Review of Vermont Yankee Thermal Discharge Permit Requirements and Analysis of Connecticut River Water Temperature and Flow

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1.0 Introduction

This report presents a review of National Pollutant Discharge Elimination System (NPDES) thermal discharge permit requirements for the Vermont Yankee Nuclear Power Station and an analysis of water temperature and river flow in the Connecticut River upstream, downstream, and adjacent to the Power Station. The NPDES permit specifies that the temperature rise associated with Vermont Yankee's thermal discharge be calculated using an equation. The equation, referred to as Equation 1.1, is described and its suitability for this application is evaluated and discussed.

An analysis of Connecticut River water temperature and river flow was conducted using continuously-recorded data provided by Vermont Yankee and the United States Fish and Wildlife Service. Five years (2006 through 2010) of summertime (May through September) data were analyzed and are presented. An analysis was also conducted comparing the NPDES-permitted river temperature rise associated with the Vermont Yankee discharge to the actual river temperature rises observed in the Connecticut River. In addition, river water temperature recorded by the United States Fish and Wildlife Service from as far as 22.5 miles downstream of the Vernon Dam are presented and compared to river temperature recorded near the Power Station.

The review and analysis resulted in the following findings:

1. The use of Equation 1.1 to compute the temperature rise as a surrogate for the actual, readily available temperature rise measurements has resulted in the river routinely experiencing temperature increases below the Vermont Yankee Power Station that are far greater than those specified in the permit.
2. Vermont Yankee does not submit data characterizing heat rejection rate to the river and this is an important omission because the rate is used in Equation 1.1 to calculate NPDES-permitted temperature rise. These data are reportedly utilized by Vermont Yankee, are readily available, and should be included in the information submitted for review.
3. Use of Equation 1.1 is inappropriate because its underlying assumption that conditions in the Connecticut River's Vernon Dam impoundment result in complete mixing of thermal discharge waters is invalid.
4. On most days, actual water temperature rises in the Connecticut River at downstream Station 3 and at the fishway exceed the permitted temperature rise, often by several degrees Fahrenheit and for extended periods of time.

Based on these findings, we recommend the following:

1. Replace Equation 1.1 with a more appropriate, accurate, and protective approach.
2. Conduct a fisheries review of the water temperature measurements in the fishway and throughout the entire thermal plume, extending beyond 22.5 miles below Vernon Dam, to evaluate the potential for harm to fish and likelihood of avoidance due to elevated water temperatures.
3. Obtain and review the Vermont Yankee records of the heat rejected to the river.

This report is organized as follows:

- ***Section 2.0 – Review of Vermont Yankee's NPDES Thermal Discharge Permit*** - describes the Vermont Yankee NPDES permit conditions that allow ambient river temperature to be increased and a discussion of those conditions.
- ***Section 3.0 – Analysis of Ambient Water Temperature and River Flowrate Data*** - provides ambient water temperature data upstream, downstream, and in the fishway near the Vermont Yankee discharge along with descriptions and discussion;
- ***Section 4.0 – Discussion*** – including observations, findings, and recommendations.

2.0 Review of Vermont Yankee's NPDES Thermal Discharge Permit

A summary of Vermont Yankee's NPDES thermal discharge permit is provided below. The calculation method utilized in the permit to estimate river temperature increase is described and discussed. Also, a description of critical NPDES permit compliance-related data sets is provided and missing data are highlighted.

2.1 Temperature Increase Limitations

Vermont Yankee is currently operating under NPDES permit #3-1199 issued on March 30, 2006 (VT ANR 2006). During the period May 16 through October 14 of each year, the permit constrains Vermont Yankee's thermal discharge to the Connecticut River based on ambient water temperature measured at Station 7 (situated upstream) and Station 3 (situated downstream). Vermont Yankee continuously monitors ambient water temperatures at Stations 7 and 3. As shown in Table 1, Vermont Yankee is allowed to increase the calculated ambient temperature of the Connecticut River by different amounts depending on ambient upstream temperatures at Station 7. For example, from June 16 through October 14, if the temperature at Station 7 is 66°F, then the maximum allowable increase in temperature above ambient at Station 3 is 3°F (see Table 1). In addition, the NPDES permit specifies that if the ambient temperature at Station 3 is greater than or equal to 85°F, then Vermont Yankee must "reduce the thermal output of the discharge to the extent that the average hourly temperature at Station 3 does not exceed 85°F."

Table 1. Vermont Yankee NPDES Permit: Temperature Rise Limitations

During the period of May 16 through June 15:		**During the period of June 16 through October 14:**	
Temperature at Upstream Station 7	Increase in Temperature Above Ambient at Station 3	Temperature at Upstream Station 7	Increase in Temperature Above Ambient at Station 3
Greater than 63° F	2° F	> 78° F	2° F
59 to 63° F	3° F	> 63 to 78° F	3° F
55 to 59° F	4° F	> 59 to 63° F	4° F
Less than 55° F	5° F	≤ 59° F	5° F

2.2 Use of a Simple Equation to Calculate Ambient Temperature Increase

Based on the presence of continuously-recorded water temperature upstream and downstream of the Vermont Yankee Station and the NPDES permit limiting ambient water temperature rise, it may appear that Vermont Yankee is required to limit increases in Connecticut River water temperature to within specified ranges. There is, however, no such requirement in Vermont Yankee's NPDES permit. The NPDES permit instead specifies that Vermont Yankee calculate a theoretical river temperature increase

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and does not regulate the actual temperature rise in the Connecticut River (with the exception of a prohibition on river temperature exceeding 85°F at Station 3). Specifically, the Vermont Yankee NPDES permit states that: "The increase in temperature above ambient shall mean plant induced temperature increase as shown in equation 1.1". Equation 1.1 is defined in Vermont Yankee's 1978 316 Demonstration report (Aquatec 1978) as follows.

$$\triangle T_r = H / (\rho C_p Q_r) \quad \text{……………}\textbf{Equation 1.1}$$

where:

$\triangle T_r$ is the plant-induced temperature increase in the river (°F);

H is the heat rejection rate to the river (MW);

ρ is the density of water;

C_p is the specific heat of water; and

Q_r is the river flow rate (cfs).

Equation 1.1 is a simple equation that calculates the temperature rise in the river based on the rate of heat delivered to the river (H) divided by the rate of volumetric flow (Q_r) in the river. The density and specific heat of water are properties of water and are included as constants. Equation 1.1 assumes instantaneous and complete mixing in the receiving waterbody meaning that any heat discharged will mix completely and uniformly within the entire flow of the river. The Connecticut River at the Vermont Yankee discharge location is impounded by the Vernon Dam. The total storage volume at Vernon Dam is estimated to be 40,000 acre-feet (USACE, 1975). Flow in the Connecticut River at Vernon Dam typically varies dramatically on a daily basis, as presented in Section 3. Based on typical summertime flows ranging from 2,000 to 8,000 cfs and the total storage volume, hydraulic residence times at Vernon Dam range from approximately 2.5 to 10 days.

The hydraulic residence time is computed as the storage volume divided by the flow: in other words, it is the time for the volume to "turn over" at a particular flow rate. Looked at another way, it can be considered to be the time for water released by Vermont Yankee to fully mix with the water impounded by Vernon Dam. Since the residence times experienced in Vernon Pool are relatively long (2.5 to 10 days) compared to the observed variations in flow released at Vernon Dam (typically less than 1 day), the complete mixing presumed by Equation 1.1 does not occur.

The authors of the 1978 316 Demonstration report understood the limitations of the assumption of complete mixing implicit in Equation 1.1. The 1978 Demonstration report recommended using Equation 1.1 to estimate increases in temperature "during periods of high and gradually varying river flows, and while heat is discharged from Vermont Yankee at a constant rate" and during steady minimum flow periods (Aquatec 1978, pages 1-8 & 1-9). The accuracy of Equation 1.1 was validated in the 1978 report by comparing the calculated temperature rise during steady flow and steady heat discharge events to actual measured temperatures. It is important to recognize that the validation of Equation 1.1 applies only to these conditions. This makes sense: if the river flow and heat rejection are steady during time periods commensurate with the hydraulic residence time, there would be little variation in the "mix" of thermal discharges and river flow flowing past Vernon Dam. But, if either of those two factors (flow or heat discharged) varies significantly during the hydraulic residence time, mixing with the reservoir will be incomplete, conditions would diverge from the assumptions implicit in Equation 1.1, and actual temperature would deviate from that given by Equation 1.1. Thus, conditions of steady flow and steady heat discharge relative to hydraulic residence times are prerequisites for using Equation 1.1. Those conditions are relatively rare, particularly during critical summertime conditions, as is demonstrated in Section 3 below.

In summary, Equation 1.1 may be an appropriate equation for estimating temperature increase under conditions of relatively steady river flow and steady thermal discharge when the assumption of complete mixing is more-or-less met, but is inappropriate when the receiving waterbody flow or thermal discharge vary on time scales of less than the hydraulic residence time (2.5 to 10 days during the summer). As a result, use of Equation 1.1 to estimate river temperature rise under relatively unsteady flow or unsteady thermal discharge conditions would be expected to result in inaccurate estimates.

2.3 Lack of Heat Rejection Rate in Vermont Yankee's NPDES Reporting

Heat rejection rate to the river and river flow rate time-series data are required in order to use Equation 1.1 and to validate Vermont Yankee's temperature increase calculations. Connecticut River flow measurements are available and are reviewed in Section 3 below. The rate at which heat is rejected to the river, however, is not provided by Vermont Yankee as part of its annual reports (or any other available reports). Vermont Yankee's heat rejection rate data are also required to evaluate whether thermal discharge conditions are steady over sufficient periods of time to obtain accurate estimates of Connecticut River temperature rise using Equation 1.1, as described in Section 2.2.

Vermont Yankee's annual reports (e.g., Normandeau 2011) provide the total heat rejection rate of the Power Station on a daily average basis, but in the summer months this total heat rejection rate is divided between release to cooling towers and to the river. Vermont Yankee does not provide information specifying how the heat rejected is split and how much is imparted to the river. Without this information, there is no way to determine whether or not Vermont Yankee is compliant with its NPDES permit. Instead of this information, Vermont Yankee provides the ΔT computed by Equation 1.1 without the backup quantities used in the calculations. The calculated temperature increases submitted by Vermont Yankee are apparently accepted by the regulatory agency without independent verification.

Lack of heat rejection rate information is problematic relative to validating permit compliance. It is also problematic because, without these data, it is not possible to fully analyze the cause and effect relationship between thermal input from the Power Station and ambient water temperatures in the river. Based on review of Vermont Yankee's annual reports, it appears that the total heat rejection rate of the Power Station is nearly constant (when fully operational). At times during the summer, Vermont Yankee divides heat rejection between direct river discharge and cooling towers. At those times, there may be significant variation in the heat rejection rate to the river, depending on patterns of cooling tower use.

In summary, additional information, specifically records of the amount of heat rejected to the river and to cooling towers on an hourly basis, are needed to validate Vermont Yankee's NPDES permit compliance and to support evaluation of ambient river temperature conditions.

3.0 Analysis of Ambient Water Temperature and River Flow Data

Data provided by Vermont Yankee and by the United States Fish and Wildlife Service are presented and discussed below.

3.1 Vermont Yankee Data

Continuous water temperature measurements are collected by the Vermont Yankee Nuclear Power Station in the:

- Connecticut River at Station 7 situated 4.3 miles upstream of the Vernon Dam;
- Fishway at Vernon Dam, when operational; and
- Connecticut River at Station 3 situated 0.7 miles downstream of the Vernon Dam.

Also, the flow in the Connecticut River is measured at Vernon Dam. These measurements were obtained from Vermont Yankee in an hourly time-series format and analyzed to enhance understanding of Connecticut River water temperature conditions and associated potential adverse impacts to fish. Conditions during the months of May through September were evaluated because these months are the warmest and span some migratory fish passage periods, including when the Vernon Dam fishway is in operation.

Increases in water temperature (also referred to as temperature rise or DT) near the Power Station and the Vernon Dam are important because they could potentially be harmful to fish and may create a barrier to critical upstream migration. Temperature increases were evaluated using the following three methods:

- Permitted temperature rise, based on the NPDES-permitted temperature increase, as shown in Table 1;
- Actual temperature rise between upstream Station 7 and downstream Station 3; and
- Actual temperature rise between upstream Station 7 and the fishway at Vernon Dam.

The Vernon Dam fishway provides critically important passage to anadromous fish species. The period of operation at the Vernon Dam fishway varies from year to year. The Vernon Dam fishway commences operations each year when anadromous fish are found at the nearest downstream dam indicating that the upstream migration has begun (David Deen, conversation of July 12, 2012). Periods of operation at the Vernon Dam fishway from 2006 through 2010 were estimated based on the existence of fishway water temperature measurements and are presented in Table 2.

Figure 1 provides water temperature, river flow, and temperature rise over time during the period of May through September 2006. The upper plot shows water temperature at the upstream Station 7 (green), the Vernon Dam fishway (blue), and downstream Station 3 (red) on the left axis and river flowrate (gray) on the right axis. The lower plot shows NPDES-permitted temperature rise (black), temperature rise between Stations 7 and 3 (red), and between Station 7 and the fishway (blue). The format of Figure 1 is utilized in Figures 1 through 21.

Table 2. Vernon Dam Fishway Periods of Operation from 2006 through 2010

Year	Period of Operation	Total Number of Days
2006	June 9 - July 17	39
2007	May 23 - July 6	45
2008	June 13 - July 5	23
2009	May 15 - July 9	56
2010	May 7 - July 7	62

Water temperatures ranged from less than 65°F in May to over 81°F during the summer of 2006. River flow varied dramatically from only 1,250 cfs to over 20,000 cfs. Temperatures at downstream Station 3 and in the fishway (when operational) were consistently higher than temperatures at Station 7. The lower plot shows that the NPDES-permitted temperature rise was frequently exceeded by actual temperature rises at Station 3 and the fishway and was often above the permitted value for extended periods. For each hourly set of measurements, the actual temperature rise was obtained by subtracting the upstream temperature from the downstream temperature, resulting in the temperature rise. Actual temperature rises, from upstream to downstream (in red in Figure 1), exceeded 6°F on numerous days and temperature rises at the fishway exceeded 8°F on several occasions.

To get a closer look at the character of actual temperature rises, a four-week period during the fishway season was evaluated and is presented in Figure 2. River flowrates were high and variable during this period, ranging from 7,000 cfs to over 20,000 cfs. Actual temperature rise was often over 6°F and occasionally over 8°F, exceeding the permitted temperature rise of 3°F by 3 to 5°F. Temperature rises were observed to be lower during periods of very high river flow, such as the late June/early July period when flows exceeded 20,000 cfs. Figures 3 and 4 show flow and temperature in the river during one-week time periods during June and July 2006 and illustrate temperatures during important time periods relative to fish passage. For example, the actual temperature rise at the fishway exceeded 10°F on July 10, 2006, representing a 7°F exceedance of the permitted temperature rise (Figure 4).

Water temperature, river flow, and temperature rise during 2007 through 2010 are presented in a similar format in Figures 5 through 21. First, the full May to September time period is presented followed by four-week periods and one-week periods during the fish passage season.

- Data from 2007 are presented in Figures 5 – 8;
- Data from 2008 are presented in Figures 9 – 12;
- Data from 2009 are presented in Figures 13 – 16; and
- Data from 2010 are presented in Figures 17 – 21.

These data were provided by Vermont Yankee and demonstrate that the permitted temperature rise is routinely exceeded by actual temperature rises from upstream Station 7 to downstream Station 3 and to the fishway. In reviewing Vermont Yankee's temperature measurements collected at Station 3, apparently inaccurate measurements were observed on May 8, 2007 and on May 22-25, 2010. During these periods, the temperature measurements collected at Station 3 were disregarded.

The percentage of days when the actual temperature rise (between Stations 7 and 3) exceeded the NPDES-permitted temperature rise (as shown in Table 1) are tabulated in Table 3 by month and by year. A day was characterized as exceeding permit conditions if the actual temperature rise exceeded permitted temperature rise for at least one hour. Over the five-year period, the actual temperature rise exceeded the permitted temperature rise on 58% of days during the summertime (May 16 – October 14). During the critical fish passage month of June, actual temperature rise exceeded the permitted rise on 74% of days over the five-year period and on 93% of days in 2010.

The number of days when the actual temperature rise at the Vernon Dam fishway exceeded the permitted temperature rise for Station 3 is tabulated in Table 4. The total number of fishway operating days varied from 27 to 54 and the number of days during which permitted temperature rise was exceeded varied from 25 to 44. Over the five-year period the actual fishway temperature rise exceeded the permitted temperature rise for Station 3 on 158 of 216 days representing 73% of total days. In 2008, the fishway temperature exceeded these permitted levels on 26 of 27 days (96%) and in 2010 on 44 of 52 days (83%).

As shown in Figures 1 through 21, the actual temperature rise exceedences were not merely frequent; they were large. In many cases, the actual temperature rises were more than 4°F above the permitted temperature rise and in some cases, more than 7°F above.

River flow in the Connecticut River at Vernon Dam is highly dynamic, often increasing and decreasing by large amounts (e.g., through a range of 2,000 to 8,000 cfs) once or twice each day. This results in incomplete and variable mixing of thermal discharge waters with ambient river waters. These variable flows combined with significant residence times in the Vernon Dam impoundment make Equation 1.1 an inappropriate equation for estimating temperature rise.

Observations based on the data review are provided in Section 4.

Table 3. Tabulation of Days (by month and year) when Actual Temperature Rise from upstream Station 7 to downstream Station 3 in the Connecticut River Exceeded the Vermont Yankee NPDES-permitted Temperature Rise.

		Percent of days when actual temperature rise exceeded permitted temperature rise					
Month	Total Days Permitted	2006	2007	2008	2009	2010	Total
May	16	31%	13%	31%	38%	50%	33%
June	30	63%	83%	77%	53%	93%	74%
July	31	100%	87%	71%	29%	77%	73%
Aug	31	100%	77%	19%	48%	68%	63%
Sept	30	57%	20%	70%	97%	50%	59%
Oct	14	7%	29%	7%	21%	0%	13%
Total percent of days:		**68%**	**58%**	**51%**	**51%**	**63%**	**58%**

Table 4. Tabulation of Days (by annual fishway season) when Actual Temperature Rise from upstream Station 7 to the Vernon Dam Fishway Exceeded the Vermont Yankee NPDES-permitted Temperature Rise.

	2006	2007	2008	2009	2010	Total
Total days fishway operating	38	44	27	54	53	216
Days fishway temperature rise exceeded permitted temperature rise	25	28	26	35	44	158
% of days fishway temperature rise exceeded permitted temperature rise	**66%**	**64%**	**96%**	**65%**	**83%**	**73%**

3.2 United States Fish and Wildlife Service Data

The United States Fish and Wildlife Service (FWS) has deployed continuously-recording temperature sensors in the Connecticut River at numerous locations. FWS temperature records for 11 locations during the 2010 summertime season were obtained and analyzed. The locations of the 11 temperature sampling station are given in Table 5. The FWS stations are denoted in the “source” column and include lat/long coordinates and narrative descriptions from the FWS. Stations in Table 5, which include the three Vermont Yankee stations, are listed in upstream to downstream order. Distances relative to Vernon Dam are also indicated. Of the 11 FWS station, two are upstream, four are near Vernon Dam, and five are far downstream of the Vernon Dam. The FWS Vernon Dam station (ID#43) data file contained two temperature records without clarifying metadata and was removed from the analysis.

Figure 22 shows water temperature and river flow over time during the period of May through September 2010. This figure includes ten FWS temperature stations and three Vermont Yankee locations (Station 7, 3, and the fishway). Upstream stations are shown in shades of green, near-downstream stations are shown in red and orange, and far-downstream stations are shown in shades of purple. Near-downstream stations are situated from the Vernon Dam to 2.9 miles downstream and far-downstream stations are situated between 12.8 and 22.5 miles downstream of the dam. The Vermont Yankee stations retain the colors used in Figures 1 – 21 above: upstream Station 7 is green, fishway is blue, and downstream Station 3 is red.

Figure 22 is crowded and it is difficult to discern individual temperature records. Figure 22 illustrates the general trend that the upstream stations (green) tend to be cooler, the purple (far-downstream) and orange/red stations (near-downstream) appear to have similar temperatures with orange station spikes tending to represent the highest temperatures.

To evaluate the 2010 fishway season, two four-week periods were evaluated and are presented in Figures 23 and 24. During June 15 to July 13 (Figure 24), river flow rates typically varied through a large range (e.g., ~2,000 to ~8000 cfs) at least once per day. The highest water temperatures (orange) were at the Vernon Pool at Dam station (#43) immediately above the dam on the New Hampshire side of the river. The peak fishway temperatures (blue) coincide with the peak Vernon Pool Dam station temperatures. The near-downstream (orange/red) and far-downstream (purple) temperatures tend to be warmer than the upstream temperatures (green).

A two-week period from June 23 to July 7 was selected to illustrate water temperature dynamics in the Connecticut River (Figure 25). This time period is presented in two additional figures with some temperature stations removed to make it easier to see individual temperature records associated with far-downstream (Figure 26) and near-downstream (Figure 27) stations. Figure 25 presents all temperature data over a two-week period and illustrates that water temperature varies significantly with flow changes in the river. For example during June 25-28, river flow (gray) varies between 2,000 and 8,000 cfs concurrently with temperature changes at many stations, most dramatically in the Vernon Dam (#43) and fishway locations.

Figure 26 presents the same time period as Figure 25, but without the upstream and near-downstream stations (the Vermont Yankee stations are retained to provide reference values). In Figure 26, the far-downstream temperature records are more easily evaluated. Of the five far-downstream stations, four are consistently in the same temperature range as Station 3 and the fishway and are warmer than upstream Station 7.

At one of the five far-downstream stations (#51), situated 17 miles downstream, water temperatures are often cooler than those of the other four stations and follow different temporal patterns (see arrow and text in lower left corner of Figure 26). This record can also be observed to be different from the other far-downstream stations in Figures 23 and 24. This sampling location is situated 1.3 miles downstream of another sampling location (#52) and yet the two water temperature records follow very different patterns. River water temperature dynamics can be complex and a variety of factors can affect temperature at each location. At FWS station #51, the description provided by the FWS states that the sensor was placed "Just upstream of deep hole in corner down from cliffs" (Table 5). This passage suggests that the anomalous water temperatures could potentially be due to cooler water associated with the deep hole and inflow of cold groundwater (i.e., seepage).

Figure 27 presents the same time period without the upstream and far-downstream stations, enabling analysis of near-downstream data. In Figure 27, the FWS station just above the dam recorded the highest water temperature (labeled in upper left). Each of the near-downstream stations follows a similar temporal pattern of higher temperature during high river flow rate and lower temperature at lower flow rates. This pattern is consistent between the Vermont Yankee stations and the FWS stations during this time period.

Figure 28 and 29 present water temperature and river flow over one-week periods to enable evaluation of temporal patterns in temperature change.

Water temperatures at the far downstream stations were consistently in the same temperature range as Station 3 and the fishway and are warmer than upstream Station 7. This is an important observation because it indicates that the temperature rise added to the Connecticut River near Vernon Dam is retained for a distance of at least 22.5 miles downstream during this time period. This is likely due to several factors including the Vermont Yankee thermal discharge, the Vernon Dam impoundment, and meteorological conditions.

Observations, findings, and recommendations based on the data review are provided in Section 4.

Table 5. Locations of Water Temperature Sampling Stations
with Distance to Vernon Dam and Descriptions.

Source (ID#)	Color in Figures	Station Name	Lat	Long	Approx. miles from Vernon Dam	Description
USFWS (2405544)	light green	Bellows Falls Below Dam	43 07.982	72 26.489	-31	Adjacent to ladder entrance in tailrace, cabled off railing; water 15 feet deep.
USFWS (2405559)	light green	Upper Vernon Pool	42 53.062	72 33.152	-9	On RR at base of RT 9 Bridge. Attached to tree near older abutment (upstream side), just on side of moved bridge grass. Water 6 feet deep.
Vermont Yankee	green	Station 7	42 49.364	72 32 745	-4.3	Vermont Yankee sampling location
		Vermont Yankee Themal Discharge Location			-0.5	Not a sampling location
USFWS (2405562)	orange	Vernon Pool	42 46.283	72 30.624	-	On RL, Vernon Dam, near where barrels are tied across forebay, Tied to tree, rip rap area.; water 6 feet deep
USFWS (2405543)	NA	Vernon Dam	42 46.279	72 30.885	-	Restricted access; Set in corner fish bypass pipe & entrance to ladder (RR corner off dam structure). Water 5 feet deep
Vermont Yankee	blue	Fishway			-	Description was not provided.
Vermont Yankee	red	Station 3	42 45.921	72 30.400	0.7	Vermont Yankee sampling location
USFWS (2405563)	light orange	Turners Falls Pool 6	42 46.322	72 30.315	1.1	Attached to sycamore tree at base of dam, on RL, eddy area, wi/ grass on open area of dam face up slope, half way up Stebbins Island (on other side); water 6 feet deep
USFWS (2405566)	yellow	Turners Falls Pool 5	42 45.785	72 28.601	2.9	Attached to tree above rocky ledge, just downstream of island that is below Ashuelot River mouth (RL)
USFWS (2405553)	purple	Turners Falls Pool 3	42 38.447	72 29.128	12.8	Just downstream of Renaissance rock ledge, attached to old root wad. RR
USFWS (2405552)	purple	Turners Falls Pool 2	42 36.300	72 29.346	15.7	Just upriver (RL) of French King rock 200 yards. Water 6 feet deep.
USFWS (2405551)	purple	Turners Falls Pool 1	42 36.130	72 30.276	17	Horserace area; Just upstream of deep hole in corner down from cliffs. Cable around large boulder; 6 feet of water. RR
USFWS (2405550)	purple	Gate House	42 36 635	72 33.241	20.4	Set in entrance cavity of extended gatehouse flume fish way entrance
USFWS (2405549)	purple	Cabot Station	42 35.231	72 34.756	22.5	Set adjacent to down stream fishing entrance flume up from bypass - lowest water, 4 feet deep

Note: Distances from Vernon Dam were estimated using Google Earth and were assigned with negative values upstream and positive values downstream relative to the Vernon Dam.

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4.0 Discussion

A summary of observations, findings, and recommendations is provided below.

4.1 Observations

This review yielded the following observations:

NPDES Permit Review

1. The Vermont Yankee Power Station NPDES permit appears to seek to limit river temperature rise during the summertime to between 2 and 5°F, depending on upstream water temperatures.
2. Vermont Yankee's NPDES permit does not limit actual temperature rise in the Connecticut River, rather it specifies use of a simple equation to calculate temperature rise.
3. The permitted temperature rise equation (Equation 1.1) is based on the assumption that the thermal effluent is mixed completely and uniformly within the entire flow of the river. This assumption may be valid during periods when steady river flow and thermal discharge exceed hydraulic residence times of 2.5 to over 10 days, depending on river flow. Use of Equation 1.1 is not appropriate when river flows or thermal discharge vary significantly over time periods less than the hydraulic residence time at Vernon Dam.
4. The Power Station's time-varying rate of heat rejection to the river is not provided to regulators making it impossible to verify Vermont Yankee's NPDES permit compliance.

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5. Actual temperature rise at downstream Station 3 and at the fishway were typically higher than the temperature rise nominally permitted by the NPDES permit.
6. Actual peak temperature rises at the fishway were typically more than 2°F higher than the permitted rise and were sometimes more than twice the permitted temperature rise. Maximum actual peak temperature rise at the fishway exceeded 10°F when the permitted temperature rise was 3°F.
7. Actual peak temperature rises at Station 3 were typically more than 2°F higher than the permitted rise and were occasionally more than twice the permitted temperature rise. Maximum actual peak temperature rise at Station 3 exceeded 7°F when the permitted temperature rise was 3°F.
8. Actual temperature rise at Station 3 exceeded Station 3 permitted temperature rise on 58% of days during the study period and during 74% of June days.
9. Actual temperature rise at the fishway exceeded permitted temperature rise on 73% of days during the study period and 96% of days in 2008.
10. River flow in the Connecticut River at Vernon Dam is highly dynamic, often increasing and decreasing by large amounts (e.g., through a range of 2,000 to 8,000 cfs) once or twice each day. This results in incomplete and variable mixing of thermal discharge waters with ambient

river waters. These variable flows combined with significant residence times in the Vernon Dam impoundment make Equation 1.1 an inappropriate equation for estimating temperature rise.

11. Water temperatures at the far downstream stations were consistently in the same temperature range as Station 3 and the fishway and are warmer than upstream Station 7, indicating that the temperature rise added to the Connecticut River near Vernon Dam is retained for a distance of at least 22.5 miles downstream during this time period. This is likely due to several factors including the Vermont Yankee thermal discharge, the Vernon Dam impoundment, and meteorological conditions.

4.2 Findings

1. The use of Equation 1.1 to compute the temperature rise as a surrogate for the actual, readily available temperature rise measurements has resulted in the river routinely experiencing temperature increases below the Vermont Yankee Power Station that are far greater than those specified in the permit.
2. The lack of data submitted by Vermont Yankee characterizing heat rejection rate to the river is an important omission because rate is used in Equation 1.1 to calculate temperature rise. These data are reportedly utilized by Vermont Yankee, are readily available, and should be included in the information submitted for review.
3. The Vernon Dam impoundment conditions in the Connecticut River near the Vermont Yankee discharge do not typically result in complete mixing of thermal discharge waters making the use of Equation 1.1 inappropriate.
4. On most days, actual water temperature rises in the Connecticut River at downstream Station 3 and at the fishway exceed the permitted temperature rise, often by several degrees Fahrenheit and for extended periods of time.

4.3 Recommendations

1. Replace Equation 1.1 with a more appropriate, accurate, and protective approach.
2. Conduct a fisheries review of the water temperature measurements in the fishway and throughout the entire thermal plume, extending beyond 22.5 miles below Vernon Dam, to evaluate the potential for harm to fish and likelihood of avoidance due to elevated water temperatures.
3. Obtain and review the Vermont Yankee records of the heat rejected to the river.

5.0 References

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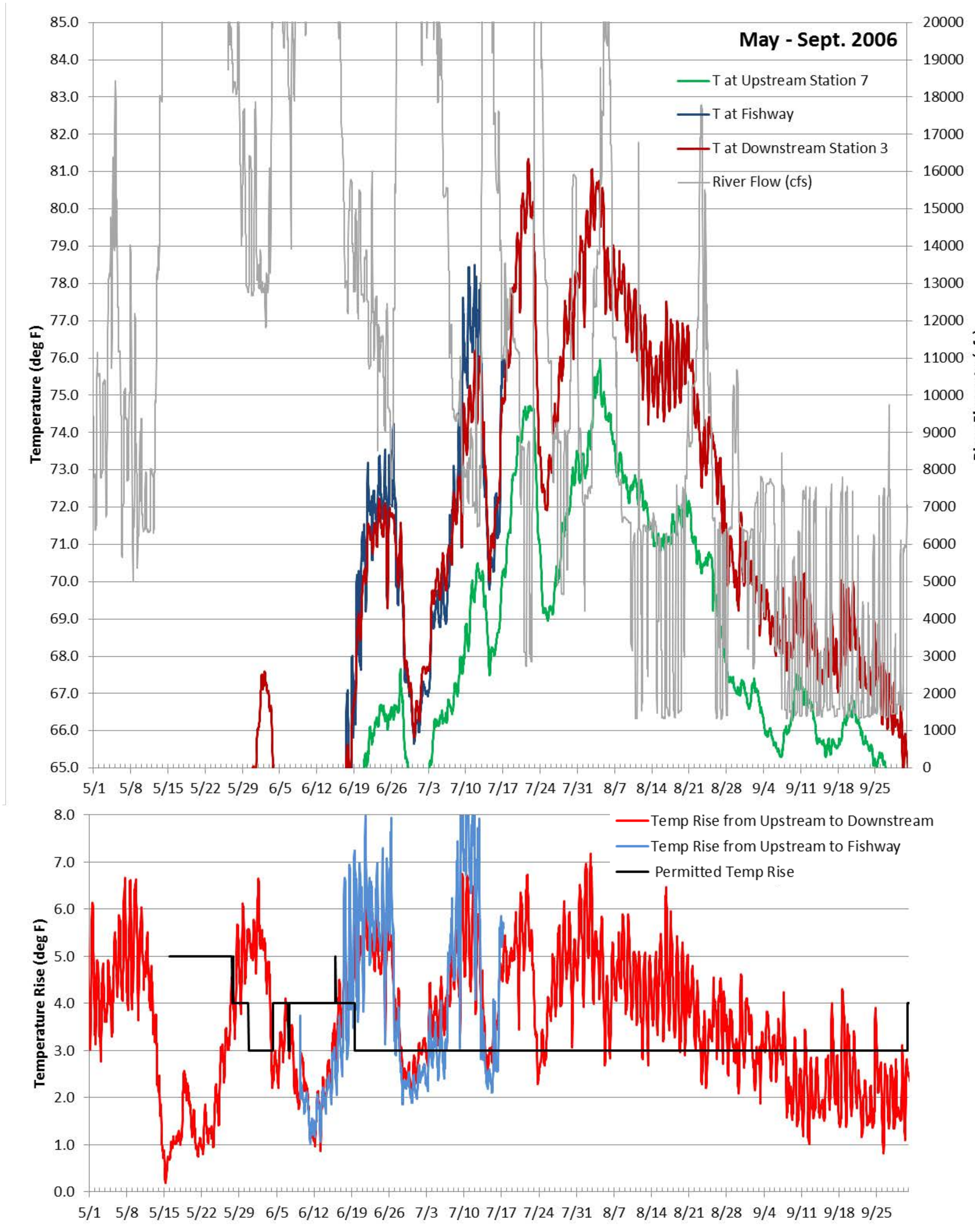

Figure 1. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, May – September 2006 (5 months).

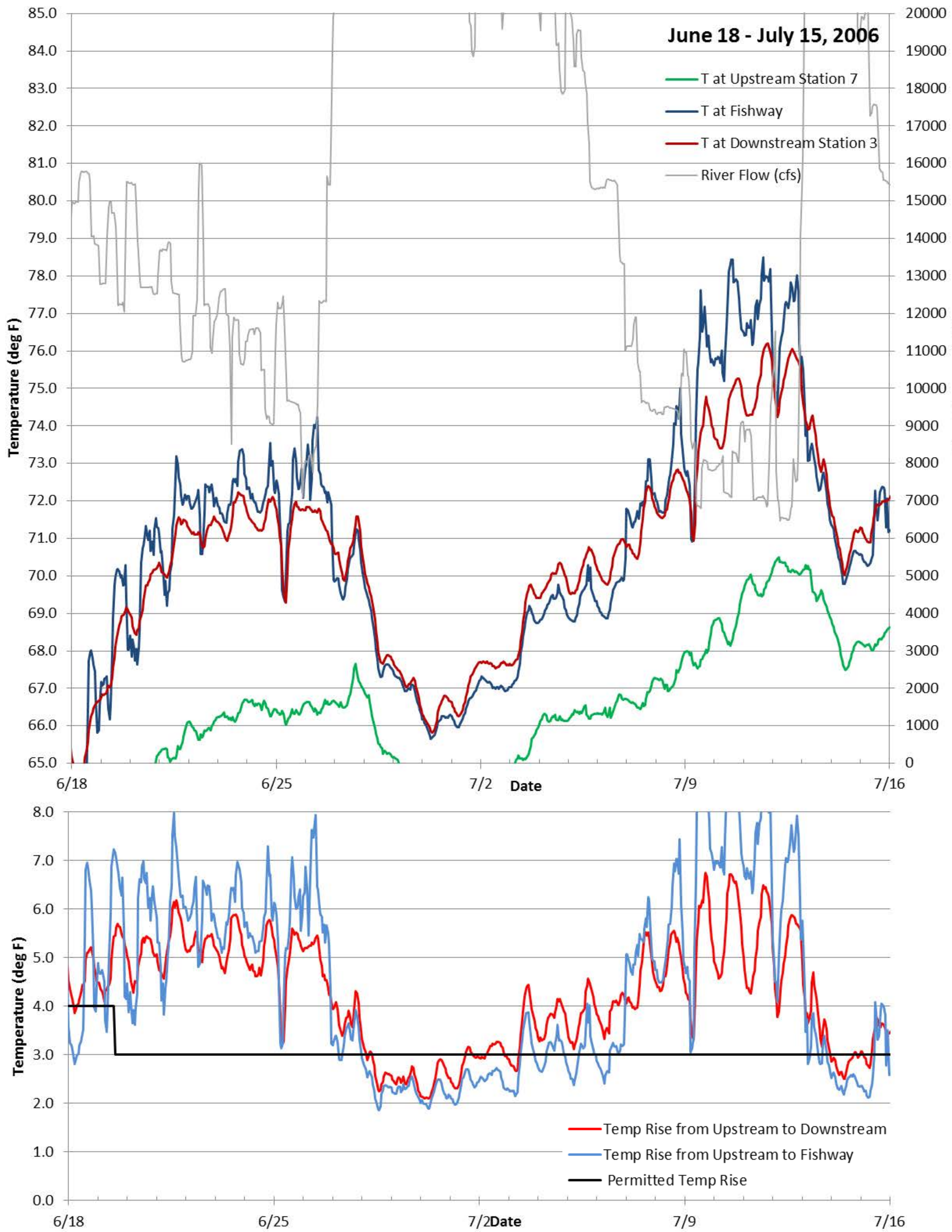

Figure 2. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 18 – July 15, 2006 (4 weeks).

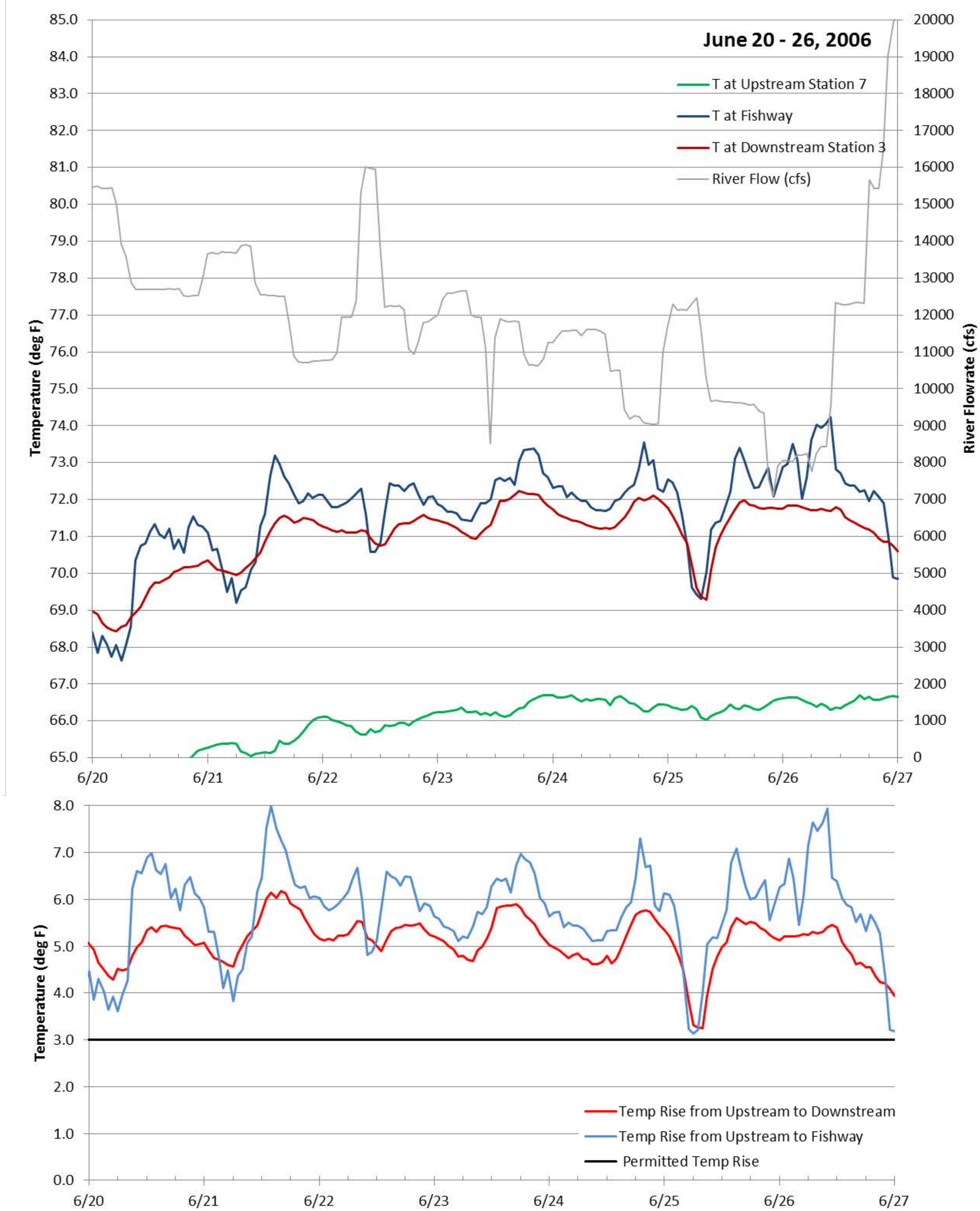

Figure 3. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 20 – June 26, 2006 (1 week).

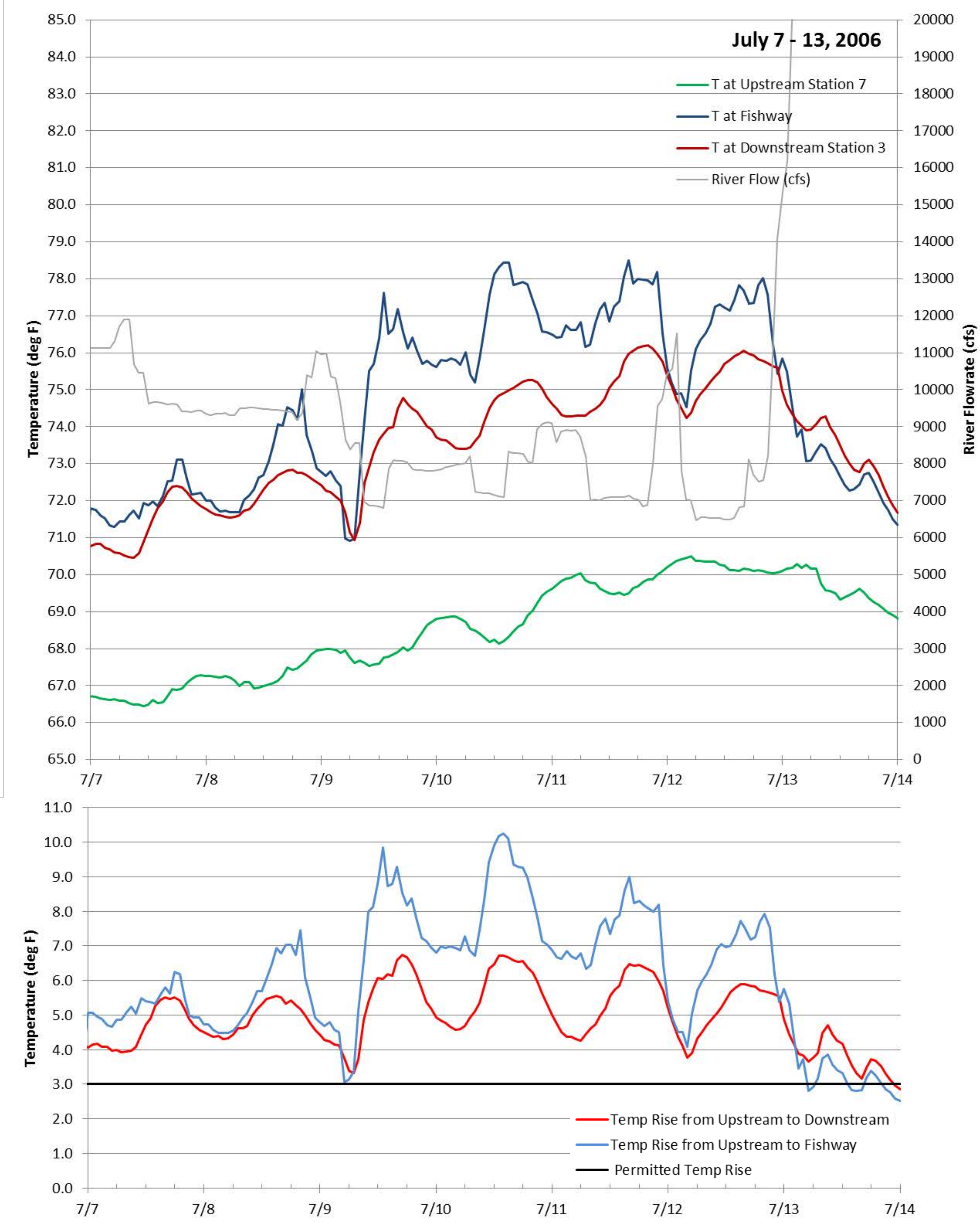

Figure 4. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, July 7 – July 13, 2006 (1 week).

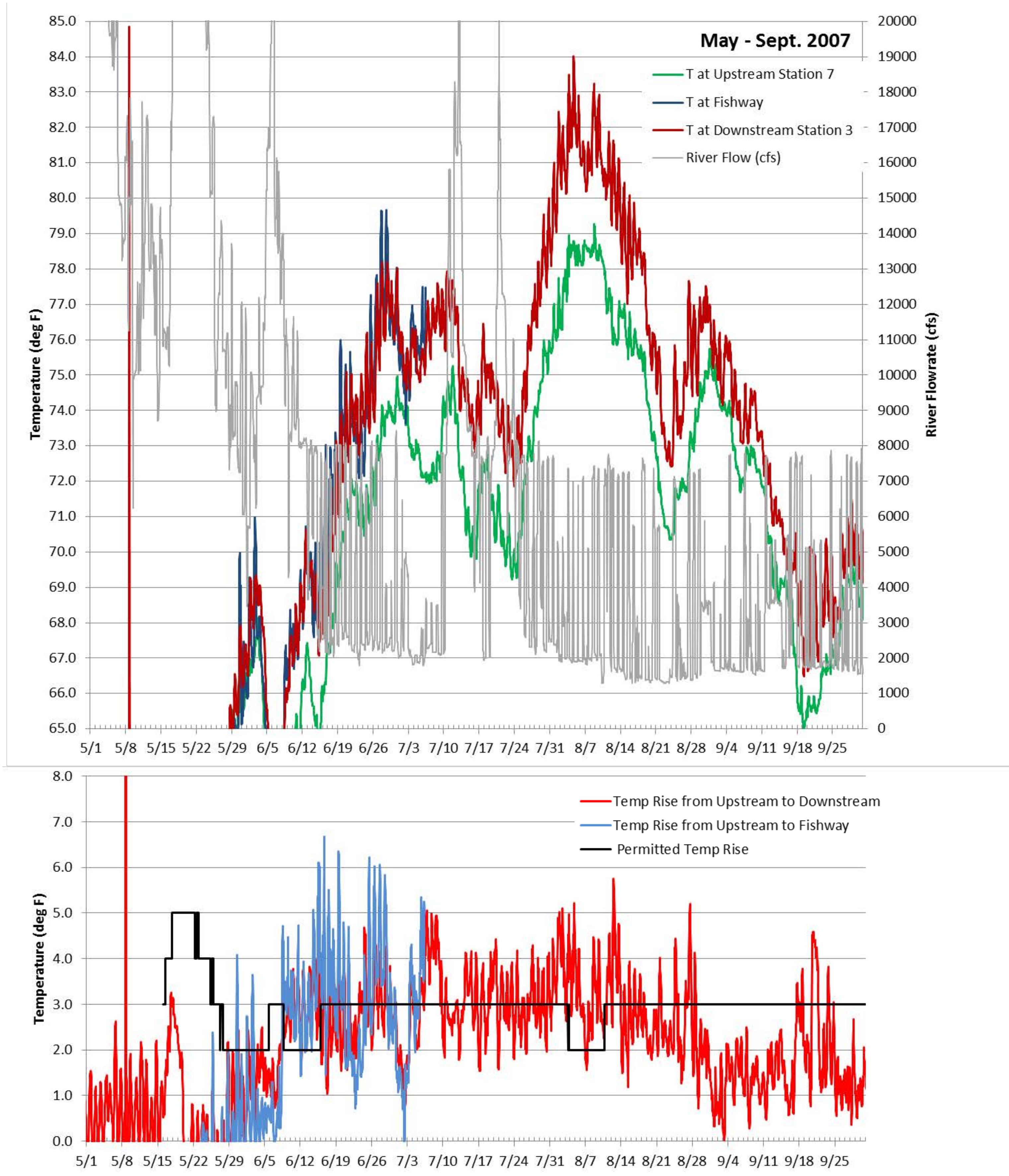

Figure 5. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, May – September 2007 (5 months).

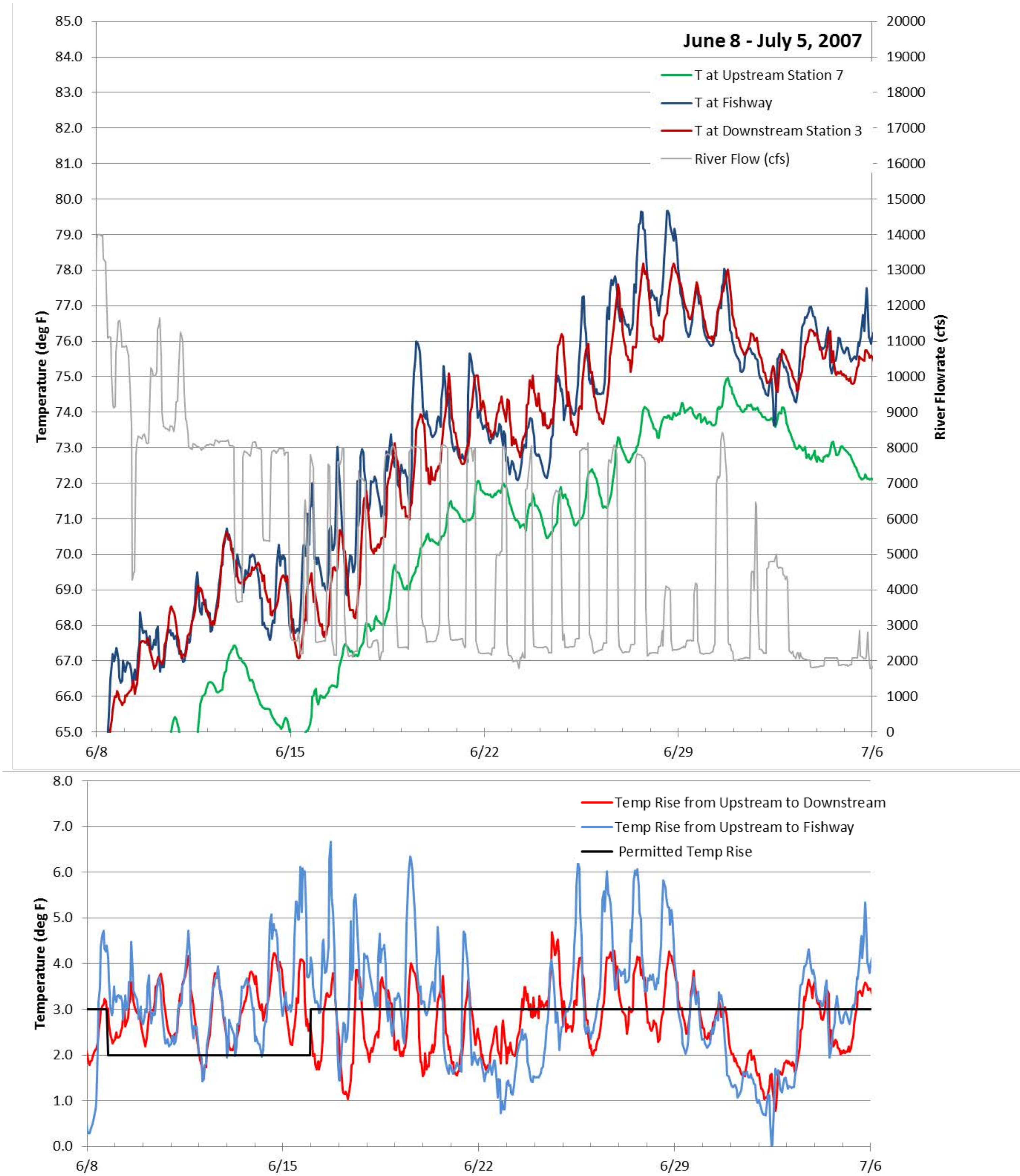

Figure 6. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 8 – July 5, 2007 (4 weeks).

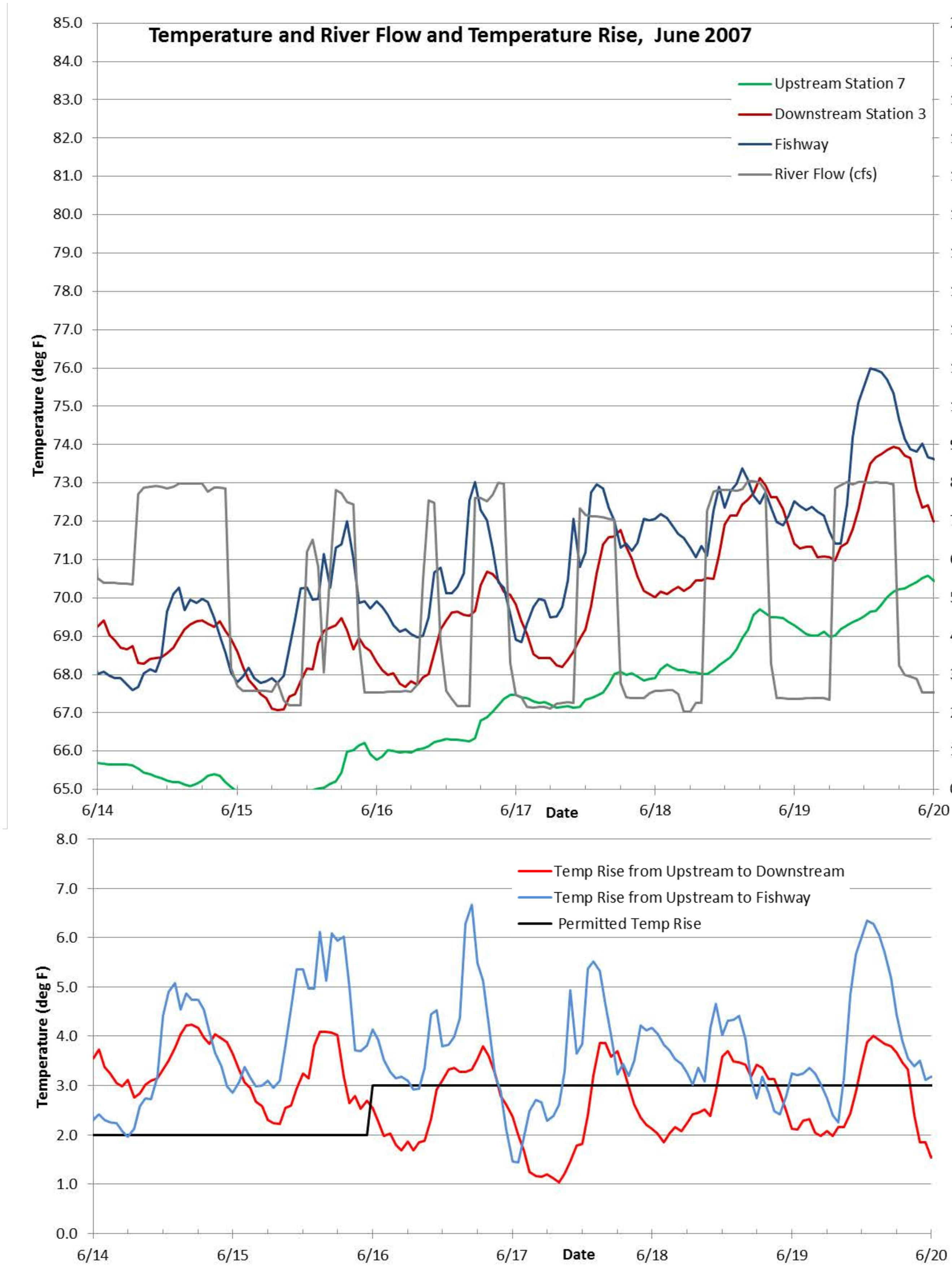

Figure 7. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 14 – June 20, 2007 (1 week).

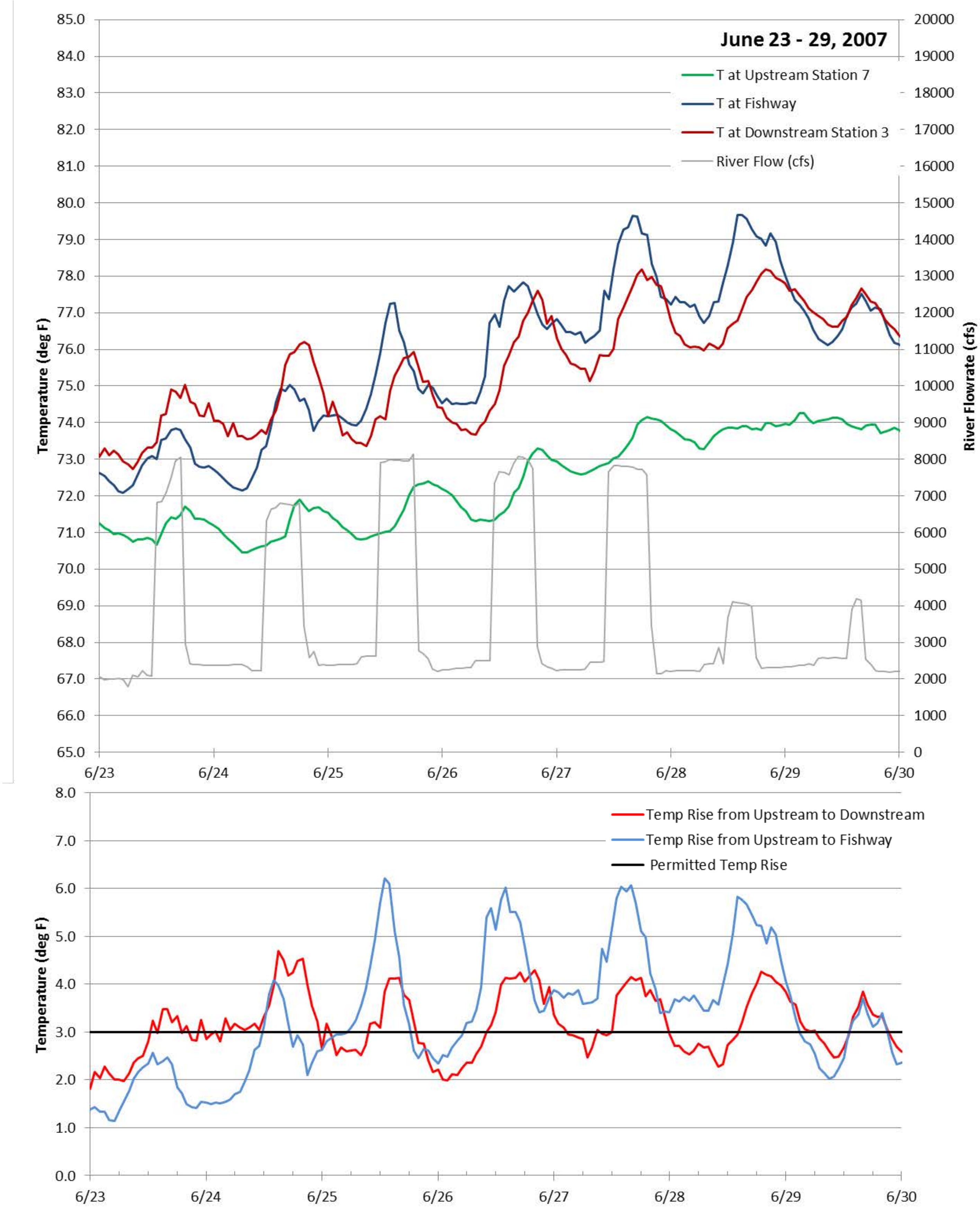

Figure 8. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 23 – June 29, 2007 (1 week).

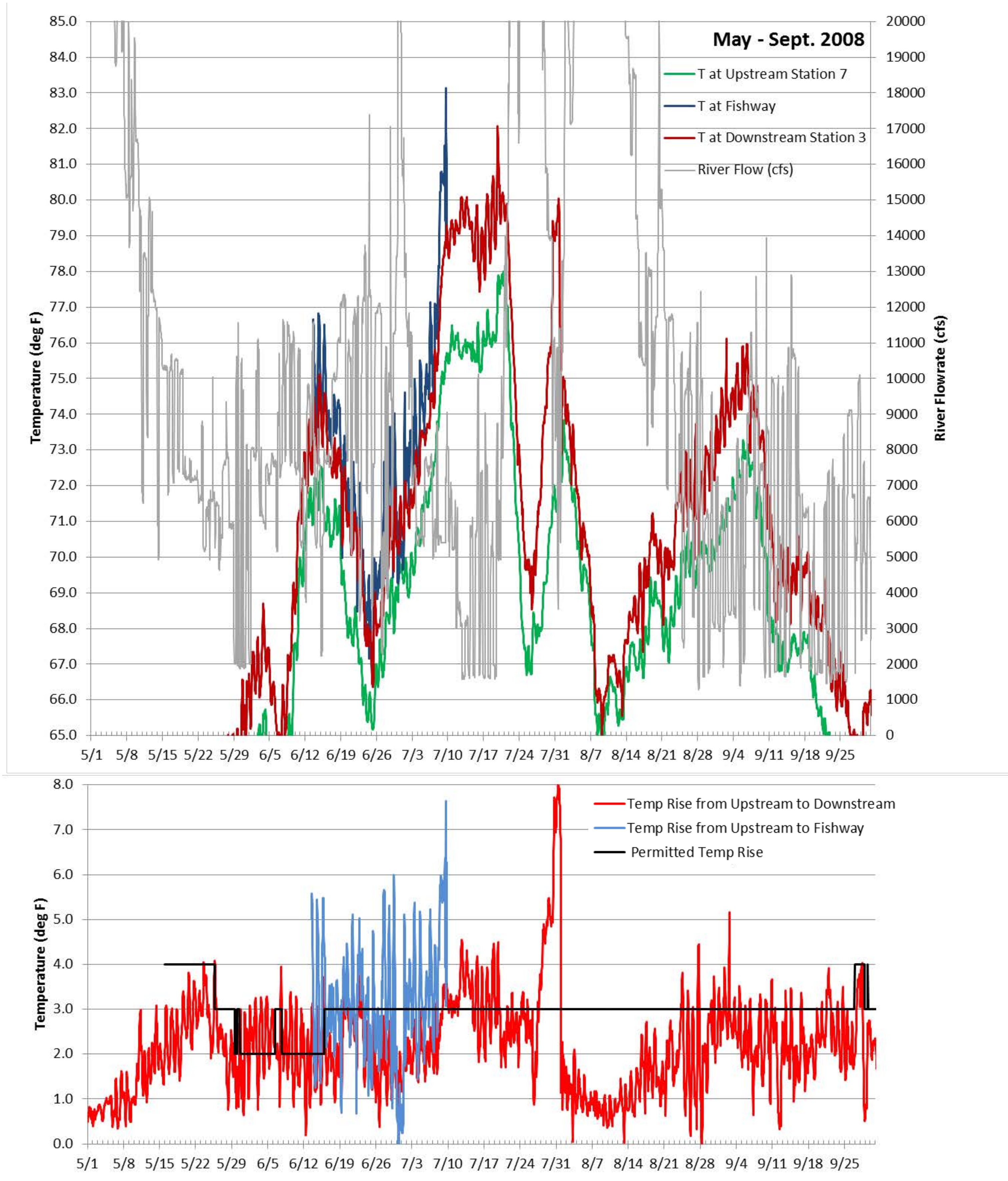

Figure 9. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, May – September 2008 (5 months).

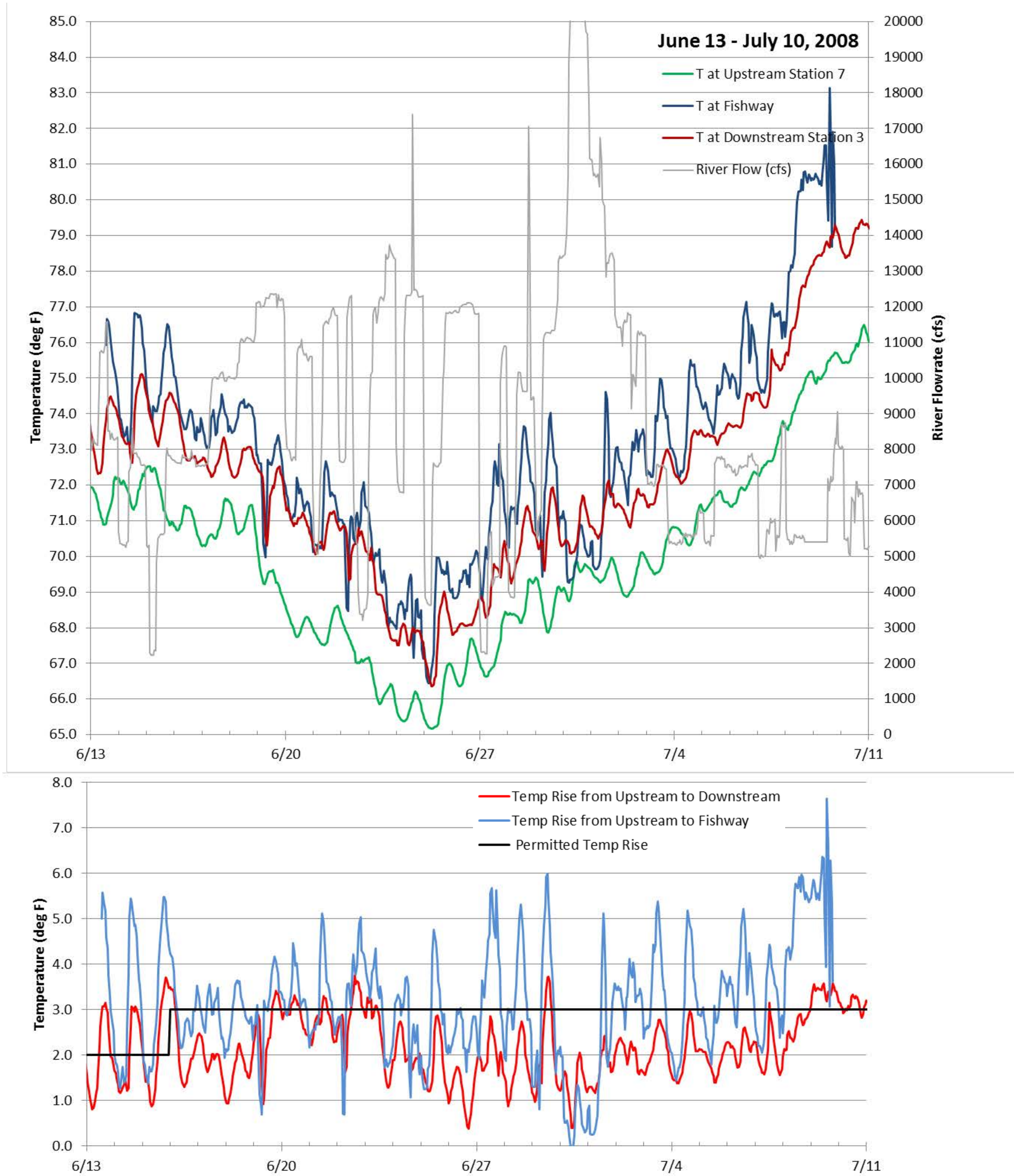

Figure 10. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 13 – July 10, 2008 (4 weeks).

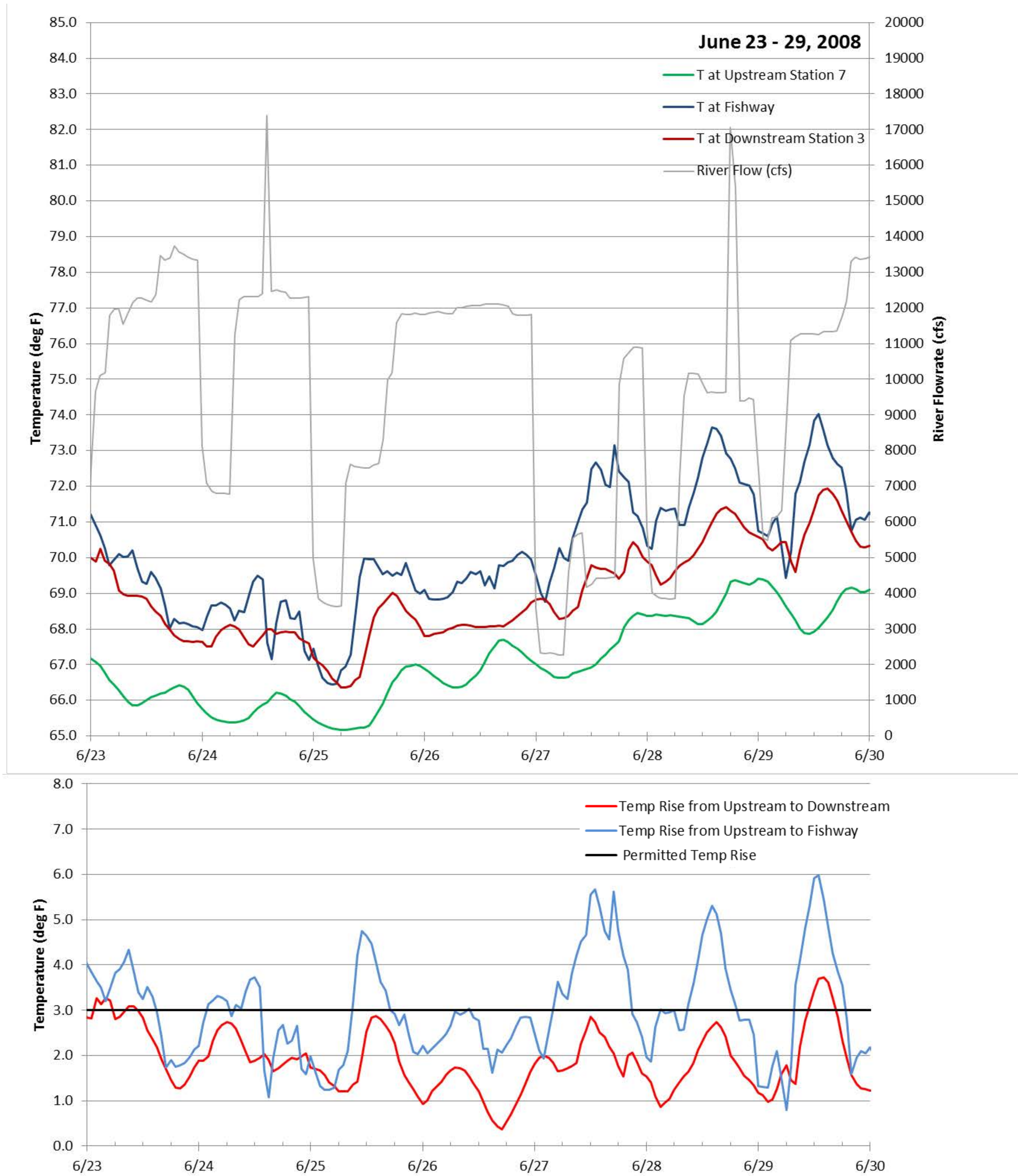

Figure 11. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 23 – June 29, 2008 (1 week).

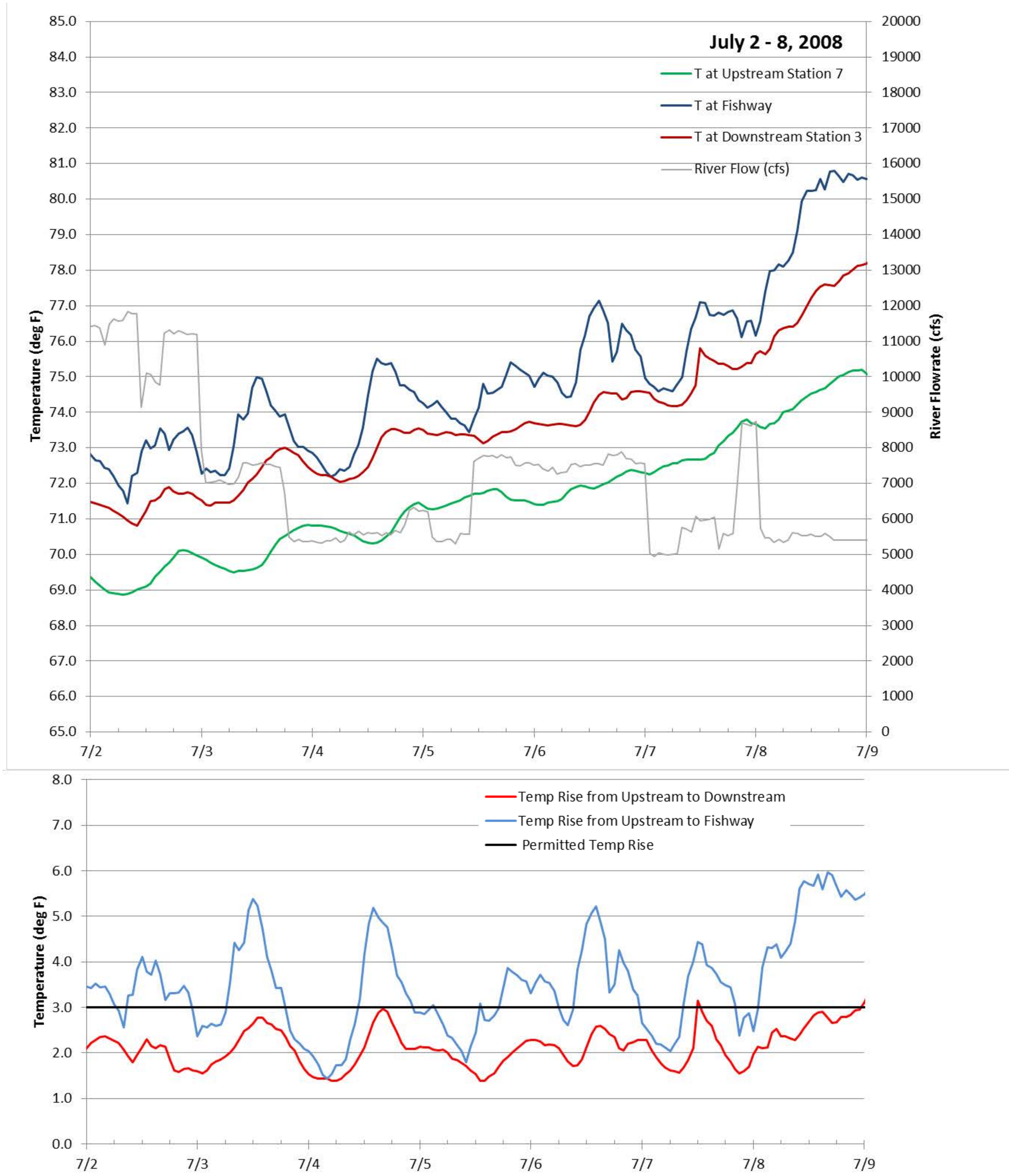

Figure 12. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, July 2 – July 8, 2008 (1 week).

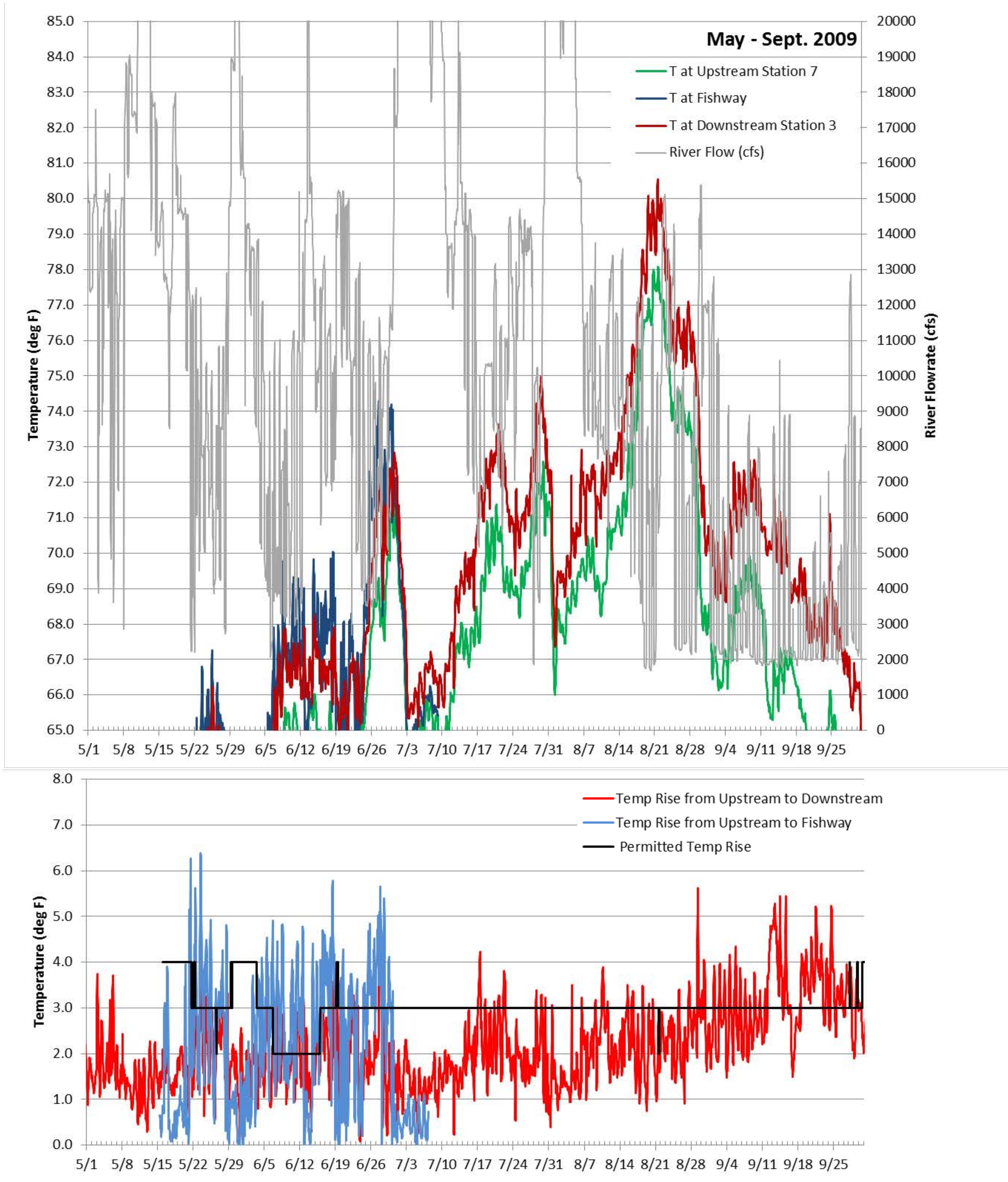

Figure 13. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, May – September 2009 (5 months).

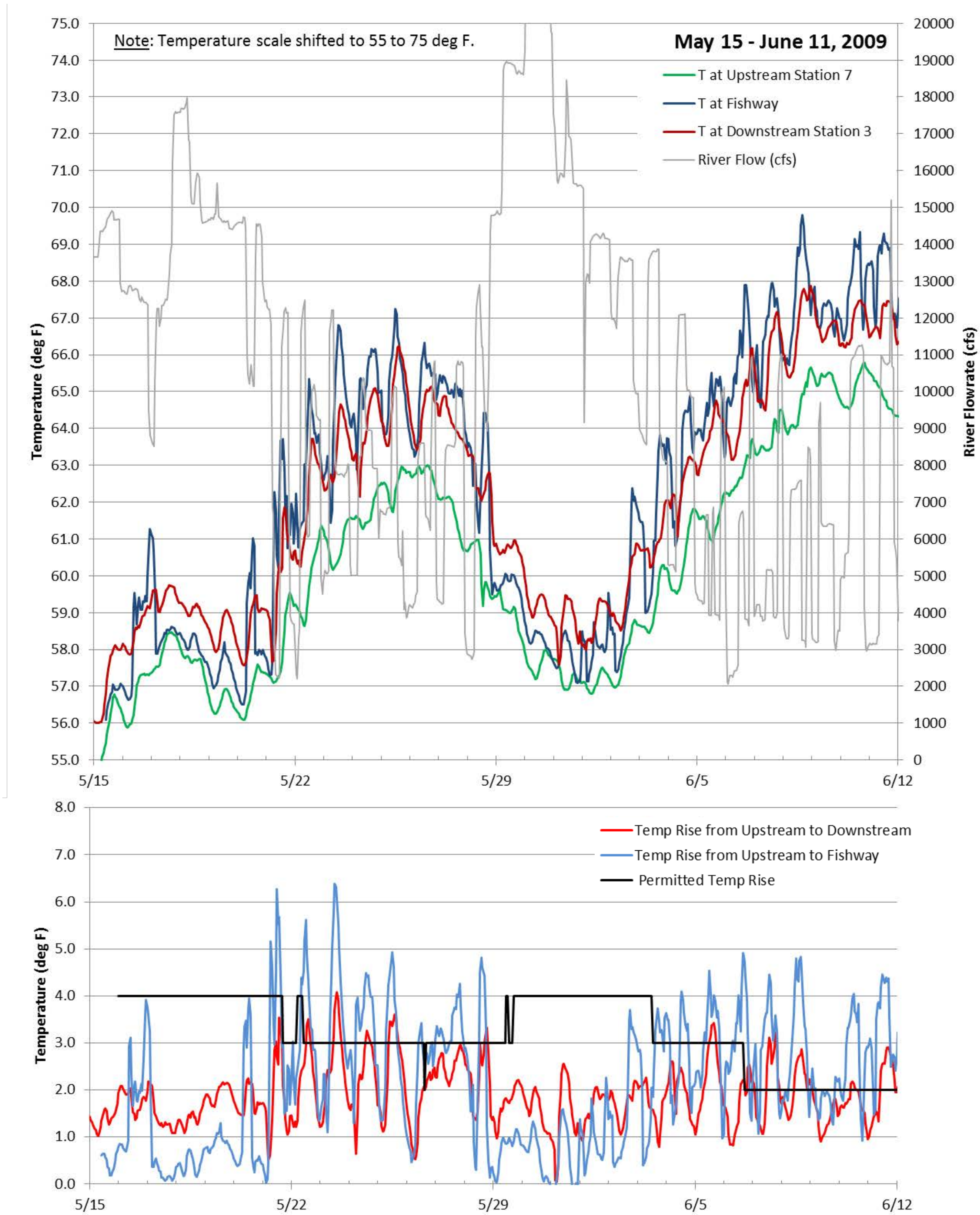

Figure 14. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, May 15 – June 11, 2009 (4 weeks).

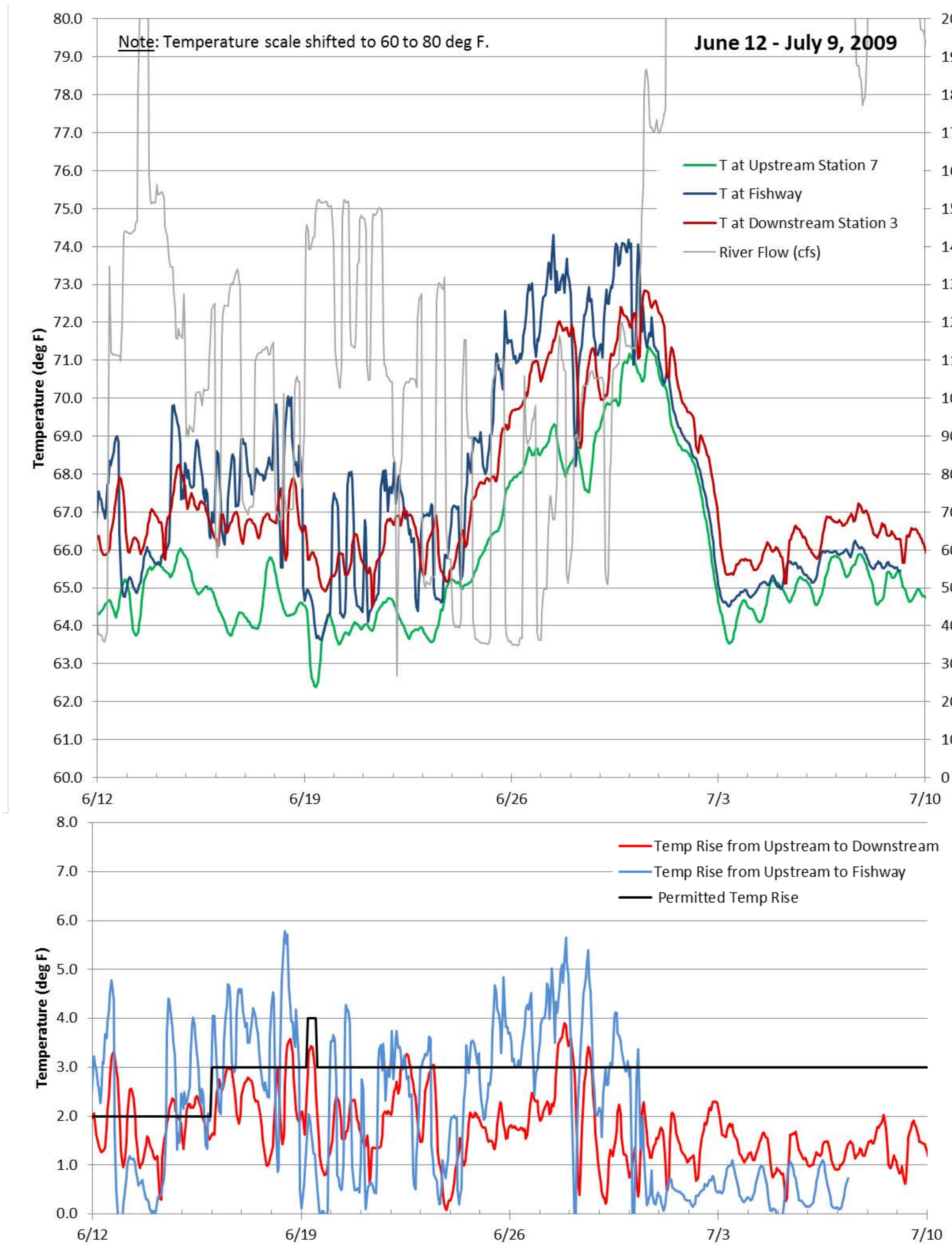

Figure 15. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 12 – July 9, 2009 (4 weeks).

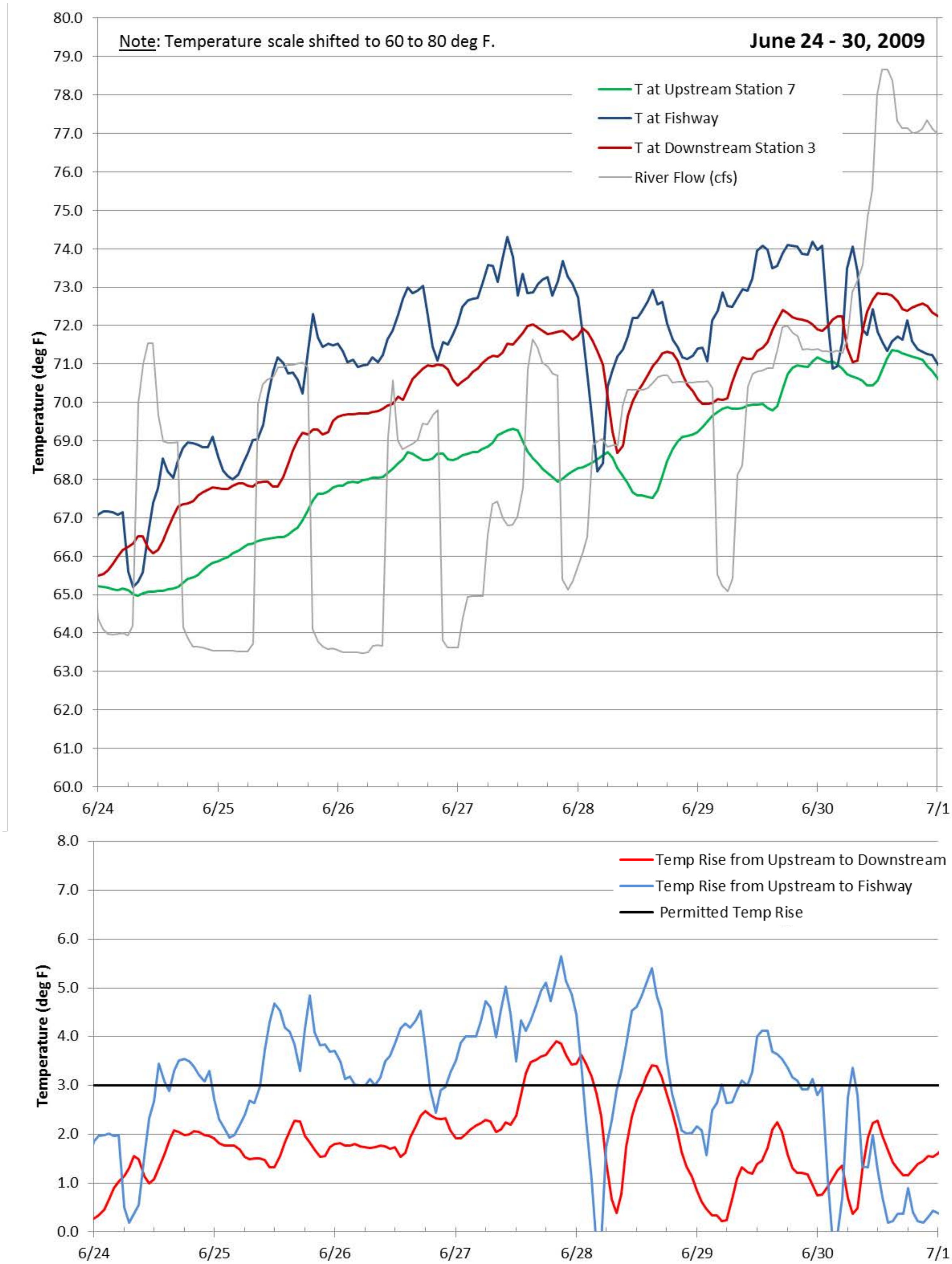

Figure 16. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut RiverJune 24 – June 30, 2009 (1 week).

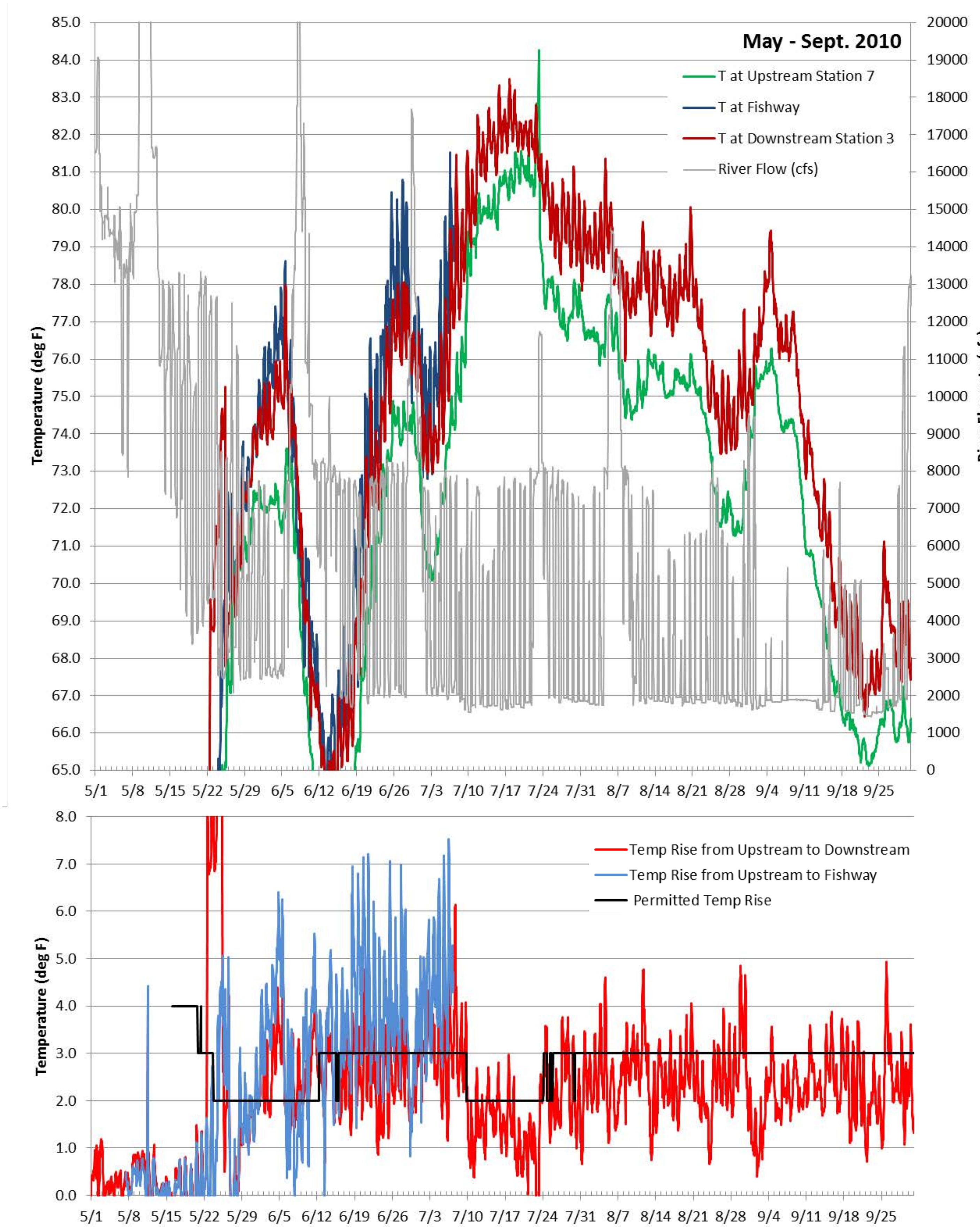

Figure 17. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, May – September 2010 (5 months).

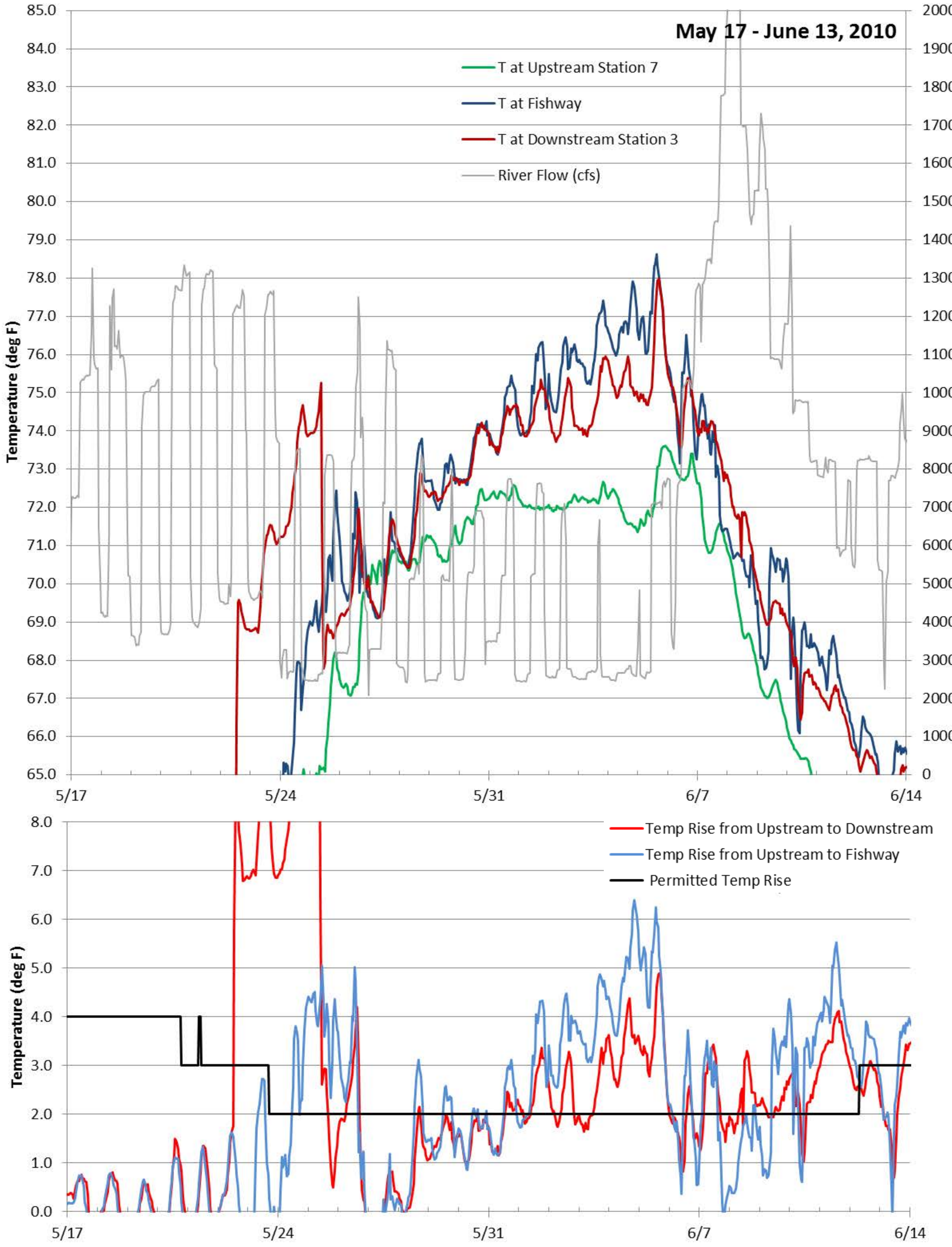

Figure 18. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, May 17 – June 13, 2010 (4 weeks).

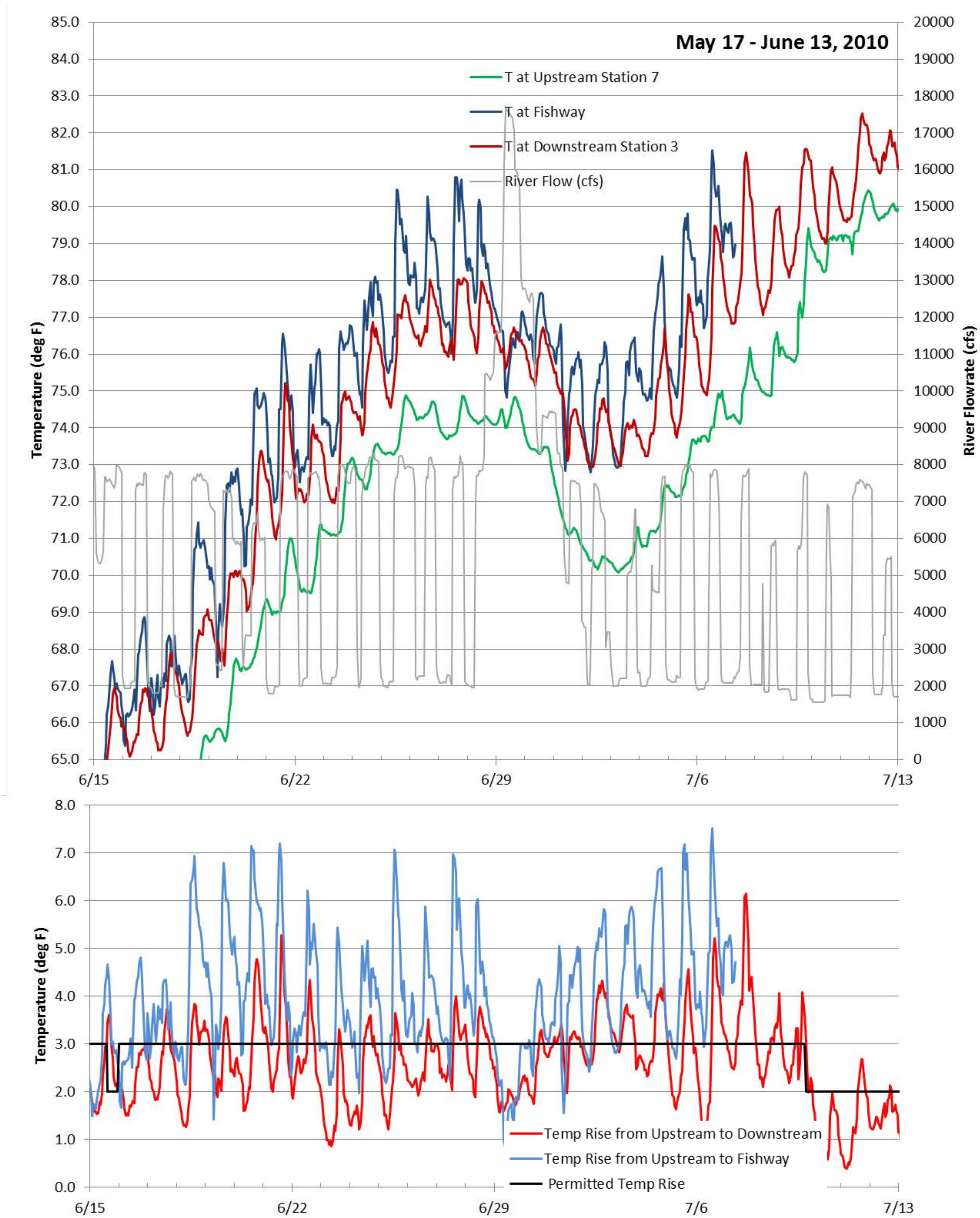

Figure 19. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 14 – July 12, 2010 (4 weeks).

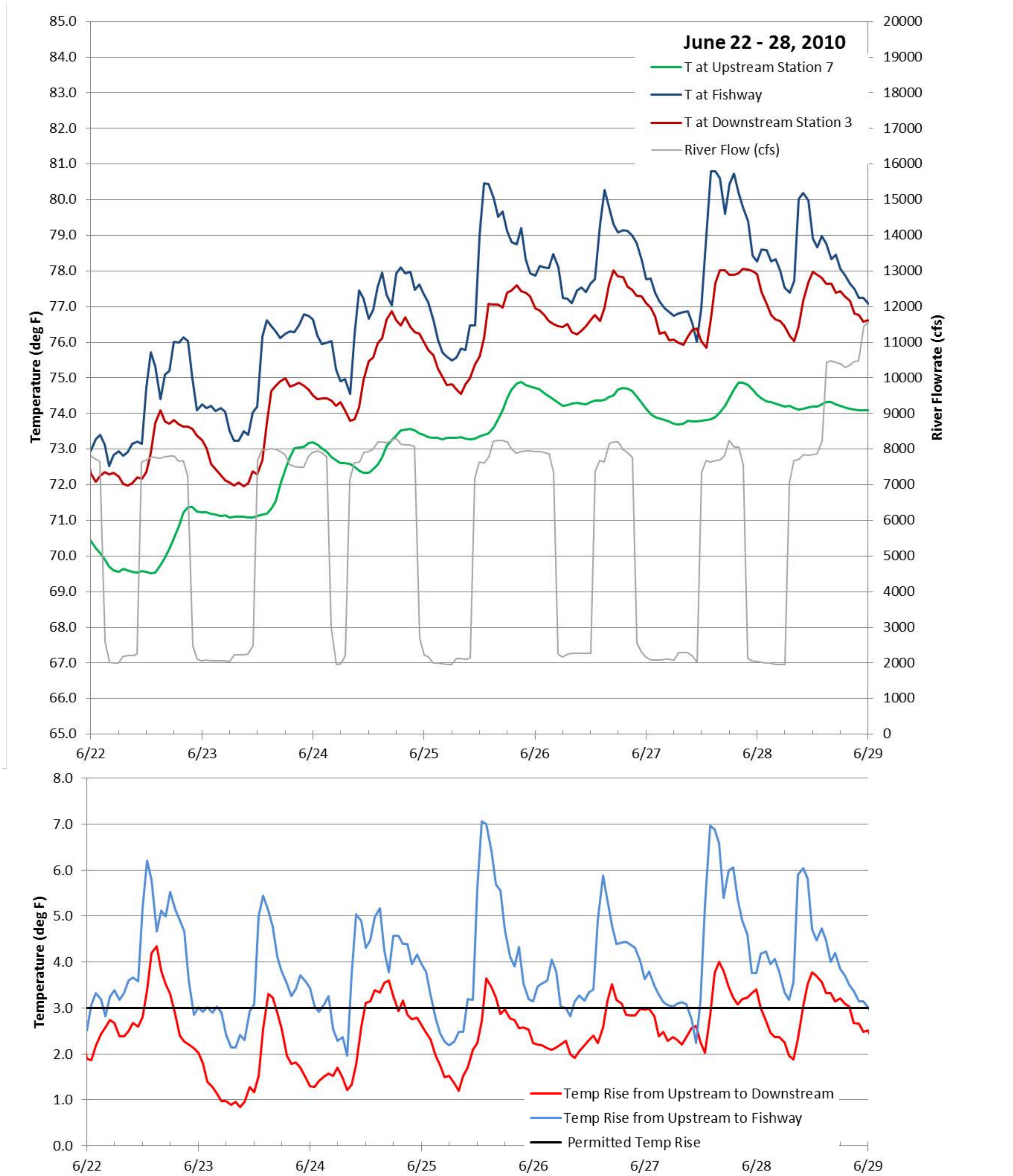

Figure 20. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 22 – June 28, 2010 (1 week).

Figure 21. Time series of water temperature, river flowrate and temperature rise near the Vermont Yankee Station on the Connecticut River, June 30 – July 6, 2010 (1 week).

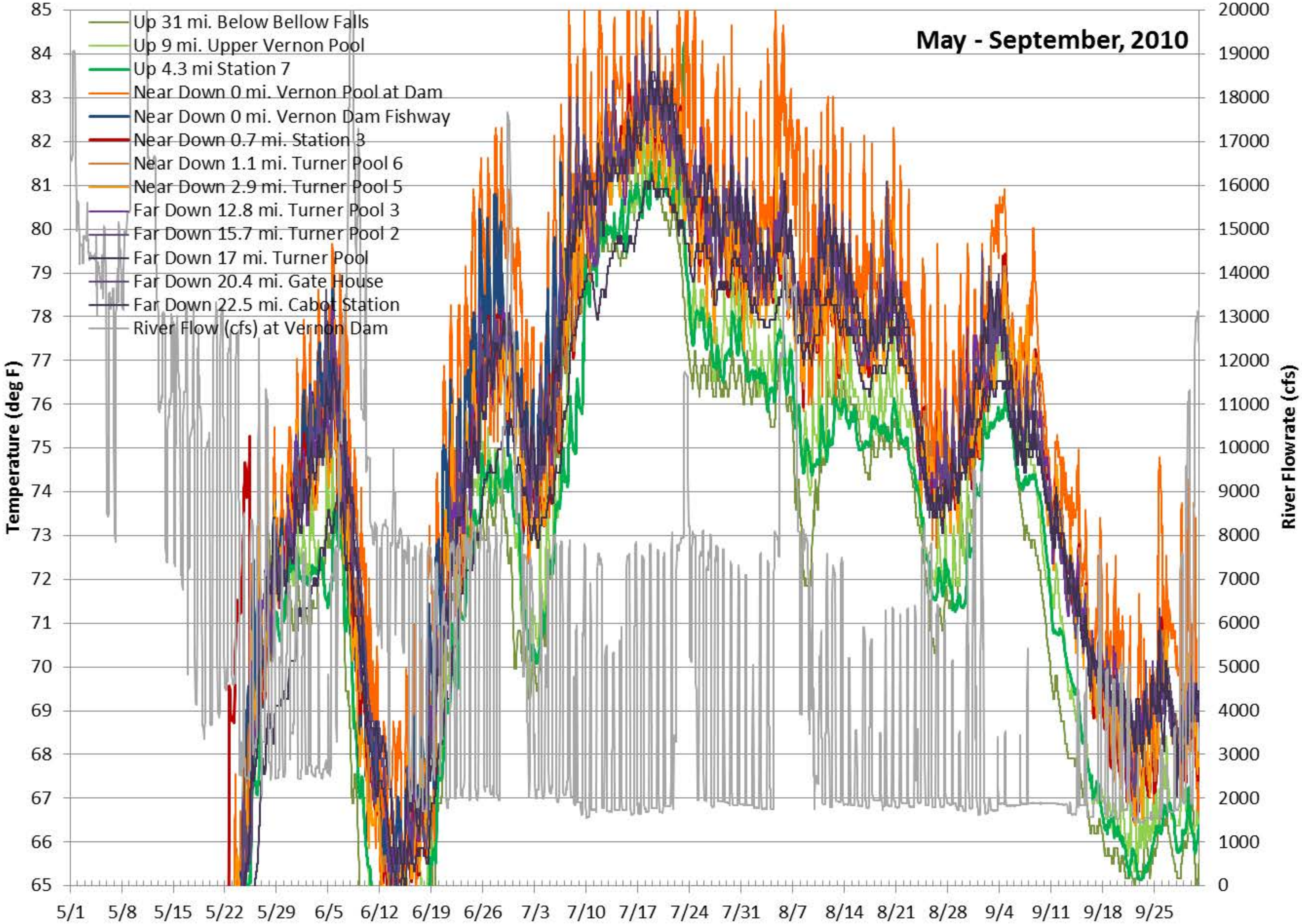

Figure 22. Time series of water temperature and river flowrate near the Vermont Yankee Station on the Connecticut River, including USFWS data, May – September 2010 (5 months).

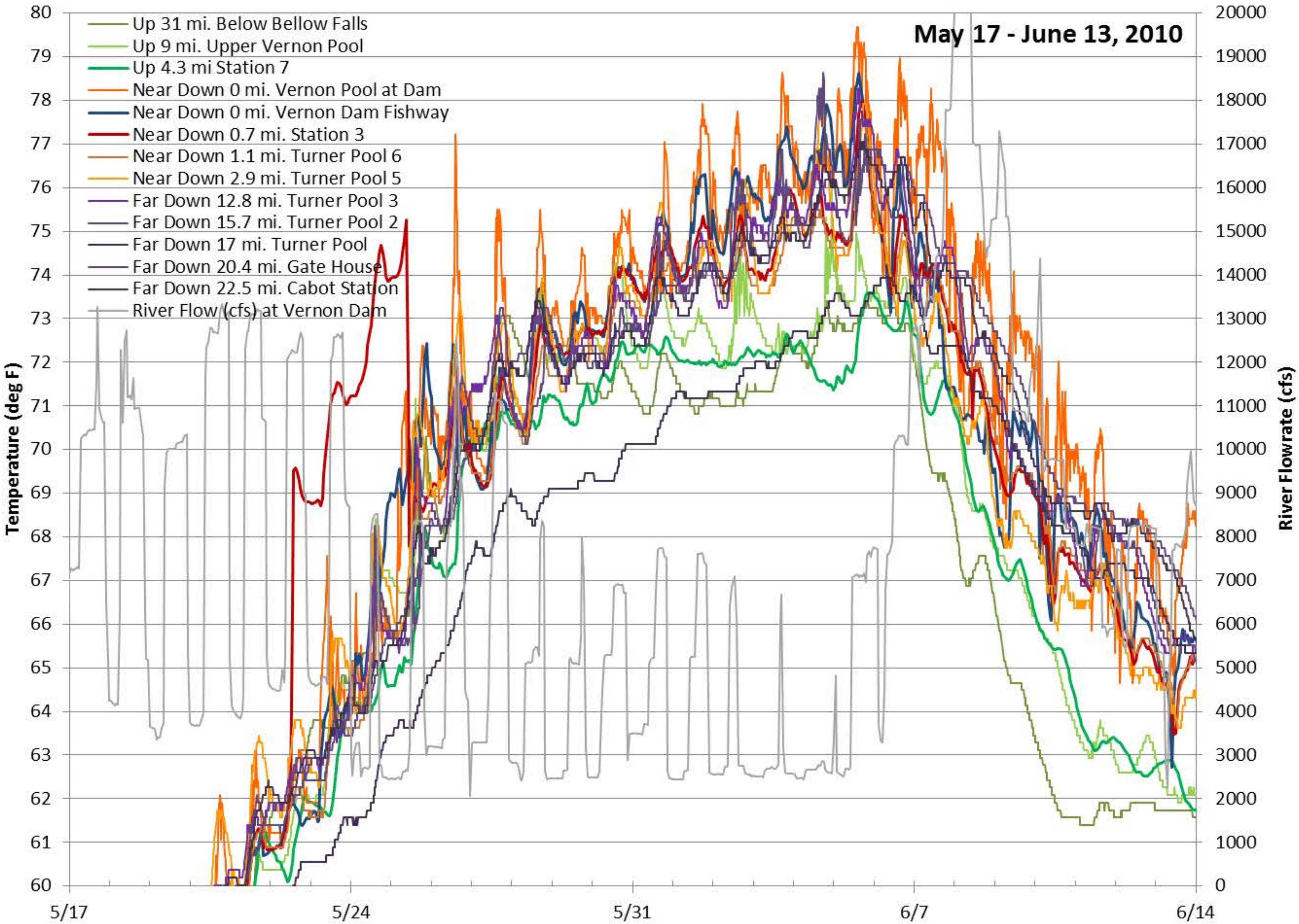

Figure 23. Time series of water temperature and river flowrate near the Vermont Yankee Station on the Connecticut River, including USFWS data, May 17 – June 13, 2010 (4 weeks).

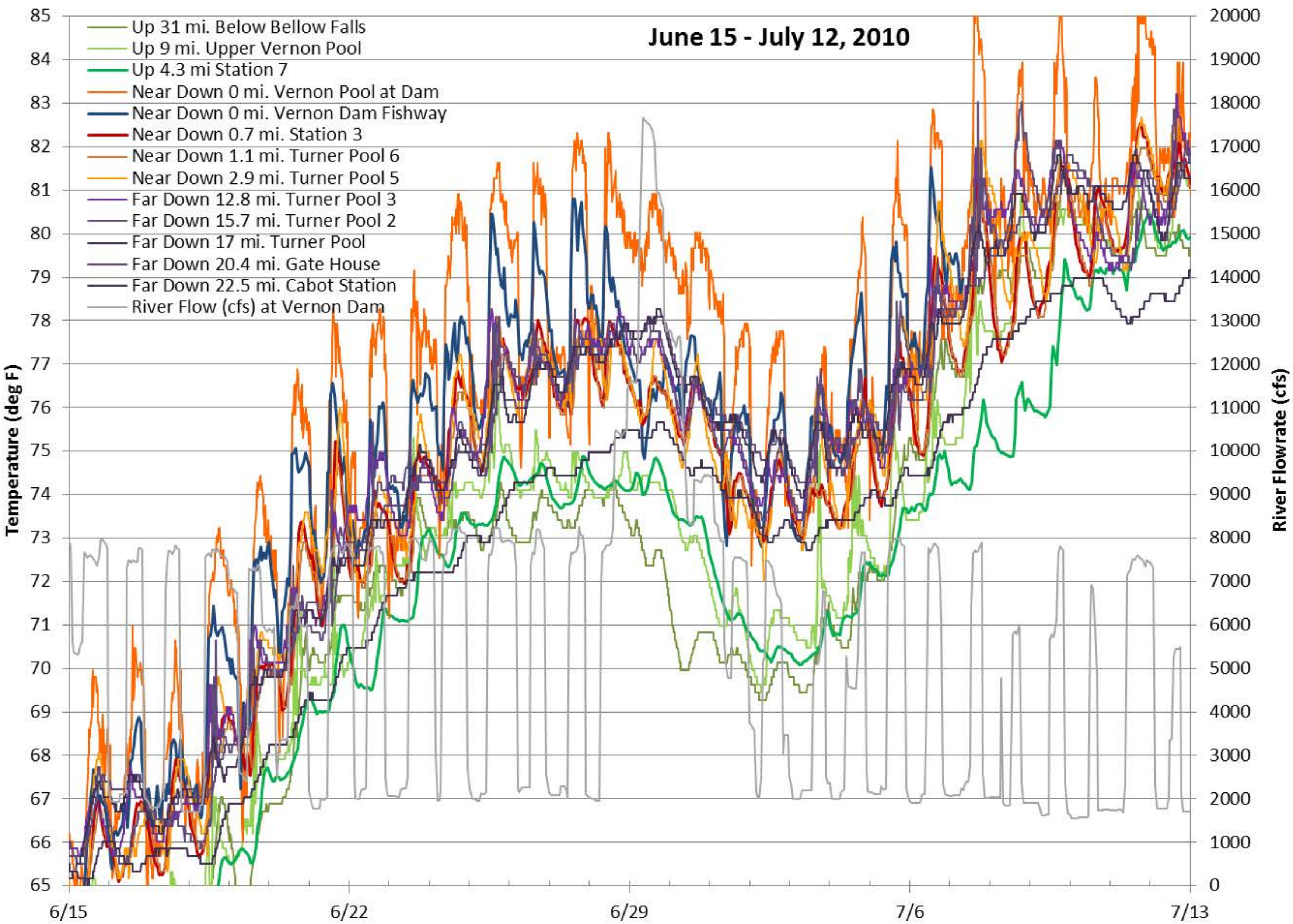

Figure 24. Time series of water temperature and river flowrate near the Vermont Yankee Station on the Connecticut River, including USFWS data, June 15 – July 12, 2010 (4 weeks).

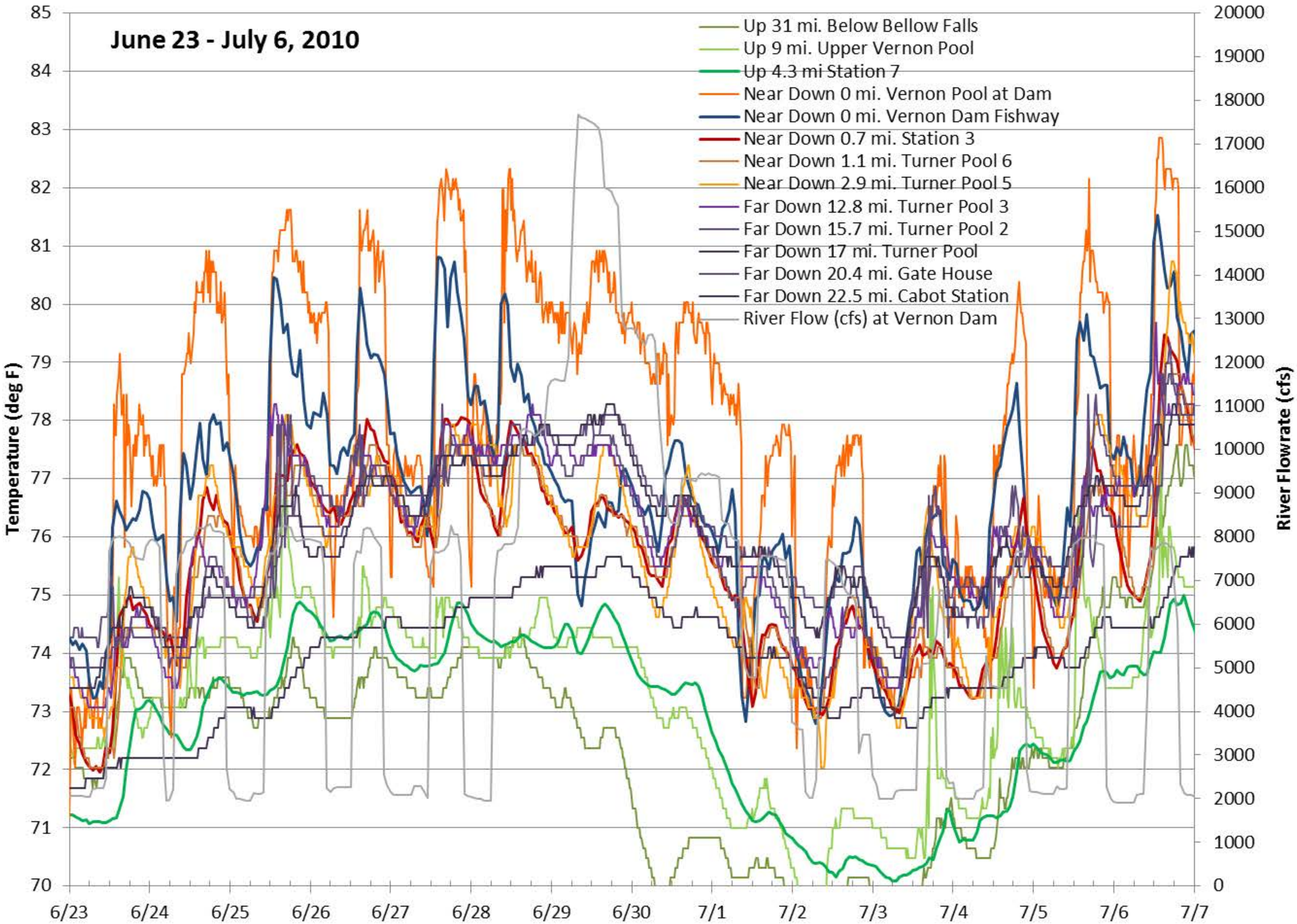

Figure 25. Time series of water temperature and river flowrate near the Vermont Yankee Station on the Connecticut River, including USFWS data, June 23 – July 6, 2010 (2 weeks).

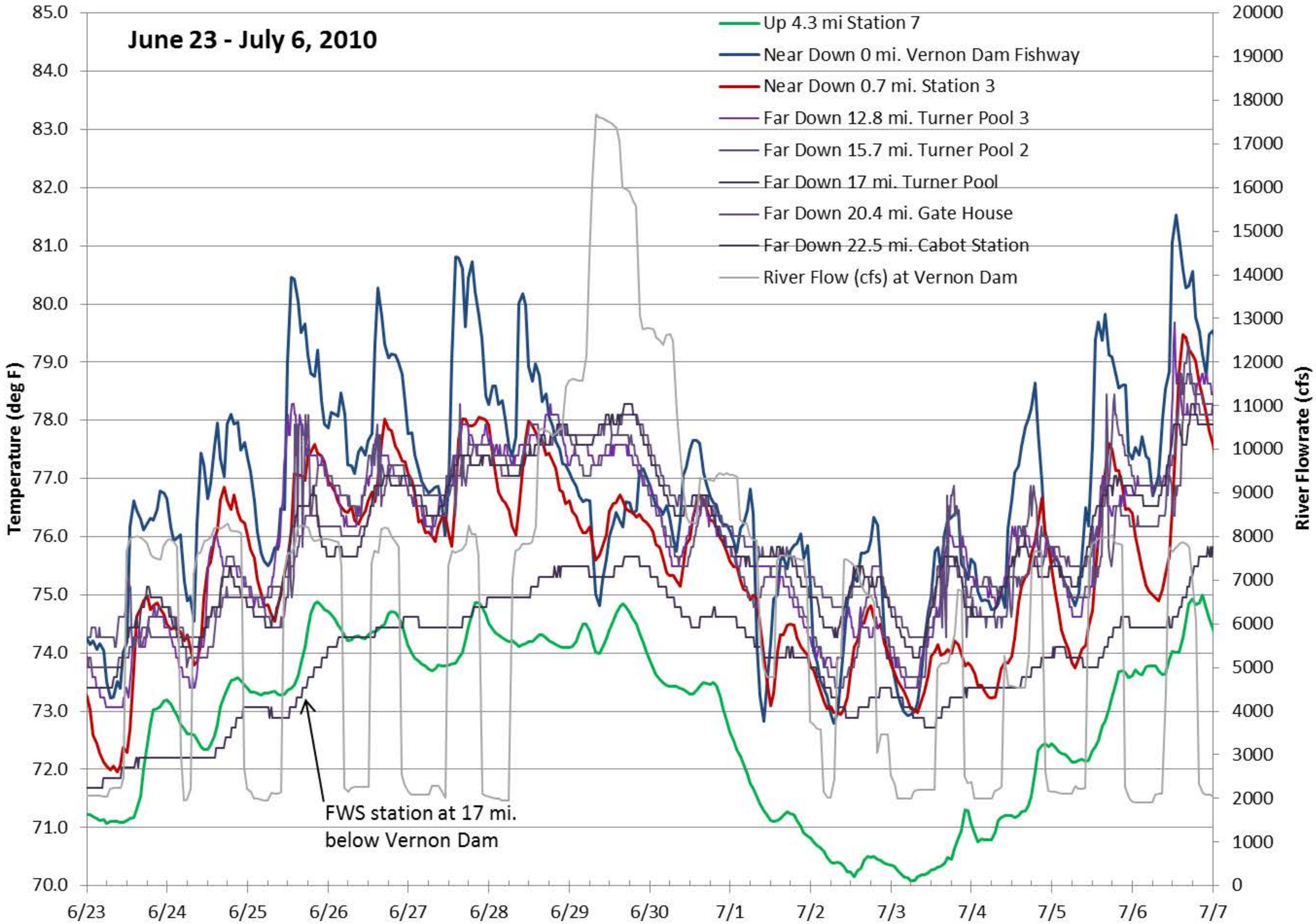

Figure 26. Time series of water temperature and river flowrate near the Vermont Yankee Station on the Connecticut River, featuring downstream USFWS data, June 23 – July 6, 2010 (2 weeks).

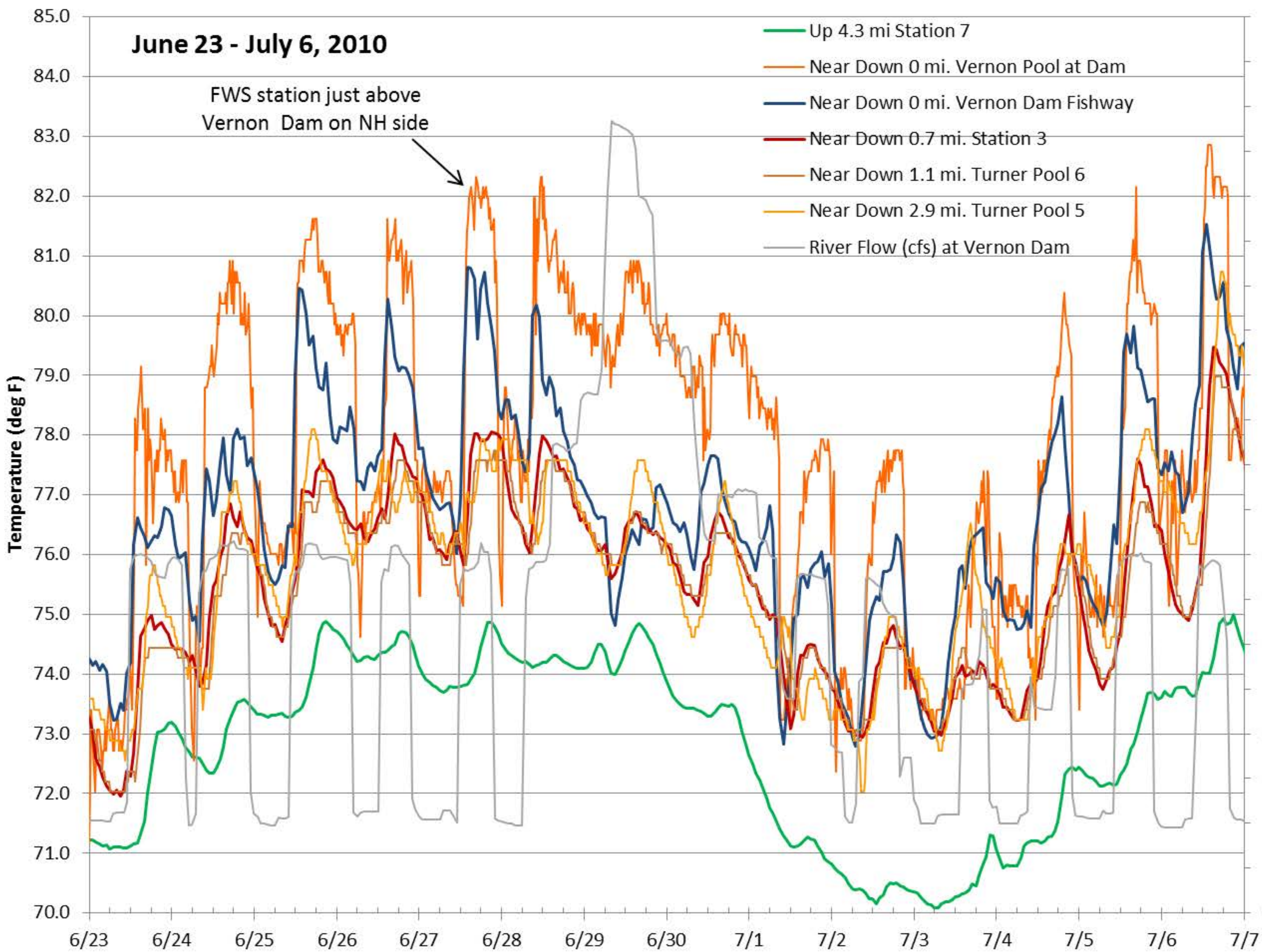

Figure 27. Time series of water temperature and river flowrate near the Vermont Yankee Station on the Connecticut River, featuring near Vernon Dam USFWS data, June 23 – July 6, 2010 (2 weeks).

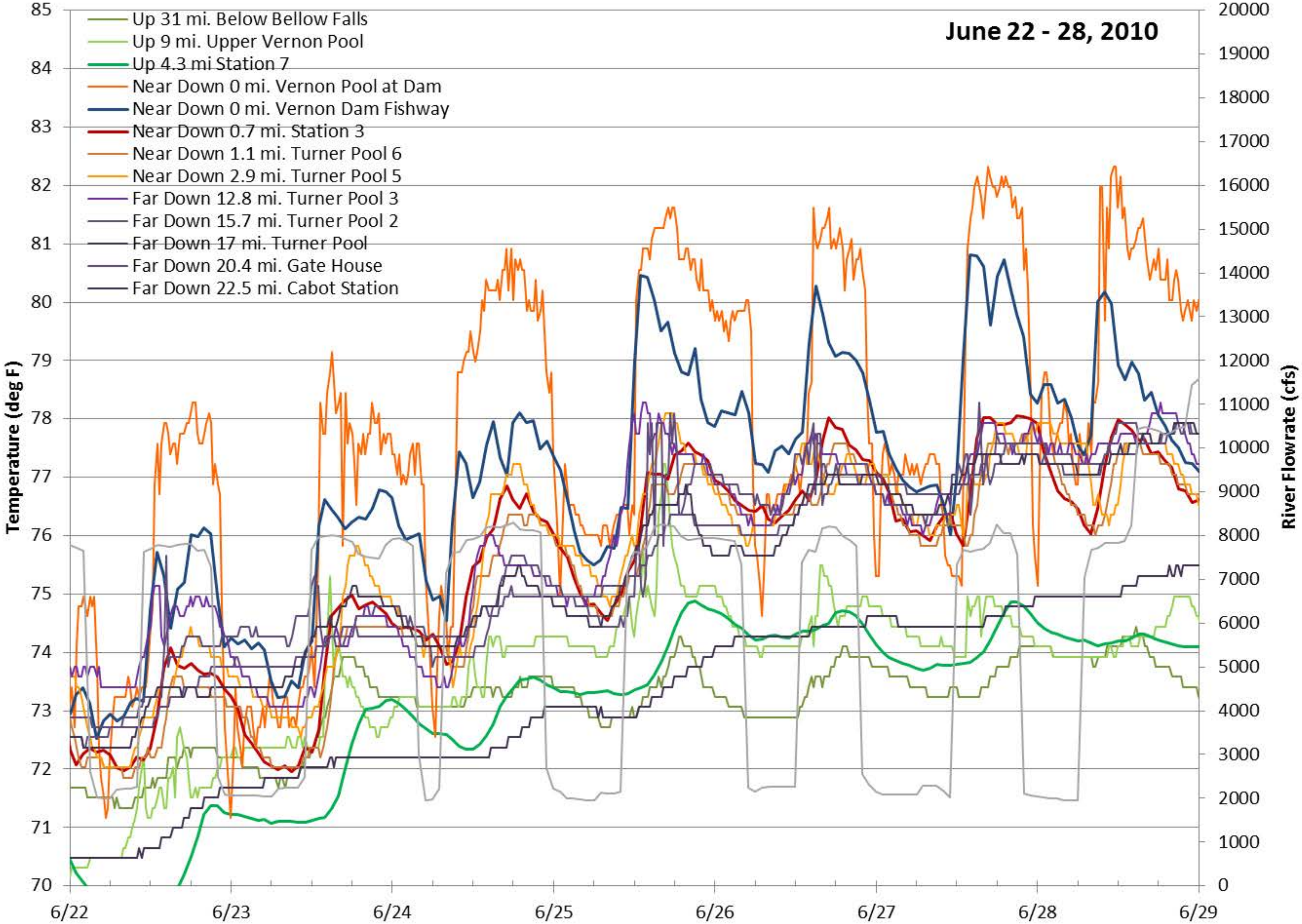

Figure 28. Time series of water temperature and river flowrate near the Vermont Yankee Station on the Connecticut River, including USFWS data, June 22 – June 28, 2010 (1 week).

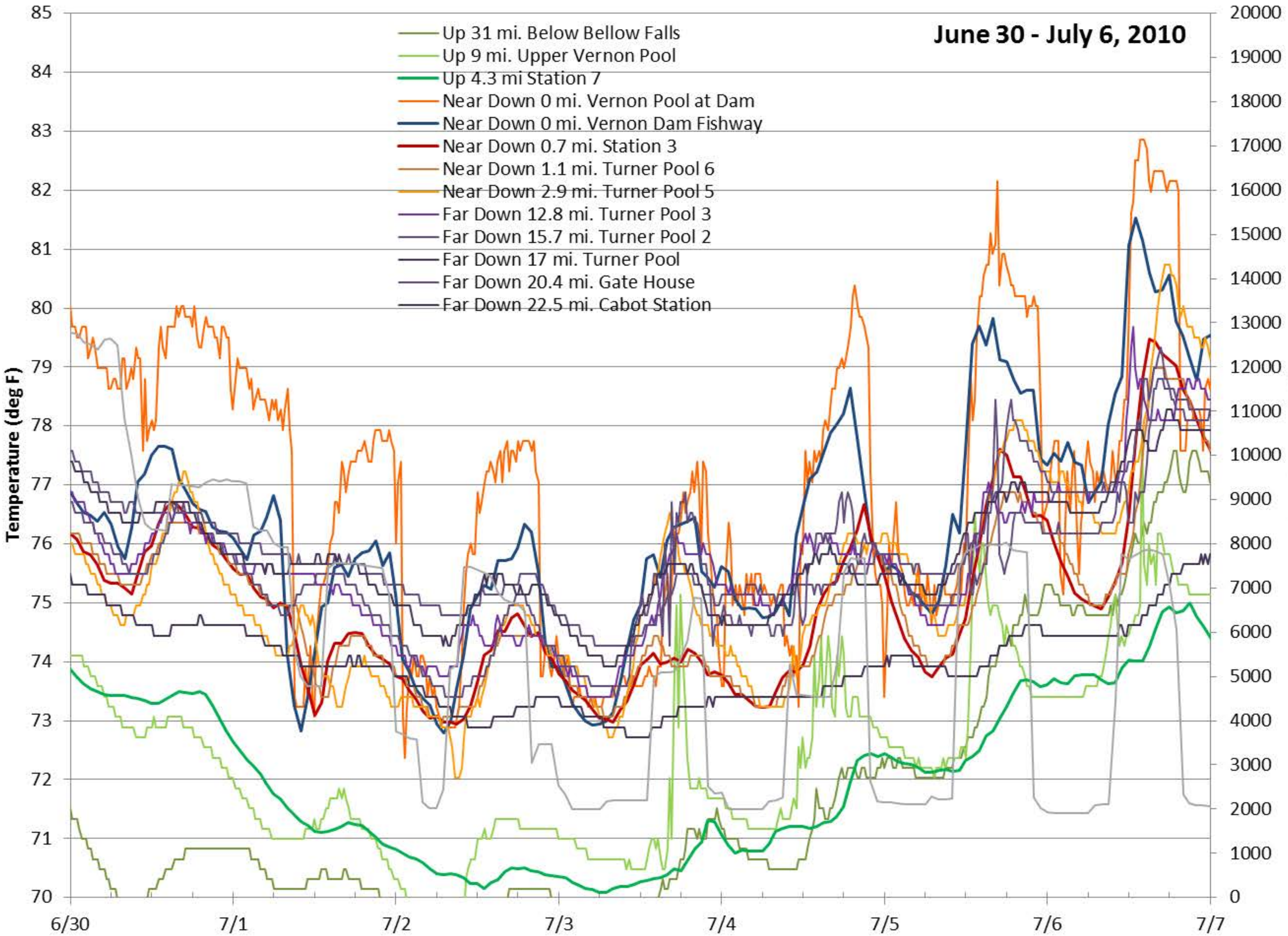

Figure 29. Time series of water temperature and river flowrate near the Vermont Yankee Station on the Connecticut River, including USFWS data, June 30 – July 6, 2010 (1 week).