Direct Estimates of the Impact of the Six Thermal Stress Releases

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Three Approaches to Estimating Cannonsville Release Impacts on Lordville Temperatures

- *Linear Regression*

  Congruent with the physical structure of the system and underlying thermodynamic principles, build a regression model which as a function of surrogate variables estimates the marginal impact of Cannonsville releases on Lordville maximum daily temperatures.

- *Physical Thermodynamic Model*

  A mixture model: Additional cold water from Cannonsville mixes with warm water at Lordville. Calculate the equilibrium temperature. Complications: The water is moving; the size of the tub is changing; Cannonsville water is warmed by ambient weather conditions as it travels to Lordville; Pepacton releases and Beaverkill flows have impact. The Cole et al (2014) paper's Heat Flux Model may be such a way to estimate the Cannonsville impact.

- *Direct Analysis of the Impact of Past Thermal Releases*

  Detailed analysis of the outcomes of the 6 thermal releases made since 2008 may permit estimation of their actual impacts, Other pulse releases, e.g. River Master directed releases, could also be analyzed directly for impact.

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Thermal Releases Made Under FFMP: 2008 to 2018

(The nominal dates provided by NYS-DEC are not exact)

1. June 12 &13, 2008
   A ramping of about 400 additional cfs from a base of about 260 cfs
2. July 8 & 9, 2010
   A ramping of about 150 cfs additional from a base of about 350 cfs
3. July 24 to 26, 2011
   A ramping of about 400 cfs additional from a base of about 600 cfs
4. June 22 to 24, 2012
   A ramping of about 220 cfs additional from a base of about 500 cfs
5. July 19 to 21, 2013
   A ramping of about 300 cfs additional from a base of about 500 cfs
6. July 26 & 27, 2016
   A ramping of about 250 cfs additional from a base of about 500 cfs

An Evaluation Dilemma

- Suppose that after a thermal release, Lordville temperatures drop. Does the temperature drop indicate that the release worked? Is the magnitude of the drop a measure of the impact of the release?
- Suppose air temperatures also dropped, or even increased after the release? What portion of the water temperature drop can be attributed to the release vs. the portion attributed to the change in air temperature?
- Our multiple regression models, reported to SEF in December, which include Stilesville discharges and Binghamton air temperatures attempt to simultaneously account for both factors. But, can this be done directly?

An Experimental Design Motivated Evaluation

- Suppose that in the time-period immediately before, during and immediately after a thermal mitigation release, other key factors, e.g. Pepacton releases, and Beaverkill discharges do not change "much."
- Suppose further that both Lordville and Fishs Eddy are essentially equally affected by changes in air temperature.
- Then, a release pulsed from Cannonsville will cause a reduction of Lordville temperatures relative to Fishs Eddy. We have an experiment in which Lordville received a "treatment", the thermal pulse, while Fishs Eddy did not and serves as a "control".
- We measure the impact of a thermal release by computing and comparing the difference between Lordville and Fishs Eddy temperatures before and after the release hits Lordville. Our focus is on the 24 hours before and after the release.

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I. Details of the Thermal Release of June 9 to 11, 2008

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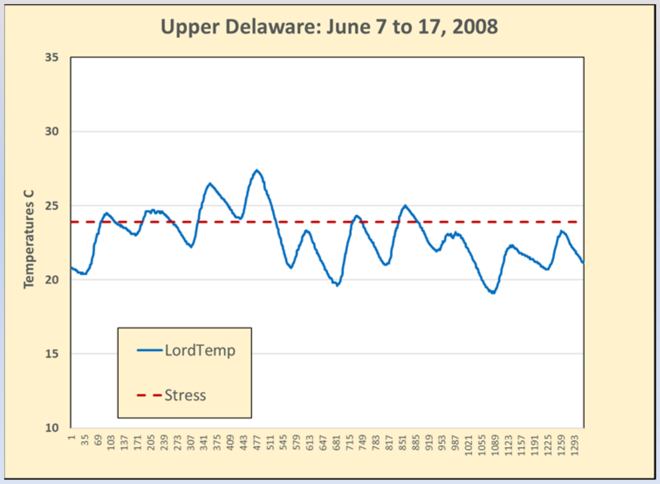
The Thermal Problem in June 2008



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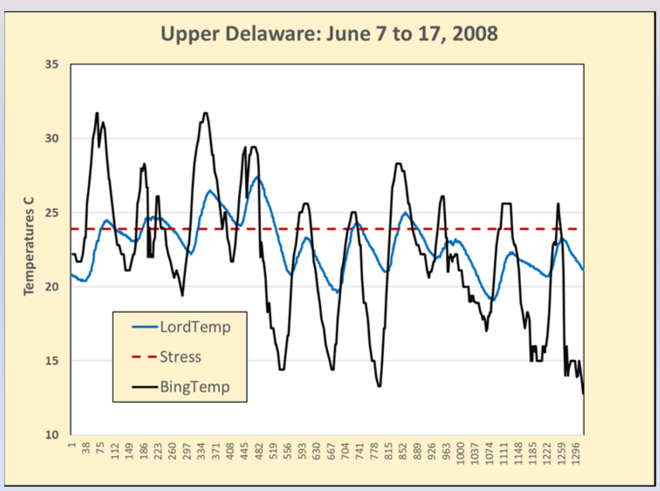
The Thermal Problem in June 2008 and Its Primary Cause



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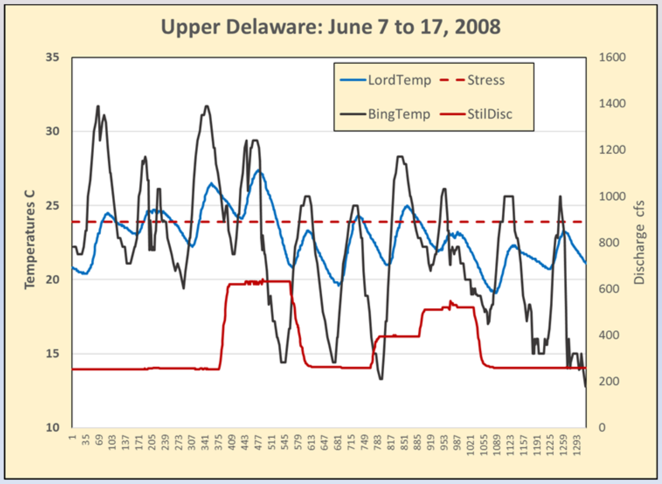
The Thermal Problem in June 2008: Its Primary Cause and Its Possible Mitigation



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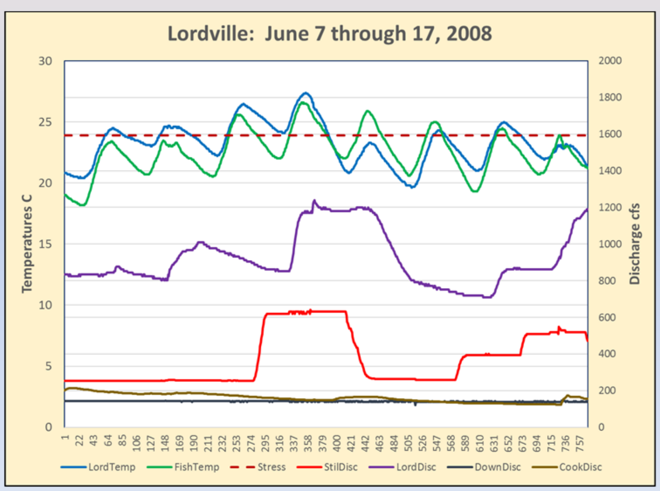
Overview of the nominal "400" cfs thermal release of June 10-11 from a base of 260 cfs



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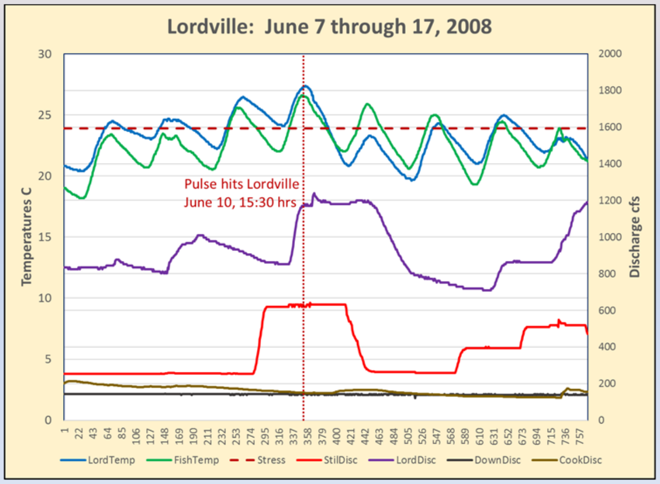
Assessing the Impact of the Cannonsville Pulse of June 10, 2008



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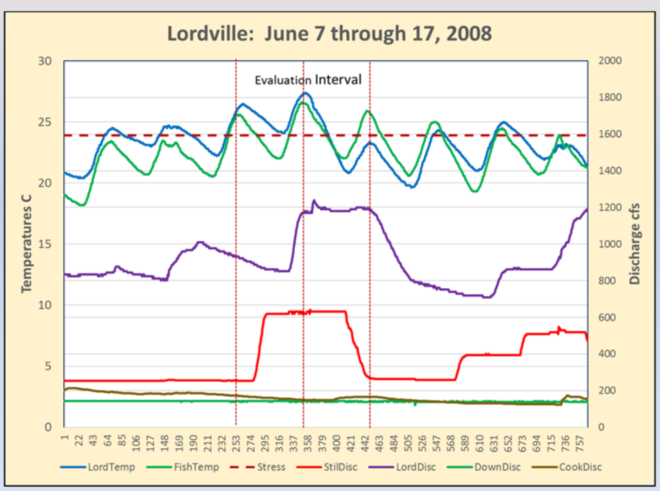
The Evaluation Interval: The 24 hours prior vs. the 24 hours post pulse arrival at Lordville.



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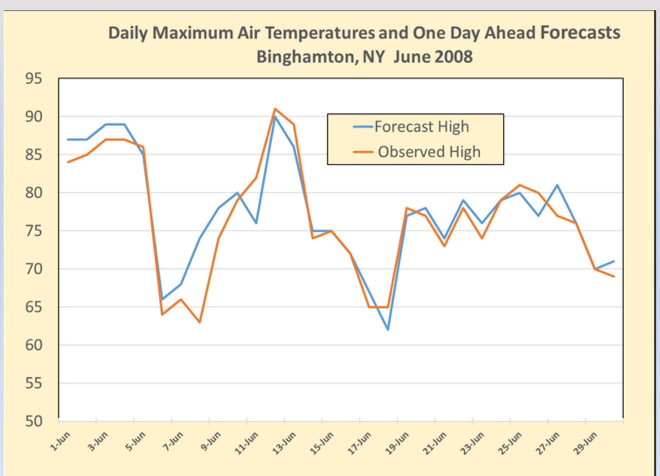
About the Thermal Stress Release of 2008

- A stress relief release pulse of about 378 cfs discharged about 539 cfs days of additional water between June 9 and June 11. We examine the surrounding time-period from June 7 to June 17.
- During this time interval, except for the pulse, Cannonsville releases, Pepacton releases and Beaverkill discharges were essentially constant.
- The river went into stress (23.9˚C) at 14:45 hrs on June 7. It had been close to stress on the two preceding days. Despite the thermal release, it remained in or close to stress until 1:00 hrs on June 11. It was in stress for about 62 hours.
- When the river went into stress, the discharge at Lordville was about 1,000 cfs
- Binghamton daily maximum air temperatures during this time were:

Date	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun	16-Jun	17-Jun
High ˚F	66	63	74	79	82	91	89	74	75	72	65

NWS: Binghamton, NY One Day Ahead Forecasts June 2008

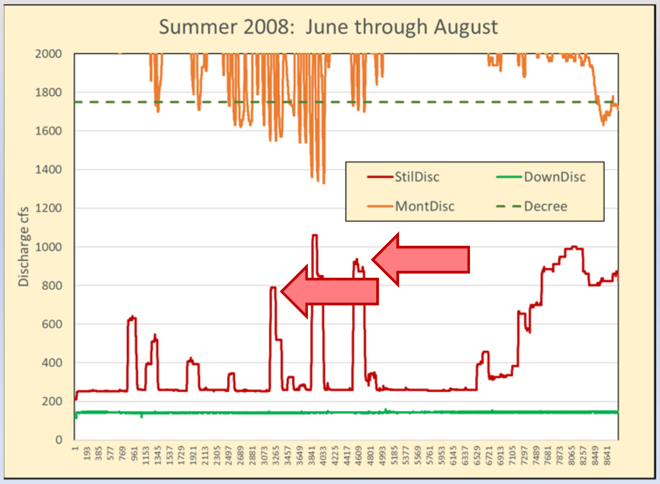


The Result of the June 2008 Thermal Release

- The release began from a base of 253 cfs at 21:30 hrs on Jun 9, peaked at 2:00 hrs on Jun 10 at 631 cfs until 7:30 hrs on Jun 11, dropping back to 263 cfs at 18:00 hrs on Jun 11. About 539 cfs days of extra water was released over 1.875 days. The pulse, itself lasted for 1.2 days.
- There was about a 12 hour delay until the pulse reached Lordville at about 15:30 hrs on Jun 10.
- For the 24 hours before the release hit Lordville, temperatures there averaged 1.5 ˚C higher than at Fishs Eddy. The temperatures crossed at 3:00 hrs on Jun 11. For the 24 hours after they were 0.2 ˚C lower, for a net reduction at Lordville relative to Fishs Eddy of 1.7 ˚C
- A metric of pulse impact is 378 /1.7 = 222 cfs/ ˚C, or 0.45 ˚C per 100 cfs.
- The post-pulse reduction in Lordville versus Fishs Eddy appeared to endure to about 18:30 hrs on Jun 12 when the temperature differences again reversed.

The Rest of the Summer 2008

During the summer 2008 there were about 8 River Master directed releases. These could be analyzed in a similar manner.



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II. All Six Thermal Releases

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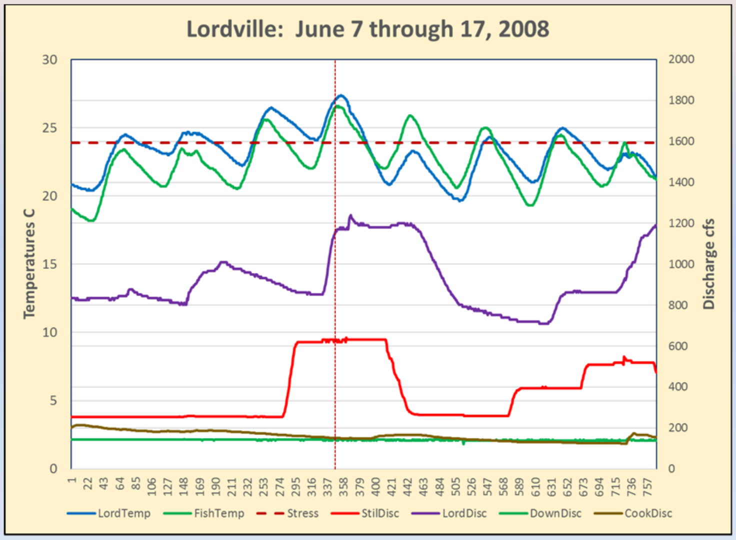
Release 1. June 9, 2008

Pulse: 378 cfs, 1.2 days: 1 Stress Day Mitigated: Impact -0.45˚C per 100 cfs



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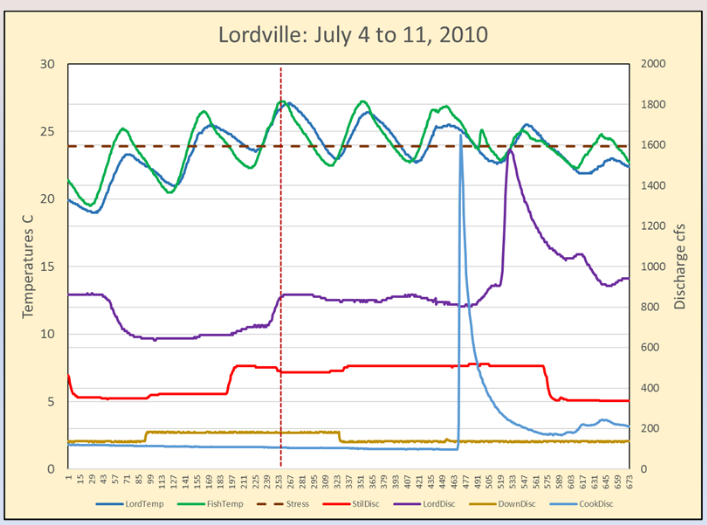
Release 2. July 5, 2010

Pulse: 138 cfs, 4.25 days: No Stress Relief: Impact +0.22˚C per 100 cfs



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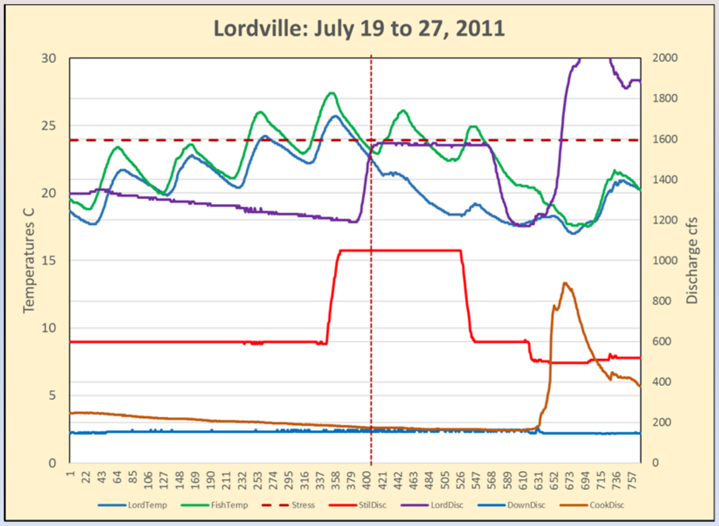
Release 3. July 22, 2011

Pulse: 387 cfs, 1.7 days: 2 Stress Days Mitigated: Impact -0.67 ˚C per 100 cfs



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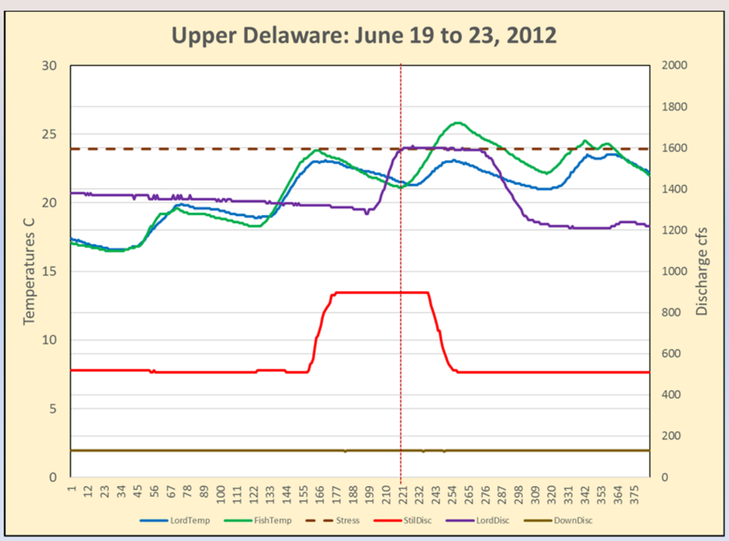
Release 4. June 20, 2012

Pulse: 387 cfs, 1.03 days: 1 Stress Day Mitigated: Impact -0.44˚C per 100 cfs



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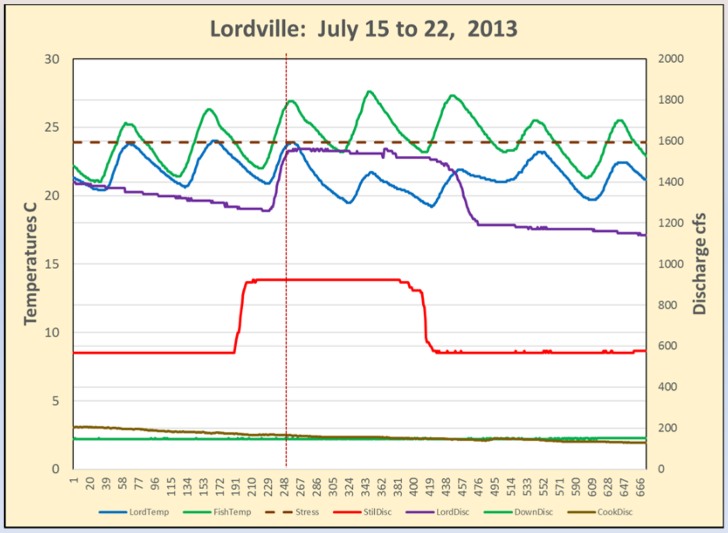
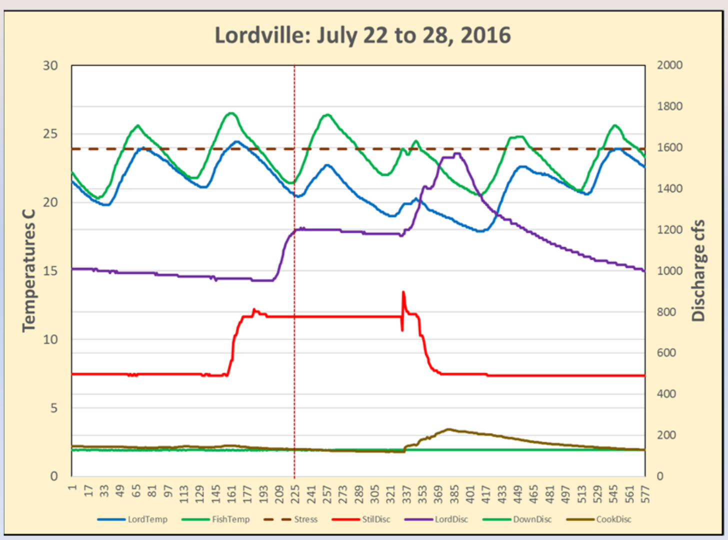
Release 5. July 16, 2013

Pulse: 356 cfs, 1.8 days: 2 Stress Days Mitigated: Impact -0.62˚C per 100 cfs



Release 6. July 23, 2016

Pulse: 278 cfs, 1.8 days: 1 Stress Day Mitigated: Impact -0.68˚C per 100 cfs



Details: Six Thermal Releases: 2008 to 2018

	June of 2008	July of 2010	July of 2011	June of 2012	July of 2013	July of 2016
Bing MaxTemp at Pulse Start ˚F	89	90	93	90	87	88
Stilesville Base Rate (cfs)	253	372	598	510	567	498
Stilesville Pulse Level (cfs)	631	510	1050	897	923	776
Stilesville Pulse Magnitude (cfs)	378	138	387	387	356	278
Stilesville Ending Rate (cfs)	263	340	598	510	567	498
Lordville Base Rate (cfs)	852	662	1200	1350	1260	953
Lordville Level During Pulse (cfs)	1100	835	1570	1600	1550	1200
Release Start Time	6/9 21:30	7/5 23:30	7/22 14:25	6/20 5:15	7/16 23:30	7/23 15:00
Time Reached Pulse Level	6/10 2:15	7/6 2:30	7/22 19:00	6/20 20:00	7/17 4:45	7/23 19:00
Time Pulse Reached Lordville	6/10 11:30	7/6 16:30	7/23 6:15	6/21 7:15	7/17 14:45	7/24 7:15
Time Start Drop	6/11 7:30	7/9 22:30	7/24 12:00	6/21 11:30	7/19 0:00	7/25 15:15
Time Return to Base Rate	6/11 18:00	7/10 5:30	7/24 16:15	6/21 16:15	7/19 10:30	7/25 20:45
Total Additional Water	552	513	849	342	794	563
Release Duration (days)	1.85	4.25	2.06	1.03	10:48	2.24
Pulse Duration (days)	1.22	3.83	1.7	0.64	1.8	1.84
Relative Temp Drop ˚C	1.70	-0.3	2.6	1.7	2.2	1.9
Impact Metric I (cfs/˚C)	222	-460	149	227	162	146
Impact Metric II (˚C/100 cfs)	0.45	-0.22	0.67	0.44	0.62	0.68

Conclusions

- Five of the six thermal releases were of a similar magnitude and had similar impact in lowering Lordville temperatures below the stress limit and lowering them relative to the 'control' at Fishs Eddy.
- Release 2 was substantially lower in magnitude and failed to avoid exceeding the stress limit, nor produce a measurable benefit.
- The average "24-hour impact" of the 5 successful thermal releases was -0.58 ˚C per 100 cfs, that is 180 cfs per ˚C . This metric is in the ballpark of the regression derived estimates (195 cfs ˚C) of the marginal impact of Cannonsville releases on Lordville maximum temperatures reported to SEF on 12/18/2008.
- The average pulse over the 5 successful thermal releases was 357 cfs, and the average amount of additional water released was 620 cfs.
- 7 thermal stress days were avoided by these 5 releases.

Updated Tally of Stress Days: 2008 to 2018

The preceding analysis suggests 7 additional stress days to the tally in our November report. A simulation of the summer 2015 reducing the high Cannonsville drawdown to normal FFMP releases adds no additional stress days. The revised table is

Lordville: Counts of Days withTmax >= 75˚ F)

	May	Jun	Jul	Aug	Sep	Summer
2008	0	9	9	1	0	19
2009	0	0	0	0	0	0
2010	4	2	15	1	2	24
2011	0	0	5	0	0	5
2012	0	2	5	8	0	15
2013	0	0	4	0	0	4
2014	0	0	0	0	0	0
2015	0	2	0	0	0	2
2016	4	0	5	1	0	10
2017	0	0	0	0	0	0
2018	0	0	6	0	0	6
11 Years	8	15	49	11	2	85

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Possible Implications for the Proposed FFMP 2017 Thermal Mitigation Policy

Our analysis suggests increasing the number of stress days during the historical period from 78 to 85 and the amount of water needed for each day of mitigation from 200 to 350 cfs, possibly more.

This suggests that the budgeted 2,500 cfs days will not be adequate.

Water Needed for Mitigation (cfs days)

	@ 200 cfs per day	@ 350 cfs per day	@ 620 cfs per day
2008	3800	6650	11780
2009	0	0	0
2010	4800	8400	14880
2011	1000	1750	3100
2012	3000	5250	9300
2013	800	1400	2480
2014	0	0	0
2015	400	700	1240
2016	2000	3500	6200
2017	0	0	0
2018	1200	2100	3720
11 Year Average	1545	2705	4791

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Still Open Research Issues

- *How reliably can thermal stress events be forecasted?* How far in advance? Their duration? Their intensity? How useful are NWS forecasts of high air temperatures, and sequences of high air temperatures (heat waves)?
- What should be the rules /guidelines for triggering thermal releases and setting their magnitude and duration? Do the seasonal guidelines already proposed make sense? (The different criteria for before and after July 7.) Are they workable?

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The END

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Appendix

A Regression 'Confirmation'

Our Regression "Model 1" (Prior day Stilesville Discharge, Prior Day Binghamton Average Air Temperature and same day Fishs Eddy Average Temperature) was fitted to aggregated data from the week before and week after the five 'successful' thermal releases. The adjusted Rsq was 84.5% and the impact metric was 128 cfs per ˚C -- here the marginal reduction in Lordville temperature for an increase in Stilesville discharge .

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	190.437	63.4790	122.35	0.000
StilDiscP	1	82.950	82.9499	159.88	0.000
FishsTavg	1	59.906	59.9059	115.46	0.000
BingTavgP	1	0.707	0.7074	1.36	0.247
Error	64	33.205	0.5188		
Total	67	223.642			

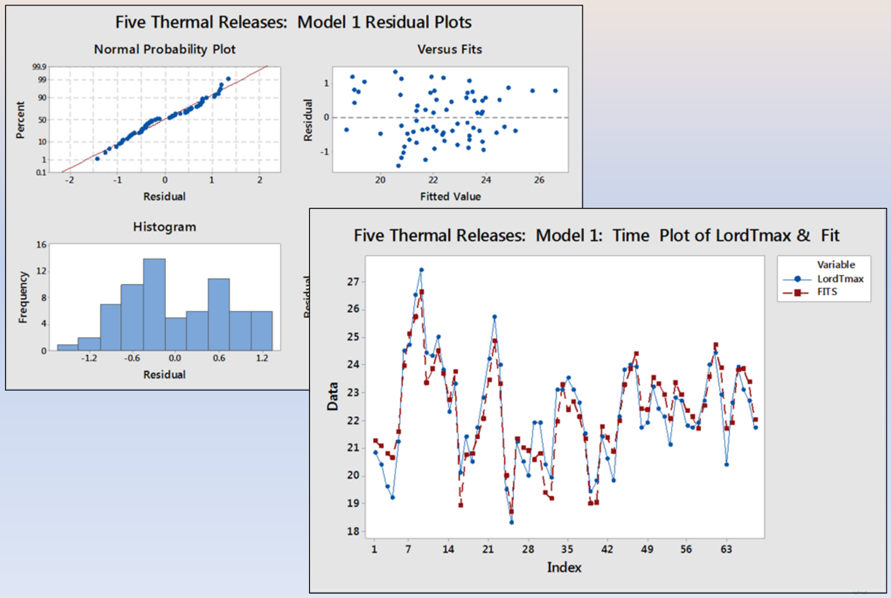
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.720302	85.15%	84.46%	83.15%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	7.03	1.09	6.45	0.000	
StilDiscP	-0.007767	0.000614	-12.64	0.000	1.30
FishsTavg	0.7954	0.0740	10.75	0.000	3.13
BingTavgP	0.0307	0.0263	1.17	0.247	3.23

Model 1: Five Thermal Releases: Quality of the Fit



Thermal Stress

- While recognizing that there is debate, even within SEF, about the appropriate specifications of river temperatures that put trout in thermal stress, and that the Decree Parties drafted a thermal mitigation proposal that SEF has been charged to analyze, itself, uses several different temperature targets, this report focuses primarily on the 75˚ F (23.9˚ C) as an initial working criteria.
- Should this phase of research be successful, its methods or results may be applicable to the analysis of other stress conditions, e.g. 68 ˚F limit, a 77 ˚F limit, three successive days at 75 ˚F, etc.

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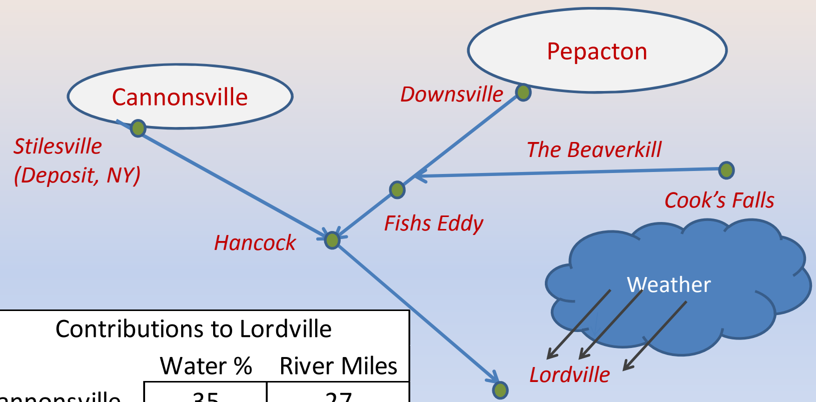
An Engineering Perspective to Cooling Lordville



Contributions to Lordville

	Water %	River Miles
Cannonsville	35	27
Pepacton	11	42
Beaverkill	22	35
Tributaries	32	-

Summers 2008 to 2018, when Lordville is below 5,000 cfs

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

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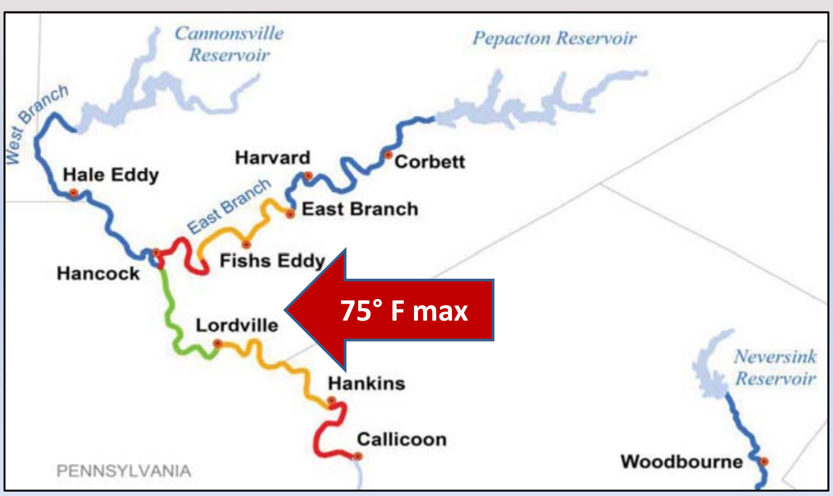
Our Focus: Mitigating Thermal Stress From Hancock to Lordville via Pulsed Releases from Cannonsville

(Keep maximum river temperature below 75° F)



Source: Joint Fisheries White Paper, January 2010

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