Innovative Tools for Water Quality/Quantity Management: New York City's Operations Support Tool

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HEPEX Workshop

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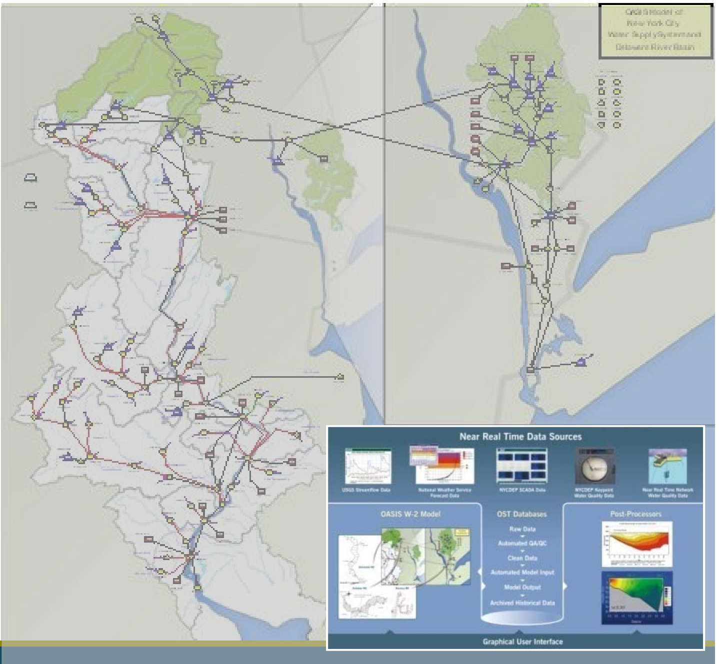

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Environmental Engineers & Scientists

HYDROLOGICS
Advancing the management of water resources

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global science solutions

CAT-330: Catskill Turbidity Control Study
Design Services for the Development of an Operations Support Tool

NYC's Operations Support Tool (OST)
Outline

- NYC Water Supply System
- What is OST?
- How can OST help planning and operations?
- Use of Ensemble Hydrologic Forecasts in OST

New York City Water Supply

- 3 systems – Delaware, Catskill, and Croton
- 19 reservoirs & 3 controlled lakes
- 2,000 square mile watershed in parts of 8 upstate counties
- Serves 9 million people (1/2 of population of New York State)
- Delivers ~ 1.1 billion gal per day
- Unfiltered supply (Cat/Del)

What are NYC's Water Supply Challenges?

Water Quality

- Goal is to meet demand with highest quality water possible
- Maintain government allowed filtration avoidance
- Intermittent turbidity events threaten supply goals and filtration avoidance

NYC's Water Supply Challenges, Continued

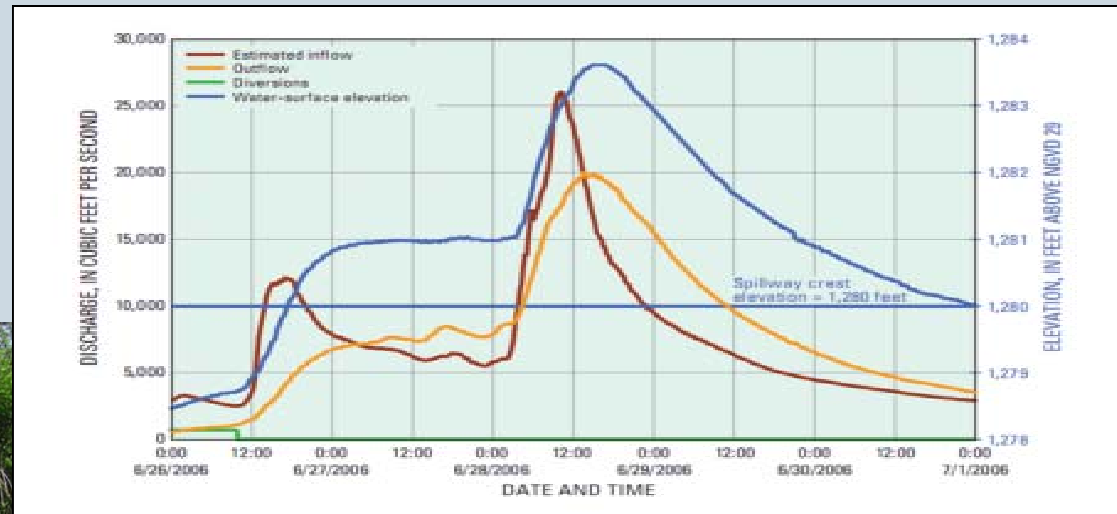
Water Supply Reliability

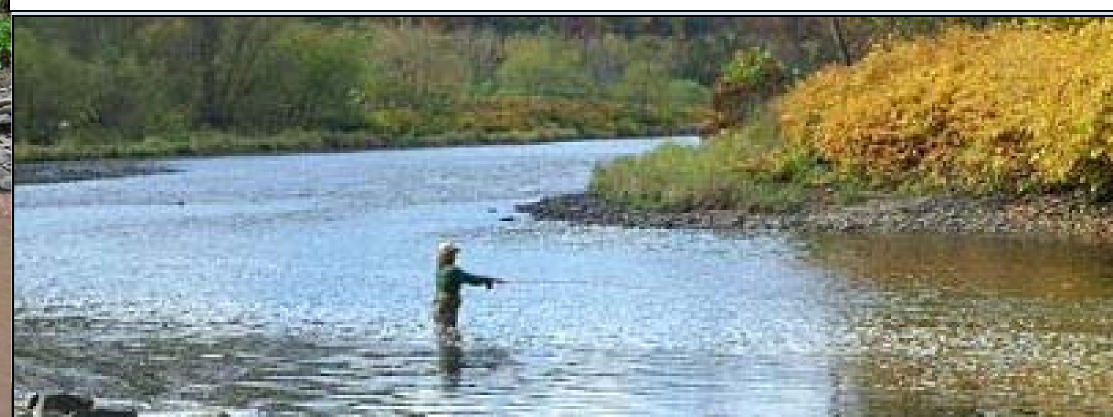
- Threat of multi-year drought
- Potential for outages in critical system components
  - Major aqueduct repairs required in near future
  - New infrastructure connections

NYC’s Water Supply Challenges, Continued

Downstream Impacts

- Maintenance of ecological flow requirements and fisheries habitat
- Spill mitigation
- Turbidity control





Managing the Water Resource Challenges

Traditional Approaches

- Water Quality Issues
  - Filtration
  - Add aluminum sulfate for turbidity (discouraged by regulators)
  - Additional infrastructure
- Supply Reliability Issues
  - Find and develop additional supply
  - Reactive consumption restrictions

Planning and Operational Approaches

- NYC system is large and flexible
- Modeling studies suggested creative system/reservoir operations and planning can effectively manage challenges

Examples of Planning and Operations Approaches

Water Quality

- Reducing sub-system diversions during times of impaired water quality
  - How long can other sub-systems meet demand without jeopardizing total system reliability?

Reliability

- Preemptively reduce diversions and/or releases to prepare for forecasted drought
- Estimate if system shutdowns can be safely completed given projected hydrology

Downstream Impacts

- Quantify “excess” water that can be released to promote fisheries habitat

Operations Support Tool (OST) to Support the Planning and Operations Approach

Real Time Decision Support

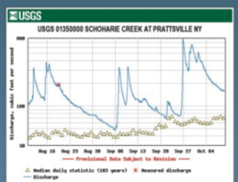
- Ingests real-time data (system conditions) and ensemble hydrologic forecasts
- Uses current conditions, forecasts, and operating rules to quantify risk of system failure

Long-Term Performance Evaluation and Rule Development

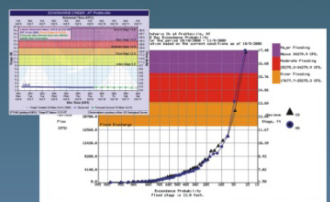
- Uses hindcasts and historical hydrology to test, evaluate, and optimize operating rules

OST Components

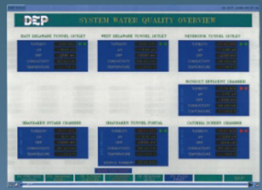
Near Real Time Data Sources



USGS Streamflow Data

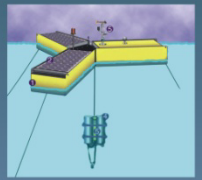


National Weather Service Forecast Data



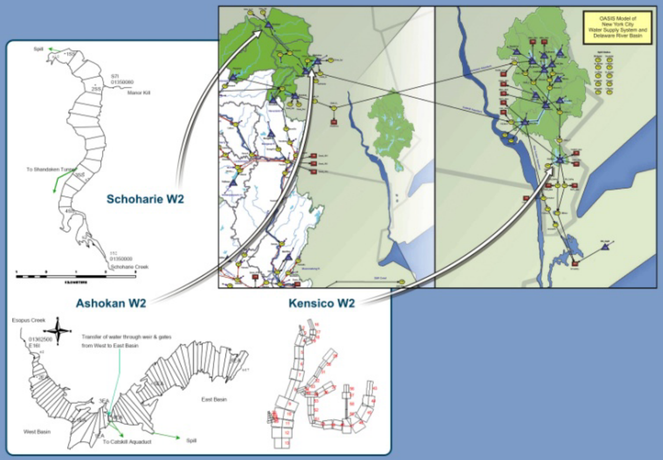
NYCDEP SCADA Data

NYCDEP Keypoint Water Quality Data



Near Real Time Network Water Quality Data

OASIS W-2 Model



OST Databases

Raw Data

Automated QA/QC

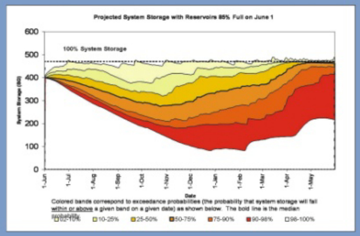
Clean Data

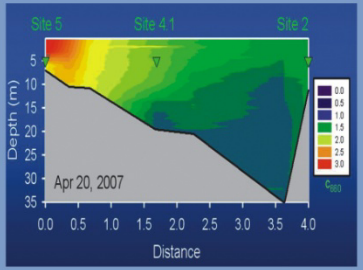
Automated Model Input

Model Output

Archived Historical Data

Post-Processors

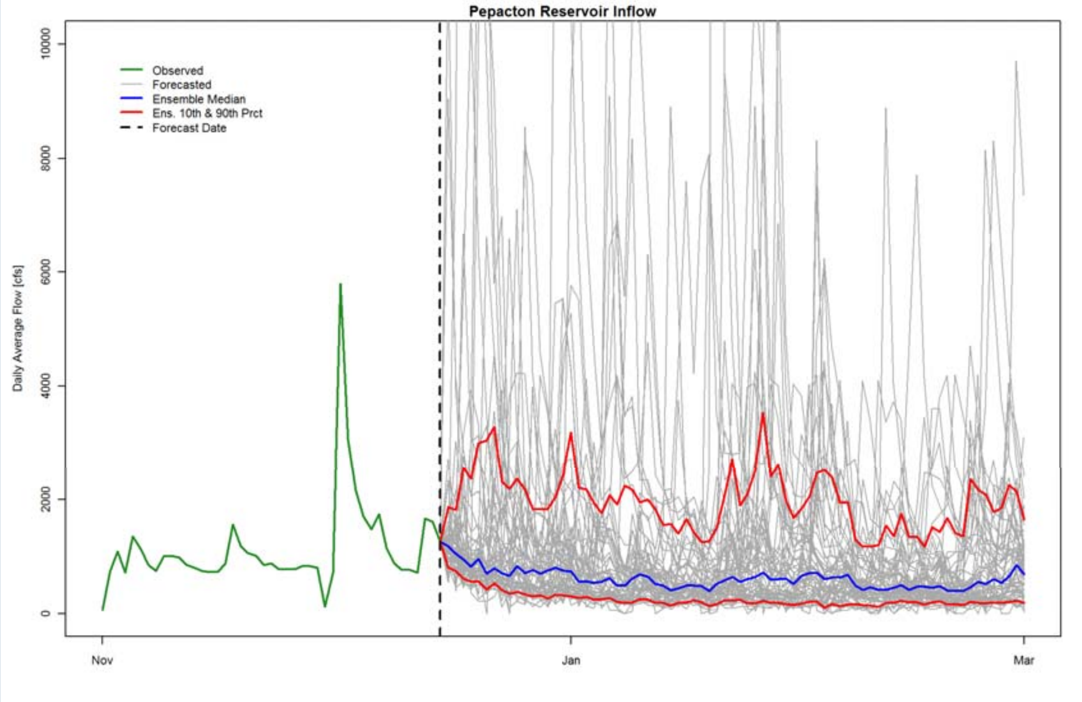




Graphical User Interface

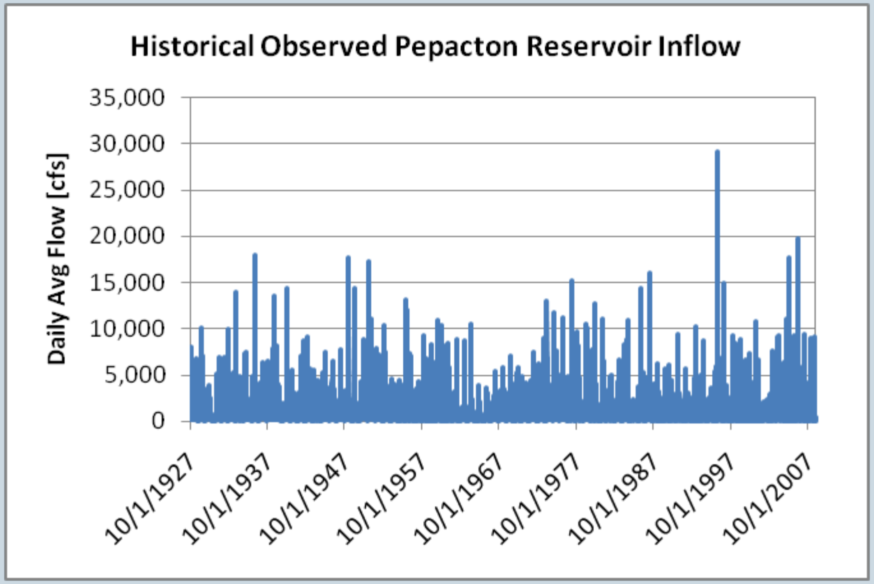
Ensemble Hydrologic Predictions in OST

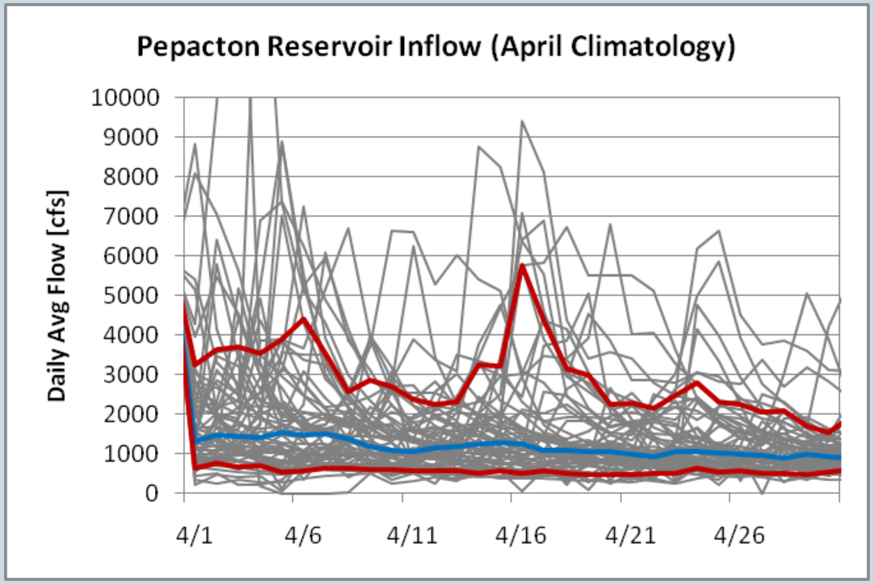
- Ensemble hydrologic predictions are a critical component of OST
- Currently only statistical forecast methods are operational
  - Climatology
  - "Conditioned" climatology (Hirsch/eHirsch methods)



- Hydrologic forecasts will be part of OST in the near future

Statistical Forecasts: Non-Conditioned Climatology





- Most simple "forecast"
- Basically reformat historical hydrology into an ensemble

Statistical Forecasts: Conditioned Climatology
The Hirsch Method*

- Streamflow has a monthly serial correlation
  - "Last month was wet, this month is likely to be wet, too"
- Can take advantage of this using an Autoregressive model

$$X_t = R\,X_{t-1} + e$$ (Autoregressive lag-1 model)

*Hirsch, R. M. (1981). Stochastic Hydrologic Model for Drought Management. *Journal of the Water Resources Planning and Management Division* , 303-313.
Hirsch, R. M. (1979). Synthetic Hydrology and Water Supply Reliability. *Water Resources Research* , 1603-1615.

Statistical Forecasts: Conditioned Climatology Extended/Experimental Hirsch Method (eHirsch)

General Concept:

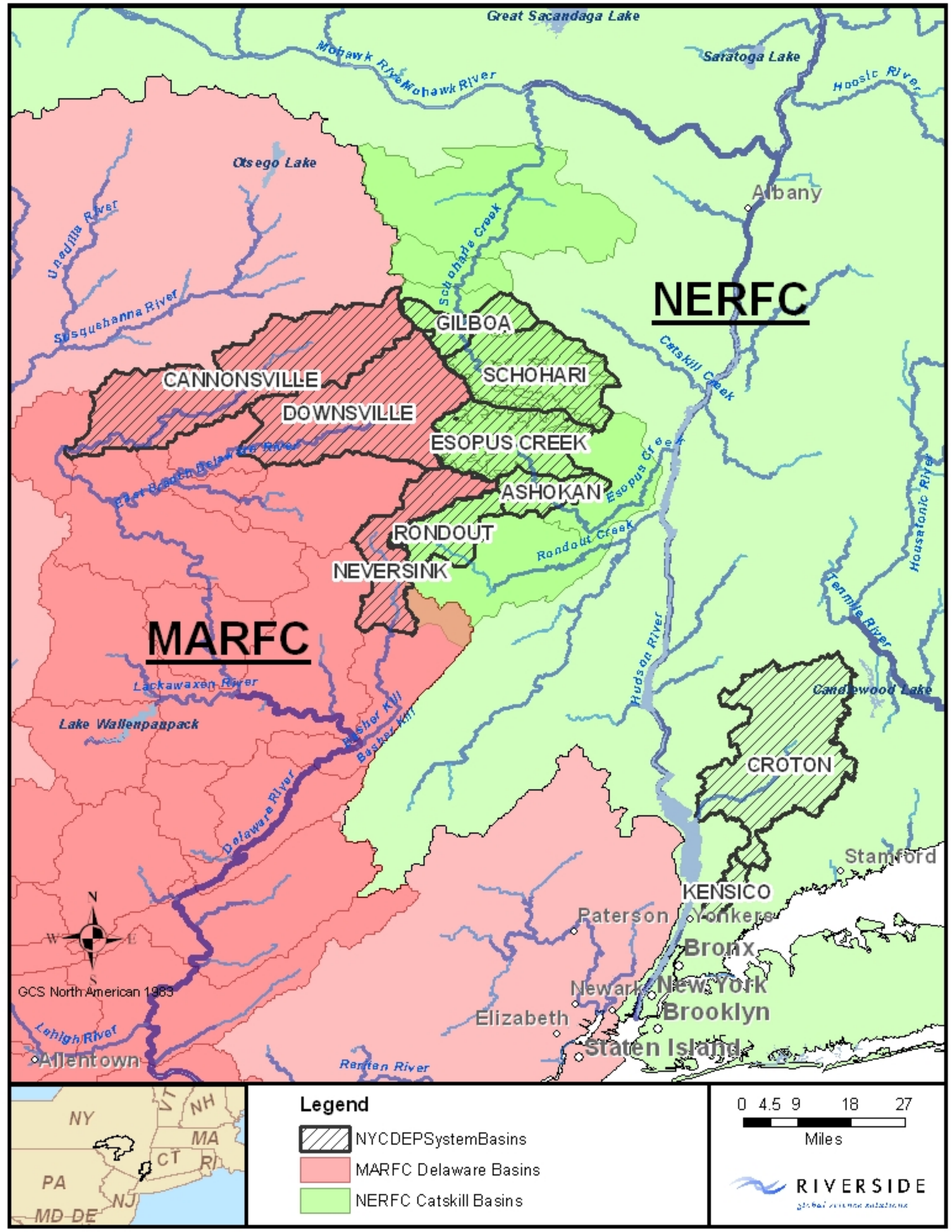
- Hirsch concept can be “extended” to daily time step
- Incorporate recent flow observations
    - Improve short-term skill

General Formulation:

- Compute ensemble traces for a future period based on
    - Recently observed flows preceding the forecast day (‘assimilation period’)
    - The historical correlation of flows during the assimilation and forecast periods

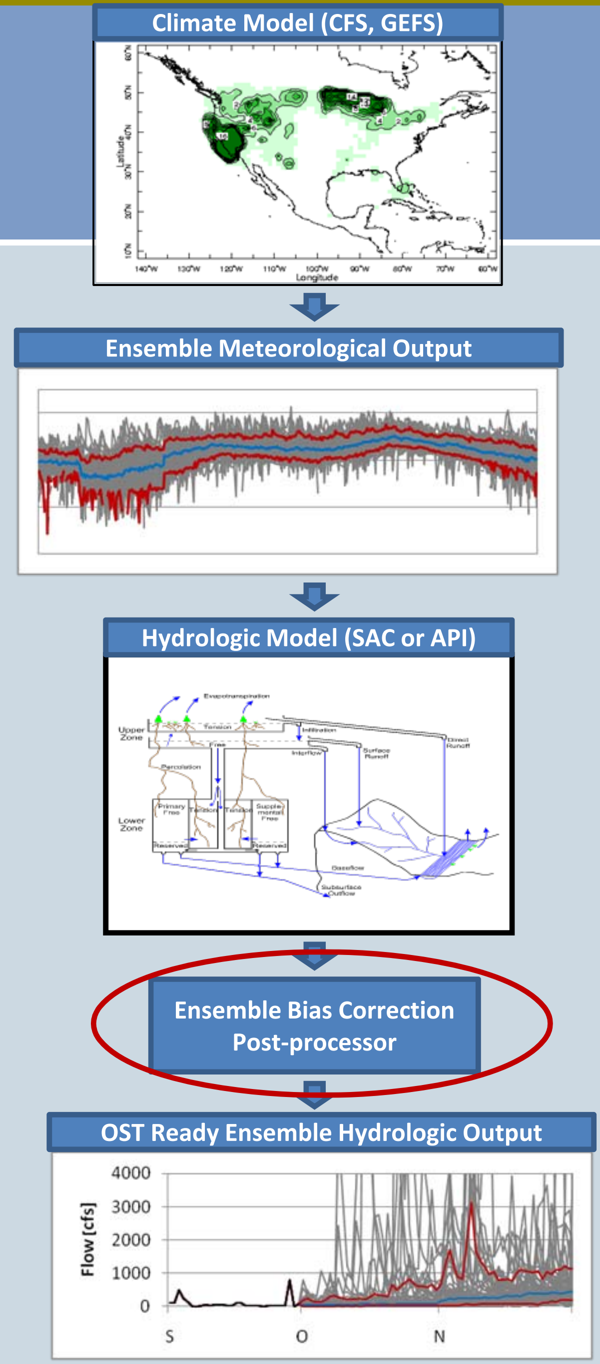
Hydrologic Forecasts

- Streamflow forecasts provided by two National Weather Service (NWS) offices
  - Middle Atlantic River Forecast Center (MARFC)
  - Northeast River Forecast Center (NERFC)
- NYCDEP has contributed $1M to accelerate NWS development



Future Hydrologic Forecasts for OST

- Climate & meteorological models provide ensemble output
- Met outputs fed into hydrologic model
  - SAC, API
- Raw hydrologic ensembles bias corrected and fed into OST
- Should provide further gains in short term (days to month) skill



Summary

- NYC has a complex system with many operation challenges
- Substantial system flexibility allows for creative operations and planning to manage many challenges
- OST provides operators with a tool to quantitatively and robustly evaluate and develop operating rules/decisions
- Ensemble hydrologic predictions are a critical component of OST

Thanks!

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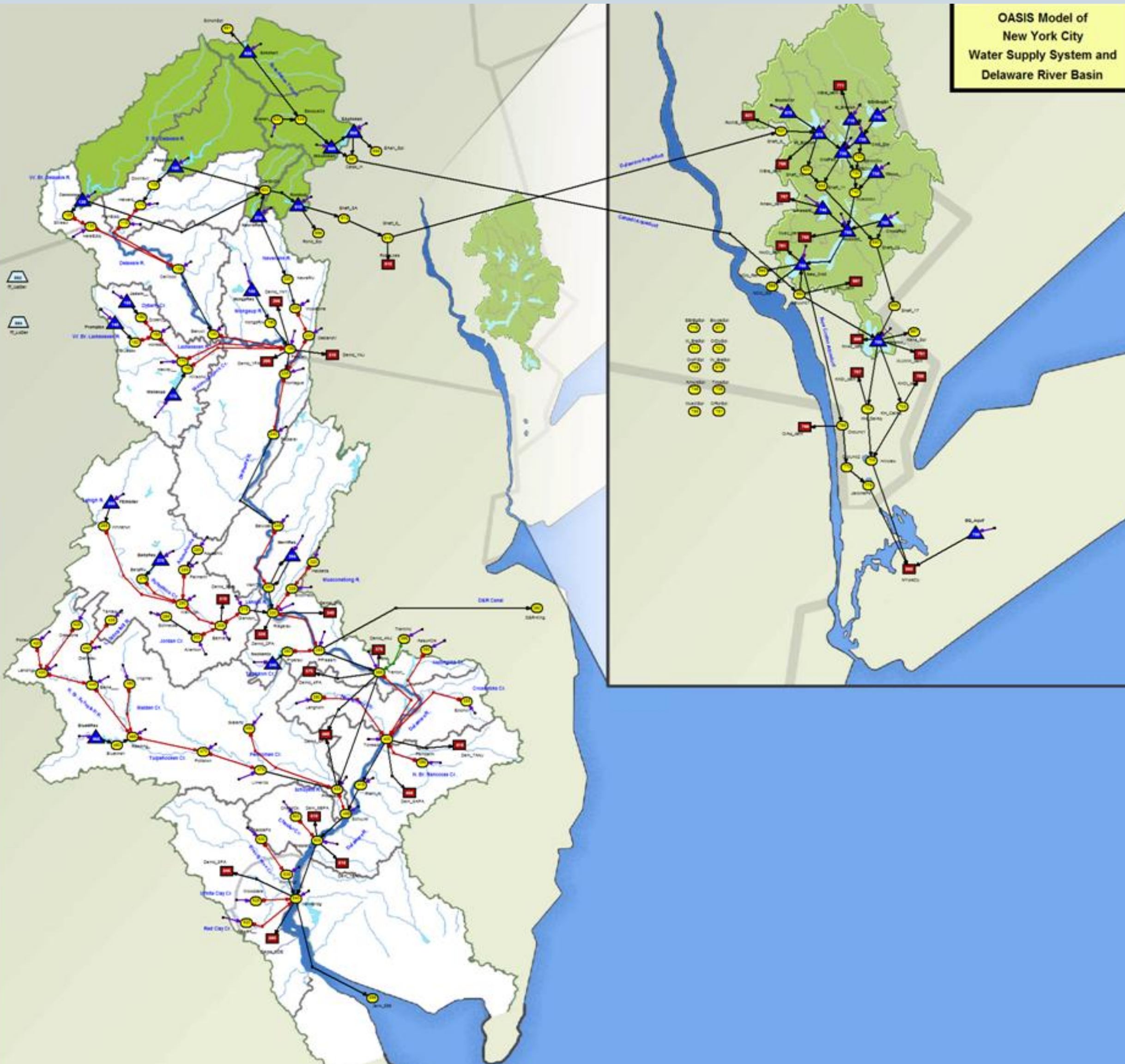
ADDITIONAL MATERIAL

How will the OST help Operations?

- Quantify the performance of alternative operations
- Provide robust assessment of:
  - Expected inflows
  - Diversion needs
  - Release requirements
  - Storage levels
  - Drought risk
  - Water quality conditions
- Support operating decisions that meet water quality and environmental objectives:
  - Maximize additional benefits while maintaining water supply reliability
  - More robust water quality-based operation

- **DOES NOT** tell operators what to do
- **DOES** help operators examine how they can best meet multiple objectives
- **DOES** provide quantitative basis for decision-making

Operations Support Tool: Underlying Models OASIS-W2 Linked Modeling Framework



- OST builds on the OASIS-W2 model framework developed under Catskill Turbidity Control Study
- **<u>OASIS</u>**: Mass-balance reservoir system operations model (HydroLogics)
- **<u>W2</u>**: 2-D reservoir water quality models (NYCDEP, Upstate Freshwater Institute)
- OASIS simulates operation of the reservoir system using operating rules and linear programming
- Makes decisions every day about how much water to divert and release from each reservoir

OASIS-W2 Model Linkage: Dynamic Feedback Between Operations and Water Quality

What water quality is available for withdrawal?

What is the most reliable way to move water around the system?

CE-QUAL-W2

- Schoharie Reservoir
- Ashokan Reservoir
- Kensico Reservoir

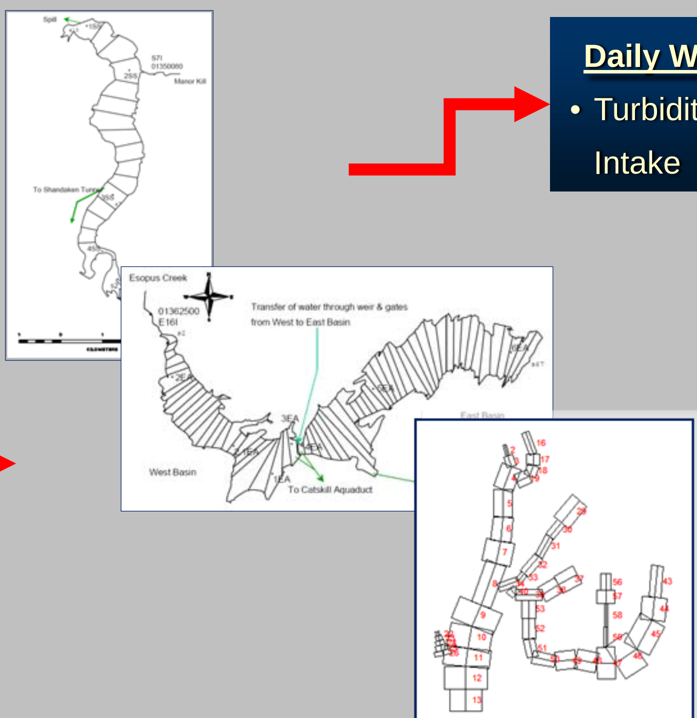
Daily Simulation

1948 – 2008 (61 yrs)

n = 22,189 days

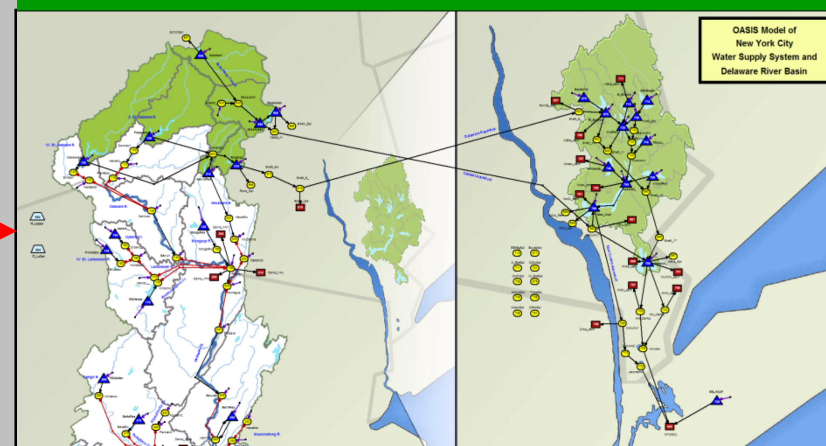
OASIS Model

NYC Reservoir System & Delaware River Basin



Daily Water Quality Info

- Turbidity (& Temp) at the Intake

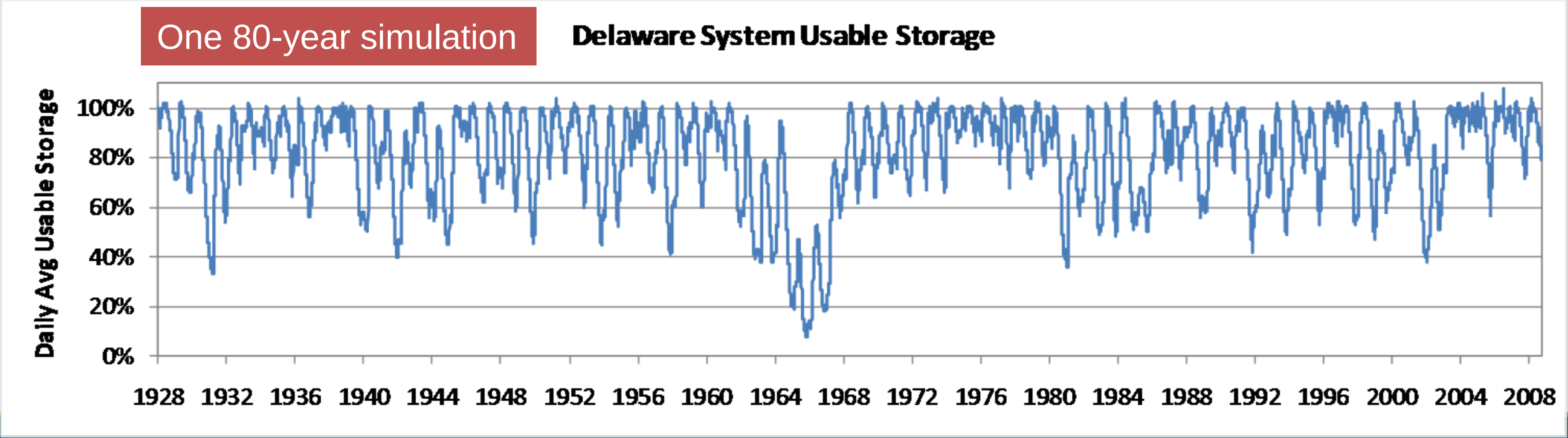


Daily Diversion & Release Decisions

- Diversions from Schoharie & Ashokan Reservoir
- Releases from Ashokan Reservoir (Waste Channel)
- Operation of Ashokan Dividing Weir Gates
- Ashokan turbidity / Kensico alum treatment
- **System-wide diversions and releases**

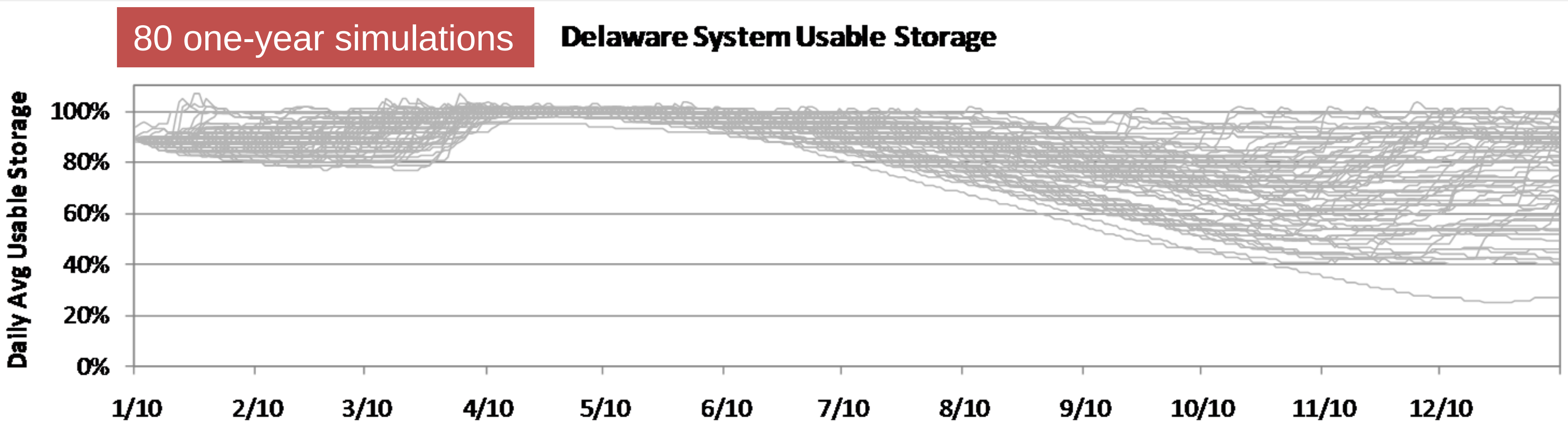
OST in Simulation Mode

- One (typically long) timeseries
  - Typically use historical hydrologic inflow data
- Applications
  - Development/testing of long-term operating rules
    - Catskill turbidity control
    - Delaware Basin release rules
  - Climate change impact assessment
  - Capital planning / alternatives analysis



OST in Position Analysis Mode

- Multiple short simulations covering the same calendar period and starting at the same initial reservoir storage position
- Each simulation uses a different hydrologic inflow sequence (“***trace***”); collectively referred to as an ***ensemble inflow forecast***
- Application: Daily / weekly operations support
  - Evaluate impact of near-term decisions on system performance
    - Short-term (~2 week): water quality, peak flows
    - Mid-term (~1 month – 1 year) : reservoir balancing, release planning, refill probability, outage planning



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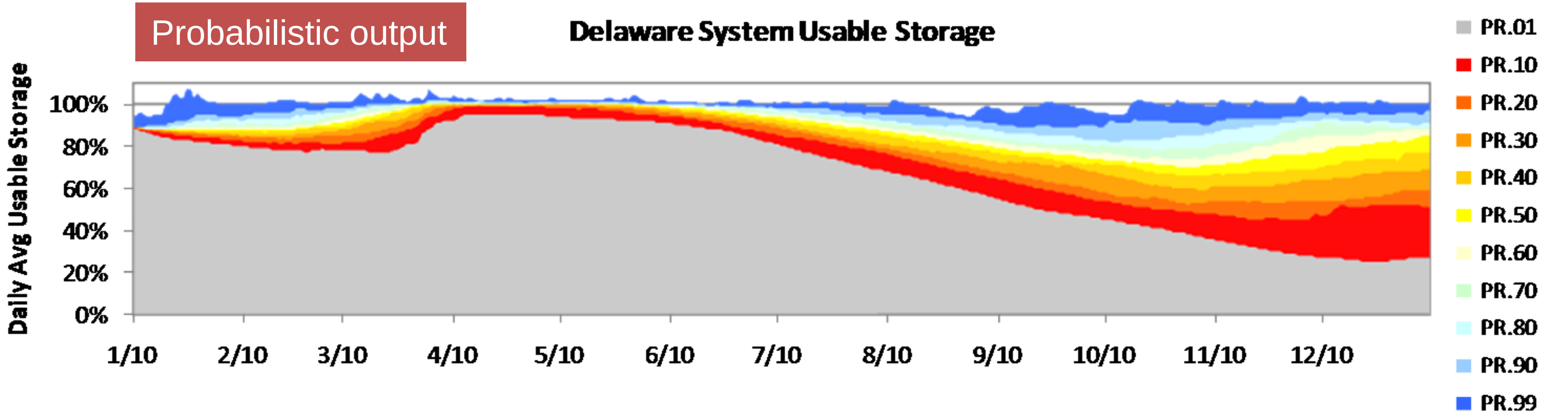
Probabilistic output



How is the OST used for Operations Support?

Today's System

- Reservoir levels
- Infrastructure status
- Water quality

Inflow Forecasts

- Probabilistic forecasts at all system nodes
- Reflect variability in historical record
- Account for today's basin conditions

Operating Rules

- Standard long-term rules
- Modified rules to address today's issues

Future Status / Performance Measures

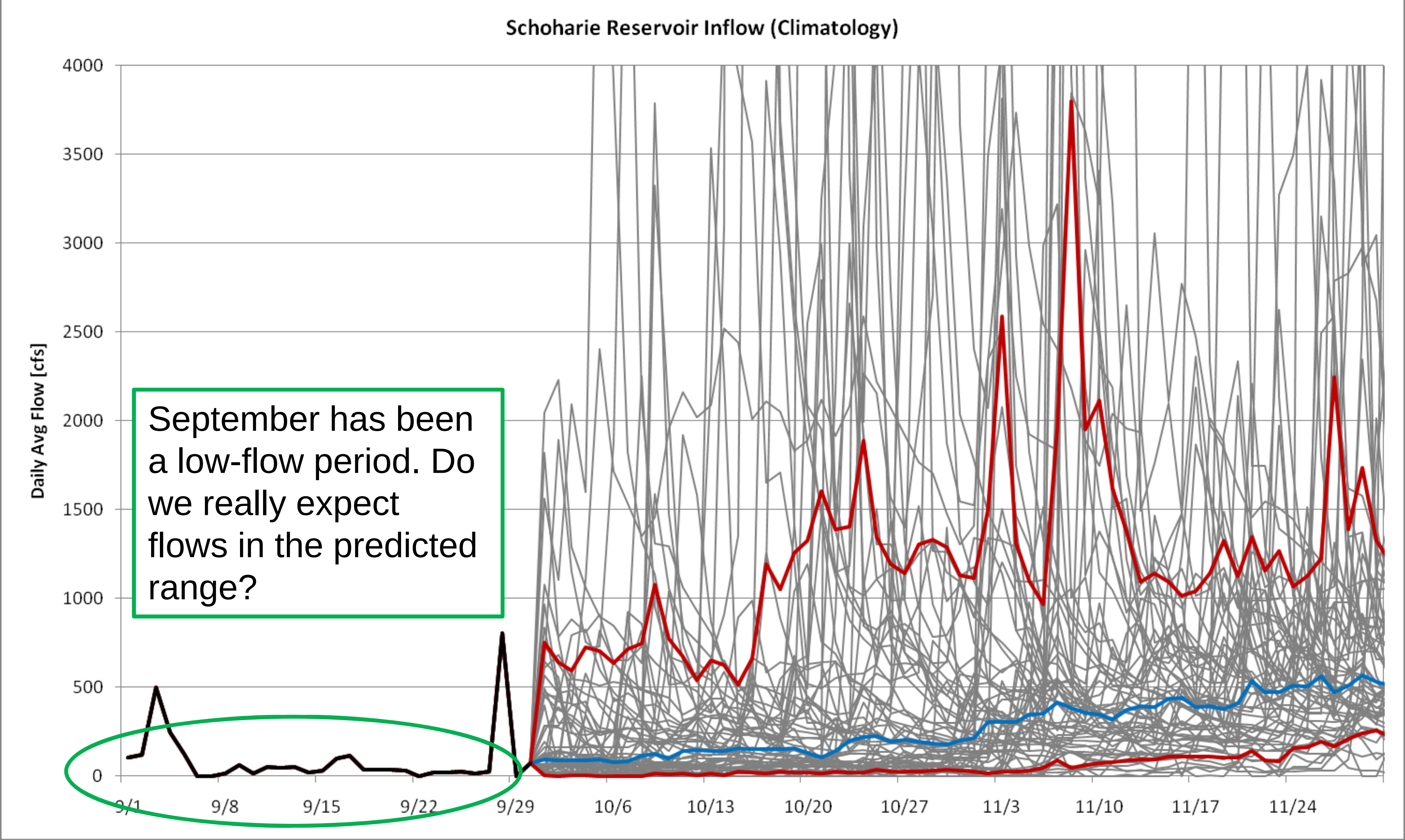
Look ahead over the coming days/weeks /months at the likelihood of:

- System refill
- Available storage for releases
- Drought conditions
- Turbidity levels
- Alum treatment

Today's Decision

- Which operations best balance water supply reliability, water quality, and environmental objectives?
- How much to divert from each reservoir?
- How much to release from each reservoir?

Climatology as a "Forecast"



The Hirsch Method in OST

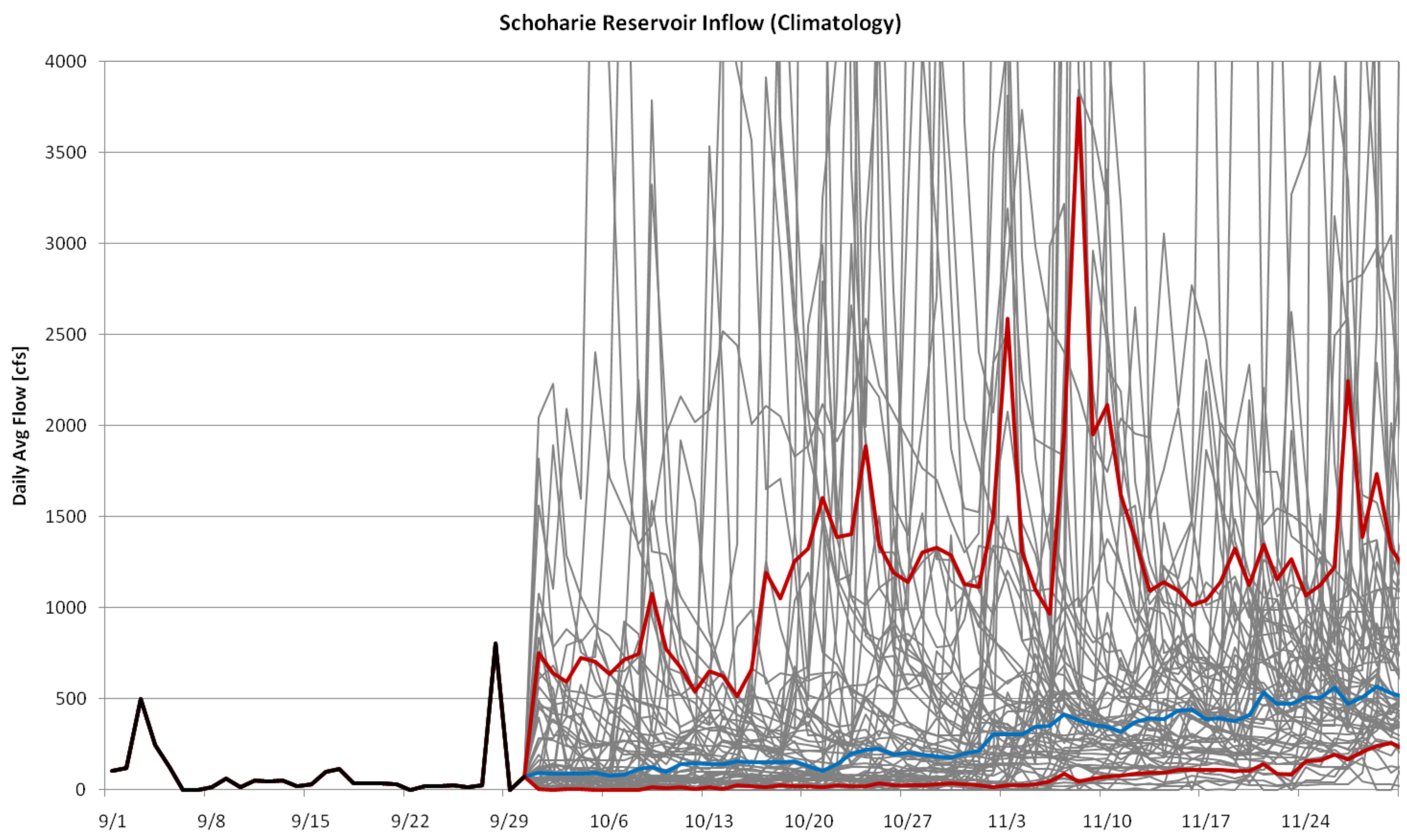
Developing Ensembles:

- Hirsch equation applied to historical observations (1927-2008), errors are computed and stored for each year
  - 81 time series of errors
- In a new forecast, all stored errors are applied individually → ensemble of 81 time series predictions
  - Preserves spatial and temporal nature of historical events
  - Preserves cross correlation in flows between basins

Developing Daily Data:

- OST runs using daily data
- Monthly predictions disaggregated by multiplying by ratio of historical daily flows to historical monthly average

Comparing Climatology to Hirsch Method: Low Flow Antecedent Conditions



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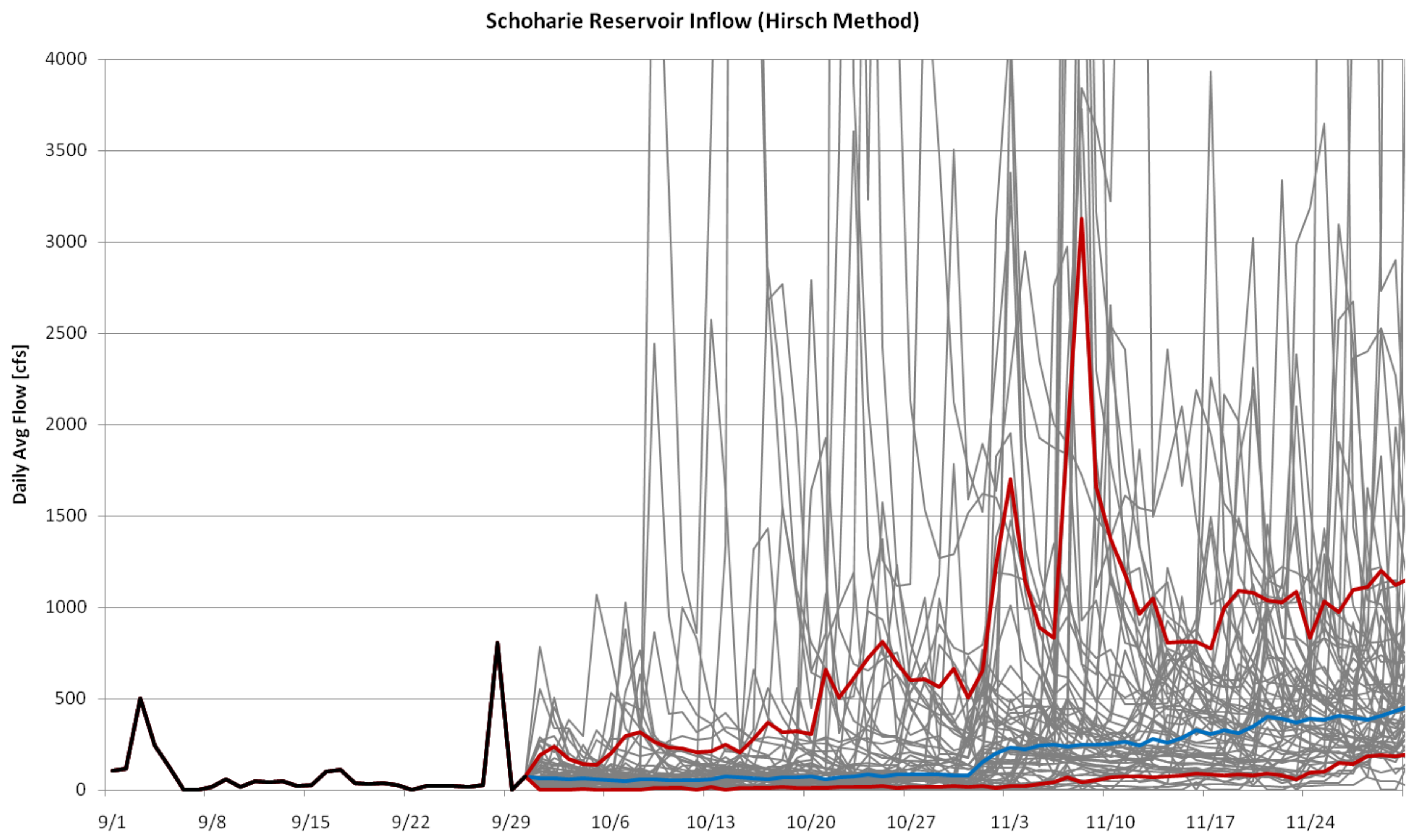
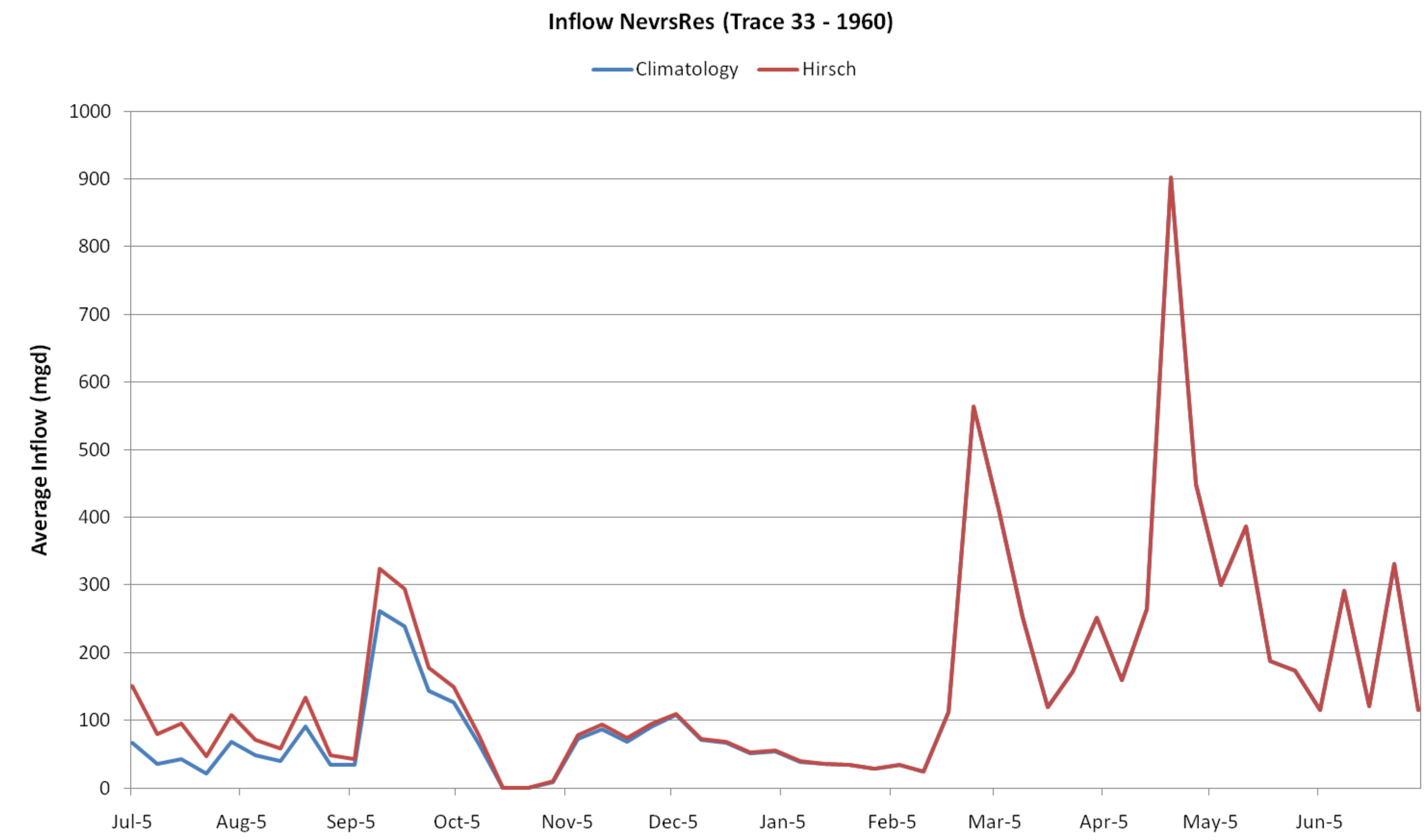


Hirsch Decay to Climatology



eHirsch Formulation (cont.)

$$Z_1 = A \cdot Z_2 + V \qquad \textbf{(Eq. 1)}$$

Z_1 = Flows to be forecasted

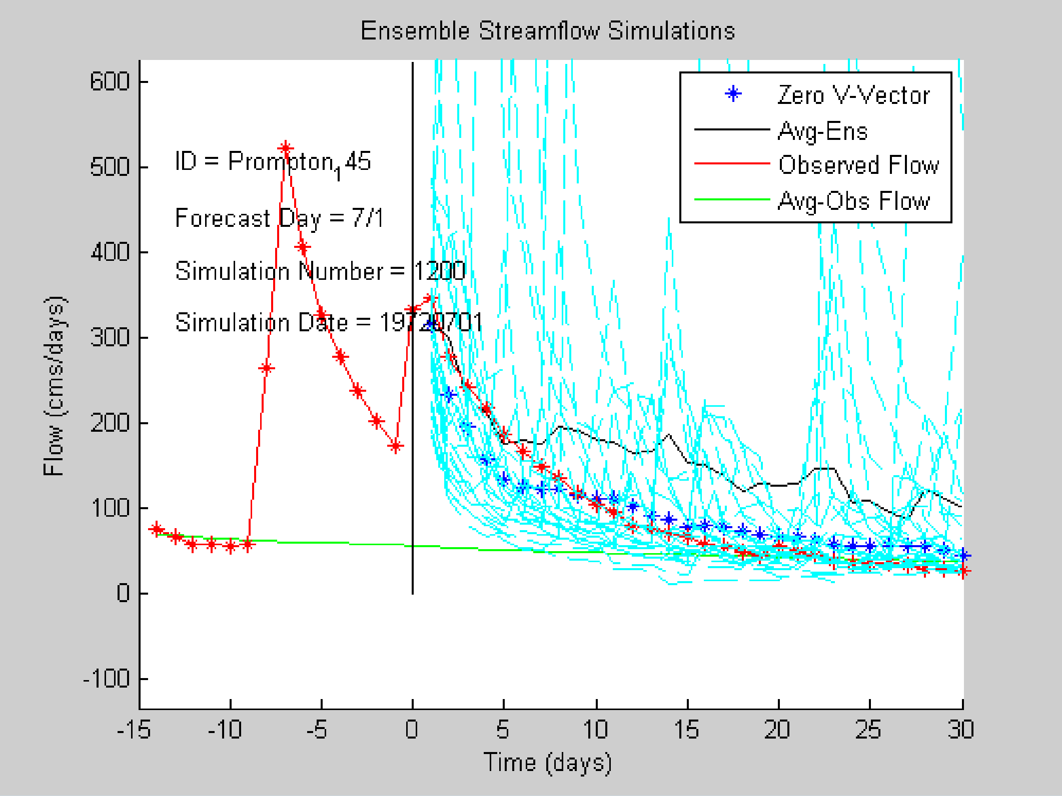
Z_2 = Flows recently observed in the assimilation period

A = Matrix correlating historical flows in the assimilation period to historical flows in the forecast period (‘A-matrix’)

V = Vector of errors when the method is applied to the historical data. One V-vector is required for each day of the year.

eHirsch Formulation (cont.)

- $A \cdot Z_1$ computes a ‘baseline’/’Zero-V’ forecast
- Adding V to the baseline
  - Adds the historically observed variability
  - Generates one forecast trace for each historical year analyzed
  - Thus creates the ensemble forecast



eHirsch Formulation (cont.)

- Transformations
  - Required to
    - Obtain normal distribution of errors
    - Produce more reliable results
  - Thus, Equation 1 is solved in 'z-space'
  - All flow data are transformed to z-space using
    - An empirical Cumulative Distribution Function (CDF)
    - A Normal Quantile Transformation (NQT)