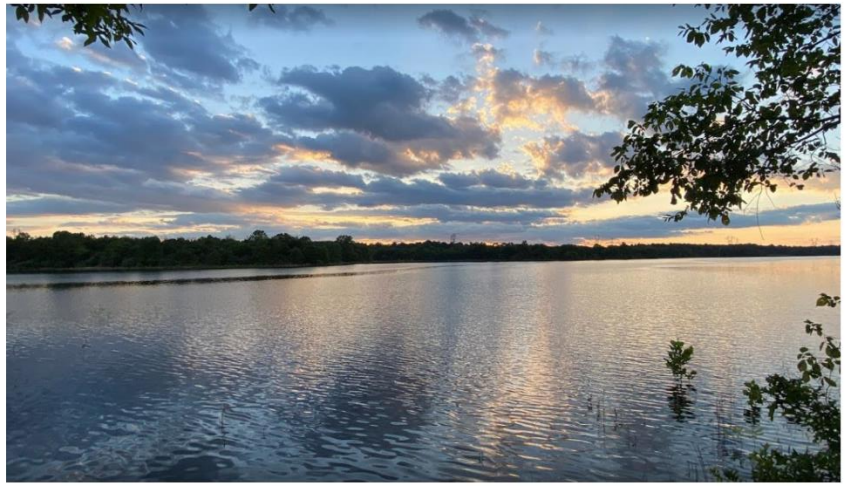
Appendix D: Webinar, “Forecast Informed Reservoir Operations,” by Hazen & Sawyer

Hazen



Forecast Informed Reservoir Operations

Drought Exercise

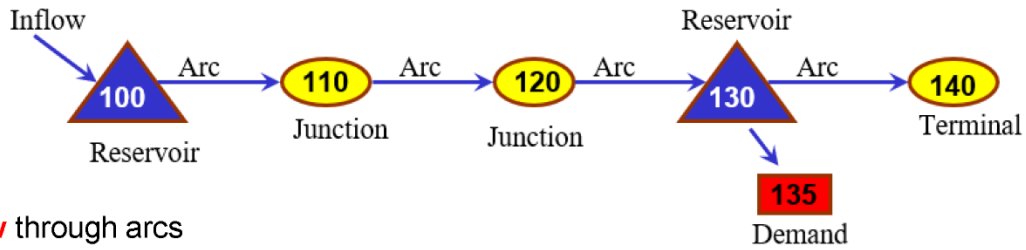
November 17, 2020

Outline

- OASIS Intro
- Forecast Options
- WMA Forecast Dashboard Demo
- FIRO Examples
  - Aquarion Water Company (CT)
  - Delaware River Basin
  - Water Quality (Turbidity) NYC
  - West Point Lake Flood Control (GA)
  - City of Rocky Mount (NC)

OASIS Software

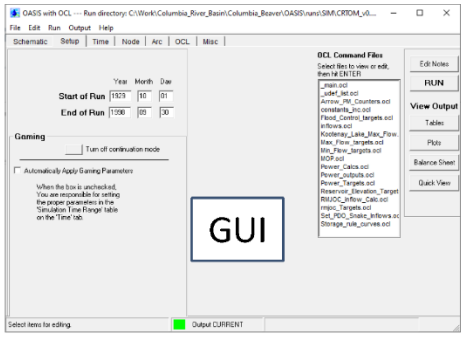
Operational **A**nalysis and **S**imulation of **I**ntegrated **S**ystems

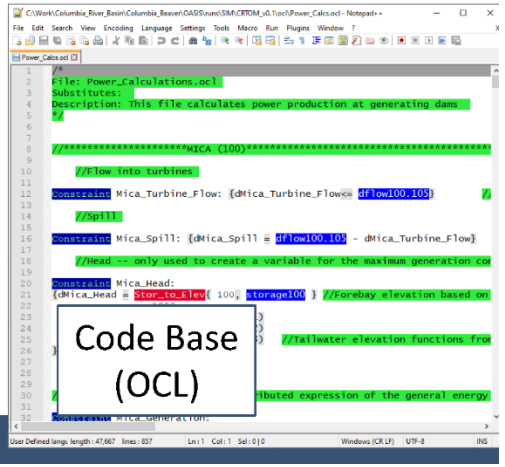


Flow through arcs
Volume stored in each reservoir
Delivery (volume) allocated to each demand node
… calculated every timestep for the period of record

Suite of programs for modeling the operations of water resources systems

Emphasis is on reservoir operations



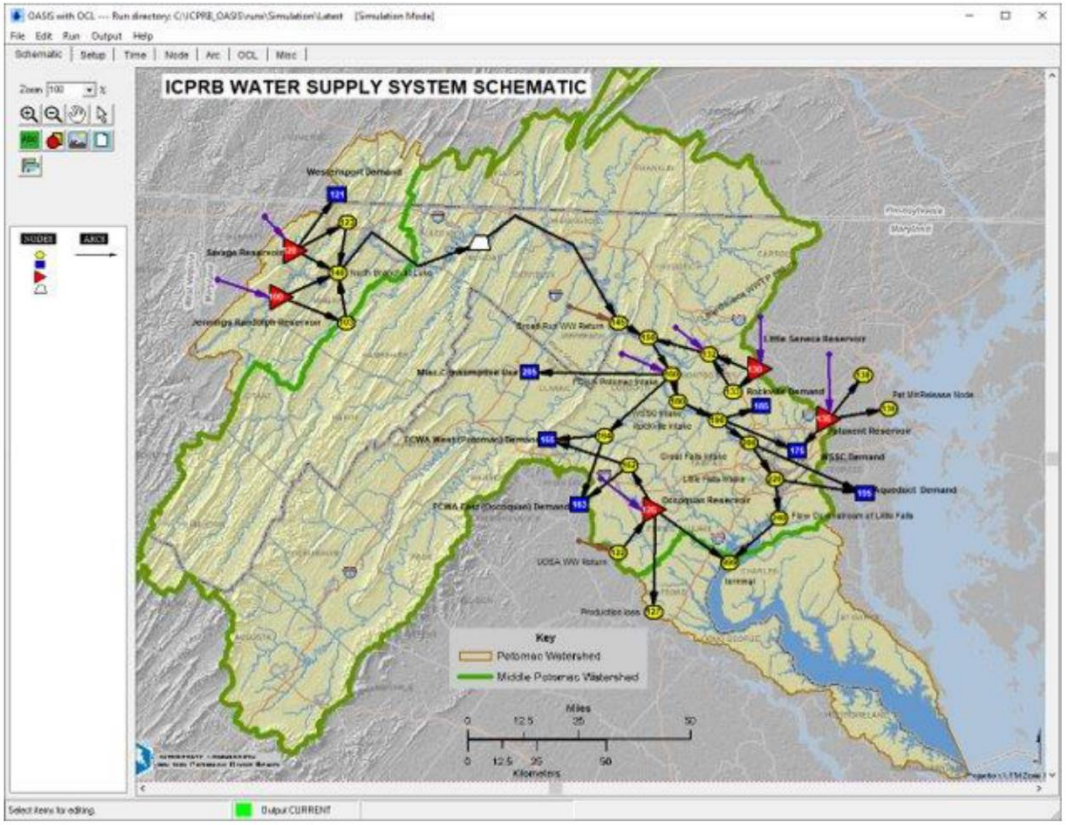


ICPRB OASIS Model

The model was built in 2004 for potential use in operational decision support

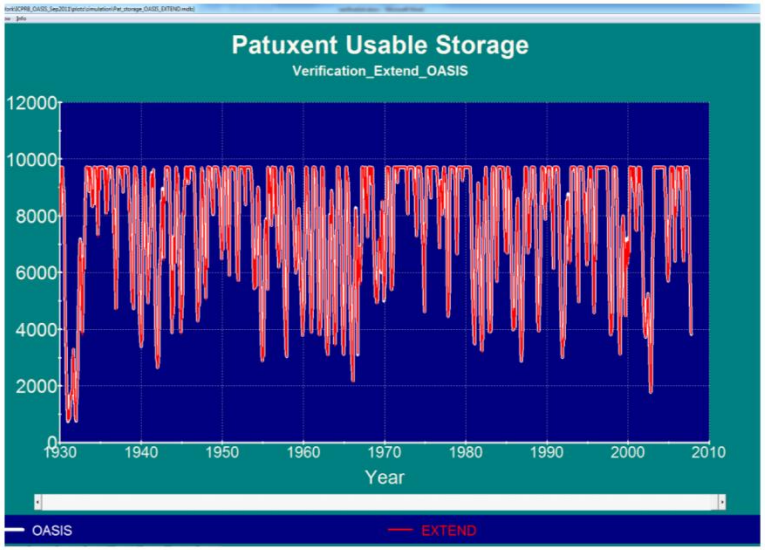
It was updated in 2012 as part of a WRF climate change study

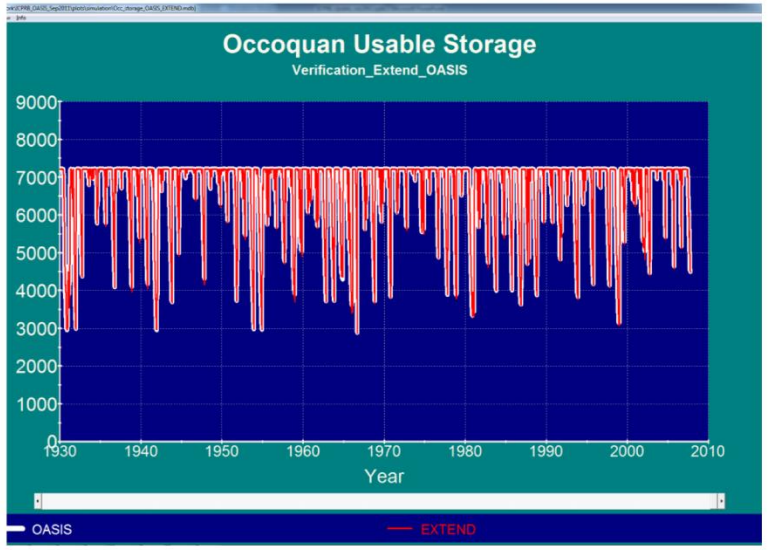
It is currently being updated again



OASIS-PRISM Verification

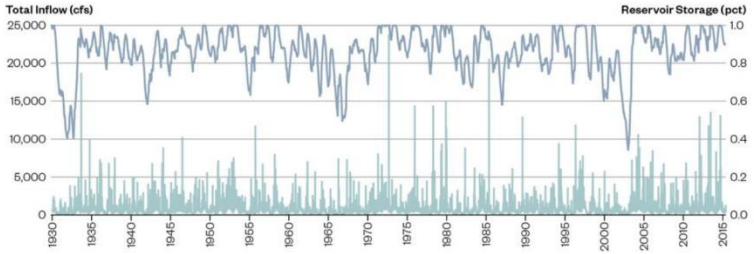
2012 Comparison Shown; recent PRISM updates are currently being implemented in OASIS



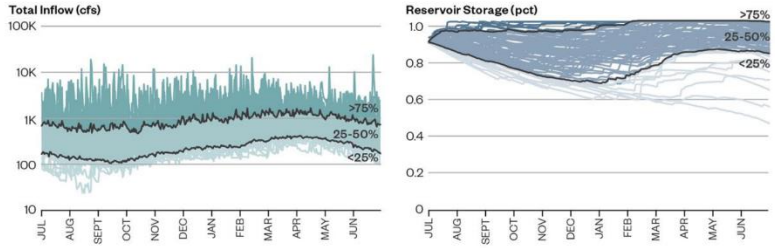


OASIS Run Modes

Simulation Mode (Planning)



Position Analysis Mode (Operations)



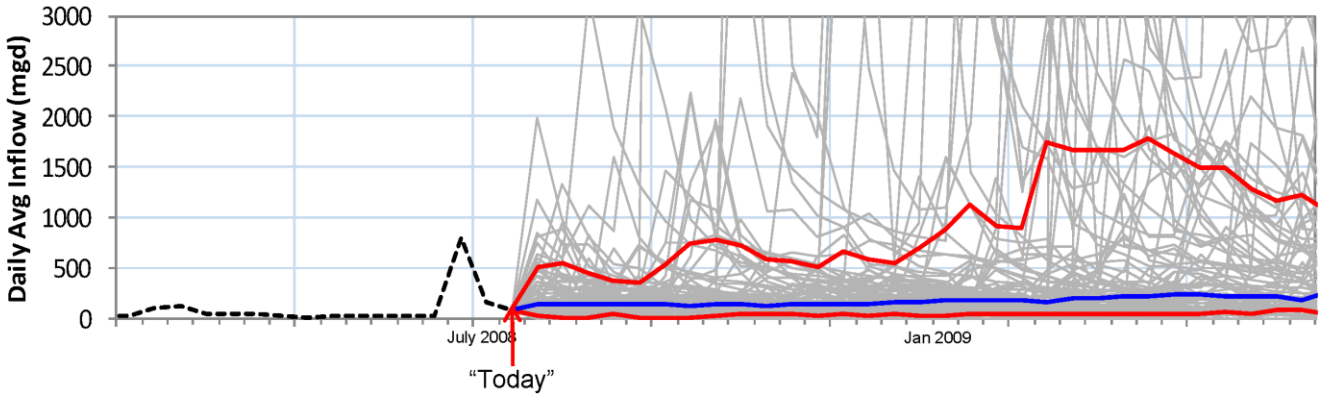
Gaming Mode (Exercises)

Point Forecasts versus Ensemble Forecasts

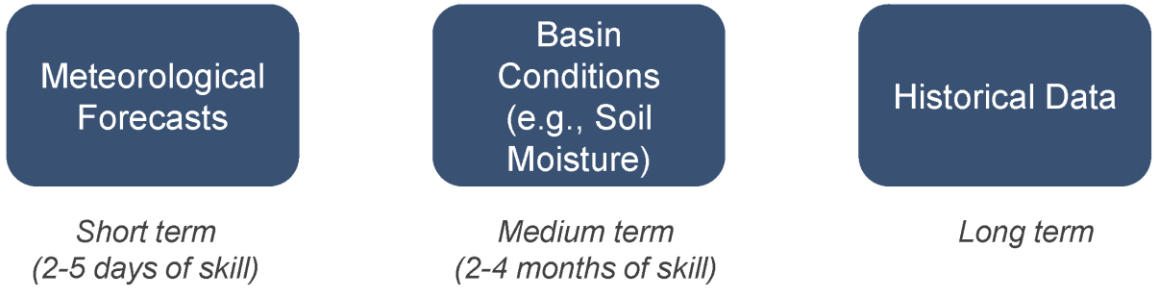
Point Forecast (a single "most likely" value)

7 pm	49°
8 pm	48°
9 pm	49°

Inflow Ensemble (one trace per year of record, assumed error, stochastic realization, climate change run, etc.)



Sources of “Skill” in Forecasts

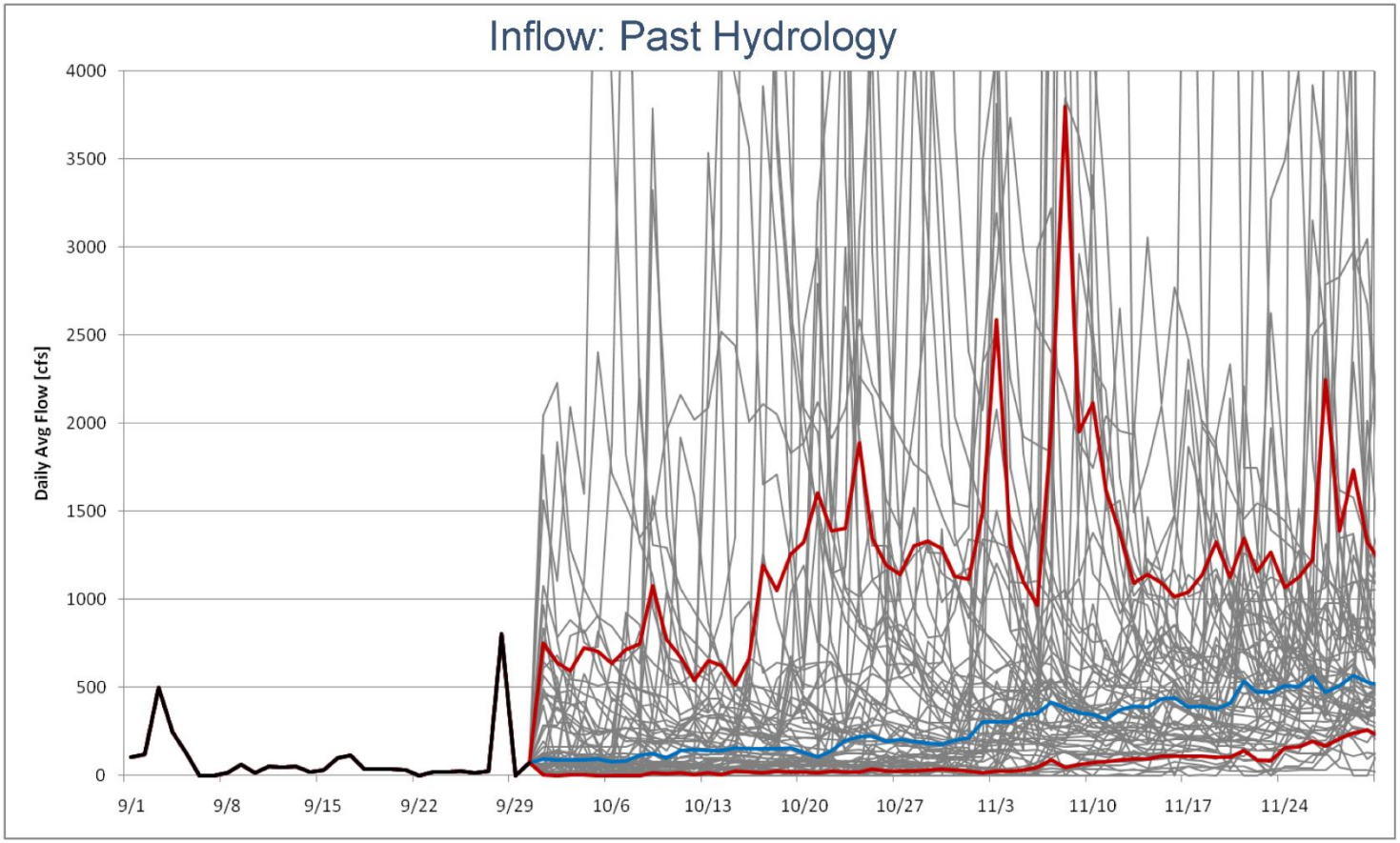


Forecast Choice Depends on Decision-Support Need

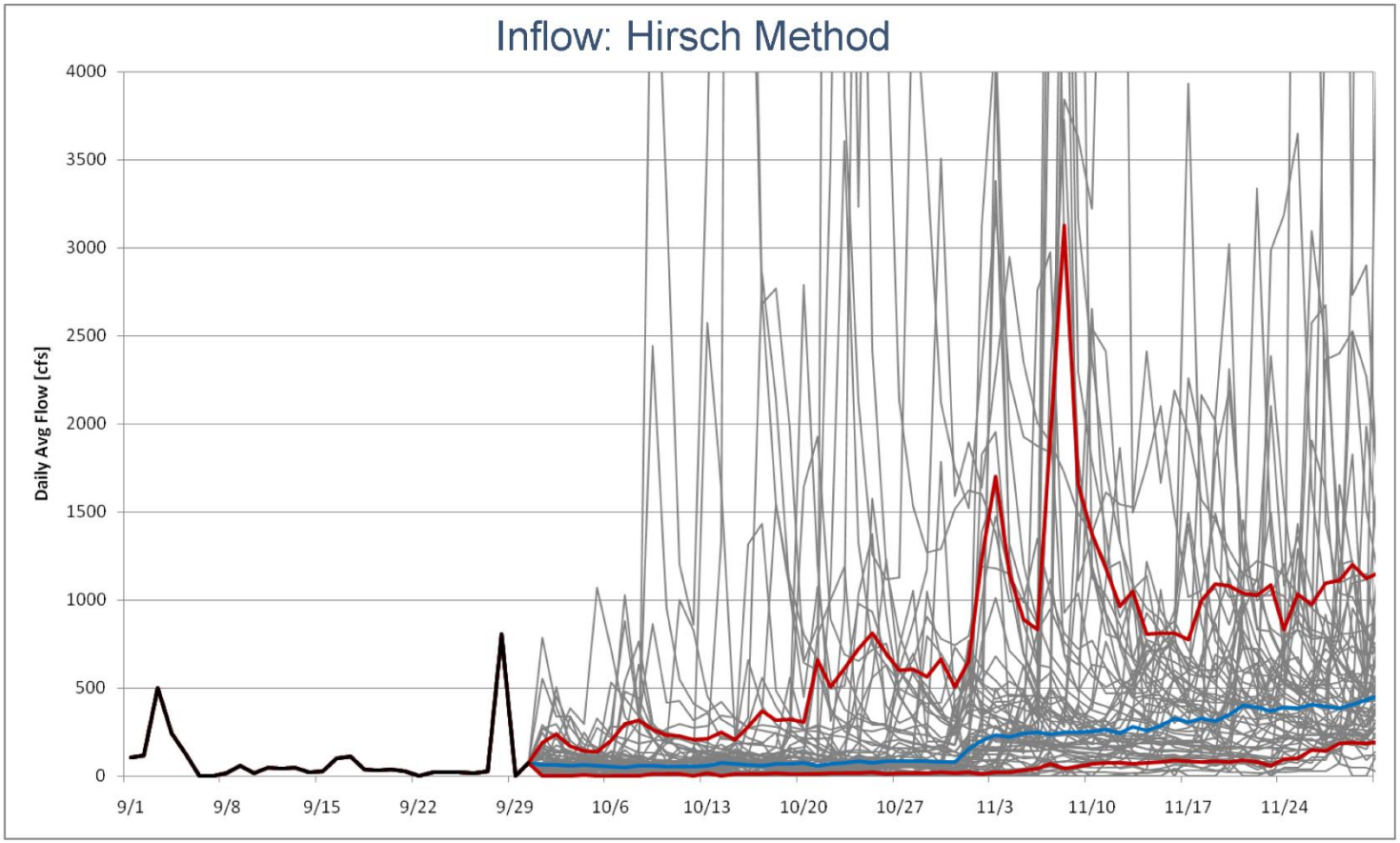
Meteorological Forecasts	Basin Conditions (e.g., Soil Moisture)	Historical Data
Short term questions i.e., likelihood of turbidity event in the next two days	*Medium term questions i.e., likelihood of JR Water Supply Call in the next three weeks*	*Long term questions i.e., likelihood of refill in next six to nine months*
		

Forecast Options

Forecast	Source	Description	Meteorological Forecasts	Basin Conditions	Historical Data
Past Hydrology	ICPRB	Period of Record unimpaired inflow used with PRISM and OASIS			●
Hirsch (Monthly AR1)	ICPRB/ Hazen	Adjust past hydrology for current soil moisture using statistical method		●	●
eHirsch (Daily GLM)	Not ready for Potomac	Adjust Hirsch for forecasted meteorology	●	●	●
Hydrologic Ensemble Forecast Service (HEFS)	NWS Middle Atlantic River Forecast Center	Short and Mid-term meteorological forecasts input to rainfall/runoff model emulating current basin conditions	●	●	●

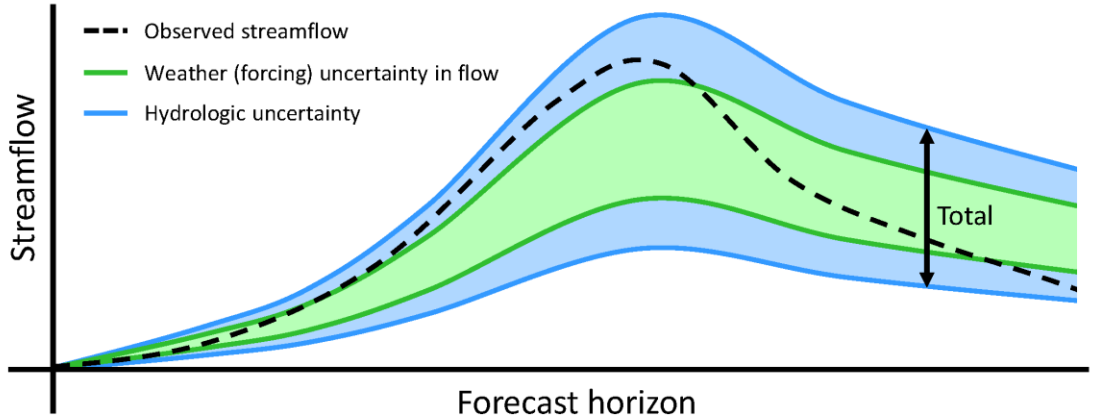

Inflow: Past Hydrology
Daily Avg Flow [cfs]
4000
3500
3000
2500
2000
1500
1000
500
0
9/1
9/8
9/15
9/22
9/29
10/6
10/13
10/20
10/27
11/3
11/10
11/17
11/24

Inflow: Hirsch Method



NWS' Hydrologic Ensemble Forecast Service (HEFS)

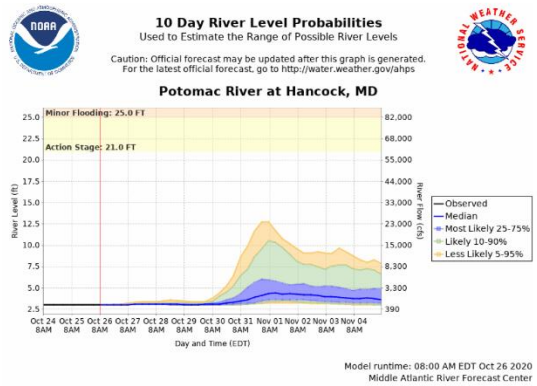
Goal: quantify total uncertainty in flow

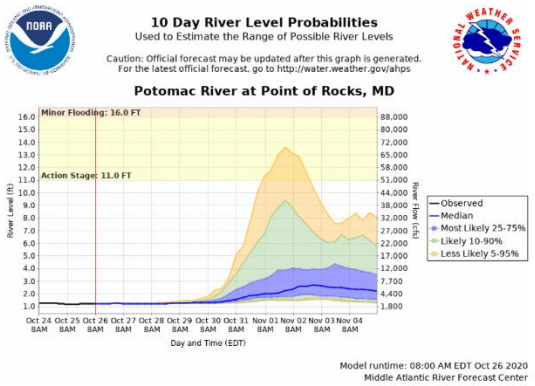


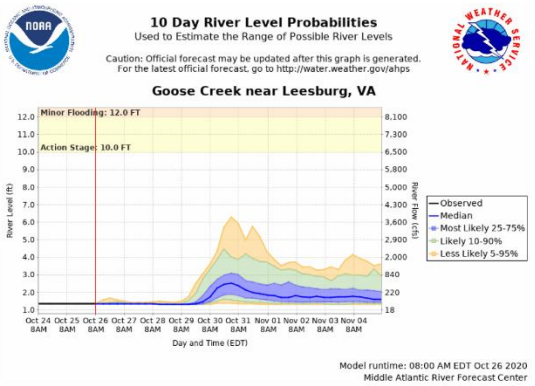
- HEFS aims to "capture" observed flow consistently
- So, must account for total uncertainty & remove bias
- Total = forcing uncertainty + hydrologic uncertainty

Slide credit: Seann Reed, NOAA NWS MARFC

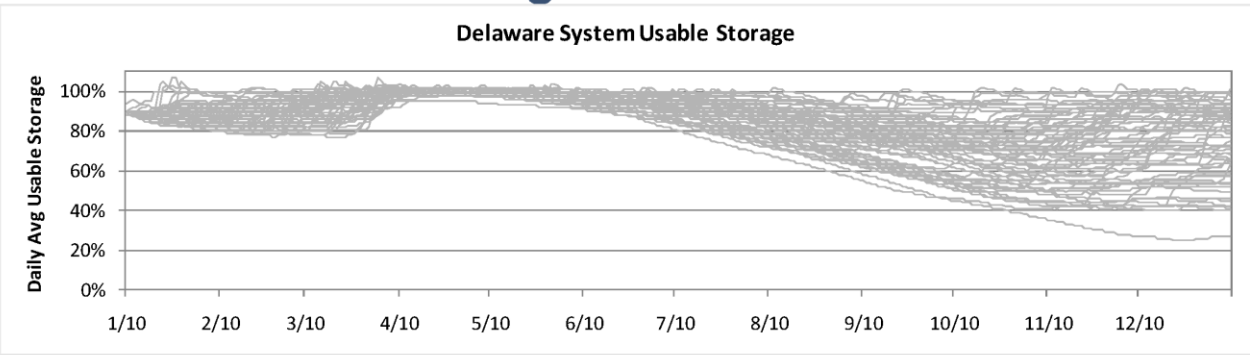
HEFS for Potomac River Basin

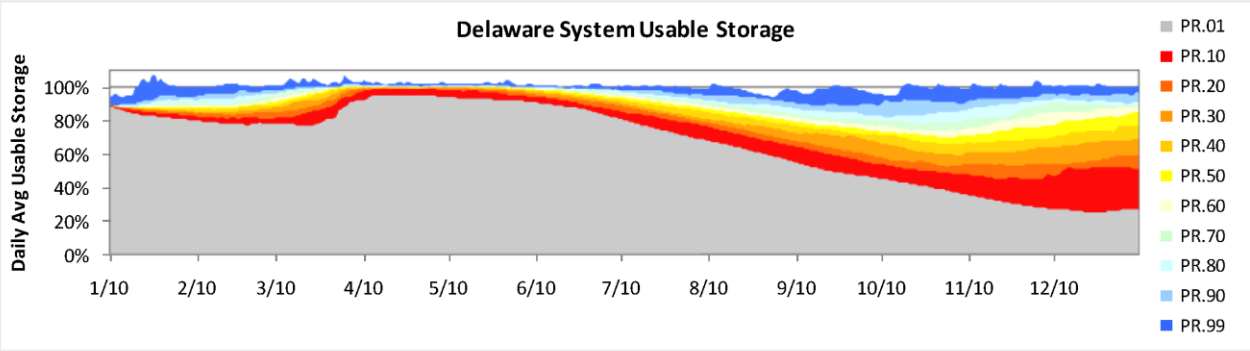




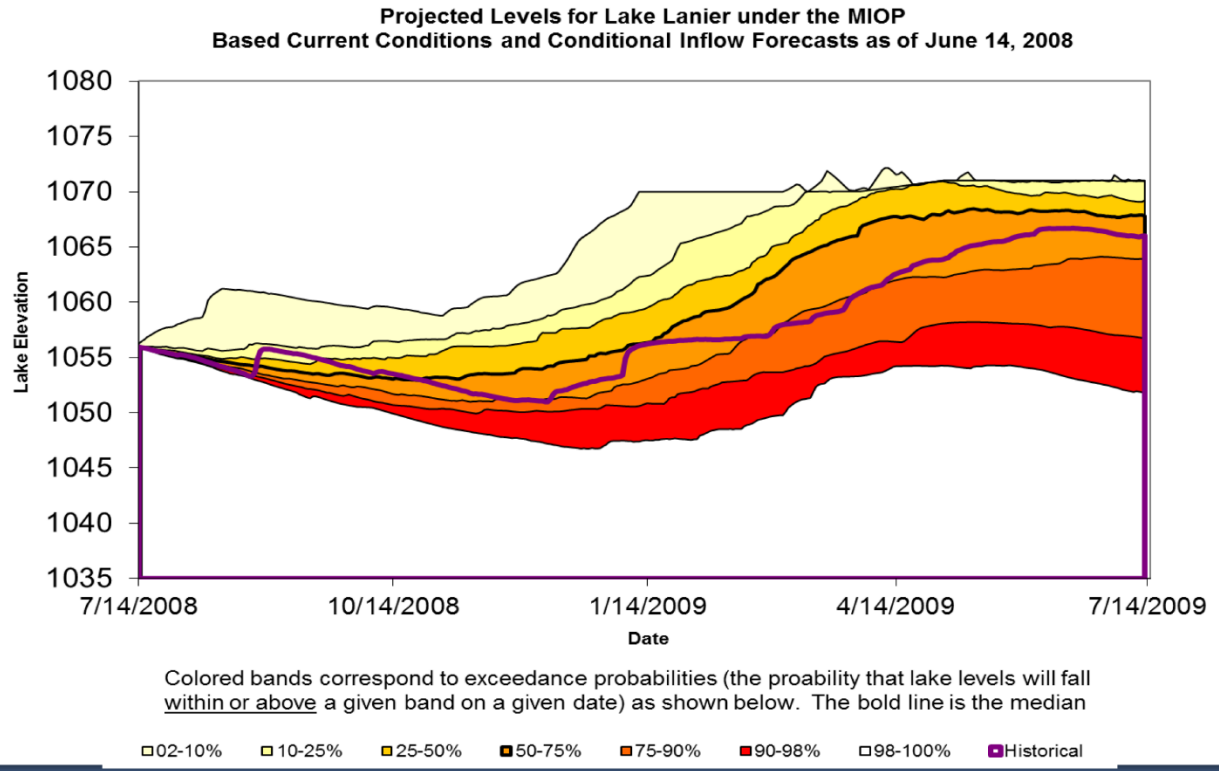


Ensembles are Run Through OASIS Model and Sorted



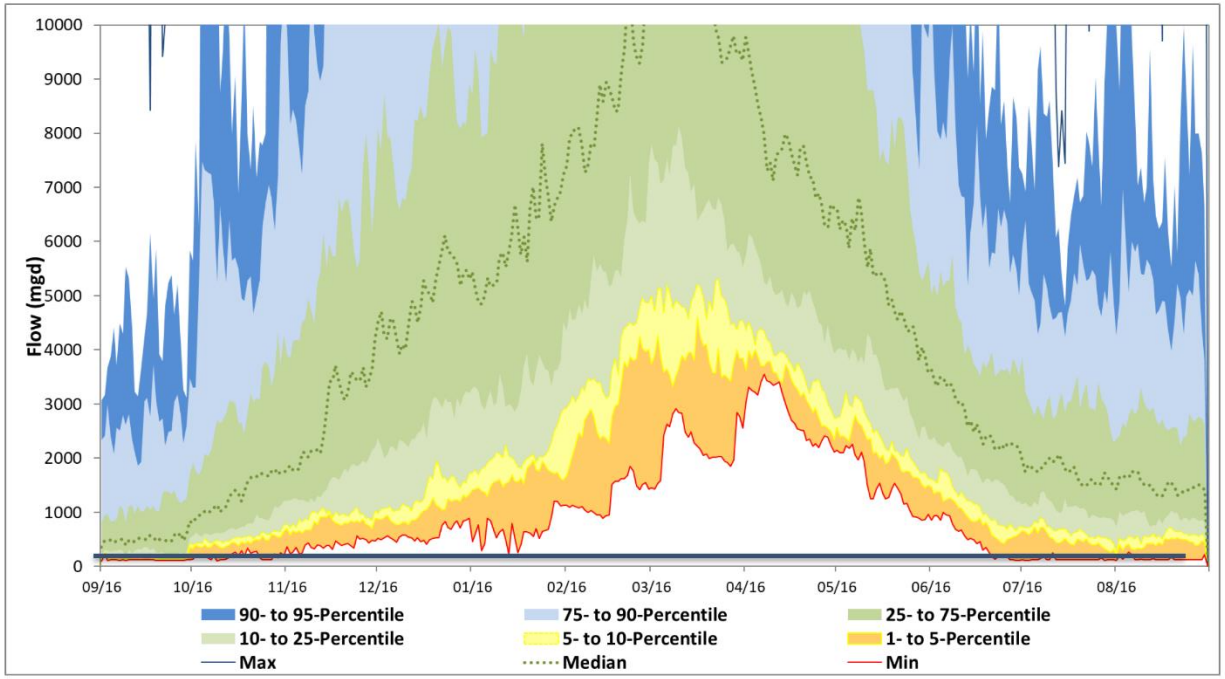


Example Using Hirsch Forecasts

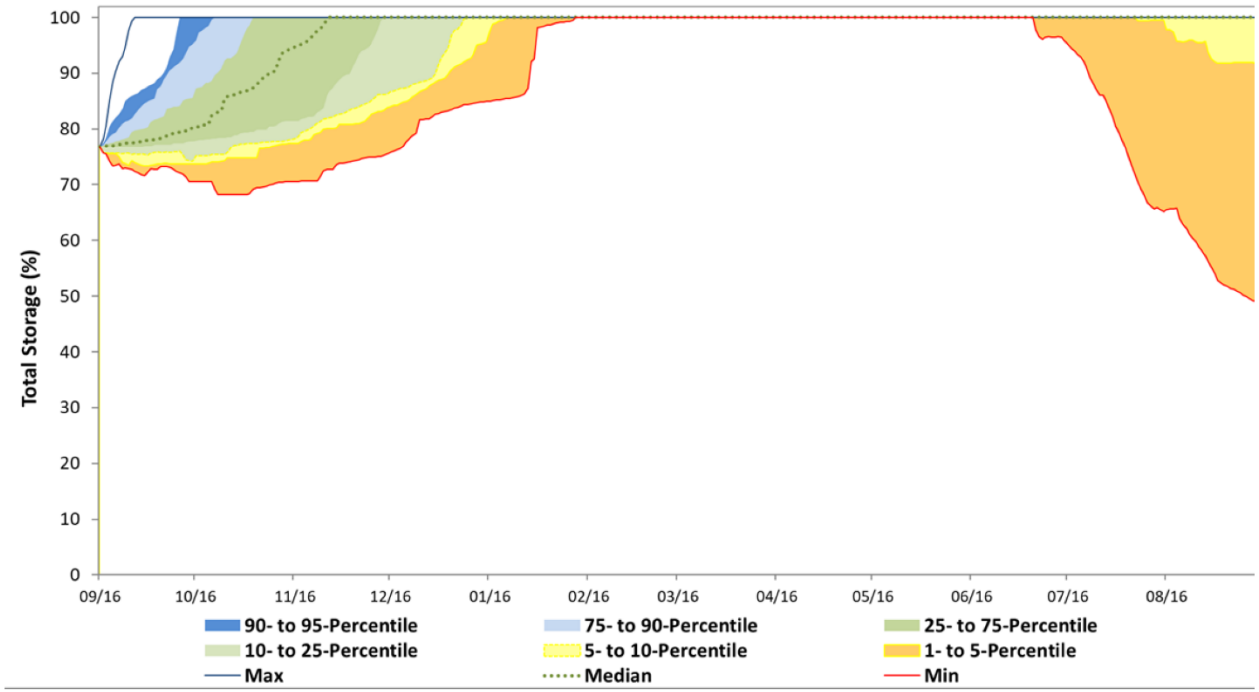


Sample Forecast for Little Falls

Simulated (Sept. 15, 2002)



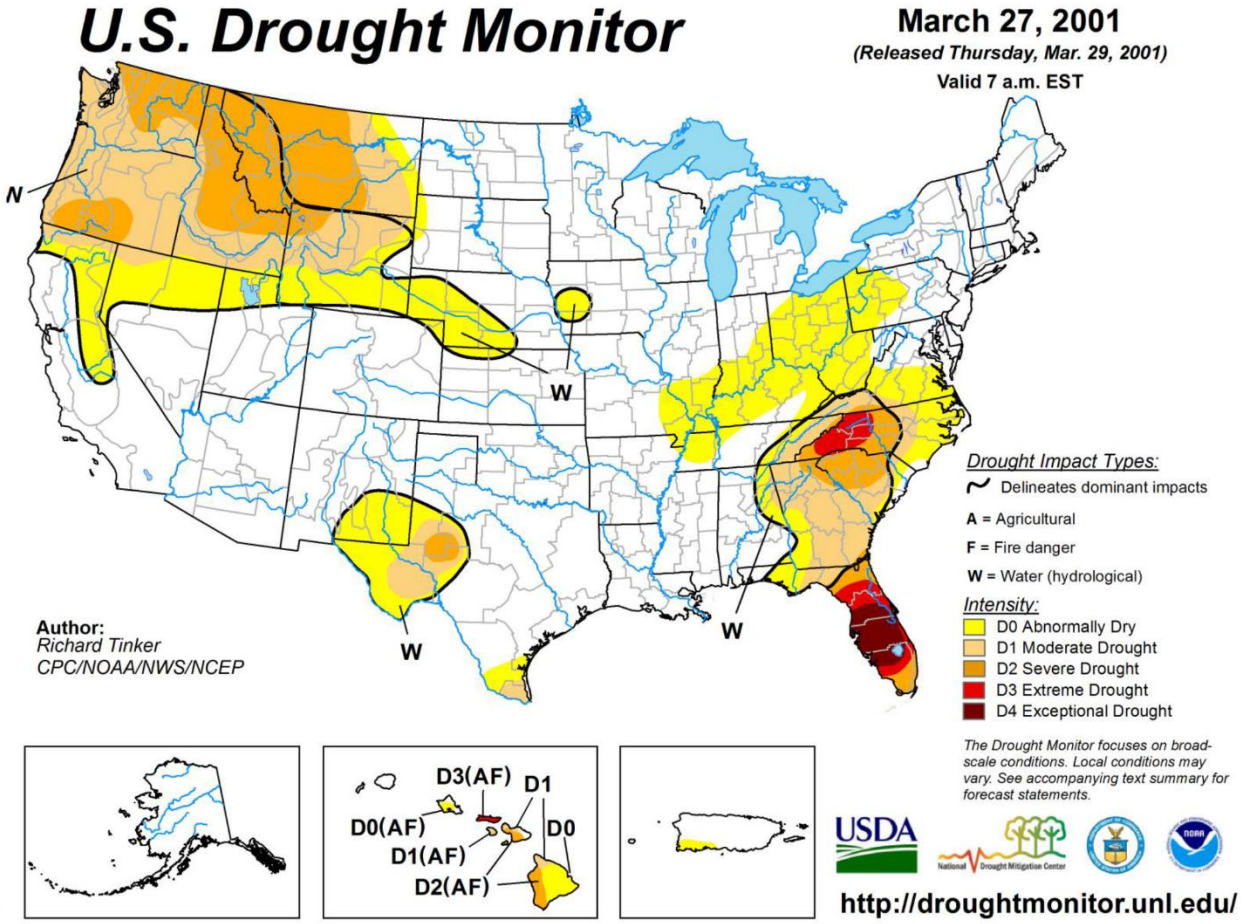
Companion Forecast for JR WS Storage



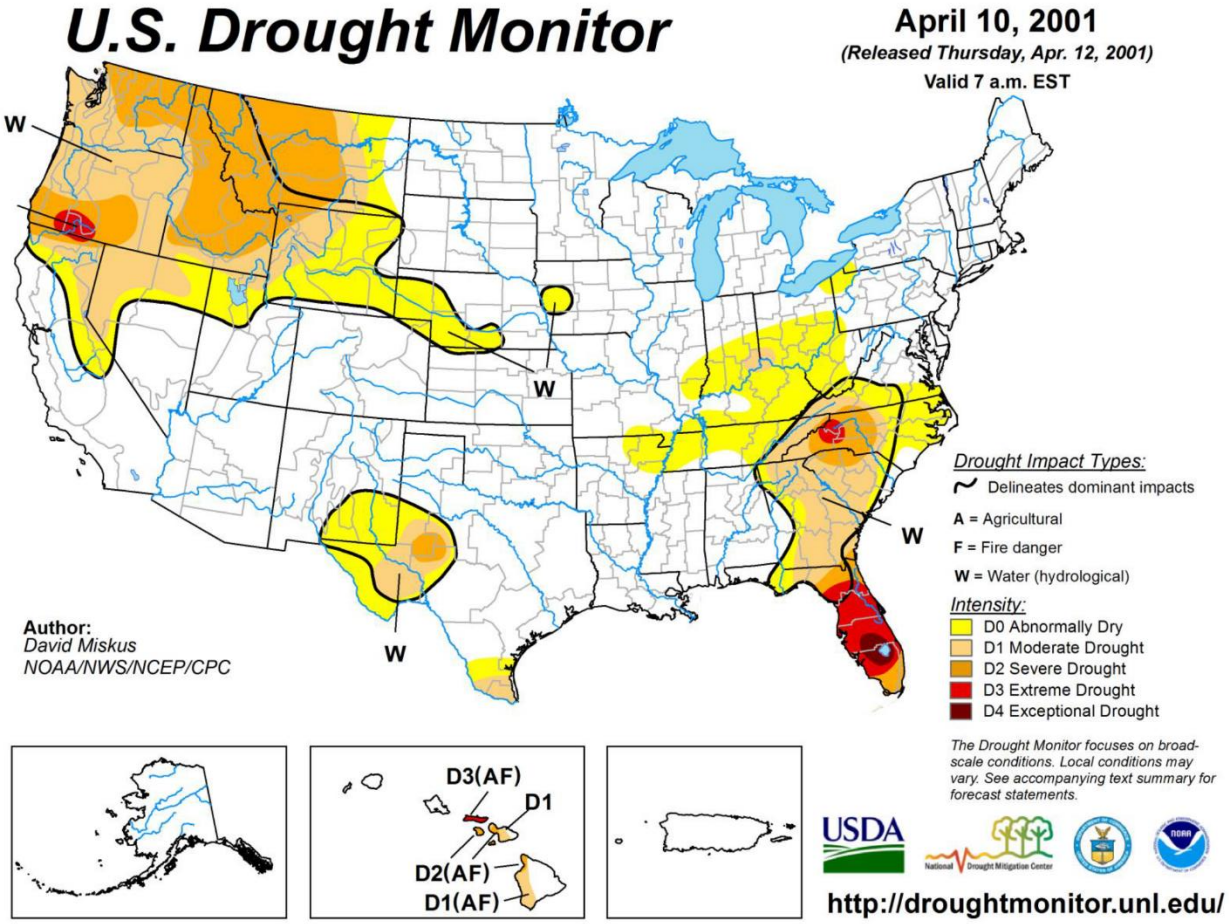
ICPRB Demonstration Drought Dashboard

Note: these runs were not done with the updated model

- Explore the 2001-2002 Mid-Atlantic drought
- 2020 and 2040 demand/sedimentation projections (projected in 2010)
- Scenarios
  - **Baseline operations**
  - **+50 mgd margin of safety (MOS) on Little Falls flow**
  - **2020 and 2040 demands**


U.S. Drought Monitor
March 27, 2001
(Released Thursday, Mar. 29, 2001)
Valid 7 a.m. EST
N
W
W
W
Author:
Richard Tinker
CPC/NOAA/NWS/NCEP
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
W = Water (hydrological)
Intensity:
D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
D3(AF)
D1
D0(AF)
D0
D1(AF)
D2(AF)
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/

Hazen


U.S. Drought Monitor
April 10, 2001
(Released Thursday, Apr. 12, 2001)
Valid 7 a.m. EST
W
W
W
W
Author:
David Miskus
NOAA/NWS/NCEP/CPC
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
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W = Water (hydrological)
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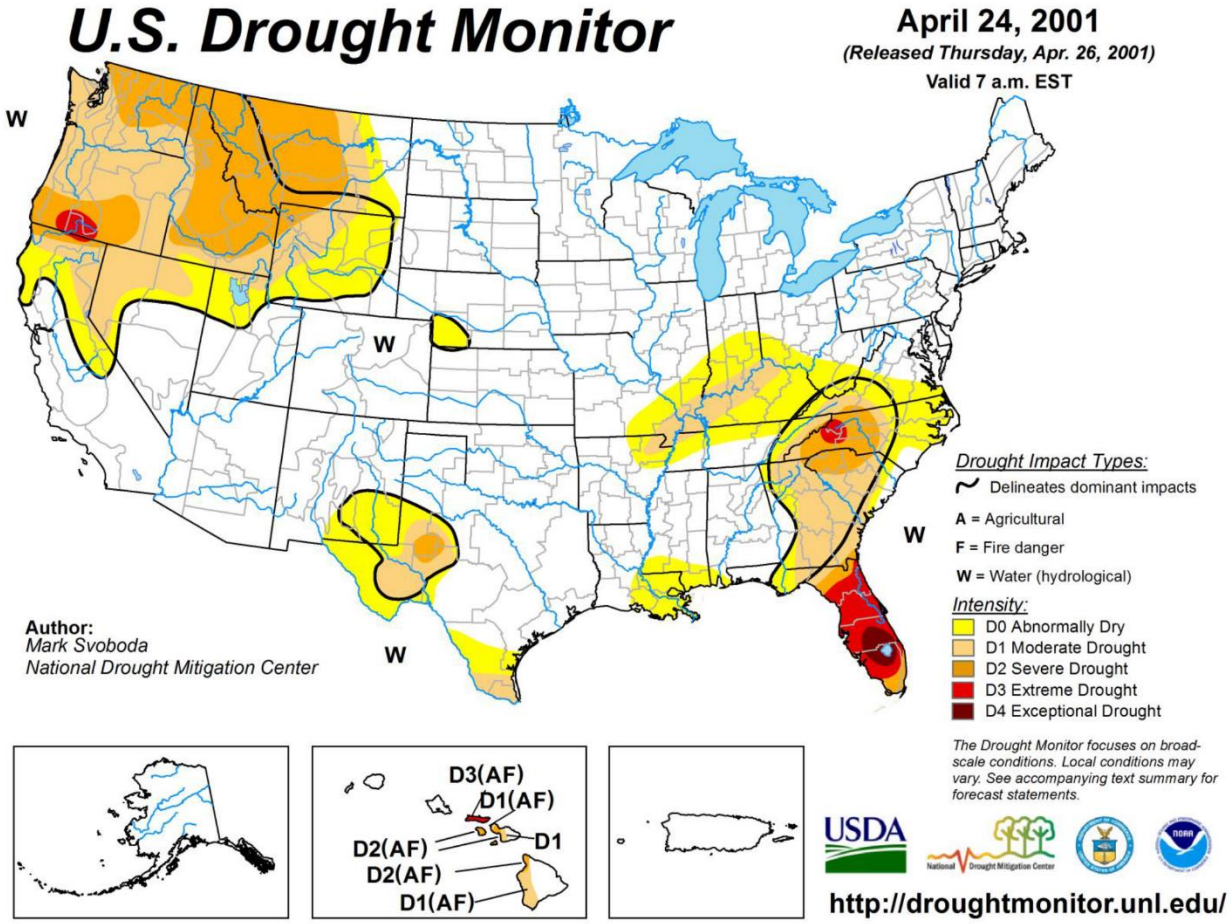
U.S. Drought Monitor
April 24, 2001
(Released Thursday, Apr. 26, 2001)
Valid 7 a.m. EST
W
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W
W
Author:
Mark Svoboda
National Drought Mitigation Center
Drought Impact Types:
Delineates dominant impacts
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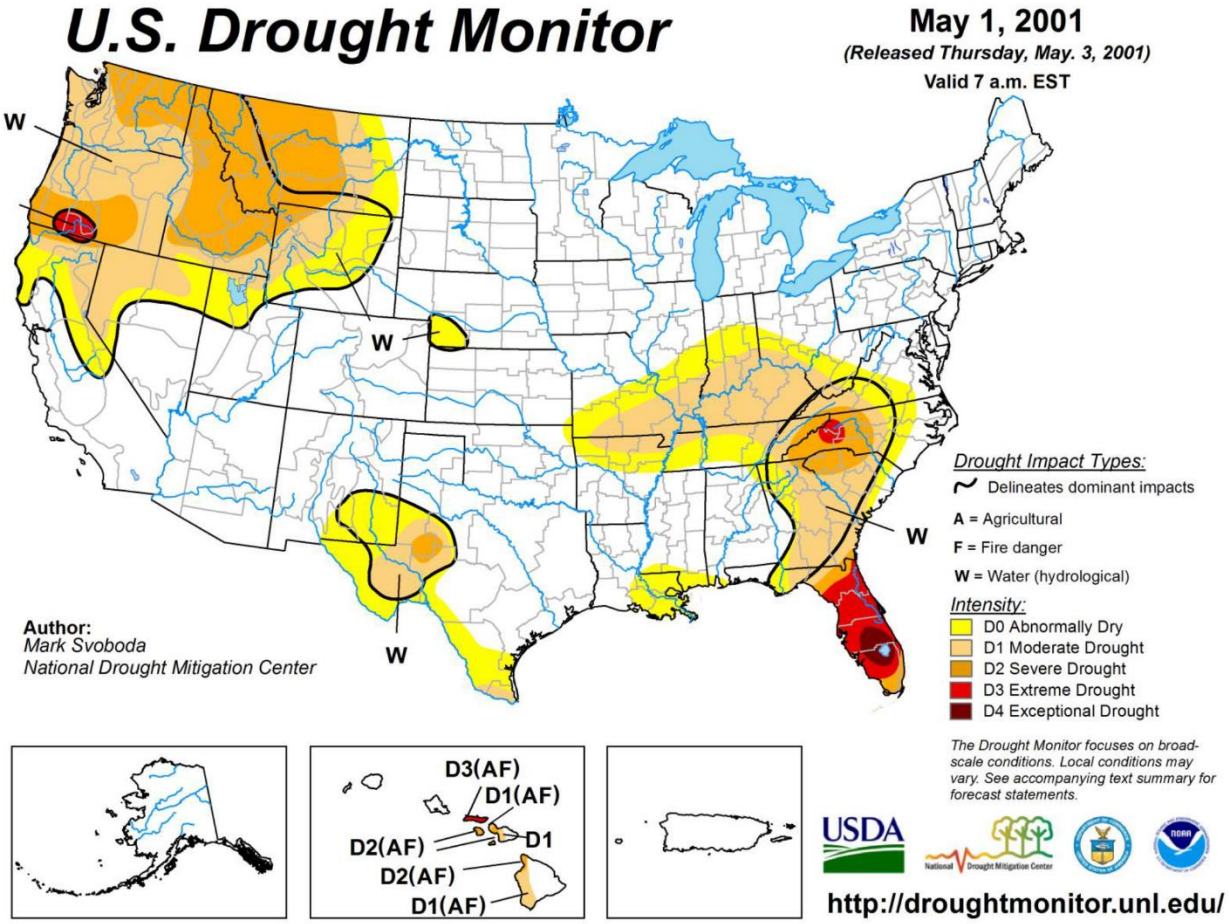
U.S. Drought Monitor
May 1, 2001
(Released Thursday, May. 3, 2001)
Valid 7 a.m. EST
W
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Author:
Mark Svoboda
National Drought Mitigation Center
Drought Impact Types:
Delineates dominant impacts
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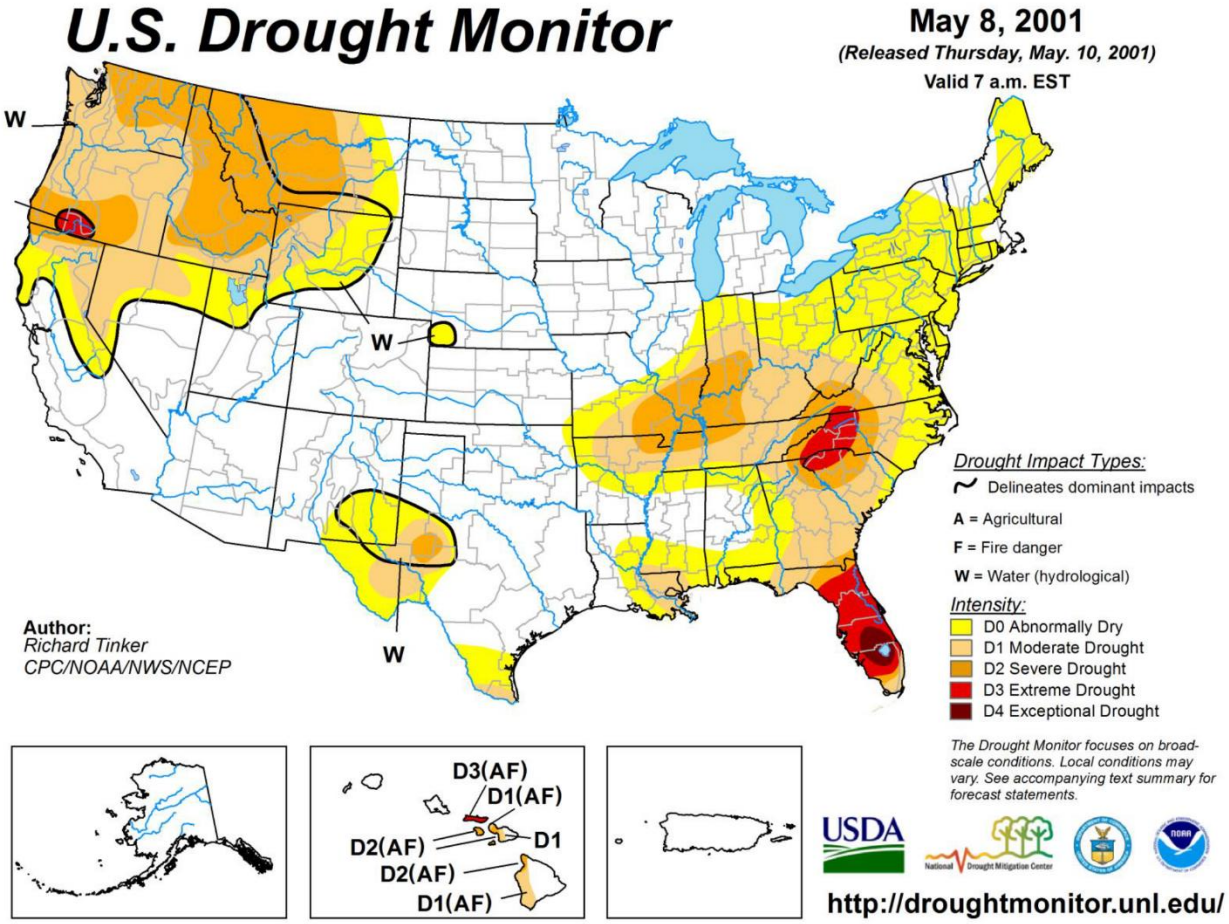
U.S. Drought Monitor
May 8, 2001
(Released Thursday, May. 10, 2001)
Valid 7 a.m. EST
W
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Author:
Richard Tinker
CPC/NOAA/NWS/NCEP
Drought Impact Types:
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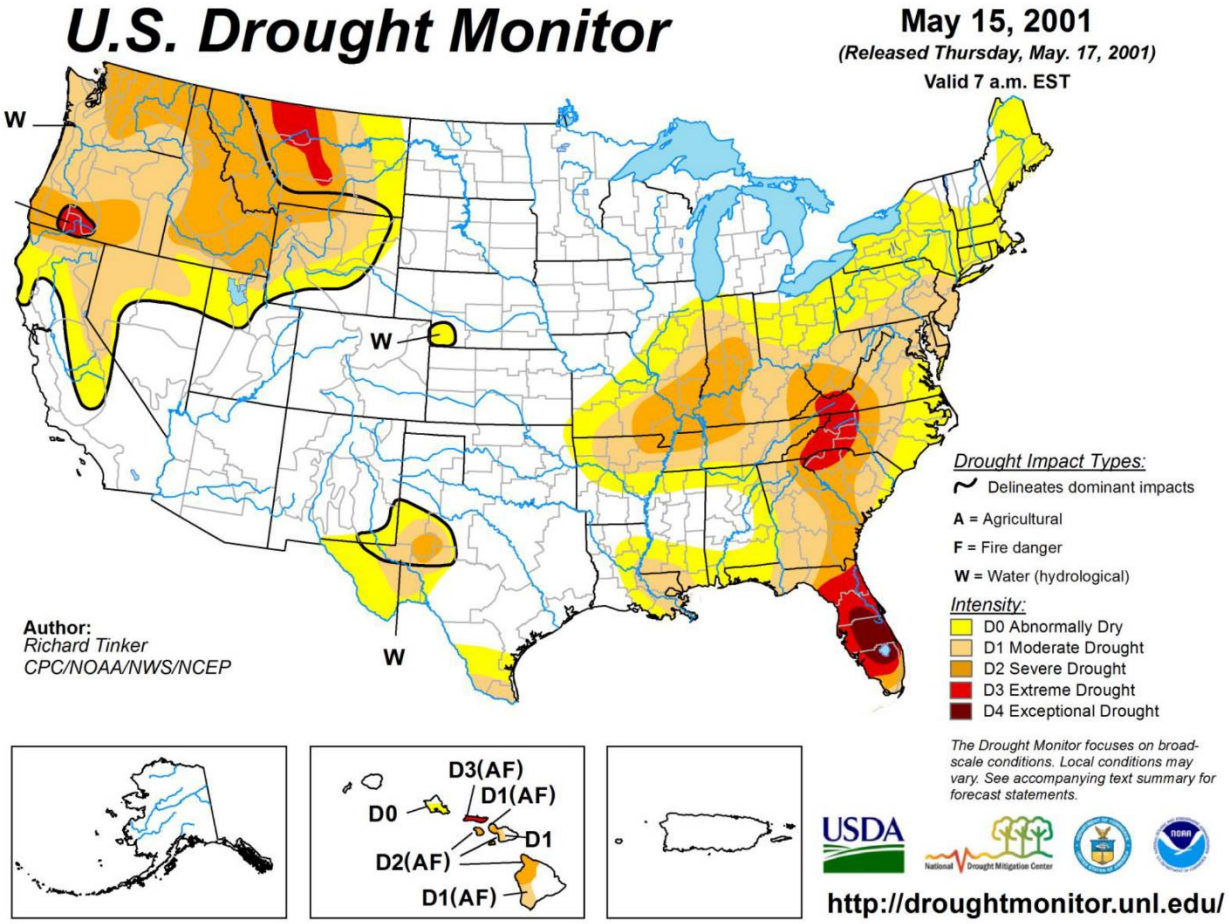
Hazen


U.S. Drought Monitor
May 15, 2001
(Released Thursday, May. 17, 2001)
Valid 7 a.m. EST
W
W
W
Author:
Richard Tinker
CPC/NOAA/NWS/NCEP
Drought Impact Types:
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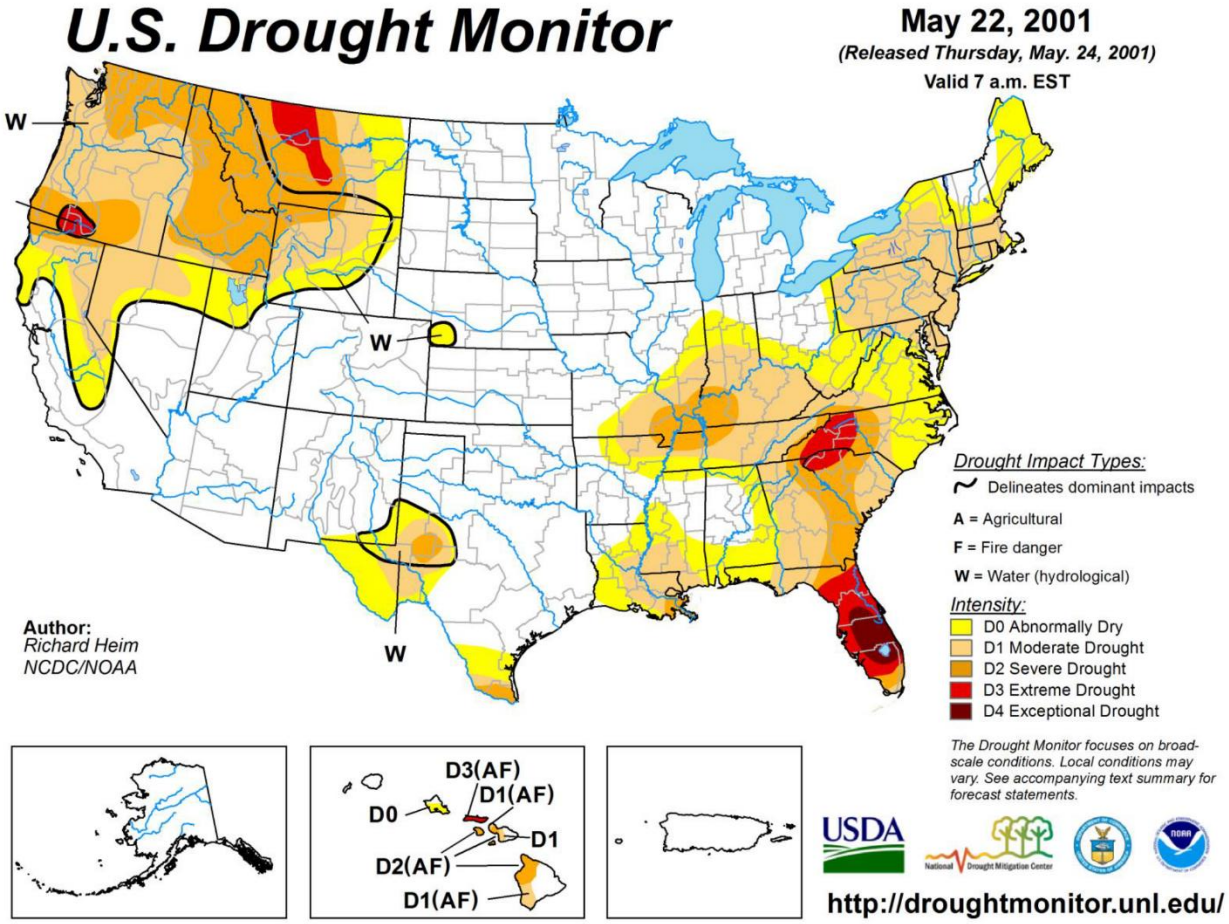
Hazen


U.S. Drought Monitor
May 22, 2001
(Released Thursday, May. 24, 2001)
Valid 7 a.m. EST
W
W
W
Author:
Richard Heim
NCDC/NOAA
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
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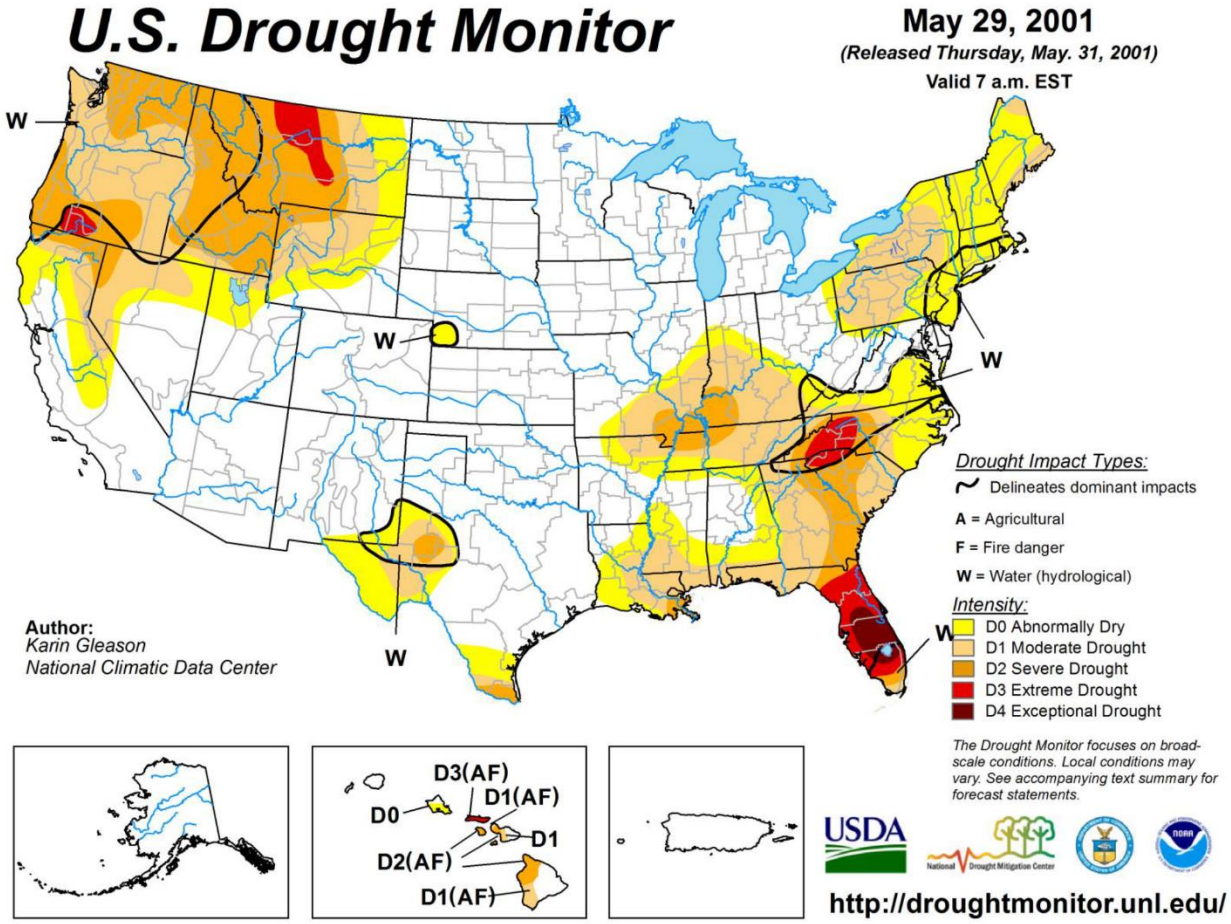
Hazen


U.S. Drought Monitor
May 29, 2001
(Released Thursday, May. 31, 2001)
Valid 7 a.m. EST
W
W
W
W
W
Author:
Karin Gleason
National Climatic Data Center
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
W = Water (hydrological)
Intensity:
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D2(AF)
D1(AF)
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/

Hazen

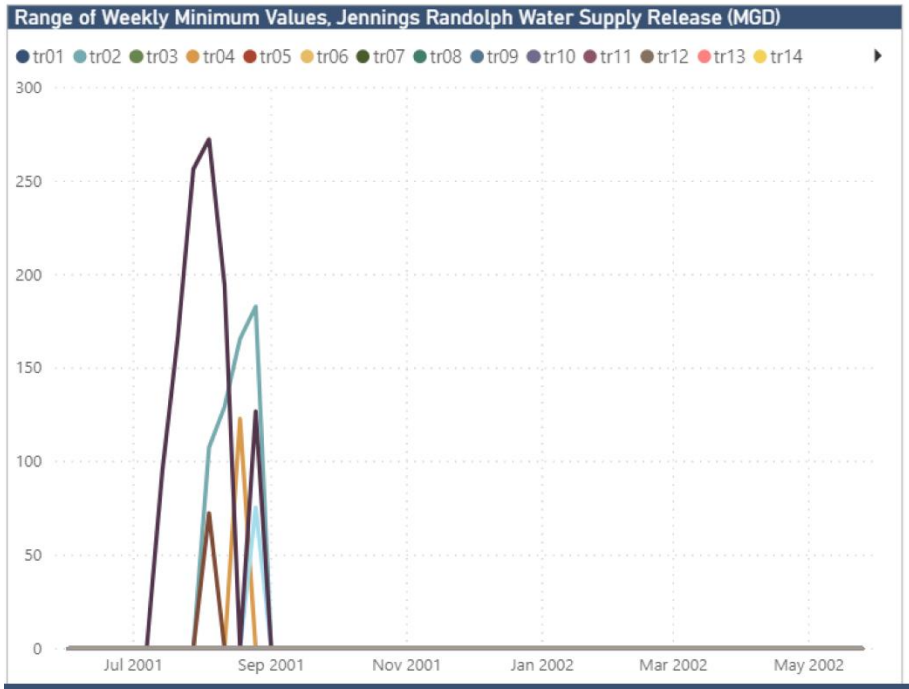
June 1, 2001

- Run OASIS with forecasted inflow
- Evaluate:
  - Predicted WMA shortage and required releases from Jennings Randolph and Little Seneca
  - Predicted flow at Little Falls
  - Risk of water use restrictions
  - Impacts on water supply reservoirs
- As drought proceeds, update predictions with new model runs, driven by new forecasts

Dashboard demo

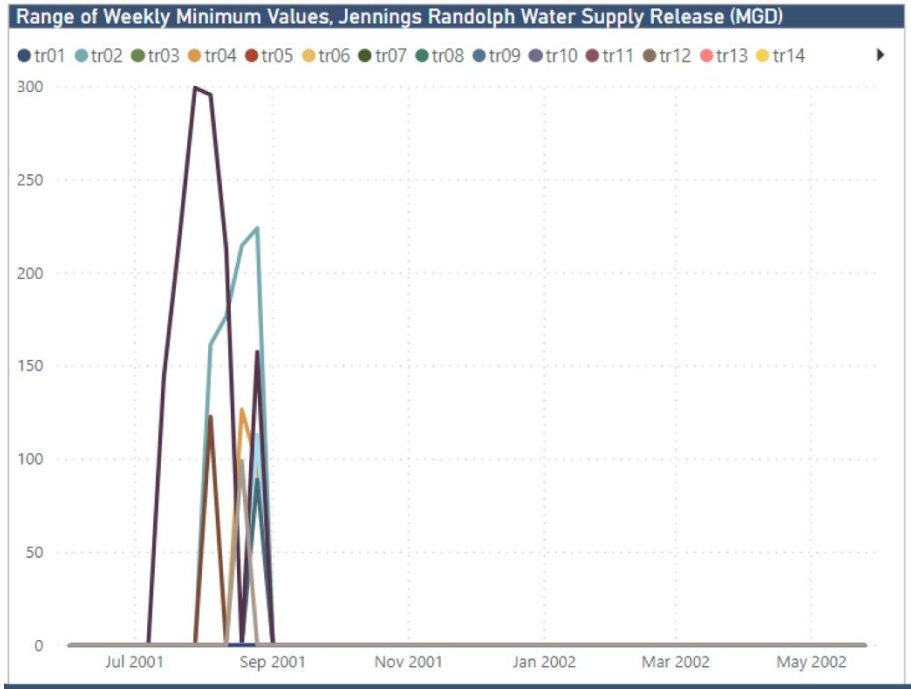
- The following screen captures are from a slightly different model run that the one shown

Five out of 73 Traces Require JR WS Releases (about 7% chance)

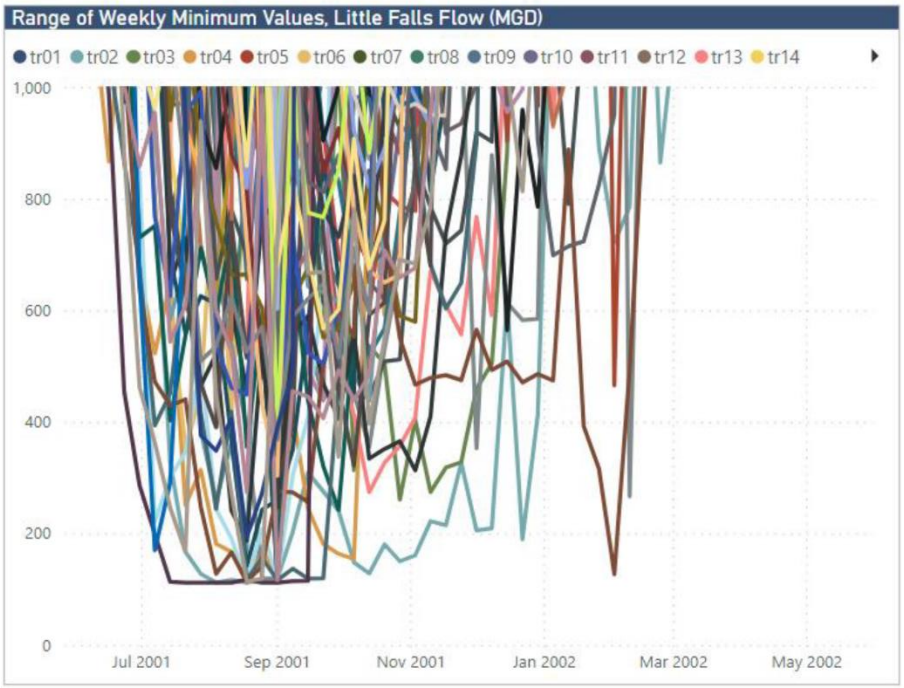


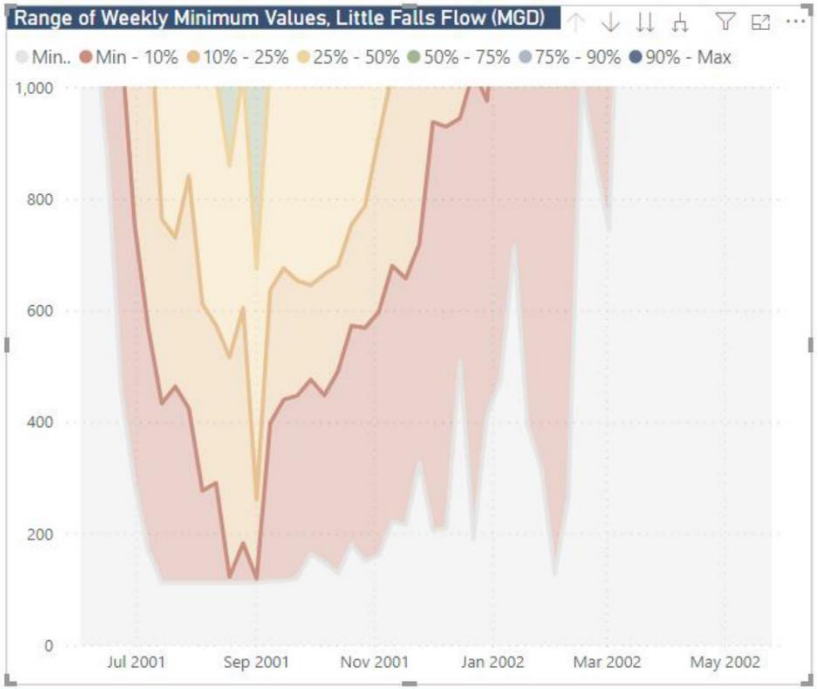
With a 50 mgd Margin of Safety, JR WS Releases Increase

In number (8 or 11%) and magnitude

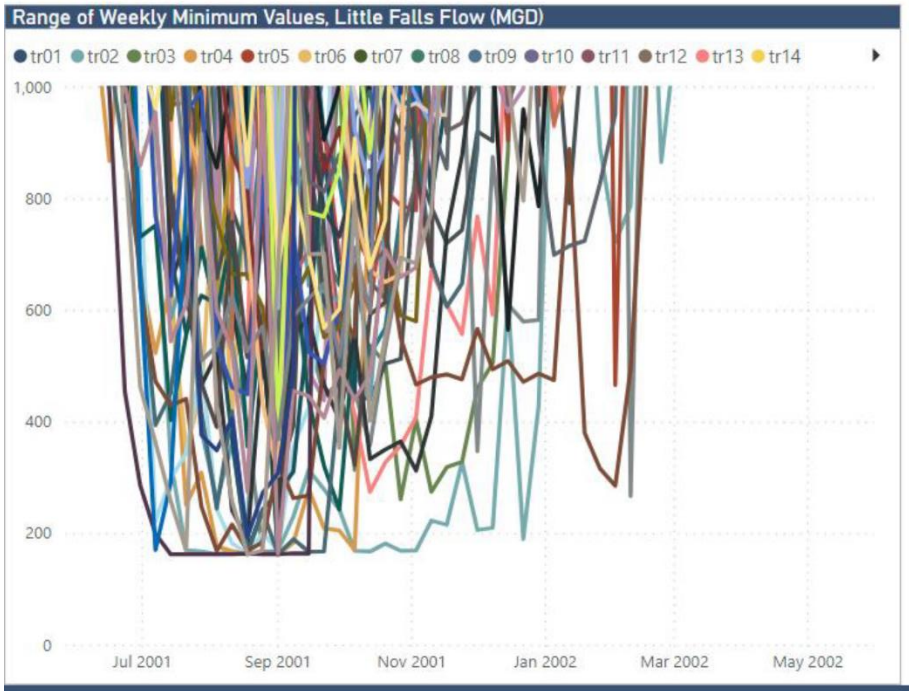


Forecasted Little Falls Flows

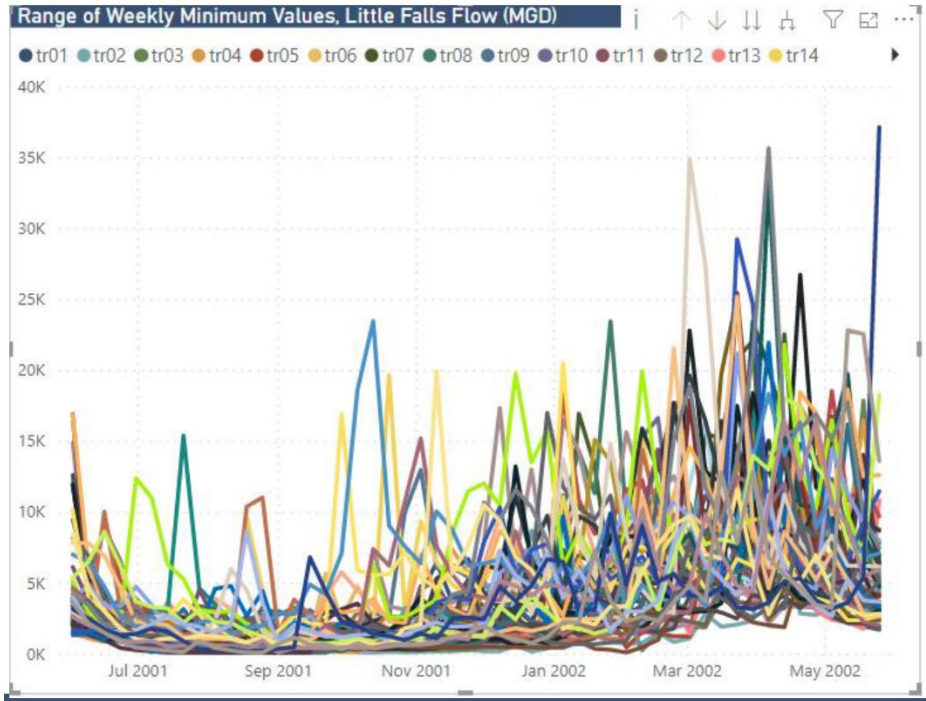


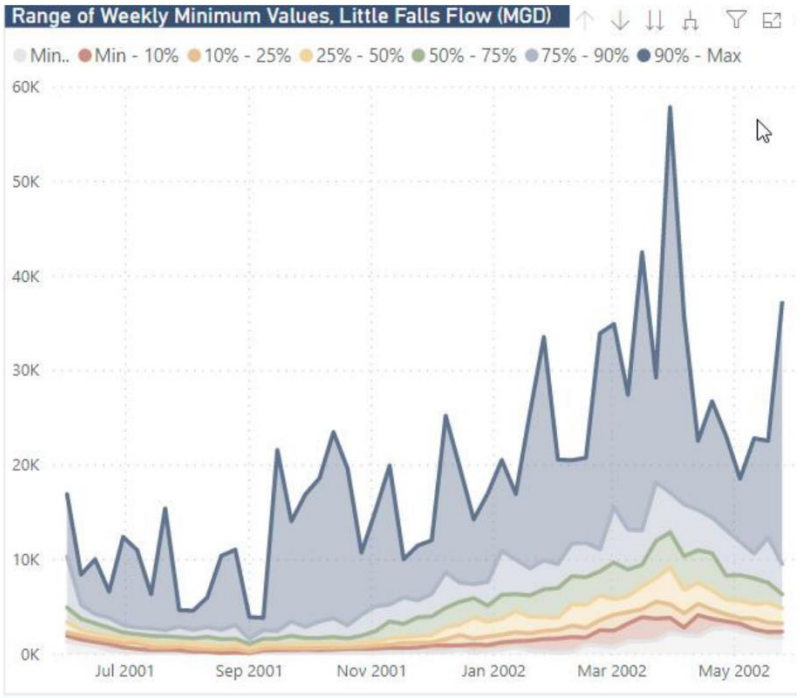


Forecasted Flows with 50 mgd Margin of Safety

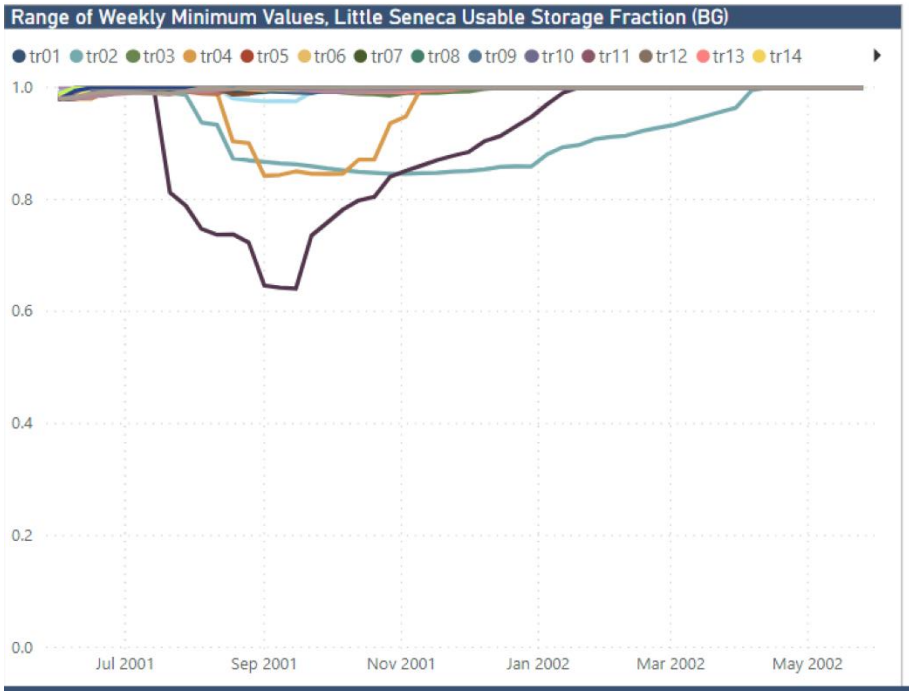


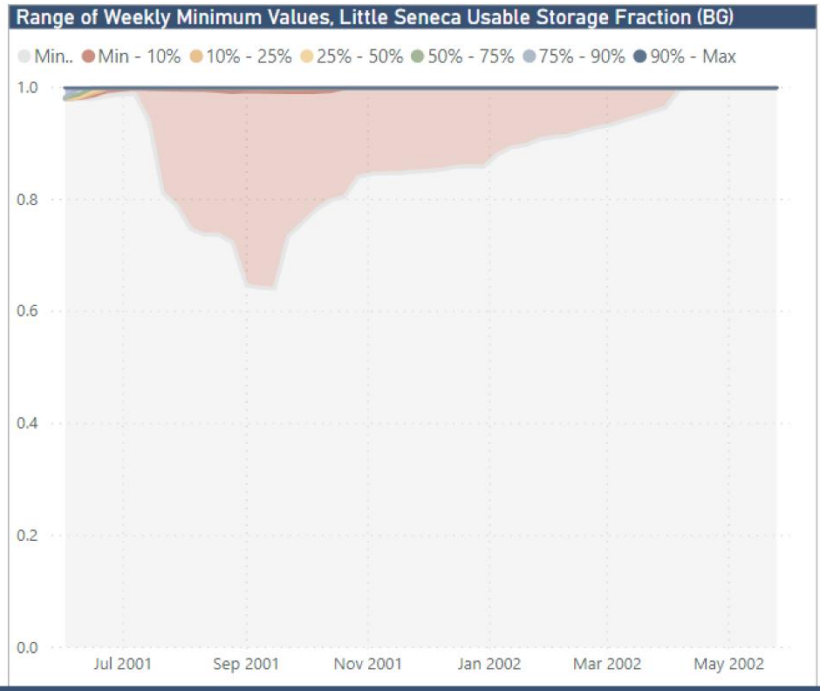
Also Very Possible It Will Get Wet (though it didn't)



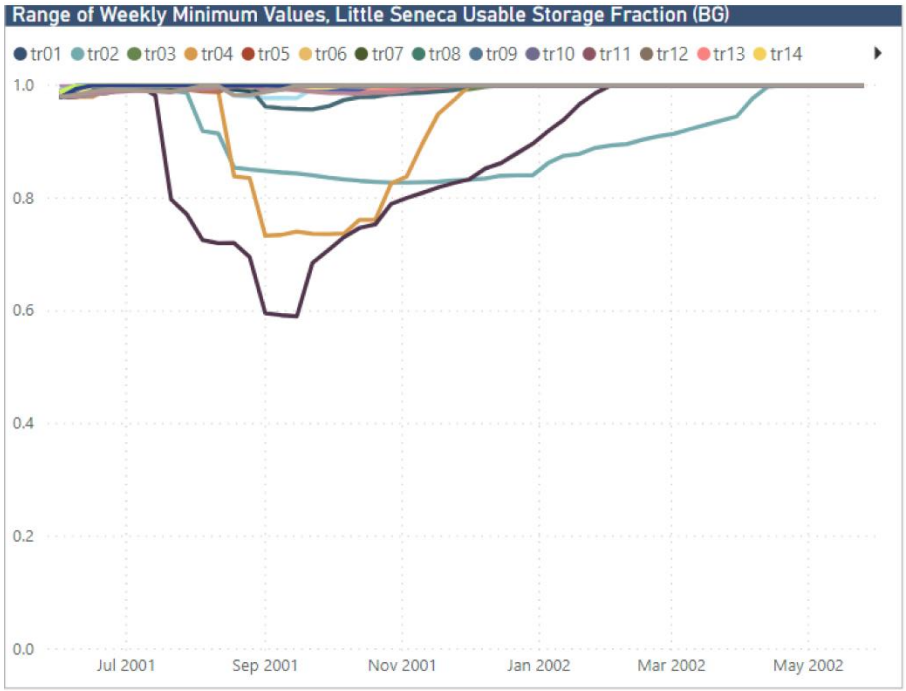


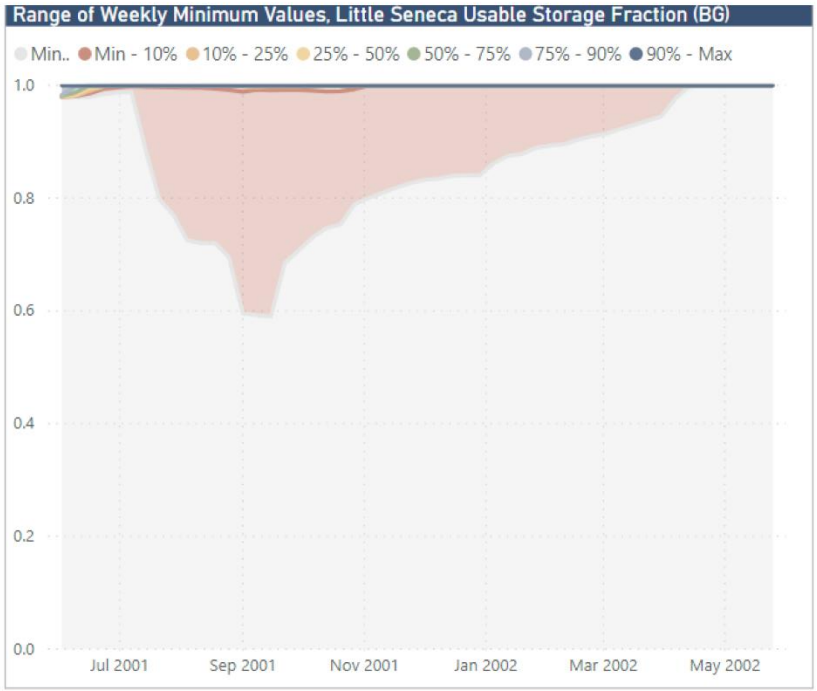
Little Seneca % Usable Storage



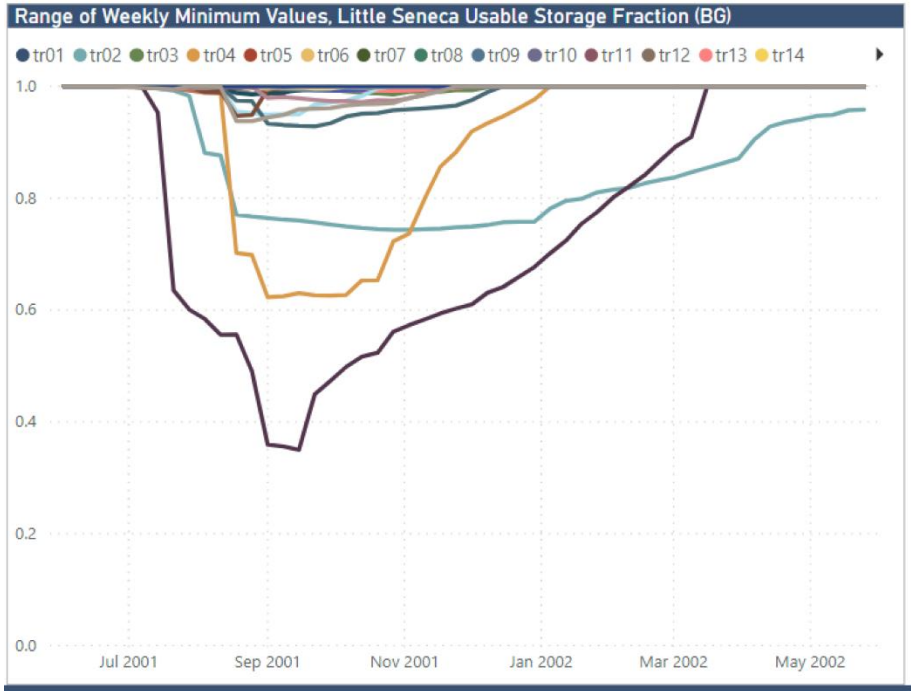


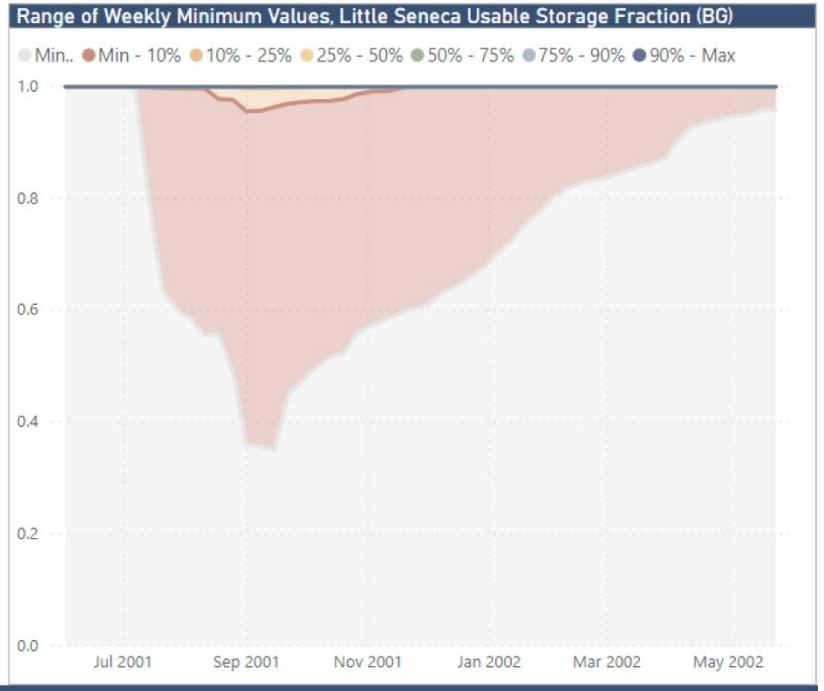
Little Seneca % Usable Storage with 50 mgd Margin of Safety



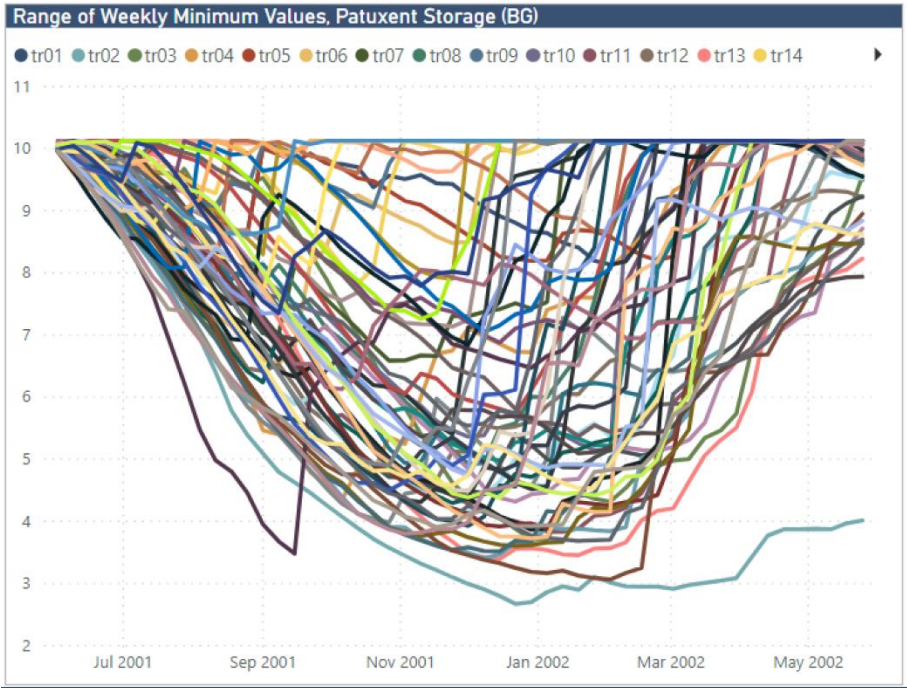


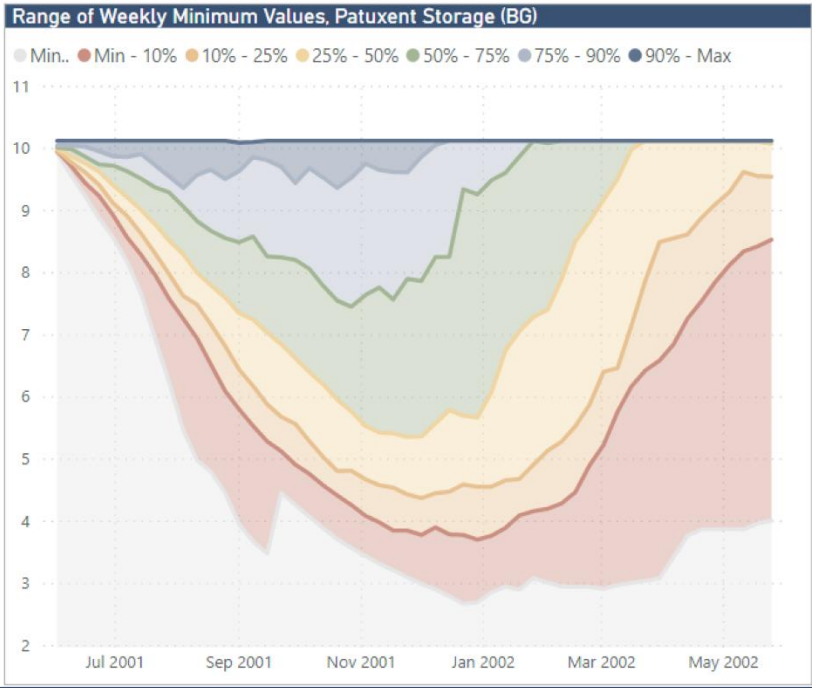
Little Seneca % Usable Storage with 2040 Demands/Sedimentation



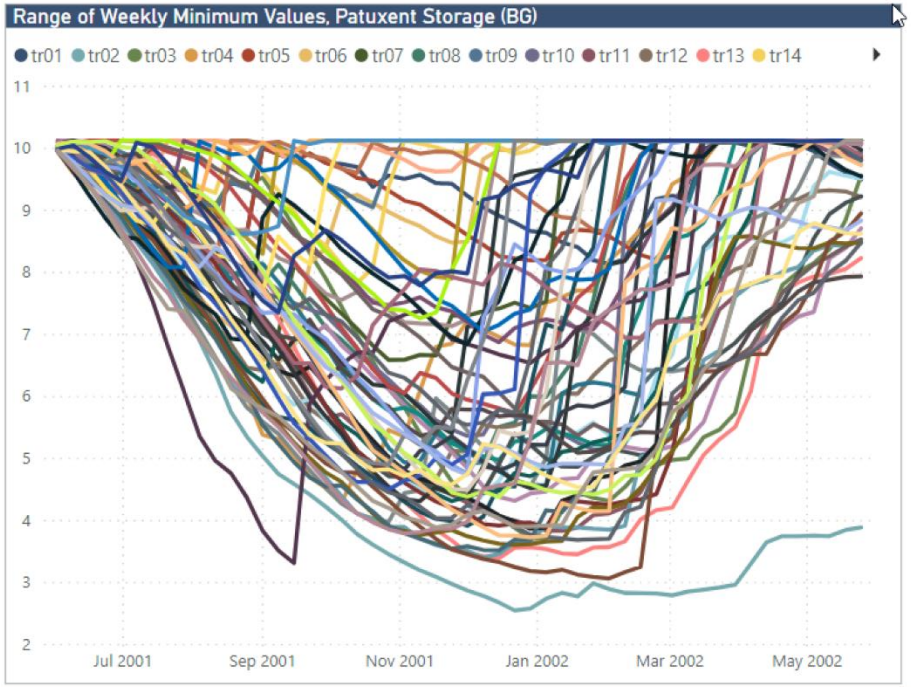


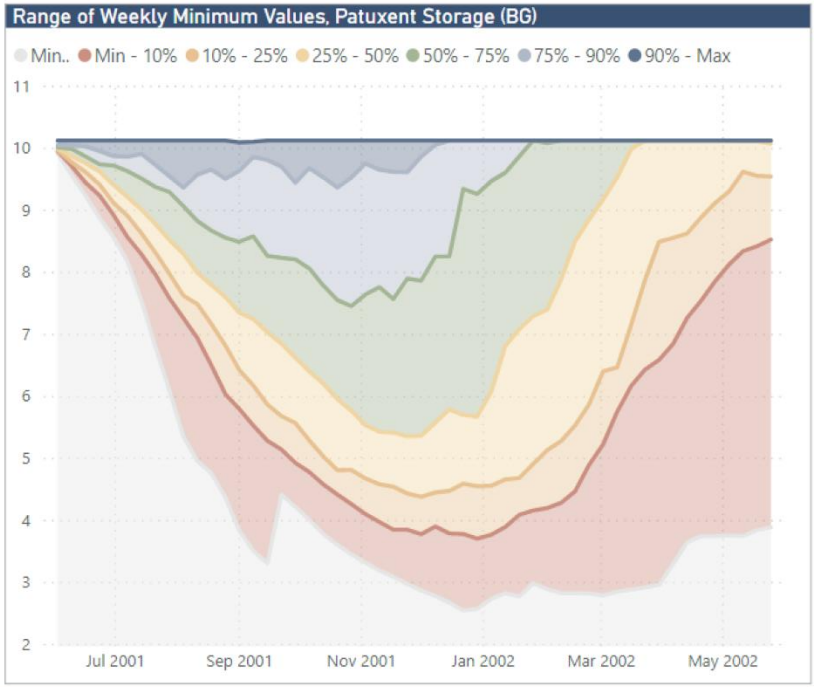
Patuxent Storage



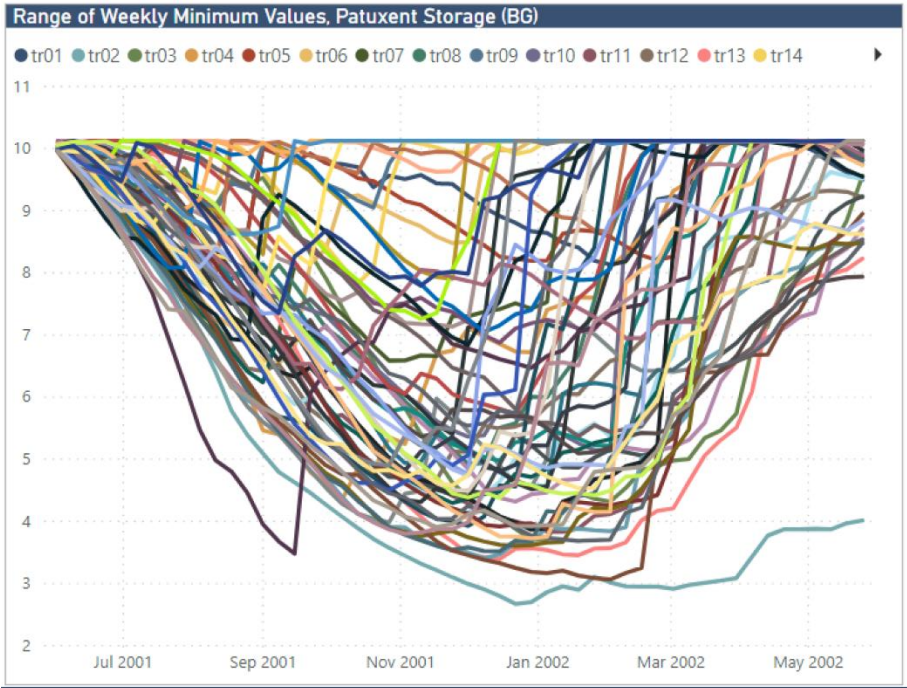


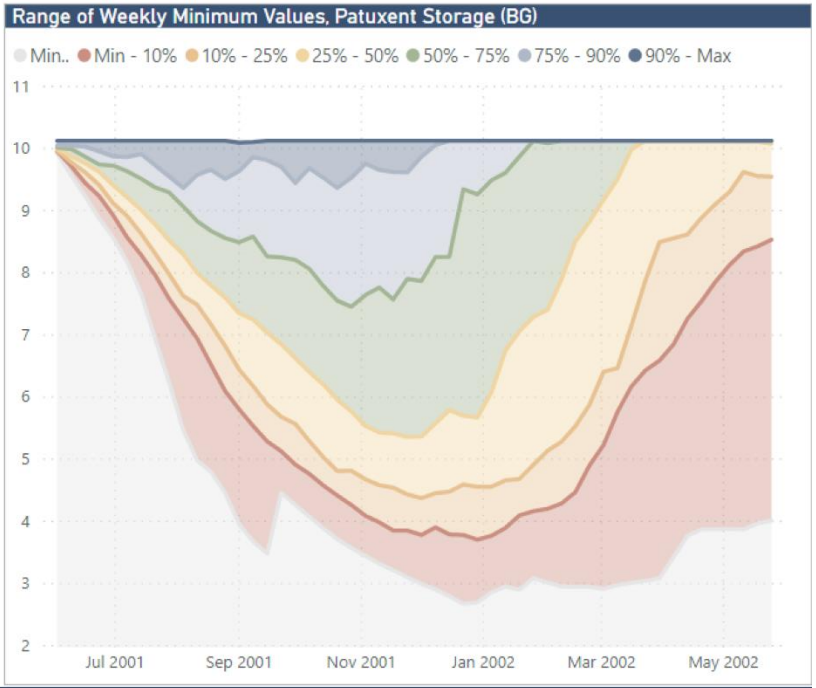
Patuxent Storage, 50 mgd Margin of Safety



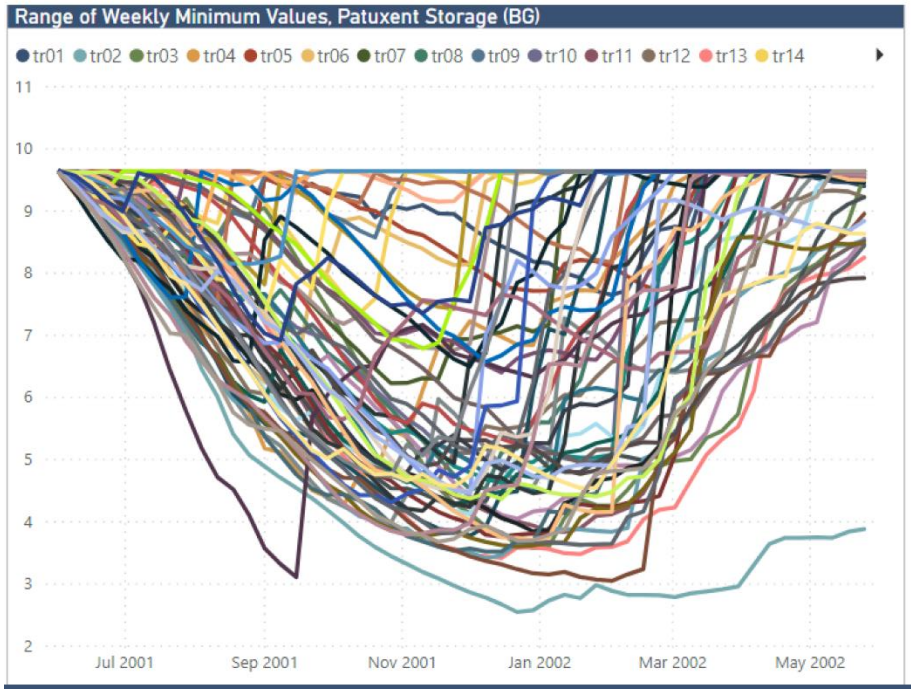


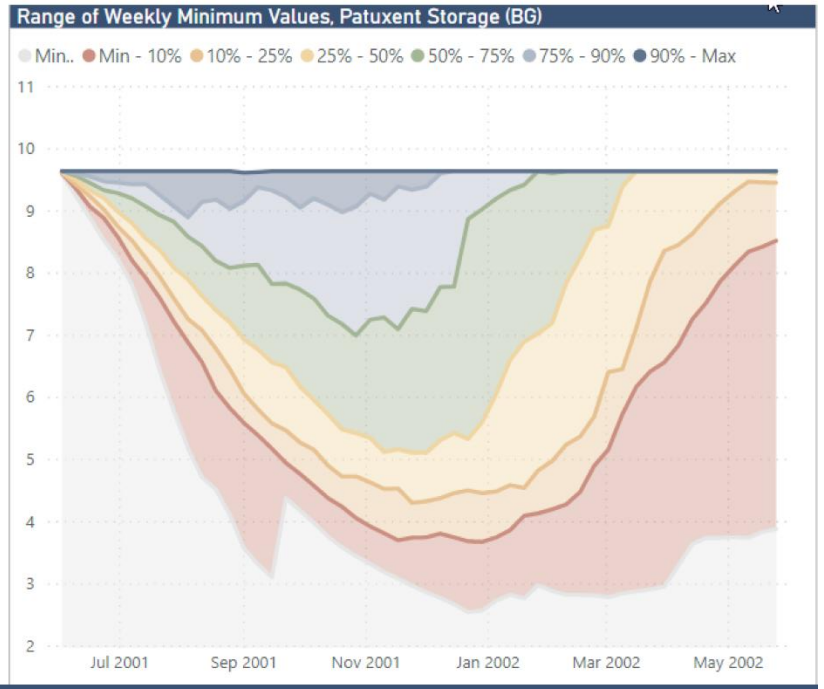
Patuxent Storage



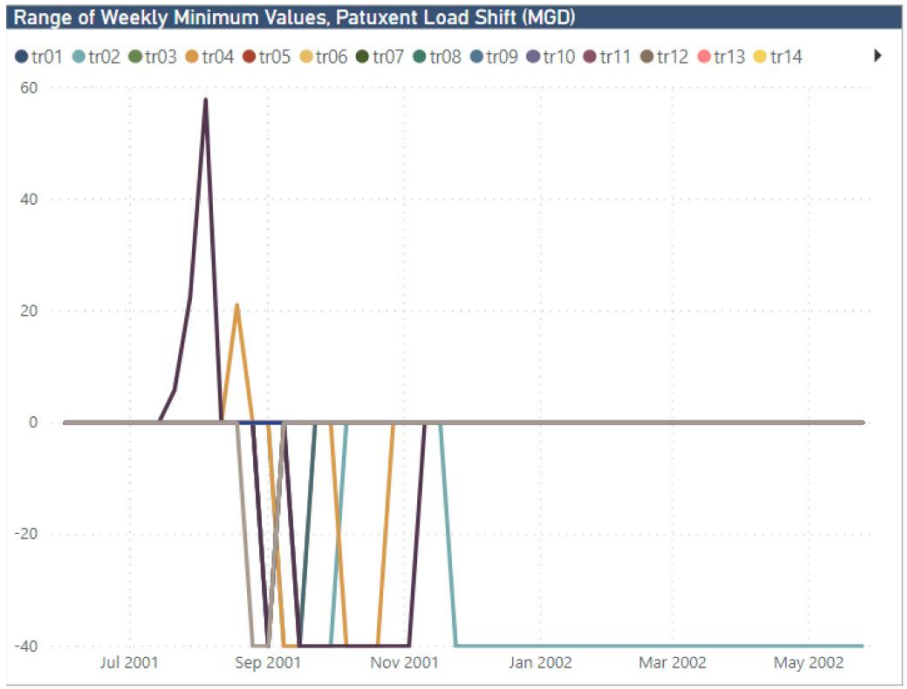


Patuxent Storage, 2040 demands/sedimentation

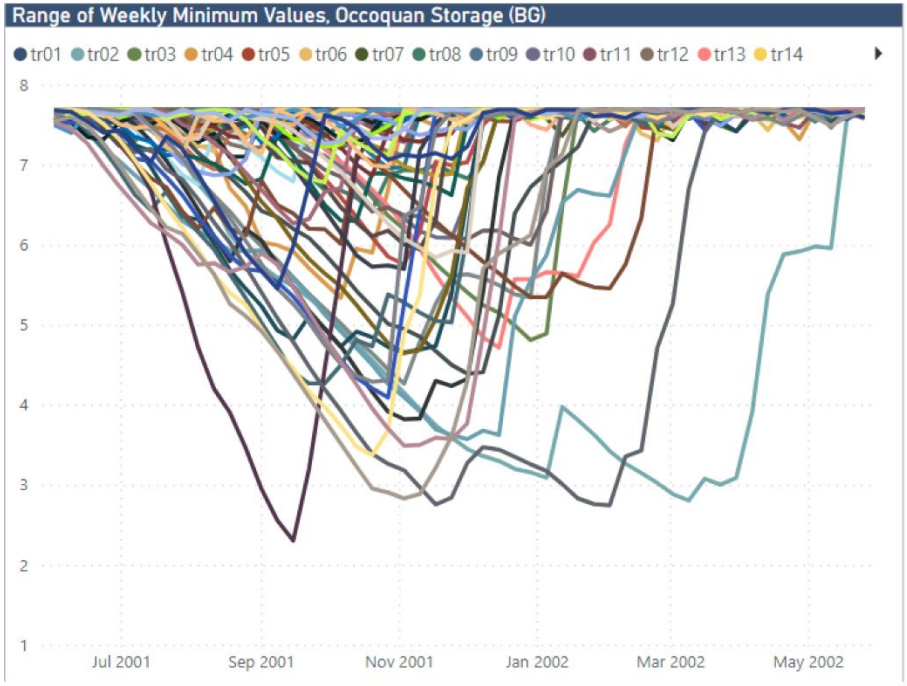


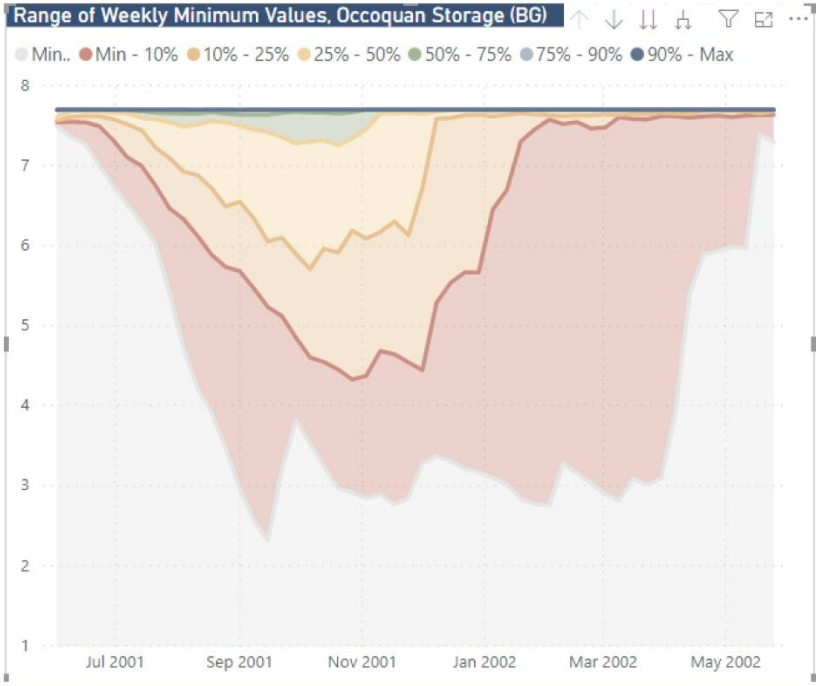


Patuxent Load Shifting

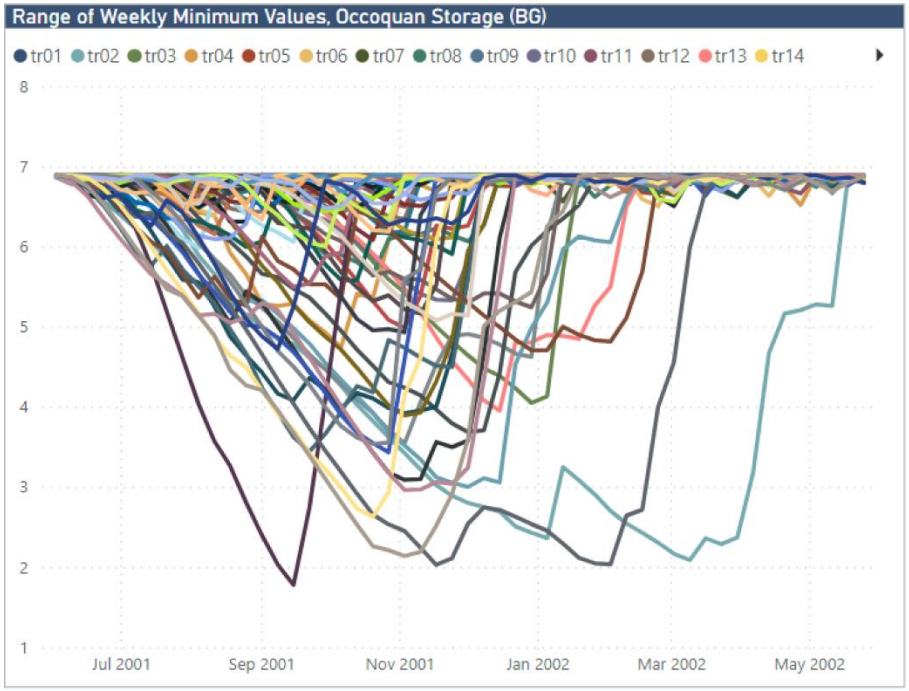


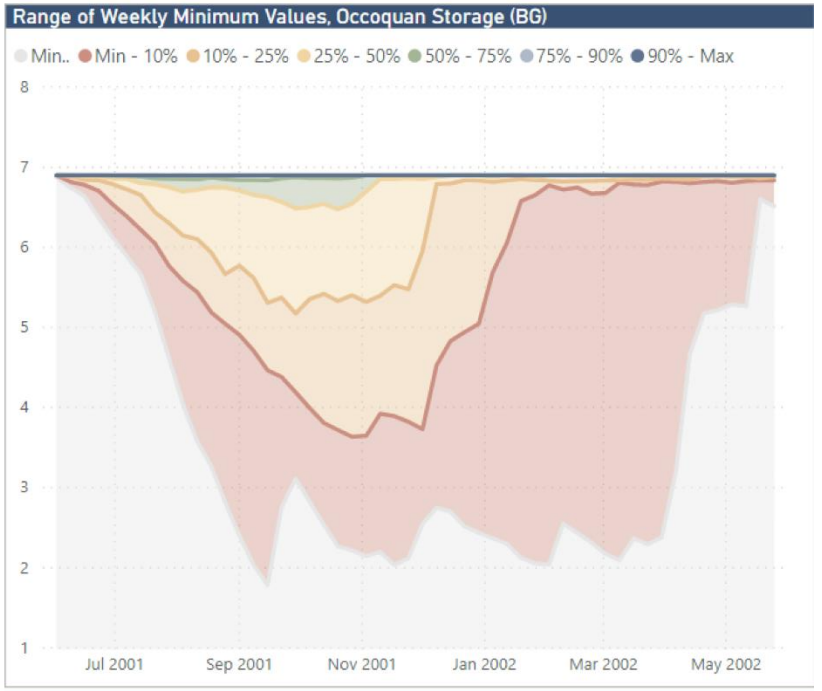
Occoquan Storage

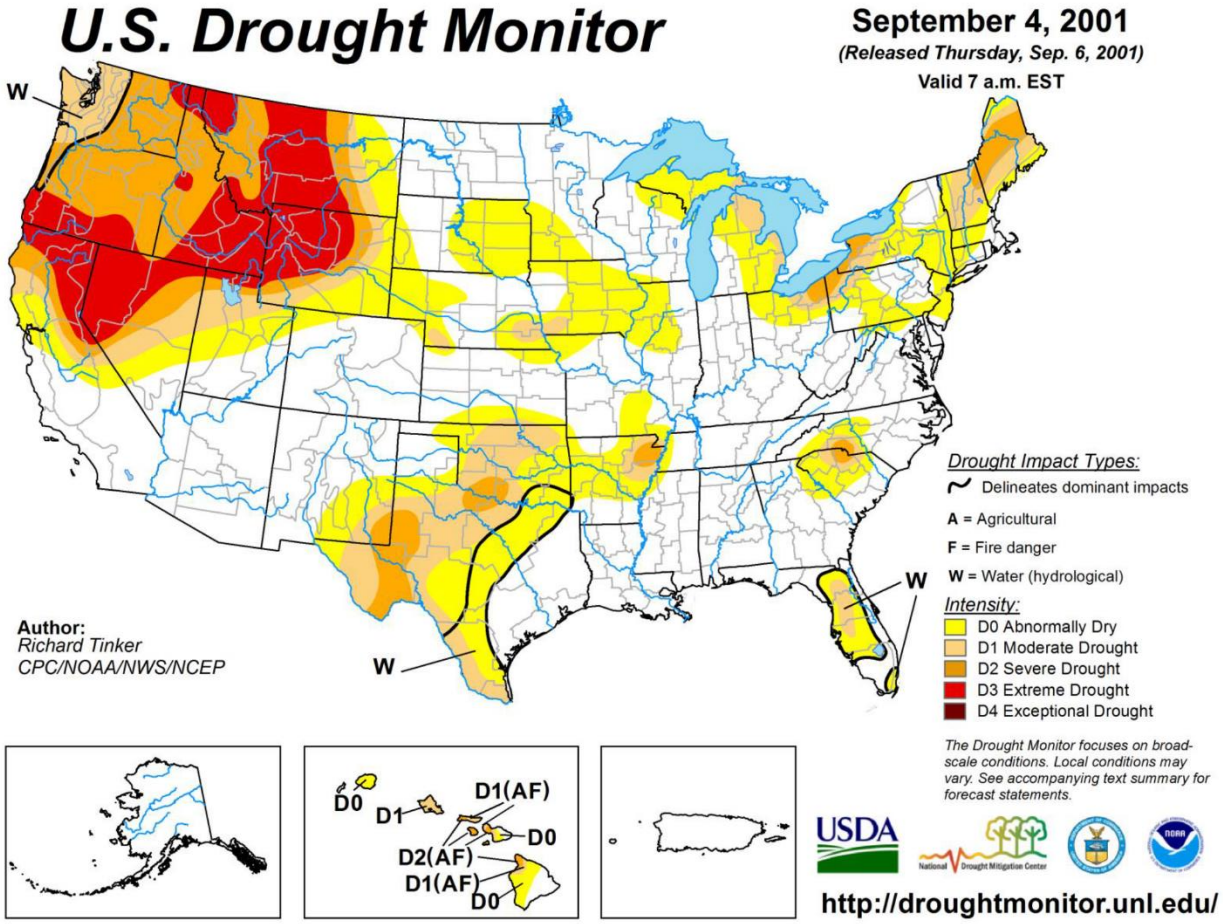




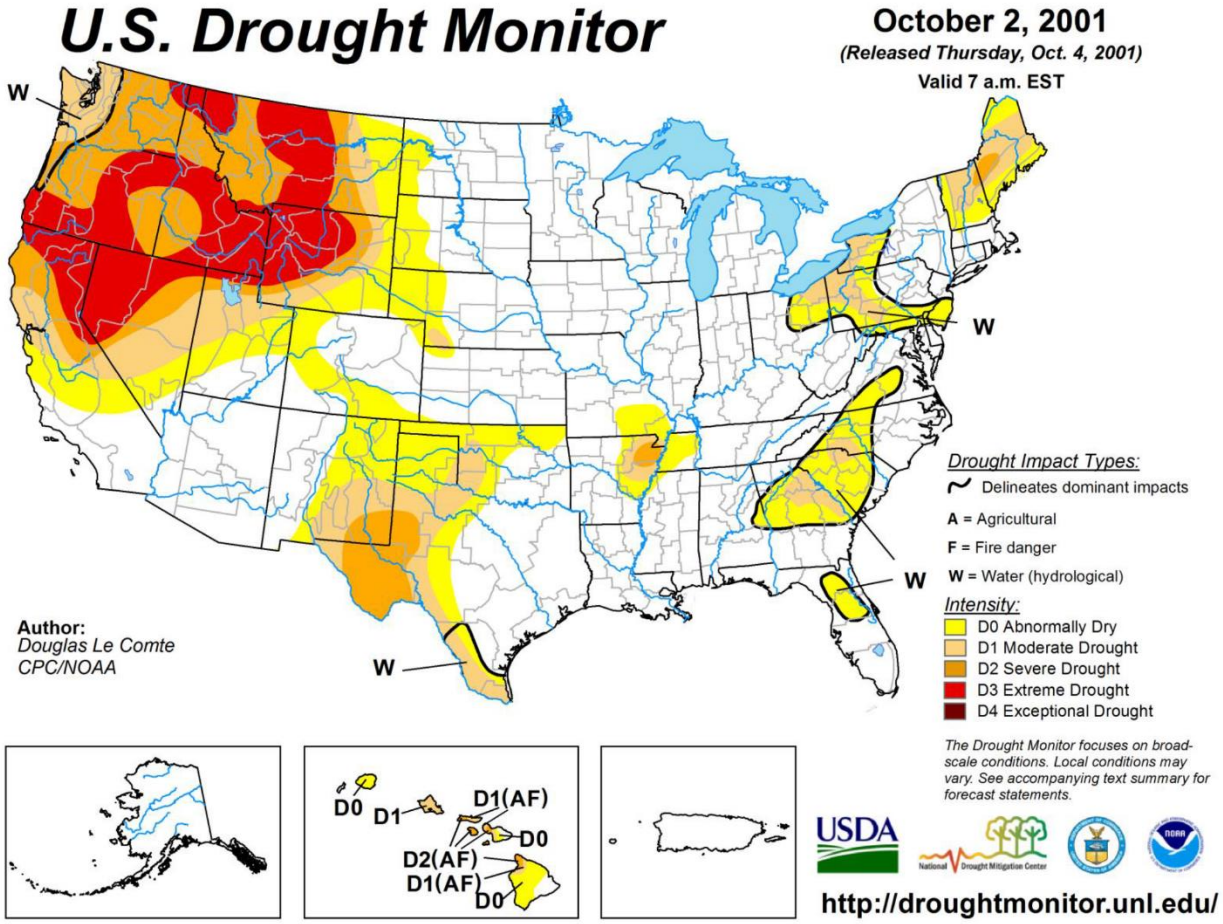
Occoquan Storage, 2040 Demands/Sedimentation






U.S. Drought Monitor
September 4, 2001
(Released Thursday, Sep. 6, 2001)
Valid 7 a.m. EST
W
W
W
Author:
Richard Tinker
CPC/NOAA/NWS/NCEP
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
W = Water (hydrological)
Intensity:
D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
D0
D1
D1(AF)
D0
D2(AF)
D1(AF)
D0
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/

Hazen


U.S. Drought Monitor
October 2, 2001
(Released Thursday, Oct. 4, 2001)
Valid 7 a.m. EST
W
W
W
W
Author:
Douglas Le Comte
CPC/NOAA
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
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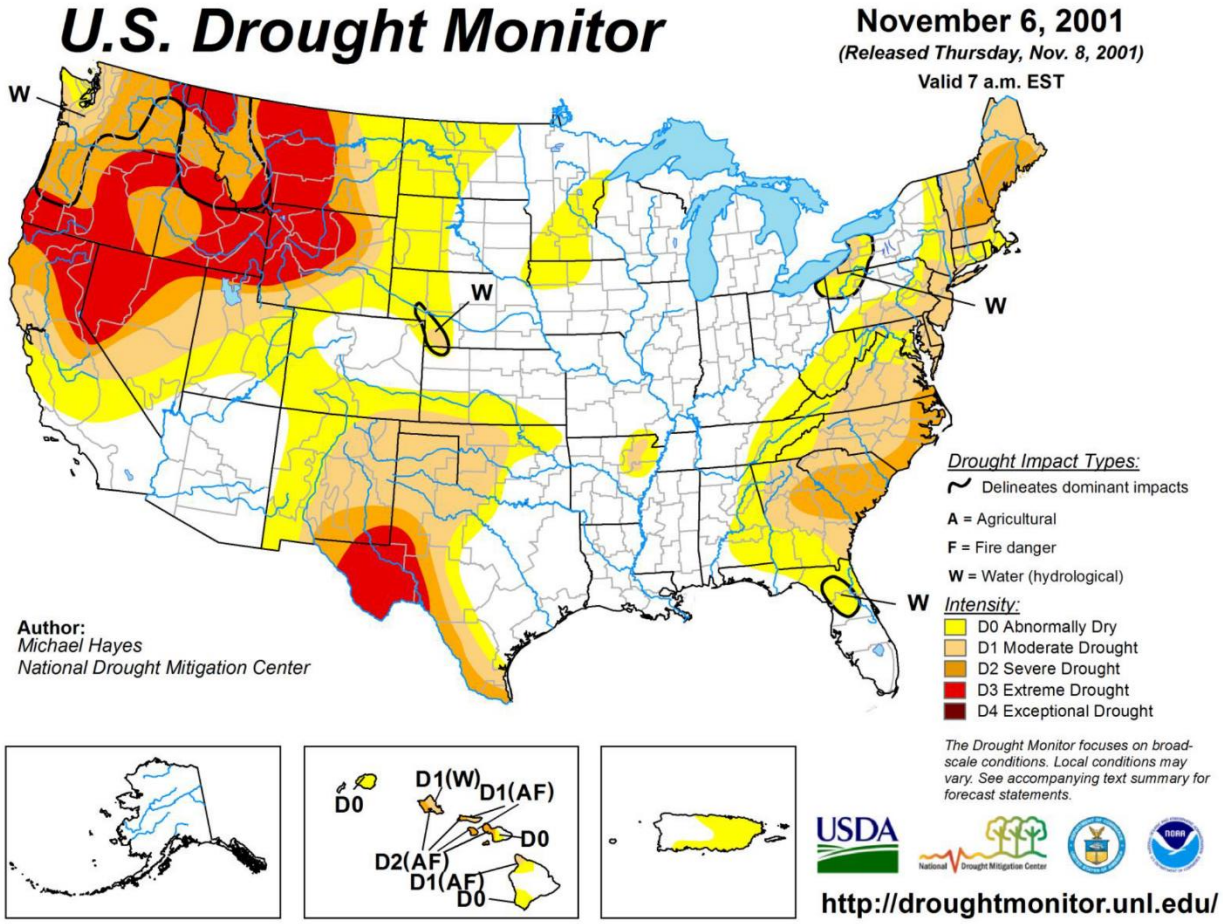
D0
D1
D1(AF)
D0
D2(AF)
D1(AF)
D0
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/


U.S. Drought Monitor
November 6, 2001
(Released Thursday, Nov. 8, 2001)
Valid 7 a.m. EST
W
W
W
W
Author:
Michael Hayes
National Drought Mitigation Center
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
W = Water (hydrological)
Intensity:
D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought
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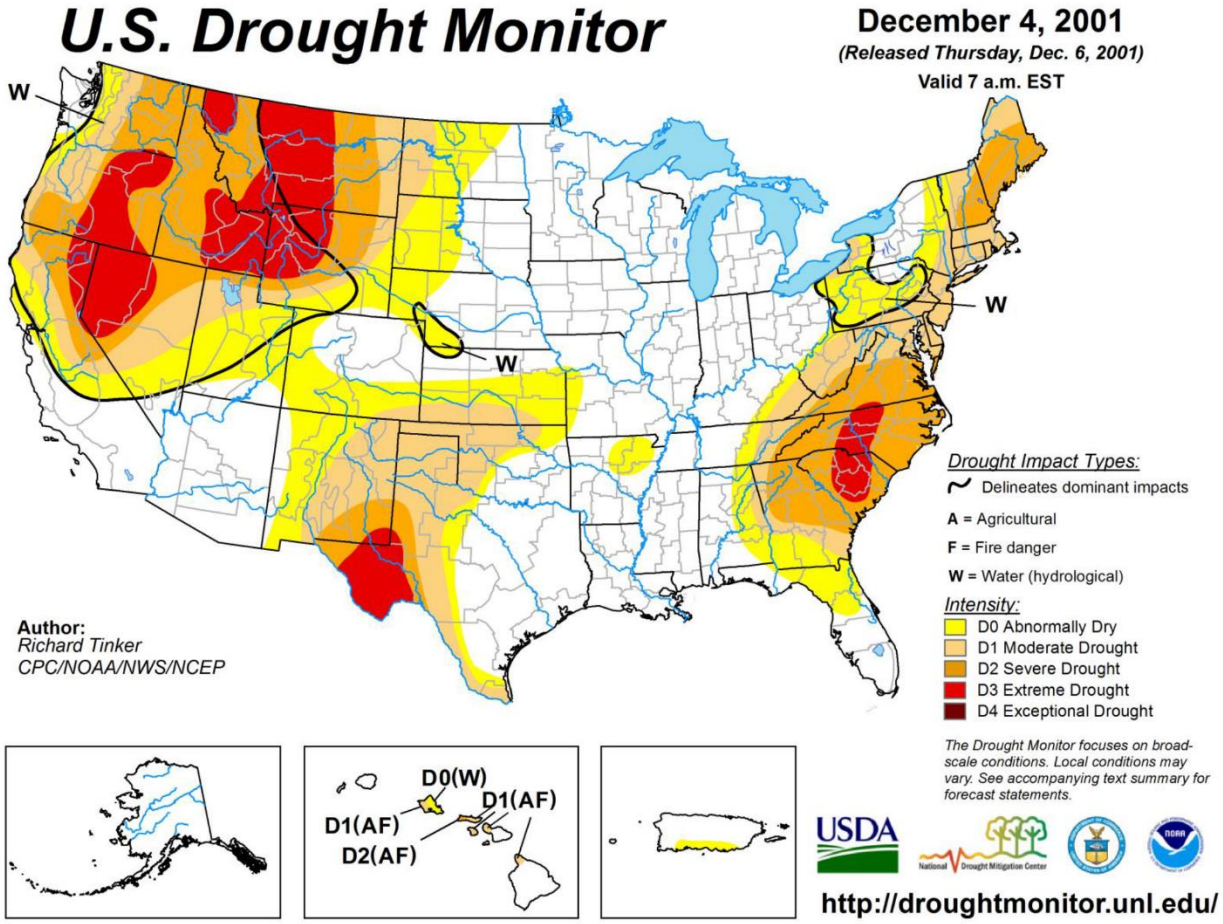
D0
D1(W)
D1(AF)
D0
D2(AF)
D1(AF)
D0
USDA
http://droughtmonitor.unl.edu/


U.S. Drought Monitor
December 4, 2001
(Released Thursday, Dec. 6, 2001)
Valid 7 a.m. EST
W
W
W
Author:
Richard Tinker
CPC/NOAA/NWS/NCEP
Drought Impact Types:
Delineates dominant impacts
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F = Fire danger
W = Water (hydrological)
Intensity:
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D4 Exceptional Drought
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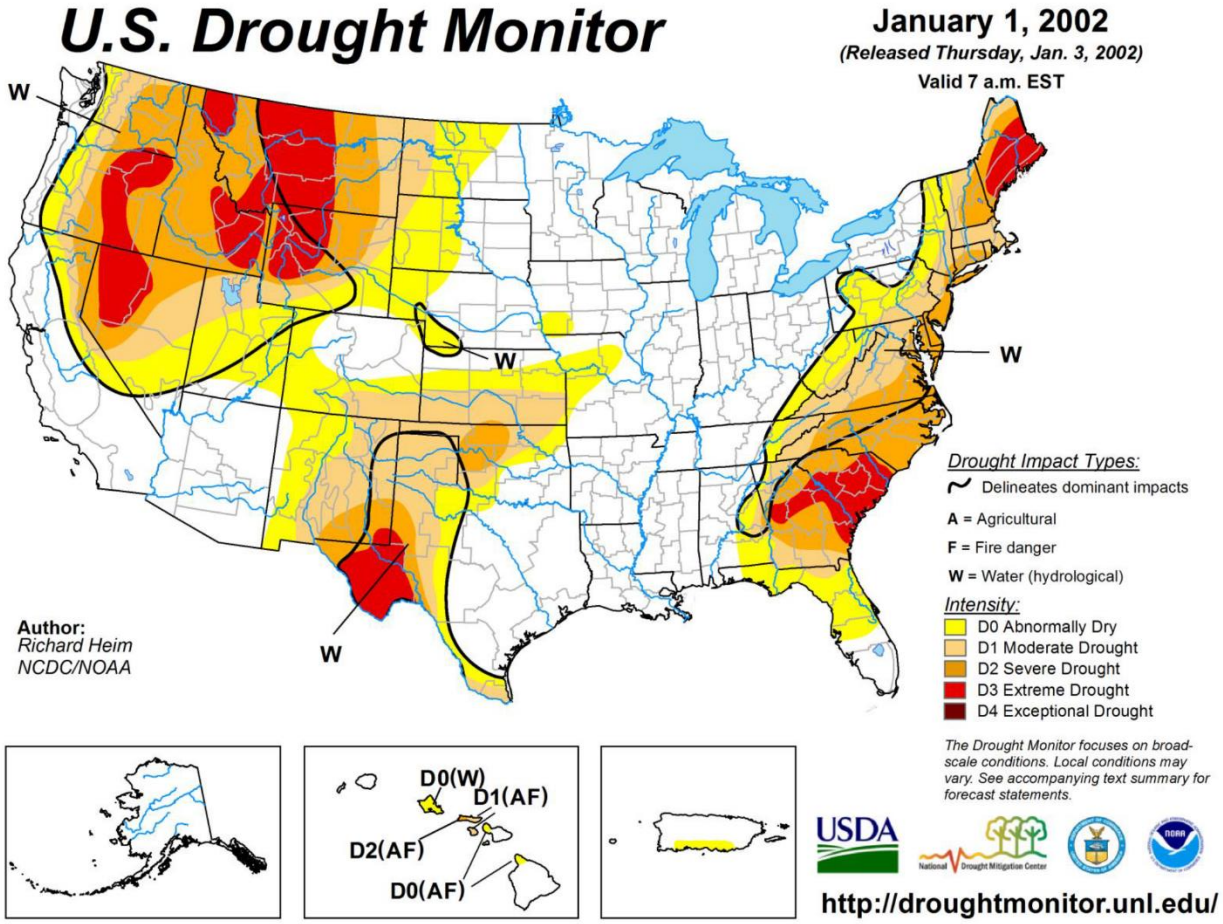
D0(W)
D1(AF)
D1(AF)
D2(AF)
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/


U.S. Drought Monitor
January 1, 2002
(Released Thursday, Jan. 3, 2002)
Valid 7 a.m. EST
W
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W
W
Author:
Richard Heim
NCDC/NOAA
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
W = Water (hydrological)
Intensity:
D0 Abnormally Dry
D1 Moderate Drought
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D3 Extreme Drought
D4 Exceptional Drought
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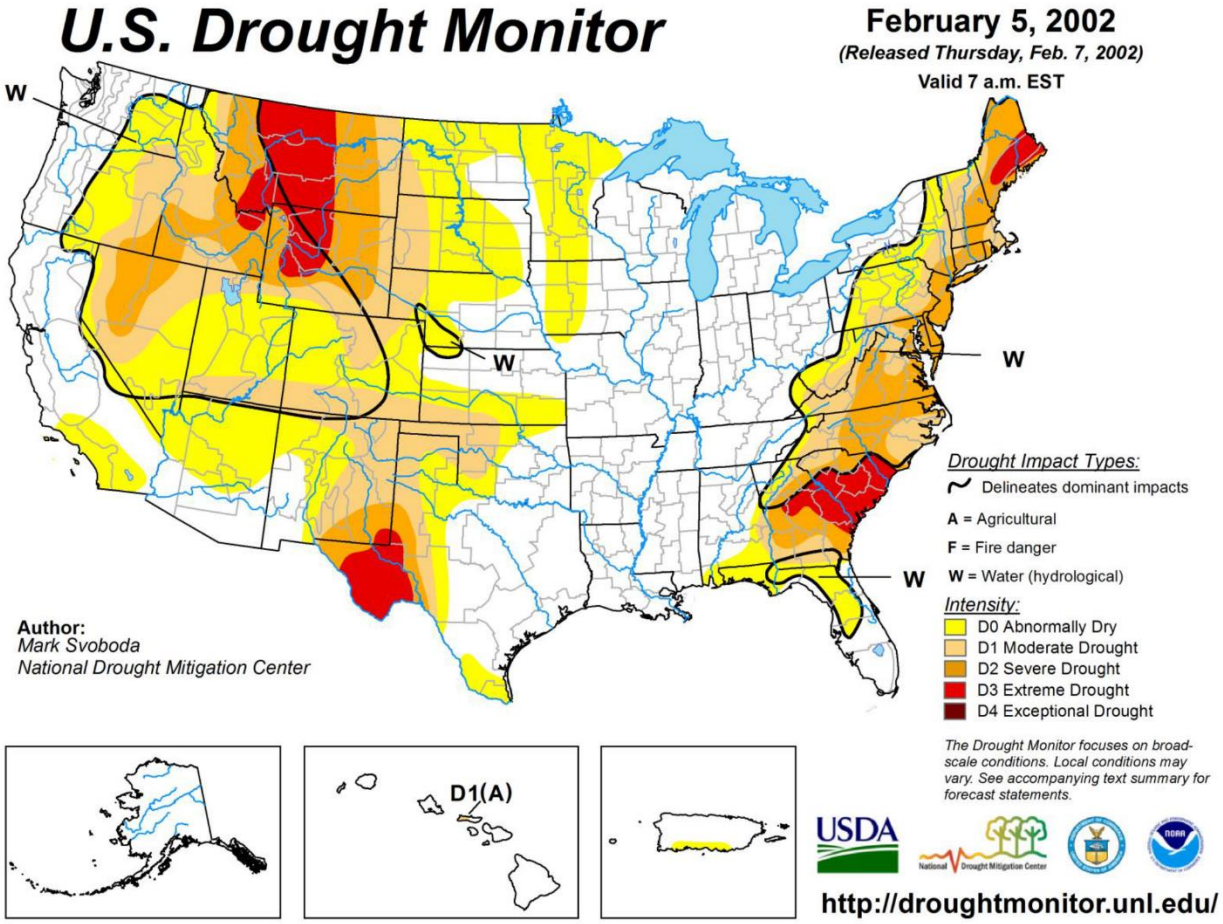
D0(W)
D1(AF)
D2(AF)
D0(AF)
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/


U.S. Drought Monitor
February 5, 2002
(Released Thursday, Feb. 7, 2002)
Valid 7 a.m. EST
W
W
W
W
Author:
Mark Svoboda
National Drought Mitigation Center
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
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Intensity:
D0 Abnormally Dry
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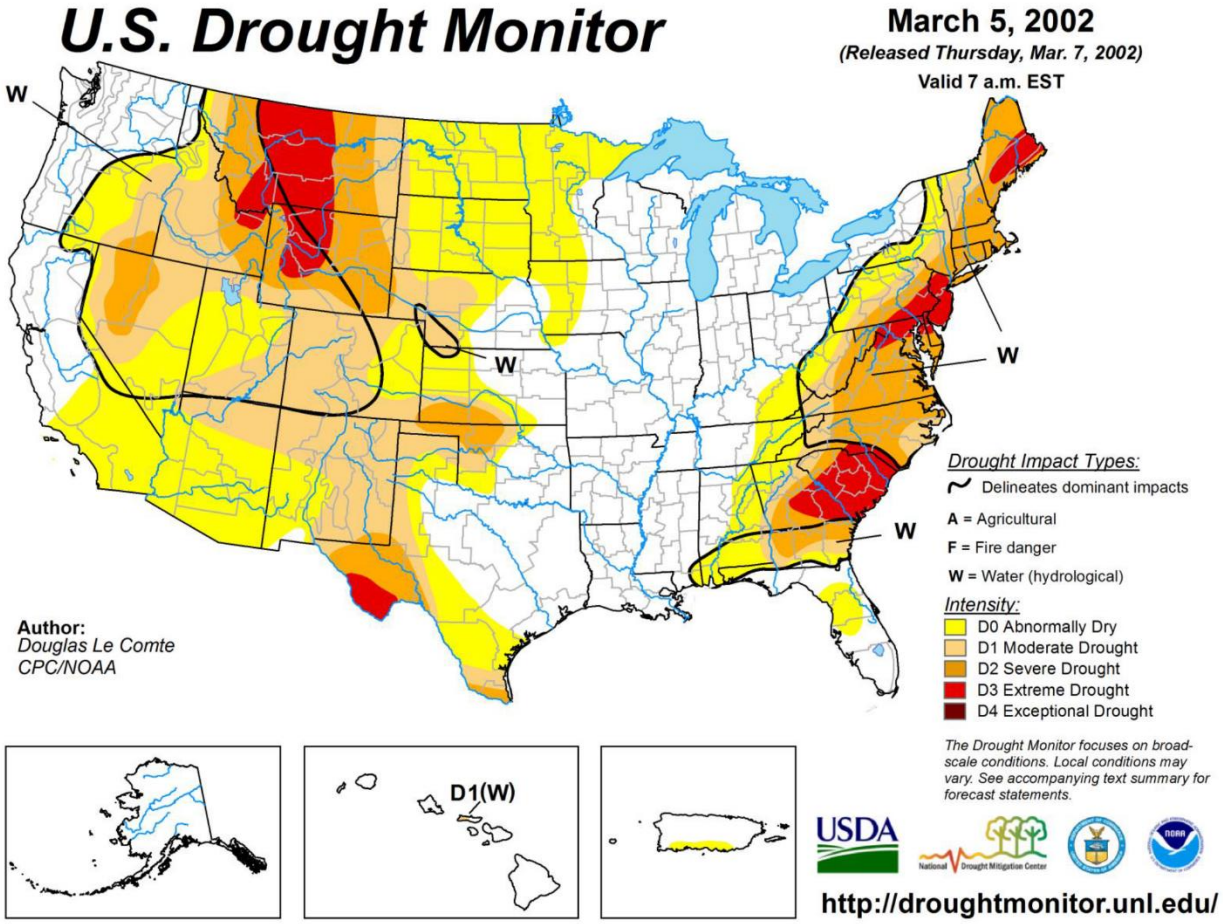
D4 Exceptional Drought
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
D1(A)
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/

Hazen


U.S. Drought Monitor
March 5, 2002
(Released Thursday, Mar. 7, 2002)
Valid 7 a.m. EST
W
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W
W
Author:
Douglas Le Comte
CPC/NOAA
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
W = Water (hydrological)
Intensity:
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D4 Exceptional Drought
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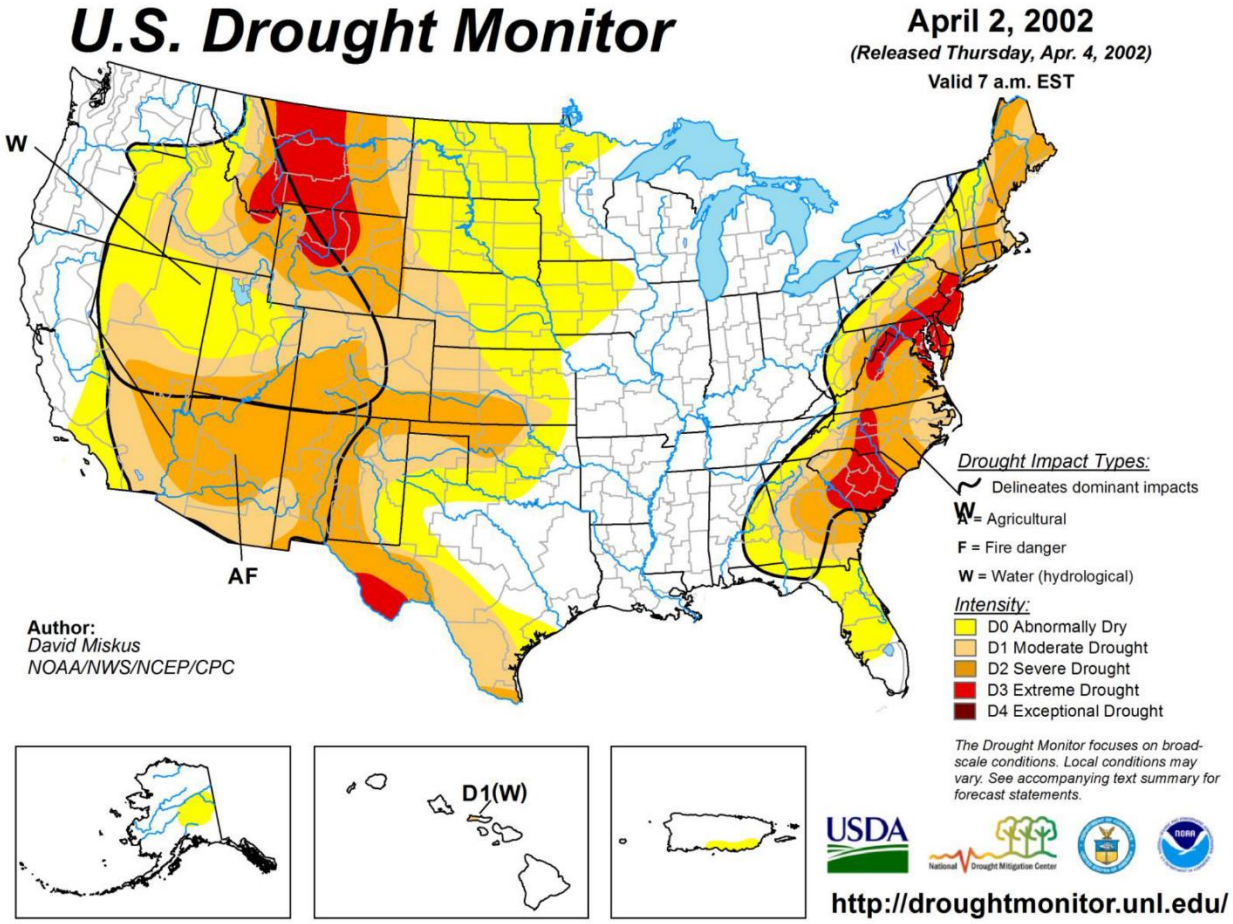
D1(W)
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/

Hazen


U.S. Drought Monitor
April 2, 2002
(Released Thursday, Apr. 4, 2002)
Valid 7 a.m. EST
W
AF
Author:
David Miskus
NOAA/NWS/NCEP/CPC
D1(W)
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
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Intensity:
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USDA
National Drought Mitigation Center
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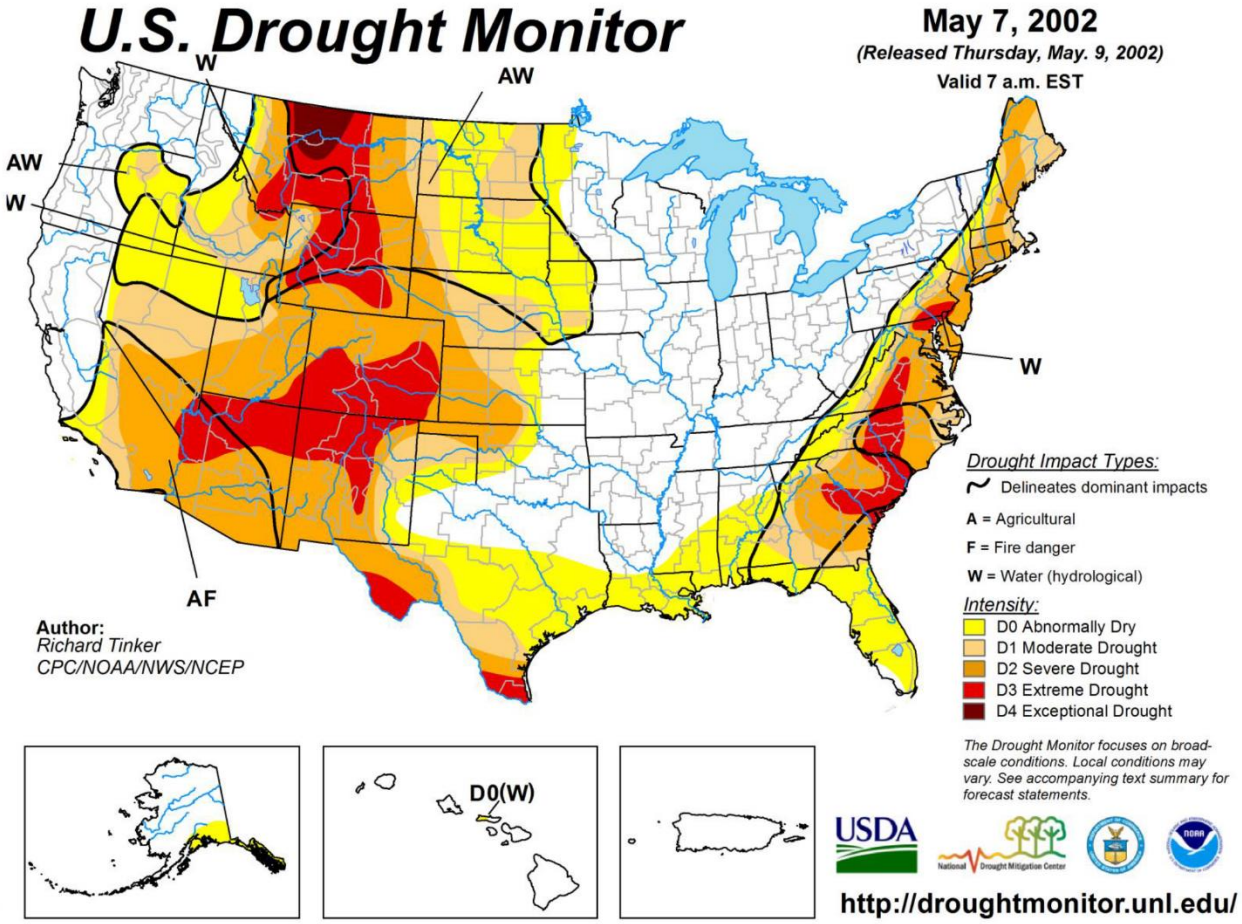
U.S. Drought Monitor
May 7, 2002
(Released Thursday, May. 9, 2002)
Valid 7 a.m. EST
W
AW
AW
W
W
AF
Author:
Richard Tinker
CPC/NOAA/NWS/NCEP
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
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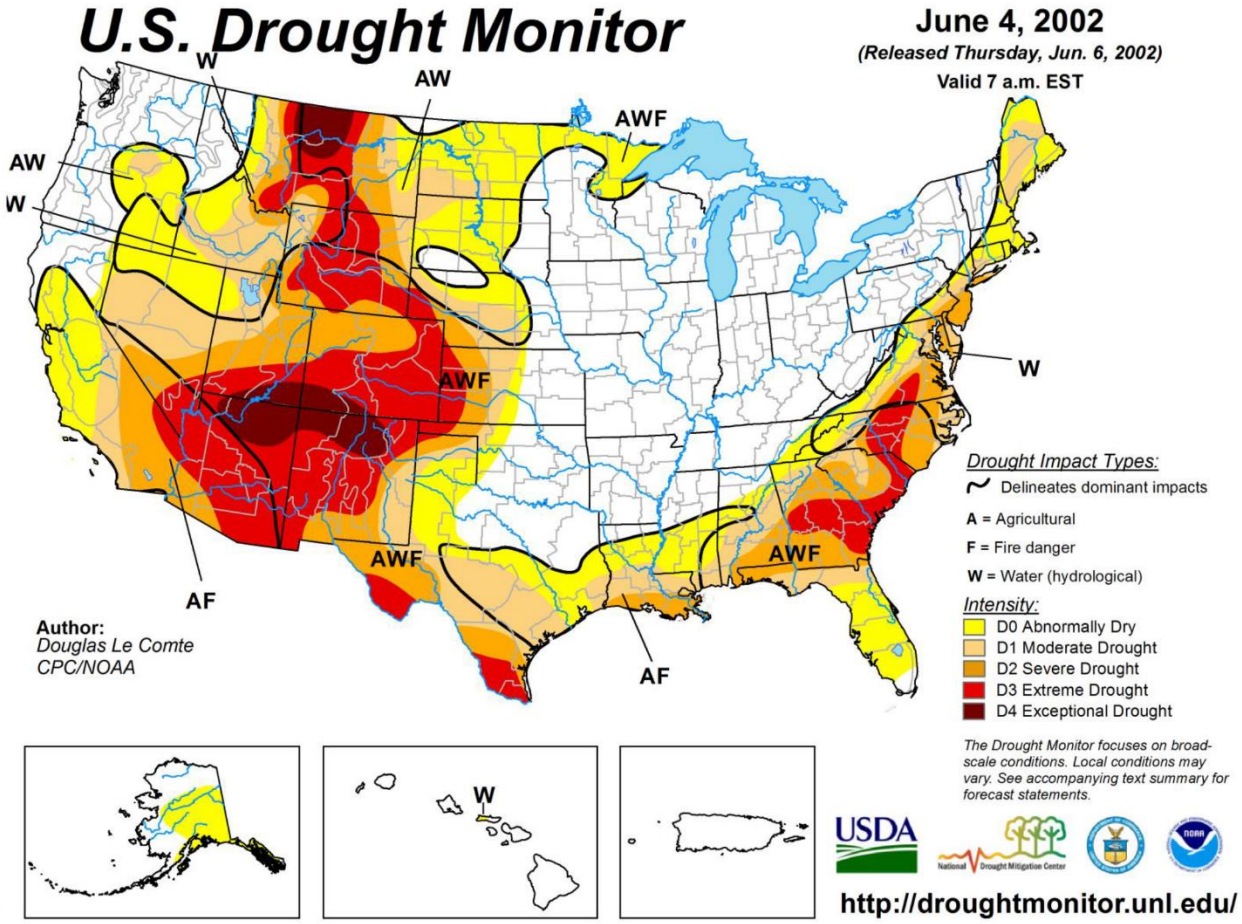
D0(W)
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/

Hazen


U.S. Drought Monitor
June 4, 2002
(Released Thursday, Jun. 6, 2002)
Valid 7 a.m. EST
W
AW
AWF
AW
W
AWF
W
AWF
AWF
AF
AF
Author:
Douglas Le Comte
CPC/NOAA
Drought Impact Types:
Delineates dominant impacts
A = Agricultural
F = Fire danger
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D4 Exceptional Drought
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.
W
USDA
National Drought Mitigation Center
http://droughtmonitor.unl.edu/

Model Output From Sept 1, 2001 and Jan 1, 2002 also shown

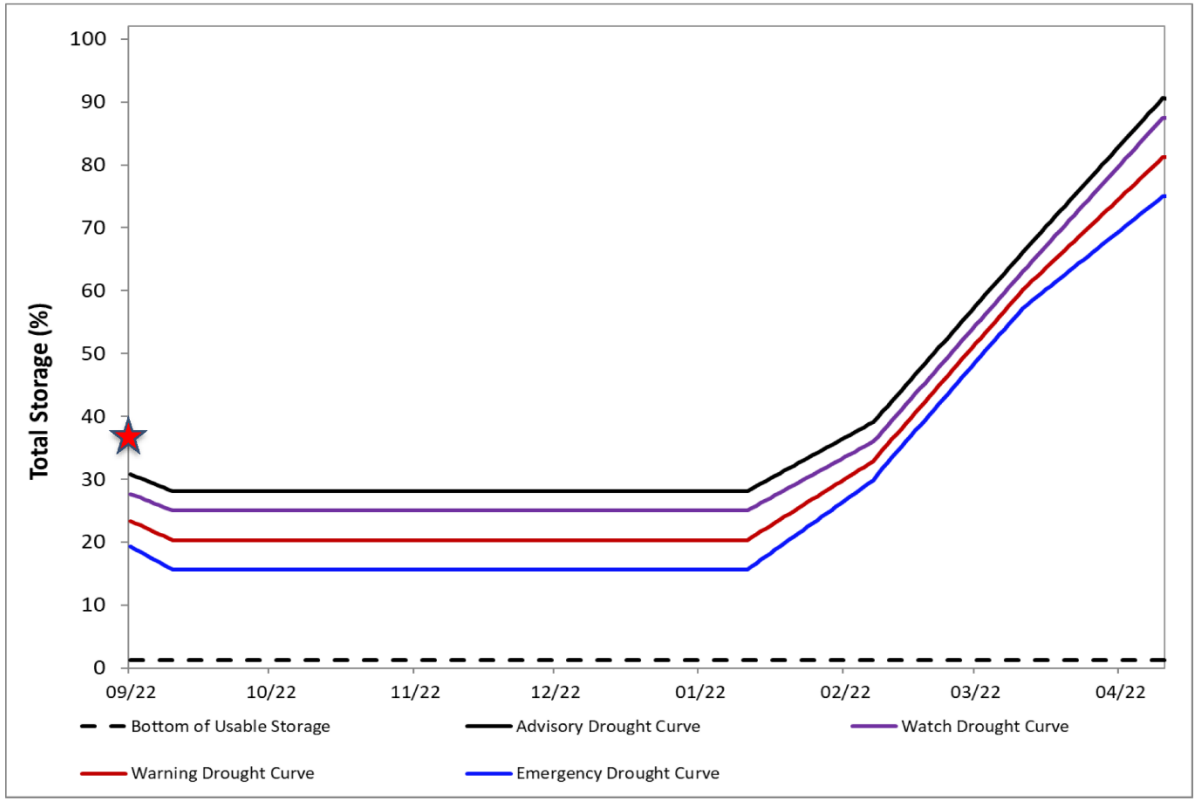
Summary from Dashboard Demo

- Existing ICPRB OASIS model is available to support decision-making through drought and other conditions
- Convert forecast information into predictions of system performance
  - Quantify the risks of undesirable outcomes
  - Evaluate the benefits of modified operations
- Support long-term planning to improve system reliability under future scenarios

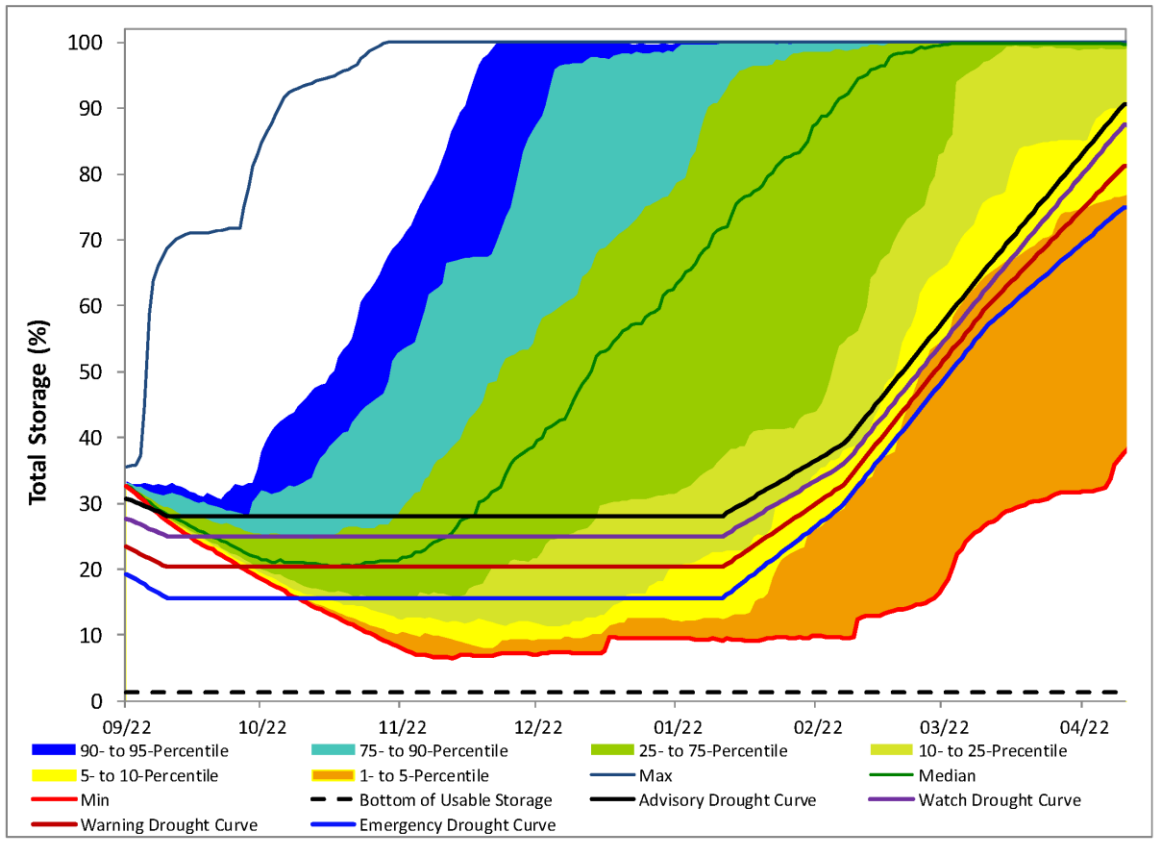
Example: Aquarion Water Company

- Aquarion Water Company provides water to Greenwich, Stamford, and Greater Bridgeport Area
- OASIS model developed for full system in 2015, 2016 one of the worst droughts on record
- How do we best balance cost and reliability?

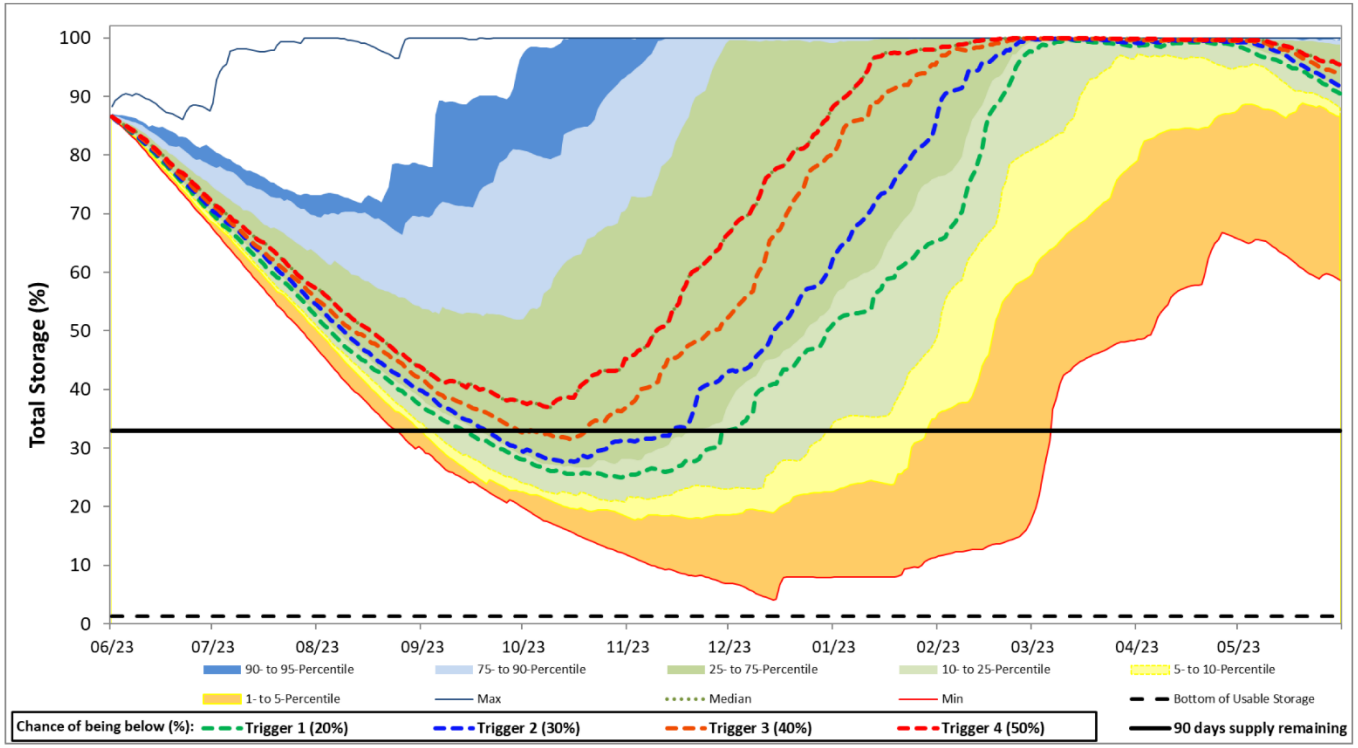
2016


Total Storage (%)
100
90
80
70
60
50
40
30
20
10
0
09/22
10/22
11/22
12/22
01/22
02/22
03/22
04/22
Bottom of Usable Storage
Advisory Drought Curve
Watch Drought Curve
Warning Drought Curve
Emergency Drought Curve

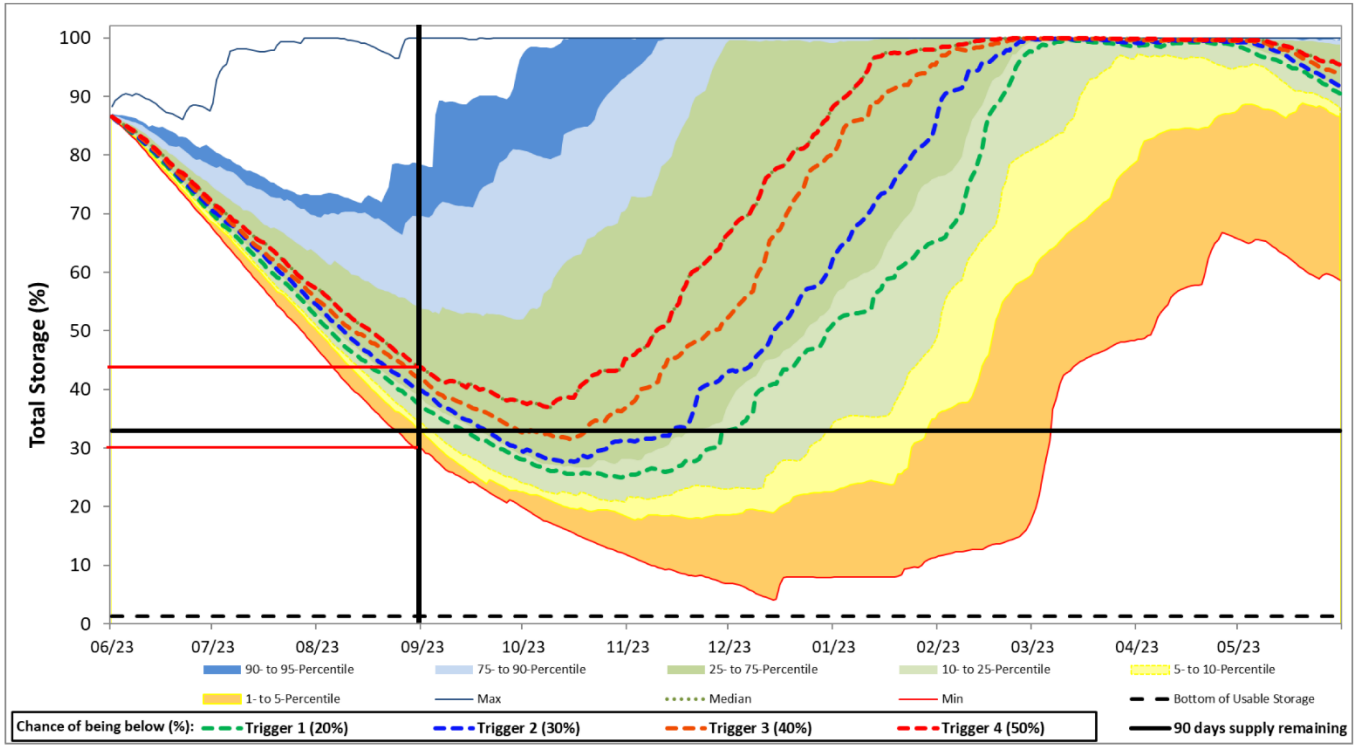
2016


Total Storage (%)
100
90
80
70
60
50
40
30
20
10
0
09/22
10/22
11/22
12/22
01/22
02/22
03/22
04/22
90- to 95-Percentile
75- to 90-Percentile
25- to 75-Percentile
10- to 25-Precentile
5- to 10-Percentile
1- to 5-Percentile
Max
Median
Min
Bottom of Usable Storage
Advisory Drought Curve
Watch Drought Curve
Warning Drought Curve
Emergency Drought Curve

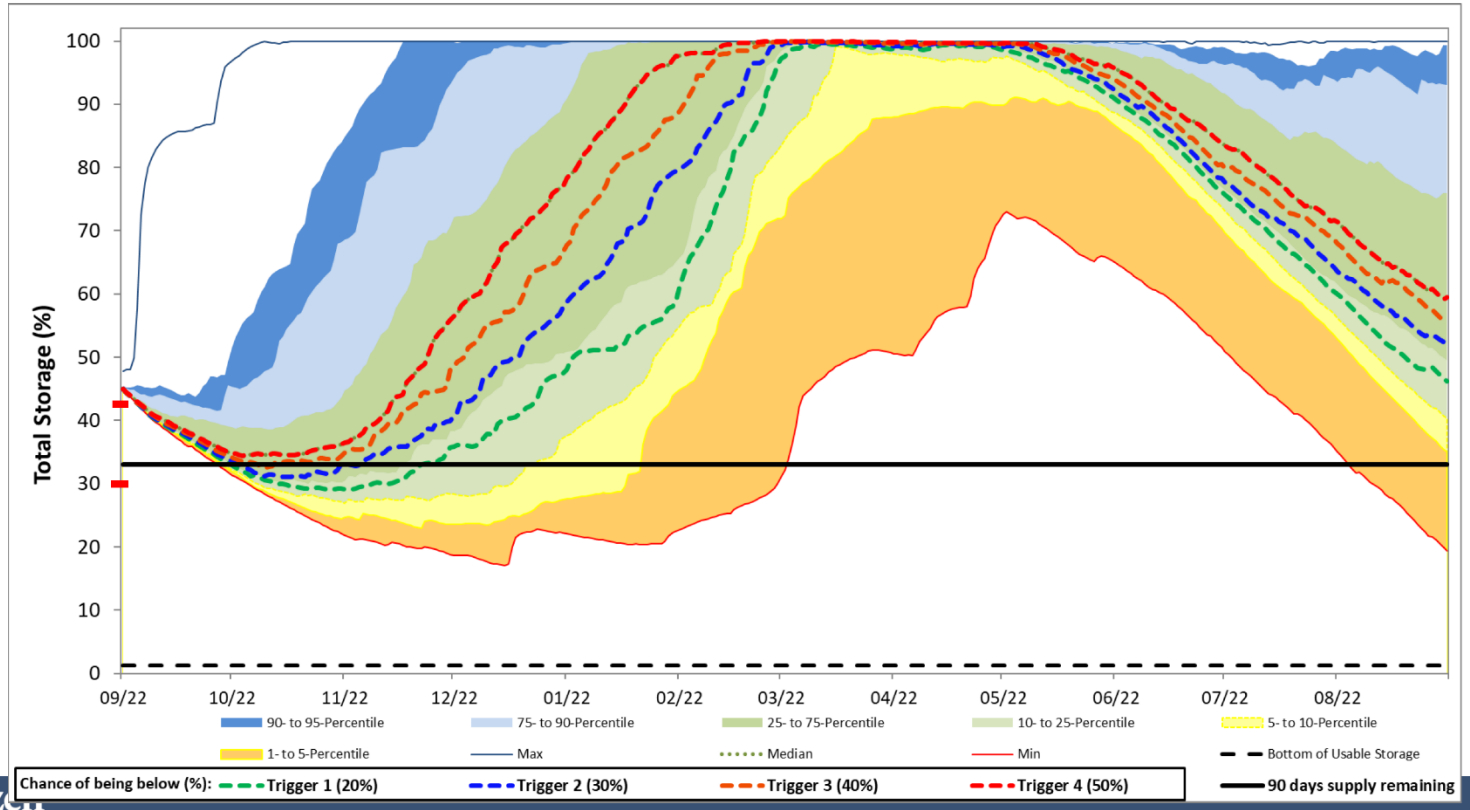
Recent Forecasts: June 2020



Recent Forecasts: June 2020



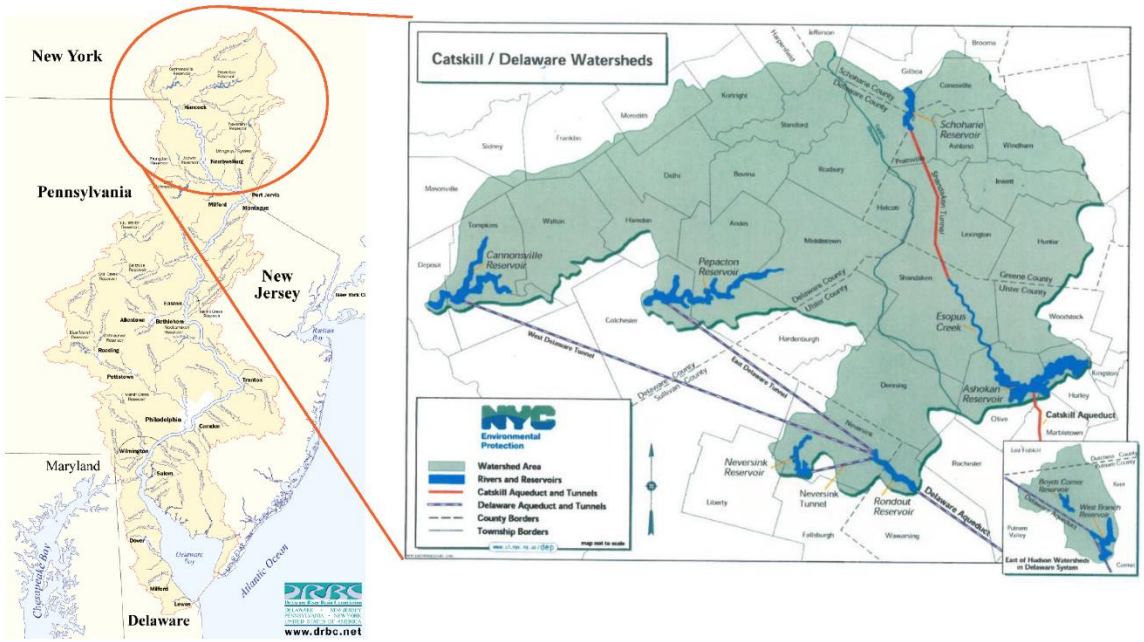
Recent Forecasts: September 2020



Delaware River Basin

Balancing water supply, water quality, fisheries, environmental, and recreation objectives

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



Delaware River Basin Compact

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

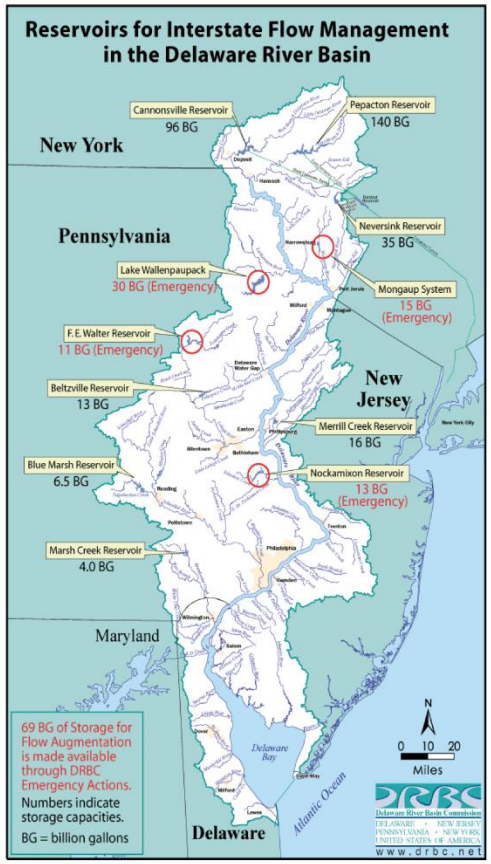
FOUR STATES SIGN DELAWARE PACT

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.



2008 Flexible Flow Management Plan

- 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

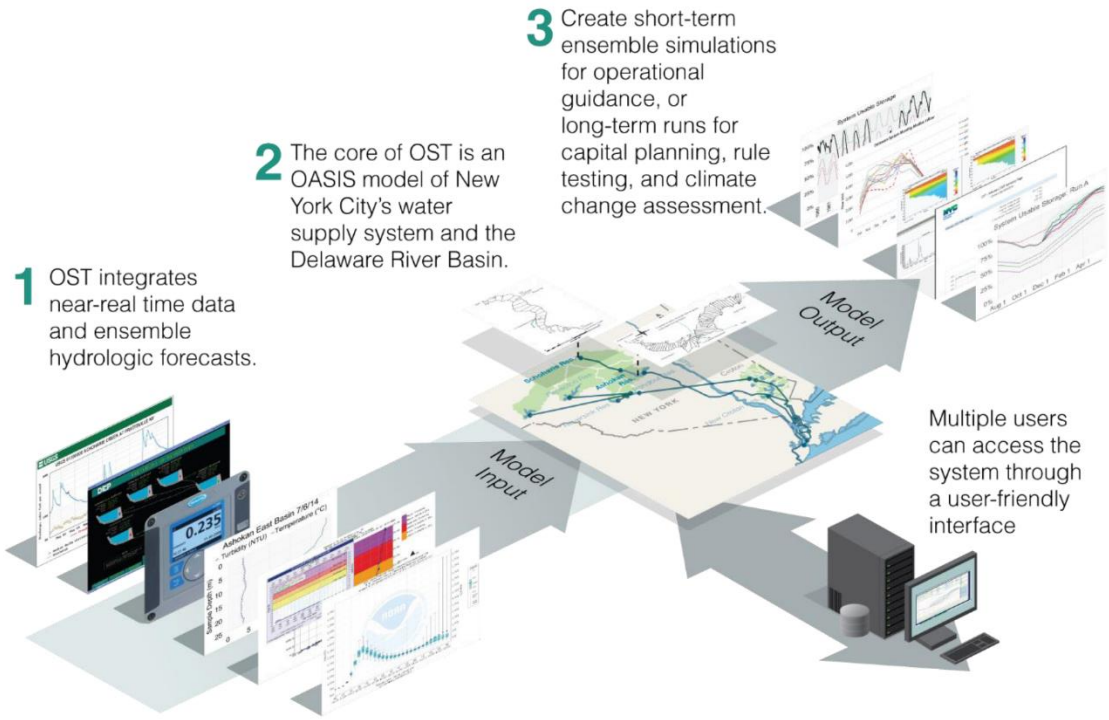
	Winter		Spring		Summer			Fall		
Cannonsville Storage Zone	Dec 1 - 31-Mar	Apr 1 - 30-Apr	May 1 - 20-May	May 21 - 31-May	Jun 1 - 15-Jun	Jun 16 - 30-Jun	Jul 1 - 31-Aug	Sep 1 - 15-Sep	Sep 16 - 30-Sep	Oct 1 - 30-Nov
L1-a	1500	1500	*	*	*	1500	1500	1500	1500	1500
L1-b	250	*	*	*	*	*	350	300	275	250
L1-c	110	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

	Winter		Spring		Summer			Fall		
Pepacton Storage Zone	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

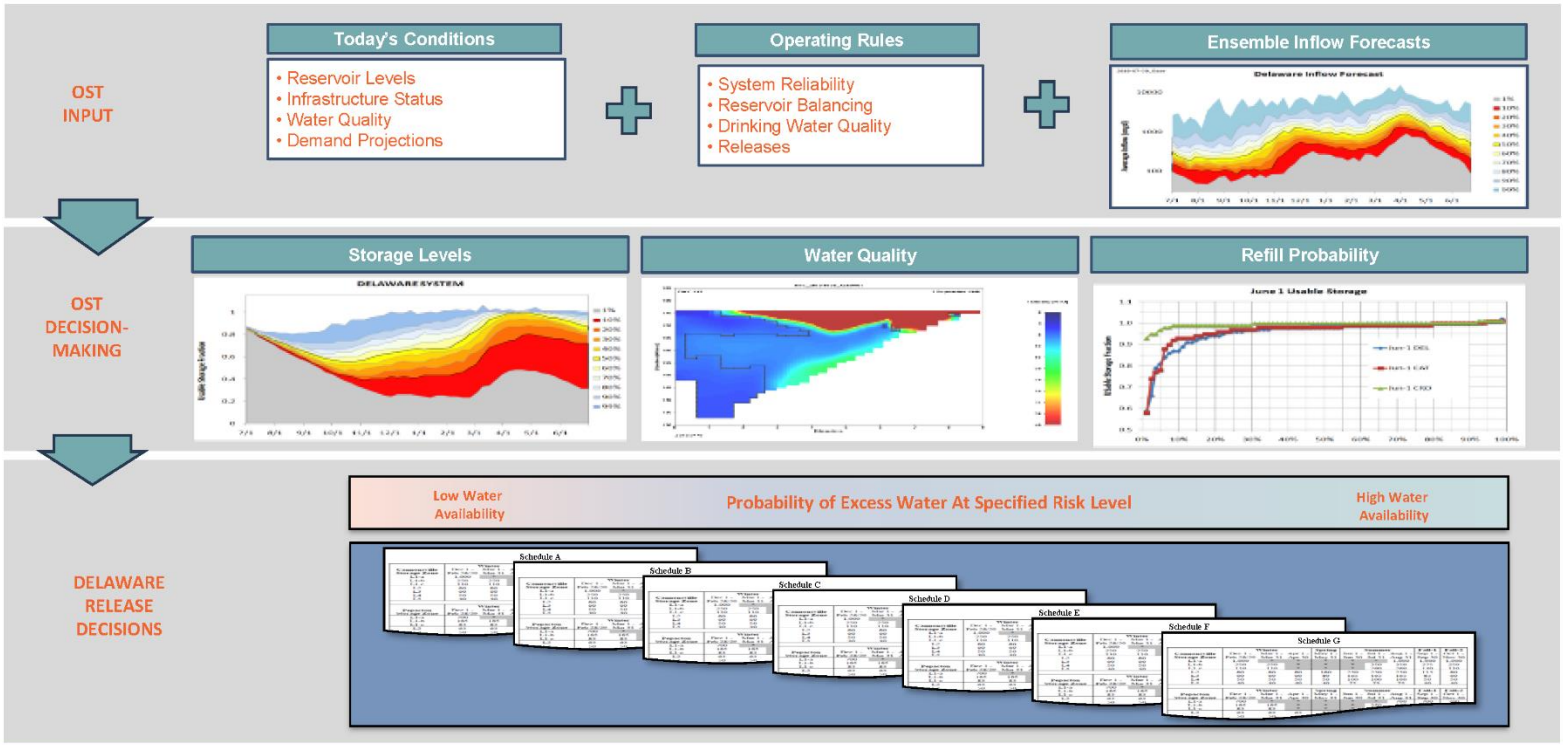
	Winter		Spring		Summer			Fall		
Neversink Storage Zone	Dec 1 - 31-Mar	Apr 1 - 30-Apr	May 1 - 20-May	May 21 - 31-May	Jun 1 - 15-Jun	Jun 16 - 30-Jun	Jul 1 - 31-Aug	Sep 1 - 15-Sep	Sep 16 - 30-Sep	Oct 1 - 30-Nov
L1-a	190	190	*	*	*	190	190	190	190	190
L1-b	100	*	*	*	*	*	125	125	85	95
L1-c	65	65	85	100	110	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.

NYC DEP's Operations Support Tool



OST-FFMP Framework

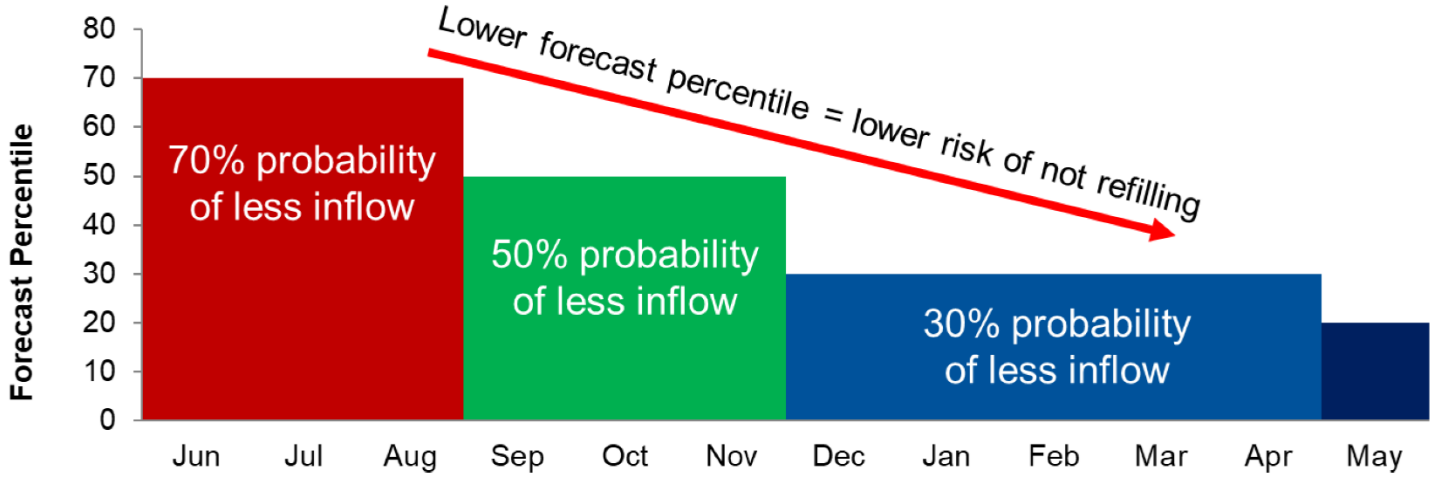


Annual Flow Balance

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
= Cumulative PCN Release Target through June 1	→	Distribute over Number of Days to June 1 and Re-Evaluate Regularly

Seasonal Risk Factor

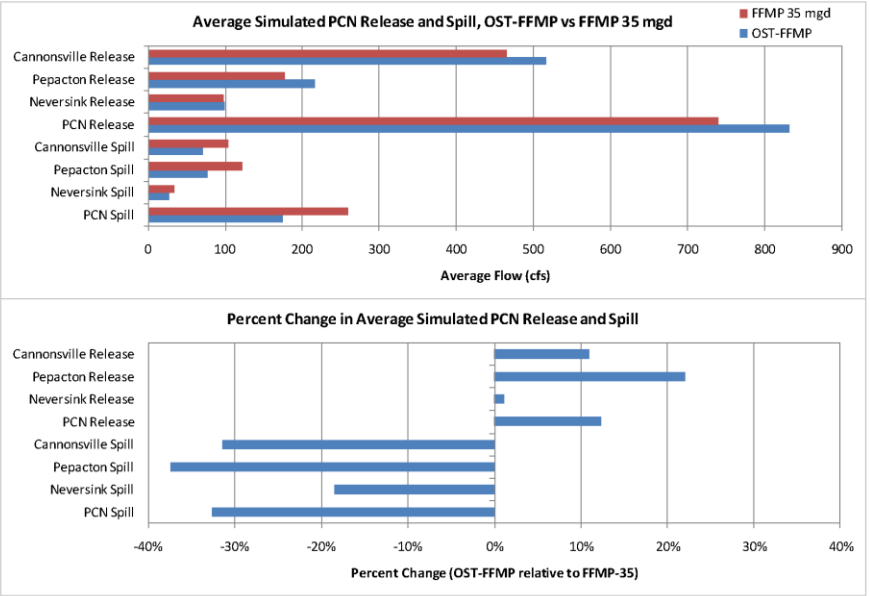
Risk represented by forecast probability – transition to more conservative when approaching June 1



Long-term Performance Testing

Using OASIS Simulation mode

- Converted uncontrolled spill into managed releases
- Increased releases for downstream uses without substantial impact to water supply reliability



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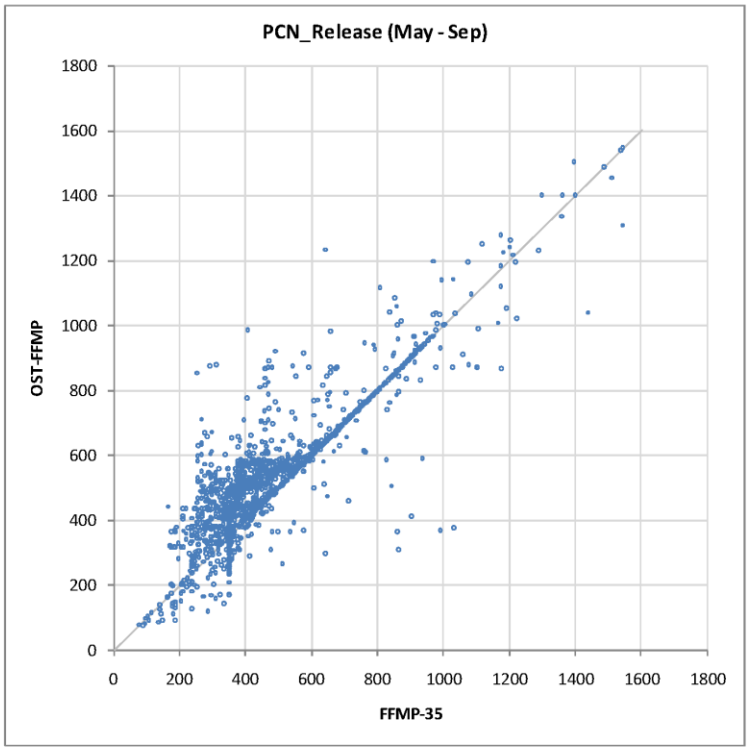
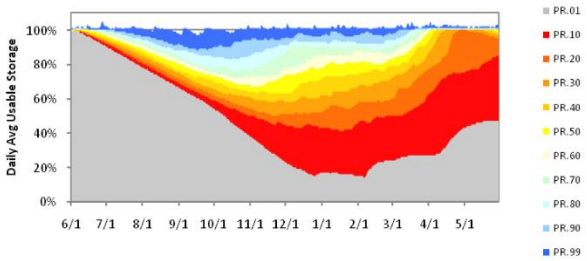
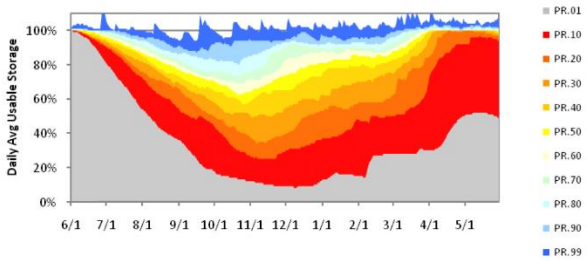


2008 FFMP (Simulated)

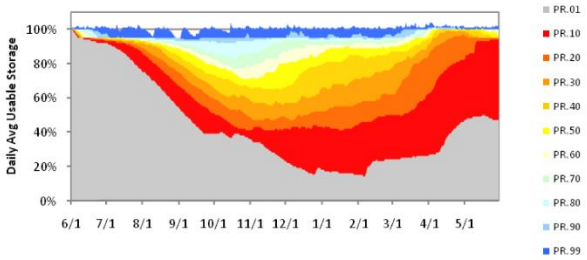
Pepacton Usable Storage



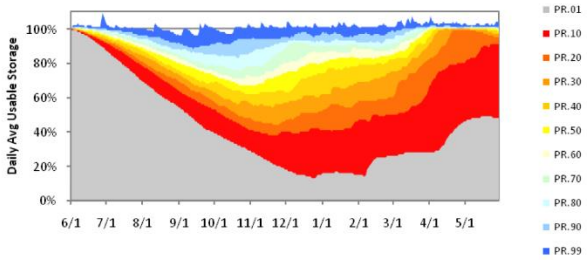
Cannonsville Usable Storage



Neversink Usable Storage

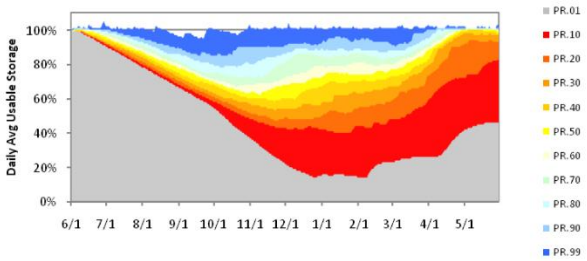


PCN Usable Storage

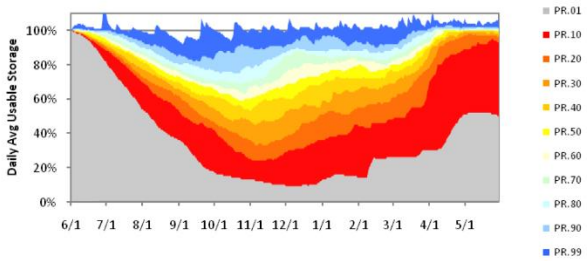


2011 OST-FFMP (Simulated)

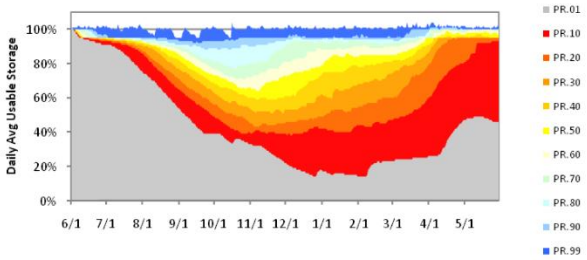
Pepacton Usable Storage



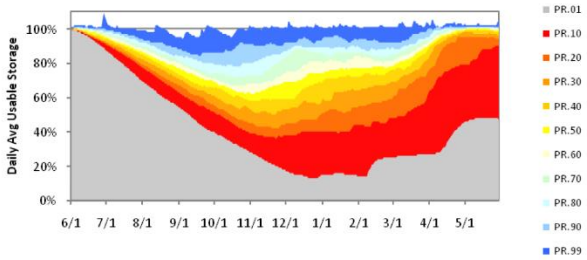
Cannonsville Usable Storage



Neversink Usable Storage



PCN Usable Storage



NYC Environmental Protection

OST-2017 FFMP Release Summary
Decision Day: 10/14/2020

General Release Mass Balance

Combined Pepacton, Cannonsville, and Neversink (PCN) Storage:	178,570	MG
+ PCN Inflow Forecast Accumulated to Jun 1:	296,926	MG
- Expected PCN Diverson Accumulated to Jun 1:	115,818	MG
-Jun 1 Storage Target:	267,460	MG
= Available Release Quantity Accumulated to Jun 1:	92,218	MG

Available Release Quantity Evenly Distributed to June 1

Available Release Quantity Accumulated to Jun 1:	92,218	MG
/ Number of Days to Distribute Release Quantity:	230	days
Current PCN Release Target:	401	mgd
Current PCN Release Target:	620	cfs

Current Storage Zone for Schedule Selection

	Usable Storage	Usable Storage + Snow Storage	Zone
PCN	66.8%	*	L2
Pepacton	74%	*	L2
Cannonsville	51%	*	L2
Neversink	80.1%	*	L2

*Not applicable (snow storage is included in the forecast)

Use Release Target and Storage Zone to Select Release Schedule

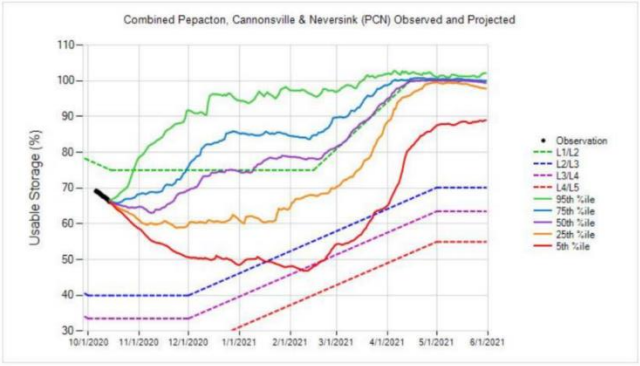
	Storage Zone, Fall (cfs)			
	Pepacton L2	Cannonsville L2	Neversink L2	PCN L2
Table-4a	50	60	35	145
Table-4b	55	75	40	170
Table-4c	60	90	45	195
Table-4d	65	105	50	220
Table-4e	70	120	50	240
Table-4f	75	135	55	265
Table-4g	80	150	60	290

Selected Schedule:Table(s) 4g

Discharge Mitigation Mass Balance

Current PCN Usable Storage:	178,570	MG
+ Current PCN Snow Storage:	*	MG
+ PCN Inflow Forecast Accumulated 7 Days:	2,487	MG
- OST-FFMP Minimum Releases Accumulated 7 Days:	1,312	MG
- Expected PCN Diversion Accumulated 7 Days:	3,580	MG
- PCN Conditional Storage Objective:	230,805	MG
= Estimated 7 Day PCN Excess over CSSO:	**	MG

*Not applicable (snow storage is included in the forecast)

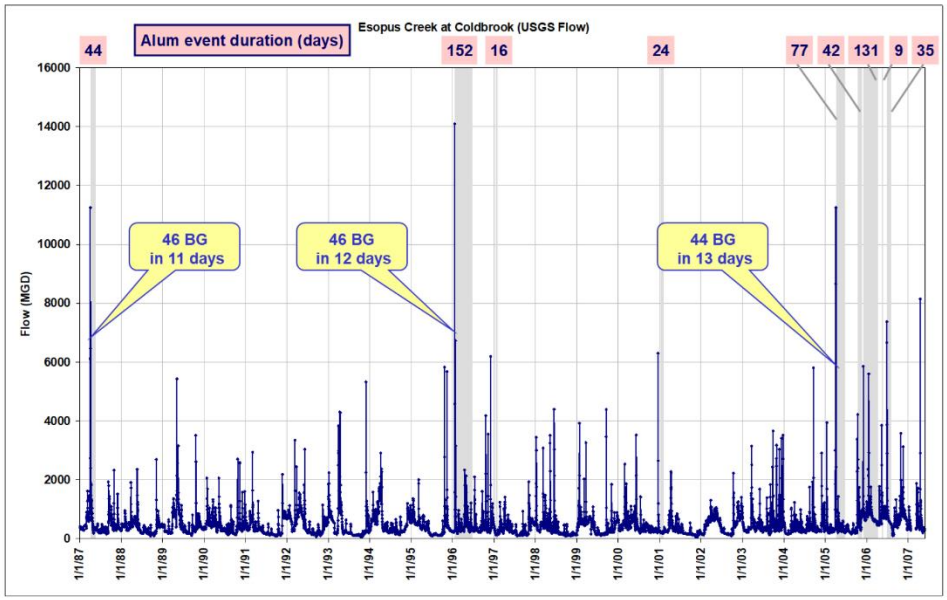


General Releases + Discharge Mitigation Releases (cfs)

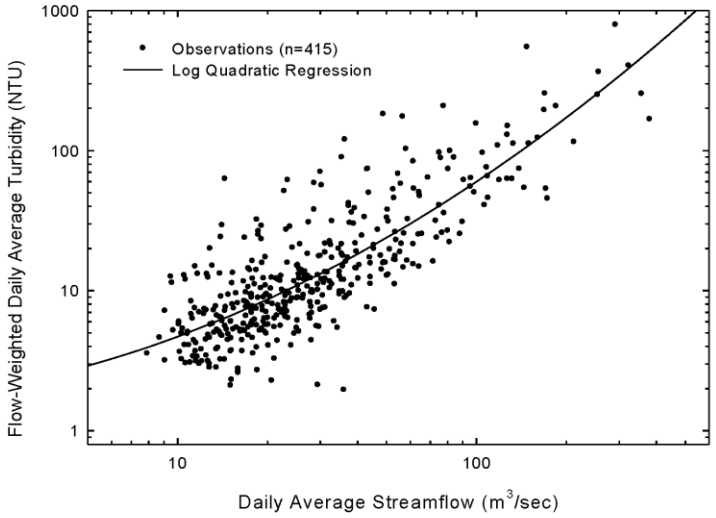
	General Release	Discharge Mitigation Release	Total
Pepacton	80	0	80
Cannonsville	150	0	150
Neversink	60	0	60
Total	290	0	290

General Releases are at Table(s) 4g

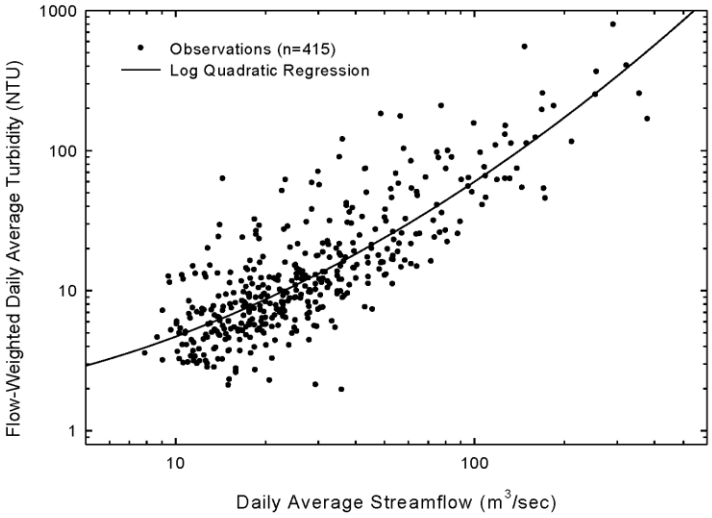
Integrated Water Supply-Water Quality Modeling

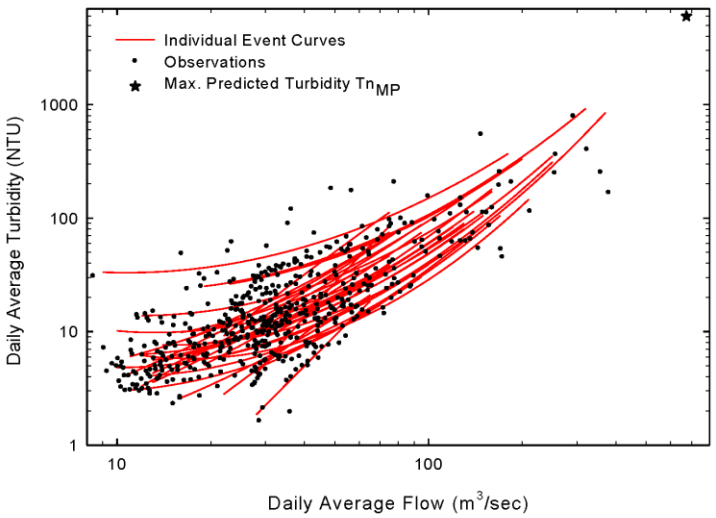


Modeling Streamflow Turbidity

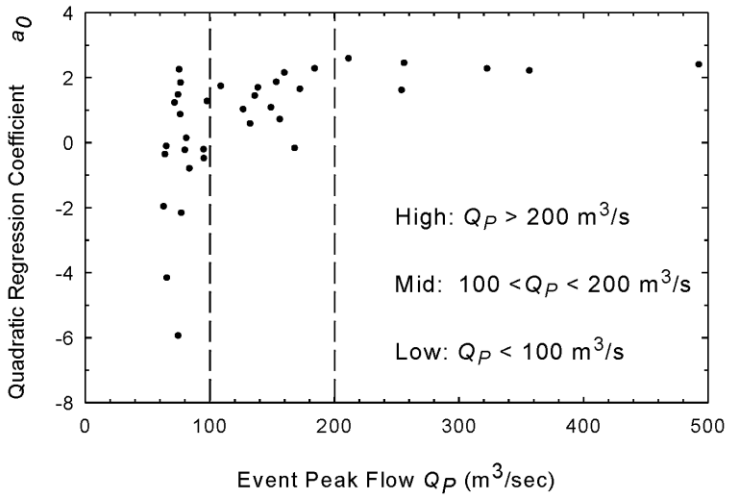


Modeling Streamflow Turbidity

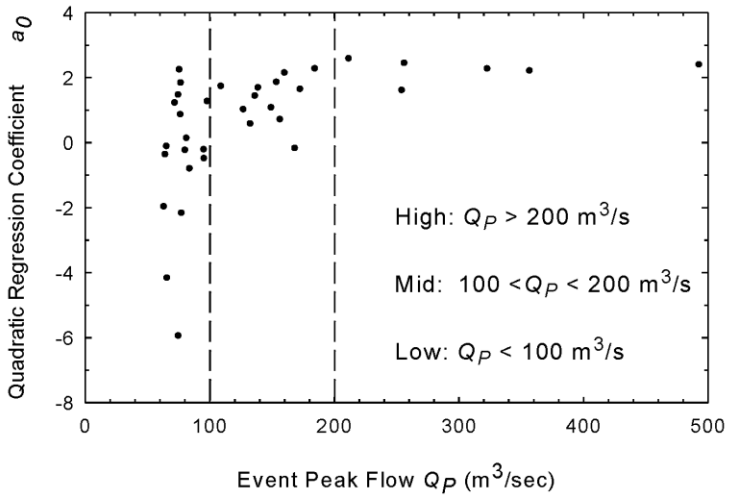


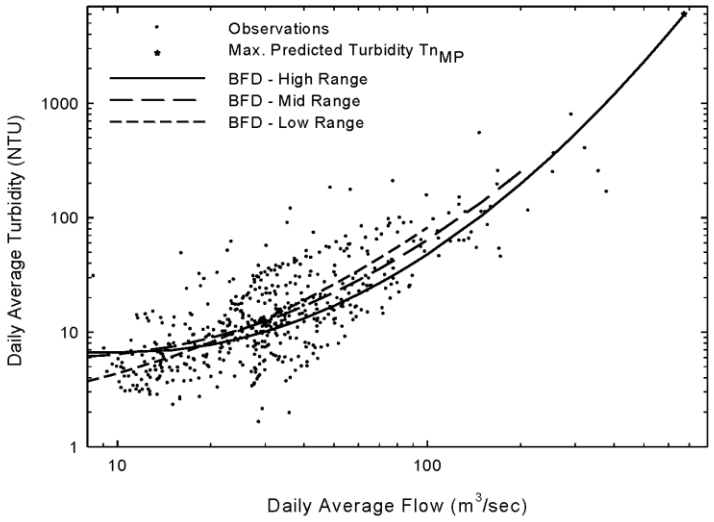


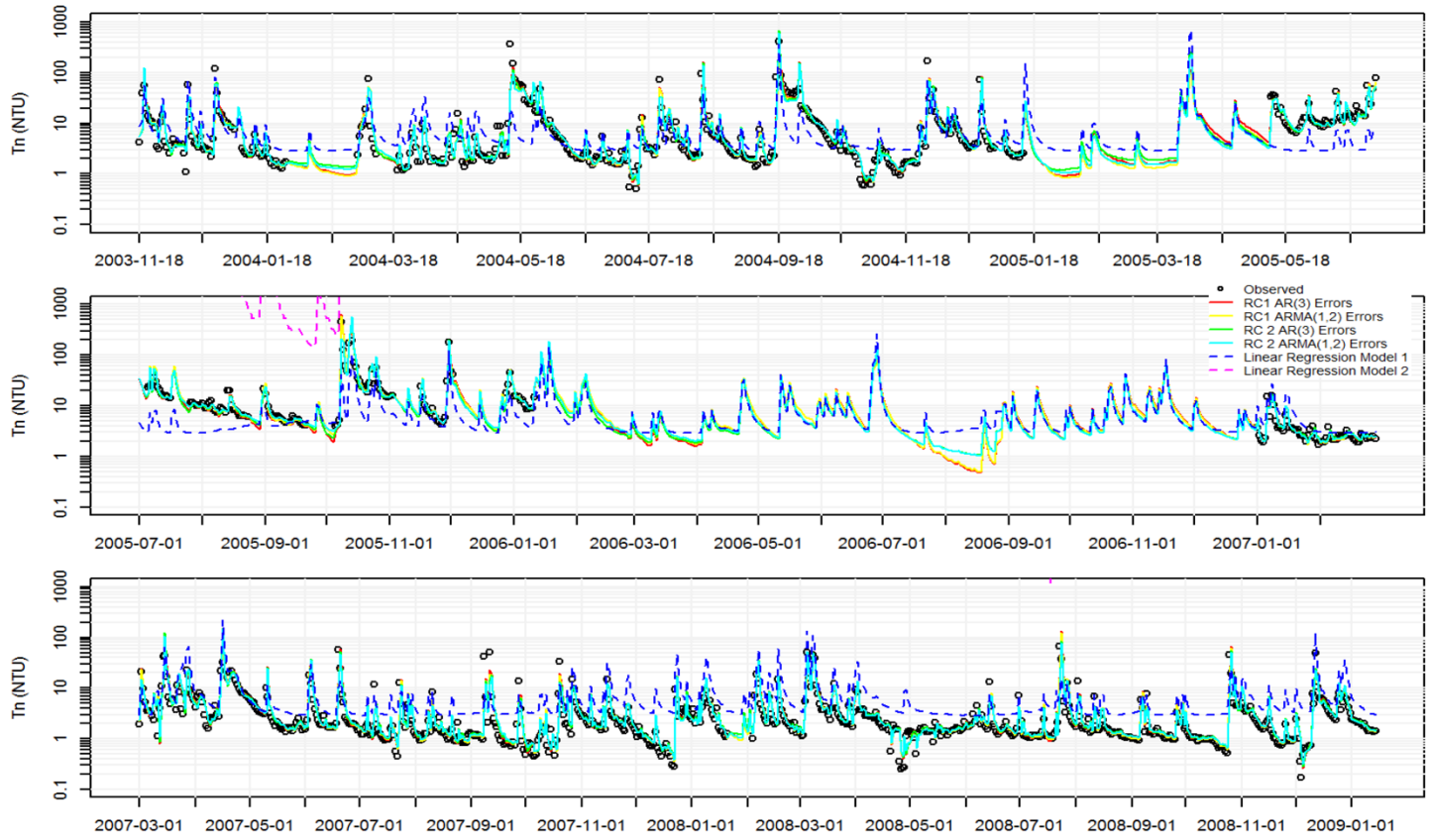
Modeling Streamflow Turbidity



Modeling Streamflow Turbidity

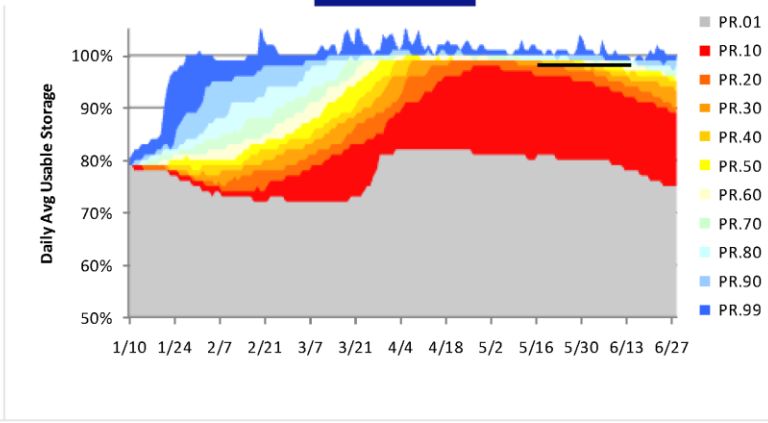





Tn (NTU)
0.1
1
10
100
1000
2003-11-18
2004-01-18
2004-03-18
2004-05-18
2004-07-18
2004-09-18
2004-11-18
2005-01-18
2005-03-18
2005-05-18
Tn (NTU)
2005-07-01
2005-09-01
2005-11-01
2006-01-01
2006-03-01
2006-05-01
2006-07-01
2006-09-01
2006-11-01
2007-01-01
Observed
RC1 AR(3) Errors
RC1 ARMA(1,2) Errors
RC 2 AR(3) Errors
RC 2 ARMA(1,2) Errors
Linear Regression Model 1
Linear Regression Model 2
Tn (NTU)
2007-03-01
2007-05-01
2007-07-01
2007-09-01
2007-11-01
2008-01-01
2008-03-01
2008-05-01
2008-07-01
2008-09-01
2008-11-01
2009-01-01

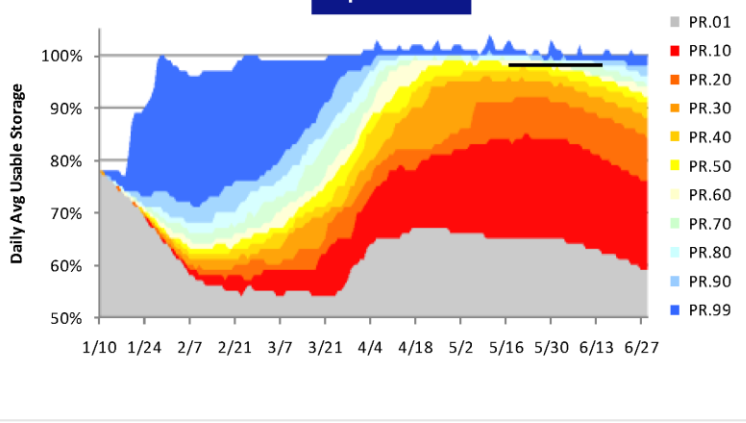
Balancing WQ and Water Supply Operations

Option A



~98% chance of refill to target
~65% chance of alum treatment

Option B



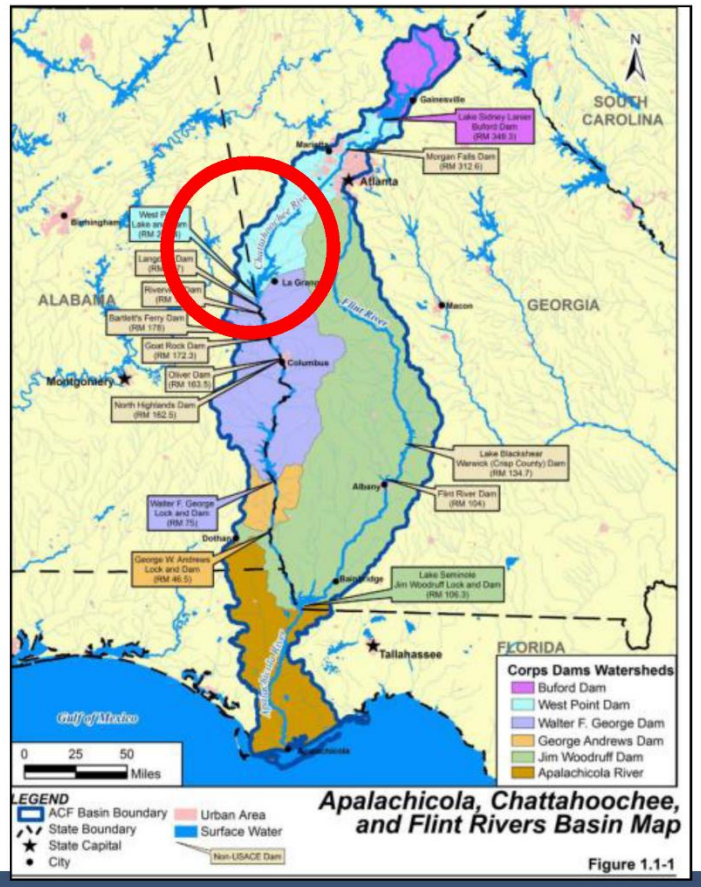
~80% chance of refill to target
~10% chance of alum treatment

Short-term Forecast Example

West Point Lake (USACE) in Georgia (ACF Basin)

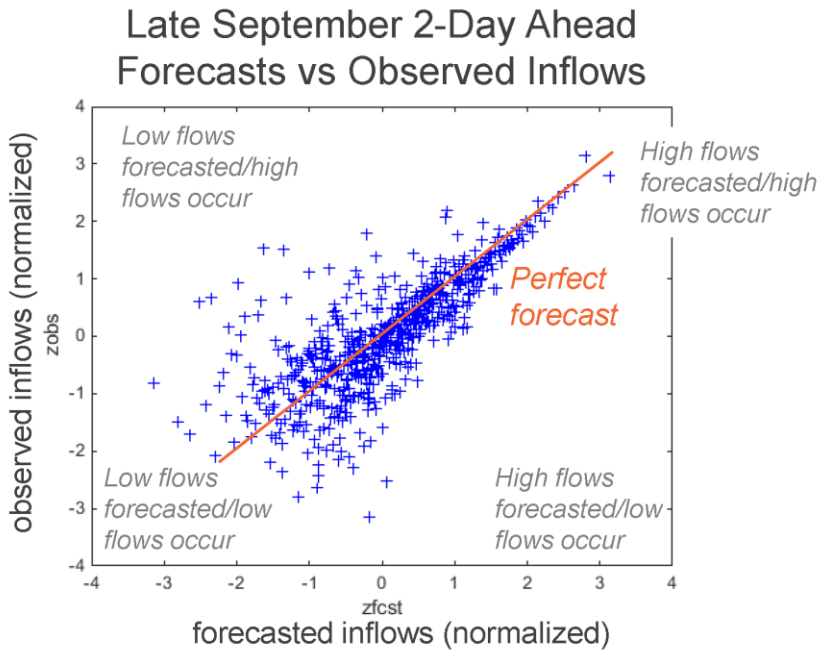
- Raising rule curve in WP Lake was identified by ACF Stakeholder group as key change to benefit basin*
  - **Higher environmental flows for longer into a drought**
  - **Less recreation impact**
  - **Mild benefit to hydropower production**
- Is it possible to raise the rule curve and maintain flood protection?

*Sustainable Water Management Plan. ACF Stakeholders. May 13, 2015



Pilot Study: Forecast Informed Reservoir Operations

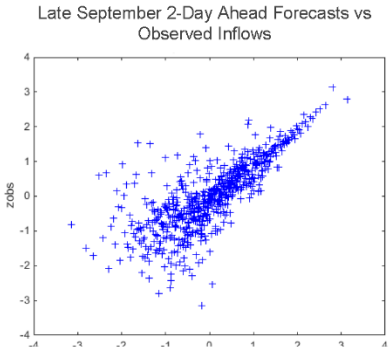
- The inflow forecasts were far and away the most skillful exactly when they could be most important - prior to flood events

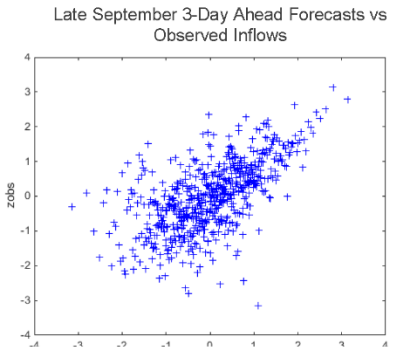


Forecasts Have Less Skill Further Out (More Scatter)

- Cumulative inflow for the next 3 days was selected
- Balanced response time with skill

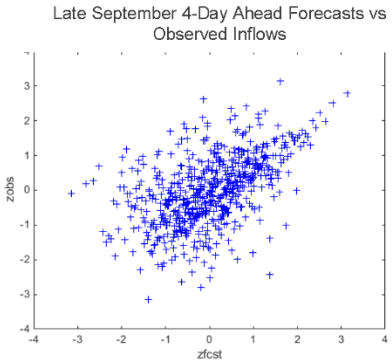
Day 2

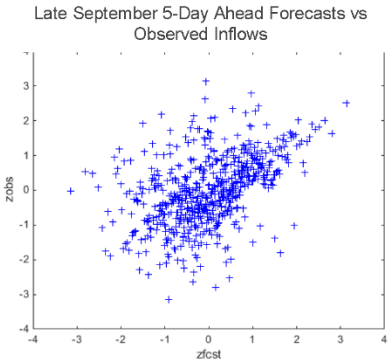




Day 3

Day 4

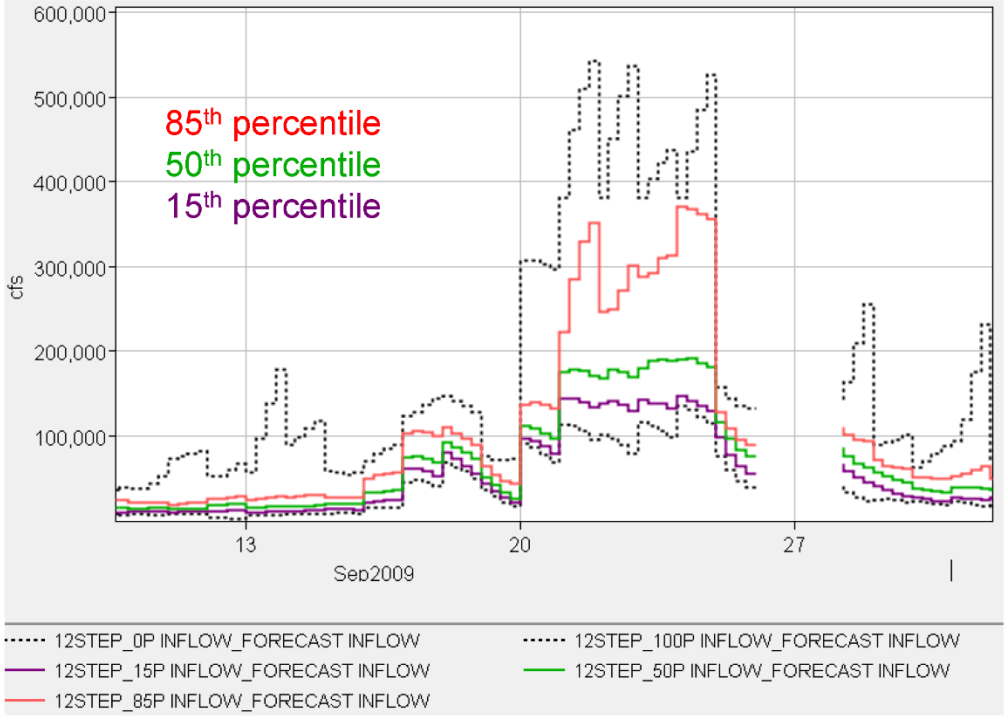




Day 5

Percentiles of Ensemble Forecasts of Inflow Volume (3-days)

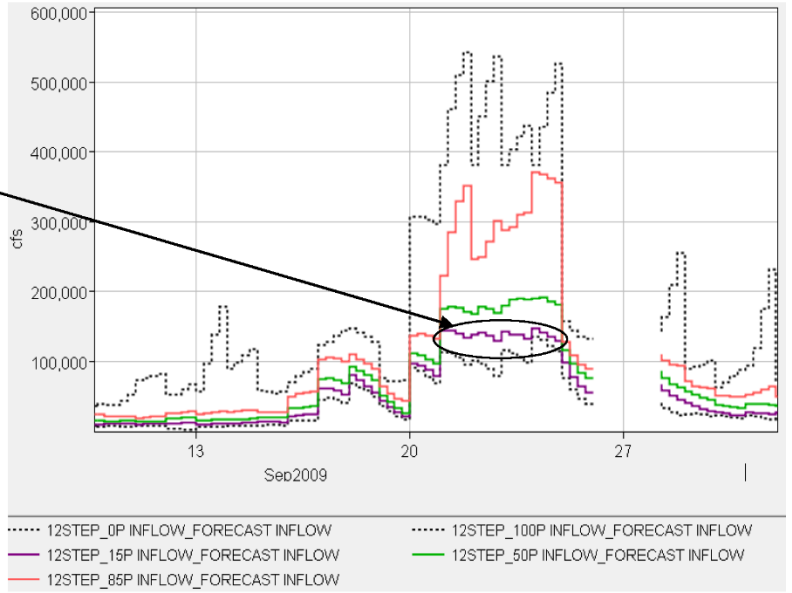
- Forecasts of high flows are all but a guarantee of at least substantial flows
- Pre-releases, therefore, would not endanger refill probability
- Limiting pre-releases inflow prevents worsening downstream flood conditions
- “Inflow Following Rule (IFR)”



Rule Details

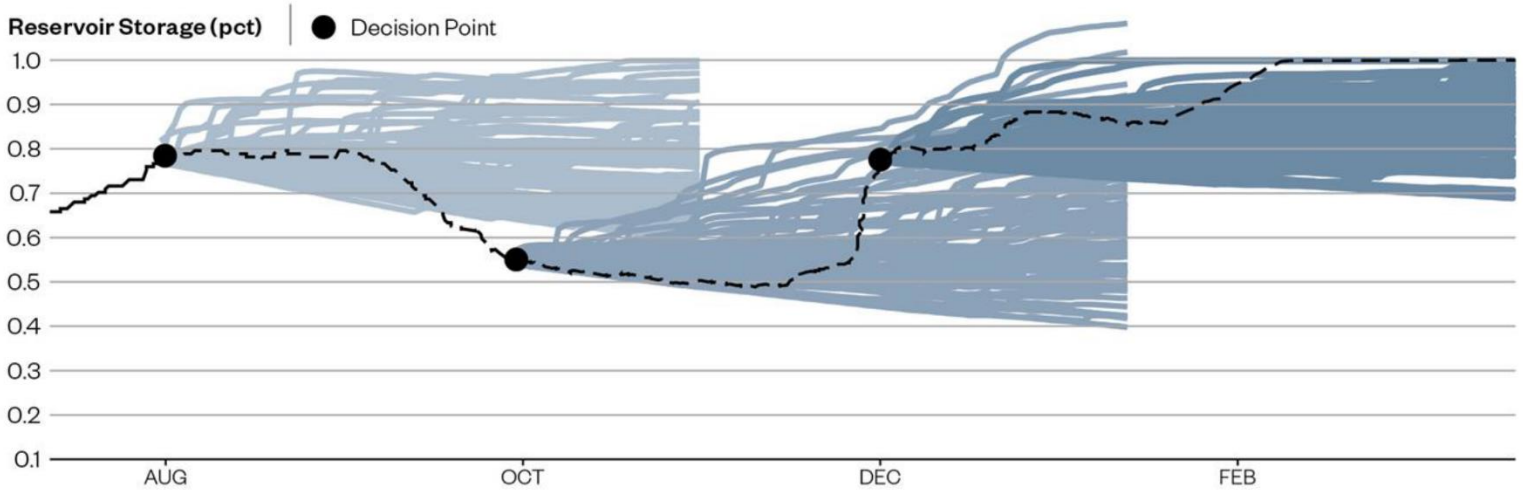
Rule is NOT dependent on predicting incoming volume

- Begin inflow following when the lower end of the forecast is sufficiently high that we're confident we'll refill what we release
  - When the 3 day cumulative **forecast is > 60k AF at the 10th percentile** then begin inflow following if we're close enough to the upper rule
- Do not release more than the turbine capacity
- Limit the inflow following release if the additional water would flood downstream at Columbus

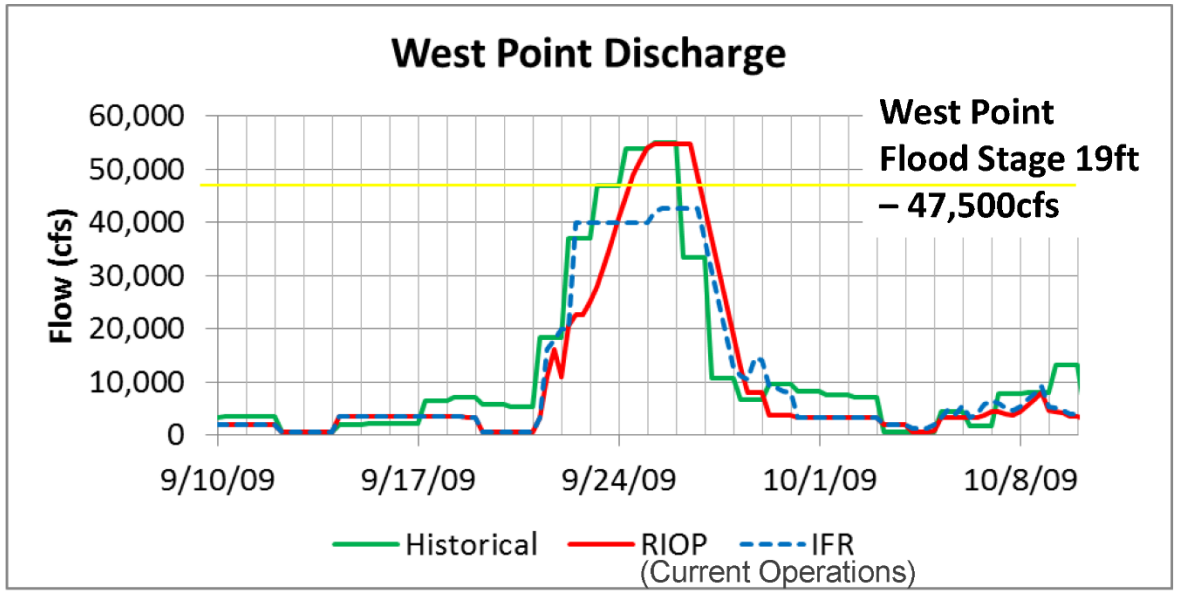


The Rule Requires Knowing the 10th Percentile Predicted Inflow During the Historical Record (Re-forecasts)

- Test potential use of probabilistic (forecast-based) triggers in operations
- Requires "re-forecasts": forecasts you would have had on that day of the simulated hydrology

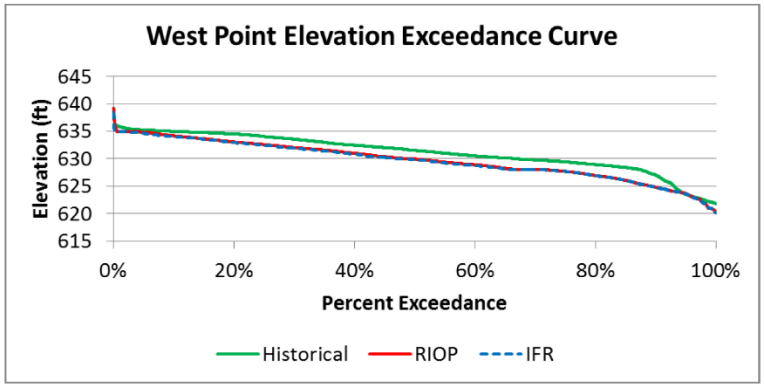


Primary Goal: Reduce the Flood Peak

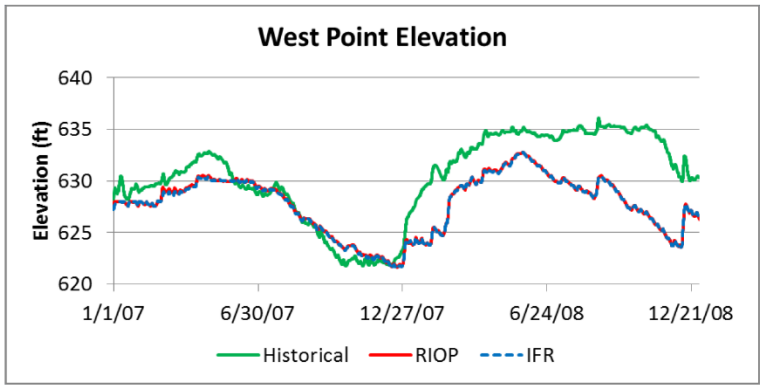


- **Reduced the peak flow of the largest flood in the 10 year record** by about 15%
  - 6,800 cfs above flood stage (54,300 cfsd total), Current Ops
  - 3,500 cfs below flood stage (44,000 cfsd total), IFR

No Negative Impact to Reliability or Hydropower Generation



No impact on stage exceedance at lower end of the curve



No additional drawdown during drought of record

	Total Gen Flow (MAF)
Current Operations	22.5
Inflow Following	22.6

Lessons Learned

Rule form chosen to exploit forecast skill

- While forecasts could not provide substantial certainty concerning the potential peak magnitude of a coming flood,
- when the forecasts were for high flows, they provide substantial certainty of potential minimum flows in the coming days
- This rule form stands the normal consideration of use of forecasts for flood control on its head
  - The temptation is to treat a forecast as certainty, and then to make additional releases as needed to minimize peak flow
  - **The IFR does the inverse. It provides for additional releases in advance of floods whenever those releases are very unlikely to be detrimental to other objectives**
  - It does not try to optimize for the current flood

Sample FIRO Rule Form

Drought Operations

Potential Drought Measures	*Potential Triggers (implement and cease)*	*Potential Performance Measures*
• Reduce withdrawals • Reduce flow requirements • Alternate sources	• Forecasted conditions (inflow, flows, reservoir levels) • Reservoir levels • PDSI, SPI, etc. • Antecedent inflow	• Frequency of implementation • Number of “false positives” • Lowest simulated stages/flows • Shortages

City of Rocky Mount, NC

Alternative to a $70 million interbasin diversion

Drought Measures	*Triggers*	*Performance Measures*
• Reduce withdrawals • Reduce flow requirements	• Probability (x%) of reservoir dropping below elevation y within z weeks	• Less than 1 in 10 years for emergency measures (20% demand reduction) • Less than 1 in 5 years for less severe demand reductions • At least 25% storage

City of Rocky Mount, NC

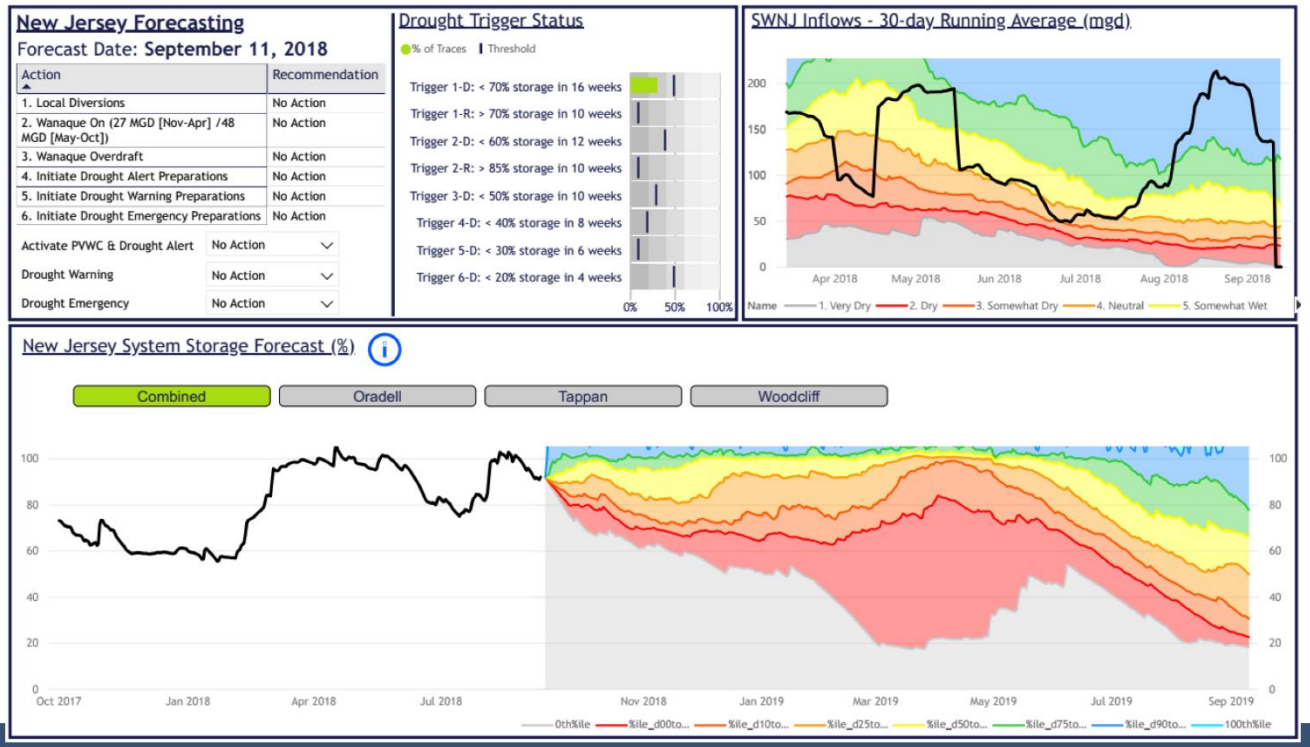
Alternative to a $70 million interbasin diversion

Drought Measures	*Triggers*	*Performance Measures*
• Reduce withdrawals • Reduce flow requirements	• Probability (x%) of reservoir dropping below elevation y within z weeks	• Less than 1 in 10 years for emergency measures (20% demand reduction) • Less than 1 in 5 years for less severe demand reductions • At least 25% storage

	x (% risk)	y (trigger elevation)	z (forecast horizon)	w (demand reduction	w (minimum flow reduction)
Phase 1	10%	120 ft	12 weeks	0	12.5%
Phase 2	15%	118 ft	8 weeks	10%	25%
Phase 3	20%	116 ft	6 weeks	18%	37.5%

Decision Support Combining Forecasts and Tested Triggers

Power BI provides dashboard interface



Summary

- There's helpful forecast information available for decision support
- Its use has been time-tested in many nearby systems
- The forecasts needed depend on the questions being asked
- You have a tool available