APPENDIX C

WATER TEMPERATURE IN THE PROJECT BYPASS REACH STUDY REPORT

Loup River Hydroelectric Project
FERC Project No. 1256

Water Temperature in the Project Bypass Reach

Loup Power District
Hydro Project

February 11, 2011

Study 4.0 - Water Temperature in the Project Bypass Reach

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Loup River Hydroelectric Project
FERC Project No. 1256

Study 4.0
Water Temperature in the Project Bypass Reach

February 11, 2011

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STUDY 4.0 WATER TEMPERATURE IN THE PROJECT BYPASS REACH

1. INTRODUCTION

The Loup River Hydroelectric Project (Project) is located in Nance and Platte counties, Nebraska, where water is diverted from the Loup River and routed through the 35-mile-long Loup Power Canal, which empties into the Platte River near Columbus. The Project includes various hydraulic structures, two powerhouses, and two regulating reservoirs. The portion of the Loup River from the Diversion Weir to the confluence with the Platte River is referred to as the Loup River bypass reach. The portion of the Platte River from the Loup River confluence to the Tailrace Return is referred to as the Platte River bypass reach. Together, the Loup and Platte river bypass reaches constitute the Project bypass reach.

The Nebraska Department of Environmental Quality (NDEQ) has established water quality standards to support aquatic life; the temperature standard for warm water is a maximum limit of 90 degrees Fahrenheit (˚F) (NDEQ, March 22, 2009). For purposes of this study, this standard is considered to be the threshold for possible fish mortality due to thermal stress. Water temperatures that exceed this standard are known as "excursions."

According to NDEQ, there have been three documented fish kills in the Loup River bypass reach between the Diversion Weir at River Mile (RM) 34.2 and the confluence with Beaver Creek at RM 25.0: one in July 1995, one in July 1999, and one in July 2004 (NDEQ, 2007). NDEQ cites low flows and thermal stress as suspected causes.

Water temperature in the Loup River bypass reach was identified as a potential Project issue because it is suspected to have been a factor in the three documented fish kills. NGPC has identified the portion of the Loup River bypass reach from the Diversion Weir to the confluence with Beaver Creek as the "main affected area for fish kills" (NGPC, February 6, 2009). In addition, water temperature in the Platte River bypass reach was evaluated.

As stated in the Introduction of the District's Initial Study Report, dated August 26, 2010, precipitation for the first eight months of 2010 was above average for most of Nebraska, including all areas within the Project Boundary. This amount of precipitation resulted in flow conditions in the Loup River, including the Loup River bypass reach, being above average. Specifically, the period of record (1944 to 2009) mean August discharge for the Loup River near Genoa is 255 cfs. Provisional USGS data for August 2010 indicates the mean discharge as 643 cfs.

2. GOALS AND OBJECTIVES OF STUDY

The goal of the study of water temperature in the Project bypass reach is to determine if Project operations (flow diversion to the Loup Power Canal) materially affect water temperature in the Loup River bypass reach (with particular emphasis between the

Diversion Weir and the confluence of Beaver Creek with the Loup River) or in the Platte River bypass reach.

The objectives of the study of water temperature in the Project bypass reach are as follows:

1. To estimate the relationship between flow in the Project bypass reach, ambient air temperature, water temperature, relative humidity, and solar radiation.
2. To describe and quantify the relationship, if any, between diversion of water into the Loup Power Canal and water temperature in the Project bypass reach.

In addition, the following two objectives were developed during performance of the study to focus the effort and reach meaningful conclusions:

3. To determine if a "critical reach" relative to water temperature excursions exists within the Project bypass reach.
4. To determine if an accurate and reasonable method exists for predicting water temperature excursion events.

3. STUDY AREA

The study area includes a portion of the Loup River upstream of the Diversion Weir, the entire Project bypass reach, and a small reach of the Platte River just upstream of the Loup River confluence.

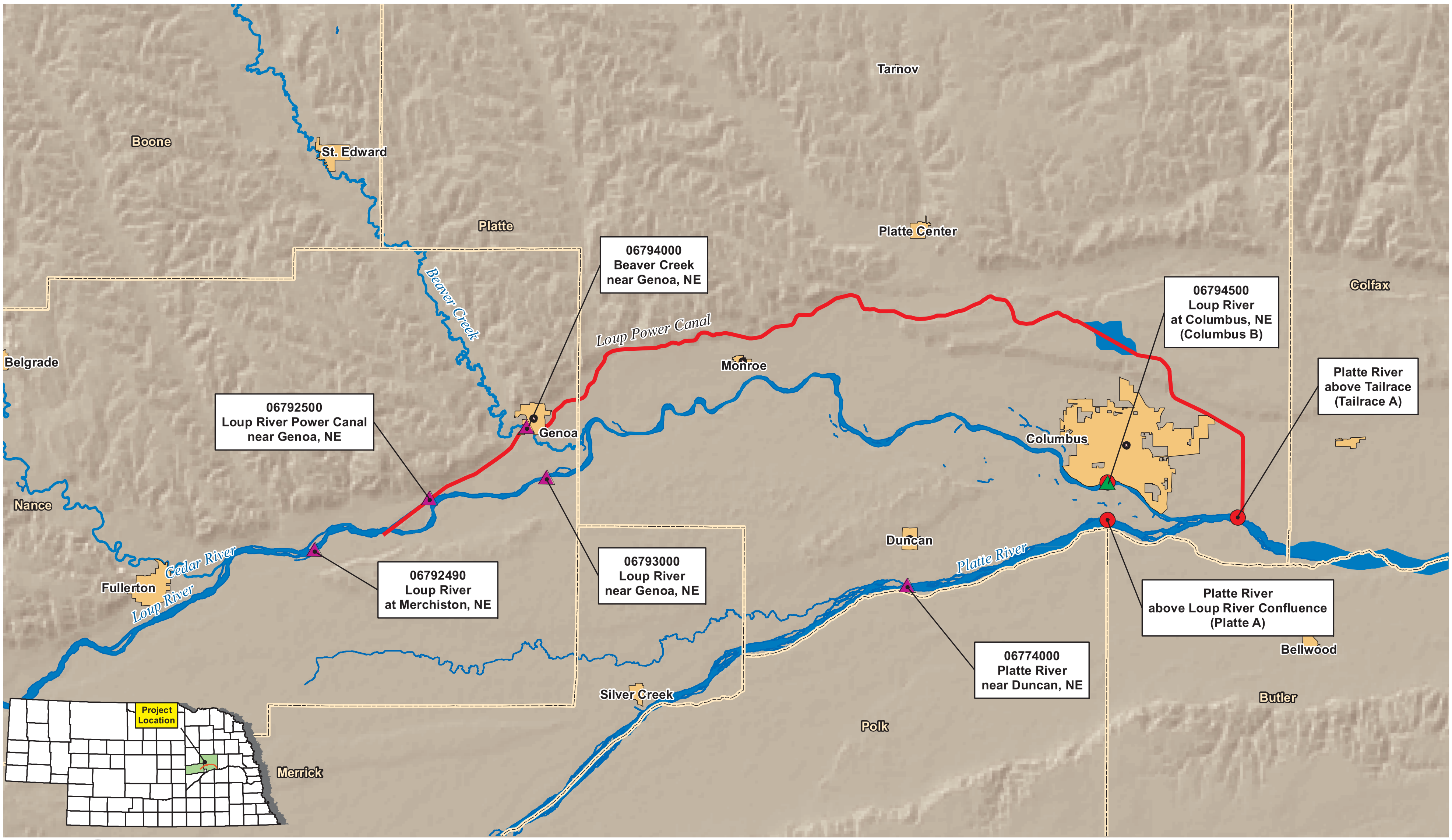
There are five study sites within the study area where data were collected:

- U.S. Geological Survey (USGS) Gage 06792490, Loup River at Merchiston, NE (upstream of the Diversion Weir)
- USGS Gage 06793000, Loup River near Genoa, NE
- NDNR Gage 06794500, Loup River at Columbus, NE
- Platte River bypass reach (just upstream of the Tailrace Return)
- Platte River upstream of the Loup River confluence

In addition, there are three locations where supplemental data were collected:

- USGS Gage 06792500, Loup River Power Canal near Genoa, NE
- USGS Gage 06794000, Beaver Creek near Genoa, NE
- USGS Gage 06774000, Platte River near Duncan, NE

The study area, including both the study sites and additional locations for data collection, is shown in Figure 3-1.



Source: Stream Gage, Nebraska Department of Natural Resources; Streams/Waterbodies, 2000 Tiger Files

Loup River Temperature Study

Loup River Hydroelectric Project
FERC Project No. 1256
Study 4.0 Water Temperature in the Bypass Reach

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DATE
Feb. 11, 2011

FIGURE
3-1

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4. METHODOLOGY

The methodology for the study of water temperature in the Project bypass reach includes three tasks, described below.

Task 1 USGS Coordination

The District coordinated with USGS regarding installation of water temperature sensors at two locations: 1) Loup River upstream of the Diversion Weir (USGS Gage 06792490, Loup River at Merchiston, NE), and 2) USGS Gage 06793000, Loup River near Genoa, NE. Data logged by both sensors are available online at the following addresses:

- Loup River at Merchiston – http://waterdata.usgs.gov/nwis/uv/?site_no=06792490
- Loup River near Genoa – http://waterdata.usgs.gov/nwis/uv?cb_00060=on&cb_00045=on&cb_00065=on&cb_00010=on&format=gif_default&period=60&site_no=06793000

Task 2 Data Collection

The data collected for this water temperature study included flow discharge values, water temperature, and weather data, as described below and as shown in Table 4-1, which follows.

Flow Discharge

Hourly flow discharge was collected at the following four USGS gaging stations from May through August 2010:

- Loup River Power Canal near Genoa
- Loup River near Genoa
- Beaver Creek near Genoa
- Platte River near Duncan

Additionally, hourly discharge values were estimated for the following three locations by combining data as indicated:

- Loup River at Merchiston = Loup River near Genoa + Loup River Power Canal near Genoa
- Loup River at Columbus = Loup River near Genoa + Beaver Creek near Genoa
- Platte River bypass reach = Loup River at Columbus + Platte River near Duncan

Water Temperature

Water temperature data collection began at the USGS sensors at the Loup River at Merchiston on May 3, 2010, and at the Loup River near Genoa on May 5, 2010. At the Loup River at Merchiston, there is a slight data gap from June 28 to 30, 2010, that is unexplained but is likely due to the probe being exposed to the atmosphere. At the Loup River near Genoa, the temperature sensor was washed away by high flows on June 10, 2010. A replacement sensor was installed on July 19, 2010. Consequently, a data gap exists from June 10 to July 18, 2010.

The District installed paired temperature data loggers[1] at the Loup River at Merchiston and at the Loup River near Genoa to check the variability of District-installed temperature data loggers against USGS sensors. Data were logged via the instrumentation from June 2 to 9, 2010, and compared to USGS data outputs to verify instrument accuracy and sampling method compatibility.

The District then installed paired temperature data loggers and collected temperature data from August 13 to 22, 2010, at the following sites:

- Loup River at Columbus, coincident with NDNR Gage 06794500, Loup River at Columbus, NE[2] (Columbus A and B)
- Platte River upstream of the Loup River confluence (Platte A and B)
- Platte River bypass reach (Tailrace A and B)

Weather Data

Hourly weather data (air and soil temperature, relative humidity, and solar radiation) were collected from May 2 to August 30, 2010, at the High Plains Regional Climate Center's (HPRCC's) Station A255649, located within the study area near Monroe, Nebraska. Solar radiation was measured as radiative flux (Kcal/m^2).

[1] The paired data loggers are two data loggers placed at the same location for redundancy.
[2] NDNR reinstated this gage in 2008 at the same location as former USGS Gage 06794500, Loup River at Columbus, NE.

Table 4-1. Data Collection

Location	Collection Device	Parameter	2010 Collection Dates
Loup River at Merchiston	USGS Sensor at Gage 06792490	Water Temperature	May 3 – June 27 July 1 – August 23
Loup River Power Canal near Genoa	USGS Gage 06792500	Flow Discharge	May 2 – August 30
Loup River near Genoa	USGS Sensor at Gage 06793000	Water Temperature	May 5 – June 9 July 19 – August 30
	USGS Gage 06793000	Flow Discharge	May 5 – August 30
Beaver Creek near Genoa	USGS Gage 06794000	Flow Discharge	May 2 – August 30
Loup River at Columbus	District Data Loggers	Water Temperature (2 probes)	August 13 – August 22
	USGS Sensor at Gage 06794500	Water Temperature	May 2 – August 30
Platte River bypass reach	District Data Loggers	Water Temperature (2 probes)	August 13 – August 22
Platte River upstream of Loup River confluence	District Data Loggers	Water Temperature (2 probes)	August 13 – August 22
Platte River near Duncan	USGS Gage 06774000	Flow Discharge	May 2 – August 30
Monroe	HPRCC Station A255649	Weather Data	May 2 – August 30

Task 3 Data Analysis

In accordance with the District's Revised Study Plan dated July 27, 2009, multiple plots were evaluated to identify general patterns and distinguish trends, as follows:

- The District used linear regression analysis of flow and water temperature data upstream of the Diversion Weir to determine if a relationship between these data exists. Flow in the Loup River at Merchiston was plotted against the temperature of the water in the Loup River at Merchiston for the period of record. The flow in the Loup River at Merchiston was estimated based on the USGS gages on the Loup River near Genoa and Loup River Power Canal near Genoa. Regressions were calculated on hourly data grouped by week and month. A select number of daily plots (days on which the NDEQ-prescribed 90˚F water quality standard was exceeded) were also created, and these regressions were plotted as well.

- The District used linear regression analysis of ambient air temperature and water temperature data upstream of the Diversion Weir to determine if a relationship between these data exists. Ambient air temperature was plotted against the temperature of the water in the Loup River at Merchiston for the period of record. Regressions were calculated on hourly data grouped by week and month. A select number of daily plots (days on which the NDEQ-prescribed 90˚F water quality standard was exceeded) were also created, and these regressions were plotted as well.
- The District used linear regression analysis of soil temperature and water temperature data upstream of the Diversion Weir to determine if a relationship between these data exists. Soil temperature was plotted against the temperature of the water in the Loup River at Merchiston for the period of record. .
- The District used linear regression analysis of flow and water temperature in the Loup River bypass reach to determine if a relationship between these data exists. Flow in the Loup River near Genoa was plotted against water temperature in the Loup River near Genoa for the period of record. Regressions were calculated on hourly data grouped by week and month. A select number of daily plots (days on which the NDEQ-prescribed 90˚F water quality standard was exceeded) were also created, and these regressions were plotted as well.
- The District used linear regression analysis of air temperature and water temperature in the Loup River bypass reach to determine if a relationship between these data exists. Ambient air temperature was plotted against the temperature of the water in the Loup River near Genoa for the period of record. Regressions were calculated on hourly data grouped by week and month. A select number of daily plots (days on which the NDEQ-prescribed 90˚F water quality standard was exceeded) were also created, and these regressions were plotted as well.
- The District used linear regression analysis of soil temperature and water temperature in the Loup River bypass reach to determine if a relationship between these data exists. Soil temperature was plotted against the temperature of the water in the Loup River near Genoa for the period of record.
- The District used linear regression analysis of water temperature in the Loup River bypass reach and relative humidity measured at Monroe to determine if a relationship between these data exists. Water temperature in the Loup River near Genoa was plotted against relative humidity for the period of record. Regressions were calculated on hourly data grouped by week and month.

- The District used linear regression analysis of water temperature in the Loup River bypass reach and radiative flux measured at Monroe to determine if a relationship between these data exists. Water temperature in the Loup River near Genoa was plotted against radiative flux for the period of record. Regressions were calculated on hourly data grouped by week and month.
- The District used linear regression analysis of water temperature upstream of the Diversion Weir and water temperature in the Loup River bypass reach to determine if a relationship between these data exists. Water temperature in the Loup River at Merchiston was plotted against water temperature in the Loup River near Genoa for the period of record. Regressions were calculated on hourly data grouped by week and month.
- Data collected from both the USGS temperature sensor and the District data loggers in the Loup River at Columbus were compared to the temperature measured in Loup River near Genoa to confirm that the reach above Beaver Creek is the critical reach of the Loup River bypass reach with respect to high temperature (that is, that no significant increases in water temperature occur downstream of Beaver Creek). If the temperature of the water at Columbus is nearly the same or cooler than the temperature near Genoa, then it can be determined that the reach above Beaver Creek is the critical reach with respect to high water temperature. However, if the temperature of the water at Columbus is much higher than the temperature of the water near Genoa, then additional temperature monitoring will be conducted at Columbus for use in developing relationships between flow, water temperature, and ambient conditions at Columbus. It should be noted that temperature monitoring beyond the scope of the District's Revised Study Plan was conducted by USGS in 2010. Specific dates of USGS water temperature data collected at both the Loup River near Genoa and the Loup River at Columbus are provided in Table 4-1.
- Data collected from District data loggers in the Platte River bypass reach and in the Platte River upstream of the Loup River confluence were compared to the temperature measured in the Loup River near Genoa to confirm that the reach above Beaver Creek is the critical reach of the Loup River bypass reach with respect to high temperature (that is, that no significant increases in water temperature occur downstream of Beaver Creek).
- Multiple regression analysis was completed for flow in the Loup River bypass reach, ambient air temperature, water temperature upstream of the Diversion Weir, soil temperature, relative humidity, and radiative flux as variables versus water temperature in the Loup River bypass reach.

Single and multiple regression analyses were performed on each plot, and each corresponding coefficient of determination (R^2) was reviewed to determine if significant relationships exist between water temperature and other analyzed parameters. The results of the analysis are presented in Table 5-3. The R^2 value represents the strength of the linear association between water temperature and other analyzed parameters and describes the proportion of the total variation in water temperature that is explained by linear regression of that parameter. R^2 values range from 0 to 1, with a higher number indicating a greater correlation. For example, an R^2 value equal to 0.10 indicates that 10 percent of the total variation in water temperature can be explained by a given parameter.

When statistical significance is mentioned in this study report, it pertains to an alpha = 0.05. The alpha is the significance level typically used in statistics, representing the probability (based on a null hypothesis) that a statistical test will generate a Type 1 Error (that is, the error of rejecting the null hypothesis when it is actually true). If alpha = 0.05, then only results of a statistical test that are less than 0.05 (that is, 5 percent likely or less, given that the null hypothesis is true) are deemed significant.

A statistical test involves a test statistic. For linear regression, the analysis of variance (ANOVA) test is a robust way to generate a test statistic (F-value). The result of such a statistical test is called the p-value, which is simply the alpha value calculated from a statistical test. For alpha = 0.05, if the p-value is greater than 0.05, one can state that the result of the linear regression is not statistically significant at the 0.05 level. For alpha = 0.05, if the p-value is less than 0.05, one can state that the result of the linear regression is statistically significant at the 0.05 level.

Single variable linear regression was performed using either MS Excel or PAW Statistics 18 (SPSS) software. All other statistical analyses were performed using PAW Statistics 18 (SPSS) software alone. Tabular and graphical presentation was performed using MS Excel.

Lastly, the District attempted to determine a predictive relationship, which could be used to determine when water temperature excursions might occur, based on the condition(s) of other measurable parameter(s).

The results of the performed analyses are provided in Section 5.

5. RESULTS AND DISCUSSION

The results of the study-related analyses performed at multiple locations along the Loup and Platte rivers are presented below as follows:

- Descriptive statistics
- Water temperature analysis for the Loup River at Merchiston
- Water temperature analysis for the Loup River near Genoa
- Water temperature comparison of the Loup River at Merchiston and near Genoa
- Water temperature analysis for other river reaches potentially affected by Project operations (that is, the Loup River at Columbus and the Platte River bypass reach)
- Potential prediction of excursion events on the Loup River near Genoa

5.1 Descriptive Statistics

Consistent with the District's Revised Study Plan (Task 2), the descriptive statistics provided in Tables 5-1 and 5-2 were collected and used to perform study analyses.

Table 5-1. Descriptive Statistics for Hourly Data

Parameter	Flow[1] (cfs)					Water Temperature[2] (°F)			Air Temp (°F)	Soil Temp (°F)	Relative Humidity (%)	Radiative Flux (Kcal/m²)
Location	Merchiston	Loup Power Canal	Genoa	Beaver Creek	Duncan	Merchiston	Genoa	Columbus	Monroe	Monroe	Monroe	Monroe
Dates (2010)	5/3 to 8/23	5/2 to 8/30	5/5 to 8/30	5/2 to 8/30	5/2 to 8/30	5/3 to 8/23	5/5 to 8/30	5/2 to 8/30	5/2 to 8/30	5/2 to 8/30	5/2 to 8/30	5/2 to 8/30
Count	2,645	2,886	2,768	2,721	2,884	2,576	1,788	1,885	2,906	2,893	2,906	2,906
Data Completeness (%)	>99	>99	>99	94	>99	96	65	88	>99	>99	>99	>99
Mean	4,952	2,417	2,416	483	3,779	75.8	74.2	72.3	71.3	74.9	74.0	201
Minimum	997	604	30	84	1,300	48.0	48.2	46.0	33.6	38.7	11	0
Maximum	28,420	3,930	26,400	5,270	12,000	93.2	94.8	95.0	98.2	114.6	100	818
Standard Deviation	4,948	487	4,686	866	2,548	9.2	10.5	8.5	11.8	12.4	19	251

Notes:

1. Flows at Merchiston were summed by adding tributary station values (see Section 4, Task 2). Flows at all other locations were obtained from USGS data.
2. Water temperatures were obtained from USGS data.

Table 5-2. Descriptive Statistics for Hourly Data for August 13-22, 2010, Special Study

Parameter[1]	Flow[2] (cfs)			Water Temperature[3] (°F)					
Location	Columbus	Duncan	Tailrace[4]	Columbus A	Columbus B	Platte A	Platte B	Tailrace[4] A	Tailrace[4] B
Count	222	222	222	210	211	217	218	190	190
Mean	675	2,258	2,933	78.4	78.5	80.2	80.1	80.1	79.9
Minimum	217	1,390	1,611	68.4	68.5	70.2	70.3	70.2	69.9
Maximum	1,959	3,040	4,539	90.8	90.9	92.6	92.4	92.3	92.2
Standard Deviation	519	463	882	5.5	5.5	5.3	5.3	5.2	5.2

Notes:

1 Data completeness is >99% for all parameters at all locations.

2 Flows at Columbus and Duncan were obtained from USGS data. Flows upstream of the Tailrace were summed by adding tributary station values (see Section 4, Task 2).

3 Water temperature data were collected from paired temperature data loggers on the Loup River at Columbus (Columbus A and B), the Platte River upstream of the Loup River confluence (Platte A and B), and the Platte River bypass reach (Tailrace A and B). The paired data loggers are two data loggers placed at the same location for redundancy.

4 "Tailrace" designates the probe located in the Platte River bypass reach, just upstream of the Tailrace Return.

5.2 Water Temperature Analysis for the Loup River at Merchiston

The results of multiple study-related analyses specific to the Loup River at Merchiston are provided below.

5.2.1 Water Temperature Relationship with Flow Discharge

A time-series presentation of flow and water temperature in the Loup River at Merchiston is presented in Figure 5-1. The spring runoff occurred during the month of June, followed by smaller discharge events in July. Flows were typically above 2,000 cfs for most dates. Water temperature increased in May, but decreased slightly during the peak of the June runoff. Temperatures continued to increase during July through mid-August, with temperature excursions above 90˚F on July 17, from July 30 to 31, and from August 8 to 12.

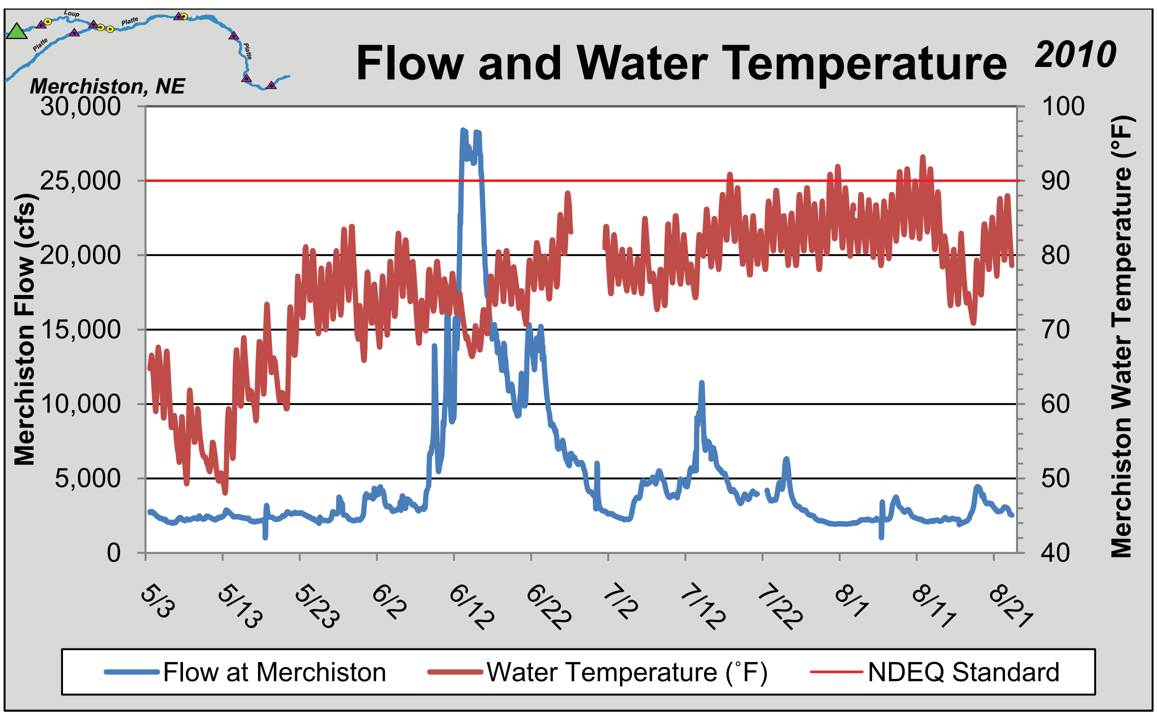


Figure 5-1. Hourly Flow and Water Temperature, Loup River at Merchiston

A direct comparison between flow and water temperature for the Loup River at Merchiston is presented in Figure 5-2. There is not a statistically significant relationship (ANOVA, alpha = 0.05) between the two variables. One explanation for the lack of a statistically significant relationship is that water temperature can vary several degrees on a given day while flow remains relatively constant. Weekly and monthly graphical comparisons are located in Attachment A; results were not typically statistically significant. Excursions above 90˚F occurred only when discharge was less than 5,000 cfs. °

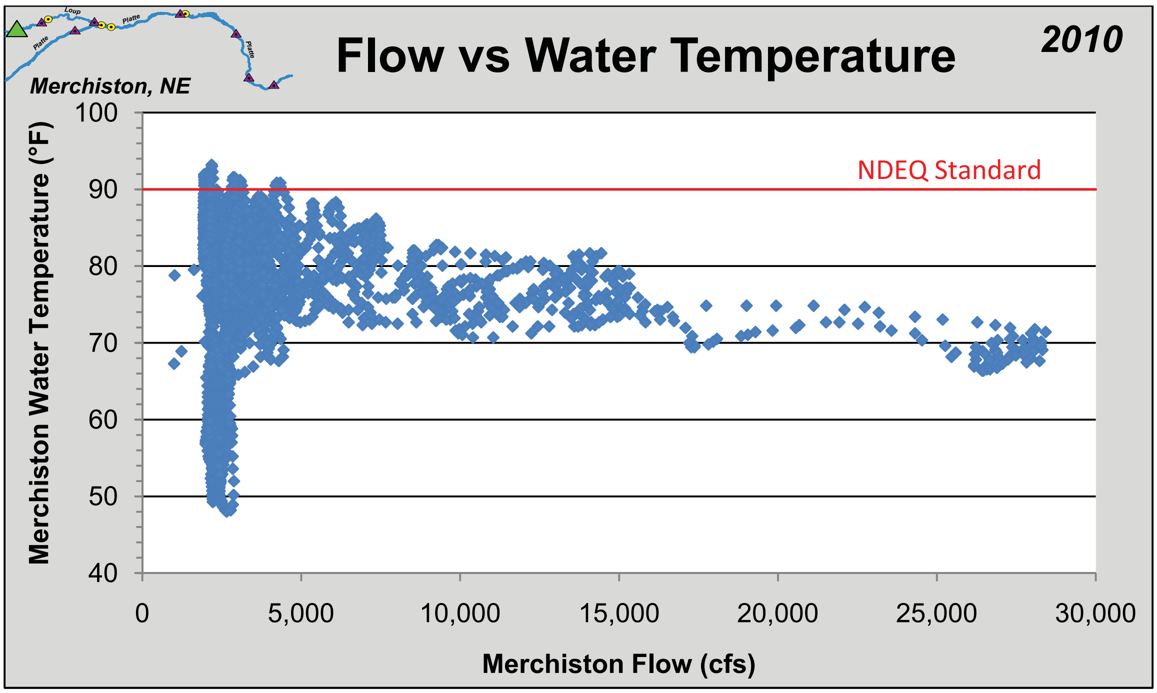
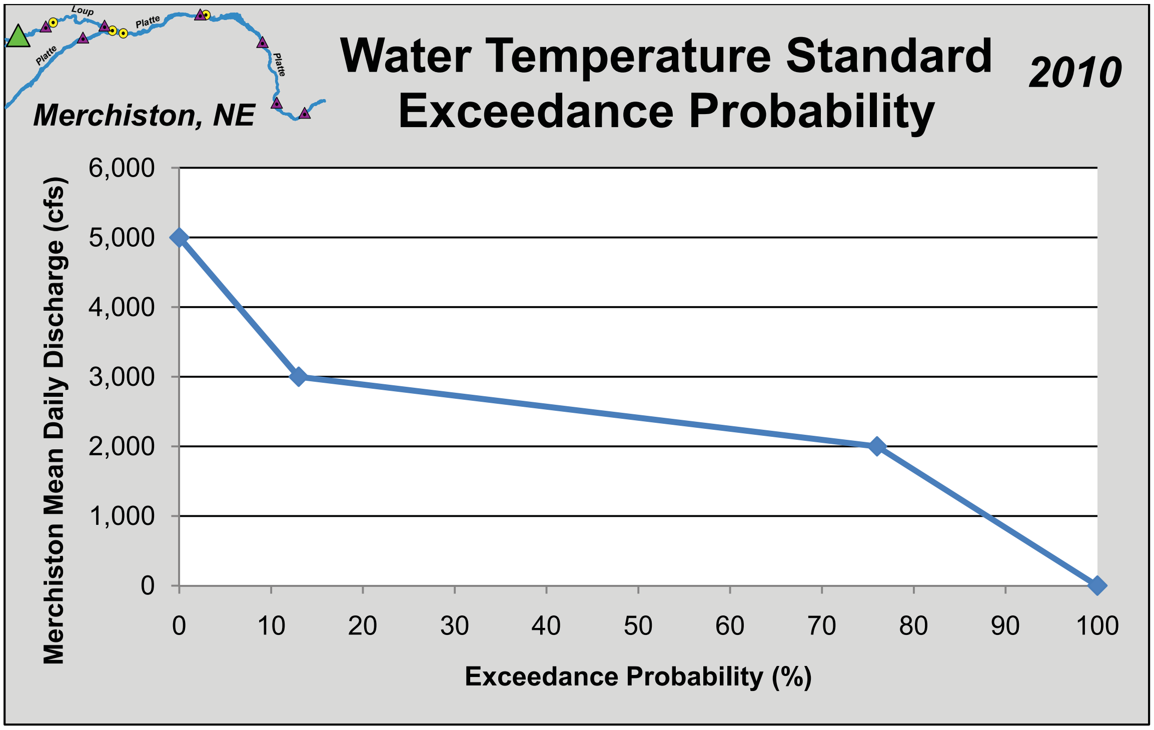


Figure 5-2. Flow-Water Temperature Relationship, Loup River at Merchiston

Despite the analysis showing no statistically significant relationship between flow and water temperature at Merchiston (as noted above), a percent probability of exceedance analysis, similar to Sinokrot and Gulliver's (2000) method, was conducted as requested by USFWS in its comment letter dated June 24, 2009. This analysis results in the probability of exceeding 90˚F based on flows and is presented in Figure 5-3. The analysis indicates that there is approximately a 45 percent probability of a temperature excursion occurring at flows less than 2,500 cfs.



Note: The lack of plotted data points is in direct correlation to the lack of measured excursions.

Figure 5-3. Exceedance Probability for Water Temperatures, Loup River at Merchiston

5.2.2 Water Temperature Relationship with Air and Soil Temperatures

Comparisons of water temperatures to air and soil temperatures are shown in Figures 5-4 and 5-5. Both comparisons indicate statistically significant relationships (ANOVA, alpha = 0.05). Water temperature excursions above 90˚F typically occurred when air temperatures were between 75˚F and 95˚F and when soil temperatures were between 85˚F and 95˚F.

Weekly and monthly plots for the air/water temperature relationship in Figure 5-4 are presented in Attachment B. At those time scales, there was more variability between the parameters and hence poorer R^2 values.

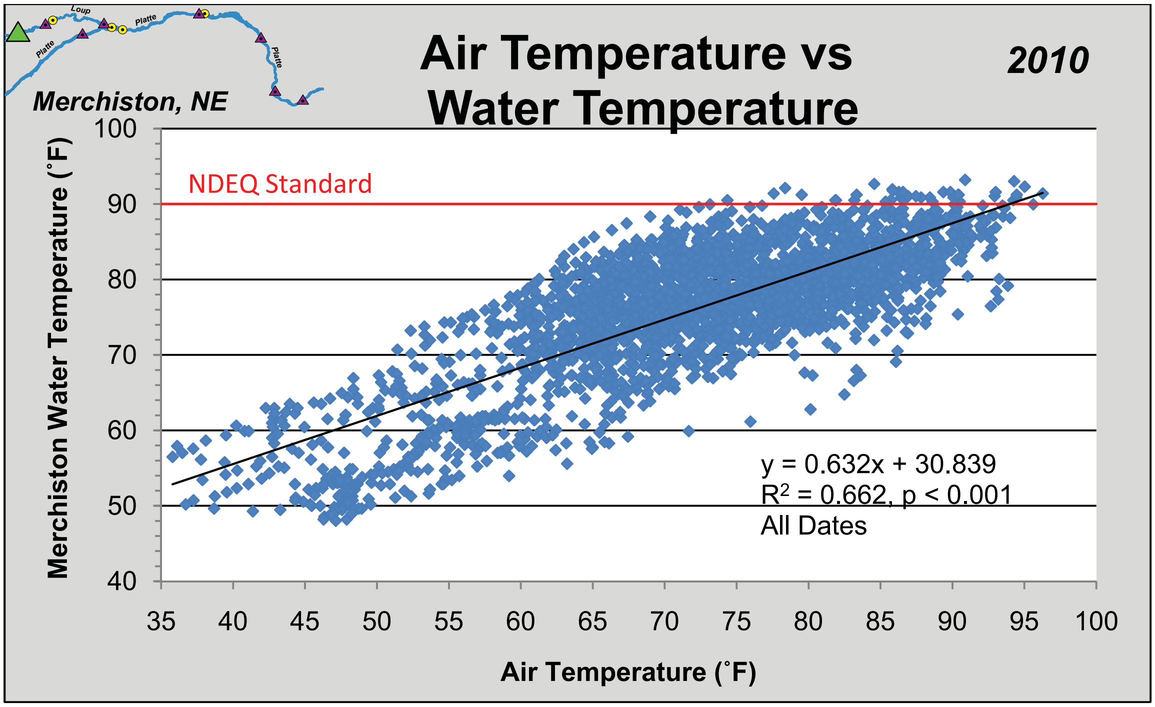


Figure 5-4. Air Temperature vs. Water Temperature, Loup River at Merchiston

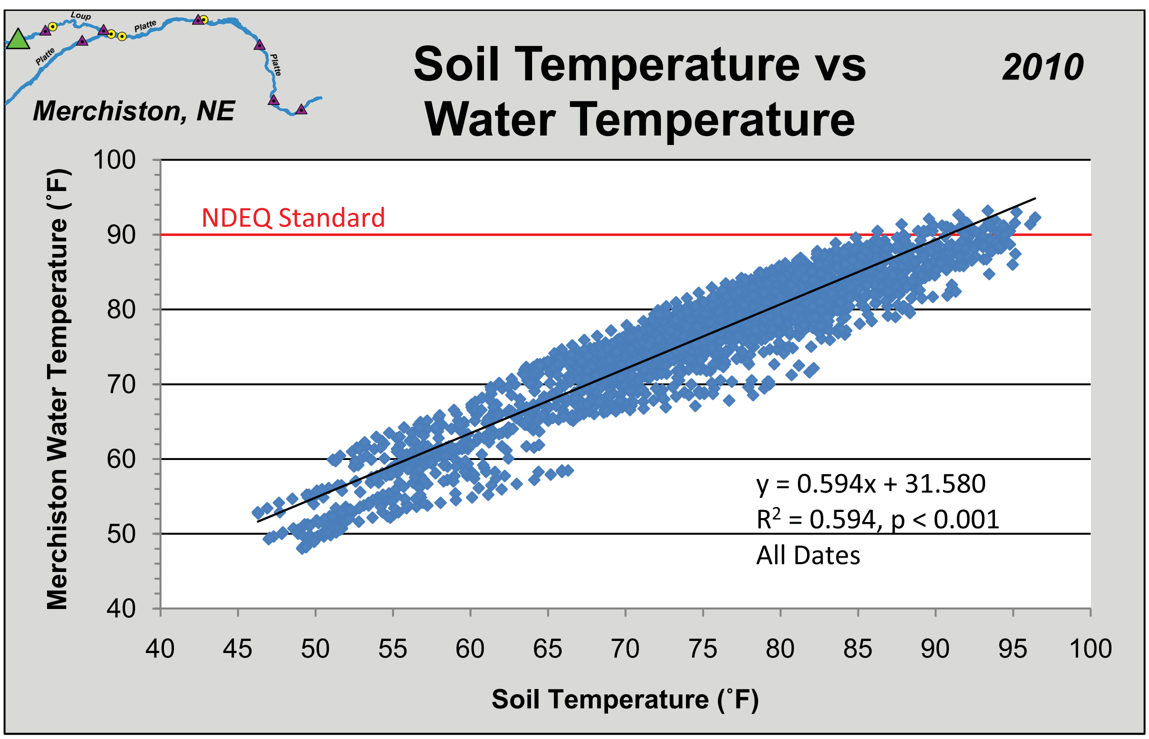


Figure 5-5. Soil Temperature vs. Water Temperature, Loup River at Merchiston

5.2.3 Summary of Water Temperature Analysis for the Loup River at Merchiston

During the 2010 study period, temperature excursions above the NDEQ-prescribed 90˚F water quality standard occurred on the Loup River at Merchiston on July 17, from July 30 to 31, and from August 8 to 12.

Relative to parameters that potentially influence the water temperature in the Loup River at Merchiston, analyses performed in association with this study determined the following, as shown in Figure 5-2 and Figures 5-4 through 5-7:

- There is not a statistically significant relationship (ANOVA, alpha = 0.05) between water temperature and flow discharge.
- There is a statistically significant relationship (ANOVA, alpha = 0.05) between water temperature and both air and soil temperatures.
- There is not a statistically significant relationship (ANOVA, alpha = 0.05) between water temperature and relative humidity.
- There is not a statistically significant relationship (ANOVA, alpha = 0.05) between water temperature and radiative flux.

5.3 Water Temperature Analysis for the Loup River near Genoa

The results of multiple study-related analyses specific to the Loup River near Genoa are provided below.

5.3.1 Water Temperature Relationship with Flow Discharge

A time-series presentation of flow and water temperature in the Loup River near Genoa is presented in Figure 5-8. The spring runoff occurred during the month of June, followed by smaller discharge events in July. Flows were typically less than 1,000 cfs during other periods recorded during the study. Water temperature increased in May, but spring flooding disabled recordings until later in July. Temperature excursions above 90˚F occurred from July 22 to 23, July 26 to 27, July 30 to August 2, and August 7 to 13.

Erratic probe behavior from July 28 through August 3 was noted, especially when night-time water temperatures were recorded as low as 64.8˚F. During this period, flows were typically less than 100 cfs, suggesting that the water temperature probe was exposed to the atmosphere. When flows increased above 100 cfs on August 4, the night-time low water temperatures increased to about 78˚F, suggesting that the probe was again immersed in water.

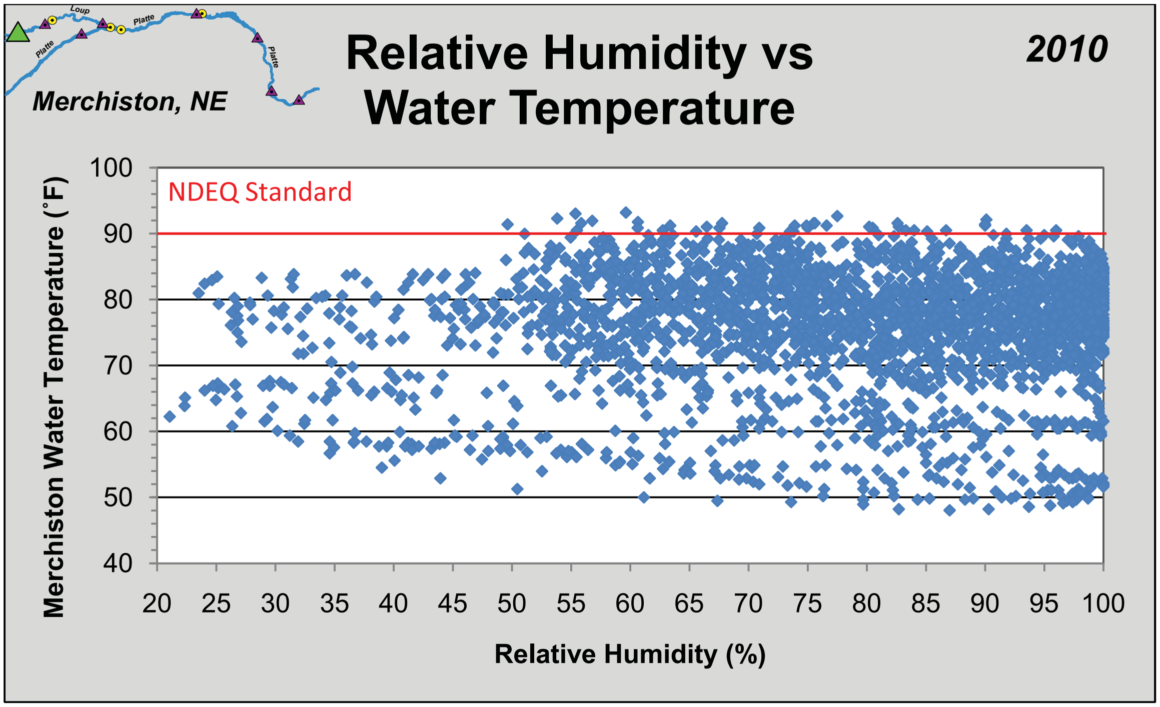


Figure 5-6. Relative Humidity vs. Water Temperature, Loup River at Merchiston

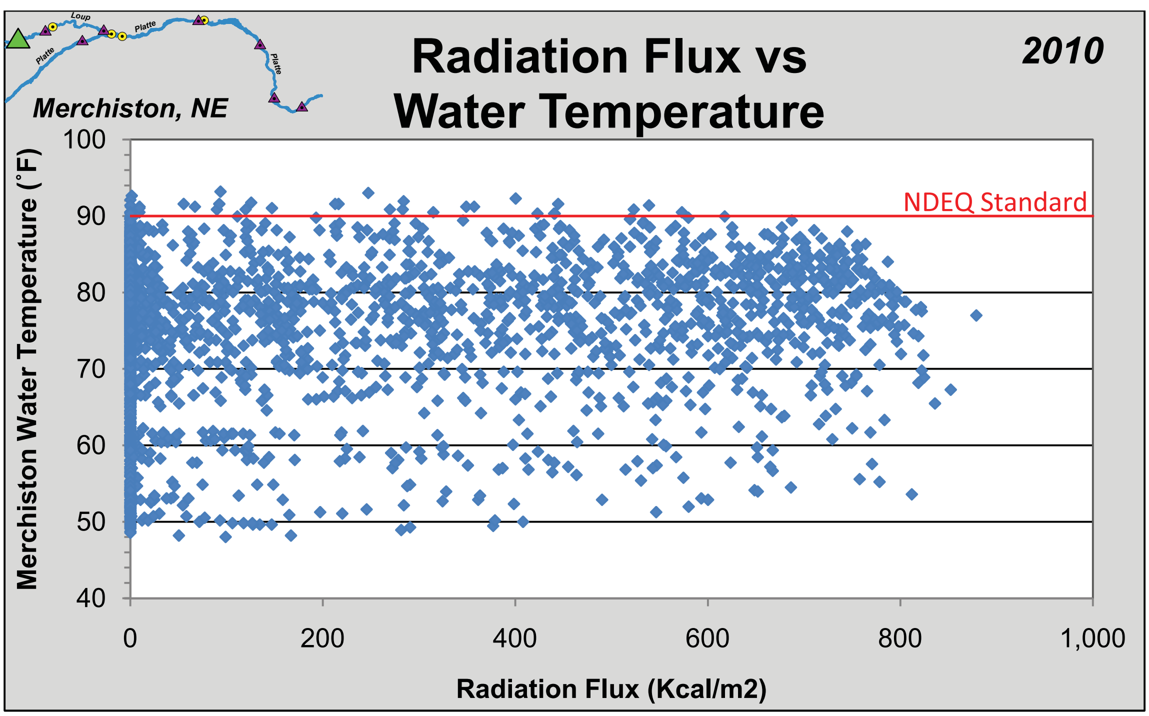
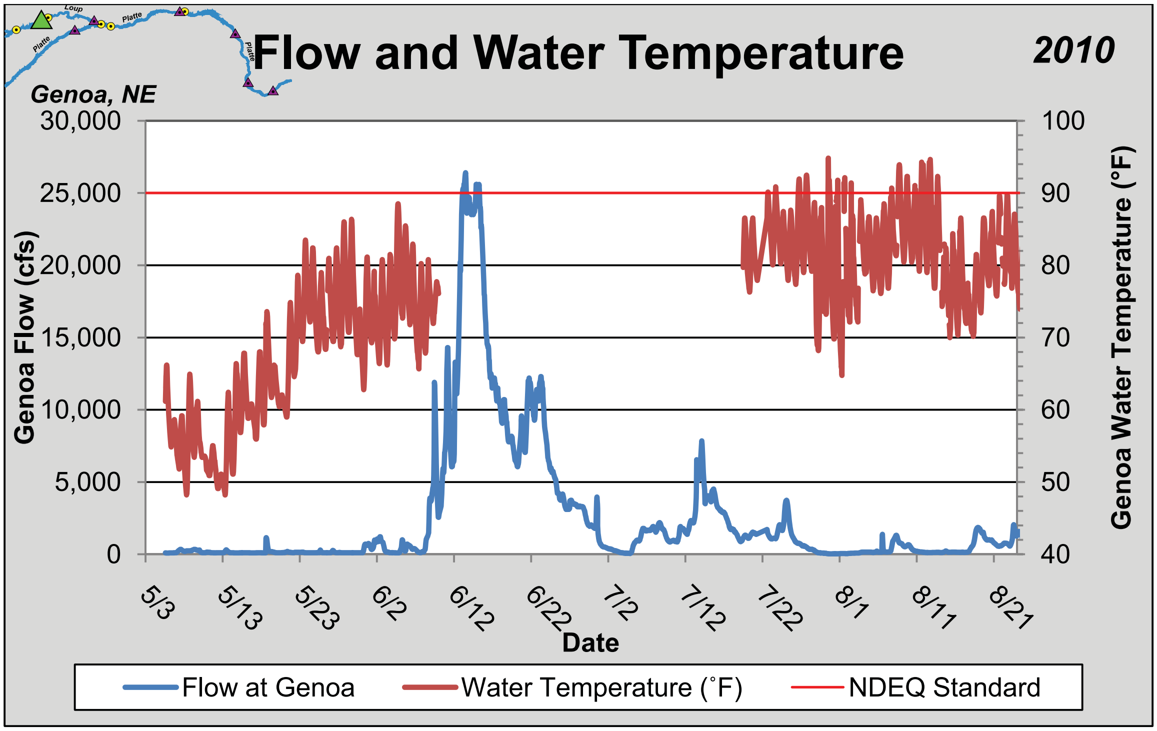


Figure 5-7. Radiative Flux vs. Water Temperature, Loup River at Merchiston



Note: The temperature sensor installed at the Loup River near Genoa was washed away by high flows on June 10, 2010. A replacement sensor was installed on July 19, 2010.

Figure 5-8. Hourly Flow and Water Temperature, Loup River near Genoa

A direct comparison between flow and water temperature for the Loup River near Genoa is presented in Figure 5-9. Consistent with what was observed at the Merchiston location, there is not a statistically significant relationship (ANOVA, alpha = 0.05) between the two variables. One explanation for the lack of a statistically significant relationship is that water temperature can vary several degrees on a given day while flow remains relatively constant. Weekly and monthly graphical comparisons are located in Attachment C; results were not typically statistically significant. Excursions above 90˚F occurred when discharge was less than 1,500 cfs.

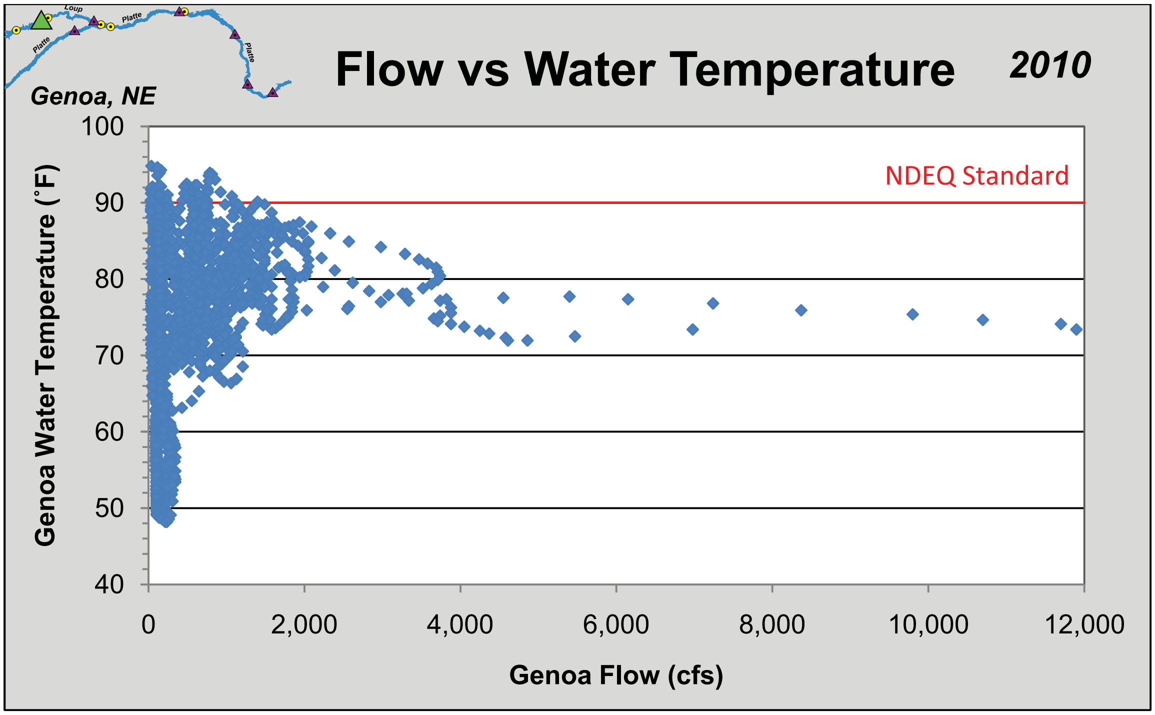
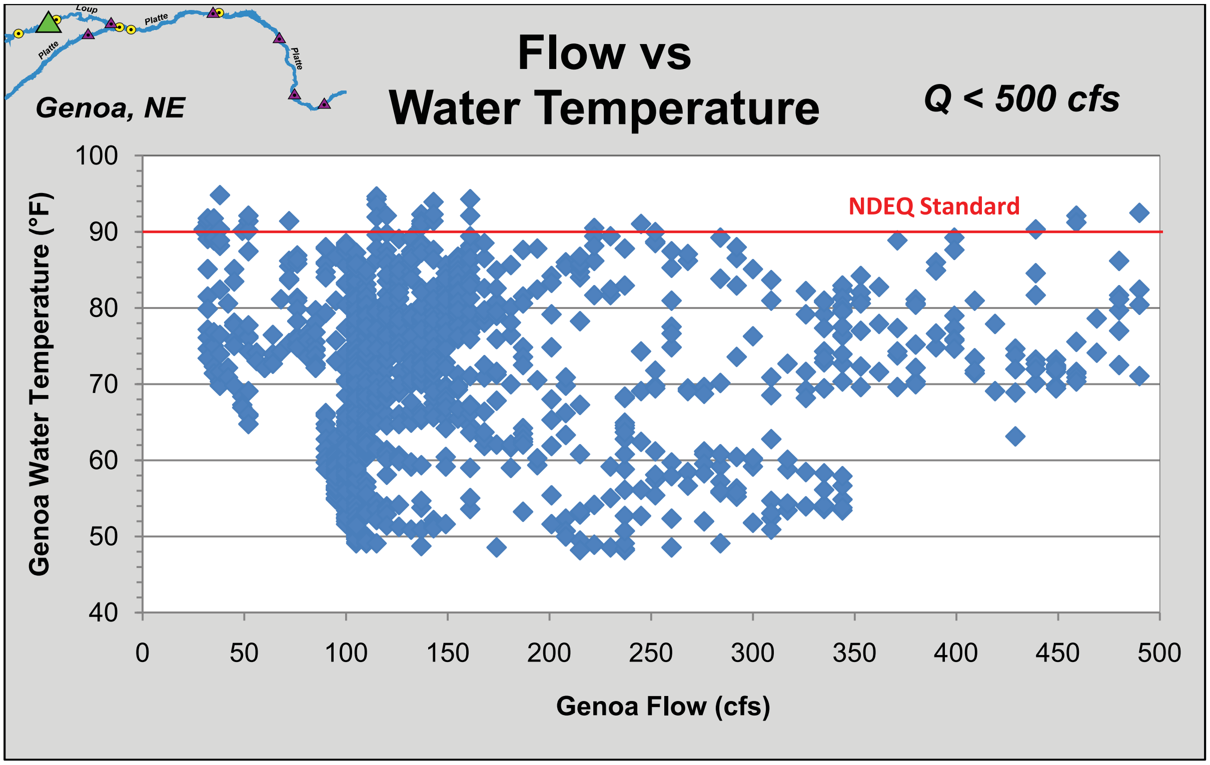


Figure 5-9. Flow/Water Temperature Relationship, Loup River near Genoa

Further analysis was performed to determine if more meaningful relationships could be found between flow and water temperature for only lower flows. Figures 5-10 through 5-15 present direct comparisons between flow and water temperature for the Loup River near Genoa for flows less than 500, 400, 300, 200, 100, and 50 cfs, respectively. No additional meaningful relationships were found by reducing the data set to only lower flow data values.



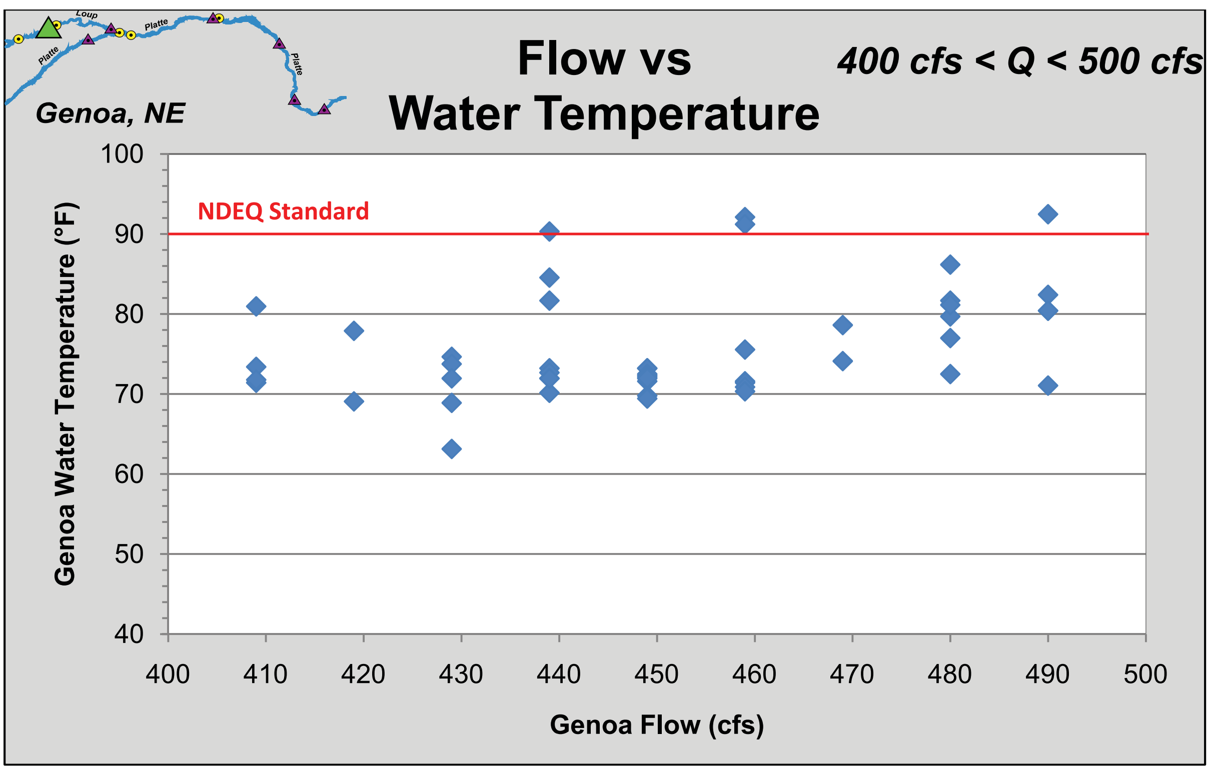
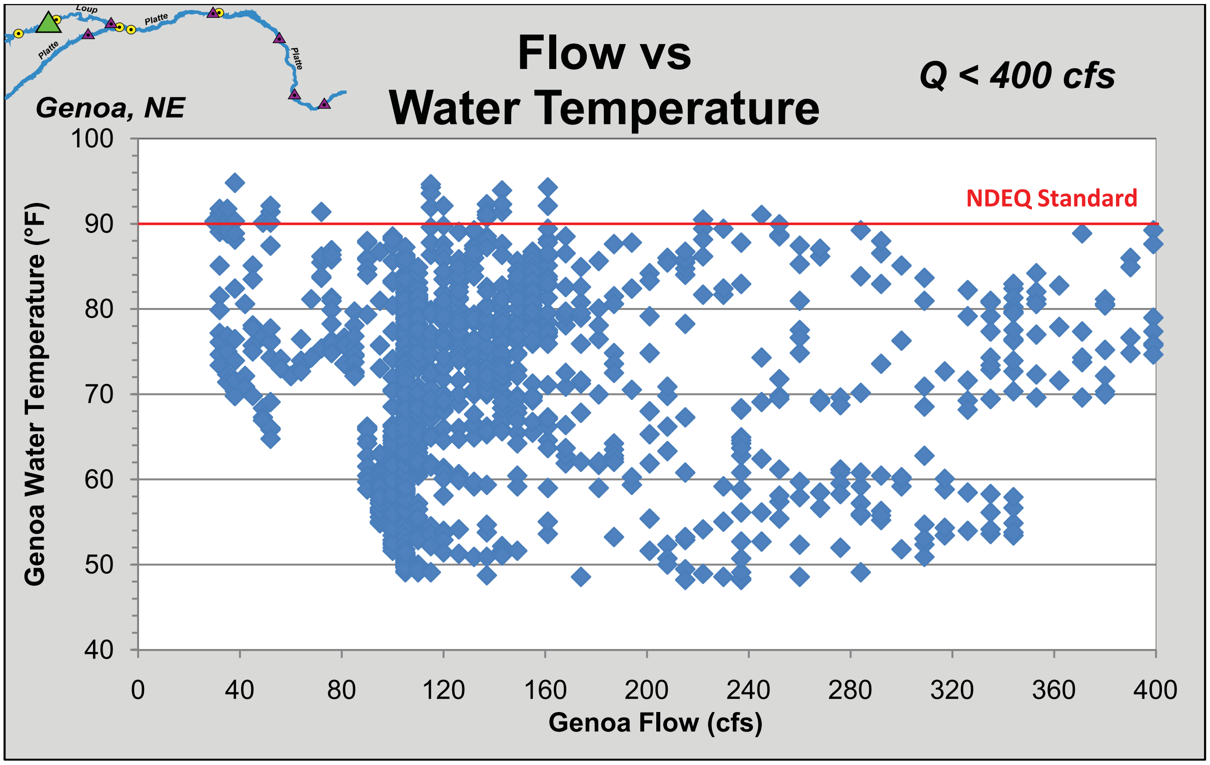


Figure 5-10. Flow/Water Temperature Relationship, Loup River near Genoa, Flows Less than 500 cfs and between 400 and 500 cfs



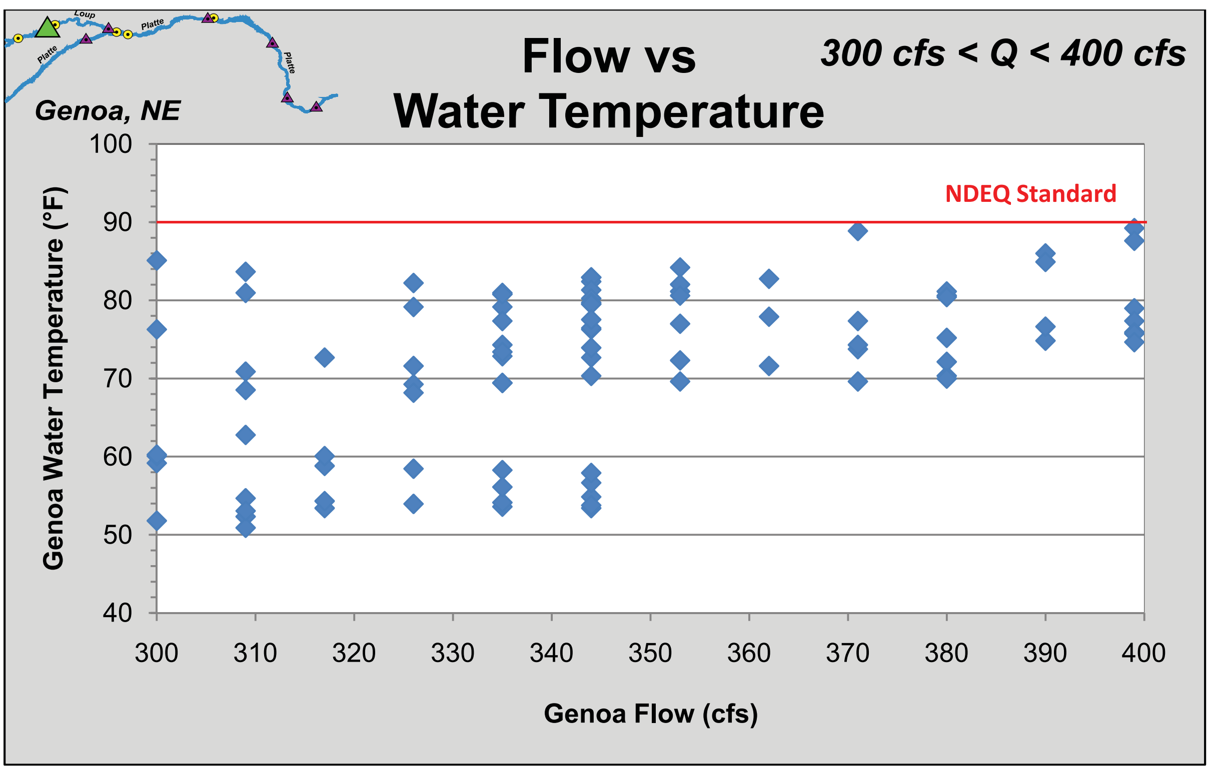
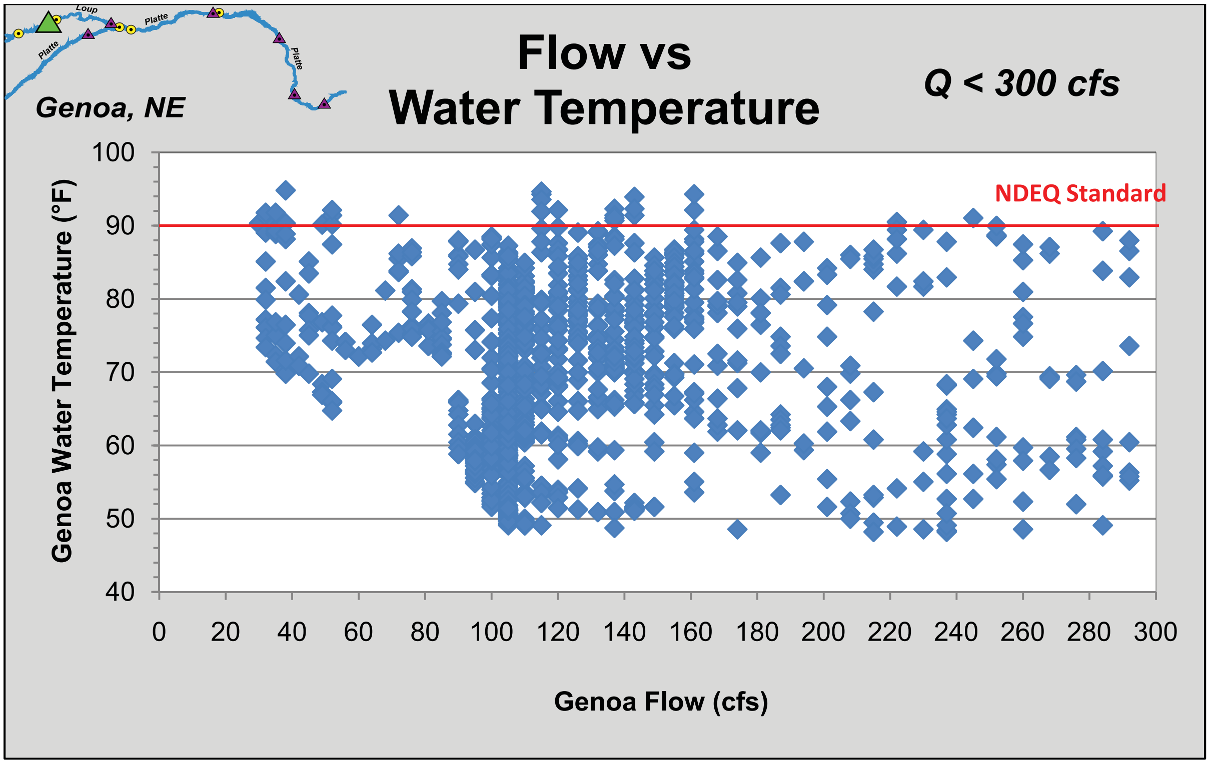


Figure 5-11. Flow/Water Temperature Relationship, Loup River near Genoa, Flows Less than 400 cfs and between 300 and 400 cfs



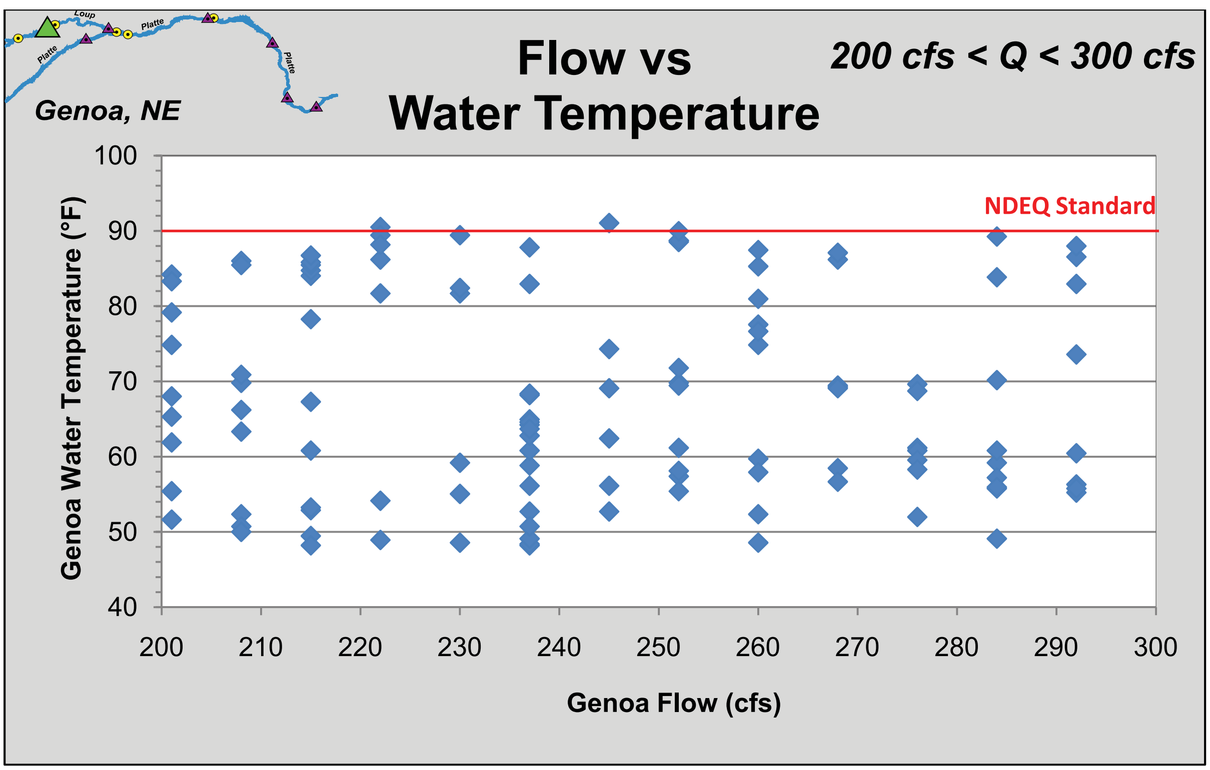
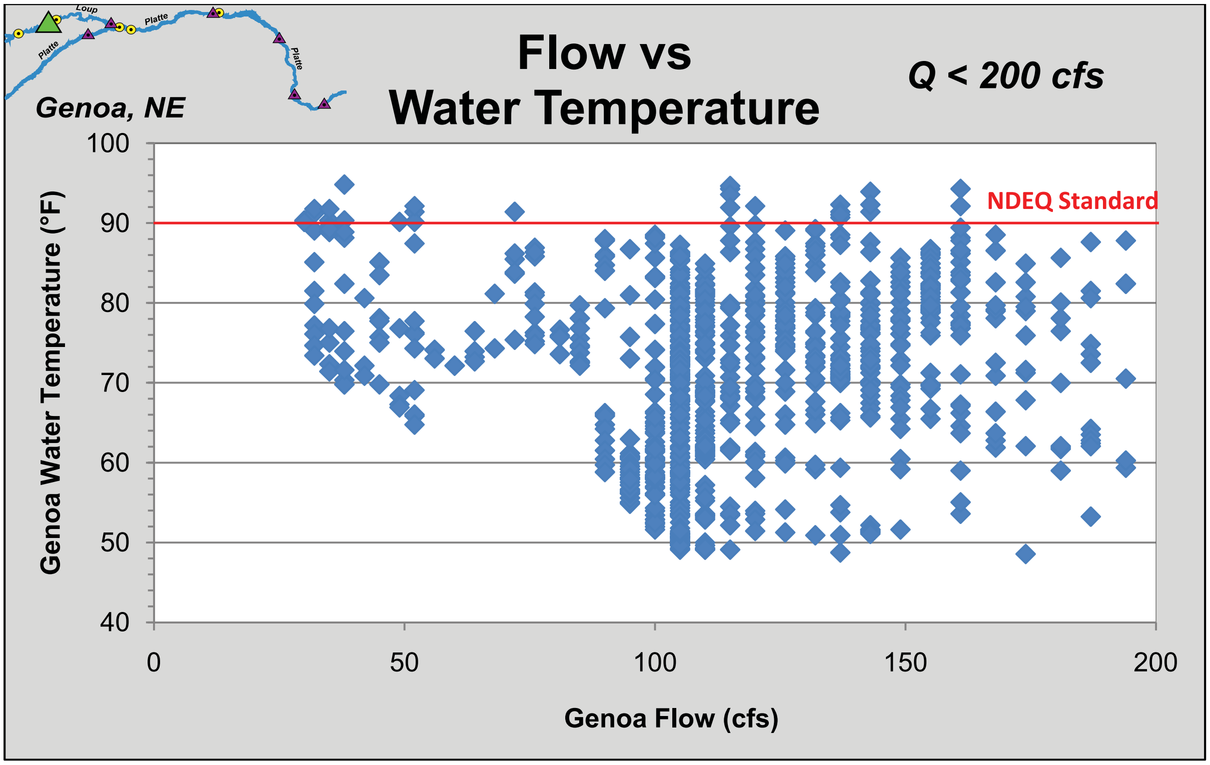


Figure 5-12. Flow/Water Temperature Relationship, Loup River near Genoa, Flows Less than 300 cfs and between 200 and 300 cfs



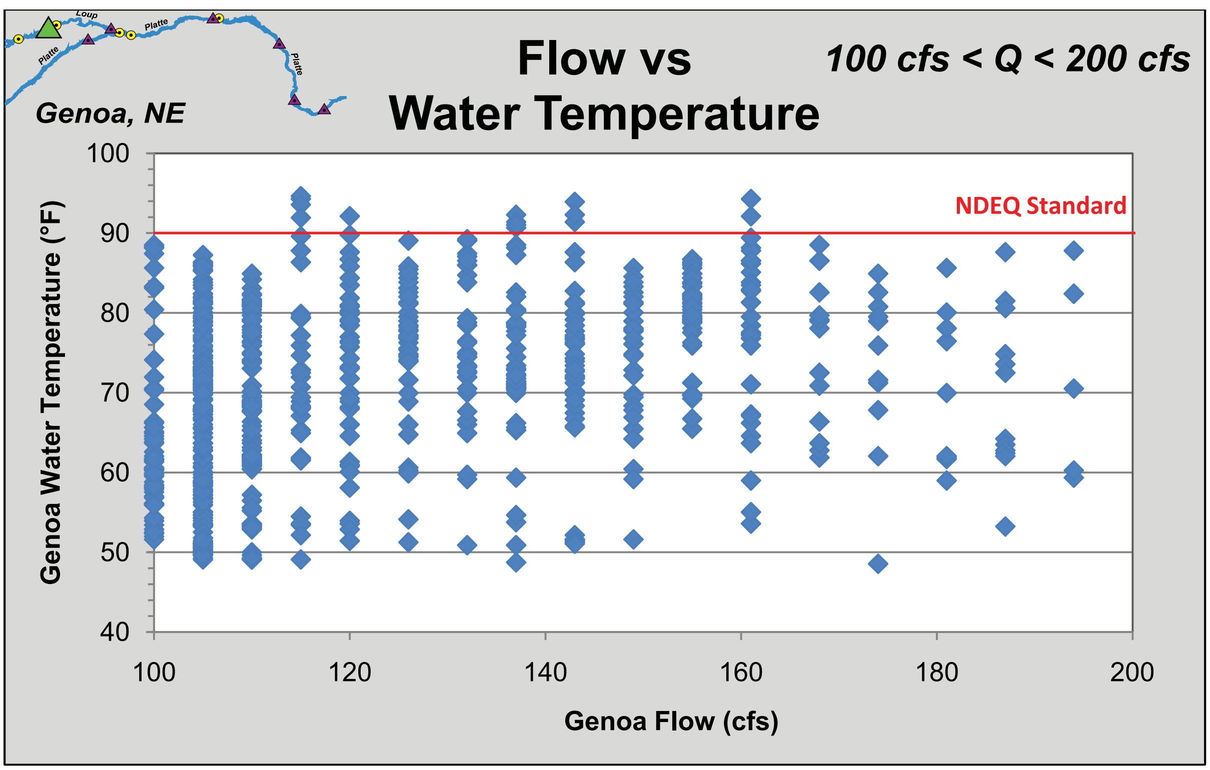


Figure 5-13. Flow/Water Temperature Relationship, Loup River near Genoa, Flows Less than 200 cfs and between 100 and 200 cfs

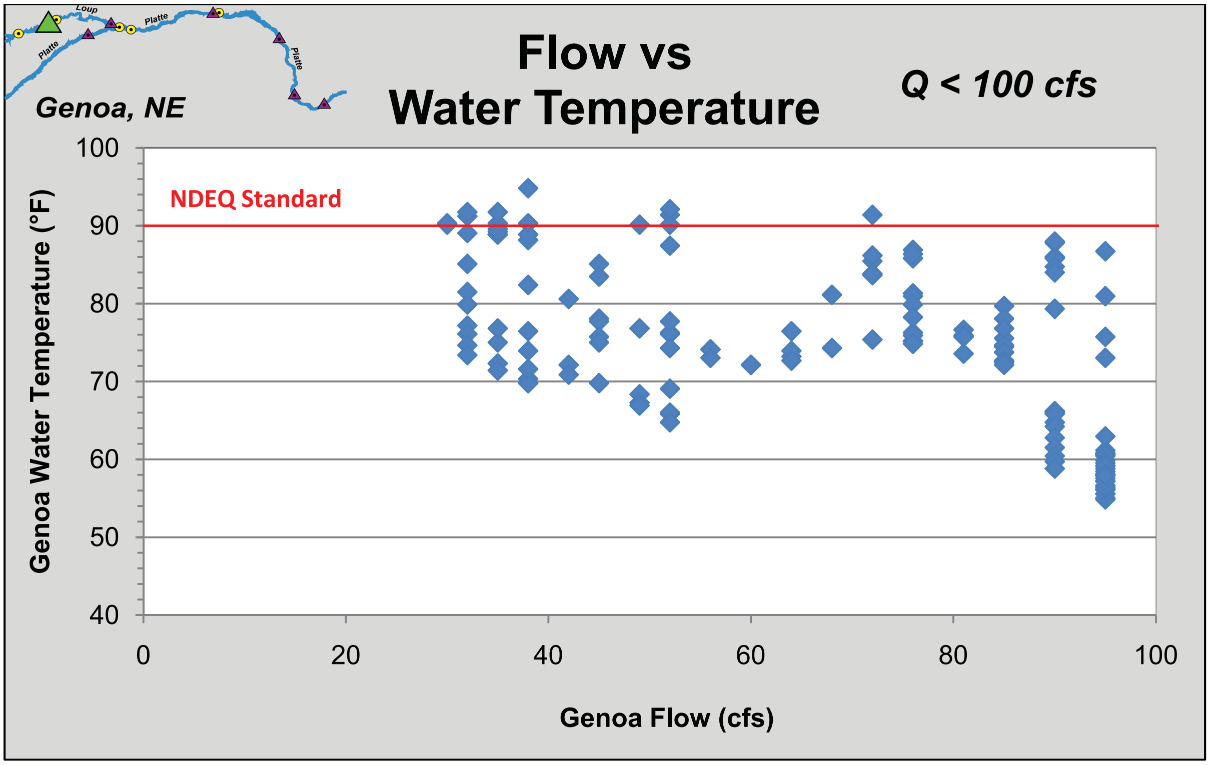


Figure 5-14. Flow/Water Temperature Relationship, Loup River near Genoa, Flows Less than 100 cfs

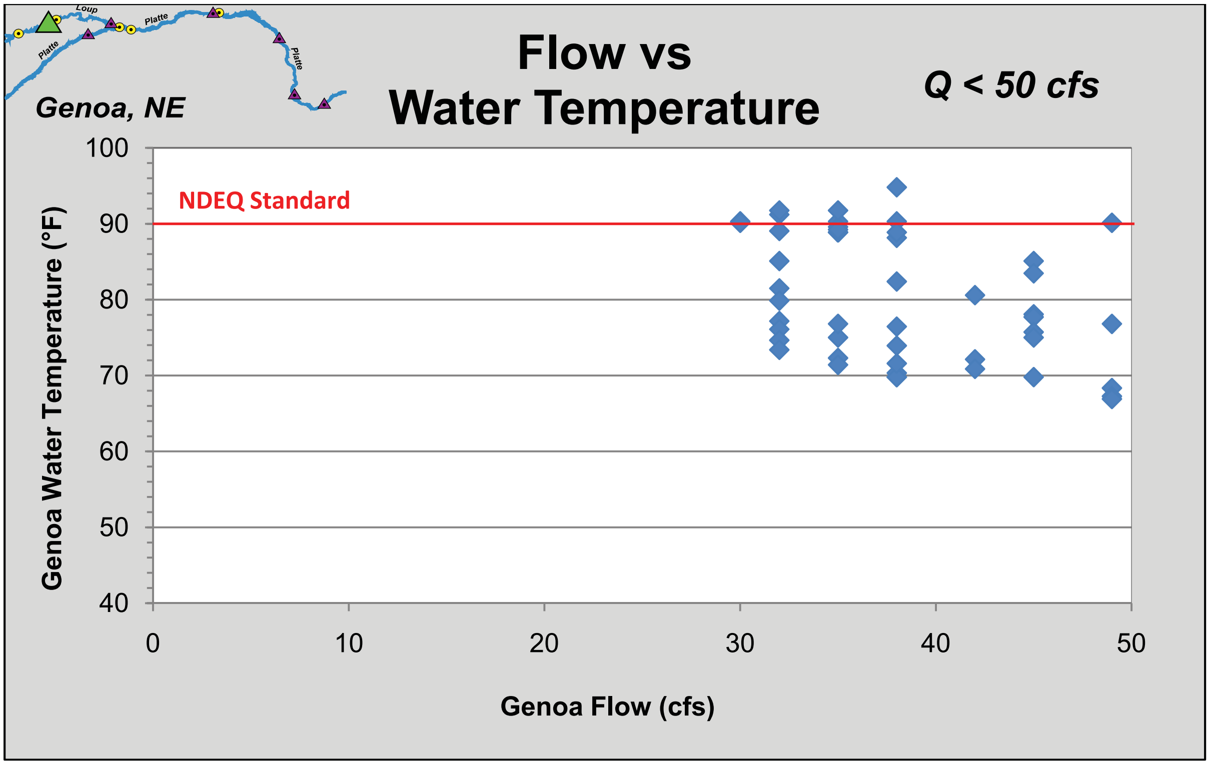
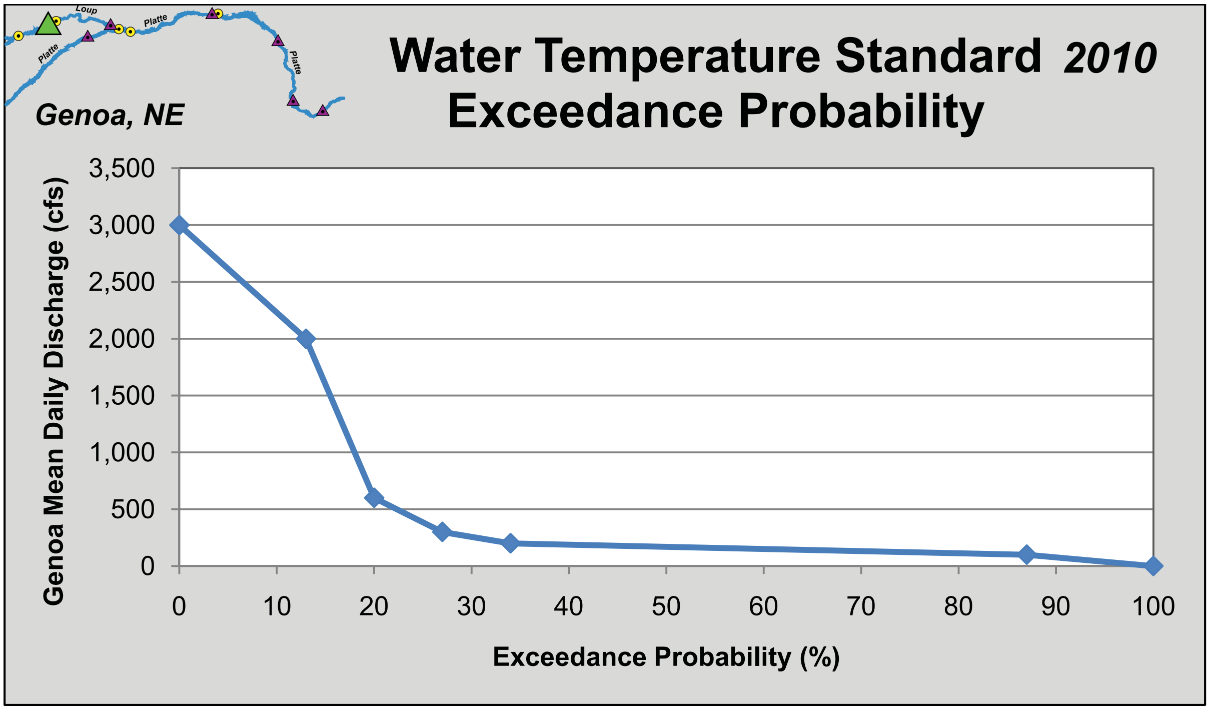


Figure 5-15. Flow/Water Temperature Relationship, Loup River near Genoa, Flows Less than 50 cfs

Despite the analysis showing no statistically significant relationship between discharge and water temperature near Genoa (as noted above), a percent probability of exceedance analysis, similar to Sinokrot and Gulliver's (2000) method, was conducted as requested by USFWS in its comment letter dated June 24, 2009. This analysis results in the probability of exceeding 90˚F based on flows and is presented in Figure 5-16. The analysis indicates that there is approximately a 60 percent probability of a temperature excursion occurring at flows less than 150 cfs.



Note: The additional data points shown above (relative to Figure 5-3) is due to an increased amount of measured excursions.

Figure 5-16. Exceedance Probability for Water Temperature, Loup River near Genoa

5.3.2 Water Temperature Relationship with Air and Soil Temperatures

Consistent with the findings observed at the Merchiston location, comparisons of water temperatures to air and soil temperatures also indicated statistically significant relationships (ANOVA, alpha = 0.05) (see Figures 5-17 and 5-18). Water temperature excursions above 90˚F typically occurred when air temperatures were between 75˚F and 95˚F and when soil temperatures were between 85˚F and 95˚F.[3]

Weekly and monthly plots for the air/water temperature relationship in Figure 5-17 are presented in Attachment D. At those time scales, there was more variability between the parameters and hence poorer R^2 values.

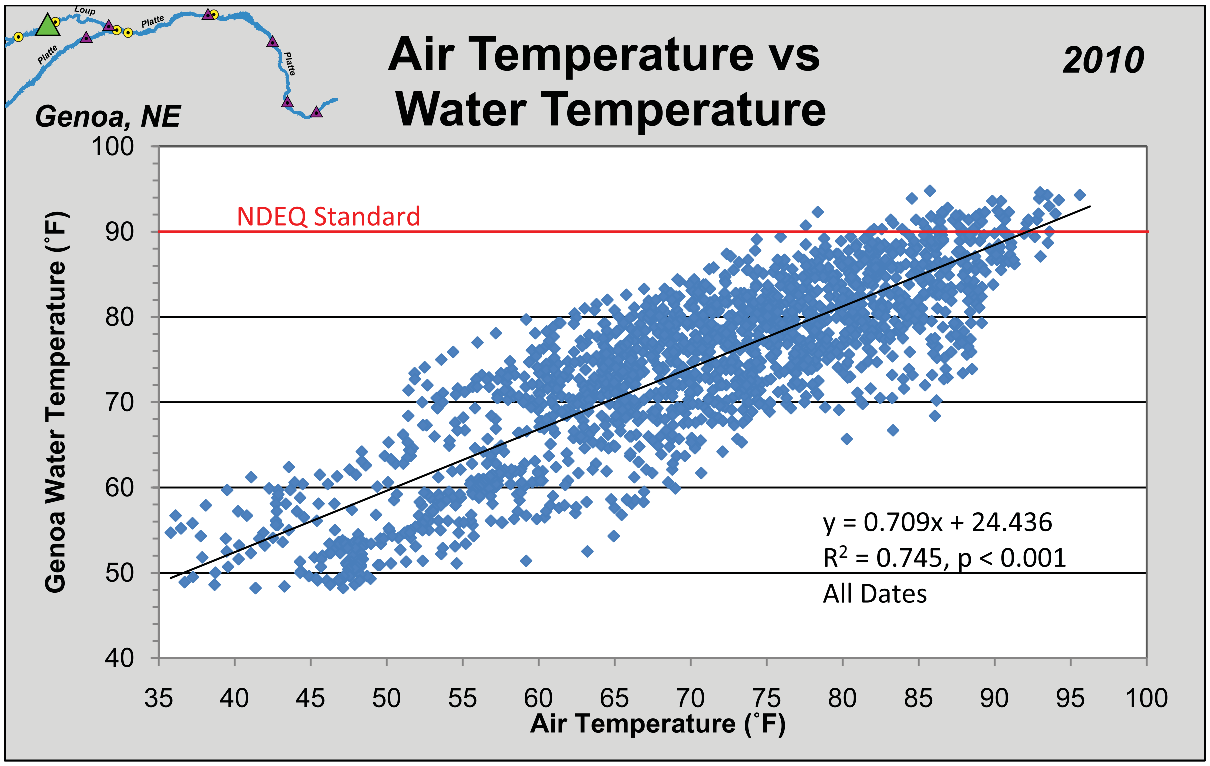


Figure 5-17. Air Temperature vs. Water Temperature, Loup River near Genoa

[3] There was not a significant improvement in either relationship when the July 28 to August 3 data (when the probe was assumed to be exposed) were removed.

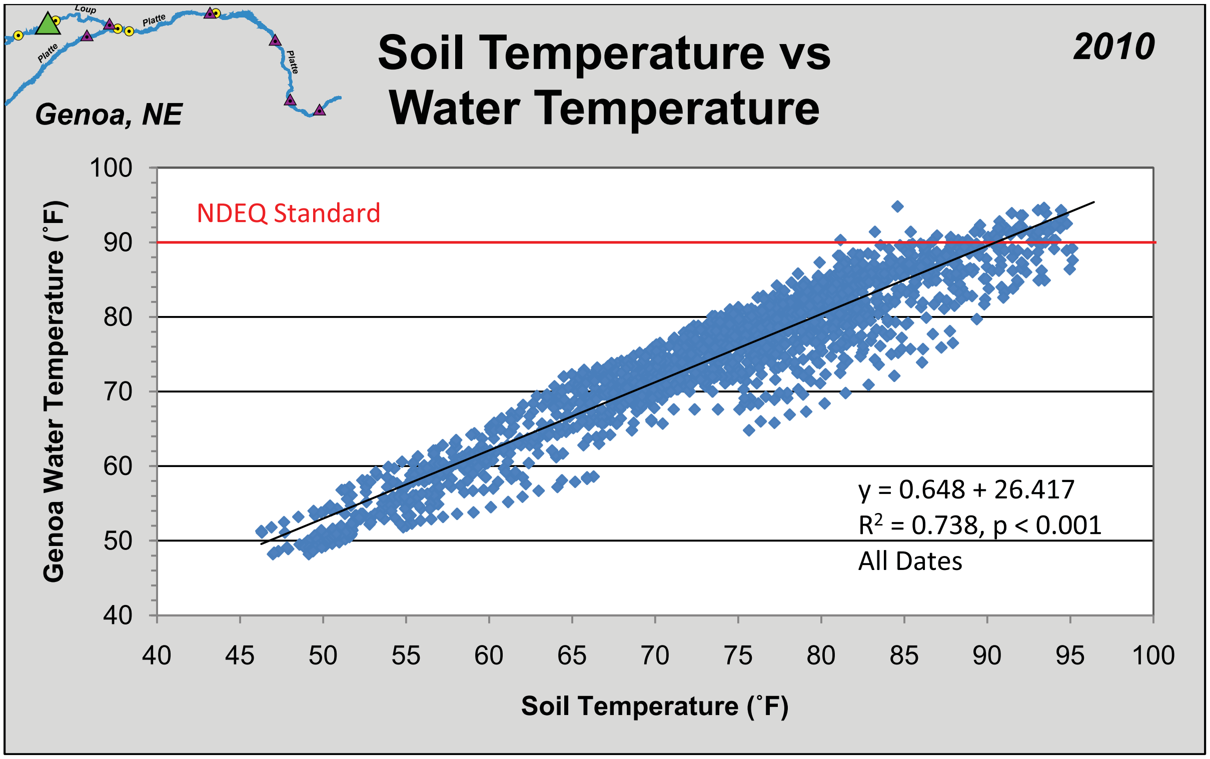
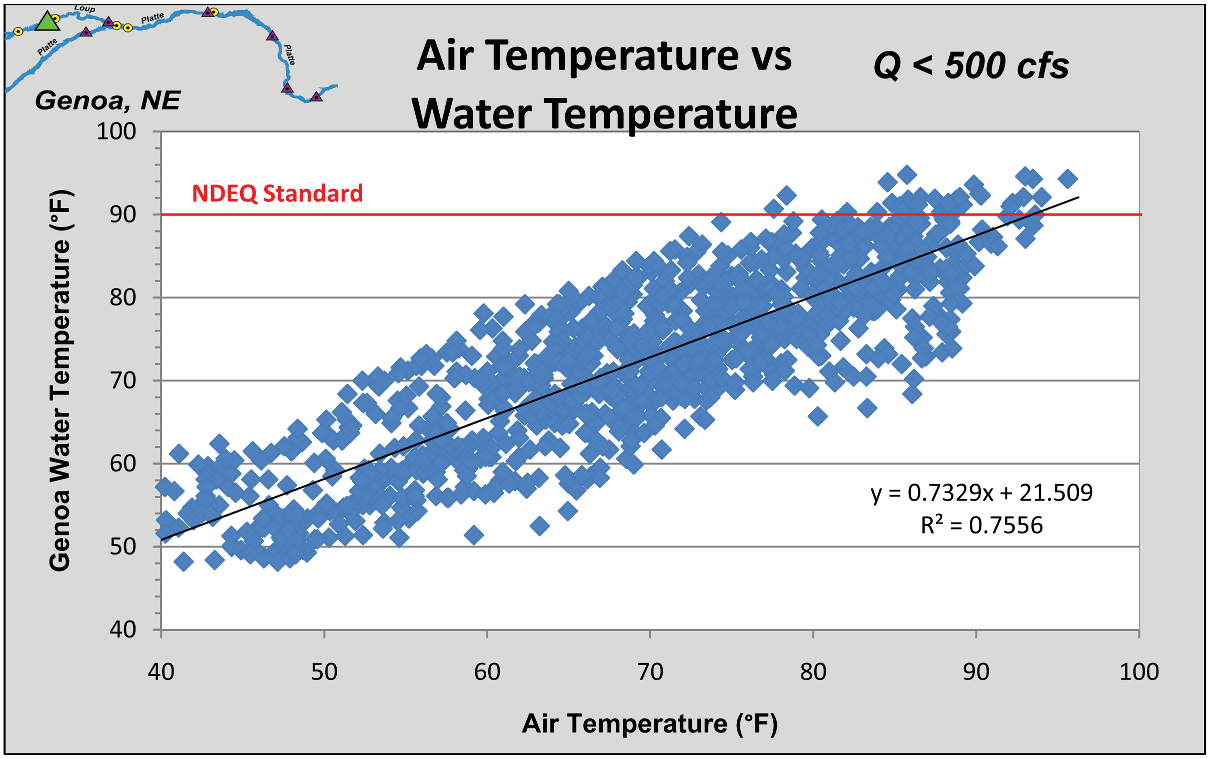


Figure 5-18. Soil Temperature vs. Water Temperature, Loup River near Genoa

Further analysis was performed to determine if more meaningful relationships could be found between air temperature and water temperature for only lower flows. Figures 5-19 through 5-24 present direct comparisons between air temperature and water temperature for the Loup River near Genoa for flows less than 500, 400, 300, 200, 100, and 50 cfs, respectively. While the R^2 value increased slightly, this is an artifact from using data points, as the graphs for 100 cfs flow ranges show. No additional stronger correlations were found by reducing the data set.



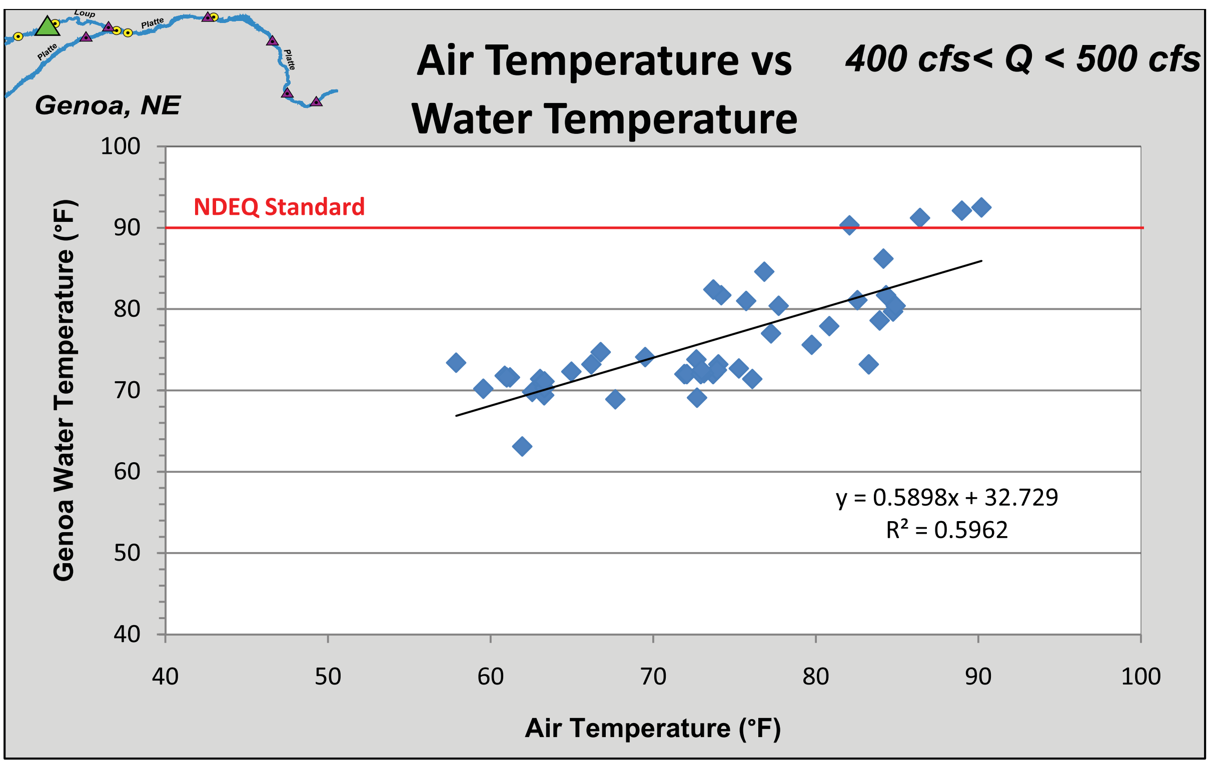
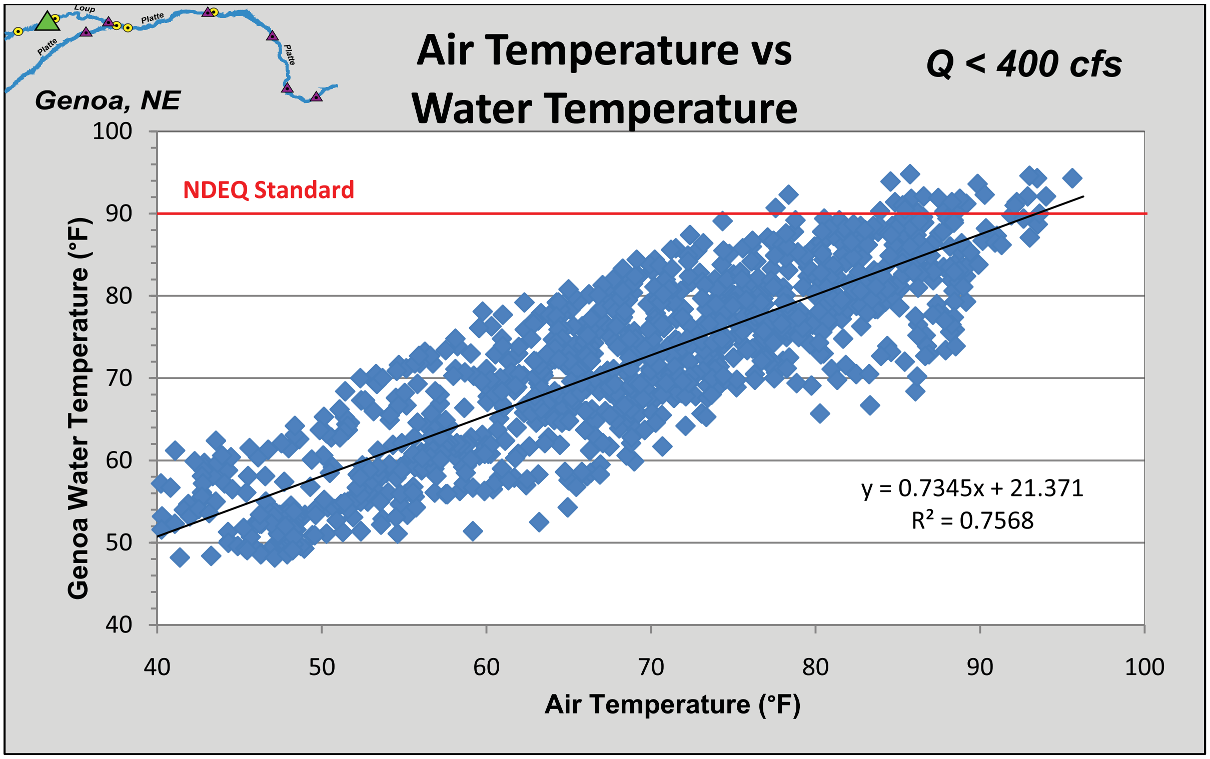


Figure 5-19. Air Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 500 cfs and between 400 and 500 cfs



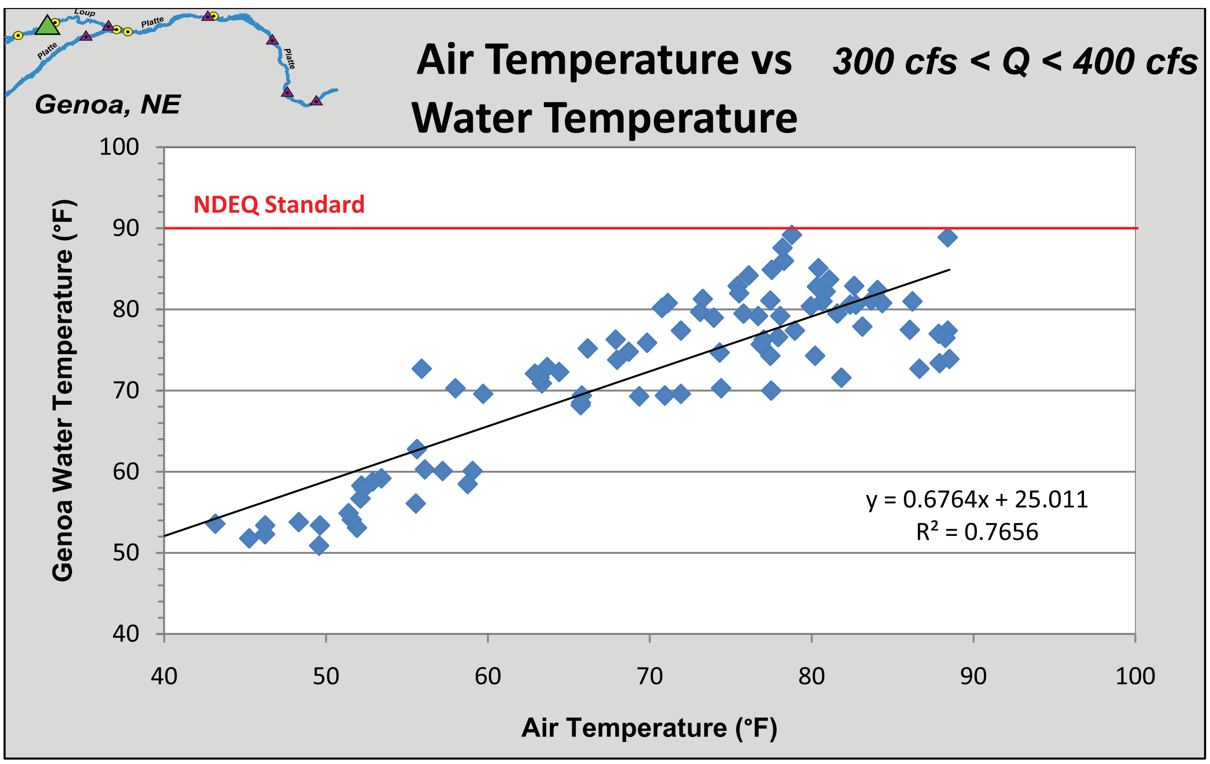
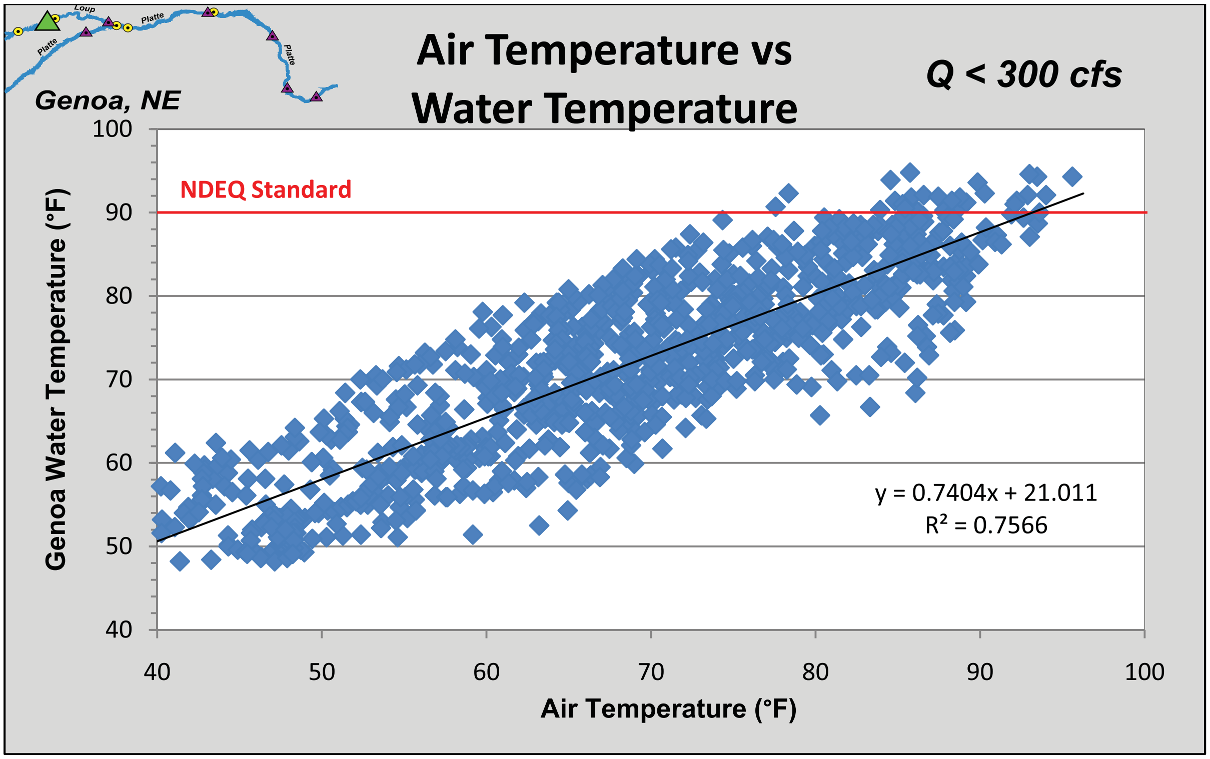


Figure 5-20. Air Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 400 cfs and between 300 and 400 cfs



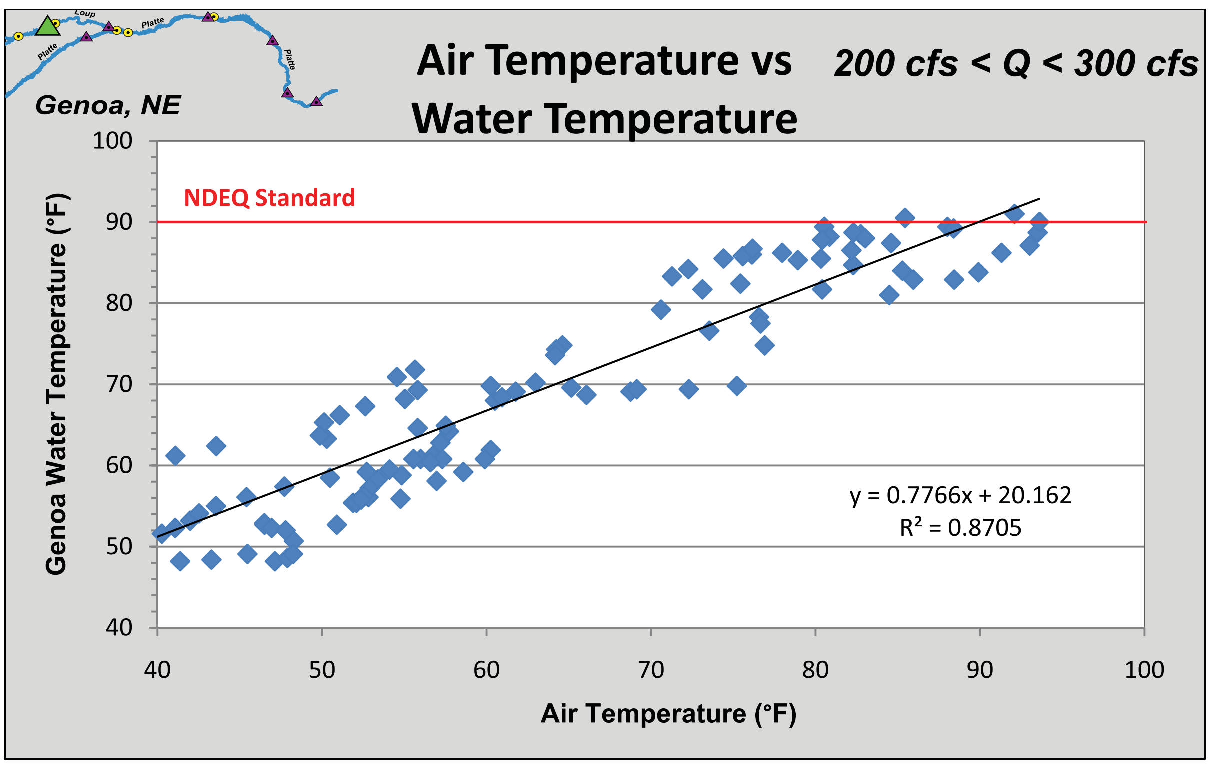
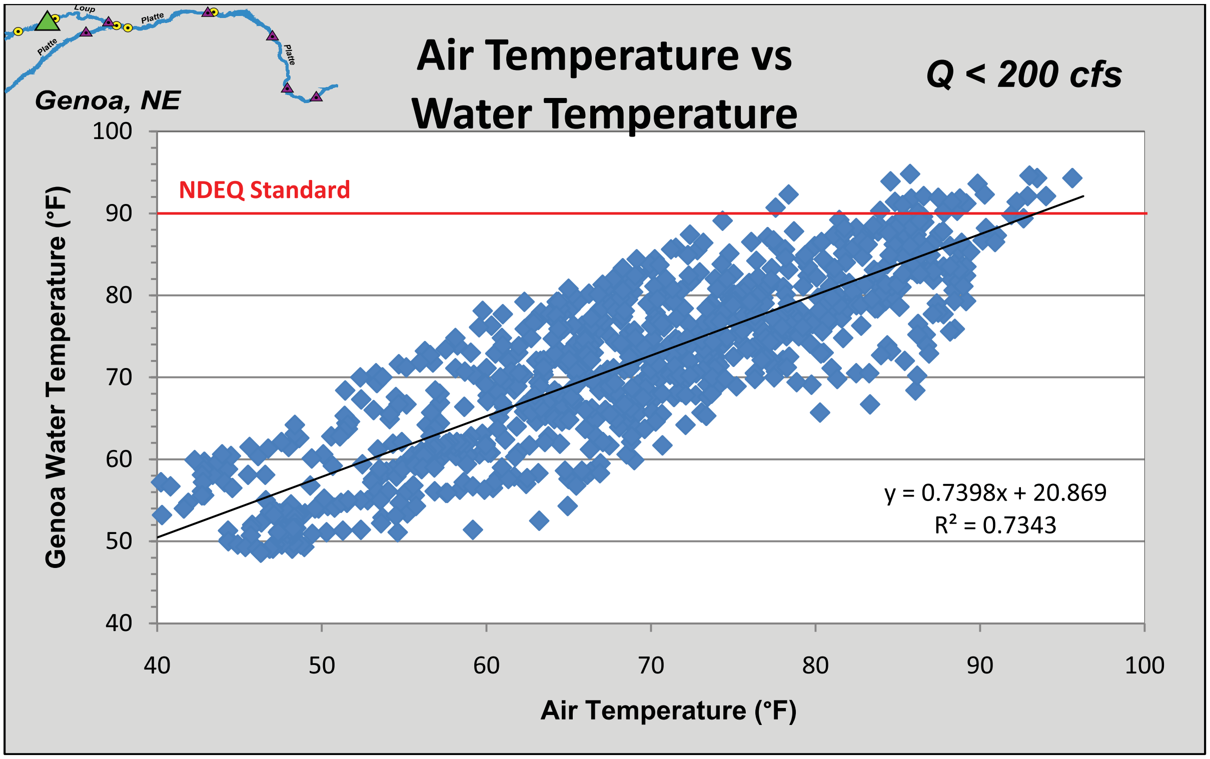


Figure 5-21. Air Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 300 cfs and between 200 and 300 cfs



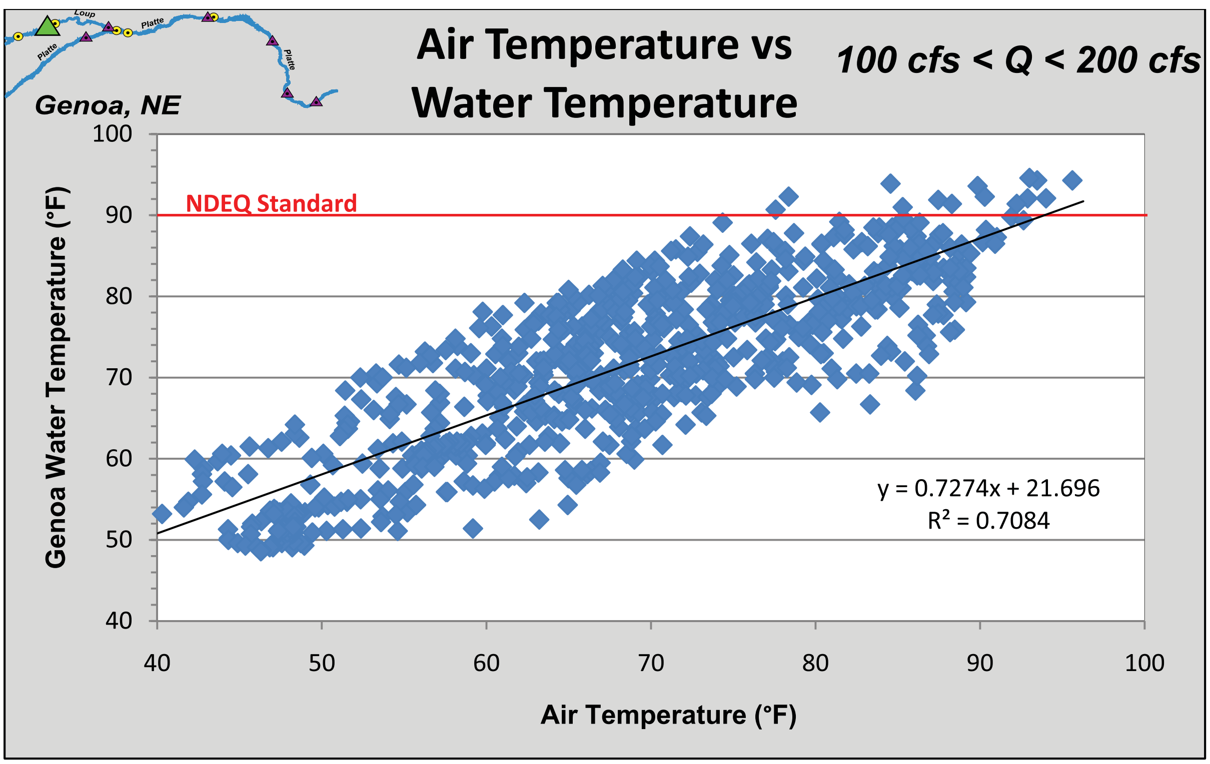


Figure 5-22. Air Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 200 cfs and between 100 and 200 cfs

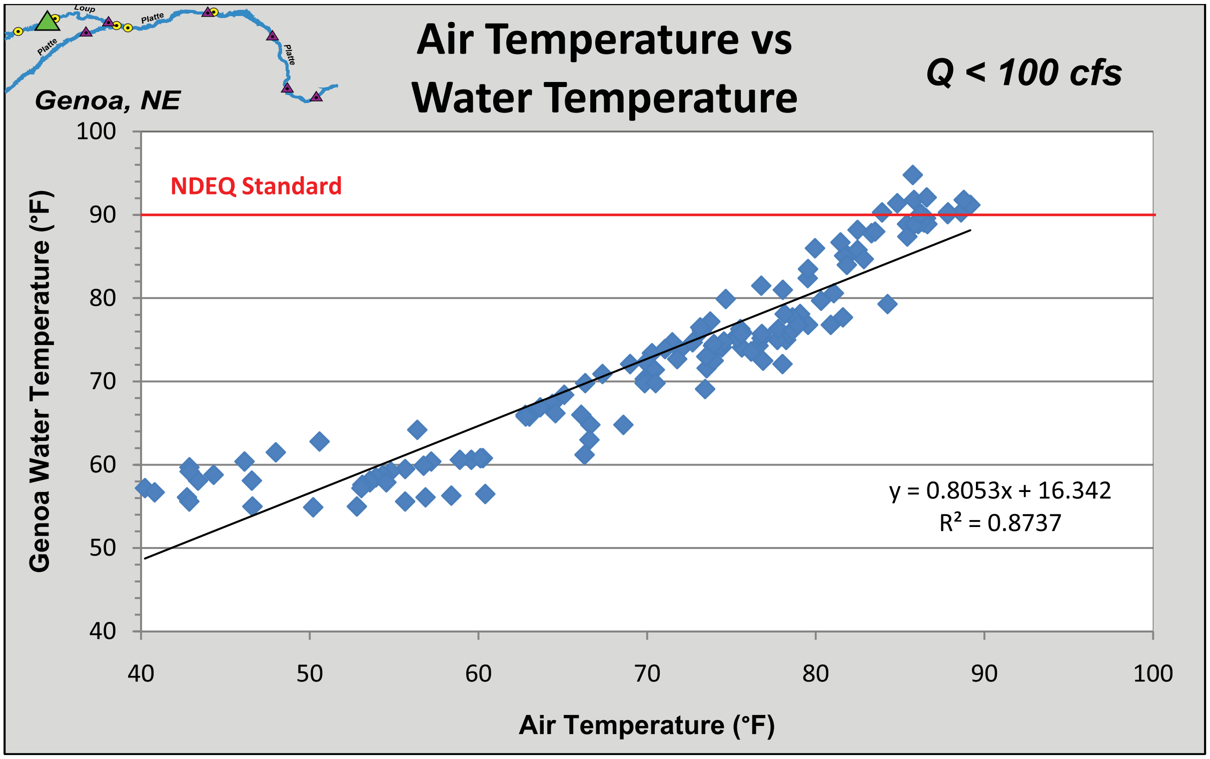


Figure 5-23. Air Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 100 cfs

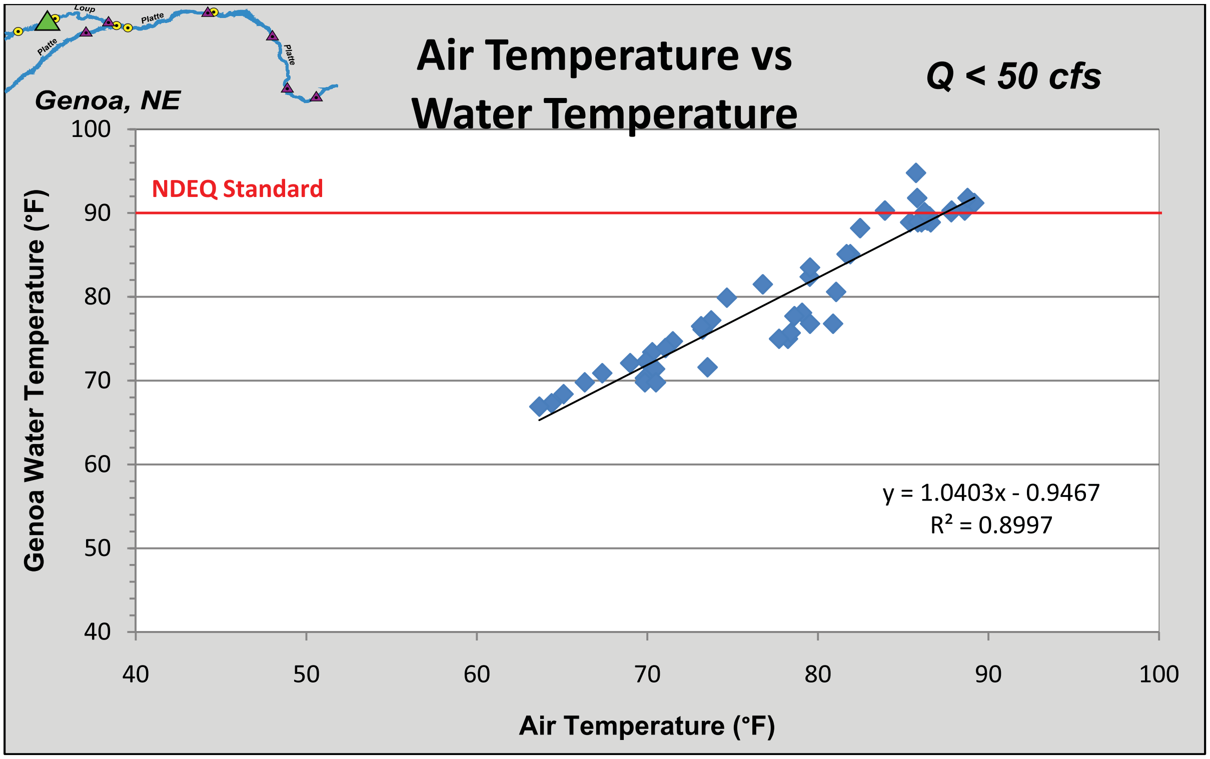
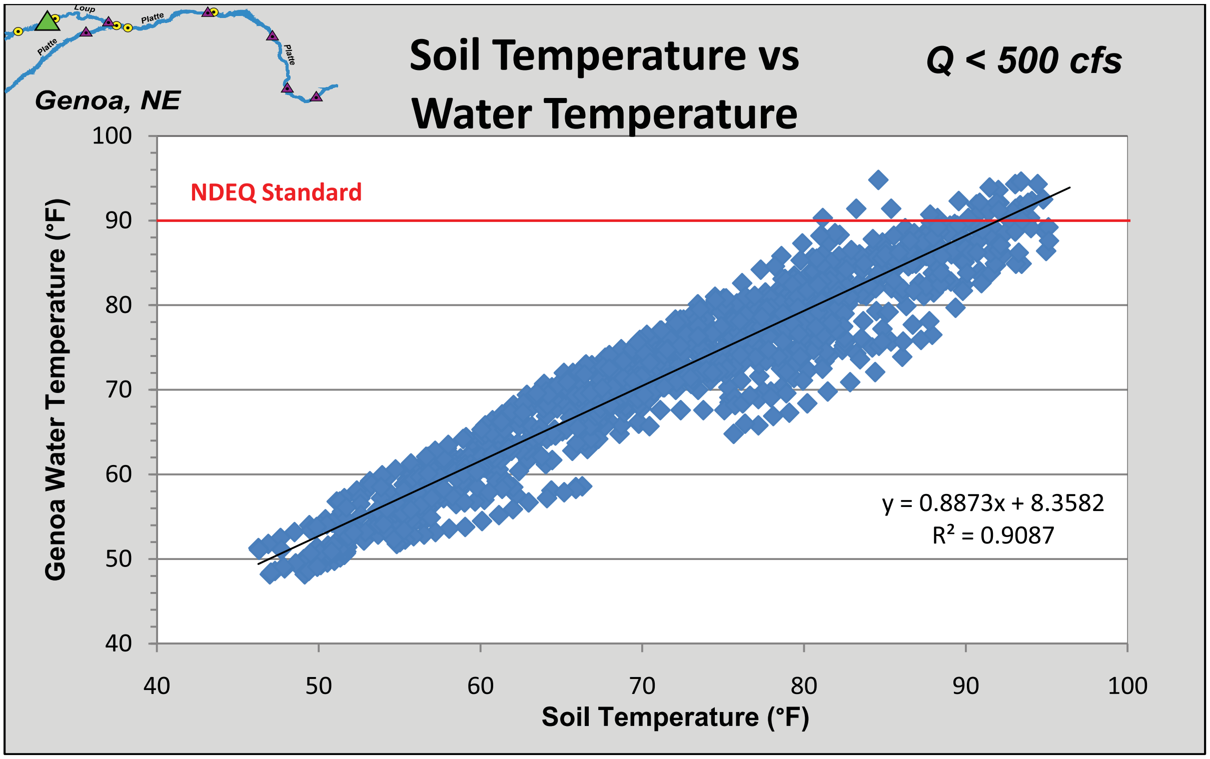


Figure 5-24. Air Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 50 cfs

Further analysis was performed to determine if statistically significant relationships could be found between soil temperature and water temperature for only lower flows. Figures 5-25 through 5-30 present direct comparisons between soil temperature and water temperature for the Loup River near Genoa for flows less than 500, 400, 300, 200, 100, and 50 cfs, respectively. No stronger correlations were found by reducing the data set.



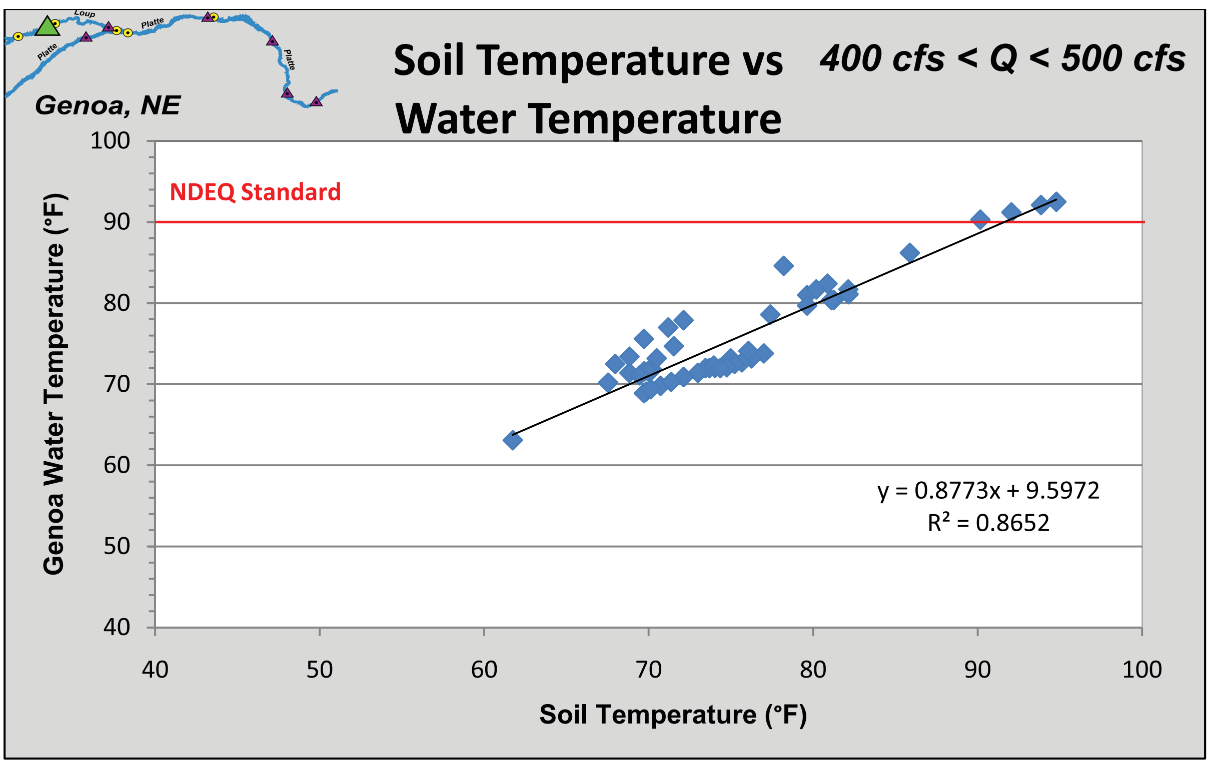
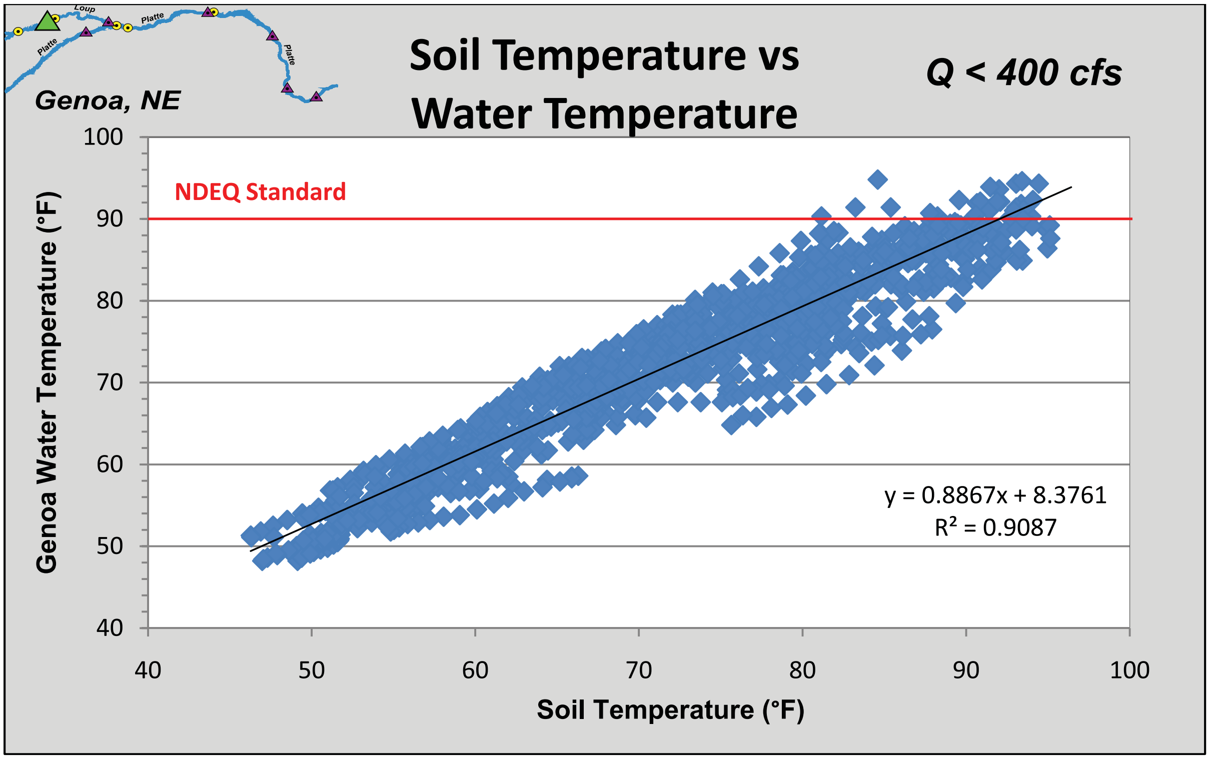


Figure 5-25. Soil Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 500 cfs and between 400 and 500 cfs



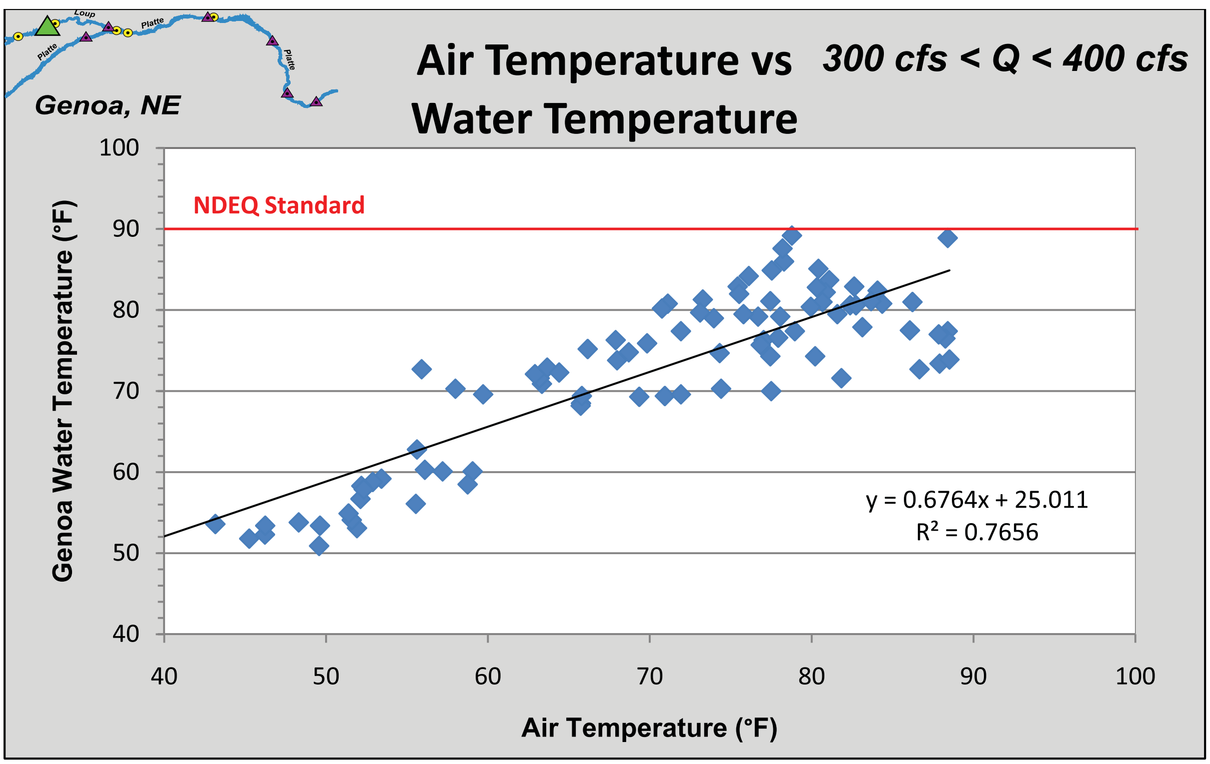
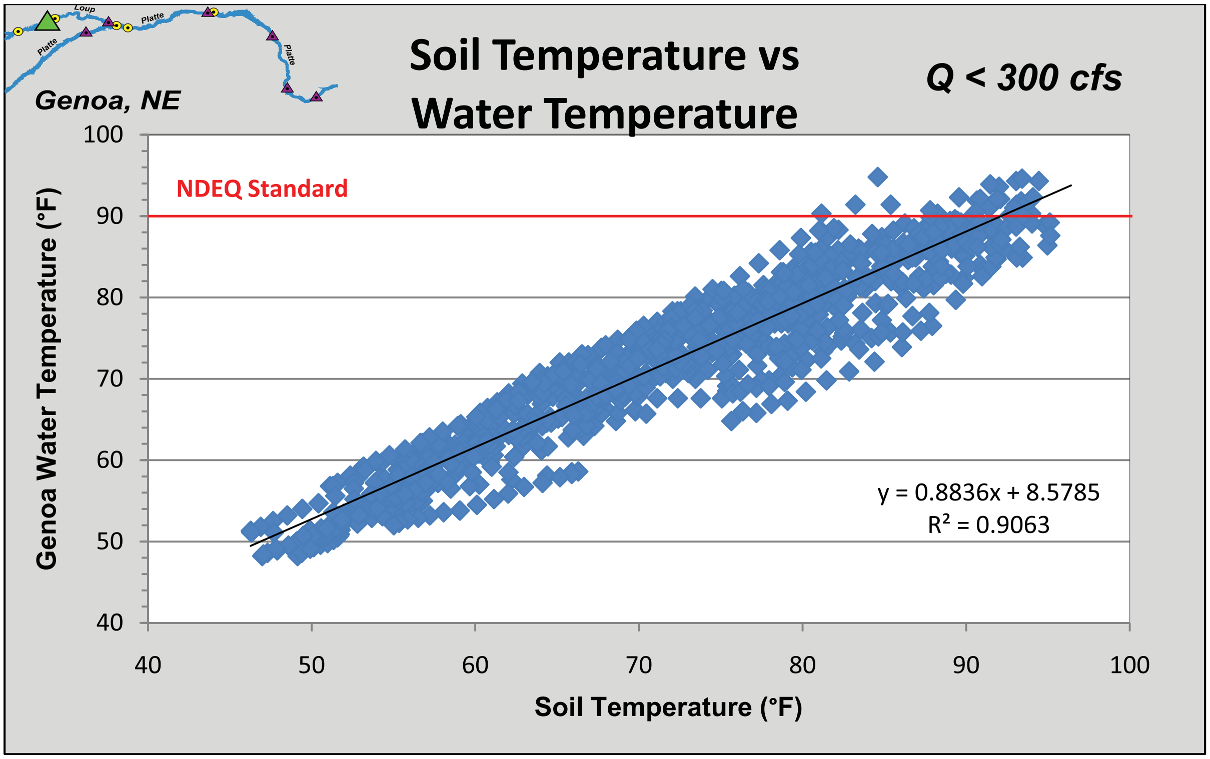


Figure 5-26. Soil Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 400 cfs and between 300 and 400 cfs



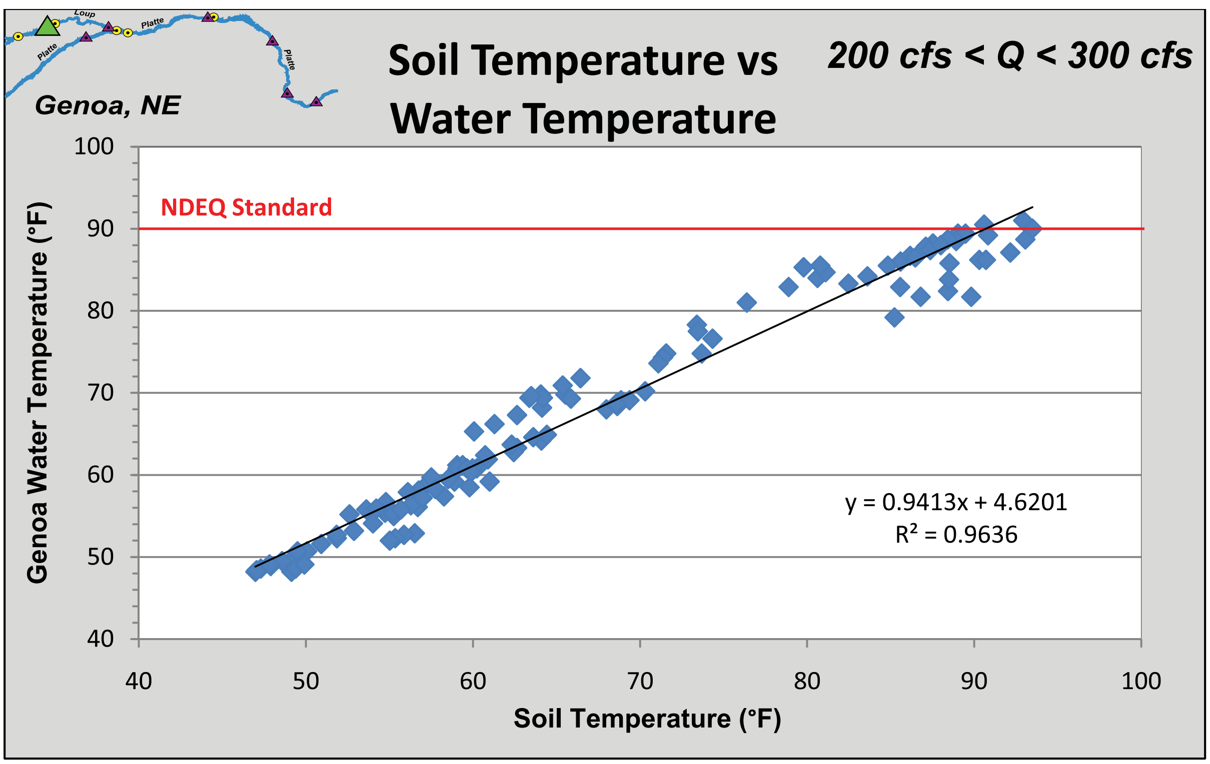
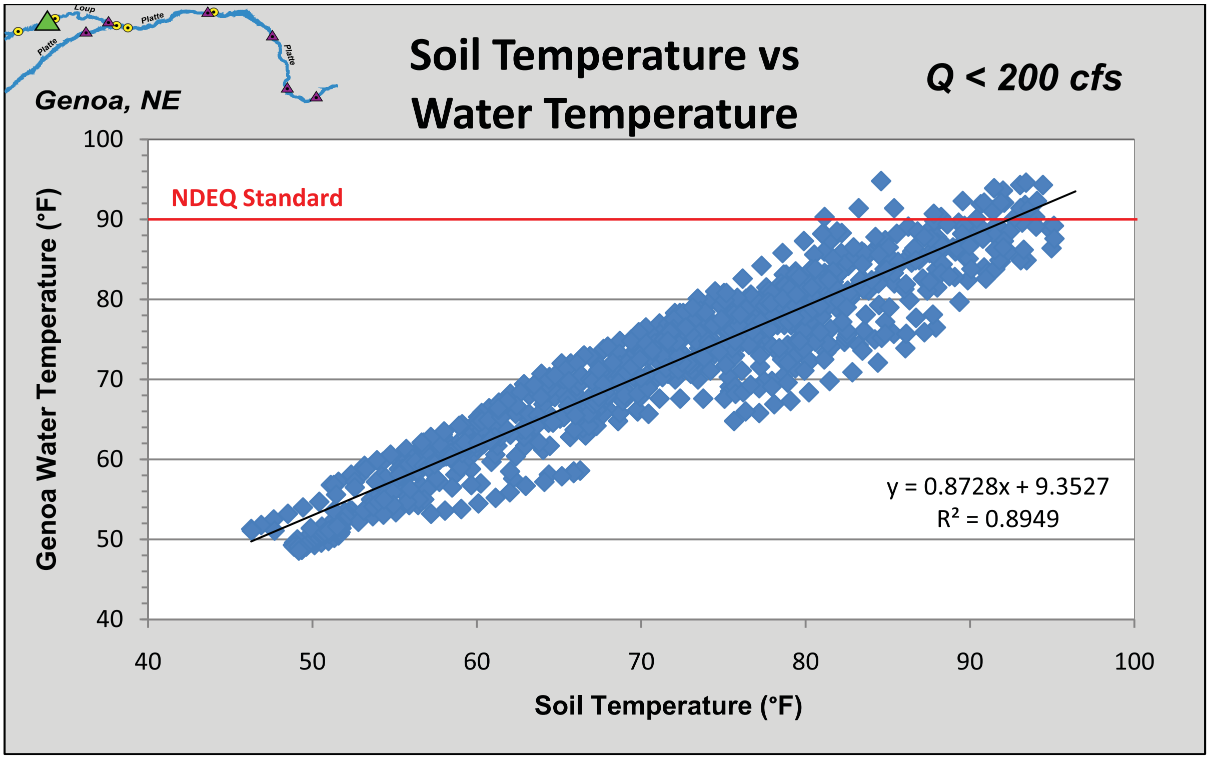


Figure 5-27. Soil Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 300 cfs and between 200 and 300 cfs



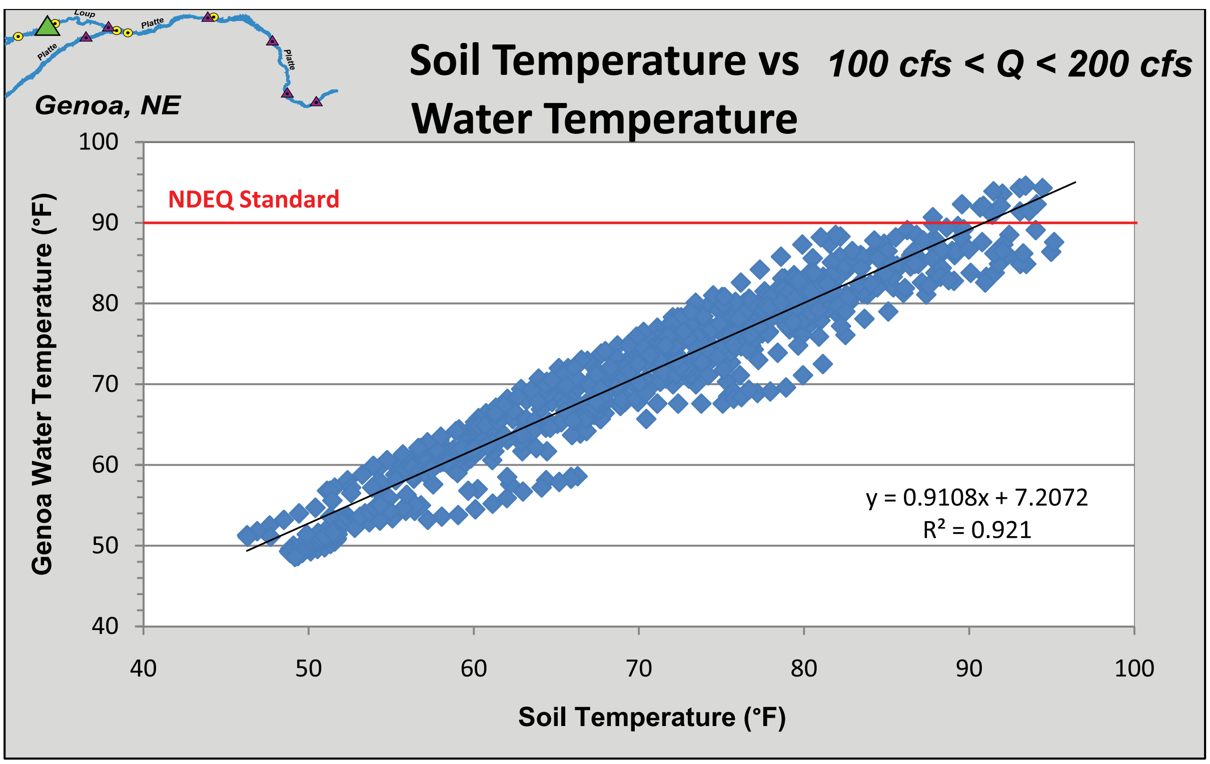


Figure 5-28. Soil Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 200 cfs and between 100 and 200 cfs

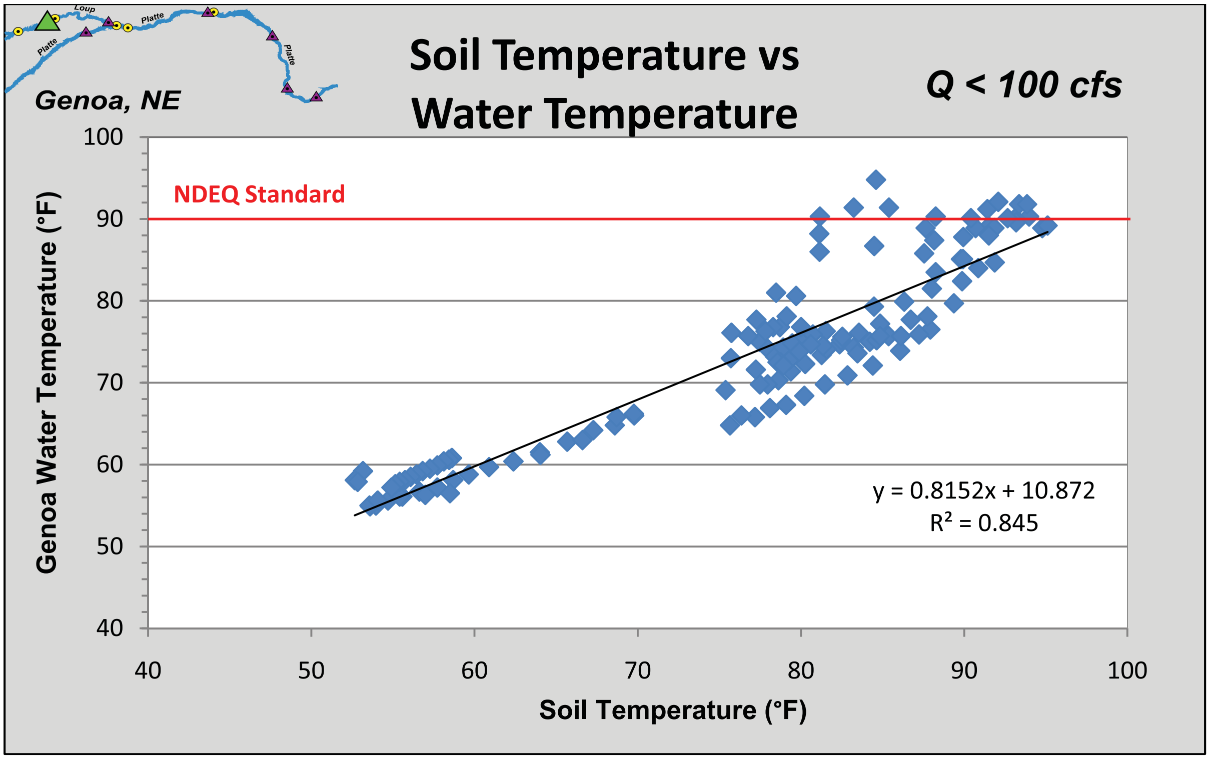


Figure 5-29. Soil Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 100 cfs

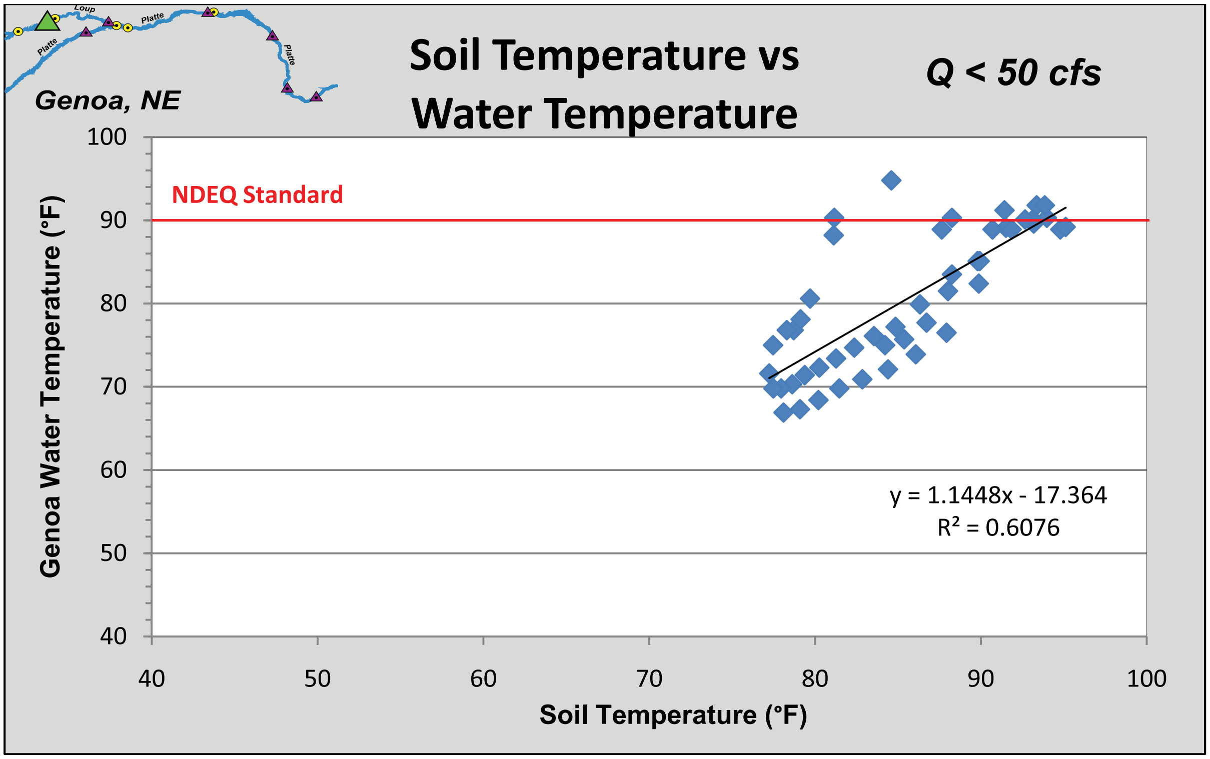


Figure 5-30. Soil Temperature vs. Water Temperature, Loup River near Genoa, Flows Less than 50 cfs

5.3.3 Water Temperature Relationship with Relative Humidity and Radiative Flux

Comparisons were also made between water temperature at Genoa and relative humidity as well as radiative flux (see Figures 5-31 and 5-32, respectively). Results indicate no statistically significant relationships (ANOVA, alpha = 0.05) between these parameters. Weekly and monthly plots of the same variables yielded similar results (see Attachments E and F).

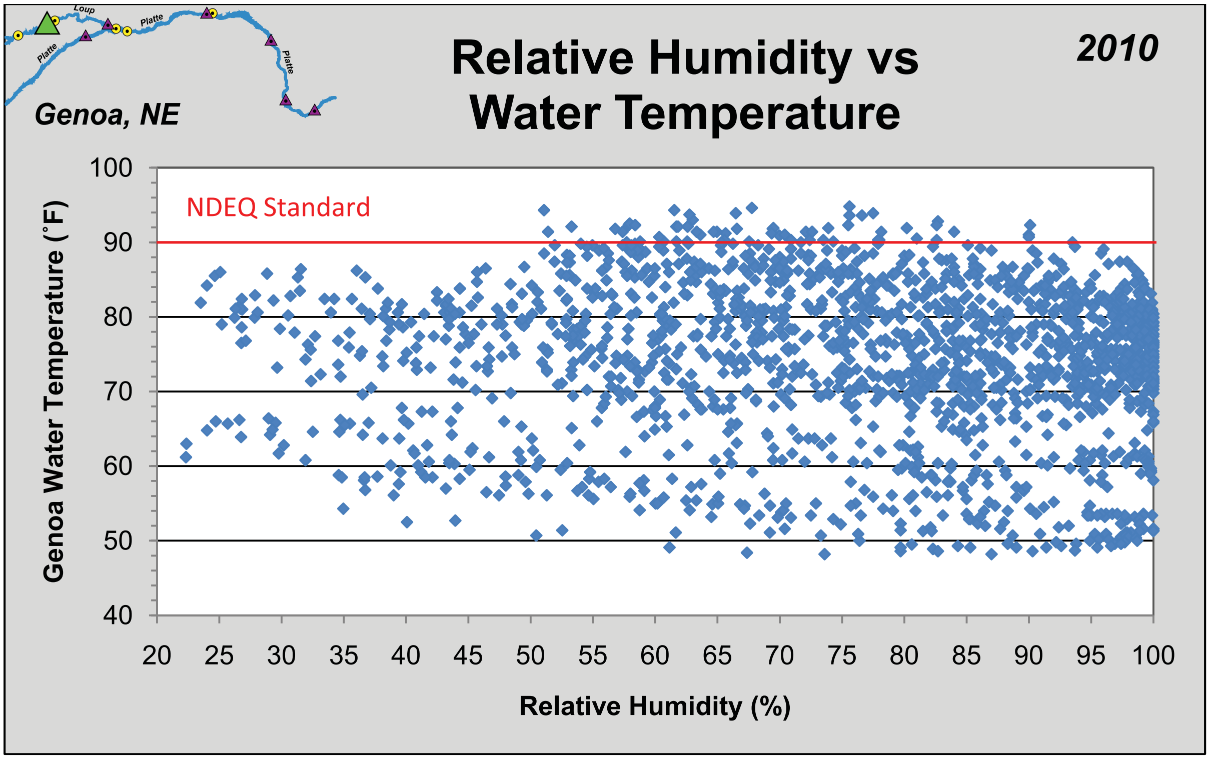


Figure 5-31. Relative Humidity vs. Water Temperature, Loup River near Genoa

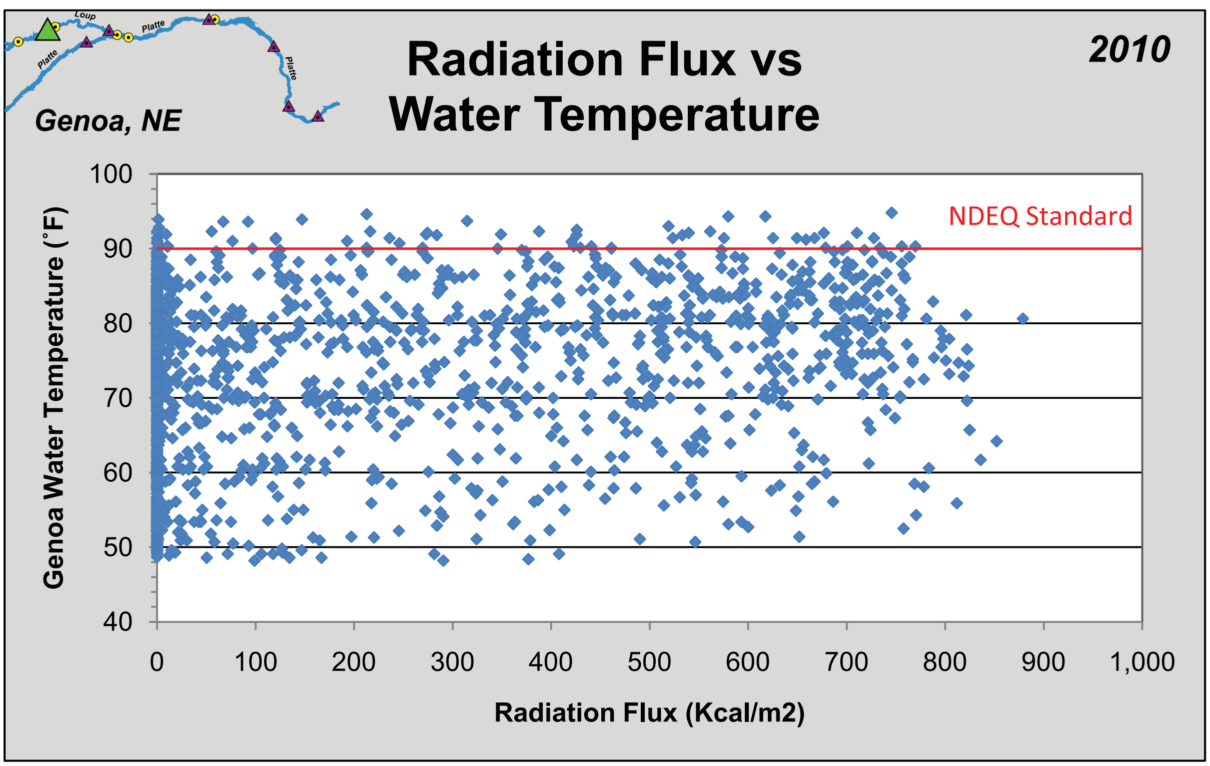


Figure 5-32. Radiative Flux vs. Water Temperature, Loup River near Genoa

5.3.4 Daily Maximum Relationships

An analysis was performed to determine if a statistically significant relationship could be found between daily maximum air temperature and daily maximum water temperature. Figure 5-33 presents a direct comparison between daily maximum air temperature and daily maximum water temperature for the Loup River near Genoa. There is a statistically significant relationship (ANOVA, alpha = 0.05) between the daily maximum air temperature and the daily maximum water temperature. Section5.3.5 further explores this relationship.

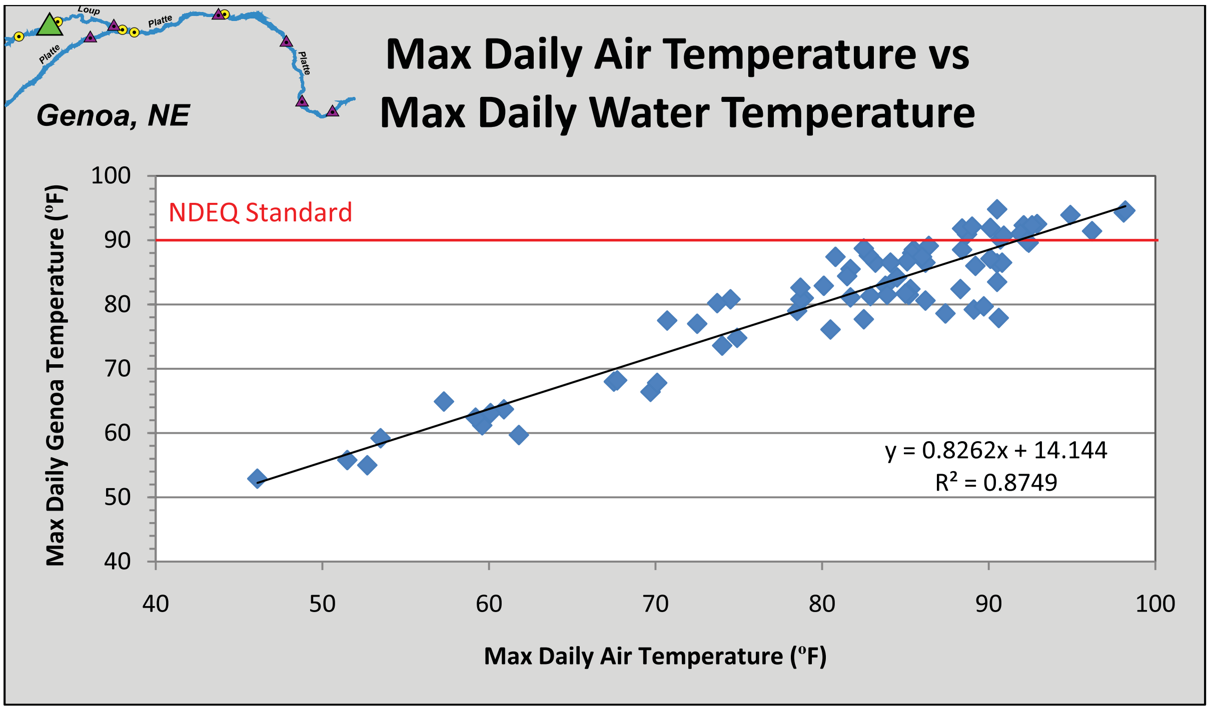


Figure 5-33. Daily Maximum Air Temperature vs. Daily Maximum Water Temperature, Loup River near Genoa

An analysis was performed to determine if a statistically significant relationship could be found between daily maximum soil temperature and daily maximum water temperature. Figure 5-34 presents a direct comparison between daily maximum soil temperature and daily maximum water temperature for the Loup River near Genoa. There is a statistically significant relationship (ANOVA, alpha = 0.05) between the daily maximum soil temperature and the daily maximum water temperature. Section5.3.5 further explores this relationship.

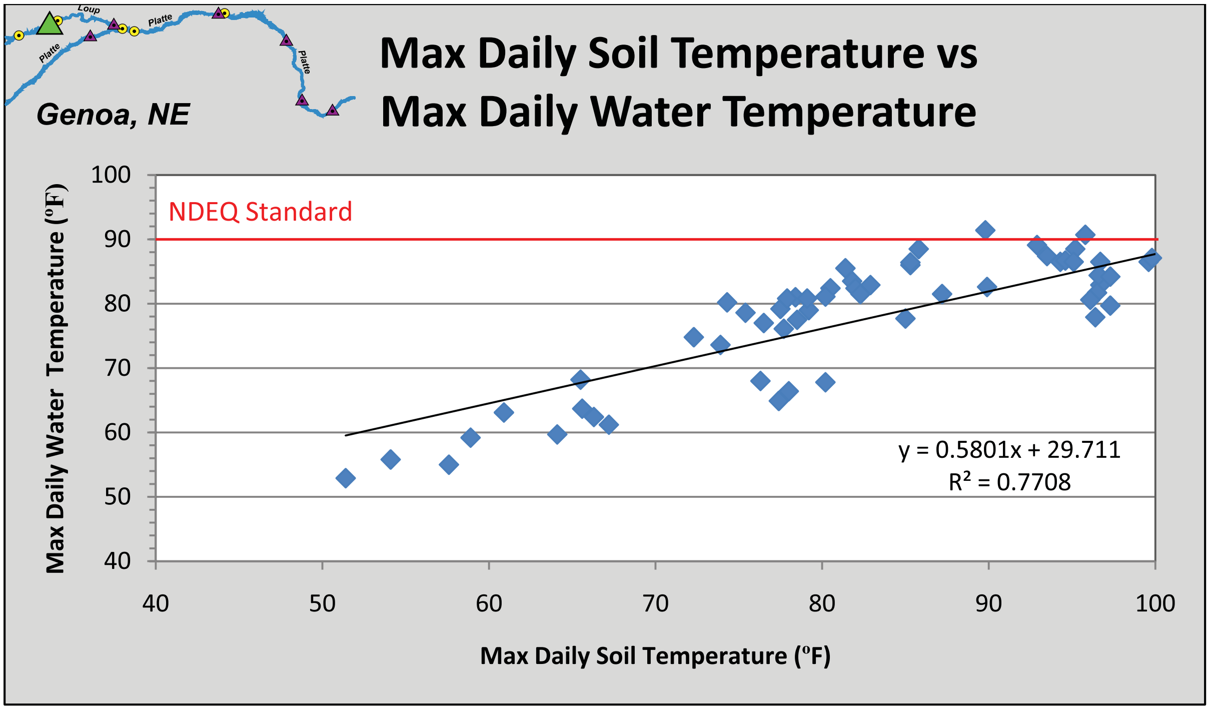


Figure 5-34. Daily Maximum Soil Temperature vs. Daily Maximum Water Temperature, Loup River near Genoa

5.3.5 Multiple Water Temperature Analysis for the Loup River near Genoa

Table 5-3 summarizes the results of linear regression analyses performed for water temperature in the Loup River near Genoa.

Table 5-3. Linear Regression Analysis for Water Temperature, Loup River near Genoa

First Variable	Second Variable	Third Variable	Daily Means		Daily Minimums		Daily Maximums		All Data	
			R^2 value	P value	R^2 value	P value	R^2 value	P value	R^2 value	P value
AIRTEMP			0.894	< 0.001	0.809	< 0.001	0.875	< 0.001	0.745	< 0.001
SOILTEMP			0.949	< 0.001	0.838	< 0.001	0.771	< 0.001	0.738	< 0.001
MERCHTEMP			0.964	< 0.001	0.897	< 0.001	0.973	< 0.001	0.927	< 0.001
GENOAFLOW			0.048	0.055	0.167	< 0.001	0.003	0.610	0.042	< 0.001
RELHUM			0.023	0.182	0.019	0.223	0.012	0.330	0.027	< 0.001
SOLAR			0.220	< 0.001	N/A	N/A	0.369	< 0.001	0.033	< 0.001
AIRTEMP	RELHUM		0.908	< 0.001	0.811	< 0.001	0.908	< 0.001	0.803	< 0.001
AIRTEMP	SOILTEMP		0.953	< 0.001	0.850	< 0.001	0.913	< 0.001	0.779	< 0.001
AIRTEMP	SOLAR		0.895	< 0.001	N/A	N/A	0.875	< 0.001	0.825	< 0.001
AIRTEMP	MERCHTEMP		0.966	< 0.001	0.907	< 0.001	0.976	< 0.001	0.943	< 0.001
SOILTEMP	RELHUM		0.952	< 0.001	0.838	< 0.001	0.772	< 0.001	0.781	< 0.001
SOILTEMP	SOLAR		0.949	< 0.001	N/A	N/A	0.810	< 0.001	0.814	< 0.001
SOILTEMP	MERCHTEMP		0.971	< 0.001	0.906	< 0.001	0.973	< 0.001	0.95	< 0.001
RELHUM	SOLAR		0.414	< 0.001	N/A	N/A	0.410	< 0.001	0.037	< 0.001
AIRTEMP	SOILTEMP	MERCHTEMP	0.972	< 0.001	0.909	< 0.001	0.977	< 0.001	0.951	< 0.001
All Variables			0.978	< 0.001	0.949	< 0.001	0.982	< 0.001	0.954	< 0.001

Note: Hourly data were used for all analyses. AIRTEMP (air temperature, F), SOILTEMP (soil temperature, F), SOLAR (radiative flux, Kcal/m2), and RELHUM (%) were all measured at Monroe, NE. MERCHTEMP (water temperature at Merchiston, F), GENOAFLOW (water discharge at Genoa, cfs). Daily minima for SOLAR were always zero.

Single and multiple linear regressions were performed to determine which factor(s) could best explain the temperature of the water in the Loup River near Genoa. The data that were used include all data collected; that is, all of the daily means, daily minimums, and daily maximums. For example, for the daily maximums, the maximum measured temperature of the water in the Loup River near Genoa and the maximum soil temperature measured at Monroe for that day would be one data point on the plot.

The first set of data in the table are single-variable linear regressions with air temperature, soil temperature, temperature of the water in the Loup River at Merchiston, water flow in the Loup River near Genoa, relative humidity at Monroe, and radiative flux at Monroe as the independent variables and water temperature in the Loup River near Genoa as the dependant variable. The next set of data in the table show the results of multiple linear regression using combinations of the same variables.

The data in the table indicate that the temperature of the water in the Loup River at Merchiston is the best predictor of water temperature in the Loup River near Genoa, while air temperature and soil temperature are the second best predictors. The multiple linear regression data in the table indicate that combining independent variables may be able to only slightly improve the prediction. Additionally, the table shows that flow, relative humidity, and radiative flux are poor predictors of water temperature in the Loup River near Genoa.

Analysis of Daily Maximum Water Temperatures

Daily maximum water temperature readings in the Genoa reach (n = 78) provide the least dispersed measures of association among water temperature, air temperature, relative humidity, and flow because the critical range encompasses only those water temperature readings that approach or exceed the critical threshold of 90˚F. The entire range of daily water temperature readings contains a majority of values, and a majority of variance about the mean values, unrelated to the critical range. Daily maximum water temperatures in the Genoa reach range from 52.90 to 94.80˚F, and daily maximum air temperatures range from 46.10 to 98.20˚F. The median daily maximum water temperature was 82.90˚F; 75 percent of water temperature readings were at or below 88.55˚F.

Multiple Logistic Regression Model of Daily Maximum Water Temperatures

The 75^{th} percentile range of maximum daily water temperature readings (88.55˚F) was used as the cut point to code the daily maximum water temperature values for a binary contrast. All values below the 75^{th} percentile range (n = 59) received a contrast code of 0, and all values above the cut point (n = 19) received a contrast code of 1. The contrast-coded temperature values served as the dependent variable in a three-step hierarchical logistic regression model that assessed the relationship among air temperature, relative humidity, and rate of flow on the likelihood of daily maximum water temperature reaching or exceeding the 75th percentile range.

Variables entered the model in the following sequence: Step 0 – no variables, Step 1 – Air Temperature (AT) entered the model, Step 2 –Relative Humidity (RH) entered the model, Step 3 – Rate of Flow (F) entered the model. Table 5-4 summarizes the results.

Table 5-4. Summary of a Hierarchical Logistic Regression Model using Three Combinations of Predictors to Estimate the Probability of Maximum Daily Water Temperature Reaching a Critical Threshold Based on Daily Maximum Water Temperature Readings

Step	Variables in the Model[1]	Pseudo R^2	True Positive Rate (Sensitivity)	True Negative Rate (Specificity)	False Positive Rate (False Alarms)	False Negative Rate (Misses)
0	None	0	0.500	0.500	0.500	0.500
1	AT	0.647	0.737	0.914	0.086	0.263
2	AT, RH	0.790	0.895	0.966	0.034	0.105
3	AT, RH, F	0.807	0.895	0.948	0.052	0.105

Note:
1 AT = Air Temperature, RH = Relative Humidity, F = Rate of Flow

On step 0, in which no data are entered into the model, expected correct and incorrect classification rates were 50 percent, reflecting random outcomes. On step 1, Air Temperature alone accounts for approximately 65 percent of the variance in the dichotomized maximum daily water temperature values, per the Nagelkerke pseudo R^2 estimate for logistic models. On this step, daily maximum water temperatures reaching or exceeding the 75th percentile range are correctly classified in about 74 percent of cases, and those values remaining below the 75th percentile range are correctly classified in about 91 percent of cases. The false positive rate (1-true negative rate) is low, but the more detrimental false negative rate (1-true positive rate) is fairly high at approximately 26 percent. This suggests that if air temperature alone were used as a predictor of daily maximum water temperatures, about 26 percent of temperature excursions reaching or exceeding the 75th percentile range would be missed. From a fisheries management perspective, the false positive rate is benign because false alarms do not result in fish mortalities, whereas false negatives or misses are detrimental because unanticipated fish mortalities can occur.

On step 2, the inclusion of Relative Humidity increases the proportion of variance in dichotomized water temperature explained by the model by approximately 15 percent; the true positive rate increases by a similar margin, and the true negative rate increases to nearly 97 percent. These changes reduce the false positive rate to about 3 percent and the false negative rate to 10.5 percent, which is a significant improvement over false negative rates on step 1. The linear combination of Air Temperature and Relative Humidity significantly improves correct classification rates over the use of Air Temperature alone as a predictor variable. The odds ratio associated with Air Temperature in the logistic regression equation on step 2 is 2.188, indicating for each positive unit change in Air Temperature, water temperature is 2.188 times more likely to reach or exceed the 75th percentile range (Menard, 2002). The odds ratio associated with Relative Humidity is 1.472. Air Temperature is the "fastest moving" predictor of water temperature, but Relative Humidity acts synergistically with air temperature in this regard.

The inclusion of Flow in the model on step 3 increases the proportion of variance in dichotomized daily maximum water temperature explained by the model by only 1.07 percent, which is less than the standard error of the regression coefficient associated with Flow. The true positive rate is unchanged, and the true negative rate decreases by about 1 percent when Flow enters the model. The odds ratio associated with flow in the logistic regression equation on step 3 is 0.527. Flow makes no measureable contribution to the classification of dichotomized maximum daily water temperature readings. The inclusion of flow in the model slightly increases the false positive rate, such that overall, the variable's inclusion is somewhat detrimental to the model's performance. The false negative rate is unchanged, indicating that a false negative rate of 10.5 percent is the best that can be obtained without a more complex model. Figure 5-35 illustrates changes in true positive and true negative rates at each step of the logistic regression model.

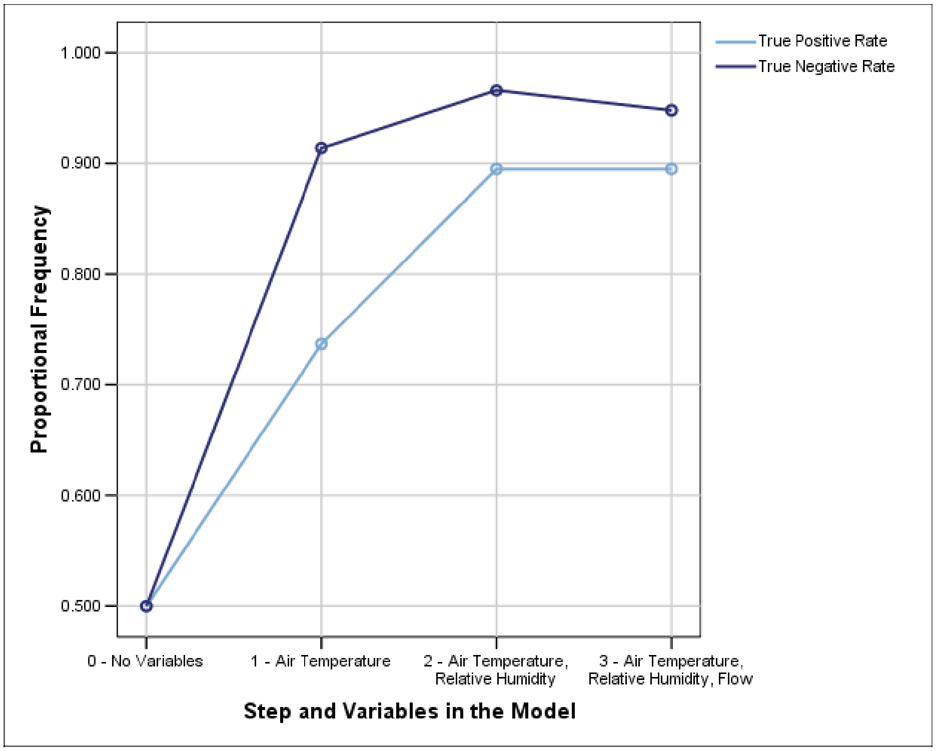


Figure 5-35. Correct Classification Rates of Maximum Water Temperatures Reaching or Exceeding the 75th Percentile Rank in a Logistic Regression Model

The true positive rate is also referred to as sensitivity, the conditional probability that the model correctly classifies a critical temperature event when one actually occurs. The true negative rate is also referred to as specificity, the conditional probability that the model correctly classifies events below the critical temperature threshold when that is the actual case (Agresti, 2002). The current model on step 2, without Flow as a predictor, achieves 91.38 percent accuracy (true positive rate +true negative rate/n), indicating it reliably measures what it is intended to measure. The model's precision, which is a measure of repeatability (Taylor, 1999), is somewhat lower at 75.86 percent (true positive rate/true positive rate + false positive rate). The model's performance is not improved by including Flow as a third predictor variable, indicating flow has no measurable effect on daily maximum water temperatures in the Genoa reach.

The logistic regression model for estimated maximum daily water temperature (Y’) from Air Temperature (AT) and Relative Humidity (RH) is:

$Y' = (0.79\ AT) + (0.388\ RH) - 107.524$.

The probability (P) of the daily maximum water temperature reaching or exceeding the 75th percentile rank is:

$P = e^{Y'}/(1+e^{Y'})$

where *e* is the base natural logarithm 2.71828.

Figure 5-36 illustrates modeled probabilities of daily maximum water temperatures reaching or exceeding the 75th percentile rank in the Genoa reach with relative humidity ranging from 70 to 100 percent.

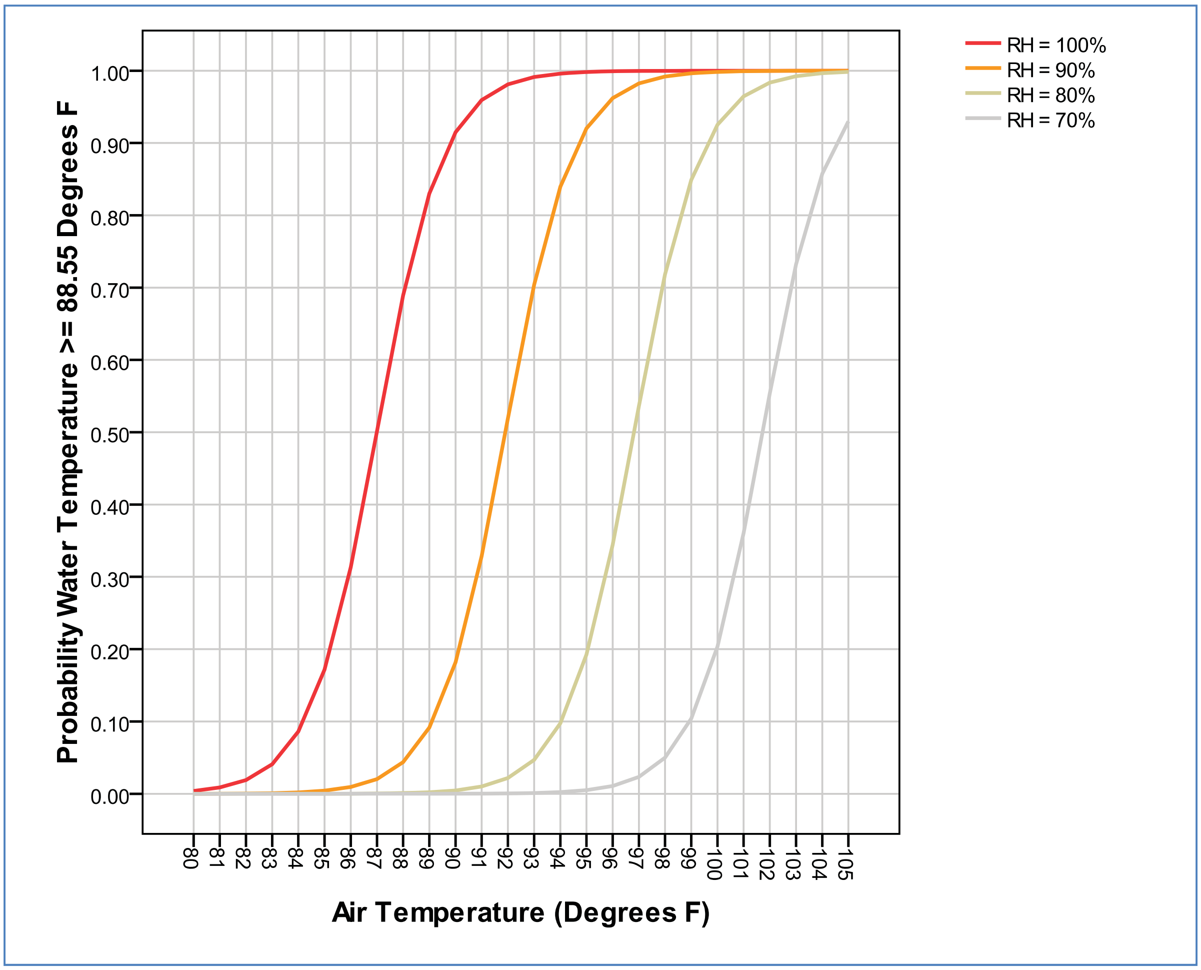


Figure 5-36. Probabilities of Maximum Daily Water Temperature Reaching or Exceeding the 75th Percentile Rank under Four Relative Humidity Conditions with Air Temperatures Ranging from 80 to 105 degrees Fahrenheit

Multiple Linear Regression Model of Daily Maximum Water Temperatures

The same analysis was conducted using multiple linear regression/correlation analysis (MRCA). Whereas the logistic regression analysis provided odds ratios and probabilities of temperature excursions to a threshold, which are useful for predictive purposes, MRCA provides more detailed information about the relationships among air temperature, relative humidity, rate of flow, and water temperature in the Genoa reach.

The use of MRCA, which contains more underlying assumptions about the data than the nonparametric logistic regression procedure, required transformation of the air temperature values, which were moderately left skewed, to cubed values, and transformation of the flow values, which were right skewed, to natural logarithms, following standard procedures outlined by Helsel and Hirsch (2002) and others. The transformed scores are indicated as AT^3 and Log Flow, below. Water temperature values, which were the dependent variable in the MRCA, also required conversion to cubed values to normalize. After transformation, these data sets were within expected limits of a normal distribution, per Kolmogorov-Smirnov (K-S) one-sample test. Relative humidity values, which were strongly left skewed, could not be normalized and were used in the analysis in raw format. Post-test analysis of regression standardized residuals indicated that although these values were multimodal and somewhat left skewed (Figure 5-37), they did not deviate measurably from a normal distribution per K-S one-sample test ($Z = 0.863$, $P = 0.445$). These results indicated that the use of relative humidity data in raw format did not compromise the validity of MRCA.

The MRCA, which followed the same three steps as the logistic regression analysis, provided details about the proportion of variance in water temperature associated with each step of the analysis, the effect size (*B*) and associated relative standard error (R.S.E. *B*), and standardized regression weight (β) of each predictor variable. In addition, each predictor variable's bivariate correlation coefficient (*r*), partial correlation coefficient (*pr*), and semi-partial correlation coefficient (*sr*) were generated for analysis. The squared partial and semi partial correlation coefficients (pr^2, sr^2, respectively) indicate the proportion of total variance in water temperature that is uniquely associated with the predictor variable of interest after removing the effects of other predictors from (1) the dependent variable and (2) the dependent variable and the predictor variable of interest. Results of the MRCA are summarized in Table 5-5. The 95 percent confidence intervals of the unstandardized regression coefficients on the final step of the analysis are summarized in Table 5-6.

The MRCA results largely mirror those of the logistic regression analysis in indicating air temperature as the predictor variable most robustly associated with water temperature. However, the MRCA, which leveraged all of the variance in air temperature, revealed additional details about the interactions among predictor variables. Notably, the increase in both air temperature and relative humidity *pr* and *sr* values over the *r* values on step 2, indicate each of these variables suppresses error variance in the other when combined in a linear regression equation. Air temperature suppresses significantly more error variance in relative humidity than vice verse, as indicated by differences between the *r* and *pr* values. After removing all variance from water temperature and relative humidity that is associated with air temperature, relative humidity accounts for only 5 percent of the variance in water temperature ($sr^2_{RH} = 0.05$)whereas air temperature accounts for 85 percent of the variance in water temperature ($sr^2_{AT}{}^3 = 0.85$).

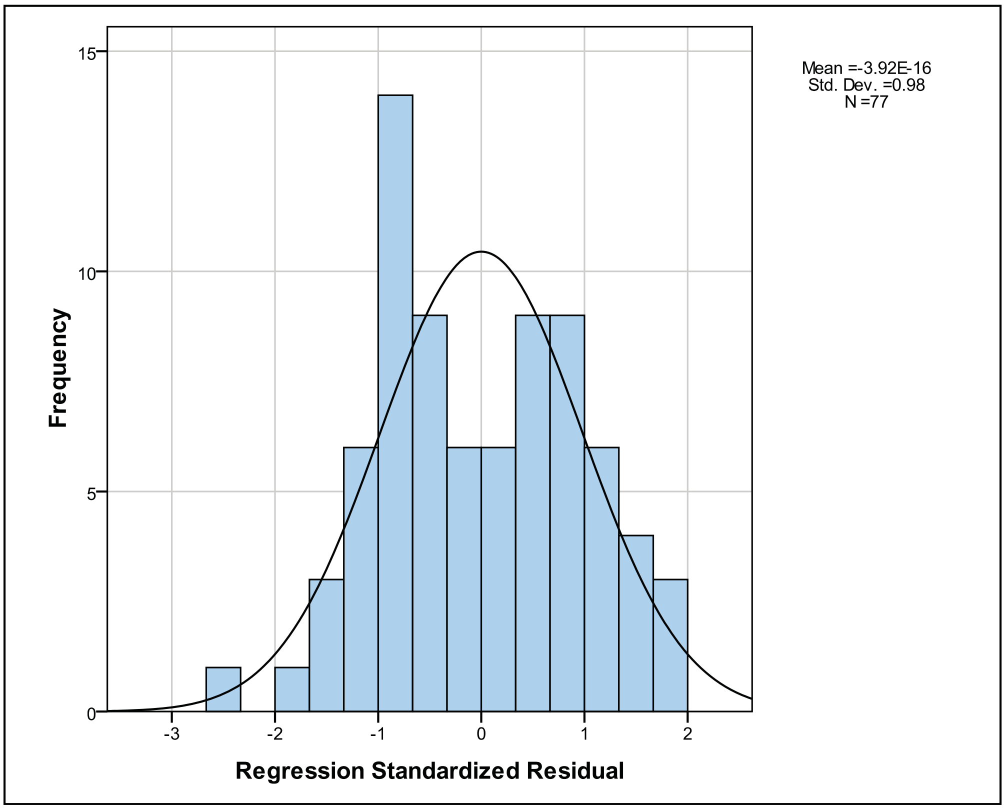


Figure 5-37. Histogram of Regression Standardized Residuals with Fitted Normal Curve Superimposed

On step 3, Log Flow is associated with a very high relative standard error of prediction. The direction of this variable's correlation with water temperature changes when combined with the other predictor variables, indicating the other predictors are suppressing a large reservoir of error variance in flow (Cohen and Cohen, 1988). After removing the effects of the other predictor variables from Log Flow and the dependent variable, Log Flow accounts for no measurable variance in water temperature ($sr^2_{LogFlow} = 0.000$).

If flow were used as the sole predictor of water temperature in a bivariate regression equation, the variable would appear to account for approximately 2 percent of the variance ($r = 0.156$, $r^2 = 0.024$). However, this modest contribution collapses to zero when all predictors are combined in a multiple regression equation. The resulting sum of squared semi-partial correlation coefficients on step 3 of the analysis (0.83) is 2 percent less than on step 2, indicating all of the relationship between water temperature and flow represents error variance. This is corroborated by the fact that, unlike the other predictor variables, the 95 percent confidence interval of *B* for Log Flow contains zero (Table 5-6). This makes it impossible to reject the null hypothesis that the true value of $B_{\text{Log Flow}}$ (the population regression coefficient) is zero and no correlation exists between flow and water temperature (Tabachnick and Fidel, 1996).

Table 5-5. Summary of MRCA Results for Daily Maximum Water Temperature Readings

Step	Adjusted R^2	Predictors	*B*	R.S.E. *B*	β	*r*	*pr*	*sr*	pr^2	sr^2
1	0.824	AT^3	0.824	5.3%	0.909	0.909	0.909	0.909	0.824	0.824
2	0.870	AT^3	0.840	4.5%	0.927	0.909	0.933	0.924	0.871	0.850
		RH	5323	1.9%	0.217	0.141	0.519	0.216	0.269	0.05
3	0.868	AT^3	0.842	4.5%	0.929	0.909	0.932	0.913	0.869	0.830
		RH	5365	1.9%	0.219	0.141	0.520	0.217	0.270	0.05
		Log Flow	-2243	284%	-0.15	0.156	-0.041	-0.015	0.002	0.000

Table 5-6. 95 Percent Confidence Intervals of Unstandardized Regression Coefficients on Step 3 of the MRCA

Predictors	95% Confidence Interval of *B*	
	Lower Bound	Upper Bound
AT^3	0.766	0.919
RH	3308.237	7420.416
Log Flow	-14949.092	10462.422

Analyses of All Water Temperature Readings above 63 Degrees Fahrenheit

Results of the above analyses serve as baselines for evaluation of the entire set of water temperature readings in the Genoa reach (n = 1,778), of which only 3.8 percent (n = 74) exceed 89.50˚F. During those events when water temperature reached or exceeded the critical threshold, flow readings ranged from 30 to 1,490 cfs.

Several problems arise in attempting to analyze the entire data set, however. Temperature readings are significantly left skewed due to a cluster of readings below 63˚F (which have no bearing on the temperature range of interest). Approximating a normal distribution requires three steps: (1) filtering of values less than 63, (2) conversion to cubes, and (3) conversion of the cubed values to natural logarithms. Even after those transformations, the values, although reasonably symmetric, are not fully normalized (Figure 5-38).

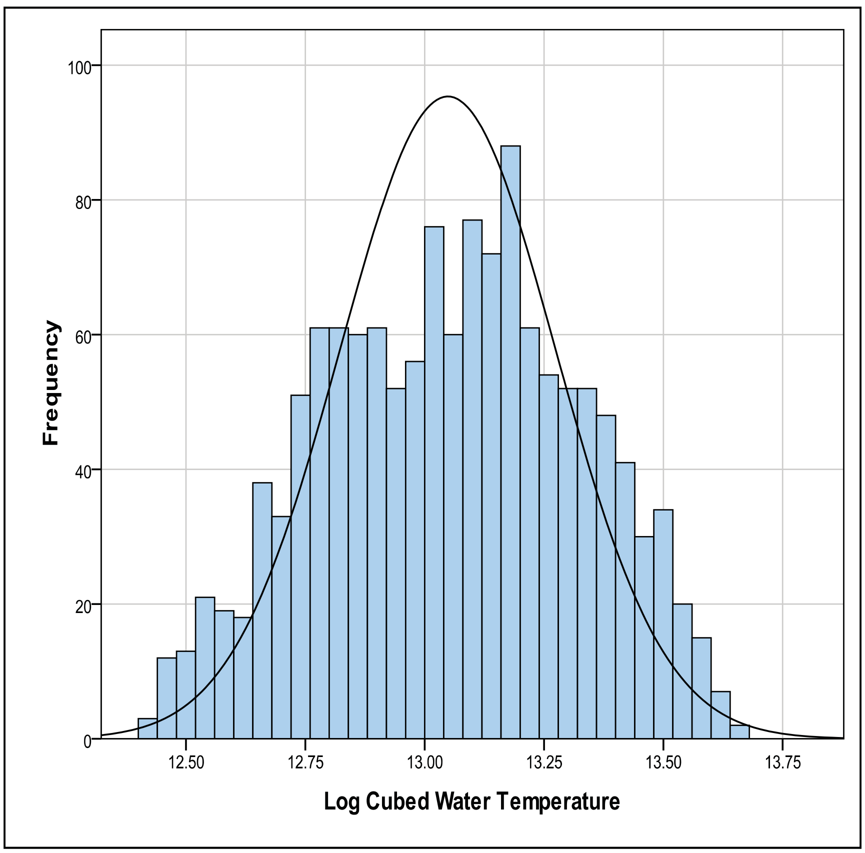


Figure 5-38. Histogram of All Water Temperature Readings above 63 Degrees Fahrenheit in the Genoa Reach after Transformations with Fitted Normal Curve Superimposed (n = 1,348)

Flow readings, which are extremely right skewed, cannot be normalized satisfactorily. The best approximation of a somewhat symmetrical distribution is obtained by a reciprocal root conversion (Helsel and Hirsch, 2002). Relative humidity values are similarly problematic. However, since the role of relative humidity is demonstrated to be auxiliary to air temperature, this variable can be omitted from a linear regression analysis that focuses on the rolls of air temperature and flow as mediators of water temperature. Air temperature readings for the larger sample are normally distributed.

Multiple Logistic Regression Model of Daily Water Temperatures above 63 Degrees Fahrenheit

Logistic regression analysis of the entire sample of water temperature readings above 63˚F follows the same procedures used for the daily maximum values. For this larger sample of readings, the 75th percentile rank occurs at 82.94˚F, which is the cut point for dichotomized water temperature readings used as the dependent variable in a three-step model.

Despite the significantly increased sample size, which should augment power (the ability to detect a genuine effect), results of the logistic regression analysis using the larger sample of 1,346 readings are considerably attenuated in relation to the results using only daily maximum readings. The true positive rate does not exceed 61.50 percent, resulting in an unacceptably high false negative rate of 38.50 percent. The model performs well, however, in predicting when temperatures will not reach or exceed the 75th percentile rank, with a true negative rate of 92.40 percent. These results are summarized in Table 5-7.

The overall odds ratio based on estimated group memberships on step three of this model is 1:19.39. Use of the model makes a correct prediction in either direction 19.39 times more likely than a random process. However, the odds of correctly predicting a temperature excursion into the 75th percentile range are only 2.04 times better than guessing. The odds ratio associated with flow in the logistic regression equation is 1.0, indicating no measurable contribution. Removing flow from the model decreases the omnibus odds ratio of making a correct classification in either direction to 1:18.17. The true positive rate increases slightly, such that the odds associated with correctly predicting a temperature excursion into the 75th percentile rank increase to 1:2.34. These changes are trivial and demonstrate a lack of predictive utility for flow measurements.

Table 5-7. Summary of a Hierarchical Logistic Regression Model using Three Combinations of Predictors to Estimate the Probability of Maximum Daily Water Temperature Reaching a Critical Threshold Based on all Water Temperature Readings above 63 Degrees Fahrenheit

Step	Variables in the Model	Pseudo R^2	True Positive Rate (Sensitivity)	True Negative Rate (Specificity)	False Positive Rate (False Alarms)	False Negative Rate (Misses)
0	None	0	0.500	0.500	0.500	0.500
1	AT	0.469	0.536	0.905	0.095	0.464
2	AT, RH	0.557	0.607	0.922	0.078	0.393
3	AT, RH, F	0.558	0.615	0.924	0.076	0.385

Multiple Linear Regression Model of Daily Water Temperatures above 63 Degrees Fahrenheit

The multiple linear regression analysis of the larger sample of readings omitted relative humidity, as noted above, and as such was a two-step model. Air temperature (AT) entered the model on step one, and the reciprocal root-converted flow values (Recip. Rt. Flow) entered on step two with the log and cube-transformed water temperatures as the dependent variable. These results are summarized in Table 5-8.

As with the logistic regression model, measurable effects based on the larger sample are attenuated such that air temperature accounts for approximately 52 percent of the variance in water temperature rather than 85 percent when only daily maximum temperatures are assessed. In this expanded sample of values, flow makes no measurable contribution to variance in water temperature. As in the daily maximum temperatures model, the 95 percent confidence interval of the unstandardized regression coefficient for flow (-60346.62 to 104993.43) is extremely large and contains a zero value, indicating that the null hypothesis of no effect must be retained (the 95 percent confidence interval for the unstandardized regression coefficient associated with air temperature ranges from 0.019 to 0.021).

Table 5-8. Summary of MRCA Results for All Daily Water Temperatures above 63 Degrees Fahrenheit

Step	Adjusted R^2	Predictors[1]	*B*	R.S.E. *B*	β	*r*	*pr*	*sr*	pr^2	sr^2
1	0.521	AT	0.020	5.0%	0.722	0.722	0.722	0.909	0.521	0.521
2	0.521	AT	0.020	5.0%	0.721	0.722	0.719	0.717	0.517	0.514
		Recip. Rt. Flow	22323	188%	0.010	0.090	0.014	0.010	<0.01	<0.01

Note:

1 AT = Air Temperature, Recip. Rt. Flow = reciprocal root-converted flow

Considered in concert, the analyses of daily maximum temperatures and the larger sample of water temperatures above 63˚F indicate air temperature is the primary force driving water temperature in the Genoa reach. The effect of air temperature appears to increase as it approaches a maximum value. At lower air temperatures, additional variables not included in the current models, such as soil temperature and vegetation cover, are probably significant mediators of water temperature as well. Flow is not a significant factor in water temperature in the Genoa reach and, as such, appears to have no utility in predicting or controlling water temperatures approaching the critical threshold.

5.3.6 Summary of Water Temperature Analysis for the Loup River near Genoa

During the 2010 study period, temperature excursions above the NDEQ-prescribed 90˚F water quality standard occurred on the Loup River near Genoa on July 22 to 23, July 26 to 27, July 30 to August 2, and August 7 to 13.

Relative to parameters that potentially influence the water temperature in the Loup River near Genoa, analyses performed in association with this study determined the following:

- There is not a statistically significant relationship (ANOVA, alpha = 0.05) between water temperature and flow discharge.
- There is a statistically significant relationship (ANOVA, alpha = 0.05) between water temperature and both air and soil temperatures.
- There is not a statistically significant relationship (ANOVA, alpha = 0.05) between water temperature and either relative humidity or radiative flux.

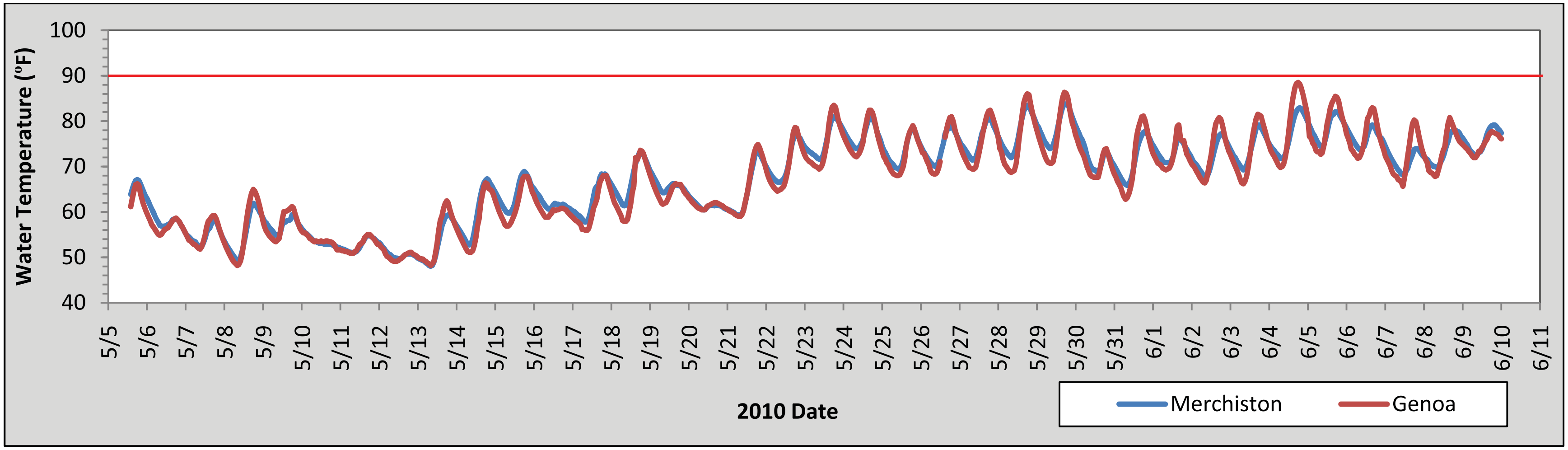
5.4 Water Temperature Comparison of the Loup River at Merchiston and near Genoa

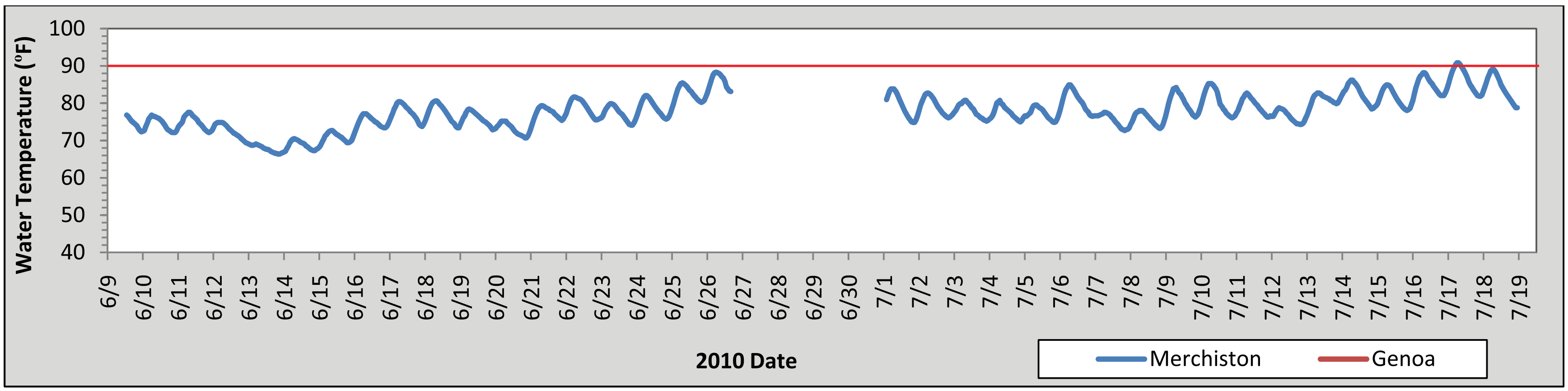
The water temperature data collected along the Loup River at both the Merchiston and Genoa locations are compared below.

5.4.1 Comparative Water Temperature Data

A time-series comparison of water temperatures between the Merchiston and Genoa locations is presented in Figure 5-39. Somewhat synchronous daily oscillations in water temperature are seen for the two locations, with peak daily values tending to be marginally greater at the Genoa location. The gap in Merchiston water temperature data is explained in Section 4, Task 2, and the errant readings for Genoa during late July and early August are explained in Section 5.3.1.

Direct comparisons of water temperatures between the Merchiston and Genoa locations are presented below. There is a statistically significant relationship (ANOVA, alpha = 0.05) between the two stations with respect to water temperature when data from all collected dates are considered, as shown in Figure 5-40). There is an even more significant relationship between these parameters when the July 28 to August 3 data (when the probe was assumed to be exposed) are removed, as shown in Figure 5-41). Weekly and monthly graphical comparisons are located in Attachment G; results are strongly statistically significant except when the July 28 to August 3 data are included.


Water Temperature (ºF)
100
90
80
70
60
50
40
5/5 5/6 5/7 5/8 5/9 5/10 5/11 5/12 5/13 5/14 5/15 5/16 5/17 5/18 5/19 5/20 5/21 5/22 5/23 5/24 5/25 5/26 5/27 5/28 5/29 5/30 5/31 6/1 6/2 6/3 6/4 6/5 6/6 6/7 6/8 6/9 6/10 6/11
2010 Date
Merchiston
Genoa


Water Temperature (ºF)
100
90
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70
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6/9 6/10 6/11 6/12 6/13 6/14 6/15 6/16 6/17 6/18 6/19 6/20 6/21 6/22 6/23 6/24 6/25 6/26 6/27 6/28 6/29 6/30 7/1 7/2 7/3 7/4 7/5 7/6 7/7 7/8 7/9 7/10 7/11 7/12 7/13 7/14 7/15 7/16 7/17 7/18 7/19
2010 Date
Merchiston
Genoa

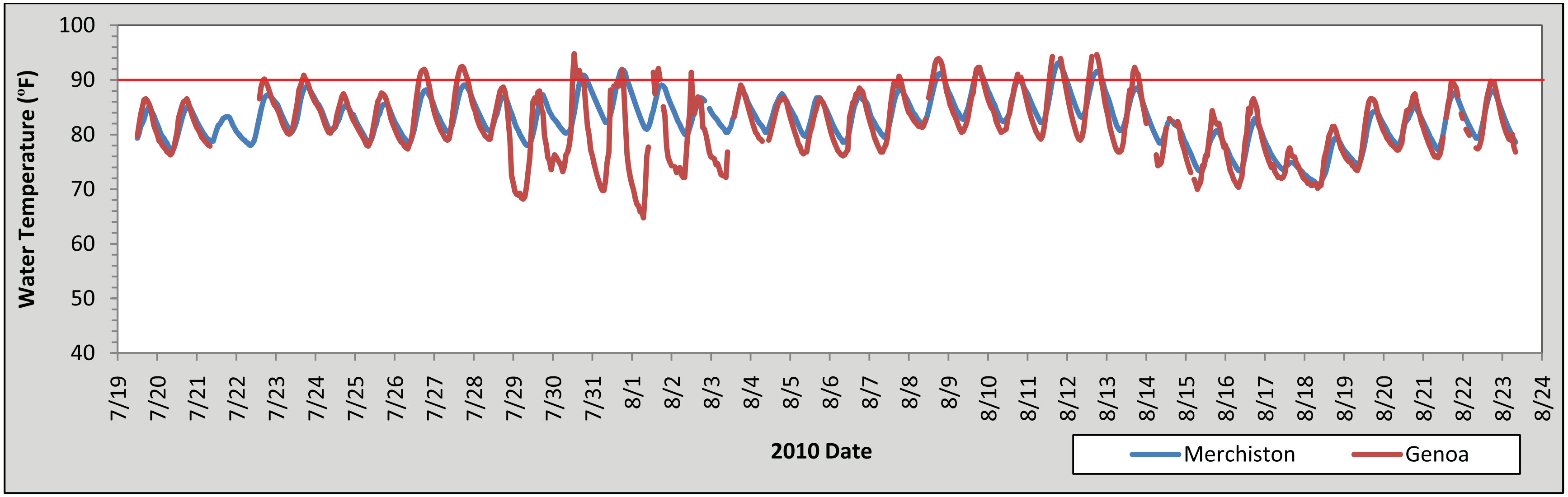

Figure 5-39. Water Temperature Time Series for Loup River at Merchiston and near Genoa

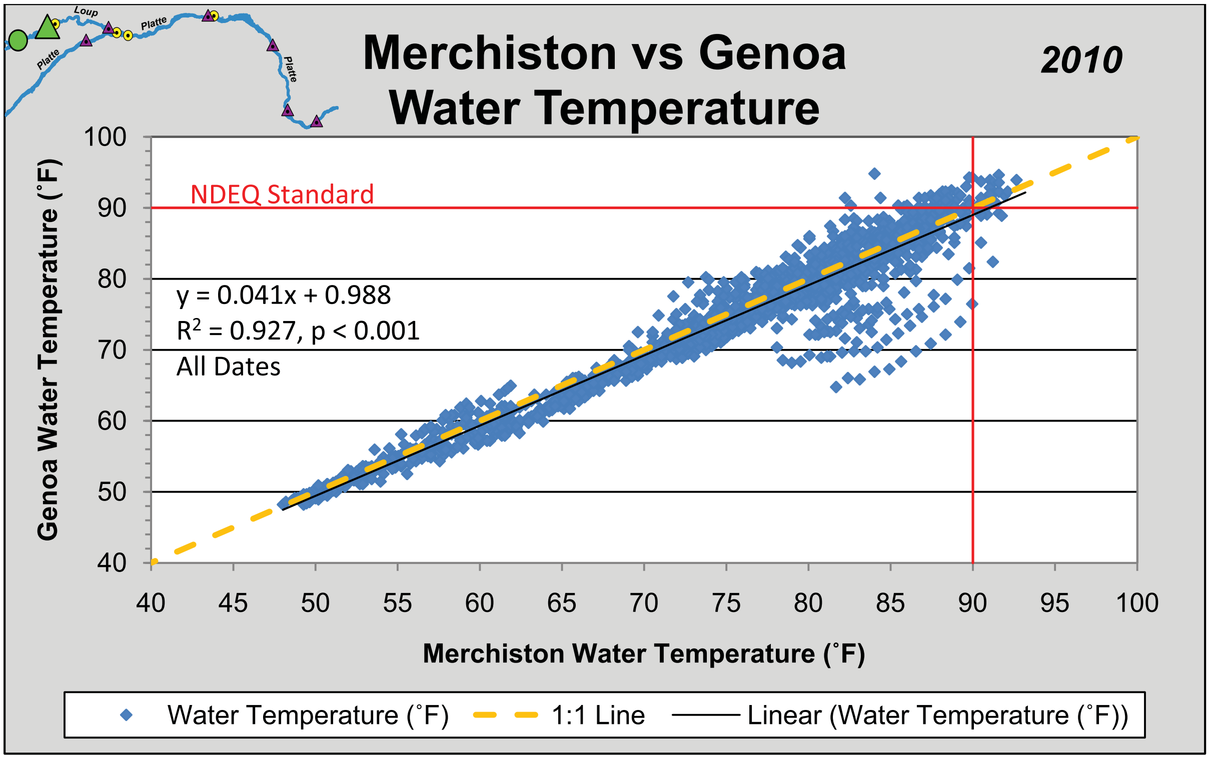

Figure 5-40. Water Temperature Relationship Between Loup River at Merchiston and near Genoa (All Data)

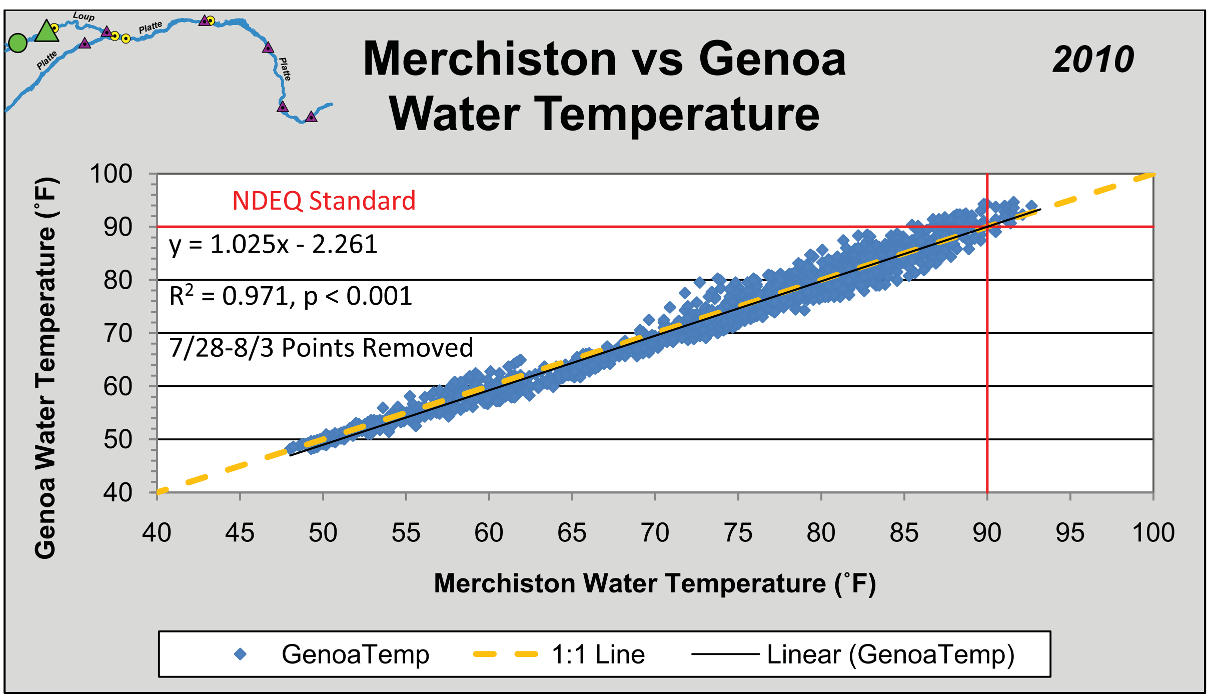

Figure 5-41. Water Temperature Relationship Between Loup River at Merchiston and near Genoa (Errant [Exposed Probe] Data Removed)

5.4.2 Summary of Water Temperature Comparison Between Merchiston and Genoa

Somewhat synchronous daily oscillations in water temperature are seen between the Loup River at Merchiston and the Loup River near Genoa. Additionally, direct comparisons of water temperatures between the sampling locations show a significant relationship between the recorded water temperatures at the two stations.

5.5 Water Temperature Analysis for Loup River at Columbus and the Platte River Bypass Reach

During study development, and in accordance with the Federal Energy Regulatory Commission's (FERC's) Study Plan Determination dated August 26, 2009, it was decided that water temperature should be analyzed not only near Genoa but also along the Loup River downstream of Beaver Creek and within the Platte River bypass reach. To facilitate this request, the District recorded water temperature data at Columbus and within the Platte River.

5.5.1 Comparative Water Temperature Data

The reaches of the Loup River between Genoa and Columbus can be examined by comparing concurrent, available, and overlapping USGS water temperature data collected at both Genoa and Columbus, which took place between May 5 and August 30, 2010. As indicated in Figures 5-42 and 5-43, temperatures are similar between the two locations. Peak daily temperatures during early June are greater at Genoa. For excursions taking place when concurrent data existed (July 22 to 23, July 26 to 27, and August 8 to 10), Genoa was out of compliance for a total of 34 hours compared to 29 hours at Columbus.

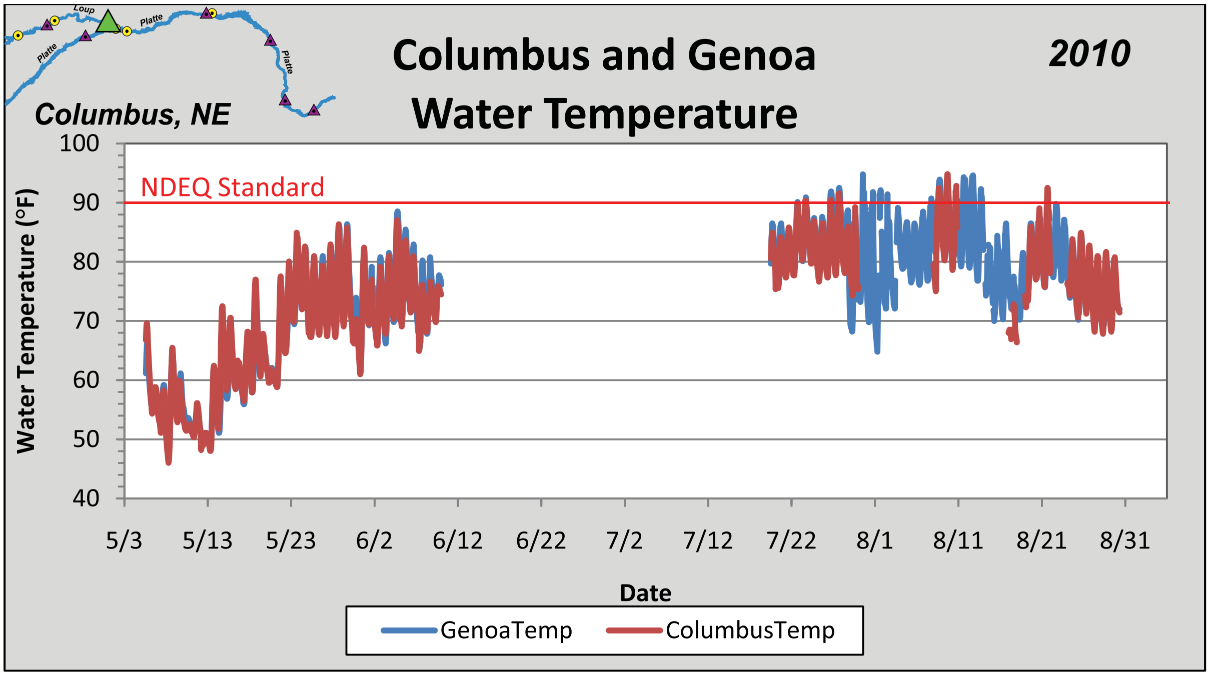

Figure 5-42. Water Temperatures, Loup River near Genoa and at Columbus

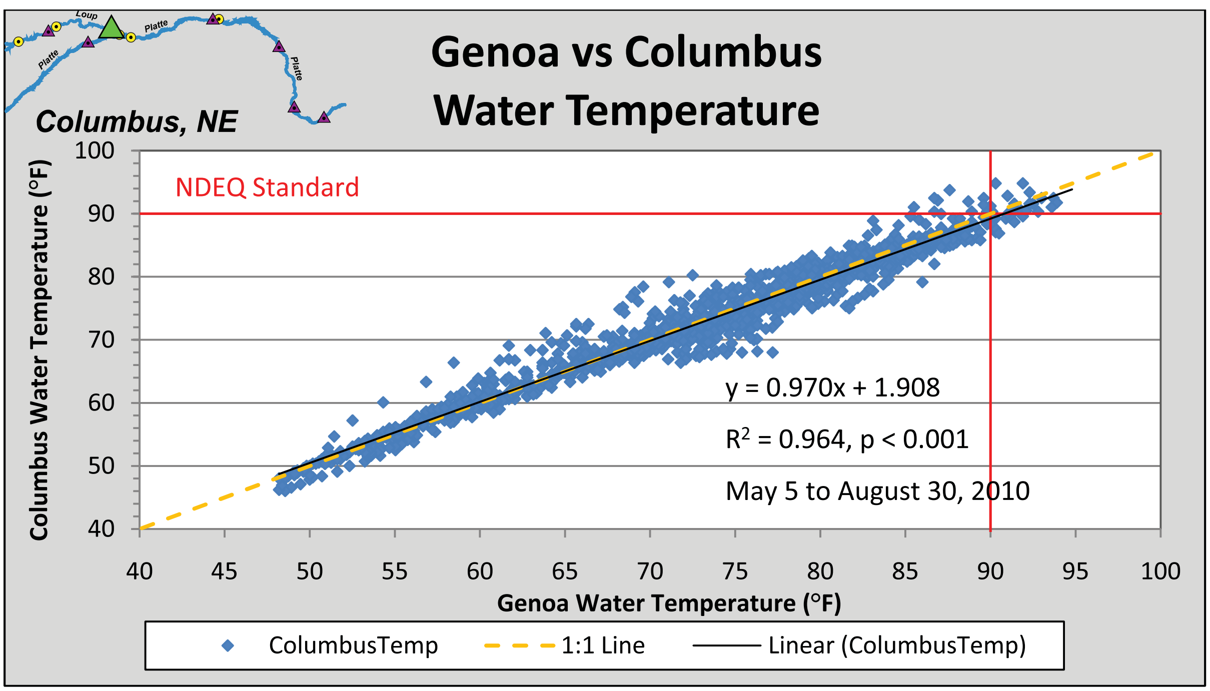

Figure 5-43. Water Temperature Relationship Between Loup River near Genoa and at Columbus

The comparison of water temperature data collected from USGS data at Genoa and and District data loggers at Columbus during August 2010 suggests little difference in behavior on an overall daily basis, as shown in Figure 5-44. The Columbus location tended to exceed that of the Genoa location from mid-morning through the afternoon hours, after which the Genoa location exceeded that of the Columbus location.

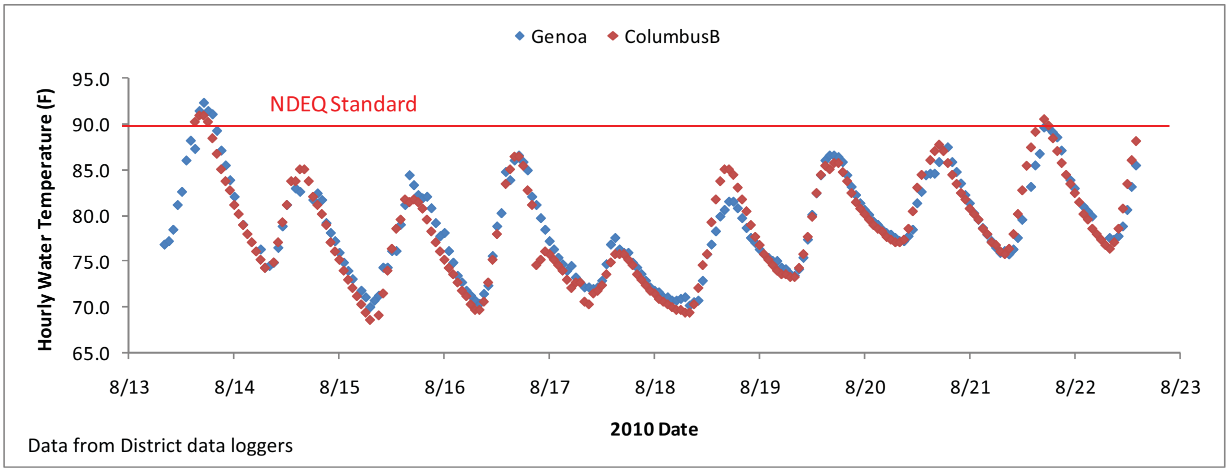

Figure 5-44. August 2010 Water Temperature, Loup River near Genoa and at Columbus

In addition to comparing Genoa water temperature data to District data loggers at Columbus, these data were analyzed relative to the water temperature data collected from District data loggers deployed in the Platte River (Platte A and B and Tailrace A and B) (see Attachment H for data logger methods and precision discussion). This was done by examining mean hourly water temperatures (see Figure 5-45). Results indicate that temperature data collected within the Platte River (Platte A and Tailrace A) have higher hourly mean temperatures compared to both of the Loup River locations at Genoa and Columbus.

One possible explanation for the temperature difference between the Loup River at Columbus and the Platte River upstream of the Tailrace Return is that the higher flows and water temperatures coming from the Platte River exert a strong influence on water temperature just upstream of the Tailrace Return. Stated another way, the Platte River exerts a stronger influence on the water temperature at the Tailrace A sampling location than do the contributing Loup River flows. As depicted in Table 5-2, the Platte River at Duncan contributed over three times more water to the Tailrace A sampling location than the Loup River at Columbus (on average during the period when temperature data were collected).

Although none of the four temperature sampling locations were statistically different (ANOVA, alpha = 0.05) with respect to flow or water temperature, the water temperature values for the Platte A and the Tailrace A locations are quite similar, especially when compared to the "outlying" Columbus B location.

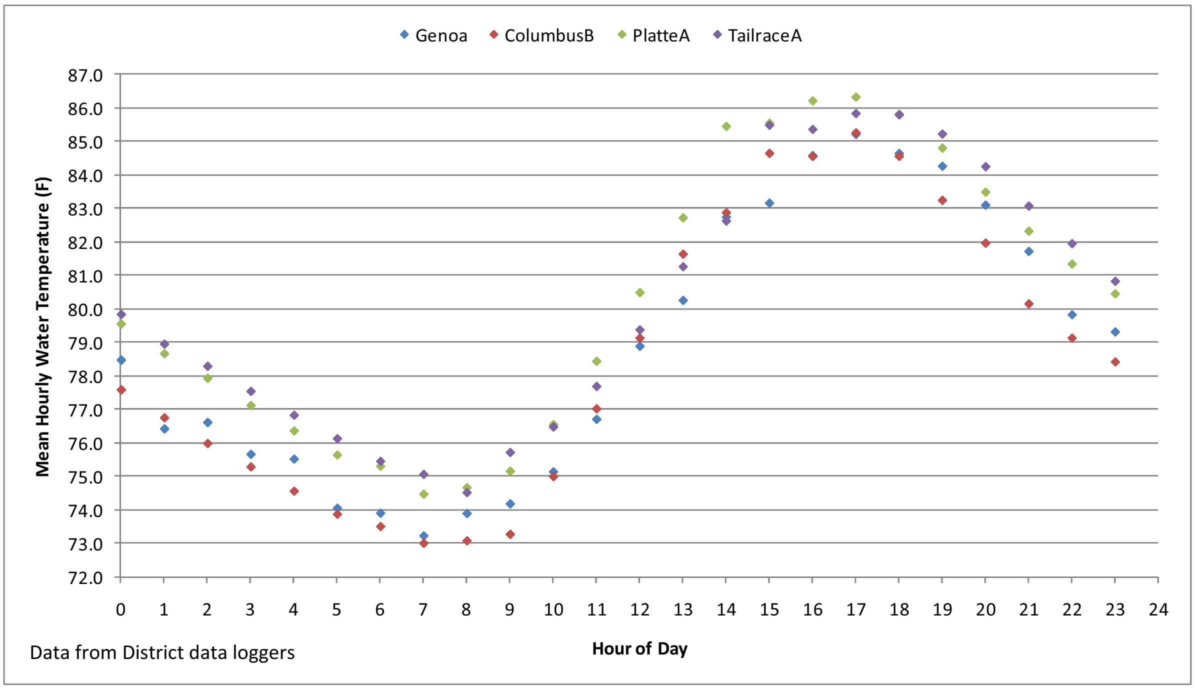

Figure 5-45. Mean Hourly Water Temperatures for Selected Locations

5.5.2 Summary of Water Temperature Reach Comparisons

The reaches of the Loup River between Genoa and Columbus exhibited similar water temperatures during May through August 2010. Comparison of water temperature data collected at Genoa and Columbus suggests little difference in water temperature behavior on an overall daily basis.

Water temperature data collected at the Platte River sampling locations (Platte A and Tailrace A) displayed higher hourly mean temperatures compared to both of the Loup River sampling locations (Genoa and Columbus B). Similarities in water temperature data between the Platte and Tailrace sampling locations suggest that the higher flows, and associated water temperature, supplied to the Tailrace location from the Platte River more greatly influence the water temperature of the Platte River bypass reach than the flows contributed by the Loup River.

5.6 Potential Prediction of Excursion Events on the Loup River near Genoa

The use of daily averages, or equations derived from regression analysis, is not appropriate to predict future excursion events on the Loup River near Genoa. There is too much variability in the relationships between variables to provide an accurate prediction of future dates on which an excursion might occur.

Instead, it was determined that a predictive variable needed to be measurable on the same day that an excursion might occur. In association with study analyses, air temperature was chosen as the parameter with the best associated potential for excursion prediction. Summer 2010 air temperature data at Monroe that were recorded on the mornings that Genoa water temperature excursions took place were examined for trends. It was found that air temperature at 8:00 a.m. provided a relatively accurate predictor of water temperature excursion events later in the day. Figures 5-46 and 5-47 depict the results of this analysis. Figure 5-46 shows that Genoa excursions took place in late July and early August. Close examination of the 8:00 a.m. air temperature indicates that a reading of 74˚F precedes an excursion in most cases. Figure 5-47 focuses on the late July and August period and again illustrates how air temperatures of 74˚F at 8:00 a.m. appear to precede excursion events.

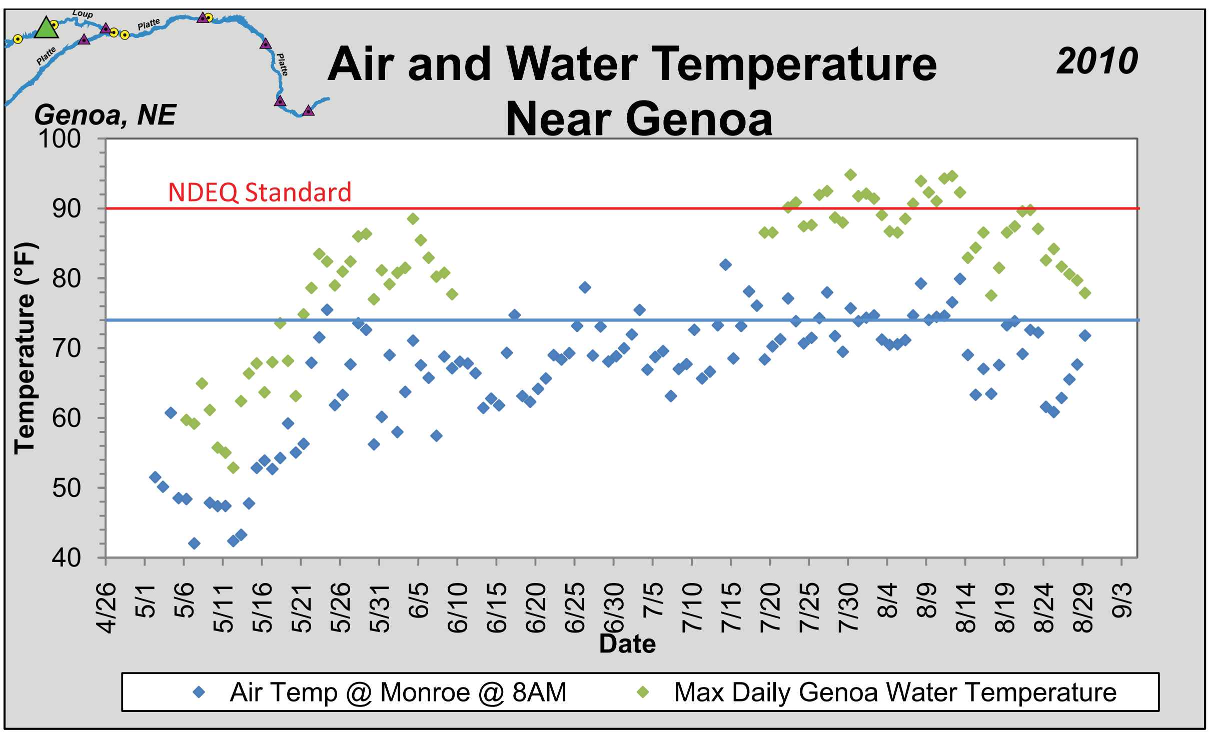

Figure 5-46. 8:00 a.m. Air Temperature and Maximum Daily Water Temperature in the Loup River near Genoa – Summer 2010

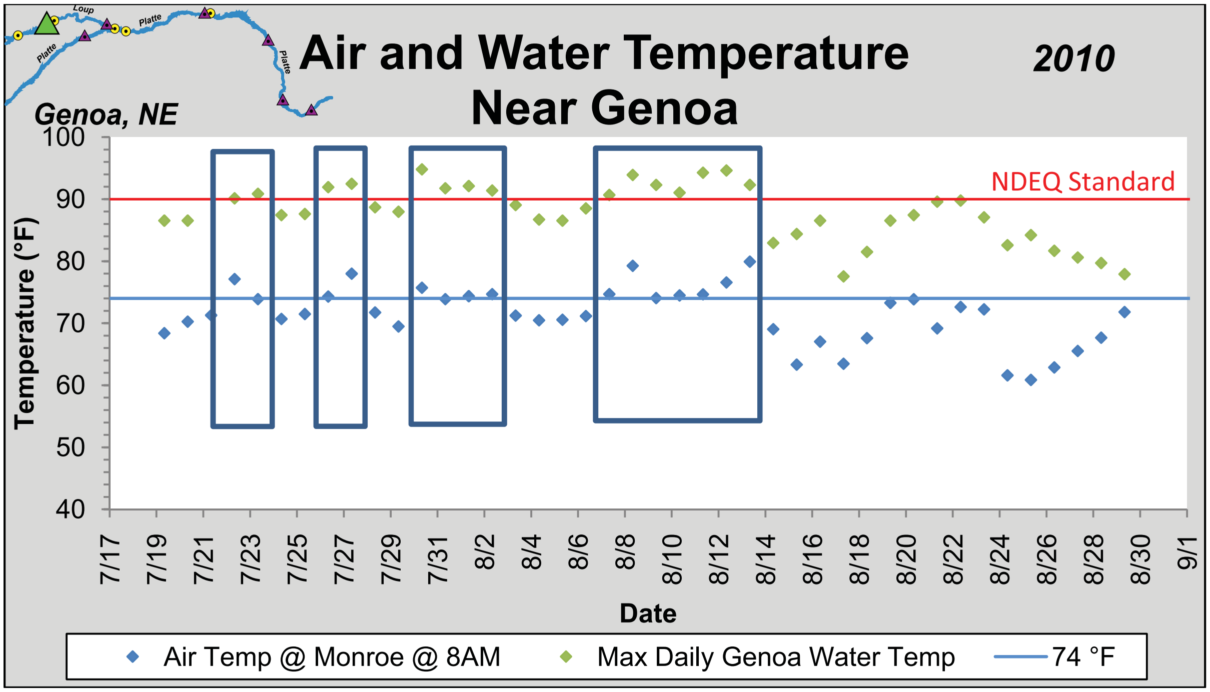

Figure 5-47. 8:00 a.m. Air Temperature and Maximum Daily Water Temperature in the Loup River near Genoa – July/August 2010

Beyond the apparent predictive relationship between air temperature at 8:00 a.m. and water temperature near Genoa later in the day (noted above), prediction of Merchiston excursion events is seemingly best facilitated by evaluating Merchiston water temperature at 9:00 a.m., as shown in Figure 5-48. When Merchiston water temperature is approximately 82˚F at 9:00 a.m., it is highly likely that a Merchiston excursion took place later the same day.[4]

[4] An exception to this trend occurred on July 30, when a lower 9:00 a.m. Merchiston water temperature occurred on a day when a Merchiston excursion was recorded.

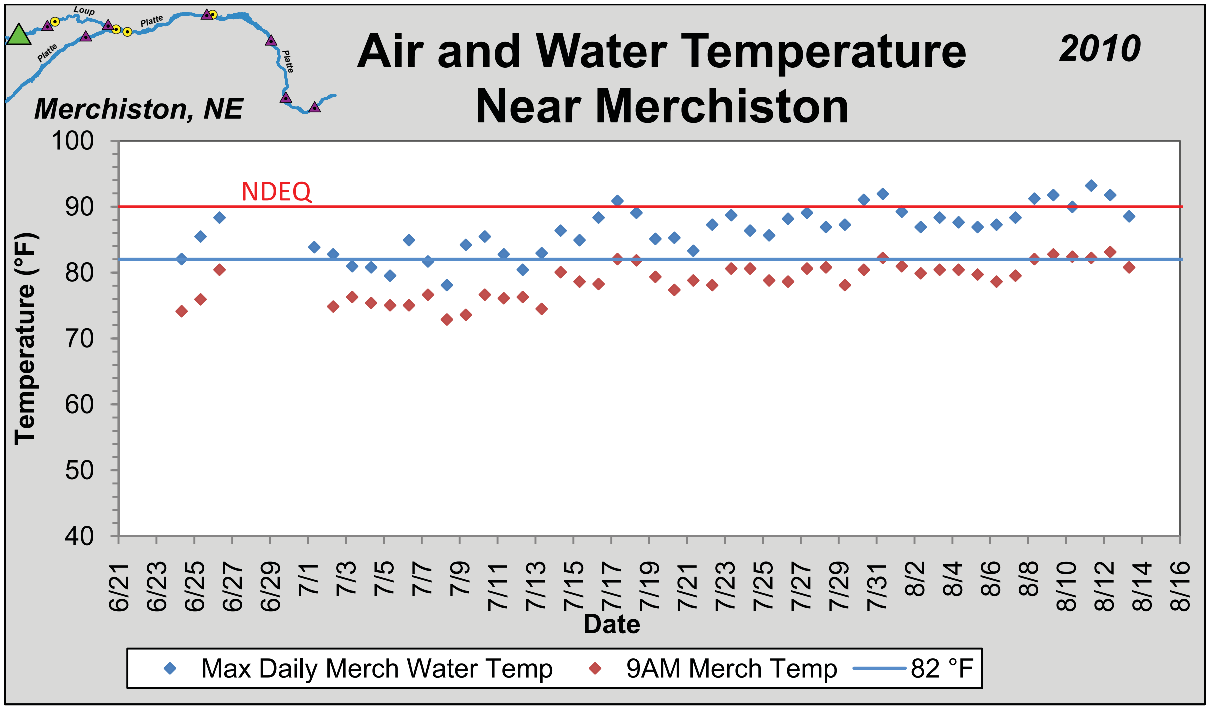

Figure 5-48. 9:00 a.m. Water Temperature and Maximum Daily Water Temperature in the Loup River at Merchiston

5.7 Summary and Conclusions

The results of the study of water temperature in the Project bypass reach are summarized below by study objective.

Objective 1: To estimate the relationship between flow in the Project bypass reach, ambient air temperature, water temperature, relative humidity, and solar radiation.

Water temperature within the Loup River bypass reach fluctuates on a synchronous daily cycle at both the Merchiston and Genoa stations, regardless of discharge conditions. This suggests that the parameter that influences water temperature also varies on a daily basis. After determining no significant relationship between flow and water temperature, relative humidity, or radiative flux, air temperature was determined to be the most influential parameter.

Objective 2: To describe and quantify the relationship, if any, between diversion of water into the Loup Power Canal and water temperature in the Project bypass reach.

Water temperature data collected in the Platte River (both upstream of the Loup River confluence and in the Platte River bypass reach) displayed higher hourly mean temperatures compared to the Loup River sampling locations (Genoa and Columbus). Further analysis concluded that the higher flows, and associated water temperature, supplied by upstream Platte River flows more greatly influence the water temperature of the Platte River bypass reach than the flows contributed by the Loup River. That is, the diversion of Loup River flows by the District is not the driver behind higher water temperatures within the Platte River between the Loup River confluence and the Tailrace Return.

Objective 3: To determine if a "critical reach" relative to water temperature excursions exists within the Project bypass reach.

The reaches of the Loup River between Genoa and Columbus exhibited very similar water temperatures during May, June, and August 2010. Based on these findings, no critical reach relative to thermal stress and potential fish kills within the Loup River bypass reach was determined. However, the data show that water temperature in the Loup River near Genoa might exceed the standard more often than water temperature in the Loup River at Columbus.

Objective 4: To determine if an accurate and reasonable method exists for predicting water temperature excursion events.

Study investigations determined that July and August water temperature excursions in the Loup River near Genoa can be predicted, with some accuracy, based on the exceedance of an identified morning air temperature threshold at Monroe. That is, when the air temperature at Monroe is at least 74˚F by 8:00 a.m., a water temperature excursion in the Loup River near Genoa is likely to occur later in the same day.

6. STUDY VARIANCE

Changes to the Water Temperature in the Loup River Bypass Reach study plan, which was approved with modifications by FERC in its Study Plan Determination on August 26, 2009, were minor and are as follows:

- An additional temperature probe was installed in the Platte River, upstream of the Loup River confluence, during the same August sampling period as the FERC-recommended sampling location in the Platte River bypass reach. This additional probe was determined necessary to isolate potential Project effects on potential water temperature excursions in the Platte River bypass reach. That is, the additional probe was necessary to determine whether potential water temperature excursions within the Platte River bypass reach were the result of Project diversion (Loup River contributing flows) or upstream Platte River contributing flows.
- Hourly weather data (air temperature, relative humidity, and radiative flux) was anticipated to be collected from a Mead, Nebraska, weather station (located nearly 70 miles from the diversion structure). Further investigation revealed that appropriate data were available from the Monroe weather station (located within the study area). To facilitate the use of the best available data, the Monroe weather station was used for this

investigation. In addition, soil temperature data were collected and analyzed along with the other aforementioned hourly weather data.

- In the Revised Study Plan, the District stated that for each relationship that would be estimated in Task 3, “A select number of daily plots will also be created. These regressions will also be plotted.” When this study of water temperature in the Project bypass reach was conducted, this analysis was begun, but it yielded no meaningful results. Therefore, daily plots were not created and regressions were not plotted.

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