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Estimating the Thermal Stress Load in the Upper Delaware

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For the Subcommittee on Ecological Flows of the DRBC
November 8, 2018 (Revised 11/13/18)
Wallenpaupack Environmental Center, Hawley, PA

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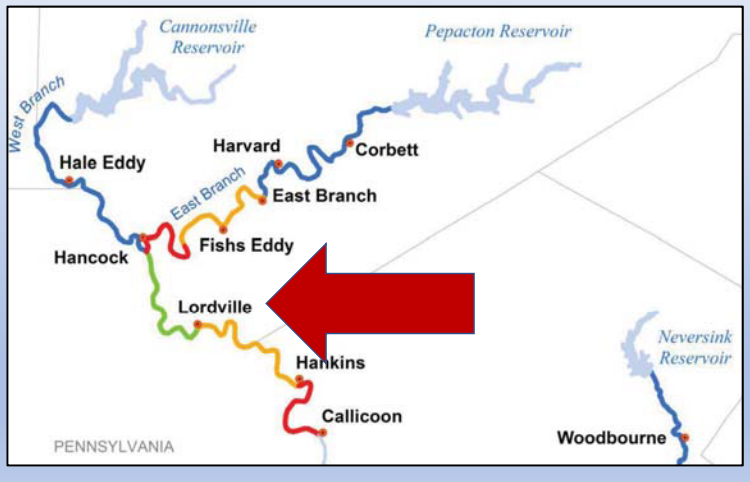
A principal focus of the FFMP 2017 thermal mitigation bank is on mitigating high water temperatures in the river reach from Hancock to Lordville. This report analyzes and estimates summer-time heat stress load at Lordville in detail, and also considers stress in the east Branch and Neversink .



Source: Joint Fisheries White Paper, January 2010

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Primary Data Source: UGSG Gage 147207, Lordville, NY

- Temperature data at Lordville not consistently available on-line prior to October 2007. Moreover, the reservoir release regime also changed significantly with the introduction of the FFMP in October 2007. Hence, I analyze temperatures from May 1 to September 30 for the years 2008 to 2018. Data available:
  - Gage height (ft), discharge (cfs), temperature (˚ C) at 15 minute intervals.
  - Daily average discharge, daily maximum, minimum and average temperature. No missing daily data.

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Proposed Thermal Mitigation in FFMP 2017

- A bank of water (2,500 cfs-days of the IERQ) allocated to 'permit' increasing releases during thermal stress events in the Delaware main stem, East Branch and Neversink. Releases made at the direction of the NYSDEC and administered by the River Master and the NYCDEP.
- The interim proposed guideline's goals at Lordville are:
  - From September 15 to July 6, prevent a 1st day above 75˚ F with use capped at 1250 cfs days.
  - From July 7 to September 14, the goal is to prevent 3 consecutive days above 75˚F or a 1st day above 77 ˚F.
- *A major issue is how big is the need? Is the proposed 2,500 cfs-day bank adequate?*

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Several Interrelated Research/Policy Issues

- *What are appropriate temperature targets?*
  - The FFMP 2017 and the draft thermal mitigation protocol, as well as earlier precedents on the Delaware, focus on a 75˚F daily max as a worst case to be avoided – and 68˚F daily max as desirable. The guidance document specifically speaks of a 75˚F daily max early in the summer and a 77˚F daily max and three days at 75˚F later.
- *What reaches of the Delaware are to be protected?*
  - Members of the trout fishing community have focused on the main stem of the Delaware -- Hancock to Lordville. The interim guidelines given to SEF also consider thermal mitigation on the Neversink and on the East Branch.
- *How should water be released during the season?*
  - What forecasts or events trigger mitigation releases?
  - In what quantities will water be released, for what duration? How will pulse release quantities be 'computed'?
  - Thermal events can occur throughout the season and be of differing durations and intensities. There is a high degree of randomness. Should water be husbanded early in the season, or is protection more important early in the season? Note that the interim guideline given to SEF has different rules applying before and after July 7. Is July 7 the best breakpoint? Is the 50/50 partition of the 2500 cfs days optimal?

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Some questions put to SEF by RFAC (per Brenan Tarrier, NYSDEC, Chair)

- Are the interim bank usage procedures [likely to be] effective?
- Is there a better way to implement the agreed-upon banks than the current interim procedures?
- How does the expected effect of elevated water temperatures vary with duration, time of day, time of year, rate of change, previous events, etc.?

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Some Working Definitions (My own)

- *Thermal Stress Day:* A day when the maximum daily river temperature exceeds 75°F (23.9 °C).
- *Extreme Thermal Stress Day:* A day when the maximum daily river temperature exceeds 77°F (25 °C).
- *Thermal Degree Day:* The daily amount by which the river maximum temperature exceeds the stress benchmark of 23.9 °C (75°F). When cumulated, this is a measure of the amount of relief needed.
- *Thermal Cooling Day:* The daily amount by which the river maximum temperature, when in stress, exceeds 23.4 °C (74°F). This is a more aggressive measure of the amount of relief needed.
- *Alleviation Period:* May 1 to September 30
- *Target Location:* Lordville on the Upper Mainstem (USGS Lordville Gage 1427207)

Thermal Stress in the Main Stem

(Lordville Gage)

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*Summary Results: A Focus on 75 ˚F and 77 ˚F (23.9 and 25.0 ˚C) over the 11 years 2008 to 2018**

- The 75˚F daily max was exceeded on 78 days, with one day reaching 81.3 ˚F.
- There were 18 such 'thermal events' --- 6 of which were partially ameliorated by the Decree Parties' special releases.
- There were some extraordinarily severe events. For example, one lasted 12 days, another lasted 10 days.
- The 77˚F daily max was exceeded on 20 days, and one such 'super thermal event' lasted 5 days.
- There were many episodes of three or more successive days over the 75˚F daily max – at least 10, depending on how you count them.

❖*Due to the rapid Cannonsville drawdown in July of 2015, data from 2015 needs to be analyzed separately, perhaps partially discounted or adjusted.*

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What about a 68 ˚F daily max?

- The 68 ˚F daily max was exceeded on 583 days ---about 35% of the summer days on average.
- In Julys, the 68 ˚F daily max was exceeded on 232 days ---about 75% of the month on average. There were a number of Julys in which essentially every day was above 68 ˚F.

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Thermal Stress Days at Lordville: 75 ˚F or higher

Number of Days Above 75˚F

Lordville USGS Gage # 1427207: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	0	8	9	1	0	18
2009	0	0	0	0	0	0
2010	4	2	15	1	2	24
2011	0	0	3	0	0	3
2012	0	1	5	8	0	14
2013	0	0	2	0	0	2
2014	0	0	0	0	0	0
2015	0	2	0	0	0	2
2016	4	0	4	1	0	9
2017	0	0	0	0	0	0
2018	0	0	6	0	0	6
Average	0.7	1.2	4.0	1.0	0.2	7.1

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Extreme Thermal Stress Days at Lordville: 77 ˚F or higher

Number of Days Above 77˚ F

Lordville USGS Gage # 1427207: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	0	3	4	0	0	7
2009	0	0	0	0	0	0
2010	2	0	7	0	0	9
2011	0	0	1	0	0	1
2012	0	0	0	3	0	3
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
2016	0	0	0	0	0	0
2017	0	0	0	0	0	0
2018	0	0	0	0	0	0
All 11 Years	2	3	12	3	0	20

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Thermal Stress at Lordville: 68 ˚F or higher

Number of Days Above 68˚ F

Lordville USGS Gage # 1427207: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	1	25	27	14	12	79
2009	0	1	21	2	0	24
2010	10	22	30	4	4	70
2011	3	10	16	10	0	39
2012	4	15	31	30	7	87
2013	3	3	22	10	2	40
2014	0	2	6	2	6	16
2015	14	13	0	14	7	48
2016	6	19	28	27	2	82
2017	0	10	22	15	5	52
2018	2	13	29	1	0	45
Average	3.9	12.1	21.1	11.7	4.1	52.9

153 days in my 'summer'

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Thermal Stress Days Before and after July 7

May 1 to July 6 | July 7 to September 30

	Before July7	July 7 & After	Total
68 ˚F	211	372	583
	36%	64%	
75 ˚F	26	52	78
	33%	67%	
77 ˚F	7	13	20
	35%	65%	

Summers 2008 to 2018, inclusive

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Mitigation Burden Metrics at Lordville : Water Cooling Degree Days in ˚C

- In addition to counting days above the several stress limits we should measure how far above these limits the river gets.
- Definitions: On day t

  "Thermal Degree Day"

  TDD_t =max($MaxTemp_t$ -23.9, 0) to cool to 75 ˚ F

  "Thermal Cooling Day"

  TCD_t =max($MaxTemp_t$ -23.3, 0) to cool to 74 ˚ F

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Thermal Degree Days: Cooling to 75˚F

Total Relief Cooling Days in ˚C Days (Above 75˚F)

Lordville USGS Gage # 1427207: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	0.0	9.6	9.6	0.1	0.0	19.3
2009	0.0	0.0	0.0	0.0	0.0	0.0
2010	4.6	0.3	18.3	0.0	0.7	23.9
2011	0.0	0.0	2.2	0.0	0.0	2.2
2012	0.0	0.3	1.7	6.1	0.0	8.1
2013	0.0	0.0	0.1	0.0	0.0	0.1
2014	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.0	0.2	0.0	0.0	0.0	0.2
2016	0.5	0.0	0.6	0.0	0.0	1.1
2017	0.0	0.0	0.0	0.0	0.0	0.0
2018	0.0	0.0	1.7	0.0	0.0	1.7
Average	0.5	0.9	3.1	0.6	0.1	5.1

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Thermal Cooling Days: Cooling to 74˚F

Total Relief Cooling Days in ˚C Days (Above 74˚F)

Lordville USGS Gage # 1427207: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	0	14.9	16.3	1	0	32.2
2009	0	0	0	0	0	0.0
2010	7.5	3.9	28.5	0.6	1.9	42.4
2011	0	0	4	0	0	4.0
2012	0	1.1	6	11.6	0	18.7
2013	0	0	1.8	0	0	1.8
2014	0	0	0	0	0	0.0
2015	0.4	1.4	0	0	0	1.8
2016	2.9	0.1	3.2	1.4	0	7.6
2017	0	0	0.3	0	0	0.3
2018	0	0.6	6.1	0	0	6.7
Average	1.0	2.0	6.0	1.3	0.2	10.5

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The Water Cooling Burden in Phases I and II

Cool To	Before July7	July 7 & After	Total
75 ˚F	15.5	41.1	56.6
	27%	73%	
74 ˚F	36.5	98.1	134.6
	27%	73%	

Total thermal and cooling degree days in ˚C during the summers 2008 to 2018

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Trigger Alerts: Days when Lordville Temperature exceeds 22˚C (71.6 ˚F)

- A 2012-2013 Joint Fisheries Thermal Proposal suggested 22˚C as an alert signal.

Number of Days Above 22˚C (71.6˚F)

Lordville USGS Gage # 1427207: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	0	16	19	6	3	44
2009	0	0	3	0	0	3
2010	7	16	26	3	3	55
2011	0	1	6	2	0	9
2012	2	7	25	19	1	54
2013	1	0	7	0	0	8
2014	0	0	0	0	0	0
2015	6	5	0	1	0	12
2016	5	5	16	17	0	43
2017	0	2	9	0	1	12
2018	0	6	24	0	0	30
Average	1.9	5.3	12.3	4.4	0.7	24.5

There were 52 such “alert” days over the 11 years

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Hancock to Lordville

The focus of the stress mitigation program is on the river reach from Hancock to Lordville. But, what happens at the head of this reach?

First, there were no days at Hancock above 75˚ F, over the 11 years analyzed.

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Hancock: Number of Days Above 68˚F
(Gage at the 191 Bridge on the West Branch)

Hancock Days Above 20 C (68F)						
	May	Jun	Jul	Aug	Sep	Summer
2008	0	9	15	4	4	32
2009	0	0	1	0	0	1
2010	6	3	8	3	1	21
2011	2	1	0	0	0	3
2012	0	0	4	6	0	10
2013	2	0	0	0	0	2
2014	0	0	0	0	0	0
2015	9	4	0	0	0	13
2016	3	0	0	2	0	5
2017	0	0	0	0	1	1
2018	0	1	2	0	0	3
11 Years	22	18	30	15	6	91

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Hancock: Average Daily Temperatures
(Gage at the 191 Bridge on the West Branch)

Hancock Average Daily Temperatures						
	May	Jun	Jul	Aug	Sep	Summer
2008	12.2	16.7	17.1	14.0	14.9	15.0
2009	13.1	14.2	15.1	14.3	14.9	14.3
2010	14.5	15.9	16.8	13.7	14.7	15.1
2011	13.4	14.3	13.8	14.9	14.9	14.3
2012	13.9	14.4	15.9	17.1	14.0	15.0
2013	13.9	13.8	14.7	14.3	13.8	14.1
2014	12.0	14.3	14.9	13.1	12.6	13.4
2015	15.9	15.6	11.0	13.1	14.4	14.0
2016	12.8	14.3	15.2	16.2	13.1	14.3
2017	11.6	14.5	15.7	15.1	14.0	14.2
2018	10.9	14.2	16.6	15.0	15.2	14.4
11 Years	13.1	14.7	15.2	14.6	14.2	14.4

Lordville temperatures average about 3˚ C higher than Hancock and are considerably more variable.

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Charts of Some 'Interesting' Summers

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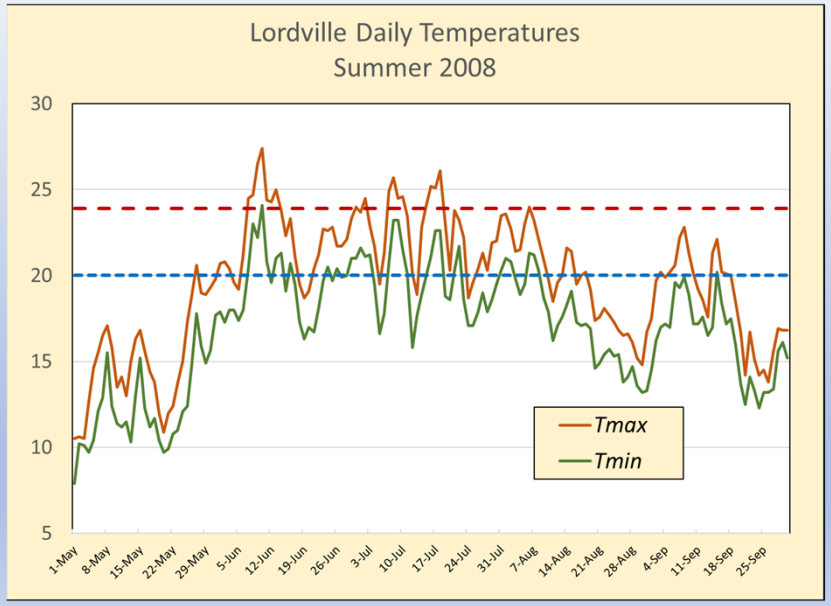
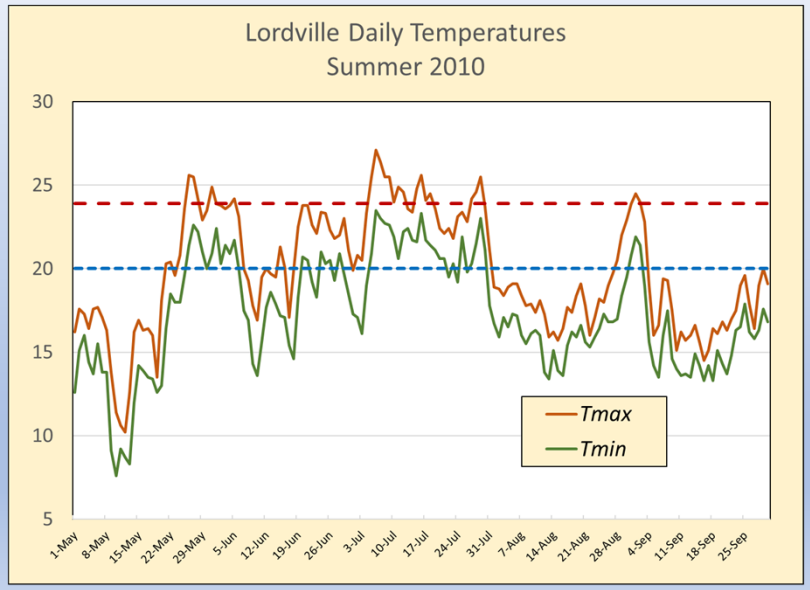
2008, First Year of the FFMP: 18 stress days, 7 extreme



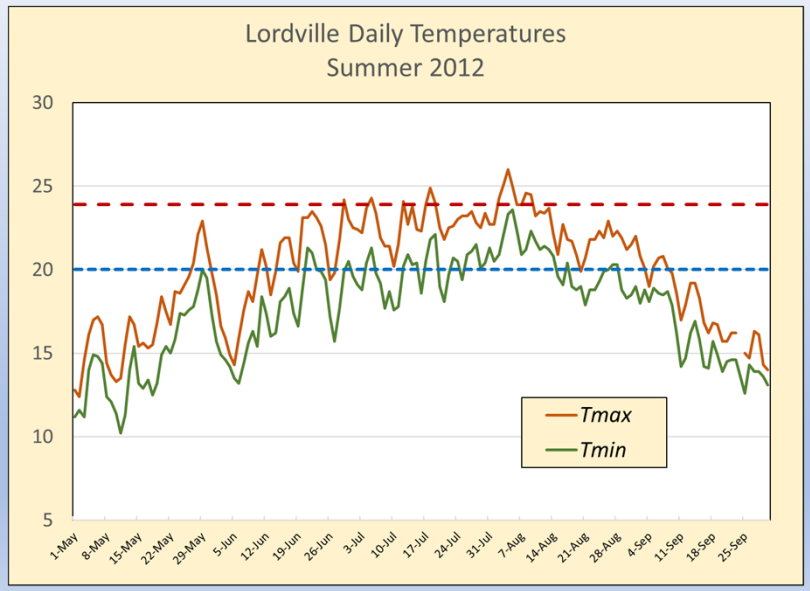
25

2010, a Challenging Year: 18 stress days, 7 extreme



26

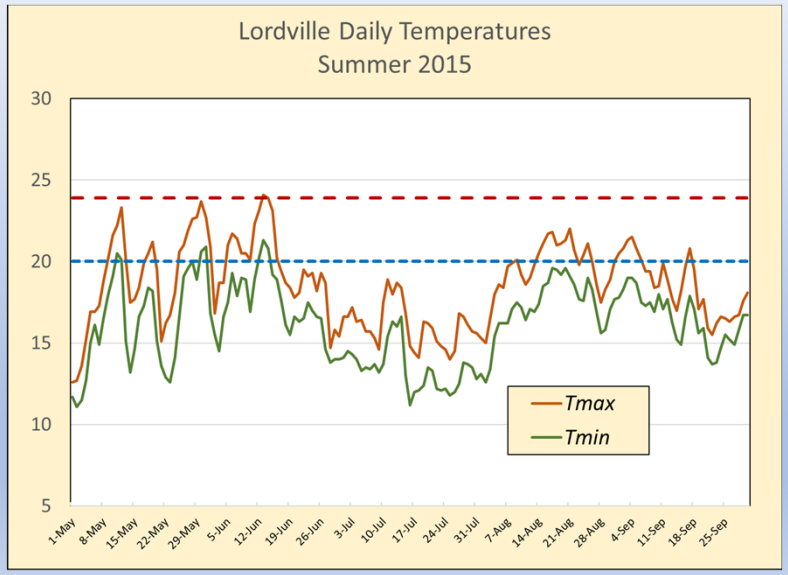
2012, another rough summer: 14 stress days, 3 extreme



27

2015, The Cannonsville Drawdown:

2 stress days, 0 extreme



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Focus on the Neversink

(Bridgeville Gage: 1436690)

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Thermal Stress Days at Bridgeville: 75 ˚F or higher

Number of Days Above 75˚F
Bridgeville USGS Gage # 14396690: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	0	2	0	0	0	2
2009	0	0	0	0	0	0
2010	0	1	8	0	0	9
2011	0	0	0	0	0	0
2012	0	1	1	1	0	3
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
2016	0	0	0	0	0	0
2017	0	0	2	0	0	2
2018	0	0	1	0	0	1
Average	0.0	0.4	1.1	0.1	0.0	1.5

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Extreme Thermal Stress Days at Bridgeville: 77 ˚F or higher

Number of Days Above 77˚F
Bridgeville USGS Gage # 14396690: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	0	0	0	0	0	0
2009	0	0	0	0	0	0
2010	0	0	3	0	0	3
2011	0	0	0	0	0	0
2012	0	0	0	0	0	0
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
2016	0	0	0	0	0	0
2017	0	0	0	0	0	0
2018	0	0	0	0	0	0
Average	0.0	0.0	0.3	0.0	0.0	0.3

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Focus on the East Branch

(Harvard Gage: 14175007)

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Thermal Stress Days at Harvard: 75 ˚F or higher

Number of Days Above 75˚F

Harvard USGS Gage # 14175007: Summers 2008 to 2018

Month	May	June	July	August	September	Summer
2008	0	0	0	0	0	0
2009	0	0	0	0	0	0
2010	0	0	0	0	0	0
2011	0	0	0	0	0	0
2012	0	0	0	0	0	0
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
2016	0	0	0	0	0	0
2017	0	0	0	0	0	0
2018	0	0	0	0	0	0
Average	0.0	0.0	0.0	0.0	0.0	0.0

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Tentative Conclusion:

- These computations of the stress load do not include estimates of the amount of water that would be needed to mitigate the burden. *Research on that question is now underway.*
- However, a back of the envelope 'guesstimate' that it would take about 300 cfs per day to reduce the stress burden by 1 thermal degree day indicates that over 2008 to 2018 :
  - On average, about 5 x 300 =1500 cfs-days would be needed to exactly hit 75˚F, or about 10 x 300 = 3,000 cfs-days to lower to 74˚F.
  - But, as a consequence of the randomness in the timing, duration and intensity of thermal events, in years such as 2008, 2010, 2012 and 2016 many stress events would be unmitigated with the proposed bank of 2,500 cfs-days

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Some Next Research Questions

- How much water from Cannonsville is needed to lower Lordville maximum temperature by 1˚F. How does this vary with the flow at Lordville? How does this vary with the air temperature in the region? With the intensity and duration of the thermal episode, etc?
- Suppose you had perfect forecasts of Lordville daily maximum temperatures (or of air temperatures in the region, etc.) and you aimed to control to exactly a 75 ˚F max, how much water would you need?
  - To achieve a 68 ˚F max? A 74 ˚F max, a 77 ˚F max? To meet RFAC's proposed guidelines?
- How will you forecast thermal events? And how well does the NWS forecast the high air temperatures that drive them?
- What does controlling Lordville temperatures to (say) a 75 ˚F max do to minimum water daily temperatures at Callicoon?

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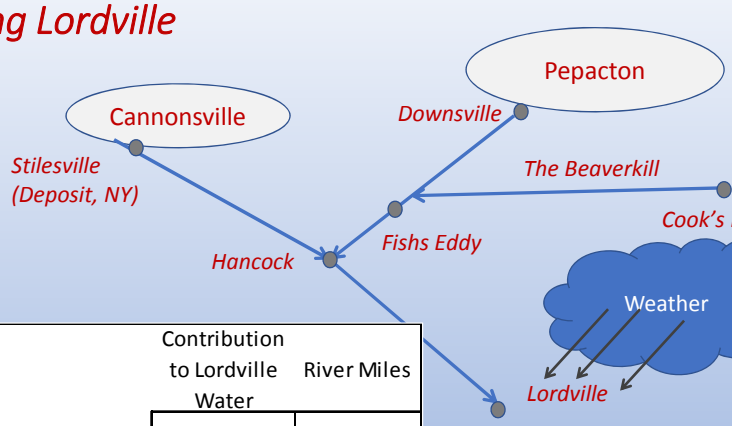
An Engineering/Thermodynamic Approach to Cooling Lordville



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

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

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Important Data Issues

- Per NYSDEC, thermal mitigation releases were made on the following dates between 2008 and 2018. Records of the magnitude and timing of those releases is not readily available and estimation appears to require 'creative' forensic water accounting :
  - June 9-11, 2008
  - July 7-9, 2010
  - July 24-26, 2011
  - June 22-24, 2012
  - July 19-21, 2013
  - July 23-25, 2016
- Four key data sources are difficult to synchronize and reconcile: River Master Reports; USGS gages at Stilesville and Lordville; NYCDEP Reservoir Operations Reports; and NYCDEP OST/FFMP Summary Reports.
- Postings of the monthly Reservoir and Streamflow Data and OST/FFMP Summary reports on the ODRM website are both still done only in pdf format. It is extraordinarily tedious to get this critical data into an electronic database

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