Thermal Stress Relief for the Upper Delaware:

It's needed. We know how to do it. It's feasible. Why not now?

Presented at RFAC
Hawley, PA
December 3, 2015

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Why We Care

A Little History

- Thermal stress relief has been a key goal of the Delaware Watershed Conservation Coalition since 2011.
- At RFAC meetings in December 2012 and again in March 2013, after a year of research, Jim Serio and I presented our analysis and proposal for an experimental relief program. Using data from 1993 to 2012 we showed that:
  - On average about 10 serious thermal stress events occur per summer, and most could be mitigated by pulsed releases of cold water from the Cannonsville reservoir.
  - The amount of water needed for relief is typically available in the reservoirs and would not put the needs of NYC or other Decree Parties at risk.
  - Thermal stress events can be forecasted, and can be avoided by preplanned action.
- Our proposal has been rejected/ignored -- without refutation. Additional data gathered since 2013 only strengthens our case. Yet, we face the summer of 2016 without a relief protocol or guidelines in place.

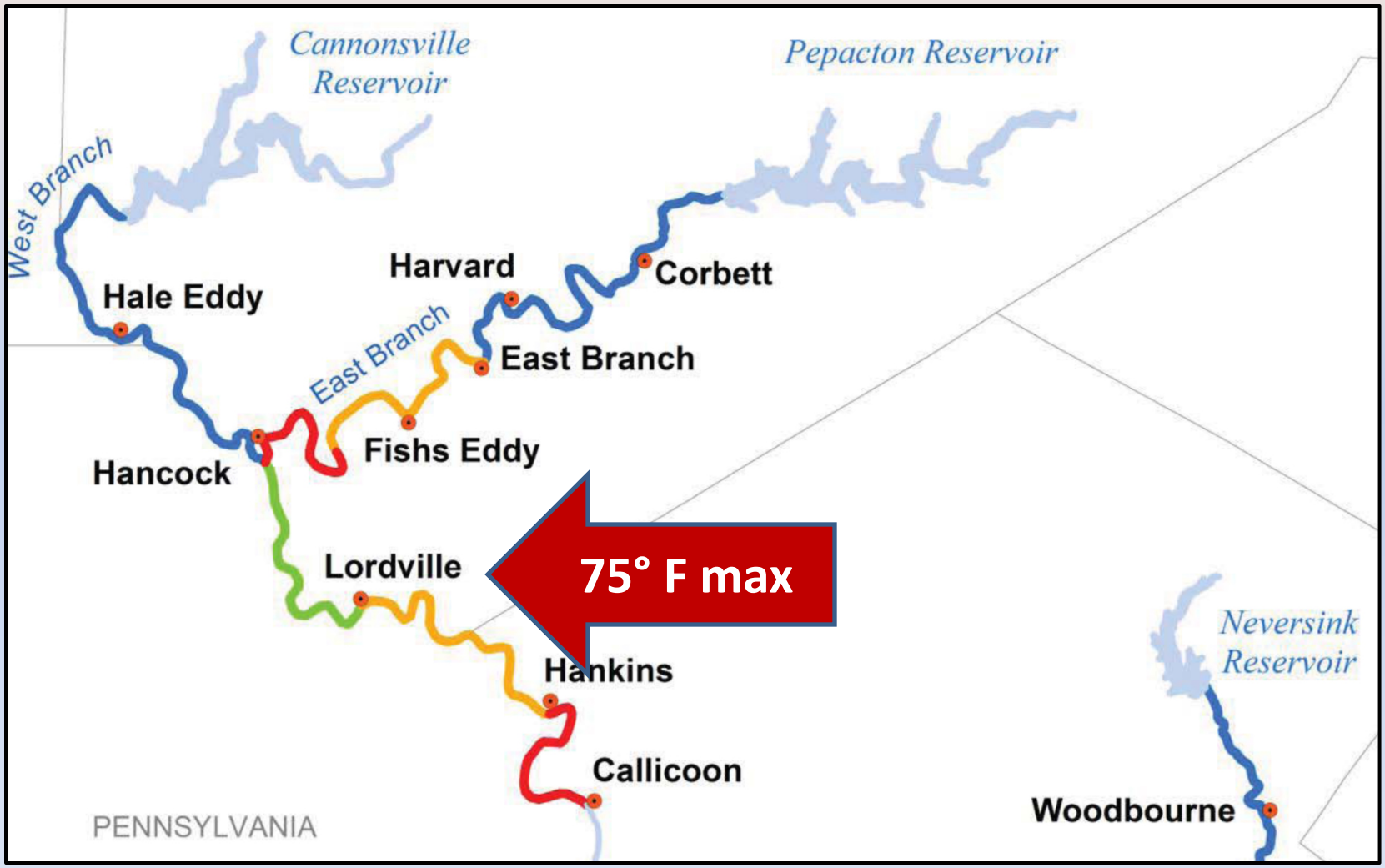
I. The Thermal Stress Problem, and Our Solution

Severe Thermal Stress

- The scientific literature shows that trout, a cold water species, are in 'severe thermal stress' whenever the daily maximum water temperature exceeds 75°F, that is, 23.9 C°.
- Use of this stress definition on the Delaware is supported by ample precedent:
  - DRBC Docket D77-20 CP Revision 1 (1977) and Revision 7, 2004, both have thermal targets of 75°F .
  - J. Douglas Sheppard, *New York Reservoir Releases Monitoring and Evaluation Summary Report Sheppard Report*, Technical Report 83-5, NYS-DEC, 1983
  - Mark Hartle, *Preliminary Report on Trout Habitat -Water Temperature Relationships in the Upper Delaware Basin*, PF&BC , SEF report the RFAC of the DRBC , August, 2010
  - John Pizzimenti, Lackawaxen River Thermal Decision Support System, Progress Report 2011

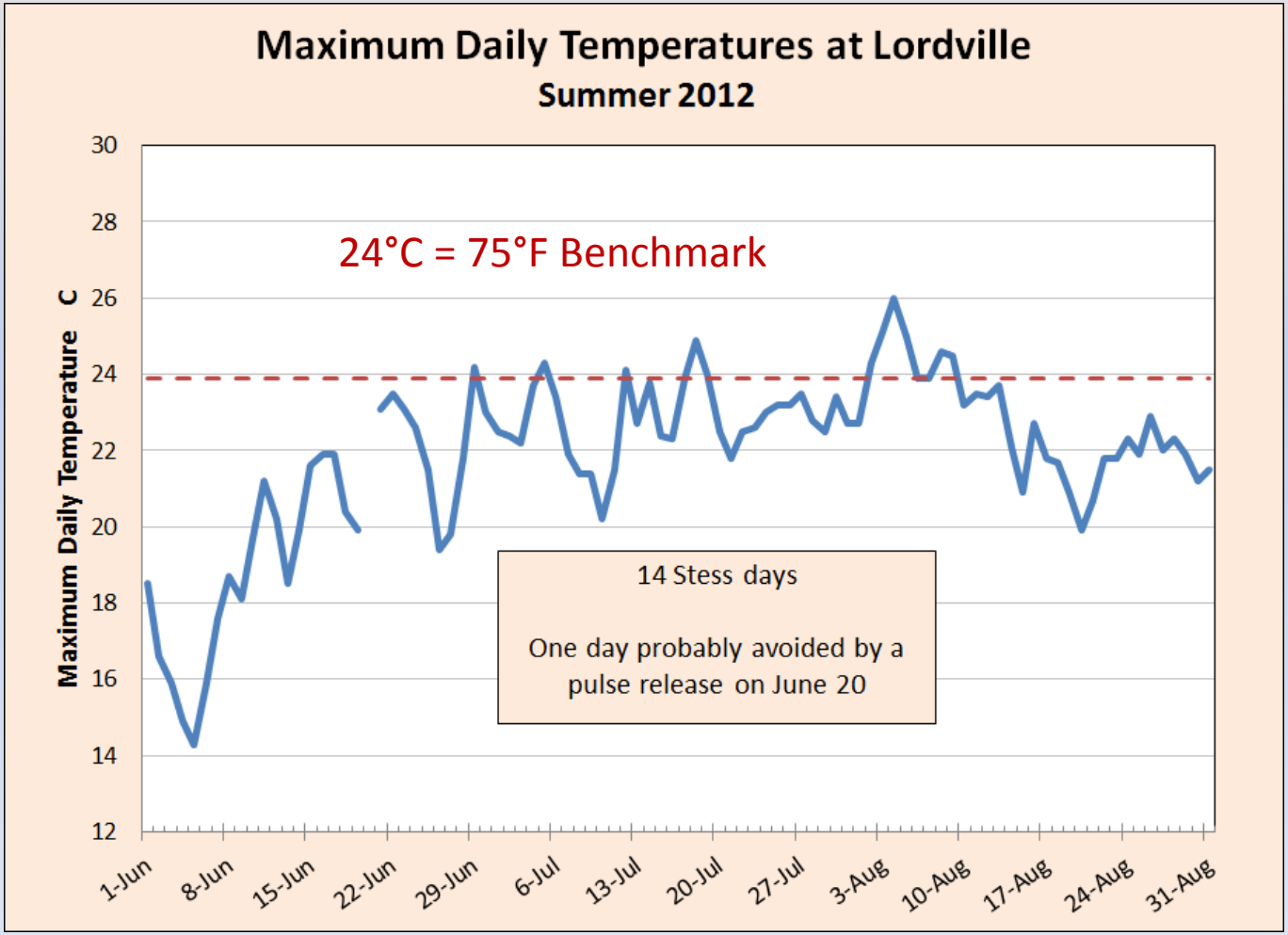
Our Focus: Mitigating Stress Down to Lordville

(Keep maximum river temperature below 75° F)



Source: Joint Fisheries White Paper, January 2010

The Need: Although, through the FFMP/OST, base releases have improved since 2007, the thermal stress problem remains: For example, there were 14 avoidable stress days in 2012.



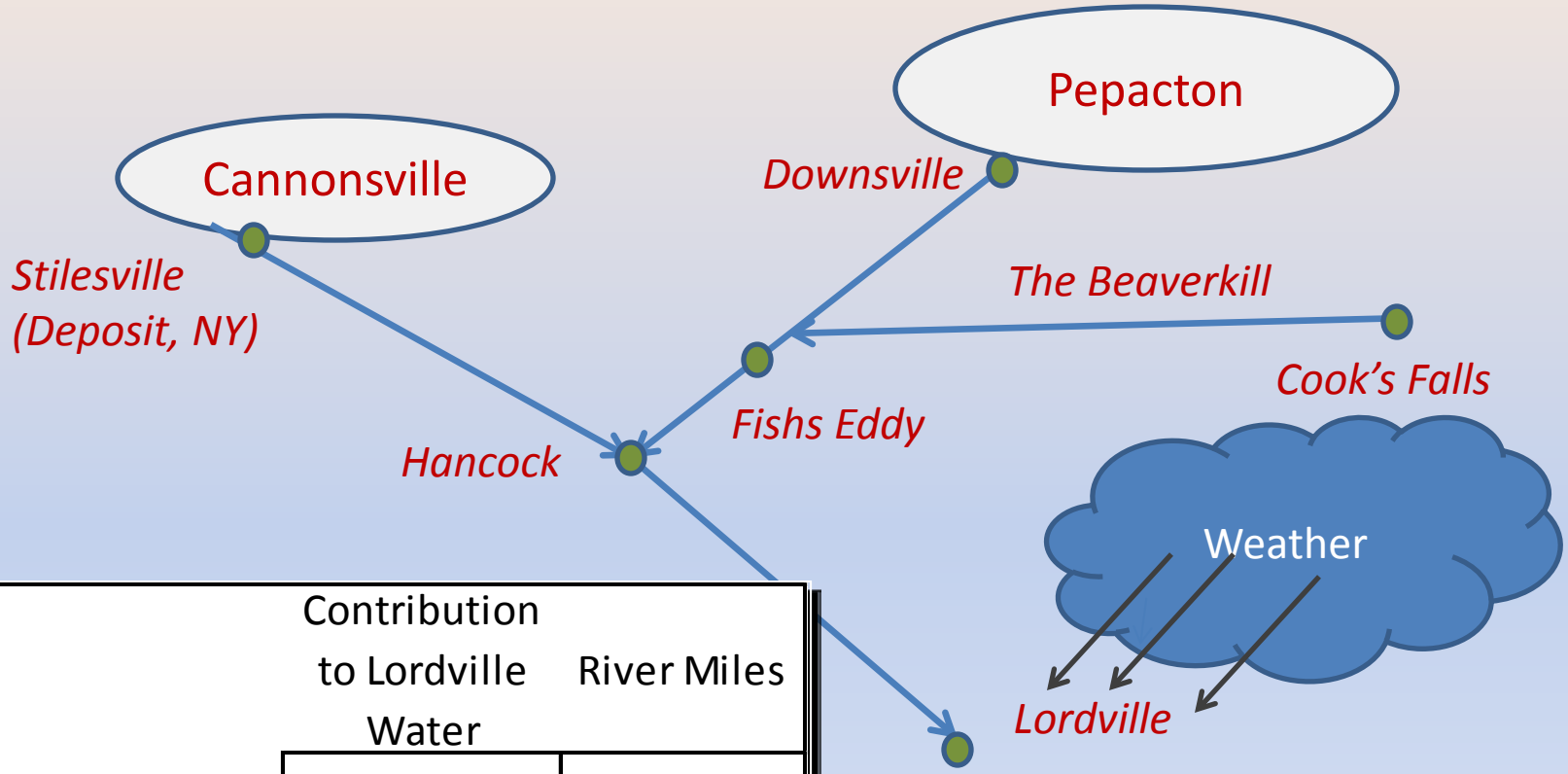
The Magnitude of the Problem:
Stress Conditions at Lordville, 1993 to 2014

Year	Stress Days	Degree Days
1993	7	4.9
1994	17	14.2
1995	23	19.3
Lordville Gage Not Operating		
2007	9	4.9
2008	18	19.3
2009	0	0.0
2010	18	18.6
2011	3	2.2
2012	14	8.1
2013	3	1.8
2014	0	0.0
Average	10.2	8.5
Minimum	0	0.0
Maximum	23	19.3

- In an average summer there were 10.2 severe thermal stress days requiring 8.5 degree days of cooling to bring them down to the 75° F benchmark.
- The worst summer, 1995, had 23 stress days requiring 19.3 degree days of cooling.

(We presented detailed analysis on the duration, severity and timing of stress events.)

Our Engineering Approach to Cooling Lordville



	Contribution to Lordville Water	River Miles
Cannonsville	31%	27
Pepacton	14%	42
Beaverkill	30%	35
Other Tributaries	25%	-

$$\frac{\partial T}{\partial t} = -\frac{\partial (QT)}{A\partial x} + \frac{\partial}{A\partial x}\left(EA\frac{\partial T}{\partial x}\right) + \frac{H_f}{\rho c_p D} + S_b$$

A Simple Linear Approximation: Typical Results:

A Regression Model with yesterday's Stilesville flow and yesterday's Deposit max air temperature, and today's Fishs Eddy maximum water temperature

```
The regression equation is
LordTmax = 4.72 - 0.00473 StilFloLag + 0.0995 DepTmaxLag +
0.500 FishTmax

498 cases used, 4 cases contain missing values

Predictor          Coef      SE Coef         T       P     VIF
Constant         4.7235       0.5169      9.14   0.000
StilFloLag     -0.00473      0.00017    -27.37   0.000   1.109
DepTmaxLag       0.09952     0.00882     11.28   0.000   1.894
FishTmax         0.49958     0.02154     23.20   0.000   1.891

S = 0.984521   R-Sq = 85.2%   R-Sq(adj) = 85.1%

Analysis of Variance
Source            DF       SS       MS        F       P
Regression         3  2759.97   919.99   949.15   0.000
Residual Error   494   478.82     0.97
Total            497  3238.79
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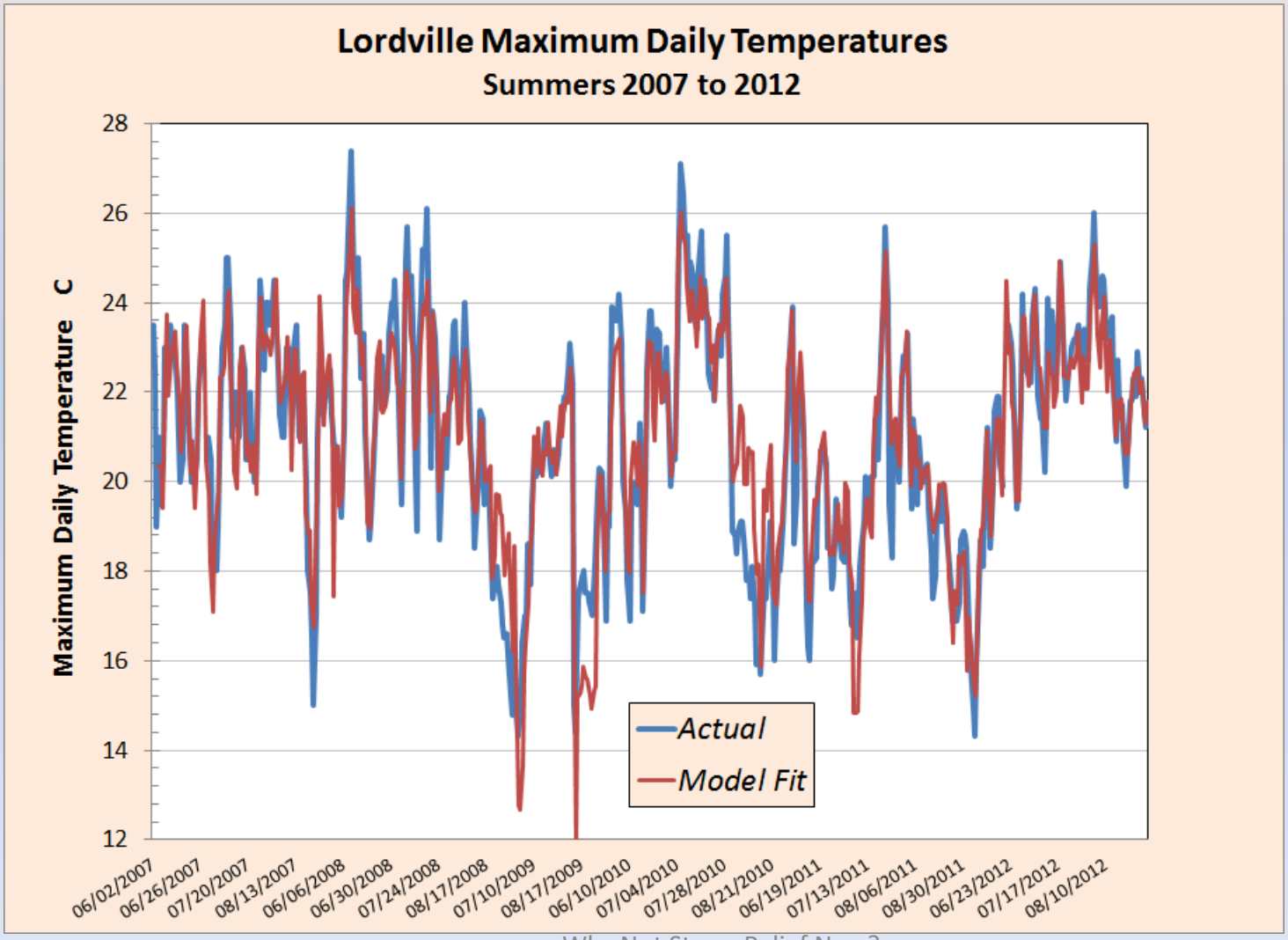
An Excellent Model Fit during Five Summers:

Model with yesterday's Stilesville flow and yesterday's Deposit max air temperature, and today's Fishs Eddy maximum water temperature



The Bottom Line:

- We estimate that:
  - *It takes about 221 cfs to lower Lordville 1°C or equivalently about 118 cfs to lower it by 1°F.*
  - Cooling to a 75°F maximum would require about 2,100 cfs days of water during an average summer, cooling during the worst summer about 4,000 cfs days .
- A modest amount of water: On average
  - 0.7% of NYC diversions
  - 10% of the excess release during the Cannonsville seepage event.
  - 22% of the special needs bank of the IERQ
  - One day of thermal relief equals the amount of excess water available daily per the NYC-Dep OST Summary reports.

We recommend that

- When river temperatures at Lordville are expected to exceed 75°F, additional water be released to lower the temperature to 75, per our estimates of 221 cfs per degree C – as long as this does not exhaust a ‘special needs’ water bank, or lower reservoir storage below ‘normal’ levels.
- (Procedural details can be developed in collaboration with the Decree Parties.)

The stress event of July 2013 confirmed the soundness of this proposal

- In mid July 2013 the Weather Bureau forecasted a heat wave, and we predicted a concomitant stress event in the river. On July 14, with the NYC reservoirs at 96.9 % capacity, the Coalition and the UDC called for a relief release from Cannonsville.
- The Decree Parties had no preplanned relief protocol in place. To make matters worse, key decision makers were unreachable during the critical days leading up to the heat wave. This led to a chaotic situation and delays in decision making.
- On July 16, after numerous petitions from the community, the Decree Parties instituted a 300 cfs pulse relief release for July 17 & 18 that essentially followed our recommendations. Severe thermal stress was largely avoided, but lack of an approved protocol resulted in avoidable anxiety, agitation and delay, less thermal protection, and a less efficient use of available water. Detailed analysis of this event confirmed the soundness of our framework, and was shared with the Decree Parties.

Consistency with Recent USGS Studies

- The USGS has been conducting extensive river temperature modeling as part of its Delaware River Basin WaterSMART Focus Area Study.
- Their research, reported in a 2014 paper in the *Journal of Hydrology*, and additional research summarized in their November 19, 2015 WaterSMART webinar, uses data and methodology paralleling our own.
- We believe that their results, although not explicitly addressing the questions we have considered, are broadly supportive of our findings.
- Moreover, the research methods used by the USGS researchers and used by us fall within generally accepted statistical methodology employed routinely by hydrologists to study River temperature problems

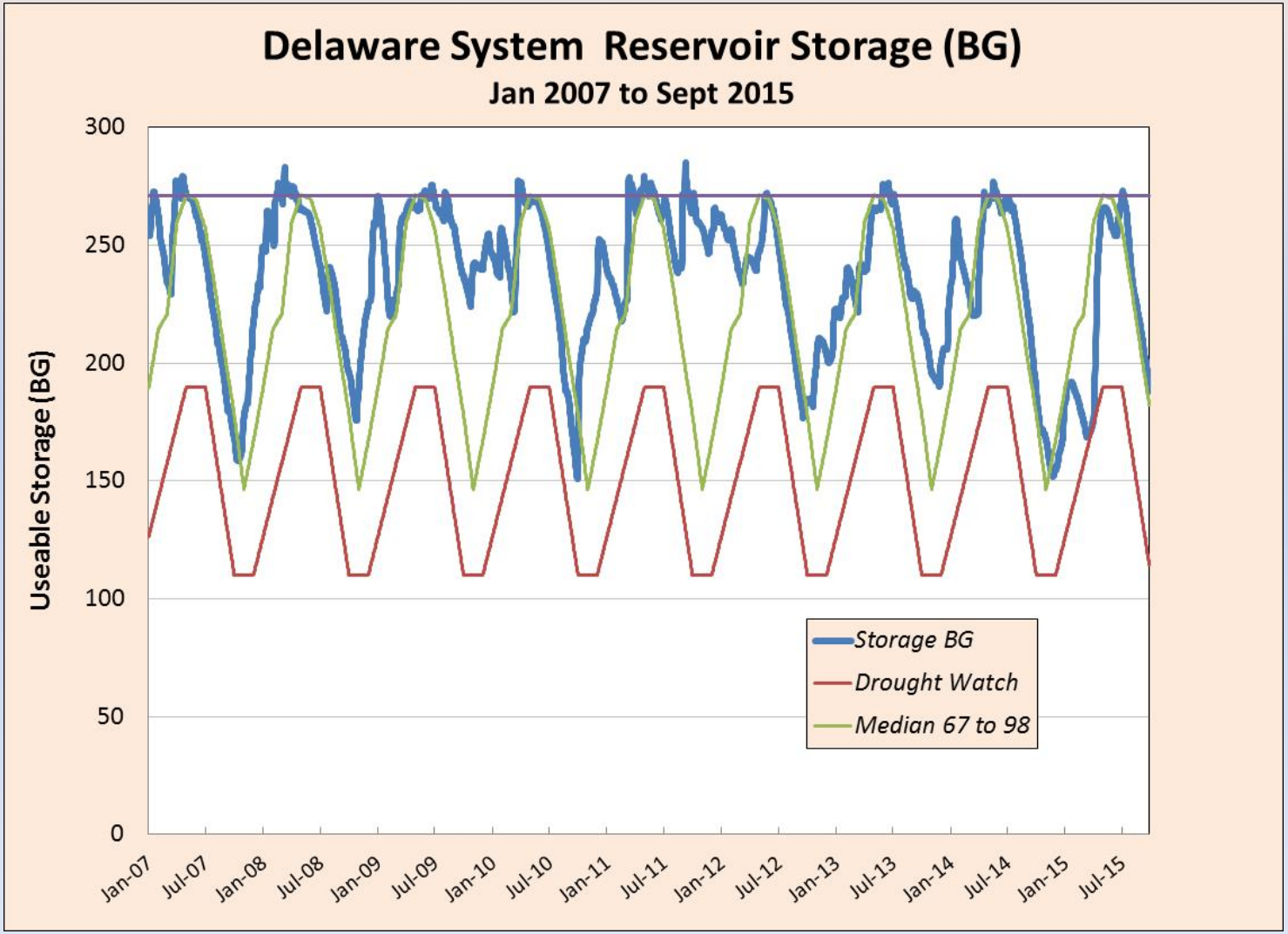
Reference: J.C. Cole et al, "Developing and Testing Temperature Models for Regulated Systems: A Case Study on the Upper Delaware River", Journal of Hydrology 519 (2014) 588 – 598

II. Water Availability for Thermal Relief

Except in all the most dire circumstances, the needed water is available.

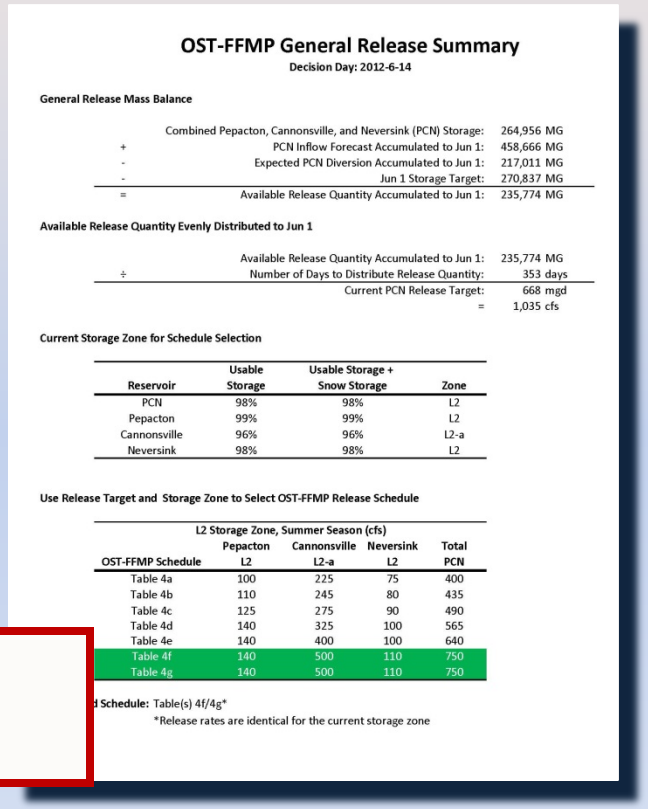
1. Actual reservoir storage since 2007 (under the FFMP rules) has been well inside the normal range (L2), averaging 22 BG above the historical median. The reservoirs have spilled in every year since 2007.
2. According to the NYC-DEP's *OST-FFMP General Release Summaries,* actual releases have averaged about 250 cfs below NYC-DEP's own computation of water available.
3. The Croton Water Treatment Facility, restores 290 mgd of high quality water to NYC's water supply. This reduces the City's dependence on Delaware water and should be reflected in an increase of the OST-FFMP's computation of available water.
4. The NYC water supply system is very robust and should be able to handle the modest amounts of water needed for thermal relief.
5. The OST/FFMP program already has an IERQ water bank of 9,423 cfs days available to meet "special needs." In most summers significant amounts of the IERQ have not been used – 7,376 cfs days unused on average since 2007.

1. There is Typically Enough Water in the Reservoirs to Support Thermal Relief



2. NYC's OST-FFMP computations show there is additional 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

These FFMP-OST Summaries are posted on the Rivermaster's website
http://water.usgs.gov/osw/odrm/weekly.html

3. Croton being online adds to NYC's available water supply

The additional 290 mgd of capacity makes NYC less reliant on the Delaware system

4. And the NYC water supply system is, by NYCDEP's own claims, and by recent experience very robust.

- In July of this year seepage occurred below the Cannonsville Dam during preparations for the proposed hydro facility and FEMA ordered that the reservoir be emptied. Though the NYC- DEP was prepared to fully empty Cannonsville if necessary to deal with the seepage problem they, stated:

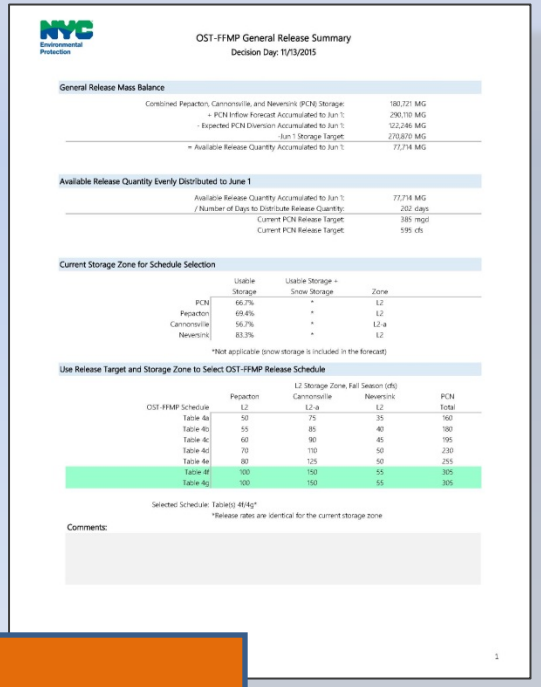
"Actions being taken at Cannonsville Reservoir do not pose a risk to New York City's water supply."

- During the seepage crisis the DEP was releasing 1,492 cfs into the river, about 900 cfs above 'normal'… far more than anything needed by a thermal relief program.
- And today, despite the July crisis, PCN reservoir storage is and has been above normal since October.

Today, notwithstanding the July Cannonsville seepage crisis, NYC-DEP estimates there is 290 cfs excess available water.

November 11, 2015 Storage at 67% (L2)

Combined PCN Storage (MG)	180,721
Inflow Forecast to Jun 1	290,110
Expected Diversions to Jun 1	122,246
Jun 1 Storage Target	270,870
Available Release Quantity	77,715
Days Remaning to Jun 1	202
Release Target MGD	385
Release Target CFS	595
Table 4g Release	305
Excess CFS Available	290



NYC Environmental Protection

OST-FFMP General Release Summary

Decision Day: 11/13/2015

General Release Mass Balance

Combined Pepacton, Cannonsville, and Neversink (PCN) Storage:	180,721 MG
+ PCN Inflow Forecast Accumulated to Jun 1:	290,110 MG
- Expected PCN Diversion Accumulated to Jun 1:	122,246 MG
Jun 1 Storage Target:	270,870 MG
= Available Release Quantity Accumulated to Jun 1:	77,714 MG

Available Release Quantity Evenly Distributed to June 1

Available Release Quantity Accumulated to Jun 1:	77,714 MG
/ Number of Days to Distribute Release Quantity:	202 days
Current PCN Release Target:	385 mgd
Current PCN Release Target:	595 cfs

Current Storage Zone for Schedule Selection

	Usable Storage	Usable Storage + Snow Storage	Zone
PCN	66.7%	*	L2
Pepacton	69.4%	*	L2
Cannonsville	56.7%	*	L2-a
Neversink	83.3%	*	L2

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

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

	L2 Storage Zone, Fall Season (cfs)			
OST-FFMP Schedule	Pepacton L2	Cannonsville L2-a	Neversink L2	PCN Total
Table 4a	50	75	35	160
Table 4b	55	85	40	180
Table 4c	60	90	45	195
Table 4d	70	110	50	230
Table 4e	80	125	50	255
Table 4f	100	150	55	305
Table 4g	100	150	55	305

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

*Release rates are identical for the current storage zone

Comments:

1

5. The IERQ is explicitly designated to meet special needs –such as thermal relief

- The Interim Excess Release Quantity (IERQ) is a complex aspect of the 1954 Supreme Court decree included in the current OST-FFMP that prevents NYC from hoarding water. It requires NYC to release water into the river over & above meeting the 1750 cfs target at Montague.
- The IERQ already includes a water bank of 9,423 cfs days available to meet "special needs." In most summers significant amounts of the IERQ have not been used – 7,376 cfs days unused on average since 2007.
- A correct proper computation of the IERQ, using the City's maximum consumption over the last five years, would increase the water available for 'special needs' by a factor of four or more. (ref. Garth Pettinger computations)

III. Forecasting and Implementation

Thermal stress events are not surprises!

Relief Action Triggers

- Thermal relief releases should be triggered by forecasts of thermal stress. The key indicators are rising river temperatures, high air temperatures and weather bureau forecasts of air temperatures and precipitation.
  - The PAF&BC has done an excellent job of forecasting thermal events over at least the last five years.
  - Our research has shown that thermal stress in the Delaware is highly correlated with temperature heat waves -- which are themselves very well forecasted by the Binghamton weather station. Since 2007 they have accurately forecasted all 8 long-duration heatwaves and the river went into thermal stress at Lordville during each of them.
- While one could wait until the river actually goes into thermal stress before making an relief release, this is damaging to the ecology and actually wasteful of water.

We Recommend a Prudent Approach

- Thermal relief releases should not be made if they would put reservoir storage levels below 'normal' (L2).
- Since the environment suffers most if reservoir levels drop below L2, the Coalition would be the last to recommend action that would risk such an event. If reservoir storage drops into L3, NYC and NJ suffer no reduction in diversions, the Montague target is reduced by 5%, but discharges into the Upper Delaware drop by 64%!!

Ref: Tables 1 and 3 of the 2015 FFMP agreement

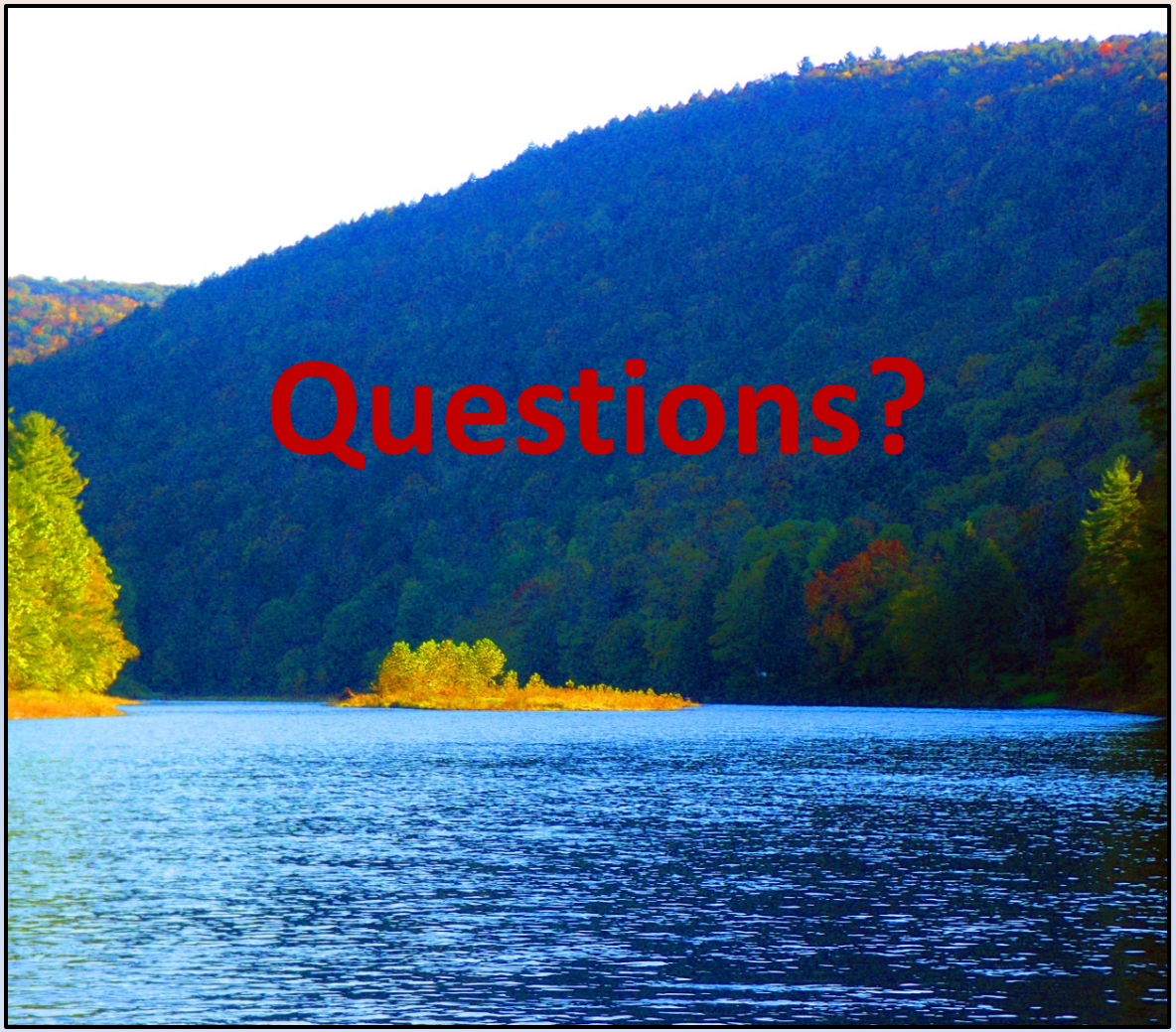
Thermal Relief Precedents

- The thermal relief framework that we are proposing is not revolutionary.
- A thermal relief bank managed by NYS-DEC was included in the predecessor to the FFMP (Rev 7).
- Similar thermal relief regimes have been used for years on the Madison River in Montana, on the Mountain Fork River in Oklahoma, on several rivers in Australia, and notably right here on the Lackawaxen, a tributary of the Delaware. (Under the supervision of the PA F&BC.)
- The concept has been researched by the USGS WaterSMART project.

IV. Closing

We Recommend

- The Decree Parties should implement an experimental thermal stress relief protocol before the summer 2016. This would protect the trout in the upper main stem from the worst stress conditions at no water availability risk to anyone, reduce the decision burden on the river's managers, and relieve the fishing community of much summertime anxiety.
- Jim Serio and I, and my colleagues at the Columbia Water Center, again volunteer to collaborate with the Delaware Watershed Conservation Coalition, the Decree Parties, the DRBC and the Office of the Delaware River Master to this end. We have worked collaboratively in the past for the benefit of all. Let's do it again.


Questions?

Appendix

From Rev 1 (1977)

C. Special Thermal Stress Releases

- Special releases may be made from one or more of the reservoirs in order to relieve thermal stress conditions which pose a threat to fisheries. The total volume of such releases should not exceed 6000 CFS days from all reservoirs. Thermal releases, with a one day lead time, would be made whenever the maximum water temperatures in designated downstream areas as determined from measurements at Callicoon, Harvard, Woodburn, or Hale Eddy is projected to exceed a maximum of 75°F or a 72°F daily average. If the 6000 CFS days reserve is not used by October 31 of any year it will not be used thereafter. No releases for relieving thermal stress would be required from November 1 to April 30 of any year. Releases for purposes of relieving thermal stress shall be at the direction of NY DEC

From Rev 7 (2004)

4. There is hereby established, for thermal and habitat protection in the tailwaters below the City Delaware Reservoirs, for the period beginning May 1, 2004 and ending May 31, 2007, a Habitat Protection Bank (HPB), with the following provisions:

A. A "Habitat Protection Bank (HPB)" of 20,000 cubic feet per second days (cfs-days) is established, which shall consist of: an Excess Release Quantity Bank (ERQB) of 5,700 cfs-days, provided from the Excess Release Quantity (ERQ); a Thermal Release Bank (TRB) of 9200 cfs-days; and a Supplemental Release Bank (SRB) of 5,100 cfs-days. Water from the ERQ shall be credited on June 15, and any water remaining from that quantity shall expire on March 15 of the following year. The 9,200 cfs-days TRB and 5,100 cfs-days SRB shall be credited on May 1, and any water remaining in these banks shall expire on April 30 of the following year. In any year during which the Drought Operations Plan for Lake Wallenpaupack is not in effect, the HPB shall be limited to 16,000 cfs-days, consisting of: an ERQB of 3,420 cfs-days from the ERQ; a TRB of 9,200 cfs-days; and an SRB of 3,380 cfs-days. Waters from the ERQ not contributed to the HPB shall be utilized to provide a proportionally-reduced increase in the Montague flow objective according to the current procedures, or may be banked in accordance with the procedures outlined in the Lower Basin Drought Management Plan. In addition, an Amelioration Bank (AB) of 3,000 cfs-days may be available subject to the provisions of Paragraph 6.

Continued

B. The TRB shall be used to direct releases during May 1 through October 31 so as to prevent to the maximum extent possible any instantaneous water temperature higher than 75° F or any daily average temperature higher than 72° F in the designated downstream areas as determined from measurements at the Hale Eddy, Harvard, Bridgeville, Hancock and Hankins gaging stations. Designated downstream areas shall mean the following waters:

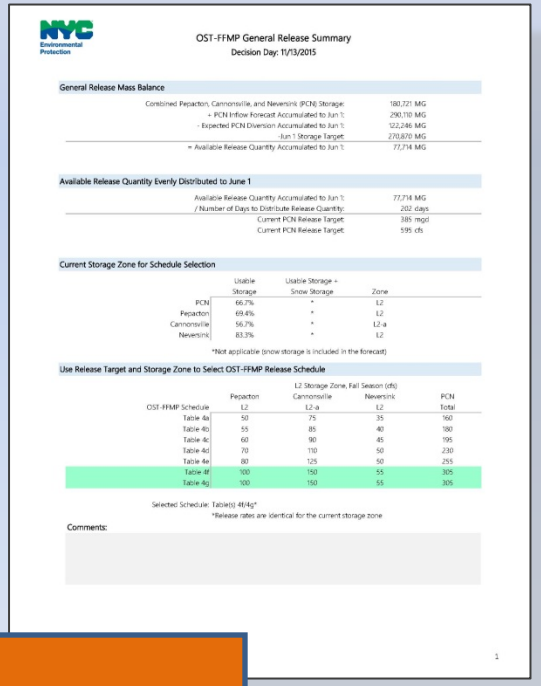
- The West Branch Delaware River between Cannonsville Reservoir and Hancock, NY
- The East Branch Delaware River between Pepacton Reservoir and the confluence of the East Branch Delaware River and the Beaver Kill
- The Delaware River between Hancock, NY and Hankins, NY
- The Neversink River between Neversink Reservoir and Bridgeville, NY

Any quantity of water remaining in the TRB after October 31 may subsequently be used for habitat protection.

True on Oct 13 to, even given the Cannonsville seepage crisis of this summer, NYC-DEP estimates there was adequate water.

October 13,2015: storage at 66% , L2

	(MG)
PCN Storage	180,130
Forecasted Inflow	302,527
Expected Diversion	141,414
June 1 Storage target	270,870
Available Release Quantity	70,374
Days Remaining	233
Release target (MGD	302
(CFS)	467
Table 4f/4g rlease (CFS)	305
Excess CFS Available	162



NYC Environmental Protection

OST-FFMP General Release Summary

Decision Day: 11/13/2015

General Release Mass Balance

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Jun 1 Storage Target:	270,870 MG
= Available Release Quantity Accumulated to Jun 1:	77,714 MG

Available Release Quantity Evenly Distributed to June 1

Available Release Quantity Accumulated to Jun 1:	77,714 MG
/ Number of Days to Distribute Release Quantity:	202 days
Current PCN Release Target:	385 mgd
Current PCN Release Target:	595 cfs

Current Storage Zone for Schedule Selection

	Usable Storage	Usable Storage + Snow Storage	Zone
PCN	66.7%	*	L2
Pepacton	69.4%	*	L2
Cannonsville	56.7%	*	L2-a
Neversink	83.3%	*	L2

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

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

	L2 Storage Zone, Fall Season (cfs)			
	Pepacton	Cannonsville	Neversink	PCN
OST-FFMP Schedule	L2	L2-a	L2	Total
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Table 4e	80	125	50	255
Table 4f	100	150	55	305
Table 4g	100	150	55	305

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

*Release rates are identical for the current storage zone

Comments:

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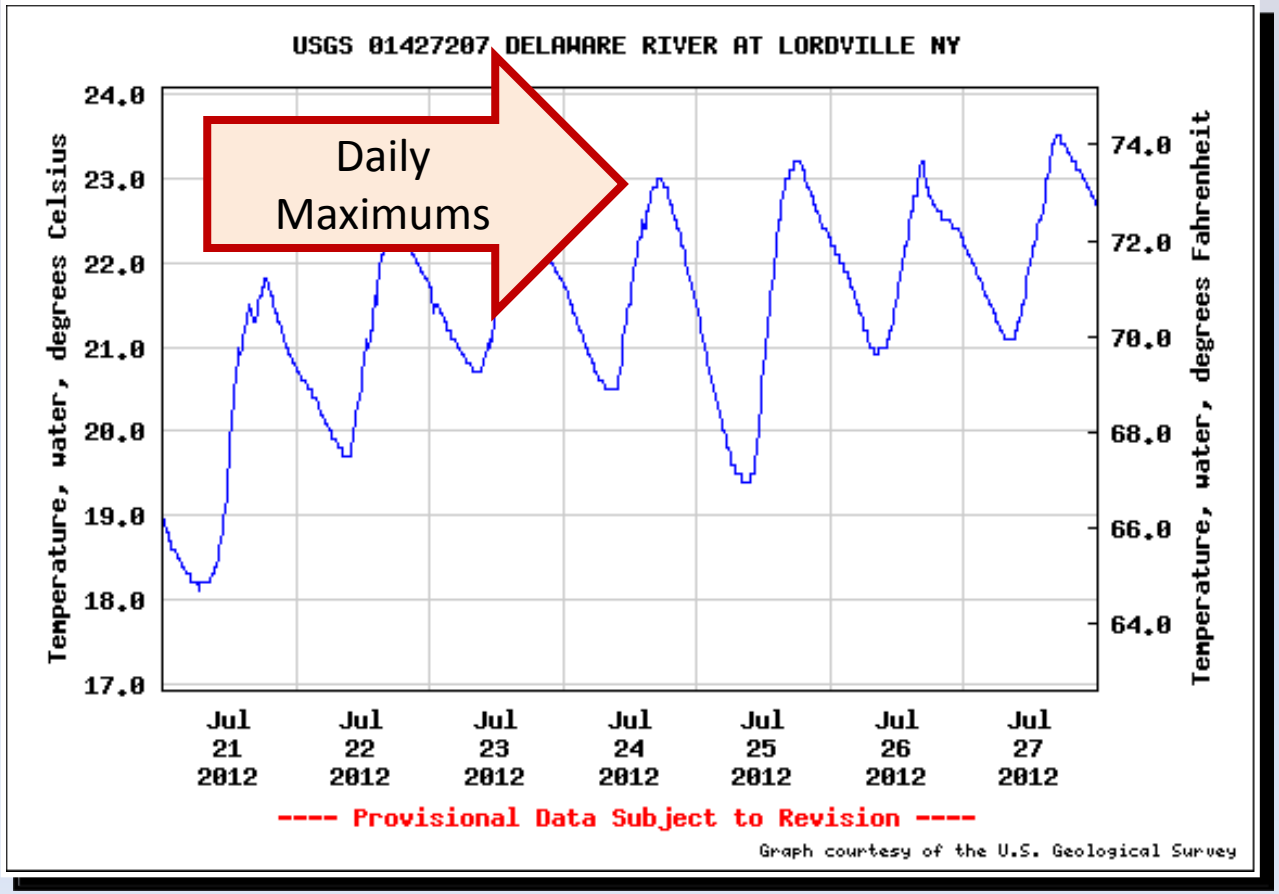
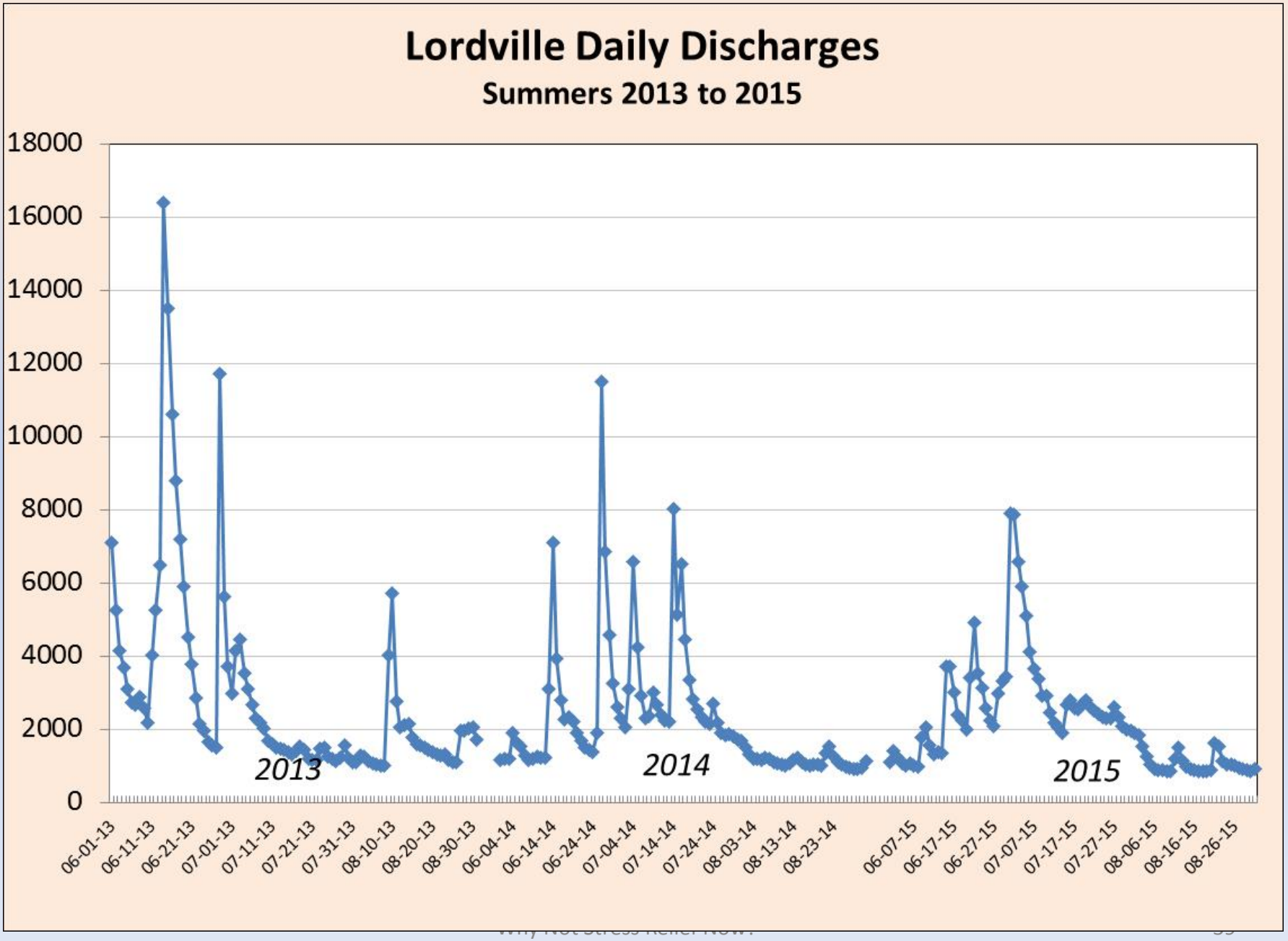
Defining Severe Thermal Stress

- The Upper Delaware River Tailwaters 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 influence of weather and weather forecasts on river temperatures is well understood.

- Local air temperatures, particularly during heat waves, have a strong influence on Upper Delaware water temperatures and on the occurrence of potential severe stress events.
- The Binghamton weather bureau office has done a good job of forecasting high daily maximum air temperatures. It identifies in advance individual days with very high temperatures and more importantly sequences of consecutive hot days – 'heat waves'. Since 2007 they have accurately forecasted all 8 long-duration heatwaves and the river went into thermal stress at Lordville during each of them.
- Relying in part on such air temperature forecasts, the PA F&BC has in recent years done an excellent job of forecasting thermal stress events.


Lordville Daily Discharges
Summers 2013 to 2015
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
2013
2014
2015
06-01-13
06-11-13
06-21-13
07-01-13
07-11-13
07-21-13
07-31-13
08-10-13
08-20-13
08-30-13
06-04-14
06-14-14
06-24-14
07-04-14
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07-24-14
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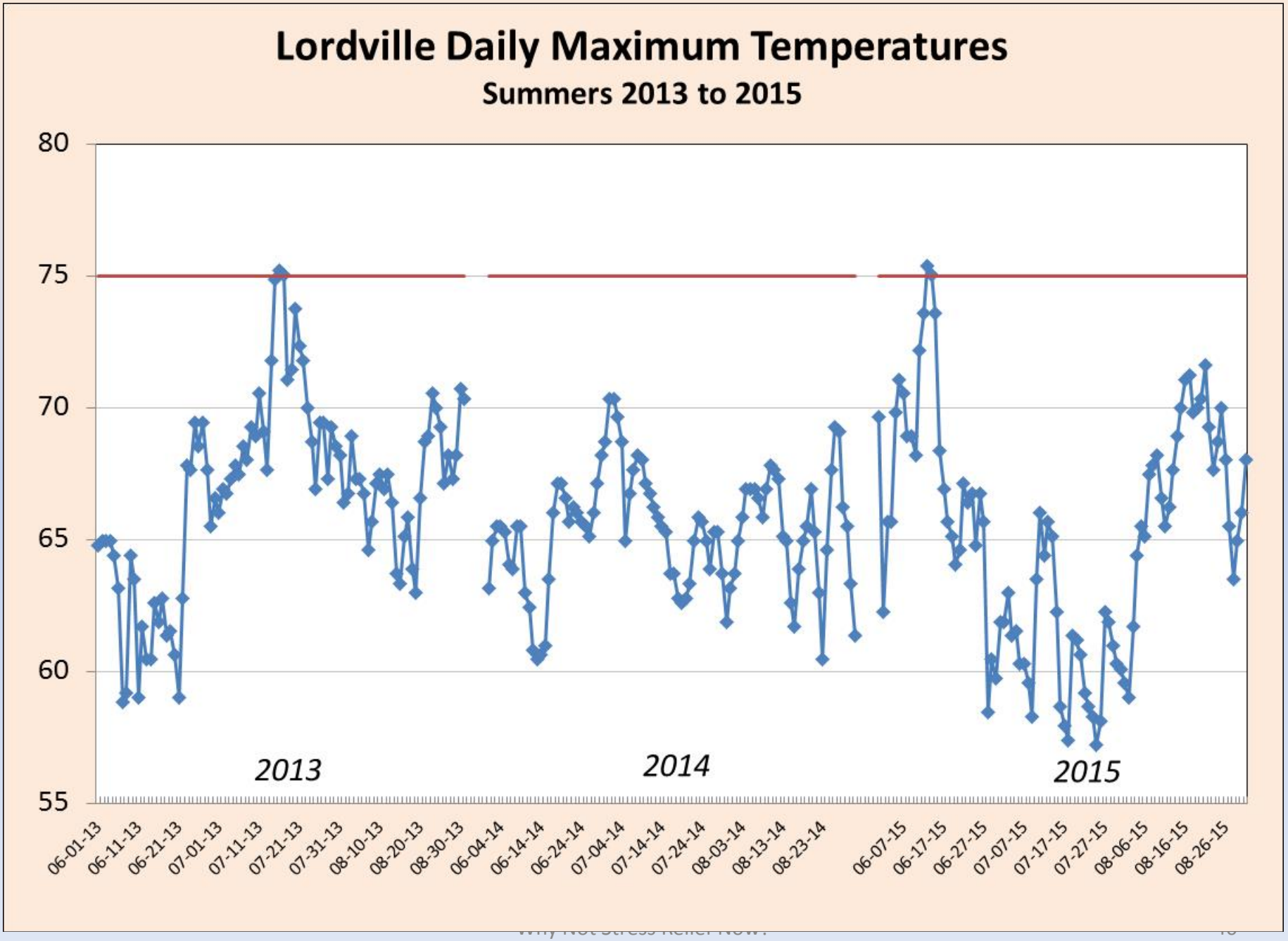
Lordville Daily Maximum Temperatures
Summers 2013 to 2015
80
75
70
65
60
55
2013
2014
2015
06-01-13
06-11-13
06-21-13
07-01-13
07-11-13
07-21-13
07-31-13
08-10-13
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