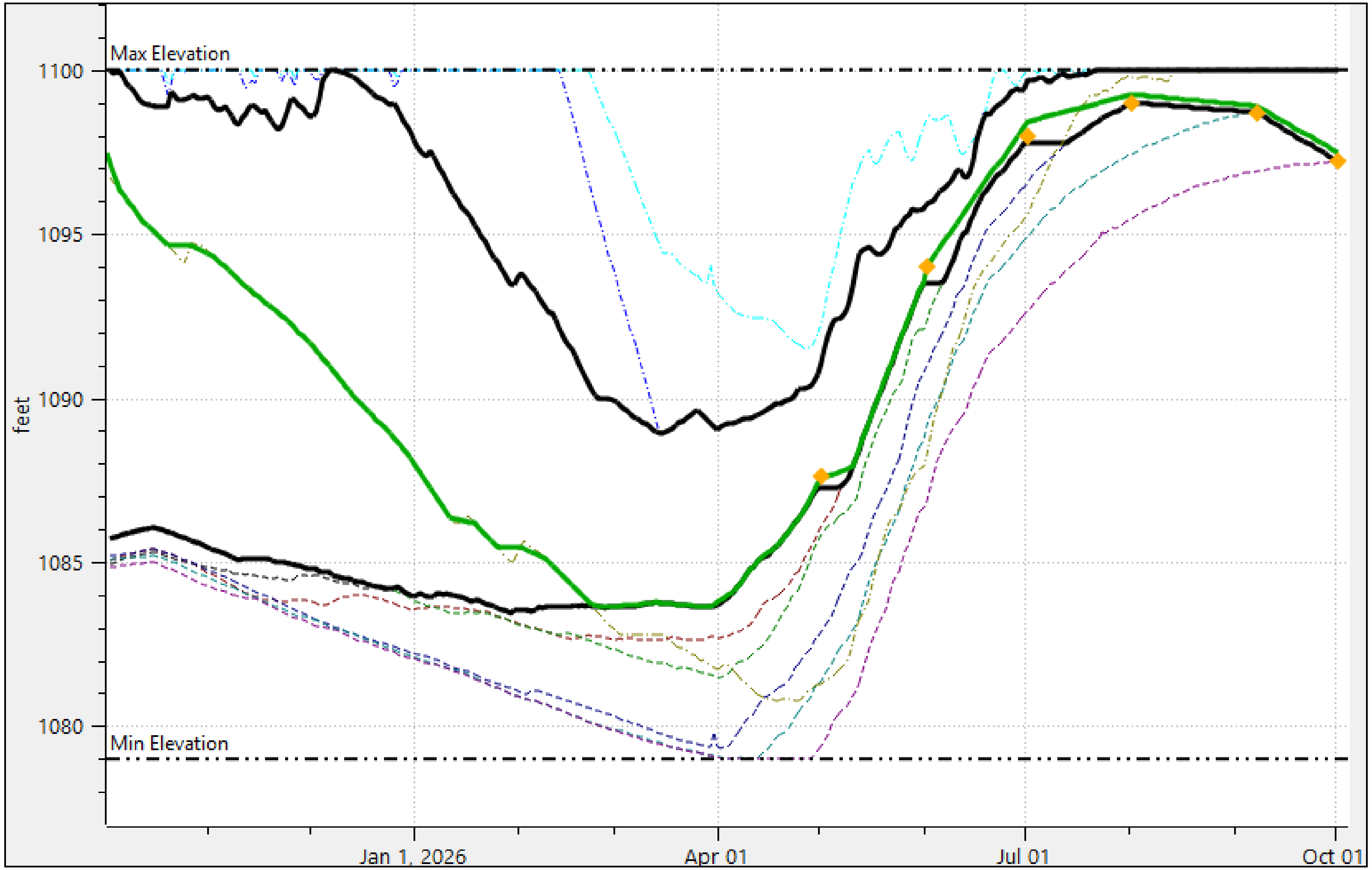
Max Elevation Envelope Curve

- Similar to Ruedi Flood Control Curve but for multiple spill limits
- Reliability Curve for each Spill Limit – based on Inflow and Max Outflow (reset at March 15 with different reliability %)
- Set Max Curve from lowest Reliability Curve "in use" (some spill limit curves for info only)



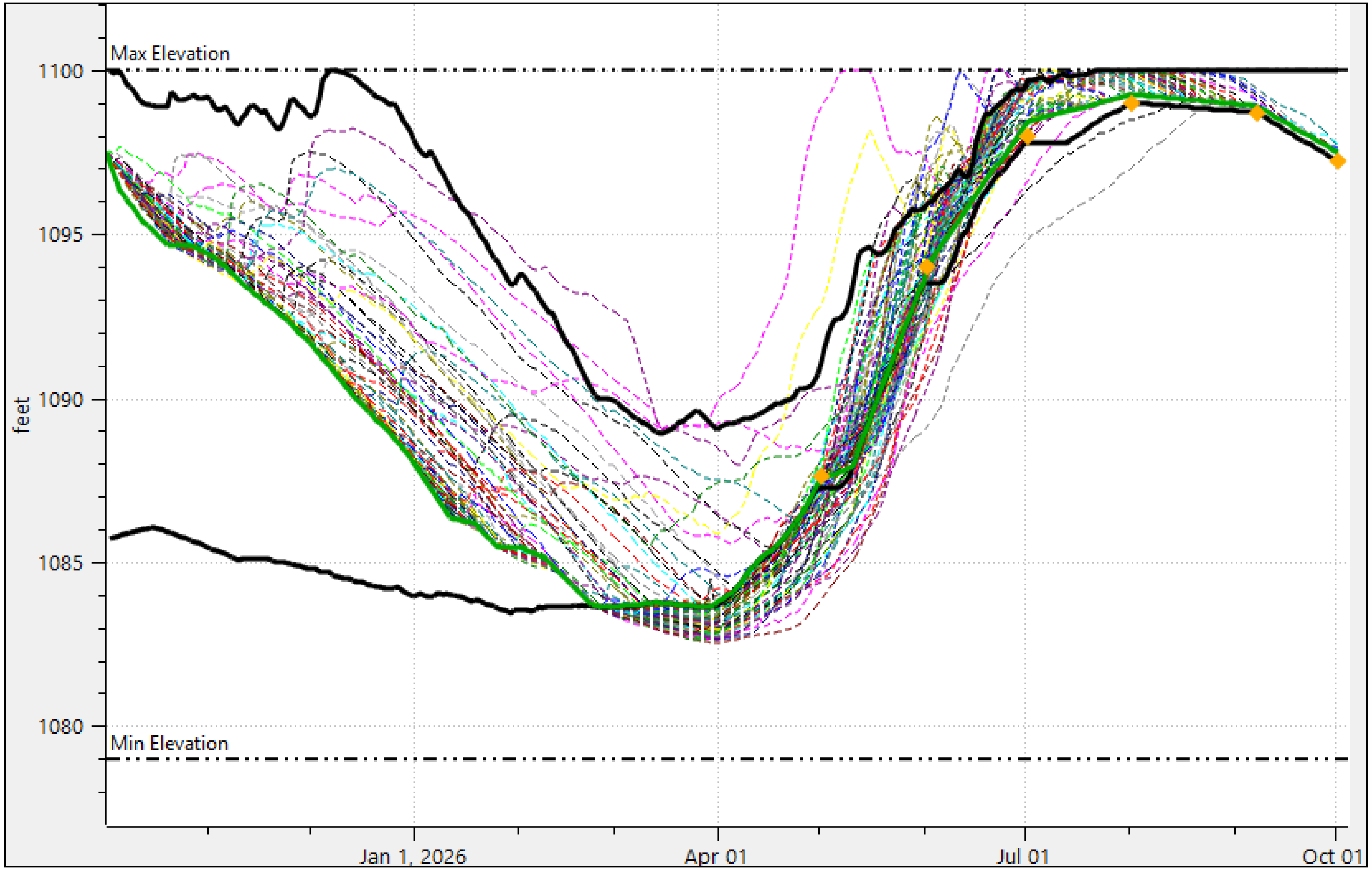
Target Curve

- Follow the Zero Spill curve until it crosses the Min Curve, then follow Min Curve
- Pass through the License Targets for May 1 and June 1
- Pass above the remaining License Targets by a specified percent



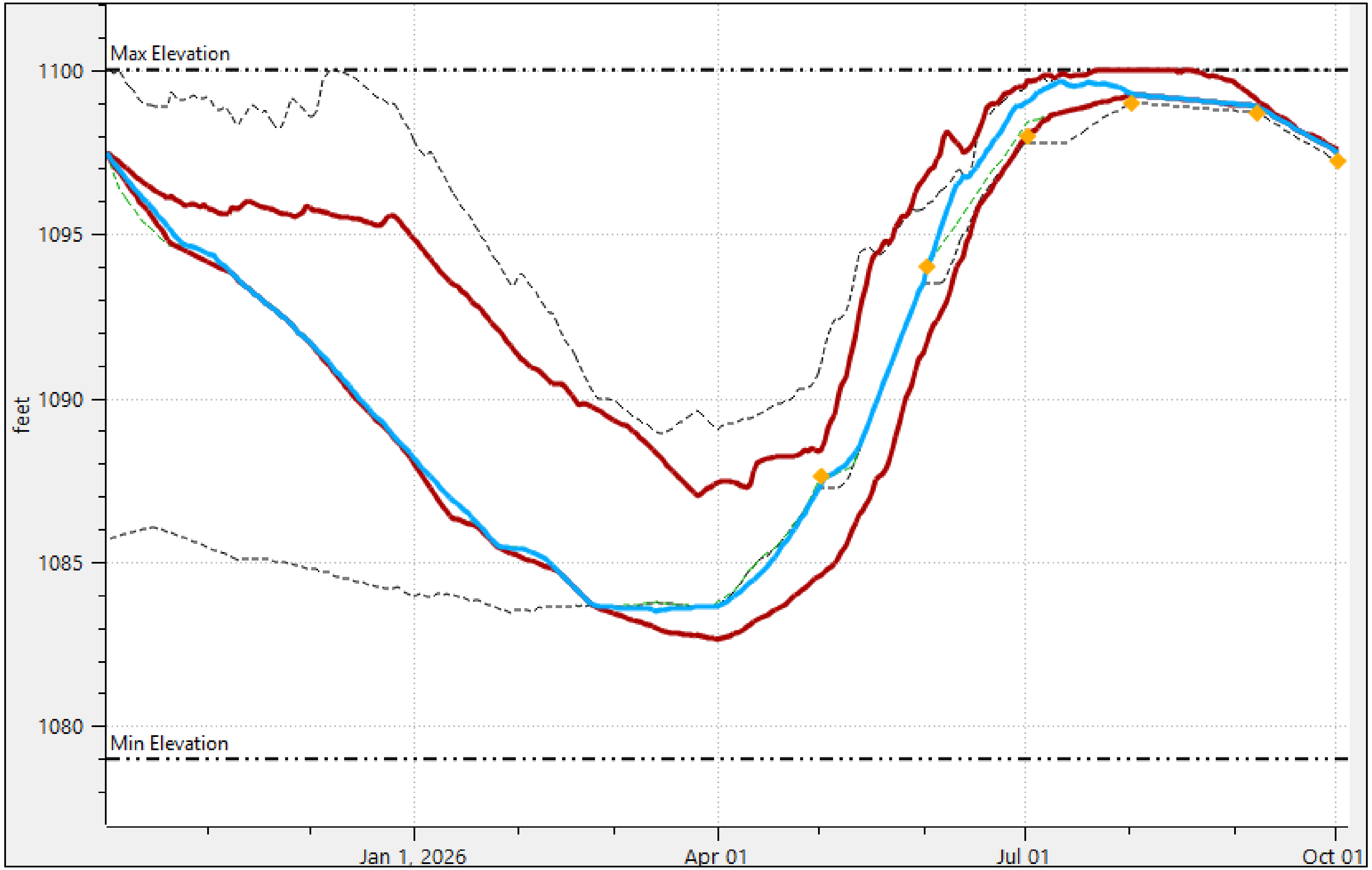
Ensemble Simulation

- MRM to simulate with each inflow trace
  - Operate to Target Curve
  - Check against higher priorities: Min Flow, Max Spill, Min/Max Elevation Curves
- Provides range of expected operations (elevations)



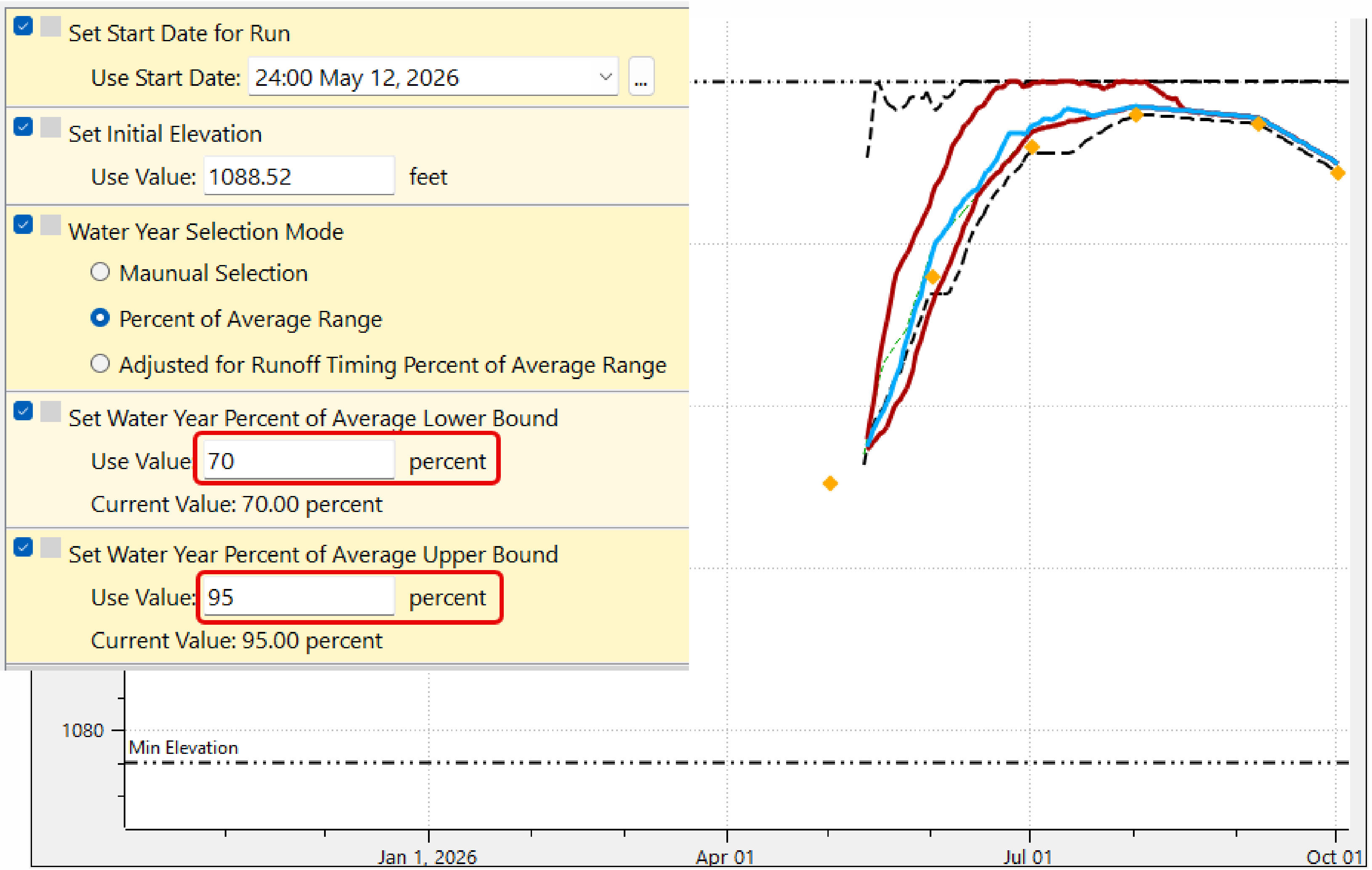
Ensemble Simulation

- MRM to simulate with each inflow trace
  - Operate to Target Curve
  - Check against higher priorities: Min Flow, Max Spill, Min/Max Elevation Curves
- Provides range of expected operations (elevations)
- Compute 5th and 95th percentile elevation range



Dynamically Updated Envelope Curves

- Refine historical water year selection as snowpack information improves
  - Percent of avg range, or
  - Manual selection
- Compute updated
  - Envelope Curves
  - Target Curve
  - Expected operating range

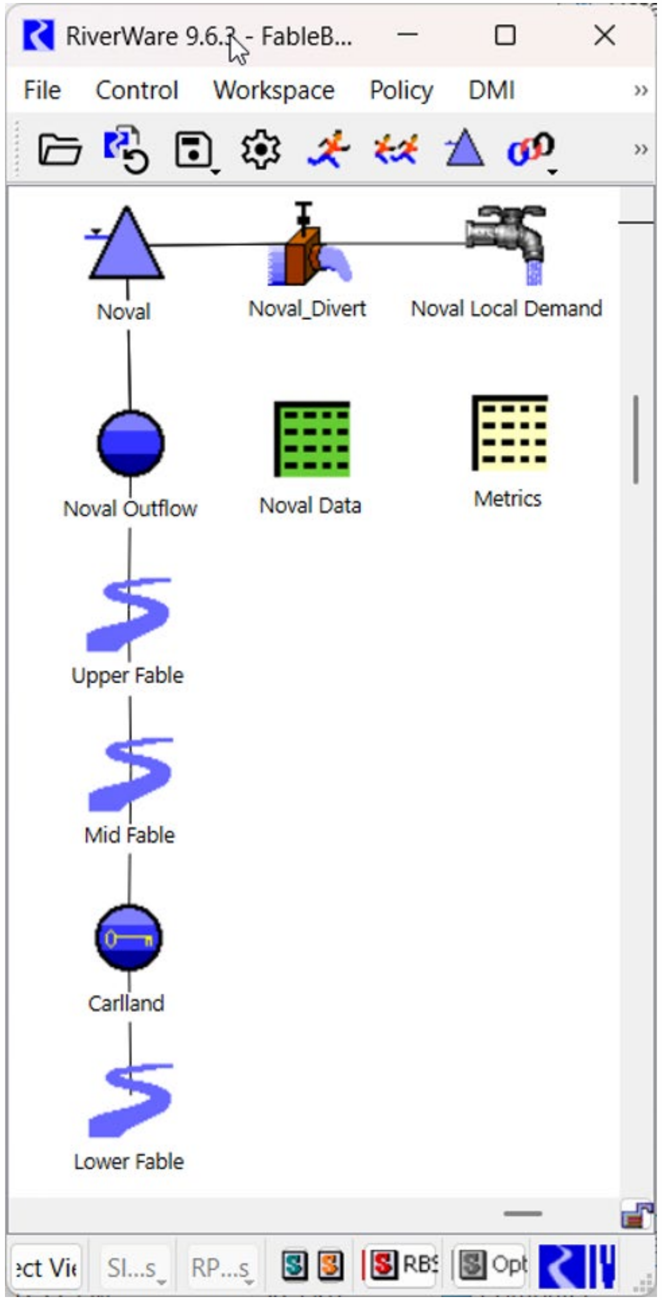


Possible Extensions

- Automate curves for wet, average, dry years
- Use a forecast ensemble instead of historical water years
- Use a short-term (10-day) forecast to refine the near-term
- “Optimize” hydropower given forecast and prices

USACE-SWD

- Demonstration study of a Texas flood control reservoir
- Study system: based on a portion of Trinity River Basin



Can changes to flood control elevations improve water supply objectives without increasing flood **risk**?

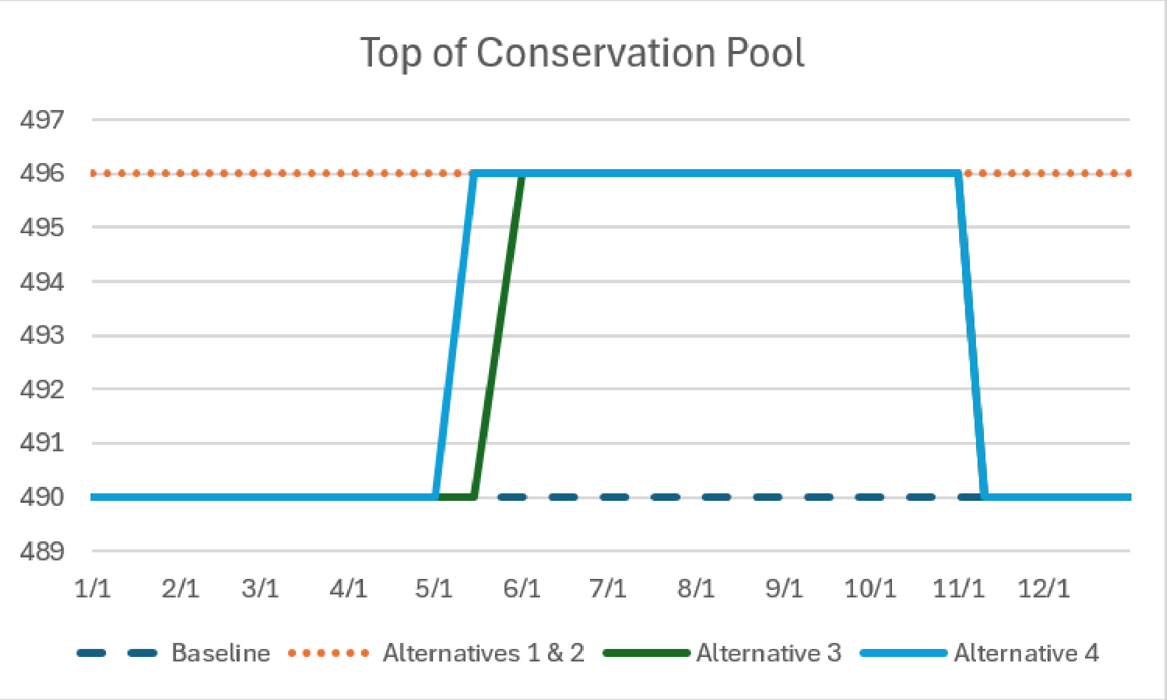
Methodology

- Convert historical inflow record to one-year inflow traces
  76 traces
- MRM with ensemble of inflow traces for
  - Baseline
  - Each alternative
- Compute metrics for each alternative
  - Water supply shortages
  - Excess discharge (flooding) downstream
- Compare across alternatives

Alternative Scenarios

- Alternatives 1 & 2: Constant Top of Conservation Pool
  - Raised 6 ft
  - Alt 2 also raised Top of Flood Pool – no change in results
- Alternatives 3 & 4: Seasonally raise Top of Conservation Pool

	Top of Conservation Pool (ft)			
	Constant		Seasonal	
Date	Baseline	Alt 1 & 2	Alt 3	Alt 4
1/1	490	496	490	490
5/1	490	496	490	490
5/15	490	496	490	496
6/1	490	496	496	496
11/1	490	496	496	496
11/10	490	496	490	490
12/31	490	496	490	490



Results

- Alternatives 1 & 2 (Constant Top of Conservation Pool)
  - Decrease in shortages – occurrences and quantity
  - One additional occurrence of flooding
- Alternatives 3 & 4 (Seasonal Top of Conservation Pool)
  - Smaller reduction in shortages
  - No additional flooding

Metrics	Baseline	Alt. 1	Alt. 2	Alt. 3	Alt. 4
# Traces with Diversion Shortage	35	19	19	31	28
Mean Shortage Vol (acre-ft)	9,650	6,640	6,640	8,800	8,400
# Traces with Excess Discharge (flooding) Downstream	3	4	4	3	3

Next Steps

- Analyze a wider set of possible guide curves
- Use seasonal forecast ensemble instead of historical inflows
- Run MRM with each guide curve
- Compare metrics across alternative guide curves
- Move forward in time with updated forecast: March 1, April 1, May 1…→ Dynamically update the preferred guide curve