



Using Hydrologic Forecasts for Dynamic Management of NYC's Reservoir Releases for the Delaware River Basin

W. Josh Weiss¹; Luke Wang¹; Paul Rush²; Thomas Murphy²

¹Hazen and Sawyer, P.C.; jweiss@hazenandsawyer.com

²New York City Department of Environmental Protection

93rd American Meteorological Society Annual Meeting
Austin, TX | January 8, 2013

❖ Background

- New York City water supply system
- Delaware River Basin
- NYC's Operations Support Tool (OST)

❖ Use of forecasts to improve Delaware River Basin release management

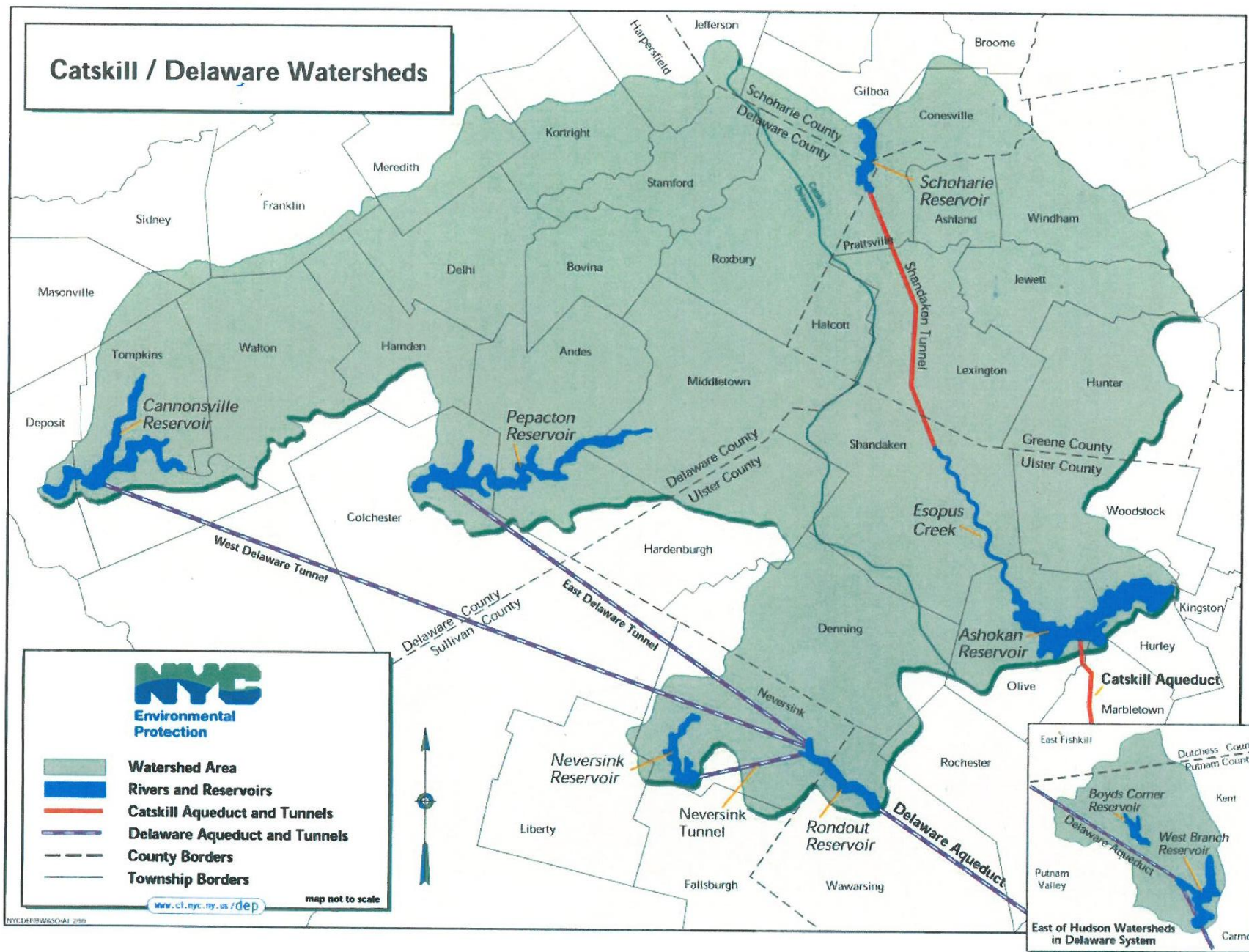
- Forecasted Available Water (FAW) approach to NYC releases
- Enhanced spill mitigation program
- Implementation and performance of forecast-based approach

NYC Water Supply System

- ❖ 3 systems – Delaware, Catskill, and Croton
- ❖ 19 reservoirs & 3 controlled lakes
- ❖ 2,000 mi² watershed in parts of 8 upstate counties
- ❖ Serves 9 million people (1/2 of New York State)
- ❖ Delivers ~1.1 BGD
- ❖ Unfiltered supply (Cat/Del)



Catskill / Delaware Systems



Delaware River Basin

- ❖ Headwaters in the Catskill Mountains
- ❖ Drains to New York State, Pennsylvania, New Jersey, and Delaware
- ❖ Water source for NYC, New Jersey (D&R Canal), Philadelphia
- ❖ Ecological and recreational value



- ❖ 1954 U.S. Supreme Court Decree
- ❖ 1961 Delaware River Basin Compact
- ❖ 1983 “Good Faith” Agreements
- ❖ 2008 Flexible Flow Management Plan



**FOUR STATES SIGN
DELAWARE PACT**

President Joins in Approving
Vast Program for Basin
Backed by Governors

COMMISSION IS SET UP

Developing of River Valley
Will Use, Conserve and
Protect Vital Supply

By **RUSSELL BAKER**
Special to The New York Times.



- ❖ Relied on release schedules based on *annual* estimation of “available water”
- ❖ Expired on May 31, 2011
- ❖ Opportunity to implement better approach to estimating available water, using ensemble hydrologic forecasts

Table 3
Schedule Of Releases (cfs)
With 35 mgd Available

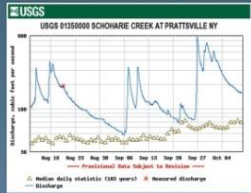
Cannonville Storage Zone	Winter		Spring		Summer			Fall		
	Dec 1 - 31-Mar	Apr 1 - 30-Apr	May 1 - 20-May	May 21 - 31-May	Jun 1 - 15-Jun	Jun 16 - 30-Jun	Jul 1 - 31-Aug	Sep 1 - 15-Sep	Sep 16 - 30-Sep	Oct 1 - 30-Nov
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	250	*	*	*	*	*	350	300	275	250
L1-c	110	110	200	250	275	275	275	275	140	110
L2	80	80	190	240	260	260	260	260	115	80
L3	70	70	100	100	175	175	175	95	95	70
L4	55	55	75	75	130	130	130	55	55	60
L5	50	50	50	50	120	120	120	50	50	50

Pepacton Storage Zone	Winter		Spring		Summer			Fall		
	Dec 1 - 31-Mar	Apr 1 - 30-Apr	May 1 - 20-May	May 21 - 31-May	Jun 1 - 15-Jun	Jun 16 - 30-Jun	Jul 1 - 31-Aug	Sep 1 - 15-Sep	Sep 16 - 30-Sep	Oct 1 - 30-Nov
L1-a	700	700	*	*	*	700	700	700	700	700
L1-b	185	*	*	*	*	*	250	200	200	185
L1-c	85	85	110	130	150	150	150	150	100	85
L2	65	65	100	125	140	140	140	140	85	60
L3	55	55	80	80	100	100	100	55	55	55
L4	45	45	50	50	85	85	85	40	40	40
L5	40	40	40	40	80	80	80	30	30	30

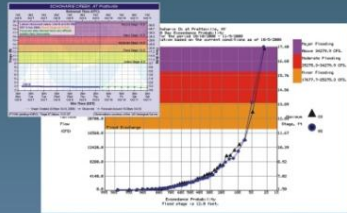
Neversink Storage Zone	Winter		Spring		Summer			Fall		
	Dec 1 - 31-Mar	Apr 1 - 30-Apr	May 1 - 20-May	May 21 - 31-May	Jun 1 - 15-Jun	Jun 16 - 30-Jun	Jul 1 - 31-Aug	Sep 1 - 15-Sep	Sep 16 - 30-Sep	Oct 1 - 30-Nov
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	100	*	*	*	*	*	125	125	85	95
L1-c	65	65	85	100	110	110	110	110	75	60
L2	45	45	75	90	100	100	100	100	70	45
L3	40	40	50	50	75	75	75	40	40	40
L4	35	35	40	40	60	60	60	30	30	30
L5	30	30	30	30	55	55	55	25	25	25

* Storage zone does not apply during this period. Releases will be made in accordance with zone L1-c.

Near Real Time Data Sources



USGS Streamflow Data



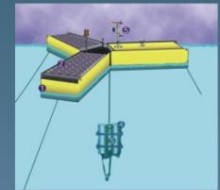
National Weather Service Forecast Data



NYCDEP SCADA Data

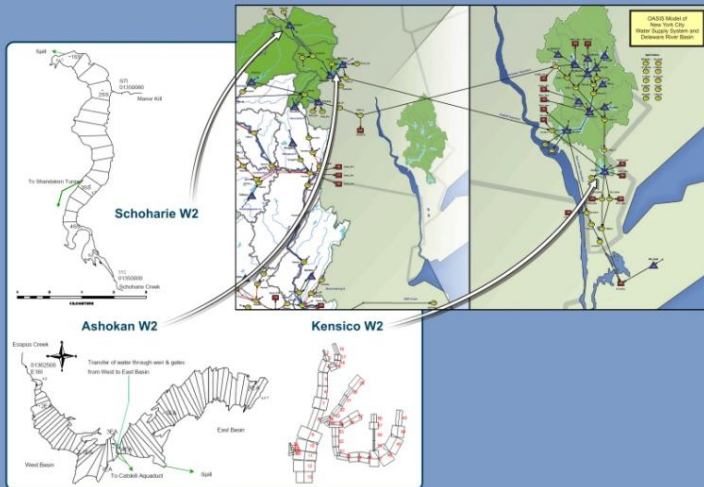


NYCDEP Keypoint Water Quality Data

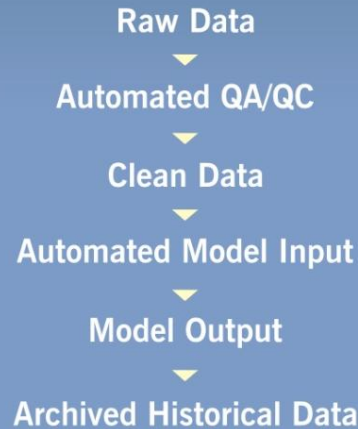


Near Real Time Network Water Quality Data

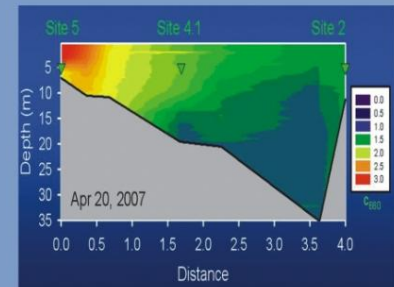
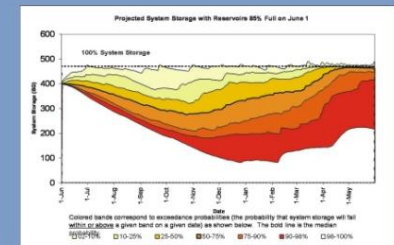
OASIS W-2 Model



OST Databases

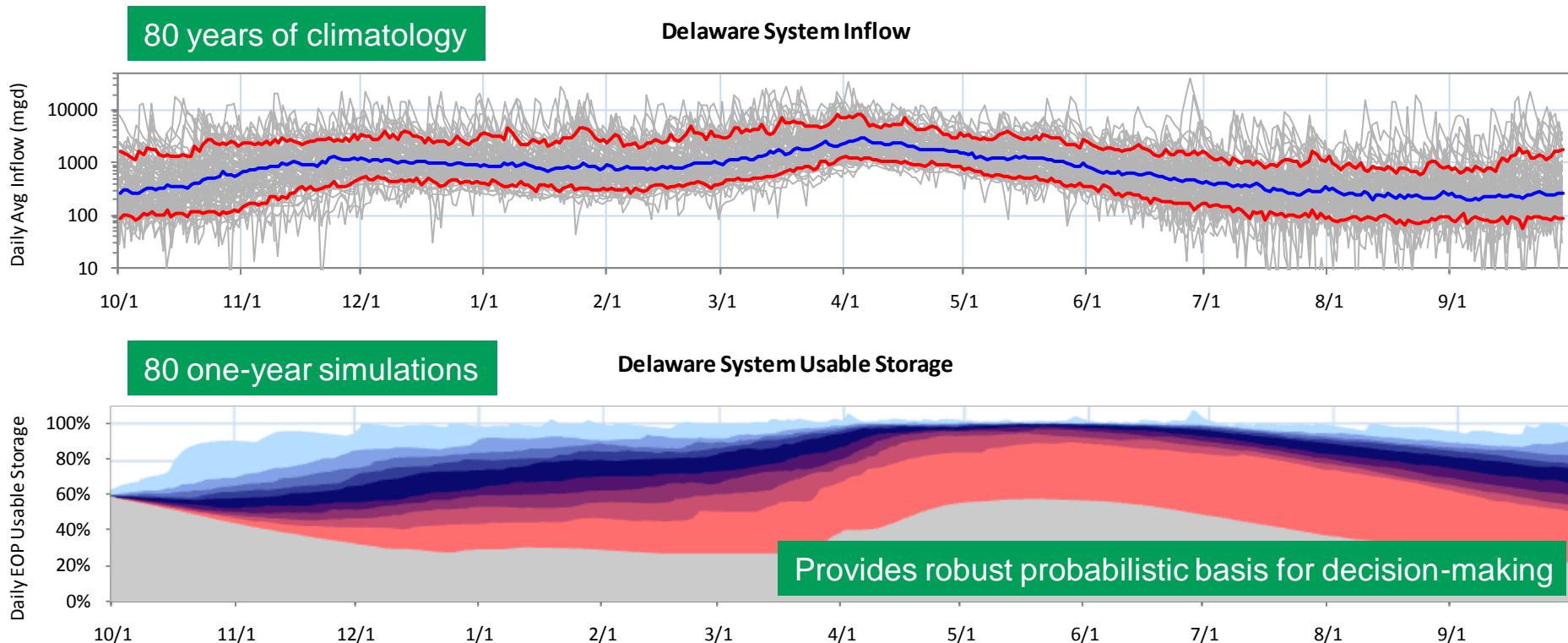


Post-Processors



Graphical User Interface

- ❖ Ensemble forecasted inflows drive model predictions over the next ~1 year
- ❖ Probabilistic output provides information on the likelihood of system refill to guide operations



OST-FFMP Framework

OST INPUT

Today's Conditions

- Reservoir Levels
- Infrastructure Status
- Water Quality
- Demand Projections

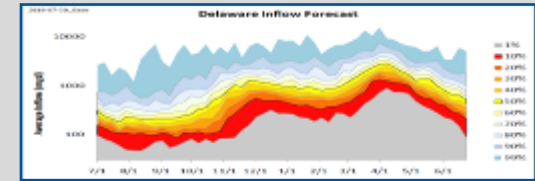


Operating Rules

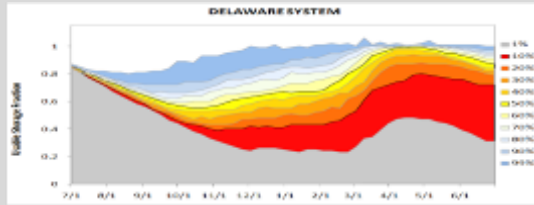
- System Reliability
- Reservoir Balancing
- Drinking Water Quality
- Releases



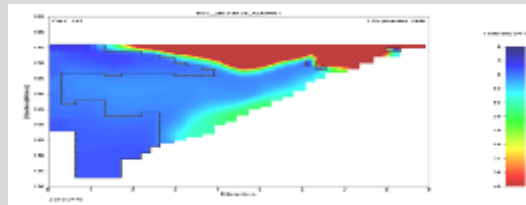
Ensemble Inflow Forecasts



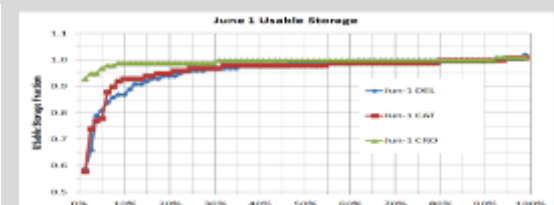
Storage Levels



Water Quality



Refill Probability



Low Water Availability

Probability of Excess Water At Specified Risk Level

High Water Availability

DELAWARE RELEASE DECISIONS

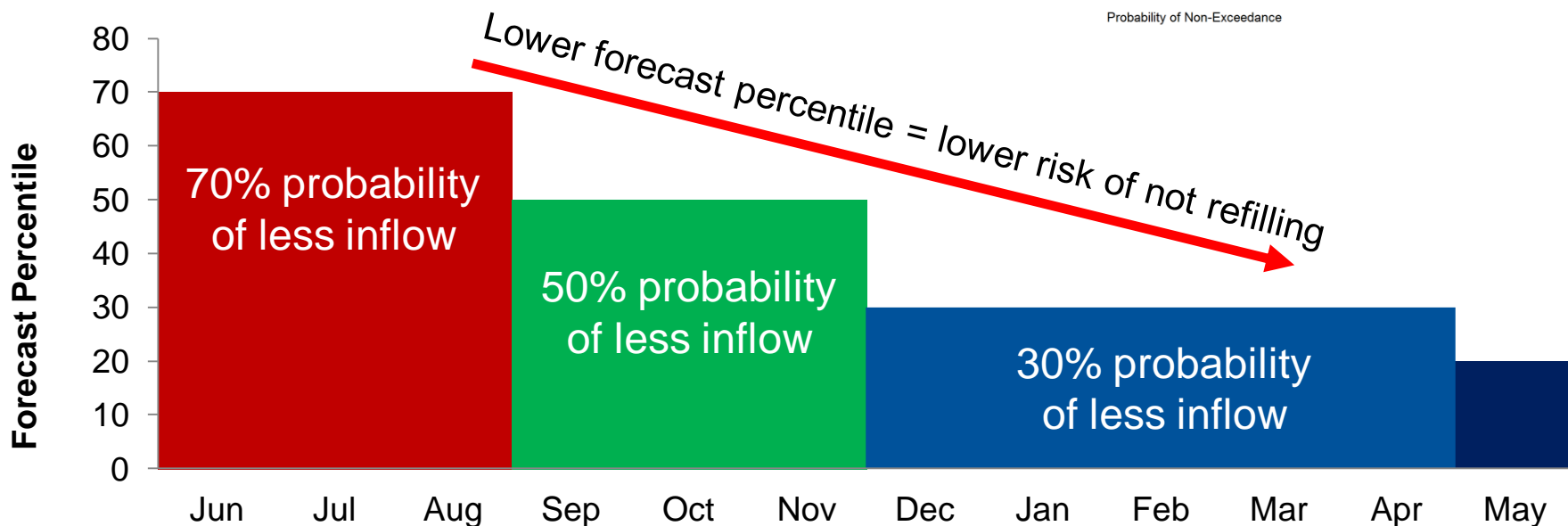
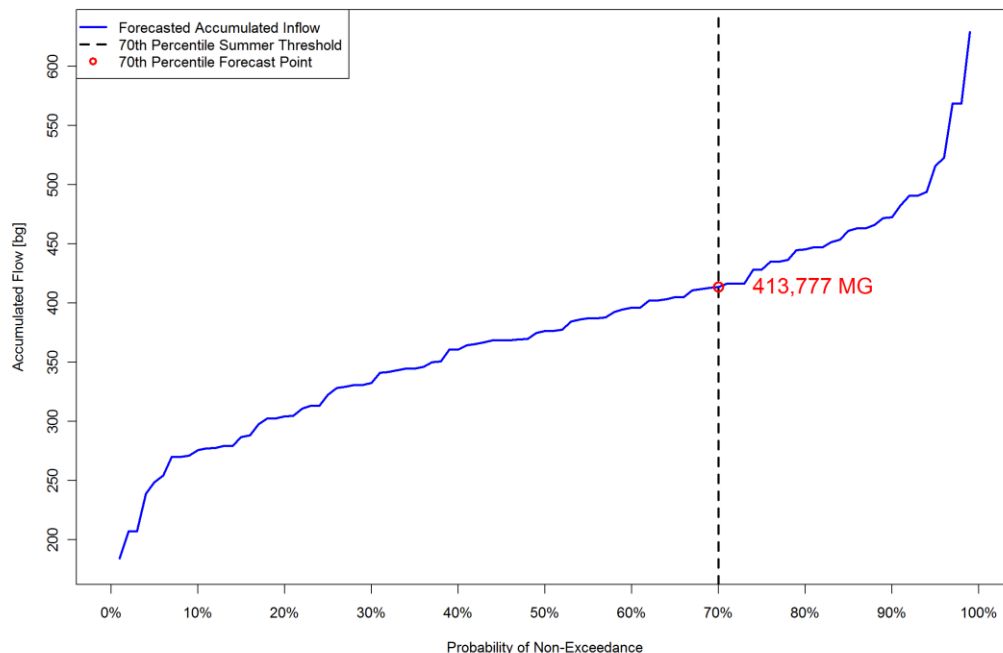
Schedule A	Schedule B	Schedule C	Schedule D	Schedule E	Schedule F	Schedule G																																																																																																																																																																								
<table border="1"> <tr><th colspan="2">Winter</th></tr> <tr><td>Common Use Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>1,000</td></tr> <tr><td>L-1b</td><td>250</td></tr> <tr><td>L-2</td><td>80</td></tr> <tr><td>L-3</td><td>60</td></tr> <tr><td>L-4</td><td>50</td></tr> <tr><td>L-5</td><td>40</td></tr> <tr><td>Preparation Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>180</td></tr> <tr><td>L-1b</td><td>85</td></tr> <tr><td>L-2</td><td>65</td></tr> </table>	Winter		Common Use Storage Zone	Dec 1 - Mar 1	L-1a	1,000	L-1b	250	L-2	80	L-3	60	L-4	50	L-5	40	Preparation Storage Zone	Dec 1 - Mar 1	L-1a	180	L-1b	85	L-2	65	<table border="1"> <tr><th colspan="2">Winter</th></tr> <tr><td>Common Use Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>1,000</td></tr> <tr><td>L-1b</td><td>250</td></tr> <tr><td>L-2</td><td>80</td></tr> <tr><td>L-3</td><td>60</td></tr> <tr><td>L-4</td><td>50</td></tr> <tr><td>L-5</td><td>40</td></tr> <tr><td>Preparation Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>180</td></tr> <tr><td>L-1b</td><td>85</td></tr> <tr><td>L-2</td><td>65</td></tr> </table>	Winter		Common Use Storage Zone	Dec 1 - Mar 1	L-1a	1,000	L-1b	250	L-2	80	L-3	60	L-4	50	L-5	40	Preparation Storage Zone	Dec 1 - Mar 1	L-1a	180	L-1b	85	L-2	65	<table border="1"> <tr><th colspan="2">Winter</th></tr> <tr><td>Common Use Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>1,000</td></tr> <tr><td>L-1b</td><td>250</td></tr> <tr><td>L-2</td><td>80</td></tr> <tr><td>L-3</td><td>60</td></tr> <tr><td>L-4</td><td>50</td></tr> <tr><td>L-5</td><td>40</td></tr> <tr><td>Preparation Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>180</td></tr> <tr><td>L-1b</td><td>85</td></tr> <tr><td>L-2</td><td>65</td></tr> </table>	Winter		Common Use Storage Zone	Dec 1 - Mar 1	L-1a	1,000	L-1b	250	L-2	80	L-3	60	L-4	50	L-5	40	Preparation Storage Zone	Dec 1 - Mar 1	L-1a	180	L-1b	85	L-2	65	<table border="1"> <tr><th colspan="2">Winter</th></tr> <tr><td>Common Use Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>1,000</td></tr> <tr><td>L-1b</td><td>250</td></tr> <tr><td>L-2</td><td>80</td></tr> <tr><td>L-3</td><td>60</td></tr> <tr><td>L-4</td><td>50</td></tr> <tr><td>L-5</td><td>40</td></tr> <tr><td>Preparation Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>180</td></tr> <tr><td>L-1b</td><td>85</td></tr> <tr><td>L-2</td><td>65</td></tr> </table>	Winter		Common Use Storage Zone	Dec 1 - Mar 1	L-1a	1,000	L-1b	250	L-2	80	L-3	60	L-4	50	L-5	40	Preparation Storage Zone	Dec 1 - Mar 1	L-1a	180	L-1b	85	L-2	65	<table border="1"> <tr><th colspan="2">Winter</th></tr> <tr><td>Common Use Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>1,000</td></tr> <tr><td>L-1b</td><td>250</td></tr> <tr><td>L-2</td><td>80</td></tr> <tr><td>L-3</td><td>60</td></tr> <tr><td>L-4</td><td>50</td></tr> <tr><td>L-5</td><td>40</td></tr> <tr><td>Preparation Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>180</td></tr> <tr><td>L-1b</td><td>85</td></tr> <tr><td>L-2</td><td>65</td></tr> </table>	Winter		Common Use Storage Zone	Dec 1 - Mar 1	L-1a	1,000	L-1b	250	L-2	80	L-3	60	L-4	50	L-5	40	Preparation Storage Zone	Dec 1 - Mar 1	L-1a	180	L-1b	85	L-2	65	<table border="1"> <tr><th colspan="2">Winter</th></tr> <tr><td>Common Use Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>1,000</td></tr> <tr><td>L-1b</td><td>250</td></tr> <tr><td>L-2</td><td>80</td></tr> <tr><td>L-3</td><td>60</td></tr> <tr><td>L-4</td><td>50</td></tr> <tr><td>L-5</td><td>40</td></tr> <tr><td>Preparation Storage Zone</td><td>Dec 1 - Mar 1</td></tr> <tr><td>L-1a</td><td>180</td></tr> <tr><td>L-1b</td><td>85</td></tr> <tr><td>L-2</td><td>65</td></tr> </table>	Winter		Common Use Storage Zone	Dec 1 - Mar 1	L-1a	1,000	L-1b	250	L-2	80	L-3	60	L-4	50	L-5	40	Preparation Storage Zone	Dec 1 - Mar 1	L-1a	180	L-1b	85	L-2	65	<table border="1"> <tr><th colspan="2">Spring</th></tr> <tr><td>Common Use Storage Zone</td><td>Apr 1 - Aug 1</td></tr> <tr><td>L-1a</td><td>1,000</td></tr> <tr><td>L-1b</td><td>250</td></tr> <tr><td>L-2</td><td>80</td></tr> <tr><td>L-3</td><td>60</td></tr> <tr><td>L-4</td><td>50</td></tr> <tr><td>L-5</td><td>40</td></tr> <tr><td>Preparation Storage Zone</td><td>Apr 1 - Aug 1</td></tr> <tr><td>L-1a</td><td>180</td></tr> <tr><td>L-1b</td><td>85</td></tr> <tr><td>L-2</td><td>65</td></tr> </table>	Spring		Common Use Storage Zone	Apr 1 - Aug 1	L-1a	1,000	L-1b	250	L-2	80	L-3	60	L-4	50	L-5	40	Preparation Storage Zone	Apr 1 - Aug 1	L-1a	180	L-1b	85	L-2	65
Winter																																																																																																																																																																														
Common Use Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	1,000																																																																																																																																																																													
L-1b	250																																																																																																																																																																													
L-2	80																																																																																																																																																																													
L-3	60																																																																																																																																																																													
L-4	50																																																																																																																																																																													
L-5	40																																																																																																																																																																													
Preparation Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	180																																																																																																																																																																													
L-1b	85																																																																																																																																																																													
L-2	65																																																																																																																																																																													
Winter																																																																																																																																																																														
Common Use Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	1,000																																																																																																																																																																													
L-1b	250																																																																																																																																																																													
L-2	80																																																																																																																																																																													
L-3	60																																																																																																																																																																													
L-4	50																																																																																																																																																																													
L-5	40																																																																																																																																																																													
Preparation Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	180																																																																																																																																																																													
L-1b	85																																																																																																																																																																													
L-2	65																																																																																																																																																																													
Winter																																																																																																																																																																														
Common Use Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	1,000																																																																																																																																																																													
L-1b	250																																																																																																																																																																													
L-2	80																																																																																																																																																																													
L-3	60																																																																																																																																																																													
L-4	50																																																																																																																																																																													
L-5	40																																																																																																																																																																													
Preparation Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	180																																																																																																																																																																													
L-1b	85																																																																																																																																																																													
L-2	65																																																																																																																																																																													
Winter																																																																																																																																																																														
Common Use Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	1,000																																																																																																																																																																													
L-1b	250																																																																																																																																																																													
L-2	80																																																																																																																																																																													
L-3	60																																																																																																																																																																													
L-4	50																																																																																																																																																																													
L-5	40																																																																																																																																																																													
Preparation Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	180																																																																																																																																																																													
L-1b	85																																																																																																																																																																													
L-2	65																																																																																																																																																																													
Winter																																																																																																																																																																														
Common Use Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	1,000																																																																																																																																																																													
L-1b	250																																																																																																																																																																													
L-2	80																																																																																																																																																																													
L-3	60																																																																																																																																																																													
L-4	50																																																																																																																																																																													
L-5	40																																																																																																																																																																													
Preparation Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	180																																																																																																																																																																													
L-1b	85																																																																																																																																																																													
L-2	65																																																																																																																																																																													
Winter																																																																																																																																																																														
Common Use Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	1,000																																																																																																																																																																													
L-1b	250																																																																																																																																																																													
L-2	80																																																																																																																																																																													
L-3	60																																																																																																																																																																													
L-4	50																																																																																																																																																																													
L-5	40																																																																																																																																																																													
Preparation Storage Zone	Dec 1 - Mar 1																																																																																																																																																																													
L-1a	180																																																																																																																																																																													
L-1b	85																																																																																																																																																																													
L-2	65																																																																																																																																																																													
Spring																																																																																																																																																																														
Common Use Storage Zone	Apr 1 - Aug 1																																																																																																																																																																													
L-1a	1,000																																																																																																																																																																													
L-1b	250																																																																																																																																																																													
L-2	80																																																																																																																																																																													
L-3	60																																																																																																																																																																													
L-4	50																																																																																																																																																																													
L-5	40																																																																																																																																																																													
Preparation Storage Zone	Apr 1 - Aug 1																																																																																																																																																																													
L-1a	180																																																																																																																																																																													
L-1b	85																																																																																																																																																																													
L-2	65																																																																																																																																																																													

Forecasted Available Water Balance

Today's Total PCN Storage	→	Current System Status
+ Cumulative PCN Inflows through June 1	→	Probabilistic Streamflow Forecasts
- Cumulative PCN Diversions through June 1	→	Estimated Volume to meet NYC Demand
- June 1 Storage Target	→	100% Usable Storage
<hr/>		
= Cumulative PCN Release Target through June 1	→	Distribute over Number of Days to June 1 and Re-Evaluate Regularly

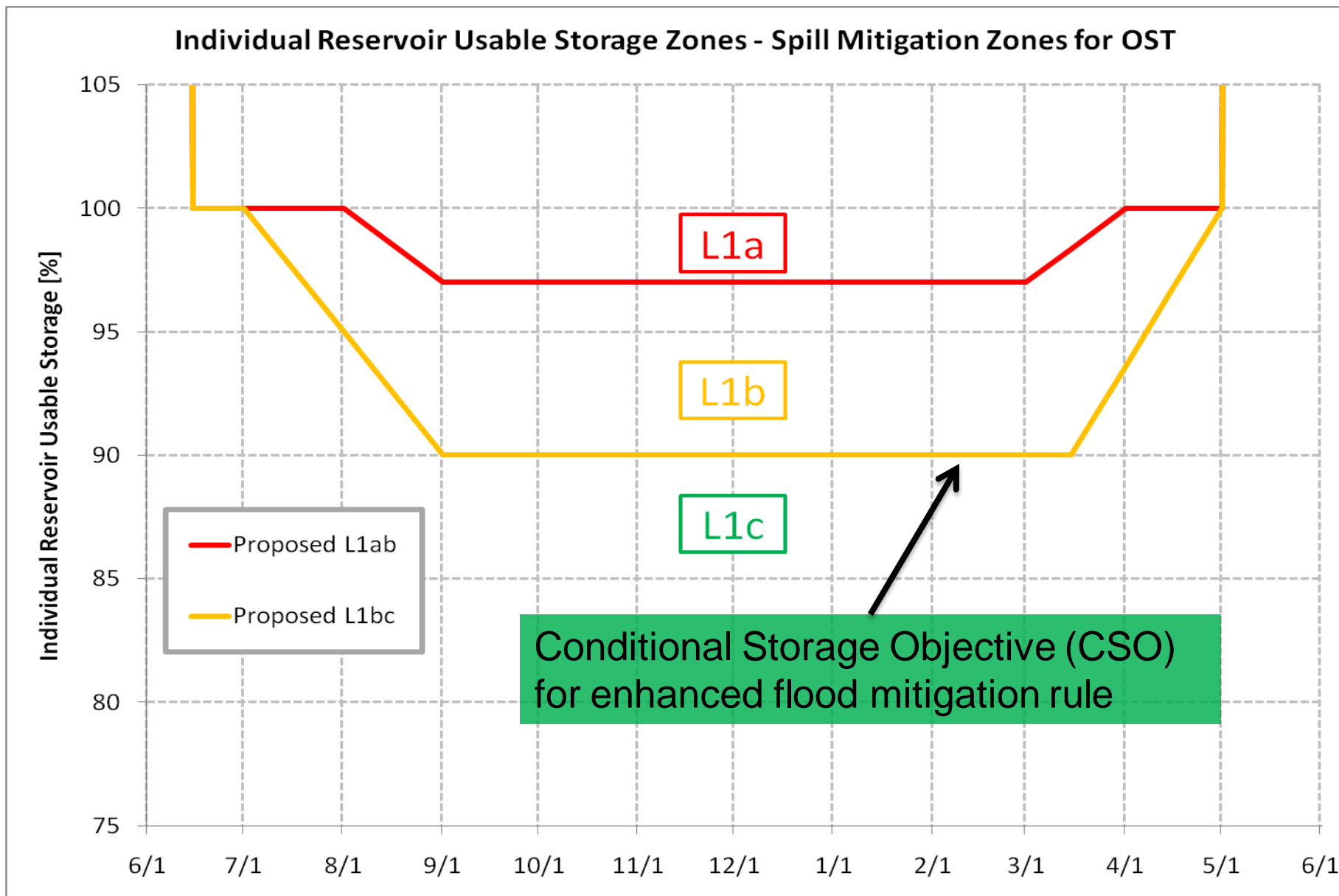
- ❖ Risk represented by forecast probability
- ❖ Transition to more conservative risk when approaching June 1
- ❖ Seasonal risk factor:

Distribution of Forecasted Accumulated PCN Inflow from Aug 1, 2007 - Jun 1, 2008



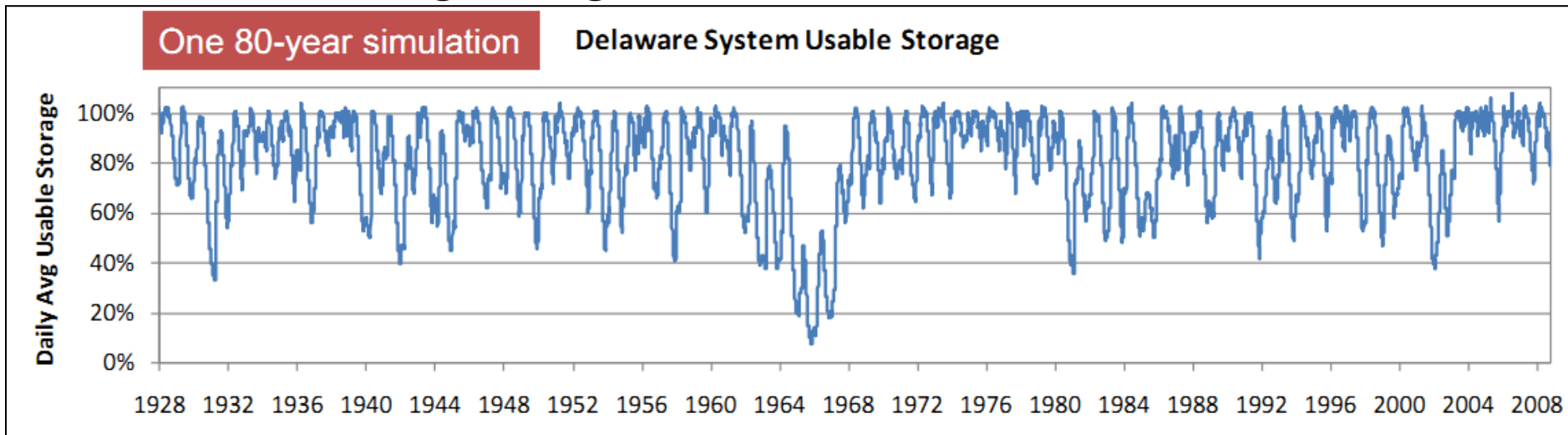
- ❖ Even full reservoirs help reduce downstream flooding
- ❖ Strong downstream pressure to maintain year-round voids in NYC reservoirs
 - Not feasible for water supply reliability
- ❖ When water is available (based on OST predictions):
 - Maintain seasonal storage target to provide spill buffer
 - Monitor short-term (24/48-hr) forecasts for possible proactive releases

Enhanced Flood Mitigation Releases

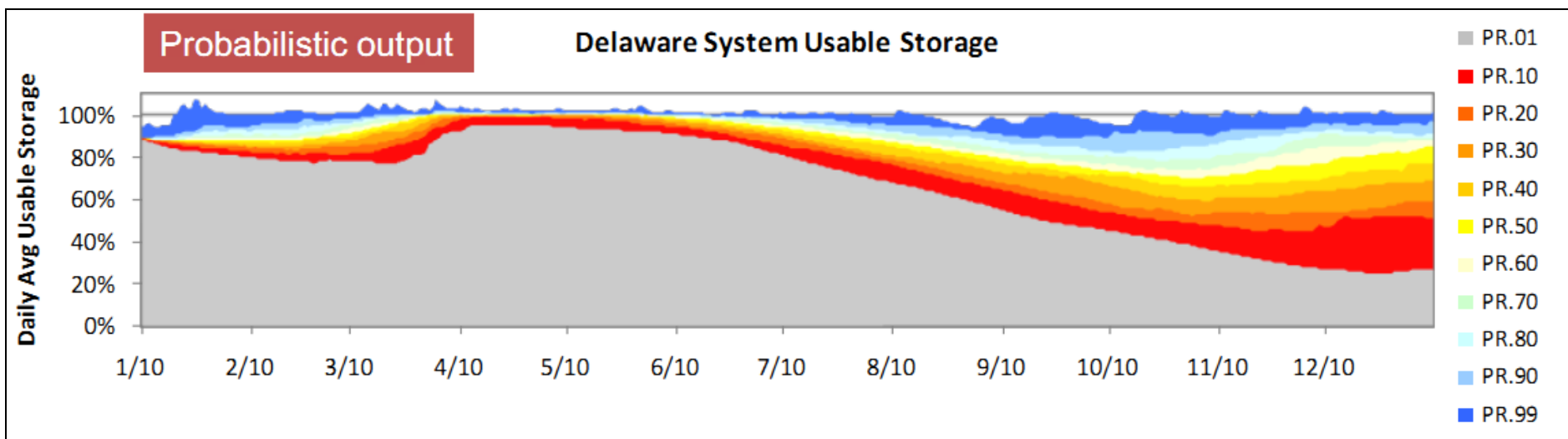


	Today's Total PCN Storage	→	Current System Status
+	Cumulative PCN Inflows over the Next 7 Days	→	Streamflow Forecasts (50 th Percentile)
-	Cumulative PCN Release over the Next 7 Days	→	Based on OST-FFMP Table Selection
-	Cumulative PCN Diversions over the Next 7 Days	→	Estimated Volume to Meet NYC Demand
-	Conditional Storage Objective (CSO)	→	Boundary between L1-b and L1-c Zones
<hr/>			
=	Predicted Storage Surplus Relative to CSO	→	Release Estimated Surplus; Re-Evaluate Daily

❖ Rule testing: long-term simulation mode

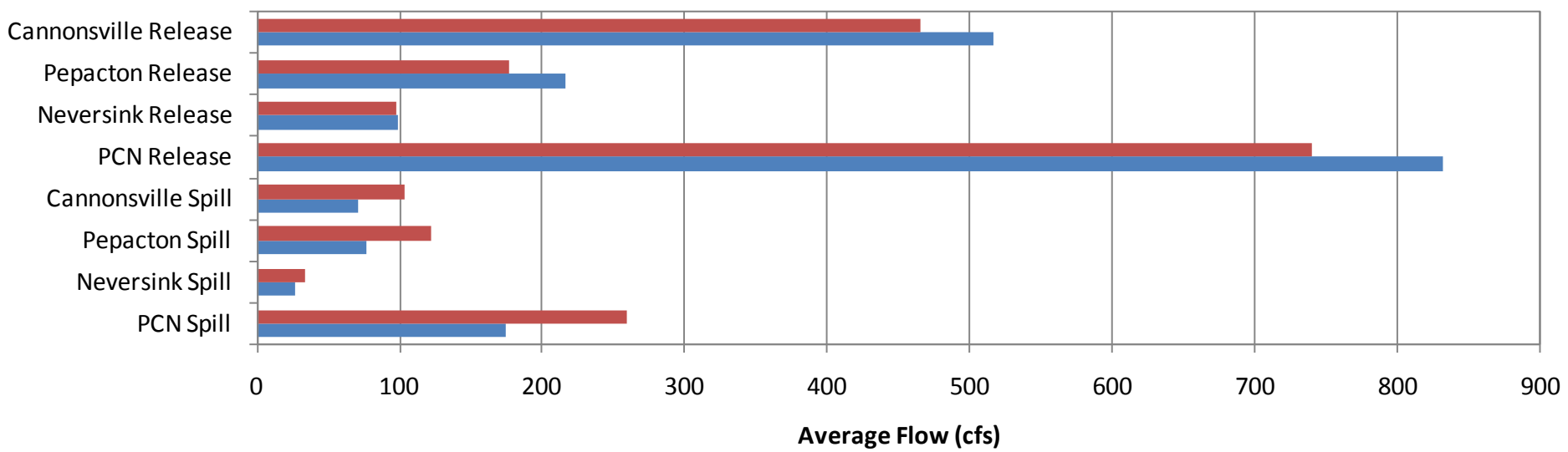


❖ Implementation: real-time position analysis mode

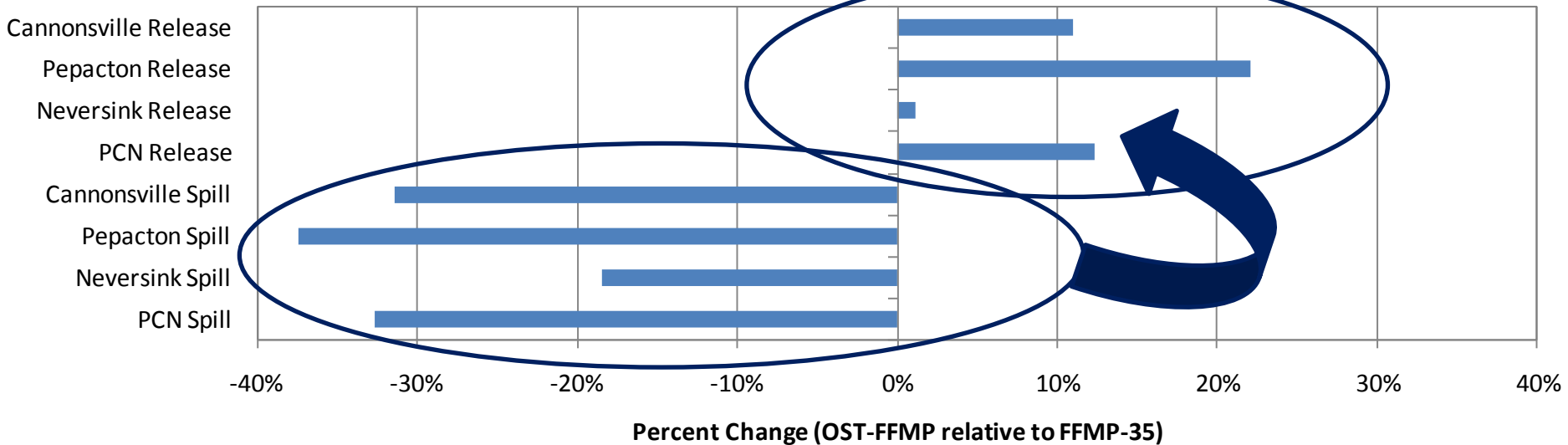


Long-Term Performance Testing (1927-2008)

Average Simulated PCN Release and Spill, OST-FFMP vs FFMP 35 mgd



Percent Change in Average Simulated PCN Release and Spill



- ❖ How to bring stakeholders on board?
- ❖ How to minimize “black box” perceptions?
- ❖ How to ensure transparency while protecting NYC system information?



OST-FFMP Agreement

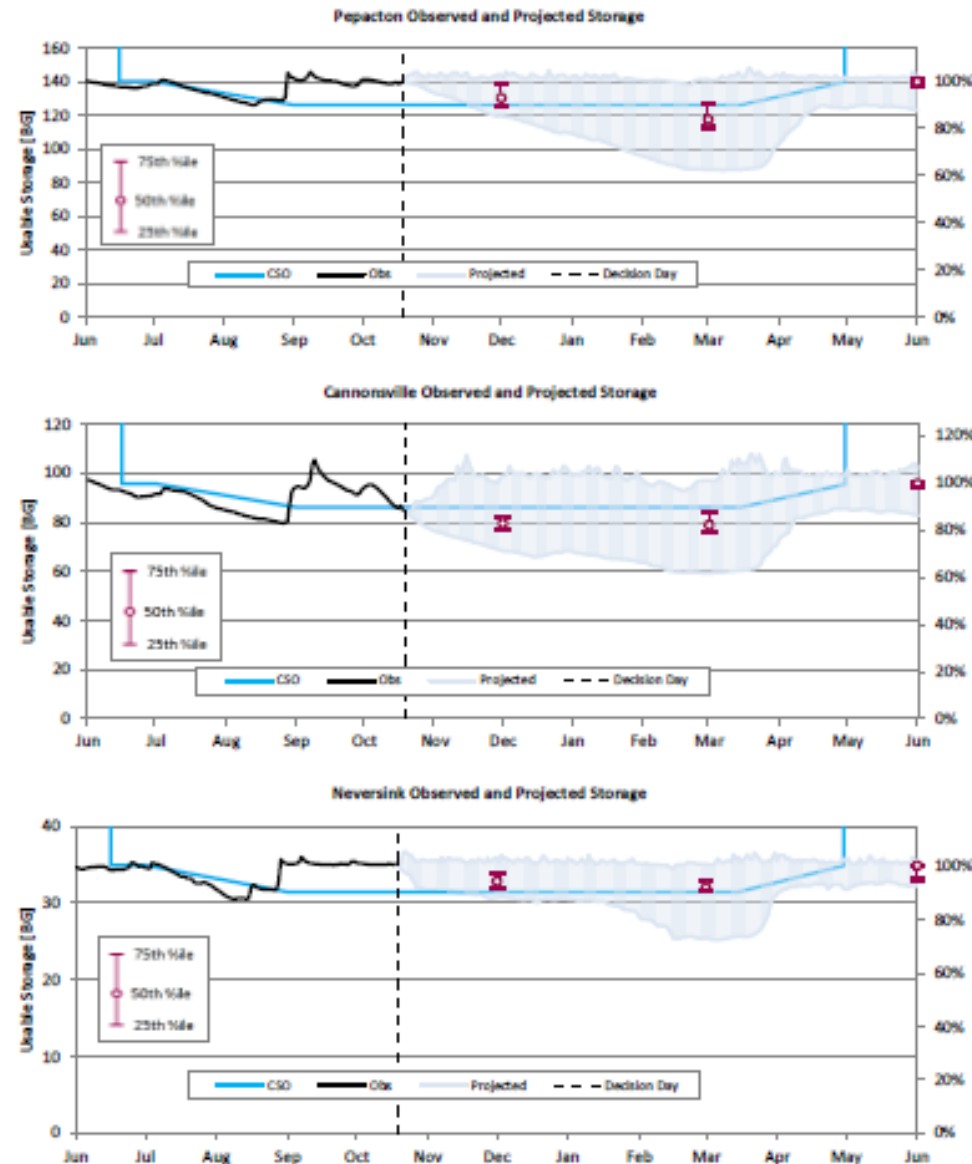
- ❖ Unanimous agreement to implement OST-FFMP program
- ❖ Implementation begun on June 1, 2011

Determine Storage Zone for Schedule Selection	Storage	Zone
Current PCN Usable Storage:	96%	L1
Current Pepacton Usable Storage:	100%	L1-a
Current Cannonsville Usable Storage:	88%	L1-c
Current Neversink Usable Storage:	99%	L1-a

OST-FFMP Schedule Fall Season (Oct 1 - Nov 30)	Release (cfs)			Total
	Pepacton L1-a	Cannonsville L1-e	Neversink L1-a	
Table 4a	700	110	190	1000
Table 4b	700	125	190	1015
Table 4c	700	150	190	1040
Table 4d	700	175	190	1065
Table 4e	700	200	190	1090
Table 4f	700	225	190	1115
Table 4g	700	225	190	1115

OST-FFMP Summary Page

Decision Day: 2011-10-19



- ❖ NOAA-ACOE-USGS Integrated Water Resources Science and Services (IWRSS) partnership
- ❖ Opportunity for pilot-testing Basin-wide OST?
- ❖ Use existing model/forecast framework



Integrated Water Resources Science and Services (IWRSS):
A Forum to Discuss this New Federal Initiative

Thursday, December 13th 2012 at Delaware River Basin Commission Office

- ❖ Forecast-based approach to DRB release management
 - Allows for frequent increased releases
 - Supports quantification of risk to water supply reliability
 - Helps convert uncontrolled spill into managed releases
- ❖ Framework for developing ‘win-win’ solutions

