Mitigating Thermal Stress to Trout in the Upper Delaware

- continued -

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A Presentation to RFAC

Trenton, NJ

March 18, 2013

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Our Purpose Today: A continuation

- To persuade the Decree Parties to include an experimental thermal stress relief program for the upper main stem in the June 2013 revision of the reservoir release rules.
- Today we extend the analysis presented at the Feb 19, 2013 RFAC meeting to consider in more detail
  - ✓ Water availability for a stress relief program
  - ✓ Forecasting of stress events
  - ✓ The PPL stress relief program on the Lackawaxen as model for what is possible on the Delaware.

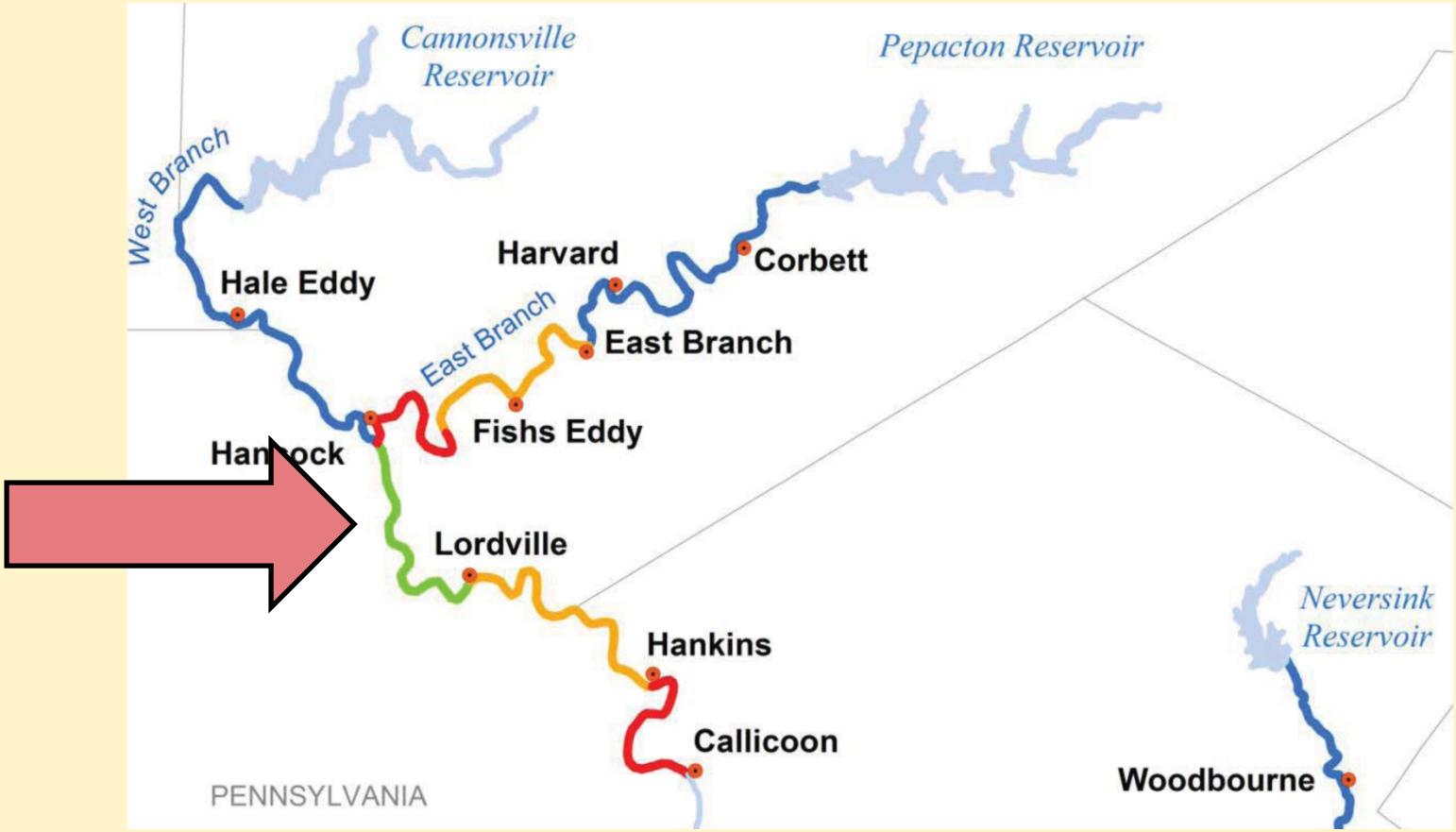
I. Brief Review of Prior Presentation

The Main Points from our February 19 Presentation to RFAC

QUANTIFICATION

- **The Magnitude of the Thermal Stress Problem:** Over the last decade the upper main stem of the Delaware has experienced an average of 12 days of severe thermal stress to trout per summer, with the worst summer having 23 severe stress days. We presented detailed analysis of the duration and severity of stress episodes.
- **The Impact of Reservoir Releases on Water Temperatures:** Via extensive regression analysis we statistically estimated that a 118 cfs additional pulse release of cold water from the Cannonsville dam can reduce summertime water temperatures at Lordville by 1°F. This estimate is robust and statistically very reliable.
- **Water Needed for Stress Mitigation:** Based on the above estimates, stress mitigation would require about 3,400 cfs days of additional releases in an average summer, while the worst summer would require about 6,500 cfs days.

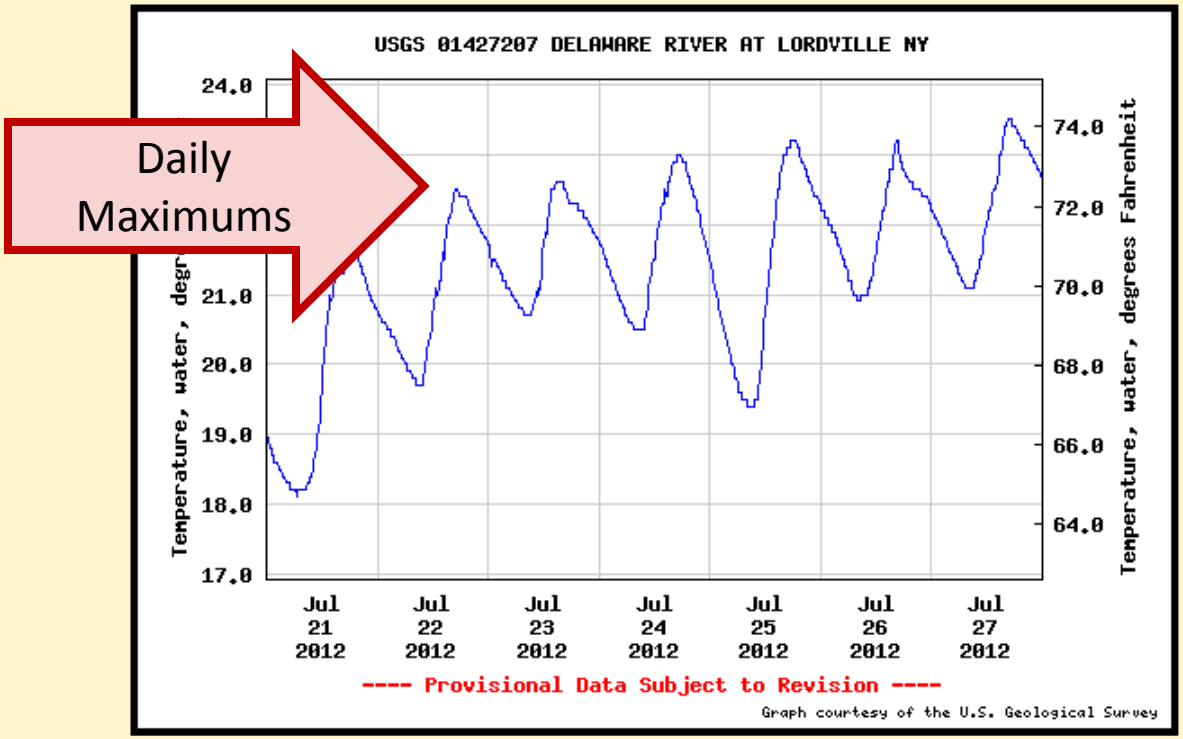
Our Stress Mitigation Focus: Ten miles of the upper main stem from Hancock to Lordville



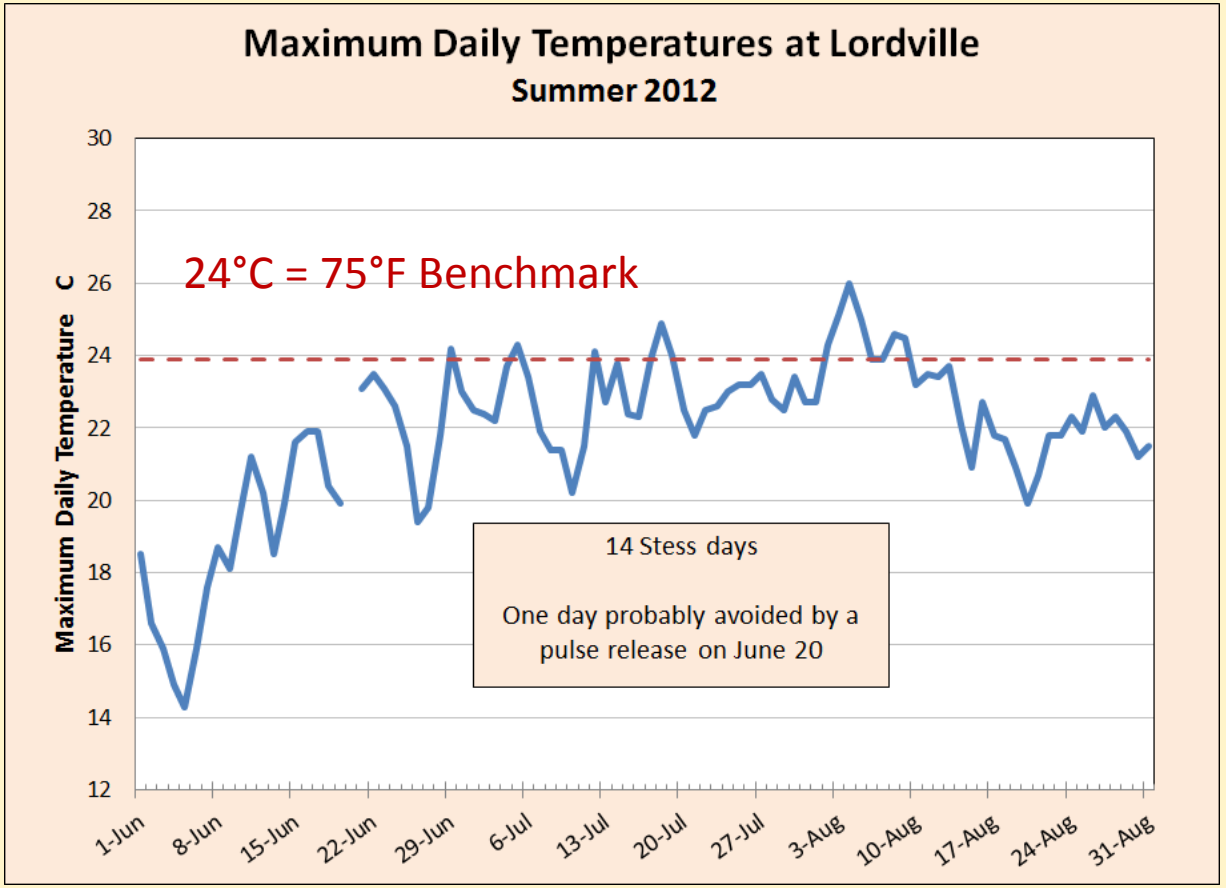
Source: Joint Fisheries White Paper, January 2010

Severe Thermal Stress

- The Delaware Watershed Conservation Coalition has agreed that trout are in ‘severe thermal stress’ whenever the daily maximum water temperature exceeds 75°F, that is, 23.9 C°.



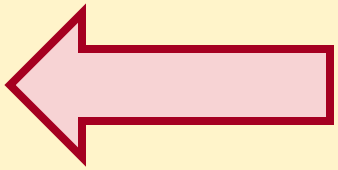
The Need: **Although there have been improvements in the base releases since 2007, the thermal stress problem remains: There were 14 stress days in 2012.**



Thermal relief is feasible at Lordville within the parameters of the FFMP/OST

- Our regressions indicate that it takes about a 211 cfs release from Cannonsville to lower Lordville by 1 °C Combining this estimate with our statistics on the magnitude of thermal stress at Lordville gives an estimate of the water needed for mitigation:

	Degree Days C	Water Needed (cfs Days)
Average Summer	**10.2**	**2,152**
Worst Summer	**19.3**	**4,072**
	Cooling Days	
Average Summer	**16.2**	**3,418**
Worst Summer	**30.8**	**6,499**



- There are 9,423 cfs-days of water in the IERQ which can support "extraordinary water needs." Thus, thermal relief is feasible at Lordville in most summers, even in an extreme summer.

II. Water Availability

Is there enough water in New York City's Delaware reservoirs to support such a thermal stress relief program?

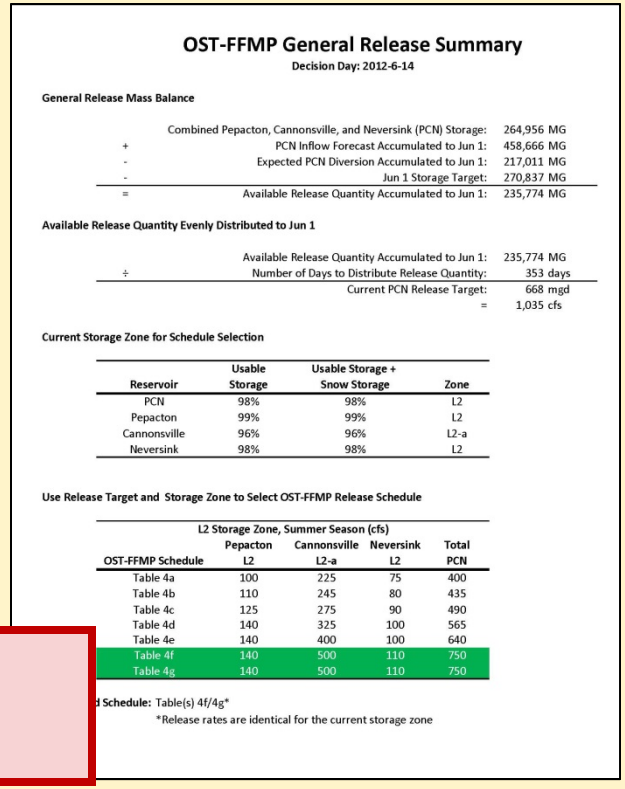
Yes, water is available to run this program

- The OST/FFMP program has a water bank of 9,423 cfs days in the IERQ to meet "special needs." In most summers significant amounts of the IERQ have not been used – 7,772 cfs days on average since 2007.
- Since 2007 reservoir storage under the FFMP has been well inside the normal storage range (L2), averaging 22 BG above the historical median and the reservoirs have spilled water in every year.
- Under OST-FFMP operations, according to the *OST-FFMP General Release Summaries,* scheduled releases have been 221 cfs below the OST-FFMP's computation of water available. (About 20,000 cfs days per summer.)
- The Croton Water Treatment Facility will restore up to 290 mgd of high quality water to NYC's water supply. This should reduce the quantity of Delaware water needed by the City and should be reflected directly in an increase of the OST-FFMP's computation of available water.

The OST-FFMP Computations of Available Water

June 14 2012: Storage at 98%, L2

	(MG)
PCN Storage	264,956
Forecasted Inflow	458,666
Expected Diversion	217,011
June 1 Storage Target	270,837
Available Release Quantity	235,774
Days Remaining	353
Release Target mgd	668
cfs	1,035
Table 4g/f Release cfs	750
Excess cfs	285



OST-FFMP General Release Summary

Decision Day: 2012-6-14

General Release Mass Balance

	Combined Pepacton, Cannonsville, and Neversink (PCN) Storage:	264,956 MG
+	PCN Inflow Forecast Accumulated to Jun 1:	458,666 MG
-	Expected PCN Diversion Accumulated to Jun 1:	217,011 MG
-	Jun 1 Storage Target:	270,837 MG
=	Available Release Quantity Accumulated to Jun 1:	235,774 MG

Available Release Quantity Evenly Distributed to Jun 1

	Available Release Quantity Accumulated to Jun 1:	235,774 MG
÷	Number of Days to Distribute Release Quantity:	353 days
	Current PCN Release Target:	668 mgd
	=	1,035 cfs

Current Storage Zone for Schedule Selection

Reservoir	Usable Storage	Usable Storage + Snow Storage	Zone
PCN	98%	98%	L2
Pepacton	99%	99%	L2
Cannonsville	96%	96%	L2-a
Neversink	98%	98%	L2

Use Release Target and Storage Zone to Select OST-FFMP Release Schedule

	L2 Storage Zone, Summer Season (cfs)			
OST-FFMP Schedule	Pepacton L2	Cannonsville L2-a	Neversink L2	Total PCN
Table 4a	100	225	75	400
Table 4b	110	245	80	435
Table 4c	125	275	90	490
Table 4d	140	325	100	565
Table 4e	140	400	100	640
Table 4f	140	500	110	750
Table 4g	140	500	110	750

Schedule: Table(s) 4f/4g*

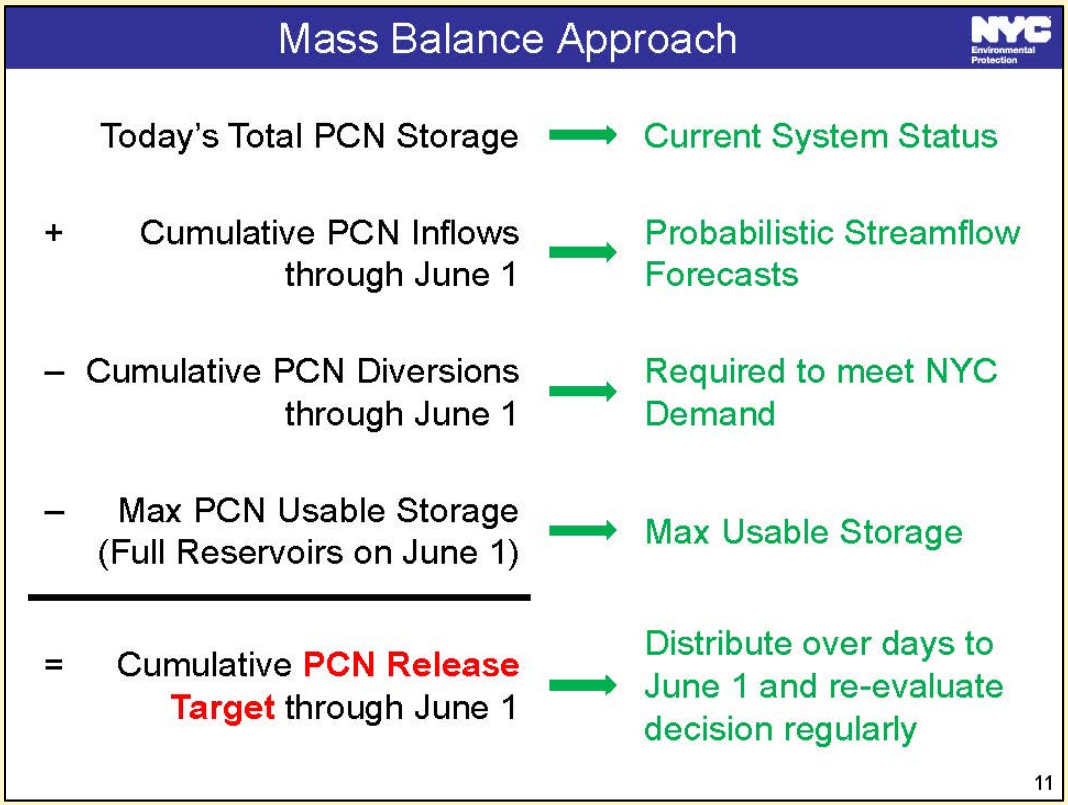
*Release rates are identical for the current storage zone

And, more water will be available from 2013 forward . . .

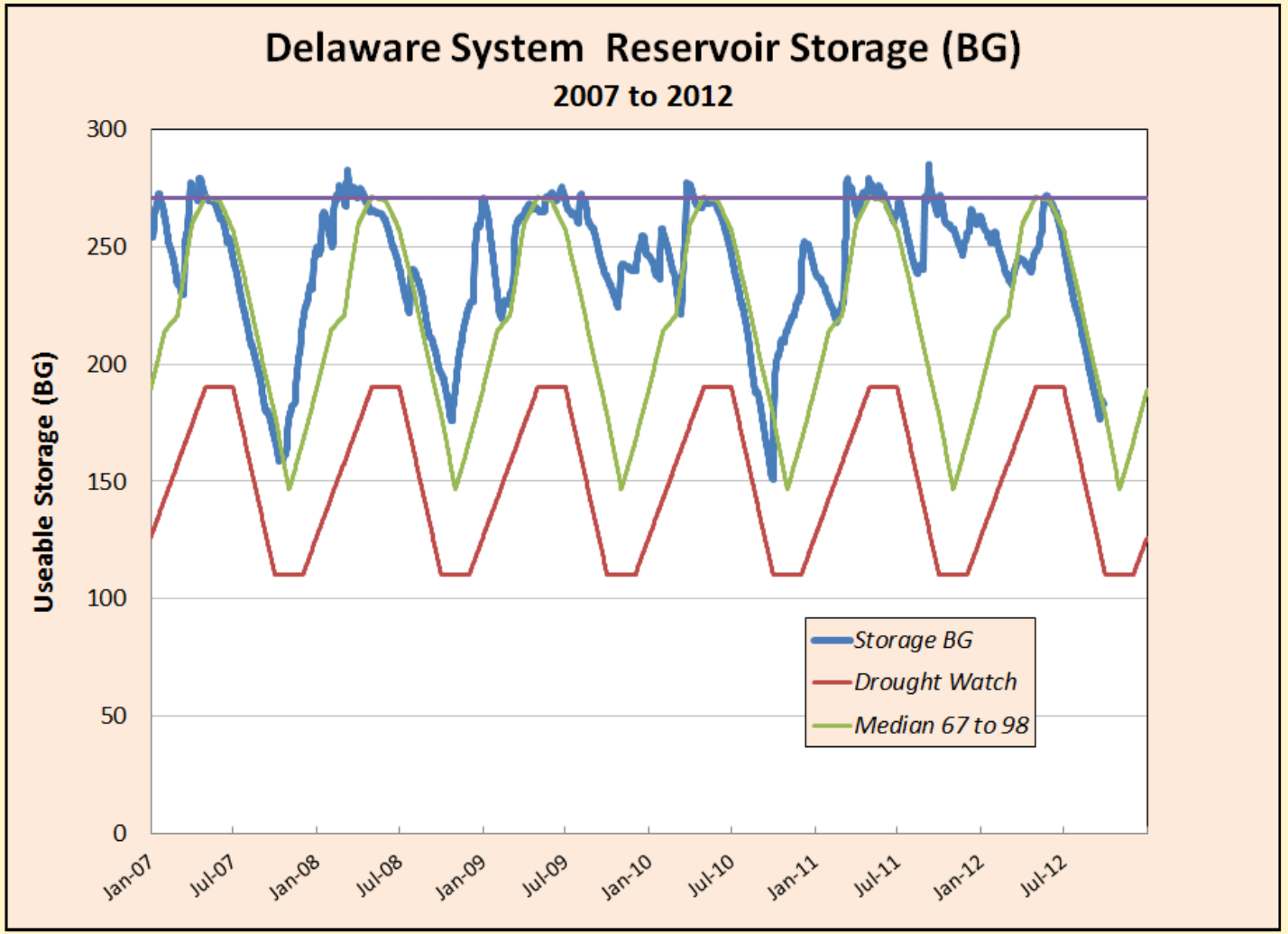
- The availability of Croton water should reduce the quantity of Delaware water needed by the City and should be reflected in the OST-FFMP computation of available water.

Diversion Forecasts decrease

Available Water (Release Target) increase



Excellent Actual Water Availability in Recent Years



Reservoir storage during the summer of 2012 was ample, but several stress relief petitions were not acted on.

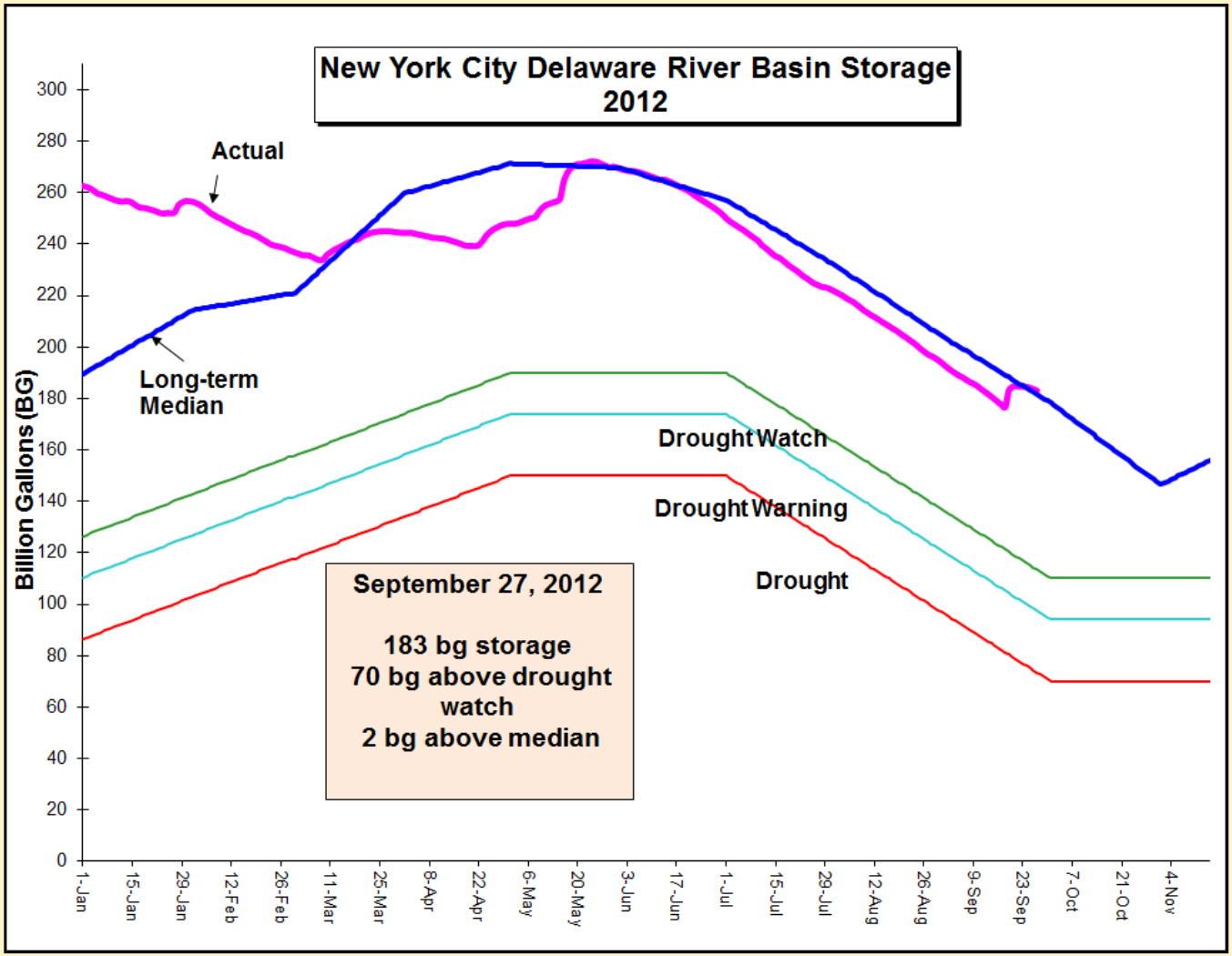


Chart courtesy of Hernan Quinodoz DRBC

Prudence in Water Use

- While our analysis shows that historically water should be available for stress mitigation, we recognize that water must be used prudently. Hence we suggest:
  - Thermal stress releases would only be recommended when storage is in the normal range (eg in L2) and when the release would not drive storage below L2.
  - Already recognized needs such as the Trenton target would have priority over thermal stress mitigation.

III. Forecasting Thermal Stress Events

The Role of Forecasts

- Although mitigation is possible after a stress event starts, particularly during long events, it is better to anticipate problems and head them off.
- Two dominant factors in forecasting stress events are:
  - The current value and trend of Lordville water temperature .
  - Current and forecasted weather conditions, particularly air temperatures and precipitation.
- By using this data, augmented with information about current flows and planned release s accurate Lordville forecasts can be generated.

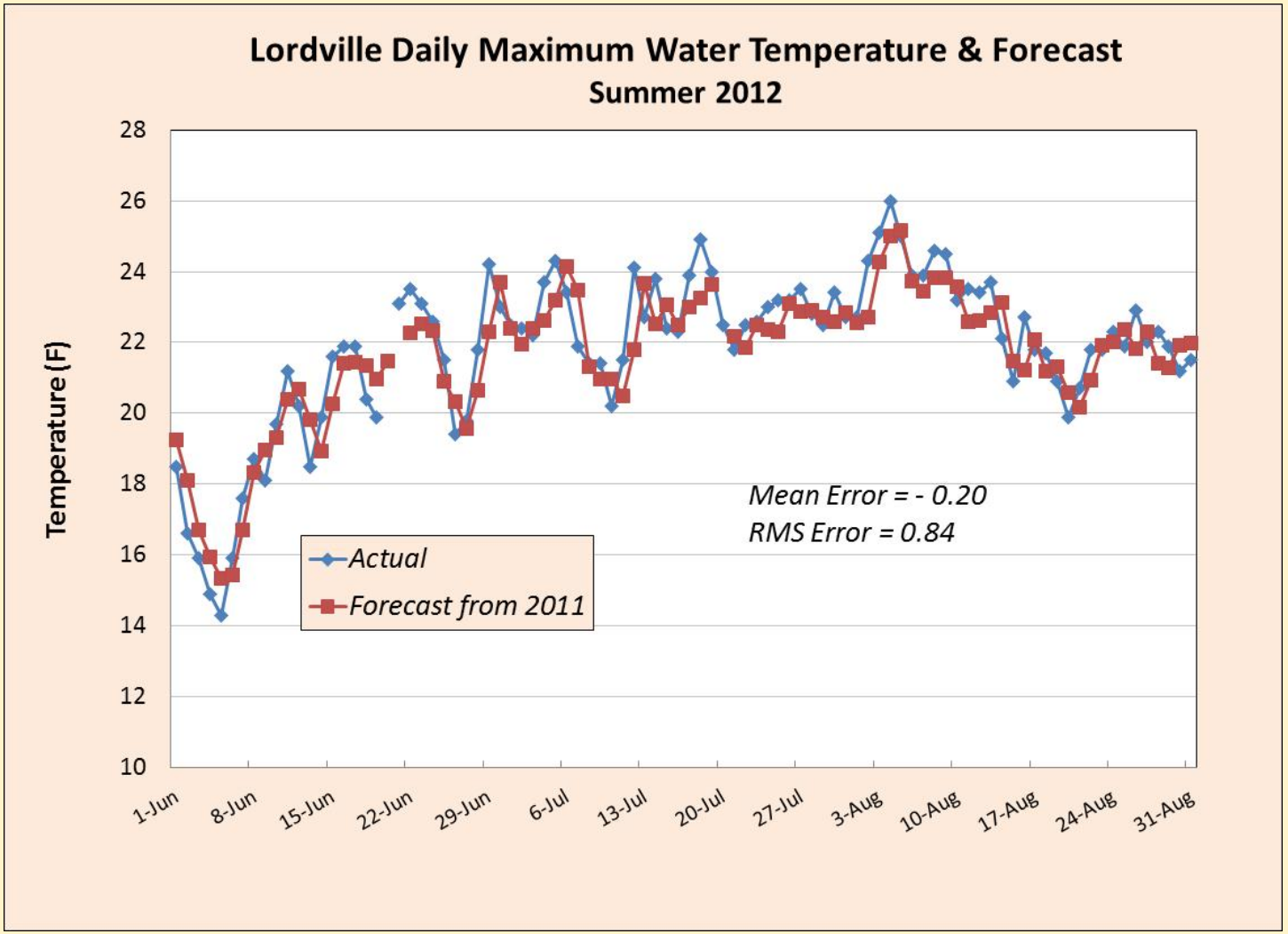
A Record of Forecasting Success

- Using such information in an informal way, the PA F&BC has done an excellent job of forecasting stress events in recent years. They accurately predicted 4 of the 5 stress events of the summer of 2012.
- To supplement their approach we are developing statistical approaches to forecasting Lordville summertime daily maximum temperatures. A reliable and quite complete data base has been assembled for the summers of 2007 to 2012.

Regression-based forecasting models for Lordville summertime daily maximum temperatures

- Our goal was to forecast the Lordville river temperatures one and two days ahead, using only information available today. Simple models using a few variables that are available daily from the USGS gages and from the NWS produce good forecasts. They are:
  - The Lordville daily maximum temperature today or yesterday
  - The Lordville daily average discharge today or yesterday
  - Stilesville discharge today or yesterday
  - Local actual air temperature today or yesterday
  - Local air temperature forecasts made today or yesterday for 7 days ahead.
- Our regression models are similar in concept to the approach being used successfully in the the PPL stress relief program for the Lackawaxen .

A Test: Forecasting 2012 with a model based on 2007 to 2011 data



A Complementary Approach: Focusing on Heat Waves

- Hot weather drives water temperatures up, but a single hot day will not itself cause a stress event. Successive hot days have a cumulative impact.
- As a test of the usefulness of the concept, we defined a 'forecasted heat wave' as 7 successive days with an average forecasted daily high temperature of 85° F or more. We found 8 such distinct (non-overlapping) forecasted heat waves in the summers of 2007 to 2012.
  - The NWS forecasts were quite accurate, these were hot periods. The average forecast error 0.6° F
  - All 8 heat waves had thermal stress events -- 2.4 stress days on average

Brainstorming a Decision Support Tool:

A Pennsylvania and NYS Fisheries Decision Template

2012 Fishery Agency Thermal Relief Decision Matrix

1. Have USGS gage notification alert when **WT @ Lordville reaches trigger temperature of 22°C.** This capability exists now.

2. Determine if discharge @ Lordville ≤ 1360 cfs or is scheduled to increase above this level

- No Continue to monitor
- Yes Check weather forecast for Hancock.
  Go to #3.

3. Check weather forecast

a. Is discharge @ Lordville < 1000 cfs and forecast max air temp for next day @ Hancock ≥ 82°F?

- No Continue to monitor thermal relief decreases likelihood of elevated WT
- Yes Recommend thermal relief. Release 250 cfs from Cannonsville from 3PM today for 24 hours.
  Reevaulate after day 1 for multiple day release.

b. Is discharge 1000-1360 cfs @ Lordville and forecast max air temp for next day @ Hancock ≥ 82°F?

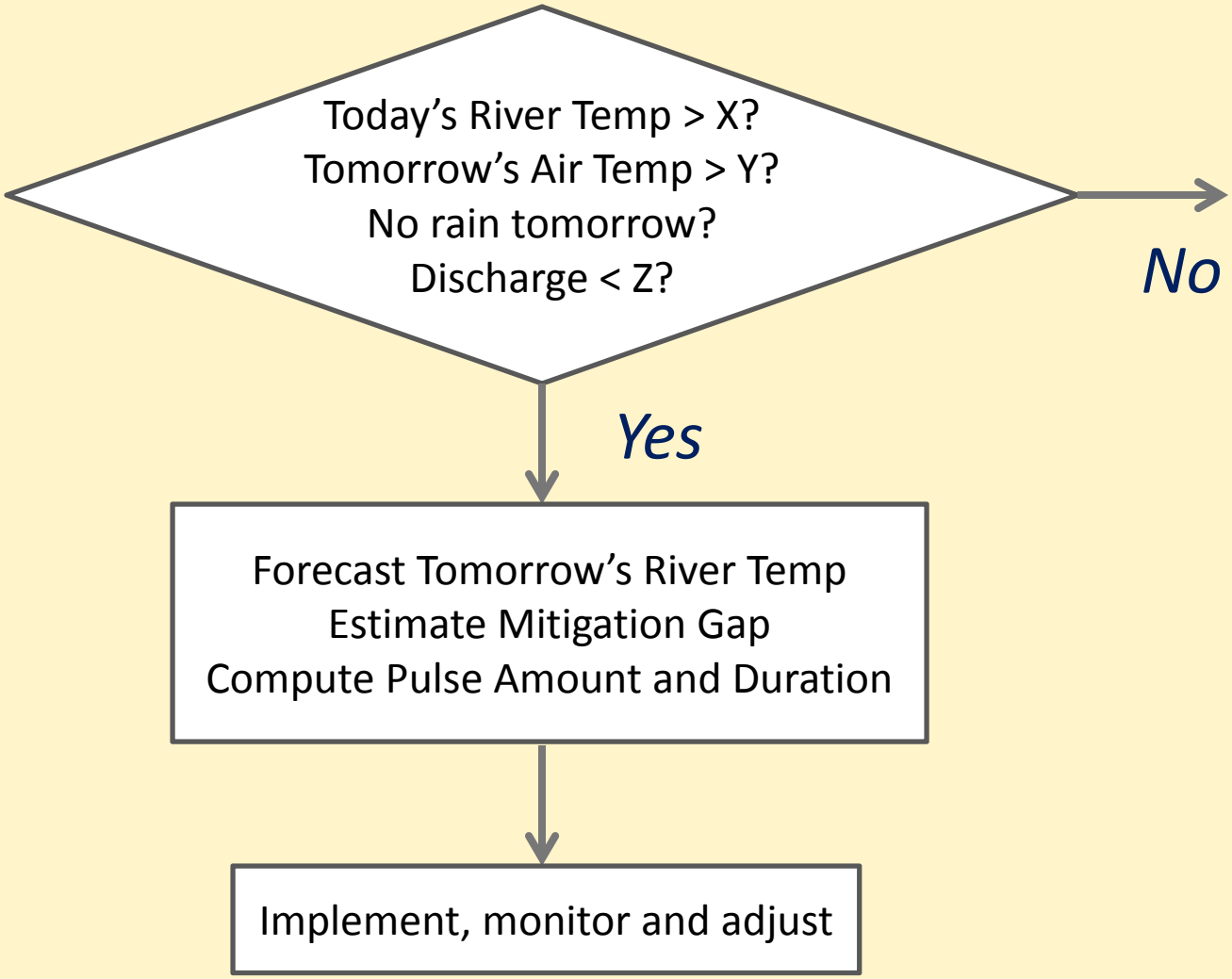
- No Continue to monitor
- Yes Recommend thermal relief. Release 300 cfs from Cannonsville from 3PM today for 24 hrs.
  Reevaluate after day 1 for multiple day release.

4. Increase release if East Branch proportion of Lordville discharge is large

Is discharge of E Branch @ Fishs Eddy >50% of Delaware River @ Lordville discharge and Lordville Q < 1250cfs?

- No No increase in thermal release
- Yes Increase thermal relief release by 50 cfs from C-ville or Pepacton.

5. Request due to consideration of unique temperature situations may occur.
Approach: Long term slow increases in air and water temperature without notable trigger events, cessation of directed releases, or warm, humid days/nights may cause water temperatures to approach critical range. Unique conditions will be evaluated as they occur.



Abstracting that: Possible Logic Tree for Pulse Decision Support

Designing a Stress Alert Procedure

- Starting with the PAF&BC logic and parameters as a basis, we have generated a set of candidate stress alert rules using yesterday's flow and temperature at Lordville, yesterday's air temperature and Cannonsville release and tomorrow's forecasted air temperature.
- A very simple rule using only data on yesterday's Lordville flows and temperatures , yesterday's air temperature and tomorrow's forecasted air temperature has about a 10% false positive and false negative rate. Incorporating more information and forecasted heat waves will improve the accuracy substantially.

A Path to Development of a Thermal Relief Protocol

PPL's Lackawaxen Temperature Regulation Program

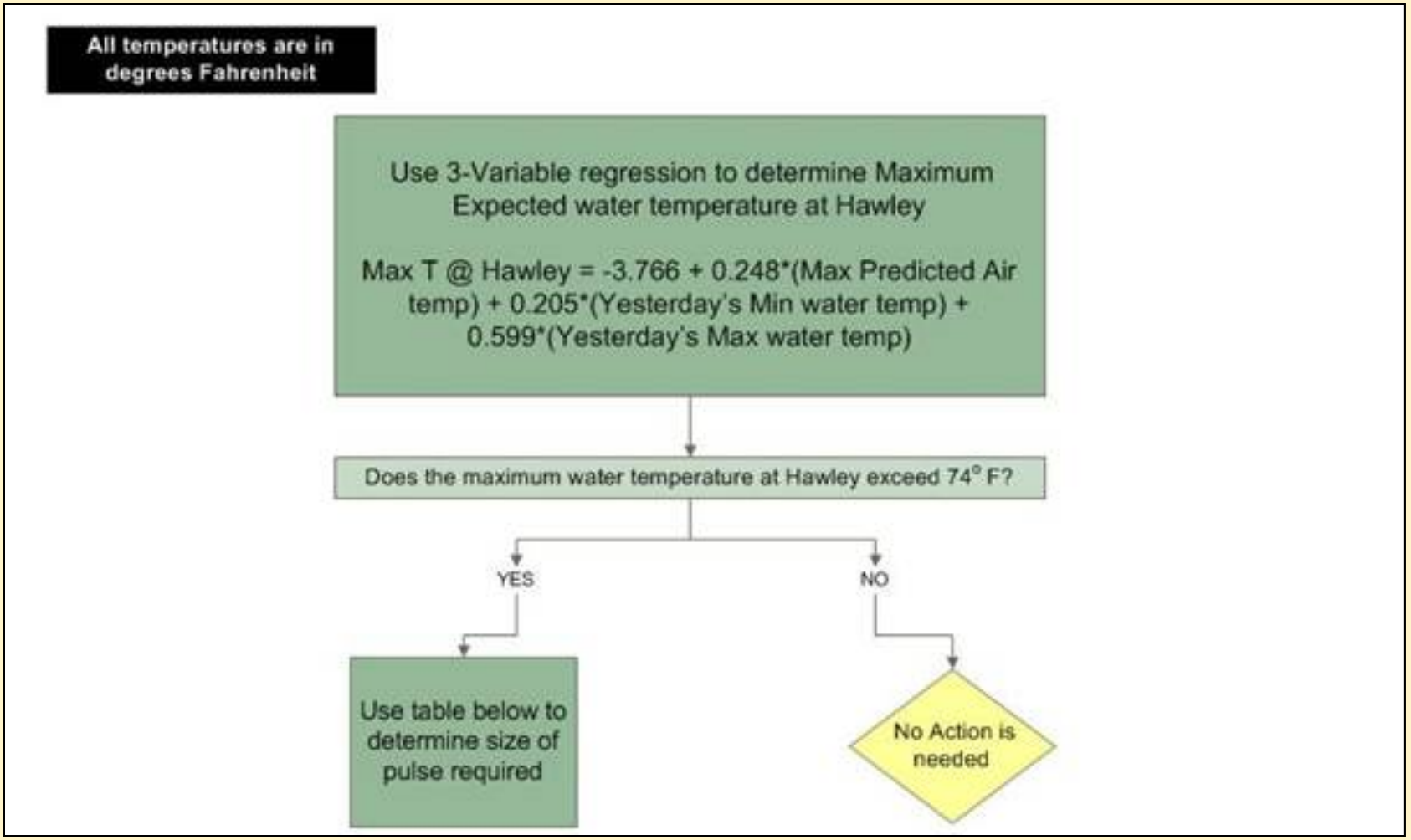
A successful local model

- Since 2010, PPL, in cooperation with the Pennsylvania Fish and Boat Commission has managed its summer power generation releases from Lake Wallenpaupack to keep water in a six-mile stretch of the Lackawaxen River downstream of their hydroelectric power plant below 75° F.
- The program is based on statistical forecasts of water temperatures and estimates of the release quantity necessary to maintain the 75° F temperature target.
- The PPL program has a temperature release bank 7,905 cfs-days.
- The program has cut stress days in half, and has not caused conflicts with other operating constraints relative to Lake Wallenpaupack.
- The PPL program has
  - fully specified protocols for its thermal releases, which are keyed to air temperatures and river flows via a table:
  - uses a regression based river temperature forecasting model

PPL Has Developed Fully Specified Protocols for Thermal Releases: Example

- For the 2011 thermal season, PPL Hydro Operators should receive several emails regularly each day (copies to GEI team and Mike Bennett):
  - • 2 a.m. Status Report Table (previous 24-hour DSS data);
    • 4 a.m. Pulse Flow start time and size; or No Action message;
    • 5 p.m. or later, Pulse Flow stop time.
- If DSS predicts < 75F at Hawley , the 4 a.m. email subject will read: DSS: No Action Needed
- If DSS predicts > 75F at Hawley, the 4 a.m. email subject will read: DSS: ACTION NEEDED
- Each email will contain specific instructions and graphics including (1) the pulse, (2) the previous week's actual river temperatures at Hawley and Rowland (matched against a 75F warning line); and a graphic of the NOAA 7-day Air Temperature Forecast (matched against a 70F warning line).
- If NOAA forecasts air temperatures above 70F, PPL should anticipate pulse instructions depending on discharge levels.
- If the DSS fails to email by 2 a.m. or 4 a.m. PPL operators should follow this protocol:

PPL uses a regression model similar to our own



PPL keys releases to temperature and river flows via a lookup table:

Maximum Predicted Air Temperature

Average Flow Hawley (cfs)	*<70F*	*70-75F*	*75-80F*	*80-85F*	*85-90F*	*>90F*
<100	No Pulse	Medium Pulse to 550 cfs (12 Mw)	Large Pulse to 700 cfs (16 Mw)	Large Pulse to 750 cfs (18 Mw)	Large Pulse to 800 cfs (19 Mw)	Large Pulse to 850 cfs (20 Mw)
100-400	No Pulse	Medium Pulse to 550 cfs (4-12 Mw)	Medium Pulse to 700 cfs (8-16 Mw)	Medium Pulse to 750 cfs (9-18 Mw)	Medium Pulse to 800 cfs (11-19 Mw)	Large Pulse to 850 cfs (12-20 Mw)
400-550	No Pulse	Small Pulse to 550 cfs (4 Mw)	Medium Pulse to 700 cfs (4-8 Mw)	Medium Pulse to 750 cfs (4-9 Mw)	Medium Pulse to 800 cfs (6-11 Mw)	Medium Pulse to 850 cfs (8-12 Mw)
550-700	No Pulse	No Pulse	Small Pulse to 700 cfs (4 Mw)	Small Pulse to 750 cfs (4 Mw)	Small Pulse to 800 cfs (4-6 Mw)	Medium Pulse to 850 cfs (4-8 Mw)
700-850	No Pulse	No Pulse	No Pulse	Small Pulse to 750 cfs (4 Mw)	Small Pulse to 800 cfs (4 Mw)	Small Pulse to 850 cfs (4 Mw)
>850	No Pulse	No Pulse	No Pulse	No Pulse	No Pulse	Small Pulse (4Mw)

We Recommend:

- We urge the implementation of an experimental thermal relief program for Lordville in the upcoming FFMP/OST revision based on these results and on the ability of the PF&BC and NYS-DEC to forecast thermal stress events.
- A goal of the program, in addition to providing stress mitigation in the coming summer, should be to conduct experiments to validate and refine the estimates of the cooling effect of Cannonsville releases on Lordville temperatures, and our ability to forecast stress events.
- We suggest a cooperative program design development with the partners being ourselves (the Delaware Watershed Conservation Coalition), NYC-DEP, PAF&BC, and NYS-DEC Bureau of Fisheries. The teamwork that led to the design of original FFMP in 2007 and to the Joint Fisheries White Paper in 2010 are models of working together for the common good.
- We recommend that SEF or RFAC or 'The Principals' or the DRBC invite the designers and operators of the PPL program on the Lackawaxen to describe its design, implementation and results to them in person.

An Offer

- The concepts we have presented today and at RFAC on February 19th are based on many hundreds of hours, perhaps more than a thousand hours of analysis. There are many details underlying them that we would be pleased to share with the Decree Parties collectively or individually at their convenience.

- We volunteer to collaborate in further development of the specifics of an experimental thermal relief program for the upper Delaware.


The End
Questions?

Appendix

Statistics of Thermal Stress at Lordville

- There were 12 stress days in an average summer; one summer (1992) had none; the worst summer (1995) had 23. The summer of 2010 had 18 stress days, 2011 had 3 and 2012 had 14.
- Stress days cluster in July: 24% of July days, compared to the summer-wide average of 13.2%. There are few stress days in May (2%) or September (1%).
- The average maximum temperature when in stress was 76.4°F, the highest maximum temperature was 81.3°F.
- The average summer had about 10 degree days, and 16 cooling days. The worst summer had 19 degree days and 31 cooling days.
- Stress events averaged 3 days in duration, with a maximum of 9 days. They also averaged 3 degree days in magnitude. The worst event had 12 degree days.

The 8 'Heat Waves' of 2007 to 2012

Wave	Start Date	Avg Obs Air High	Avg Air High Forecast	Error	Avg max WaterTemp	Stress days
1	7/31/2007	84.1	85.9	1.8	73.4	3
2	6/6/2008	84.7	85.4	0.7	73.4	3
3	7/2/2010	86.4	85.0	-1.4	75.5	4
4	8/27/2010	82.5	85.3	2.8	72.5	3
5	7/15/2011	87.3	85.3	-2.0	70.8	1
6	6/28/2012	85.1	85.3	0.2	73.1	1
7	7/2/2012	84.1	86.1	2.0	73.0	1
8	7/13/2012	84.9	85.6	0.7	74.2	3

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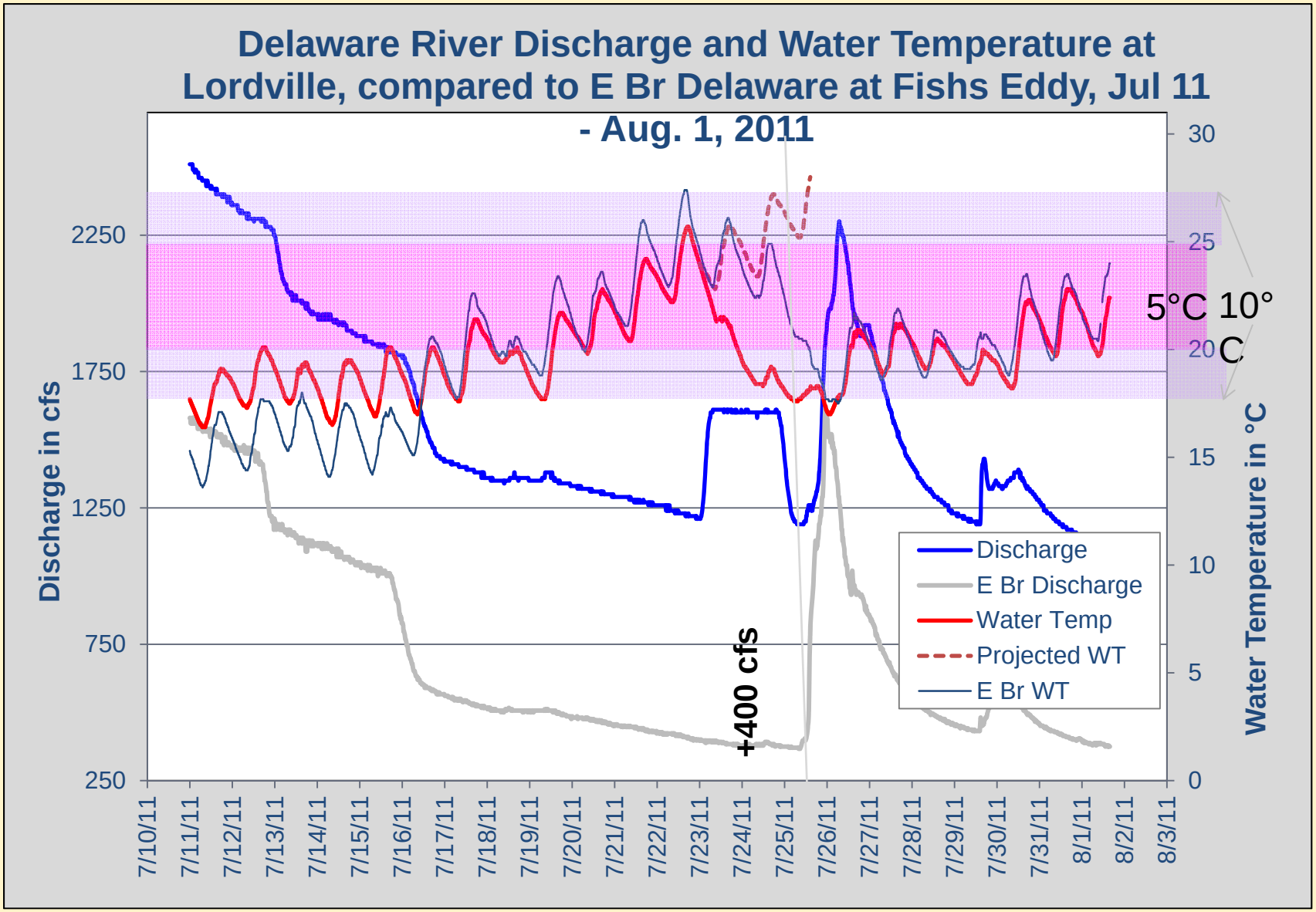
Delaware River Discharge and Water Temperature at Lordville, compared to E Br Delaware at Fishs Eddy, Jul 11 - Aug. 1, 2011
Discharge in cfs
Water Temperature in °C
2250
1750
1250
750
250
30
25
20
15
10
5
0
5°C
10°C
+400 cfs
Discharge
E Br Discharge
Water Temp
Projected WT
E Br WT
7/10/11
7/11/11
7/12/11
7/13/11
7/14/11
7/15/11
7/16/11
7/17/11
7/18/11
7/19/11
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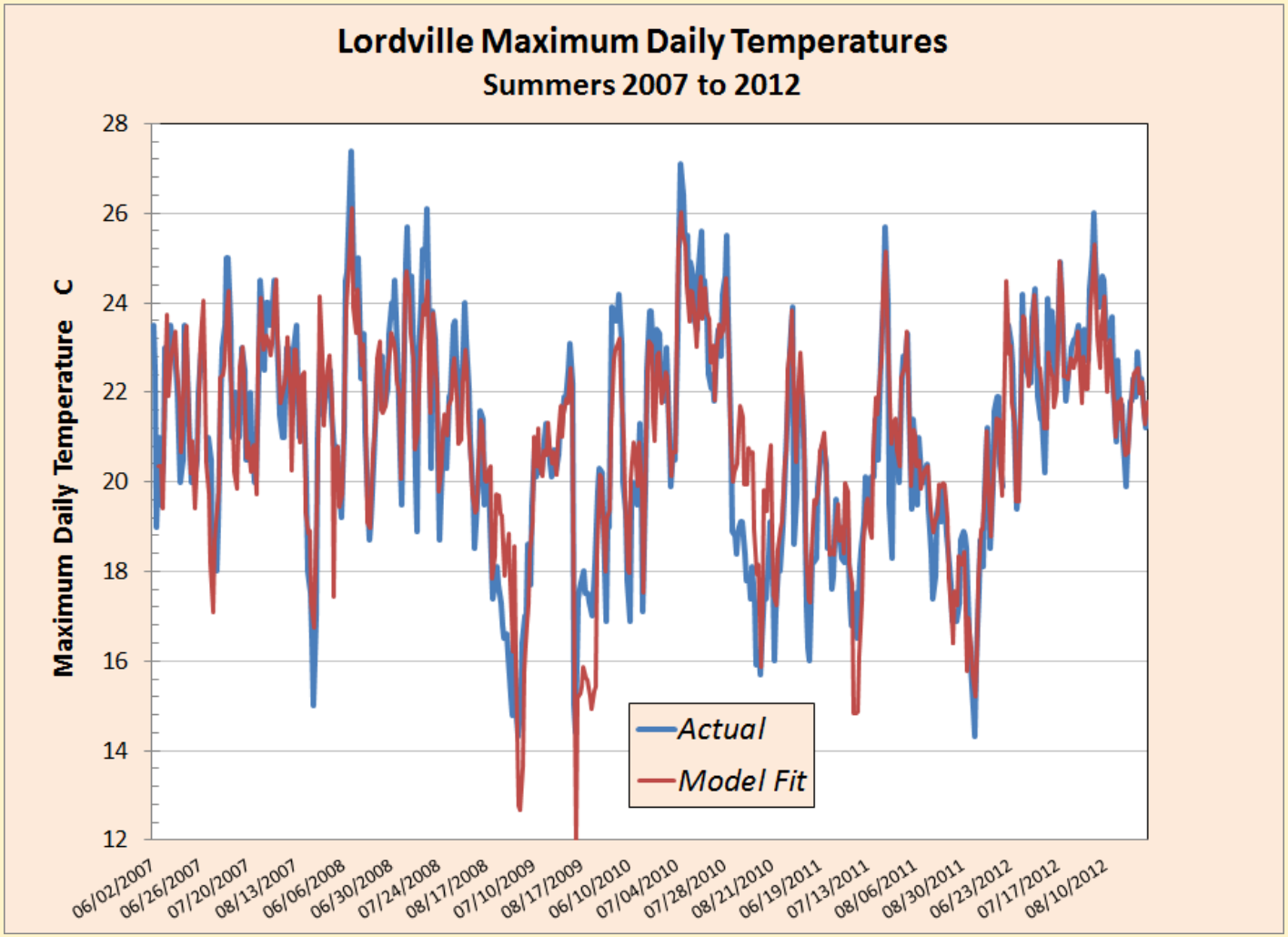
7/21/11
7/22/11
7/23/11
7/24/11
7/25/11
7/26/11
7/27/11
7/28/11
7/29/11
7/30/11
7/31/11
8/1/11
8/2/11
8/3/11

Our estimates of pulse impacts are based on a highly reliable statistical regression model based on river gage data from 6 summers



The cold water released from the dams warms and mixes with tributary water as it flows downriver