Corvallis Watershed Stream Temperature Monitoring
Summer 2013

February 10, 2014

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Executive Summary

The intensive stream temperature monitoring in the Corvallis Watershed that was begun in 2010 was continued in 2013. In addition to air and water temperatures, stream flow data was collected throughout the summer to better analyze the heat input into Rock Creek below the reservoir.

Precipitation, air temperatures, and stream flow for the last four years were compared to show the variability in some of the factors that influence stream temperature. Precipitation, and therefore stream flows, were lowest in 2013 compared to the previous 3 years. Air and water temperatures were similar in 2012 and 2013, but in the mainstem of Rock Creek, more days were slightly above the state standard of 64F for the 7-day average of daily maximum temperatures in 2013. The increase in days above the standard was probably due, at least in part, to the lower flows. In addition, the bottom of the reservoir was 2 to 5 degrees (F) warmer in 2013 than in 2012.

Stream temperatures in the tributaries continue to meet state standards for summer water temperatures. On the days when the temperature of the mainstem was high, it was less than a degree above the state standard.

Flow data was collected during the summer, and combined with stream temperatures to calculate the effect of the reservoir on stream temperatures immediately downstream in the mainstem of Rock Creek. While the spillway was flowing, an increase of approximately 2.5 to 3 degrees F could be attributed to the spillway. The effect was more noticeable in the spring and early summer when the spillway had more flow. The effect was reduced as the spillway flow diminished. By mid-July, the spillway flow was 16% of the flow in the mainstem below the confluence. The spillway had stopped flowing on July 26, 2013. Stream temperatures in Rock Creek below the confluence in the late spring to mid-summer were relatively cool when the spillway flow was higher.

Introduction

The City of Corvallis and the Siuslaw National Forest have cooperatively monitored stream temperatures in the Rock Creek Watershed during the summers of 2005, 2006, and 2010 through 2013. The ongoing objectives of the stream temperature monitoring are:

- To characterize and track trends in the stream temperatures throughout the watershed.
- To determine the effects of restoration efforts, such as plantation thinning, riparian planting, and wood placement.
- To determine if it is possible to detect effects of the reservoir on downstream temperatures, if any.

This report documents the results of the 2013 monitoring, and compares the 2013 data to previous years' monitoring data. To address the question of the reservoir's effects in more detail, streamflow data was gathered from channels around the base of the dam in 2013, in addition to the stream temperature data. Two additional monitoring sites were established in the Rock Creek mainstem between Tributary "B" and the Middle Fork of Rock Creek to see if any effects from the reservoir could be detected downstream.

In addition to the stream temperatures, air temperature was monitored at the same site as previous years to compare air and water temperatures and to see what the air temperature trend is between years.

Figures 1 through 5 show the location of the stream temperature monitoring sites.

Results of the stream temperature monitoring efforts are summarized in Table 2, which shows the 7-day average maximum temperatures for the monitoring sites.

Table 3 shows more detailed data summaries for the sites that exceeded the state standard of 64F for the 7-day average maximum temperature in 2012 and 2013. For the most part, the maximum temperatures were similar, although for the sites that exceeded 64 degrees F, the number of warm days were more numerous in 2013 than in 2012, and spread out over the summer. The increase in number of days over 64F may reflect the lower stream flows in 2013.

Graphs of the daily minimum and maximum temperatures for the individual sites are included in Appendix A. Photos of some of the monitoring sites, including the spillway flow through the summer are in Appendix B. Photos of the spillway capture the change in flow through the summer. Appendix C is a discussion of whether or not a change in temperature patterns can be detected in Rock Creek below the dam and reservoir.

Groundwater

For the first time, probes were placed in the headwaters of the North and South Fork of Rock Creek to record the water temperatures in source areas. One probe was placed at Bluff Springs off Road 2005, which drains into the South Fork. Another probe was placed just downstream of Road 2005 in the headwaters of North Fork. The results are shown in Table 1. For comparison, the temperatures in headwater streams for a tributary to the Alsea River near Waldport are included.

The groundwater temperatures in the Corvallis Watershed are cooler than other areas of the Coast Range because of the more porous basaltic bedrock. Table 1 compares headwater temperatures measured in Risley Creek, a tributary to the Alsea River not far from Waldport, to the headwaters in the Corvallis Watershed. Risley Creek is underlain by the sedimentary Tyee Formation. Even though the air temperatures were approximately 6 degrees cooler on the western side of the Coast Range at Risley Creek, the headwater stream temperatures were at least 6 to 7 degrees warmer than the Corvallis Watershed, on the east side of the Coast Range.

Table 1: Comparing headwater stream temperatures at two locations in the Coast Range.

Site	Daily maximum temperature (F)	Highest 7-day average of daily maximum temperature (F)
Alsea Tributary near Waldport, 2013		
Risley Creek, upper headwater site	57.01	56.30
Risley Creek, lower headwater site	57.96	57.68
Risley Creek AIR Temperature	79.55	75.3
Corvallis watershed 2013		
Bluff Springs, headwaters of South Fork Rock Creek	45.98	45.65
Headwaters of North Fork Rock Creek	51.02	50.12
Corvallis AIR temperature	85.85	82.52

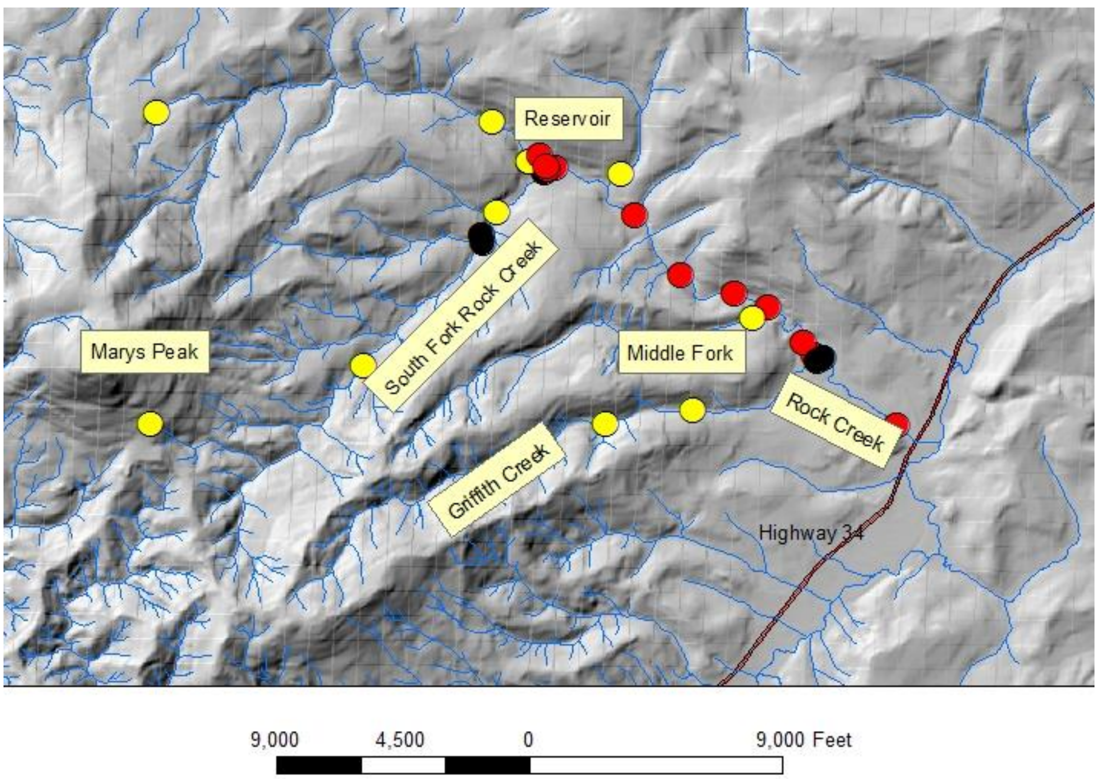


Figure 1: Overview map of all the stream temperature monitoring sites deployed in the summer of 2013. Note that there are two new ones in the headwaters on the east slope of Marys Peak, and two new sites on the mainstem of Rock Creek upstream of Middle Fork. Red dots represent sites that were above the 64F 7-day average of the daily maximum temperature standard. Yellow dots were below the standard, and black dots had no data for 2013. The same color scheme is used for all of the maps.

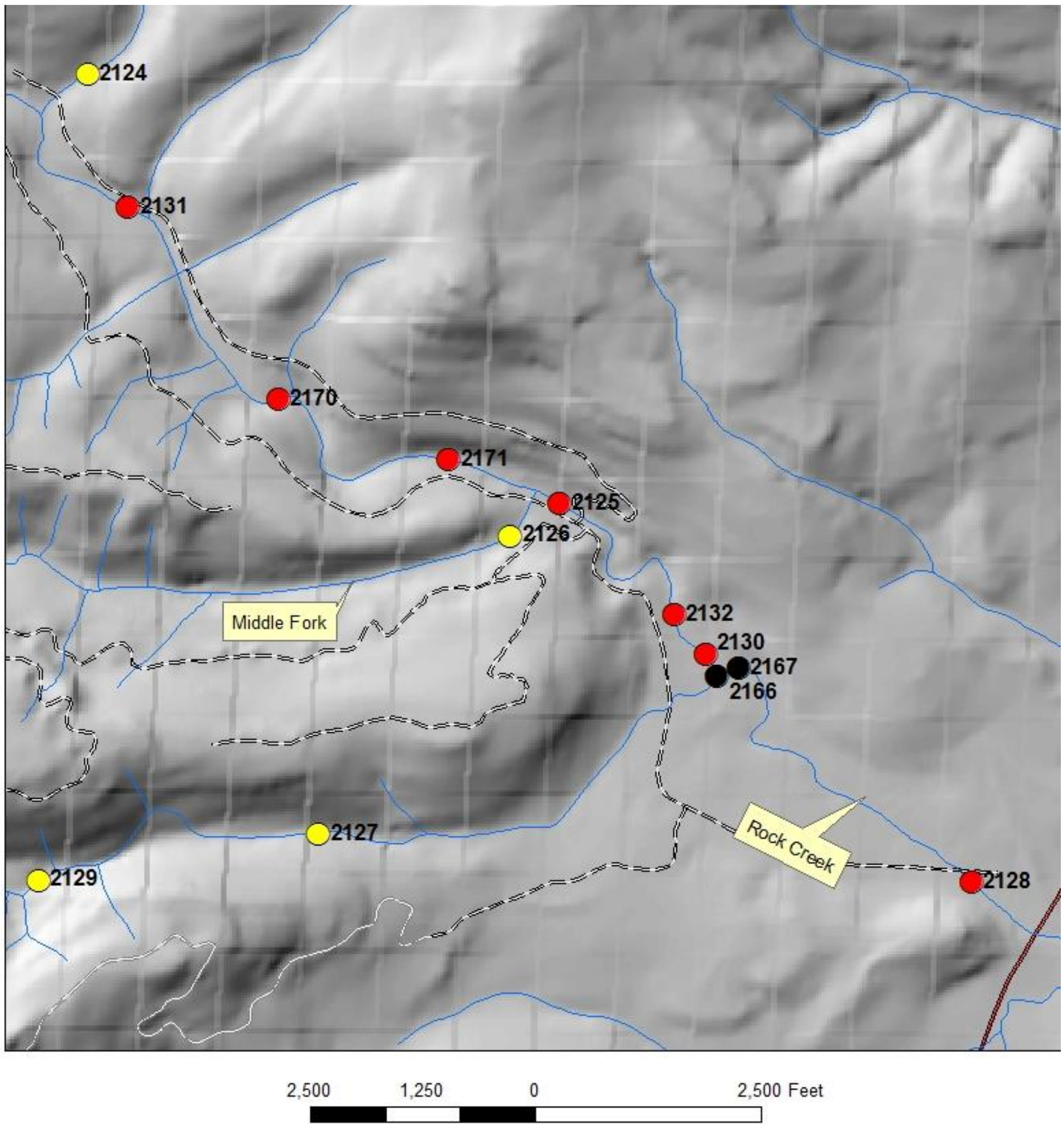


Figure 2: Stream temperature monitoring sites with 4 digit station numbers in the lower mainstem of Rock Creek, Griffith Creek, Middle Fork and Stilson Creek (station 2124). Stations 2170 and 2171 are new sites added in the summer of 2013.

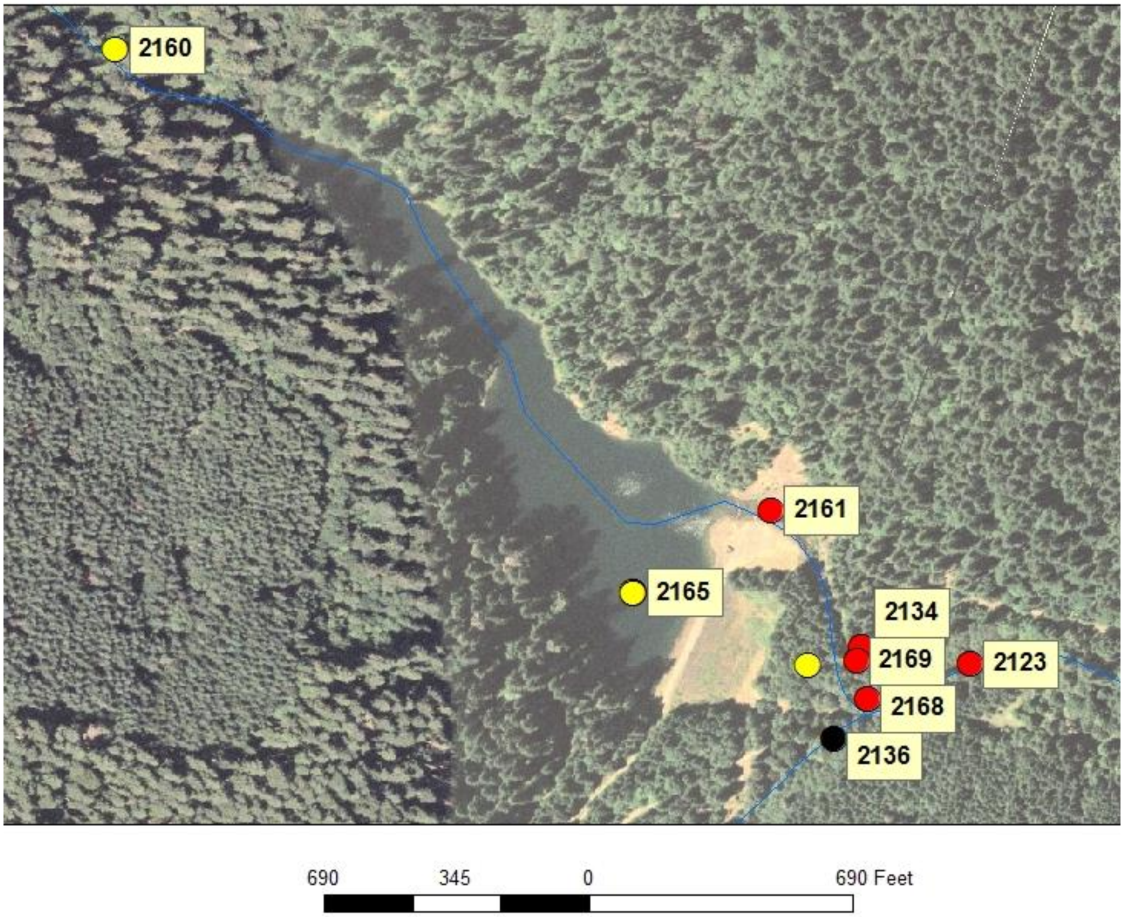


Figure 3: Stream temperature monitoring sites around the reservoir and dam. Station 2160 is in the North Fork Rock Creek just above the reservoir. Station 2165 shows the location of the probes that were installed vertically in the reservoir.

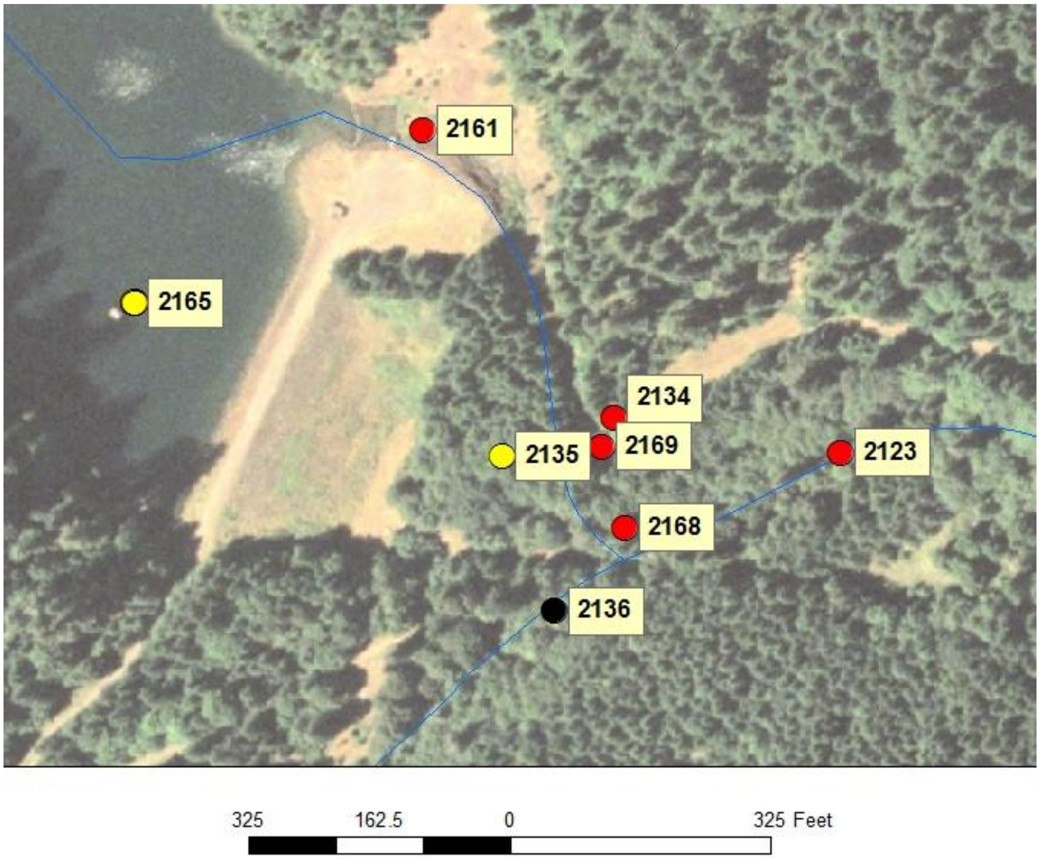


Figure 4: Closer view of the stream temperature monitoring sites around the dam.
2123: Rock Creek mainstem below the confluence of the North and South Fork Rock Creek.
2134: Pool at the bottom of the spillway
2135: Dam valve channel
2136: South Fork Rock Creek above the confluence.
2161: Top of spillway, near the metal ladder.
2165: Wooden tower in middle of reservoir with vertically suspended rope holding the reservoir probes.
2168: Channel below the spillway and dam valve channel confluence, above the confluence of the North and South Fork Rock Creek. Site integrates the contribution from the dam valve channel and spillway.
2169: Bottom of spillway in flowing portion of gravel riffle.

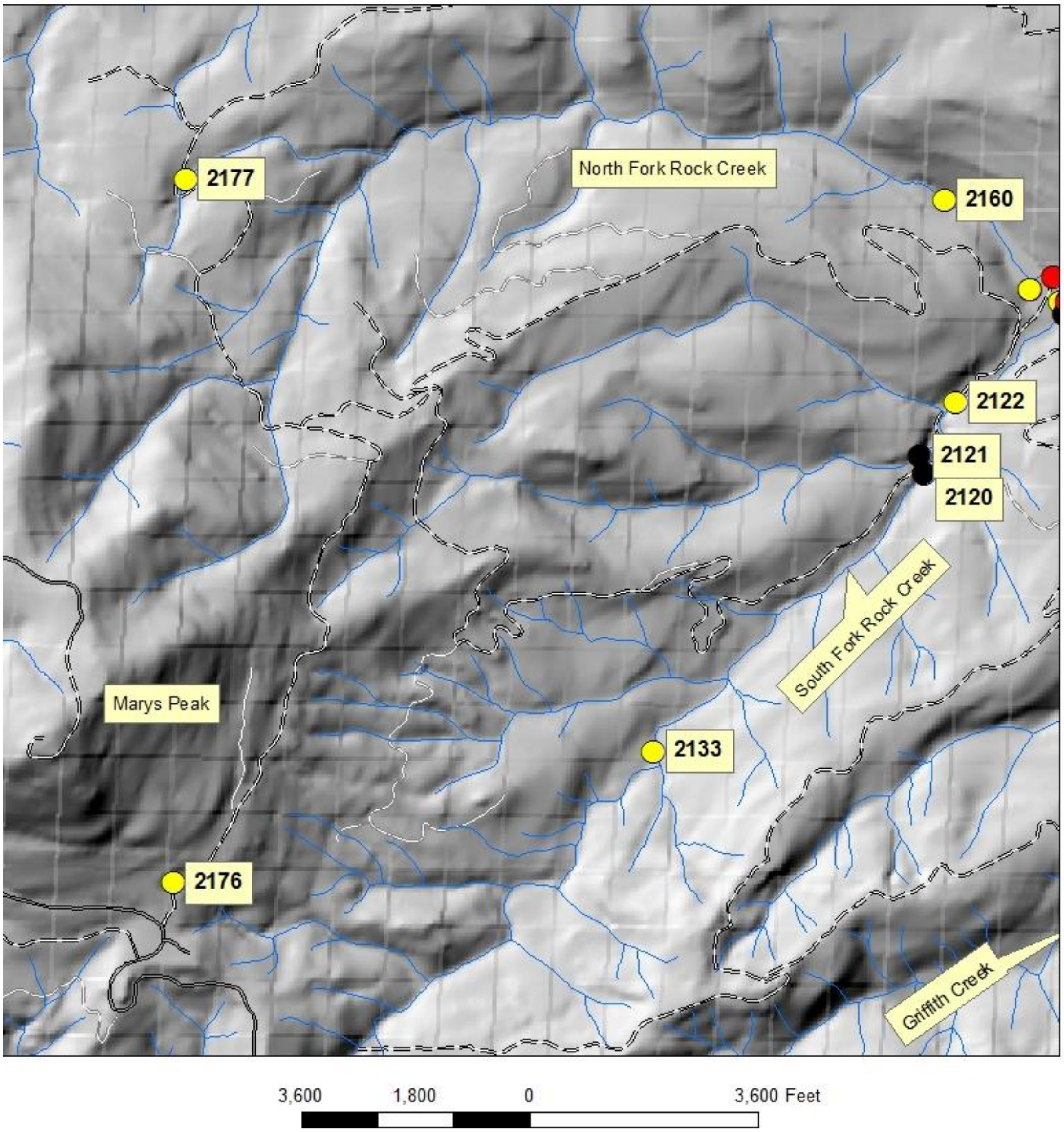


Figure 5: Stream temperature monitoring sites in the headwaters and middle portions of South Fork and North Fork Rock Creek.

Table 2: Data from multiple years for 7-day average maximum of daily high temperatures, Corvallis Watershed. Sites in the reservoir are shaded.

STREAM	LOCATION	STATION number	1978 7-day ave max	1980 7-day ave max	2005 7-day ave max	2006 7-day ave max	2010 7-day ave max	2011 7-day ave max	2012 7-day ave max	2013 7-day ave max	Objective
S FK Rock Creek	upstream from Connection Creek	2120			60.8		59.2	60.12	61.74	no data	watershed characterization, bracketting Connection Cr
Tributary to S FK Connection Creek	Tributary is upstream from and next to Connection Creek	2121			61.2		58.8	59.61	60.76	no data	watershed characterization
S FK Rock Creek	Above weir tied to trash rack	2122			60.9		58.8	60.14	61.51	60.99	watershed characterization
S FK Rock Creek AIR TEMP		2122					79.06	79.11	83.22	82.52	comparing air temp
Rock Cr mainstem Water Temp	downstream from confluence of N Fk and S FK Rock Creek	2123			66.4	67.5	61.9	61.04	63.4	64.34	monitor effects of reservoir
Rock Cr mainstem AIR TEMP	downstream from confluence of N Fk and S FK Rock Creek	2123			81	92					compare air temp
Stilson Creek	upstream from rd 111	2124			62.5		60.2	61.39	62.12	61.86	watershed characterization
Rock Creek mainstem	upstream from rd 111 bridge	2125			67.8		63.2	64.4	65.25	64.98	watershed characterization, monitor changes in riparian area and stream substrate restoration
Rock Creek mainstem AIR TEMP	upstream from rd 111 bridge	2125					81.3				

Middle Fork Rock Creek	upstream from rd 3405	2126			62.3		59.6	61.44	62.35	62.16	watershed characterization
Griffith Creek	upstream from weir	2127			60.9		59.3	60.19	61.6	61.35	watershed characterization
Rock Creek	below bridge near entrance gate	2128					64.2	65.66	66.33	65.76	watershed characterization
Griffith Creek	below thinning unit approx 1 mi from intake	2129					61.5	60.27	61.57	61.25	monitor thinning effects
Rock Cr mainstem	at waterline crossing upstream of Griffith Cr	2130					63.9	65.2	65.98	65.71	bracket outflow
Rock Cr mainstem	0.08 miles upstream from Trib "b"	2131					61.9	63.13	LOST	64.29	watershed characterization
Rock Cr mainstem	at City/pvt boundary above outflow in log complex	2132					63.3	64.49	65.84	65.37	bracket outflow
S Fk Rock Creek	below thinning stand	2133	63.5	65.94			58.3	59.26	LOST	59.86	monitor thinning effects
N Fk Rock Creek spillway below dam	pool below spillway	2134						77.04			bracket reservoir
Dam outlet small channel	Just below dam in small channel fed by valve leakage	2135							60.12	62.87	determine temperatures just below dam without spillway influence
S Fk Rock Creek	above thinning stand (HCC in 1979?)		60.54	58.13							
S Fork Rock Creek	above dam outlet and confluence with N Fork Rock Cr	2136						62.12	62.99	no data	bracket reservoir
Top of Spillway at reservoir	Near metal ladder below sill	2161							78.91	79.57	bracket reservoir
North Fork Rock Creek	Above reservoir where creek enters reservoir	2160							60.66	60.84	bracket reservoir

Reservoir, tied to tower rope, top probe initially	Installed June 5 2012 at 1.1 ft below water surface, 55' above bottom. Moved on 8/29/2012 to 105" below water surface,	2162							74.6	72.76	bracket reservoir
Reservoir, tied to tower rope, near top	Installed June 5 2012 at 3.75 ft below water surface, 50' from bottom anchor	2163							70.87	69.65	bracket reservoir
Reservoir, new in 2013	12 feet below water surface, 45.3 feet above bottom anchor	2173								67.26	bracket reservoir
Reservoir, new in 2013	17 feet below water surface, 40.3 feet above bottom anchor	2174								65.35	bracket reservoir
Reservoir, tied to tower rope, middle depth	Installed on June 5 2012 25.5 below water surface, 28.3 ft from bottom anchor	2164							62.61	64.63	bracket reservoir
Reservoir, tied to tower rope, near bottom	Installed 3.7' from bottom anchor	2165							60.65	62.66	bracket reservoir
Griffith Creek	mouth of creek	2166							62.86	no data	bracket effects of Griffith Creek
Rock Creek	just downstream of Griffith Cr mouth	2167							65.81	no data	bracket effects of Griffith Creek
Spillway/dam outlet channel, 7-day ave. max when spillway is flowing	Just below spillway and dam outlet channel convergence, and upstream of South Fork Rock Creek confluence.	2168							71.4	73.96	
Spillway/dam outlet channel, temperature after spillway stops flowing	Just below spillway and dam outlet channel c, and upstream of South Fork-Rock Creek confluence.	2168							61.1	63.08	

Bottom of Spillway	In gravel channel just below spillway, moved from stagnant pool location used in 2011.	2169							76.99	78.46	
Rock Creek mainstem	Approximately 2200 feet downstream from Trib "b"	2170								65.7	new in 2013
Rock Creek mainstem	Approximately 4500 feet downstream from Trib "b"	2171								66.77	new in 2013
Headwaters of South Fork	Bluff Springs above Road 2005	2176								45.65	new in 2013,Monitoring temperature of ground water
Headwaters of North Fork	Just downstream of Road 2005	2177								50.11	new in 2013, Monitoring temperature of ground water

Table 3: Comparison of sites that were above 64F in 2012 and 2013.

Year	Site Number	Site Description	Maximum daily high temperature	7-day average maximum temperature	Number of days that the maximum daily high is greater than 64 F	Time period when temperatures above 64 F occur	Comments, comparing 2013 to 2012
2012	2123	Rock Creek mainstem, below confluence of North and South Fork Rock Creek	65.48	63.4	5	8/4/2012 to 8/13/2012	
2013	2123	Rock Creek mainstem, below confluence of North and South Fork Rock Creek	65.92	64.34	4	6/30/2013 to 7/3/2013	Similar temperatures, but higher temperatures a month earlier.

2012	2131	Mainstem Rock Creek 0.08 miles above Trib "B"		LOST IN 2012			
2013	2131	Mainstem Rock Creek 0.08 miles above Trib "B"	65.7	64.29	6	6/30/2013 to 7/26/2013 intermittently	
2013	2170	Mainstem Rock Creek,Approximately 2200 feet downstream from Trib "B"	65.7	64.19	9	6/30/2013 to 8/6/2013 intermittently	New site in 2013
2013	2171	Mainstem Rock Creek,Approximately 4500 feet downstream from Trib "B"	66.77	65.17	17	6/28/2013 to 9/12/2013 intermittently	New site in 2013
2012	2125	Rock Creek mainstem, below Middle Fork and above the Road 111 bridge	66	65.25	9	8/4/2012 to 8/17/2012	
2013	2125	Rock Creek mainstem, below Middle Fork and above the Road 111 bridge	66.56	64.98	15	6/25/2013 to 9/11/2013 intermittently	Similar temperatures, but more days above 64, and earlier in the season.
2012	2132	Rock Creek mainstem at City property boundary upstream from plant outflow in a log complex	67.01	65.84	9	8/3/2012 to 8/18/2012	
2013	2132	Rock Creek mainstem at City property boundary upstream from plant outflow in a log complex	66.98	65.37	21	6/27/2013 to 9/10/2103 intermittently	Similar temperatures, but more days above 64, and earlier in the season.
2012	2130	Rock Creek mainstem upstream from Griffith Creek	67.63	65.98	10	8/3/2012 to 8/18/2012	
2013	2130	Rock Creek mainstem upstream from Griffith Creek	67.07	65.71	30	6/30/2013 to 9/13/2013 intermittently	Similar temperatures, but more days above

							64, and earlier in the season.
2012	2167	Rock Creek, just downstream from Griffith Creek	65.8	65.81	9	8/3/2012 to 8/18/2012	
2013	2167	Rock Creek, just downstream from Griffith Creek		no data for 2013			
2012	2128	Rock Creek below main bridge near mouth of creek, upstream from Greasy Creek confluence	67.28	66.33	14	8/2/2012 to 8/19/2012	
2013	2128	Rock Creek below main bridge near mouth of creek, upstream from Greasy Creek confluence	67.41	65.76	32	6/27/2013 to 9/13/2013	Similar temperatures, but more days above 64, and earlier in the season
2012	2122	AIR Temperature at South Fork Rock Creek	84.812	83.21	96	5/31/2012 to 10/2/2012	
2013	2122	AIR Temperature at South Fork Rock Creek	85.85	82.52	106	5/18/2013 to 10/21/2013	
	Reservoir sites						
2012	2162	Reservoir, on rope tied to valve tower top most probe, approximately 55 feet above bottom of reservoir	76.03	74.6	72	6/16/2012 to 9/19/2012	
2013	2162	Reservoir, on rope tied to valve tower top most probe, approximately 55 feet above bottom of reservoir	73.99	72.46	70	6/6/2013 to 8/16/2013	Surface temperatures slightly cooler.

2012	2163	Reservoir, on rope tied to valve tower, second probe from top, approximately 50 feet from bottom of reservoir	73.2	70.87	65	7/13/2012 to 9/13/2012	
2013	2163	Reservoir, on rope tied to valve tower, second probe from top, approximately 50 feet from bottom of reservoir	70.33	69.65	81	7/3/2013 to 9/21/2013	Slightly cooler, but more days above 64.
2012	2161	Top of Spillway, near metal ladder	86.39	78.91	51	6/14/2012 to 8/14/2012	
2013	2161	Top of Spillway, near metal ladder	80.93	79.57	44	6/3/2013 to 7/26/2013	
2012	2168	Spillway and dam valve channel between spillway and South Fork confluence	73.8	71.4	47	6/15/2012 to 8/13/2012	
2013	2168	Spillway and dam valve channel between spillway and South Fork confluence	76.21	73.96	33	6/3/2013 to 7/20/2013	Slightly warmer temperatures, but fewer days above 64. Period of warm temperatures arrived earlier.

Variability in Air Temperatures, Precipitation and Stream Flows from Year to Year

Stream temperatures are influenced by a number of factors, including yearly variations in weather conditions. Air temperatures collected in the Corvallis Watershed, precipitation data from the Wilkinson Ridge Remote Automated Weather Station (RAWS), and stream flow data are compared for the previous 4 years to show the variability from year to year.

Air Temperature Variability

Air temperature is shown as the 7-day average of the daily maximum temperature. Maximum temperatures were warmer in 2012 and 2013 than in 2010 and 2011, as shown in Figure 6. Timing of the highest temperatures during the summer also varies from year to year. In 2011, warm temperatures persisted later into September than in other years. In 2013, in contrast, the warmest temperatures were in July. This variation is also reflected in the water temperatures, with the warmest water temperatures coinciding with the warmest air temperatures each year.

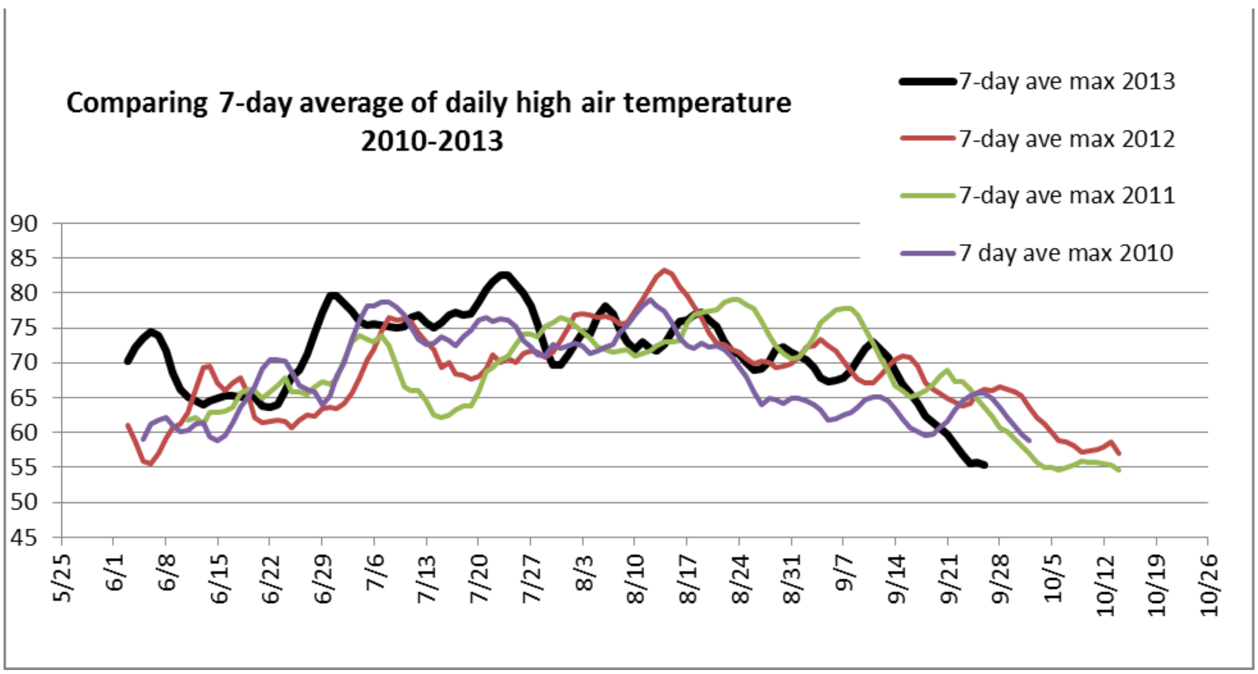
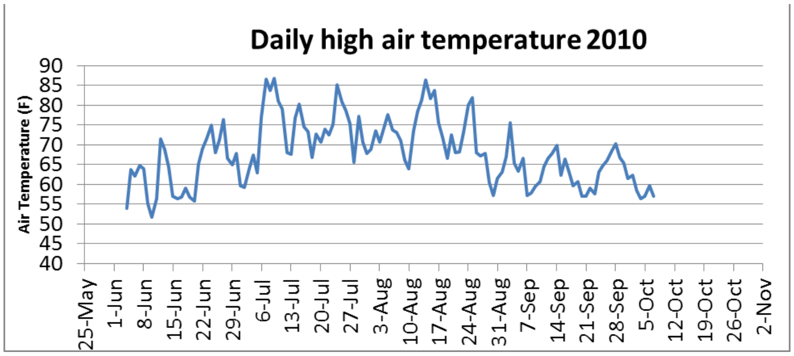
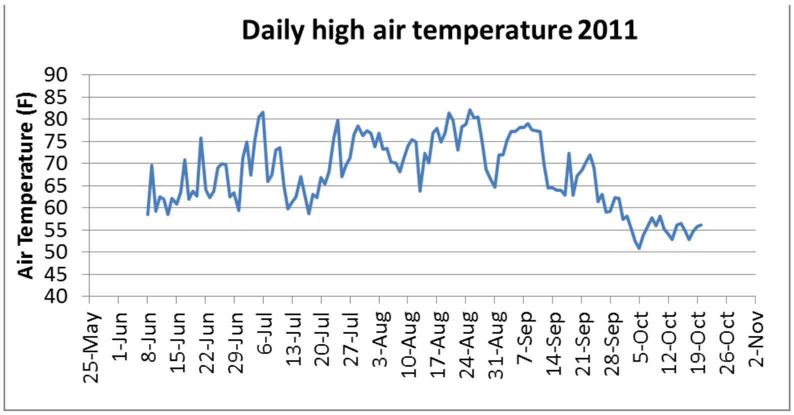
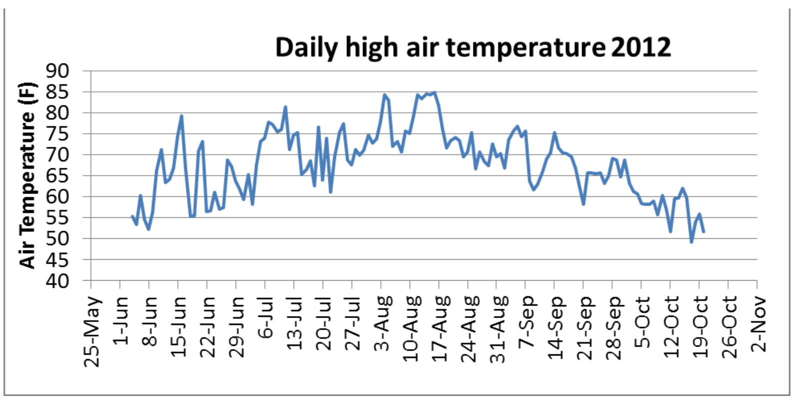


Figure 6. The 7-day running average of the daily maximum temperatures for the years 2010 through 2013.







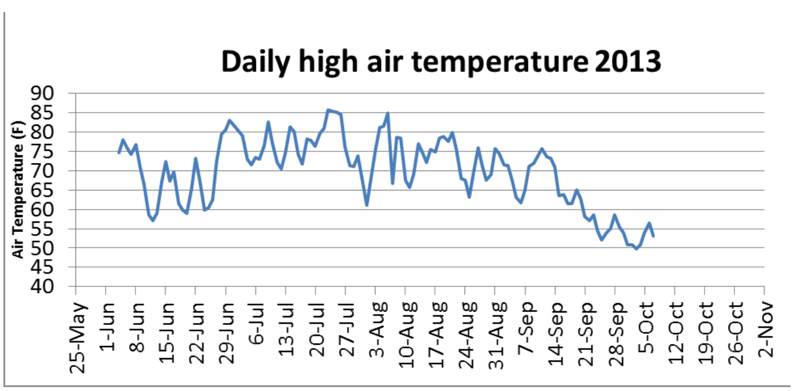


Figure 7. Comparison of daily maximum air temperatures for the last 4 years.

Precipitation Data Variability

Precipitation data for monthly total precipitation from the Wilkinson Ridge RAWS site was used to compare the years 2010, 2012 and 2013. The data for 2011 was suspect, as the station did not record any precipitation for several months in the spring for that year.

In 2013, higher amounts of precipitation fell during the first three months of the water year, which is defined as October through December (Figure 8). After that, however, the late winter and spring months were relatively dry. The big increase in September came at the end of the month, when 7.52 inches of rain were recorded between September 27 and September 30. As a result of the large rainstorm at the end of September 2013, the reservoir levels rose abruptly and re-filled the reservoir in one day.

The cumulative precipitation amounts (Figure 9) show that all three years had a similar amount of annual precipitation, with a range of approximately 10 inches. The timing of the delivery, however, varied significantly.

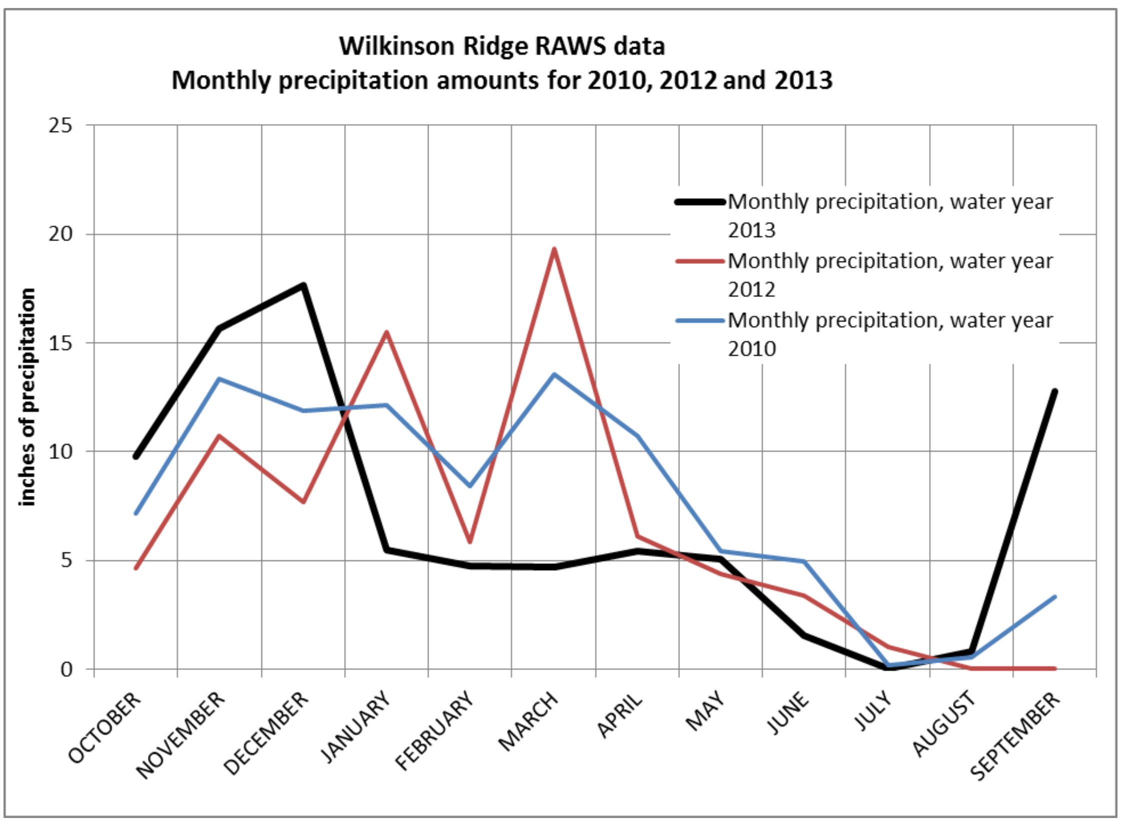


Figure 8. Monthly cumulative precipitation amounts for the Wilkinson Ridge Remote Automated Weather Station for the years 2010, 2012 and 2013. The data from 2011 was suspected, as several months recorded no precipitation.

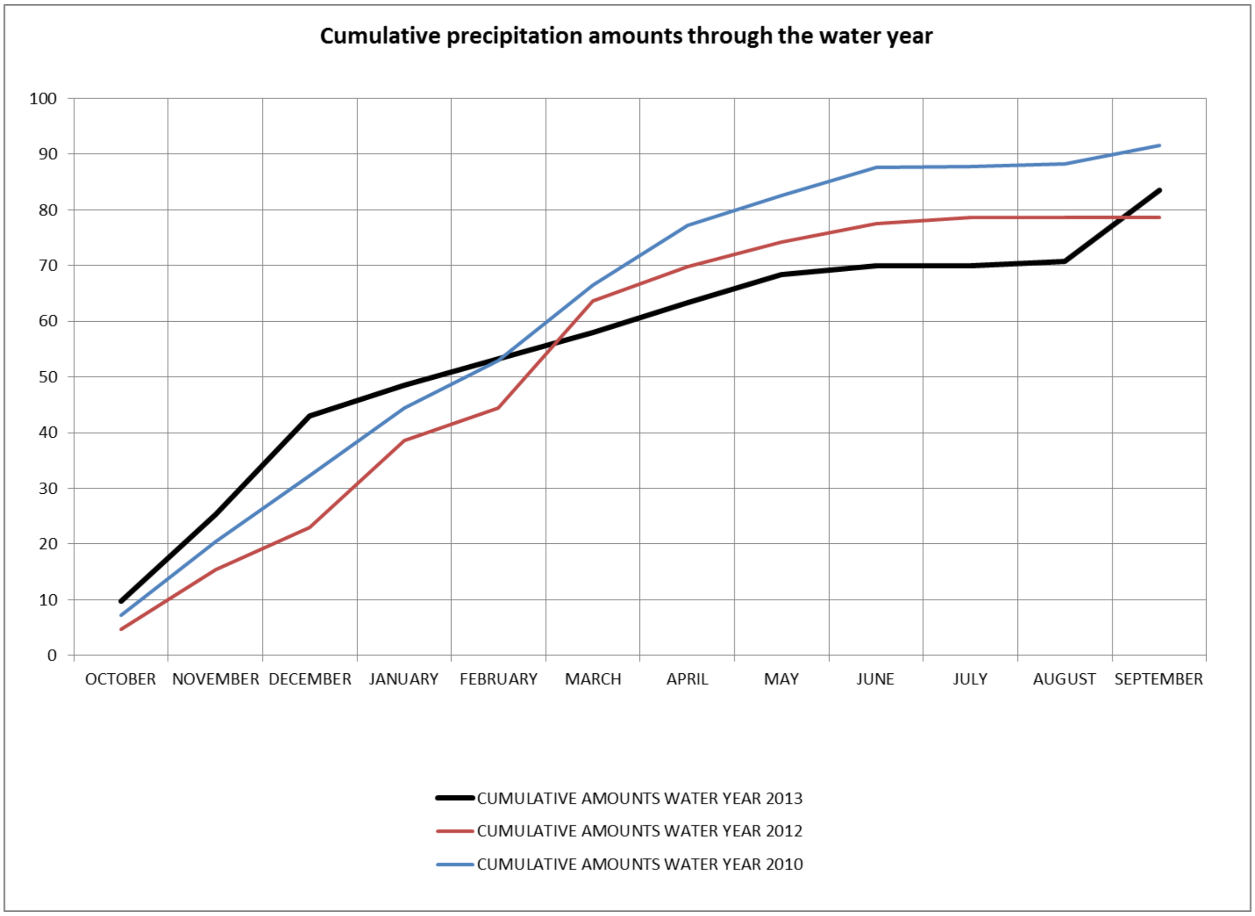


Figure 9. Annual cumulative amounts of precipitation for the Wilkinson RAWS station. The annual total amounts for each year shown are similar; however, the timing is different.

Rock Creek Streamflow Annual Variability

Daily staff gage readings at the Rock Creek bridge are shown in Figure 10 for water years 2010 through 2013. Water year 2013 has the lowest spring and summer flows of the years shown. To better illustrate the yearly trends, Figure 11 shows the average height of the staff gage per month. Again, the graph shows that the flows from January through the summer are lower than average.

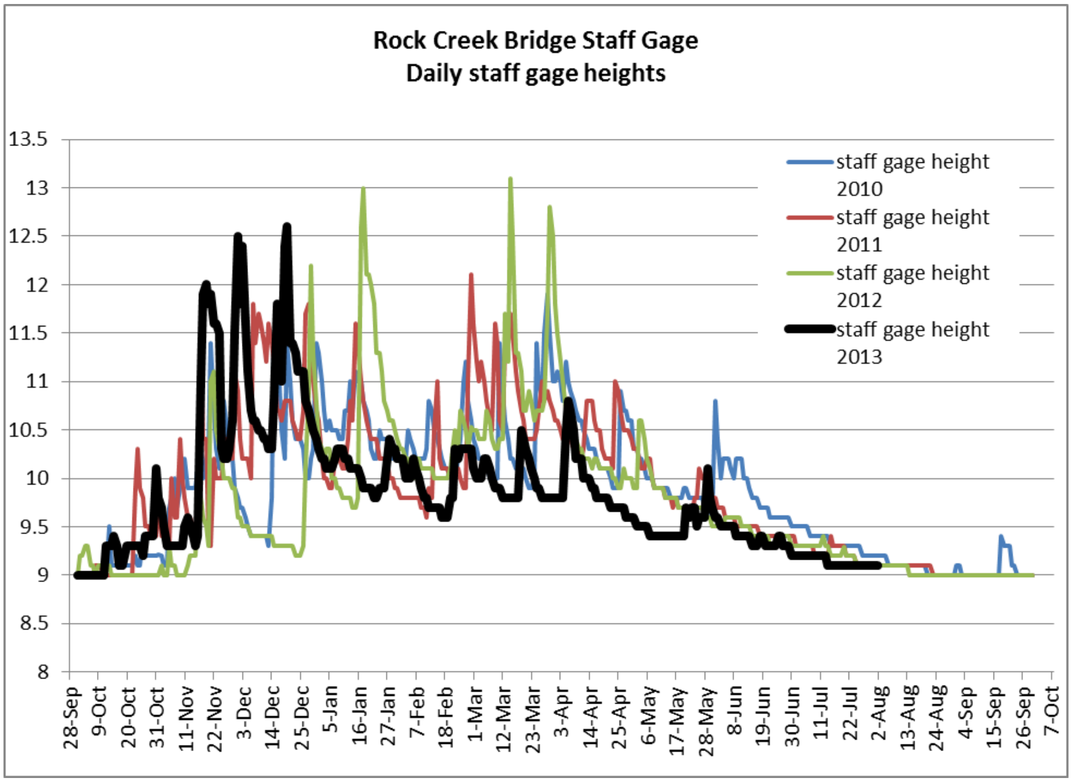


Figure 10: Daily staff gage water levels at the Rock Creek bridge for 2010-2013. Note that 2013 had lower flows starting in January.

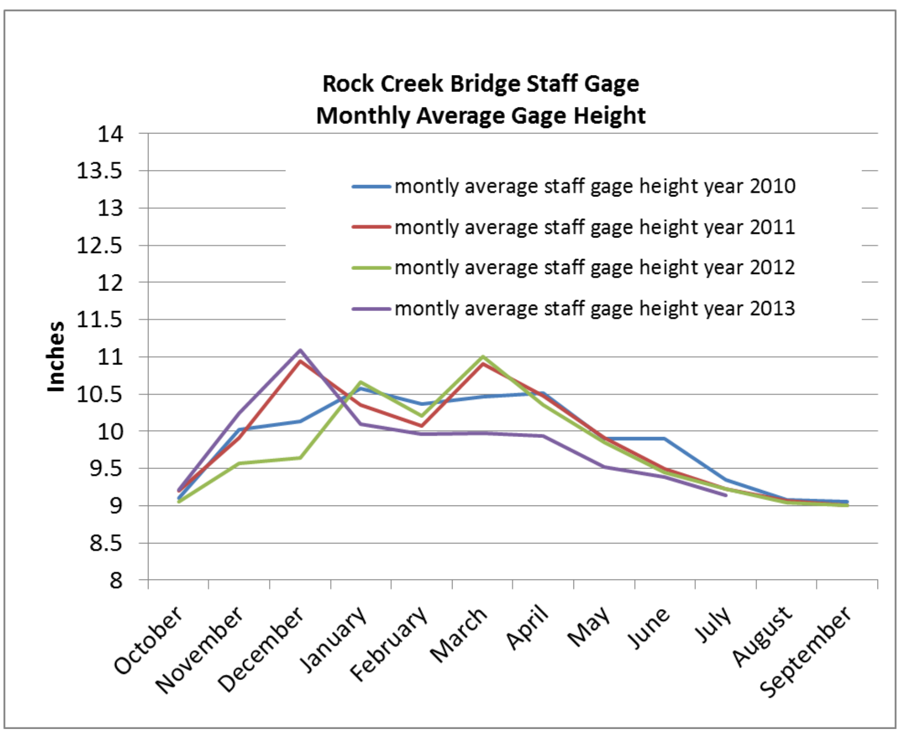


Figure 11. Monthly average of the water levels on the staff gage at the Rock Creek bridge.

Effects of Yearly Weather Variability on Stream Temperatures

One effect of the yearly weather variability on stream temperatures can be seen in Figure 12, which compares water temperature to the drainage area above that point. The lines representing different years' temperature data are all parallel, with a similar slope; however, they reflect the warmer vs. cooler years. For instance, 2012 had the highest peak air temperature, and the 7-day average of the maximum water temperature throughout the watershed reflects 2012's air temperatures.

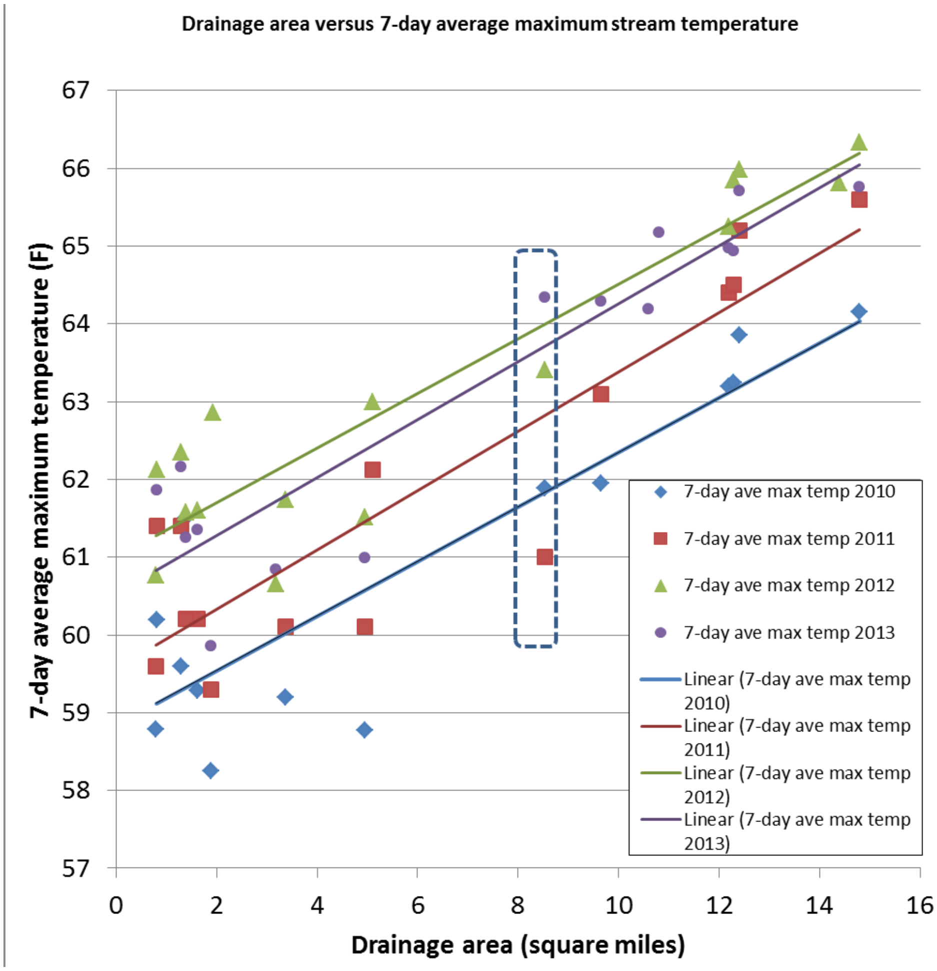


Figure 12. Comparing 7-day average maximum stream temperatures to drainage area for 4 years.

As an example of the variability in stream temperatures between years, Figure 13 shows 4 years of daily maximum stream temperatures for the Middle Fork Rock Creek. This site is on a tributary and is not downstream of the dam and reservoir.

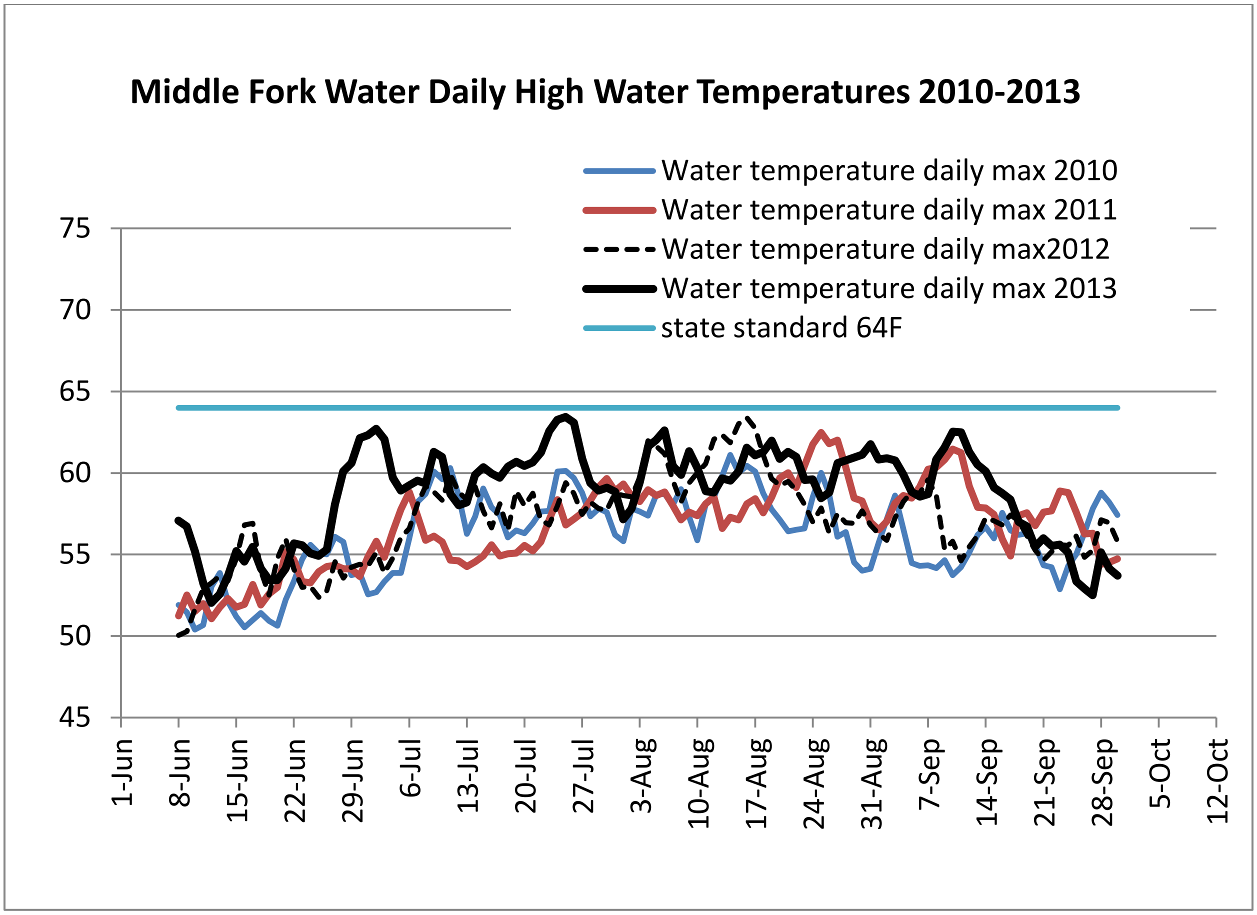


Figure 13. Differences in daily maximum stream temperatures for 2010 through 2013 for the Middle Fork Rock Creek. This site is not influenced by the dam and reservoir.

Reservoir temperatures are influenced by both stream flow and air temperatures.

Water levels in the reservoir reflect the differences between 2012 and 2013. Stream flow was lower in the spring and early summer of 2013 as compared to 2012. As a result, the reservoir stopped spilling 2 weeks earlier in 2013 (Figure 14).

Air temperatures are similar in 2012 and 2013; the difference in the 7-day average of the daily maximum temperature is only 0.7 (F) degrees between the two years. However, the air temperatures were warmer early in the season in 2013 (Figure 6). As a result of the lower stream flows and the earlier warm temperatures, as compared to 2012, water temperatures at the bottom of the reservoir were around 4 (F) degrees warmer in 2013 in May and June, and 5.3 degrees warmer in 2013 on August 19. Reservoir bottom temperatures reached a daily high of 62.7 in late September 2013 (Figure 15).

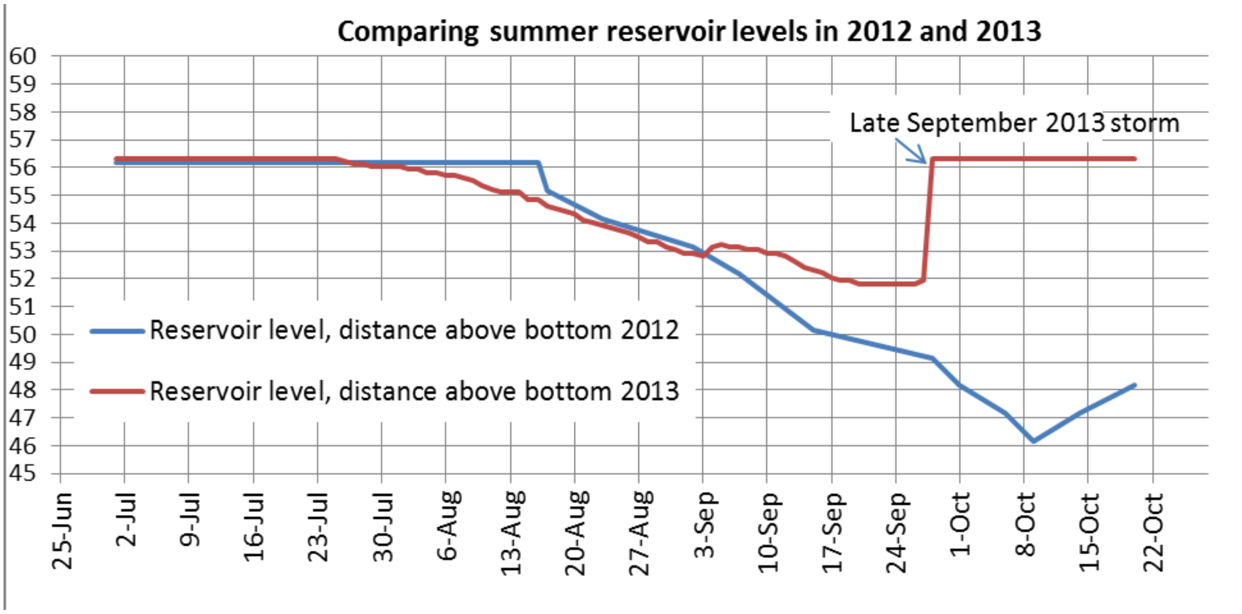


Figure 14. Comparison of summer reservoir levels in 2012 and 2013. The reservoir level began to drop on July 26, 2013; two weeks earlier than in 2012. The reservoir re-filled in one day, due to the significant rainstorm at the end of September, 2013. In 2012, the reservoir continued to drop until early October, and gradually re-filled after that.

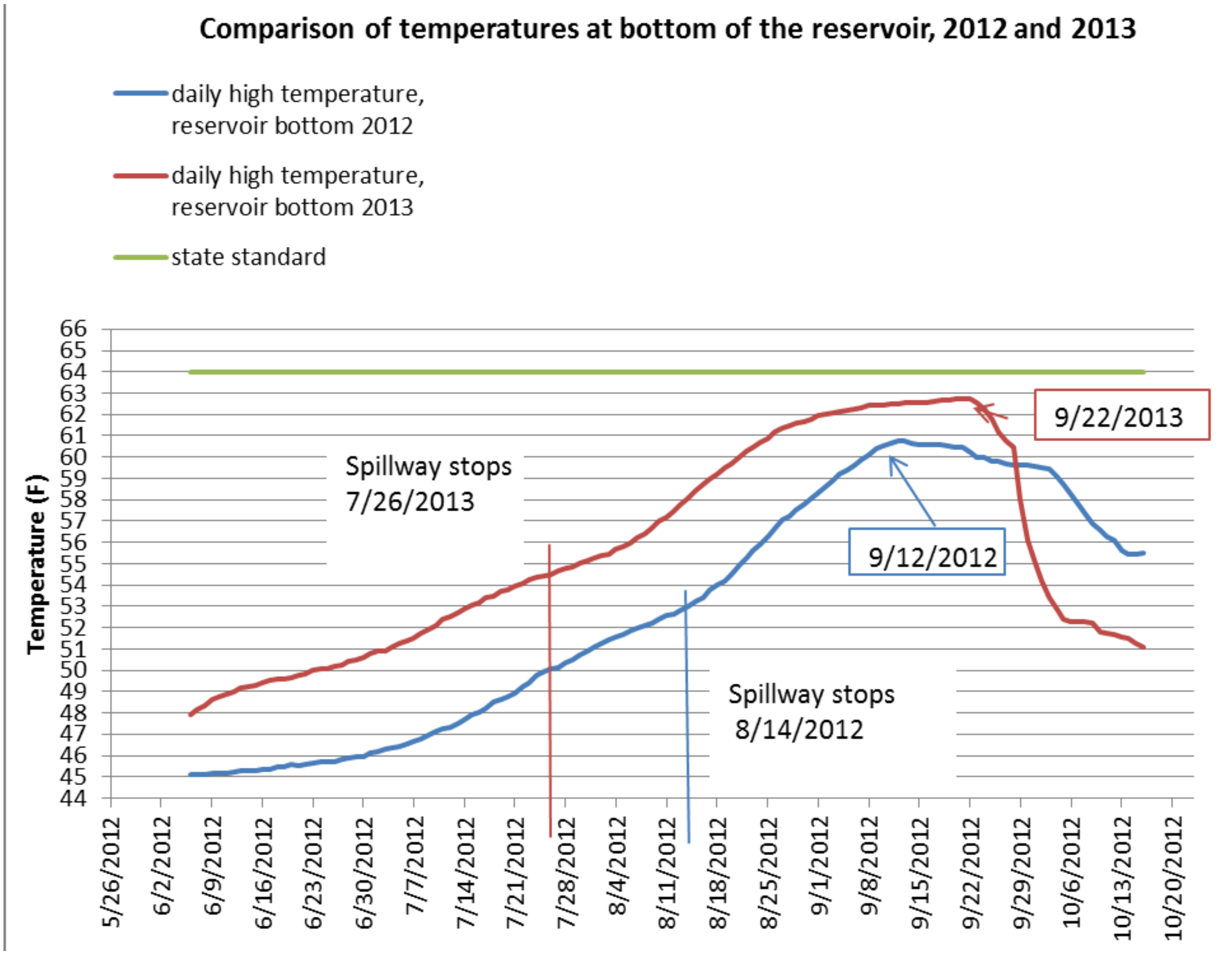


Figure 15. Comparison of the temperatures at the bottom of the reservoir in 2012 and 2013.

Temperature Monitoring Results from the Reservoir

Figures 3 and 4 show the map view of the probes that bracketed the reservoir. In addition to the probes that were placed in the North Fork Rock Creek above the reservoir, and the probes placed in channel locations downstream of the reservoir, 6 probes were suspended on a rope from the tower in the deepest part of the reservoir. Figure 16 shows the depth of the probes and the level of the reservoir through the summer. The upper 5 probes were spaced at 5 foot intervals on the rope, the 6th probe was 5 feet above the bottom of the reservoir.

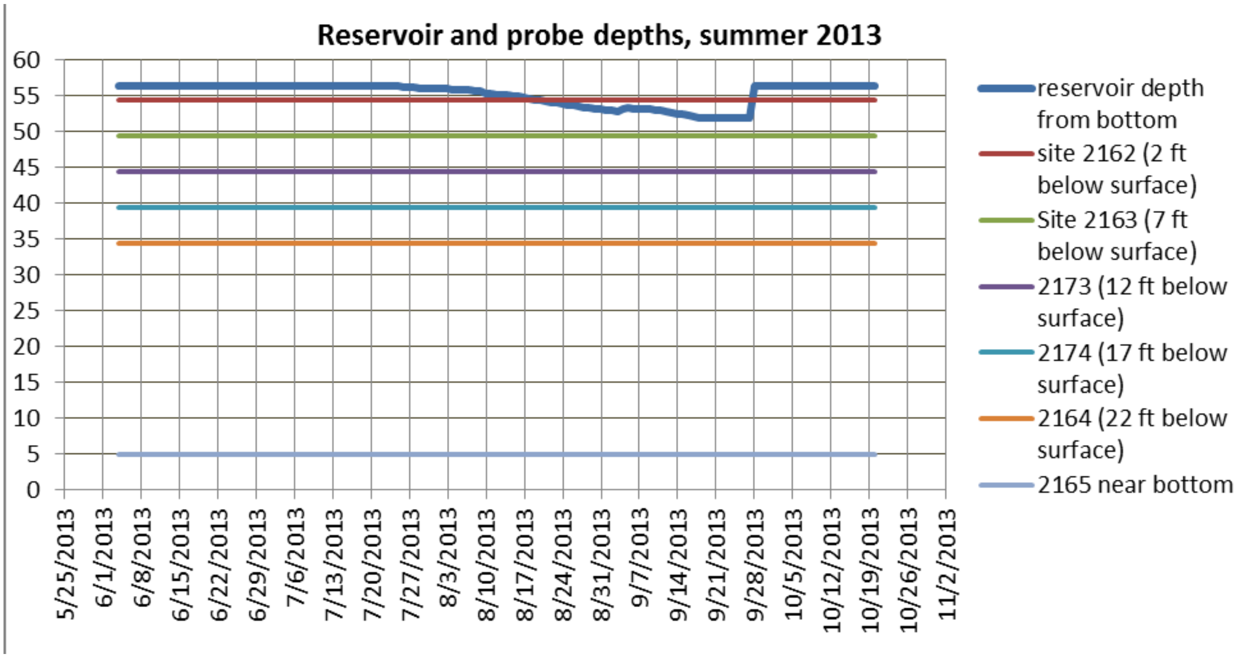


Figure 16: Depth of temperature probes on rope suspended from wooden tower in the reservoir.

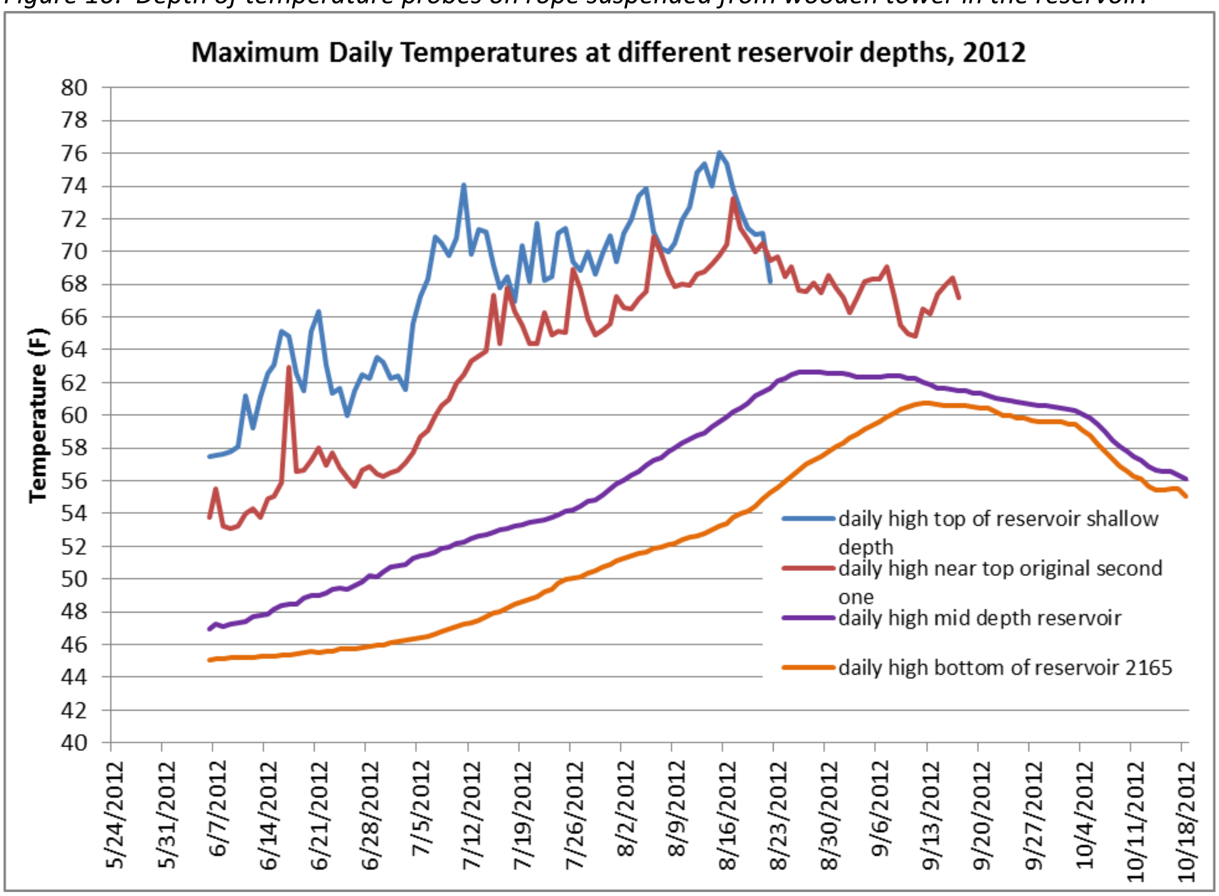


Figure 17a. Temperatures in the reservoir, 2012.

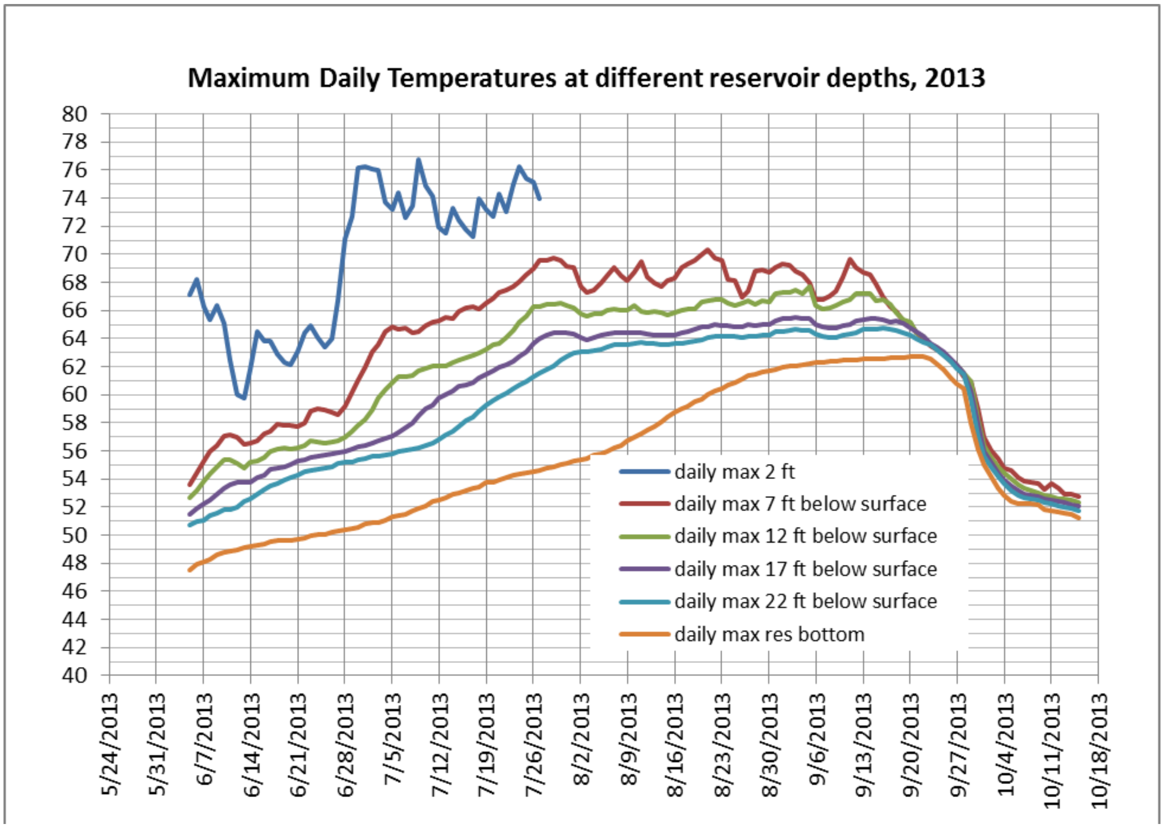


Figure 17b. Temperatures in the reservoir, 2013.

Figures 17a and b show graphs of the reservoir temperatures by depth for 2012 and 2013, respectively. Surface temperatures were similar for both years; however, the surface temperatures were warmer earlier in the season in 2013. In 2012, the bottom of the reservoir gradually cooled off beginning in mid-September. In 2013, in contrast, all levels of the reservoir cooled abruptly during the rainstorm at the end of September 2013. This late September rainstorm was unusually intense for this time of year; 7.5 inches of rain was recorded at the Wilkinson Ridge RAWS location over 3 days.

The daily temperatures in the pool at the bottom of the spillway show an interesting corollary (Figure 18). The late September storm quickly raised the level of the reservoir and uniformly cooled the water temperatures throughout the reservoir. At the same time, the temperature of the pool at the bottom of the spillway rose approximately 6 degrees (F). It is assumed that the warm temperatures on the surface of the reservoir flowed down the spillway, and were responsible for the temperature increase immediately downstream during this storm event.

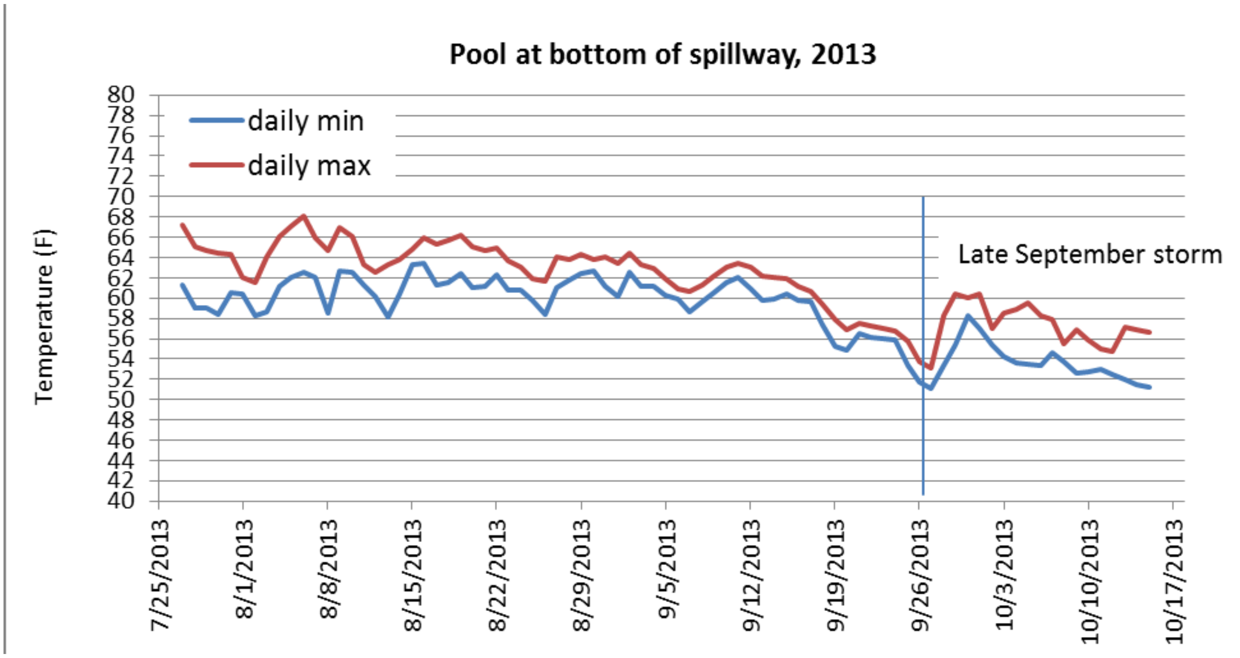


Figure 18. Water temperatures from the stagnant pool at the bottom of the spillway. No water from the spillway was flowing into this pool from July 26 to September 27. After the spillway stopped flowing, the probe that had been in the spillway channel was moved into this pool. Note that the late September rainstorm caused the daily temperatures to rise approximately 6 degrees, from 54F to 60F.

Figure 19 shows the comparison of daily maximum water temperatures around the North and South Fork confluence below the dam. The probe that was in place just above the confluence of the South Fork and the mainstem, and below both the spillway and the dam valve channel (light blue line) is very close in temperature to the spillway until early July. At that point, the temperatures just above the confluence are cooler than the spillway, reflecting the decreasing flows in the spillway. The spillway stopped flowing on July 26, 2013.

Beginning in early August, the temperatures of the dam valve channel, the bottom of the reservoir, and the mainstem of Rock Creek below the confluence begin to converge, and there isn't much difference between the bottom of the reservoir and the mainstem of Rock Creek. After early September, the bottom of the reservoir is actually warmer than the mainstem of Rock Creek.

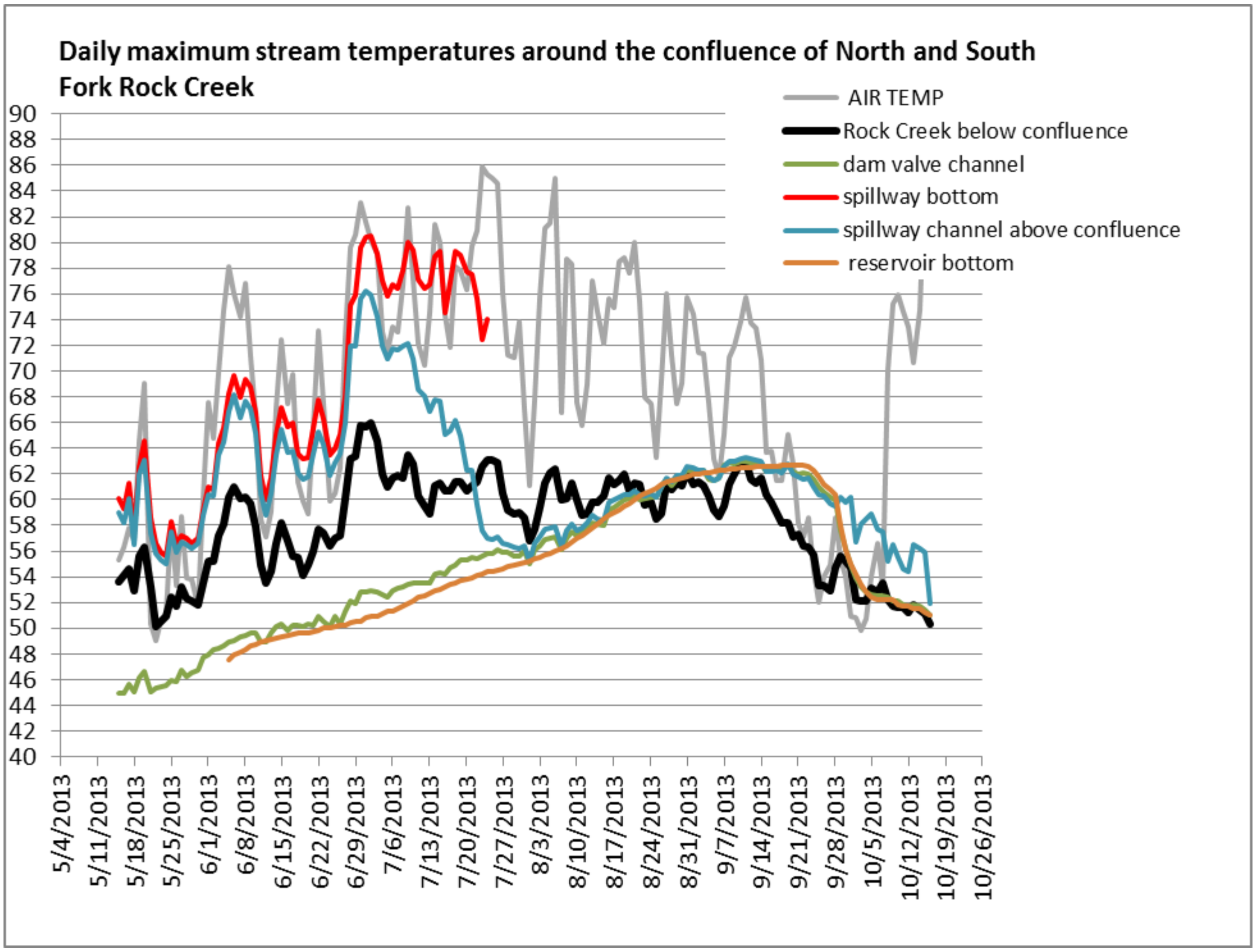


Figure 19. Comparison of daily maximum temperatures in the channels below the dam and around the confluence of the North and South Forks of Rock Creek.

Can the temperature difference between the South Fork Rock Creek above the confluence and the mainstem Rock Creek below the confluence be attributed to the spillway? If so, how much?

Background:

Temperature is a measurement independent of the quantity of water. Enthalpy is the amount of heat (calories) in a body of water and depends on the quantity of water and the temperature. For water, the calories contained in a gram of water is a number very close to the temperature in centigrade (Table 4):

Table 4: Enthalpy of water at different temperatures

Temperature (centigrade)	Enthalpy (Cal/gram) of Water		Temperature (centigrade)	Enthalpy (Cal/gram) of Water
10	*10.0636*		15	15.0659
11	11.0647		16	16.0655
12	12.0654		17	17.0650
13	13.0659		18	18.0642
14	14.0660		19	19.0633
			20	20.0622

From: CRC Handbook of Chemistry and Physics, 48th edition, 1967-1968.

The heat, measured in calories, contained in a quantity of water can be calculated by multiplying the quantity of water by the calories per gram in the water for a specific temperature, or:

Heat = mass (grams) X calories per gram at a specific temperature (See Table 1).

To determine what contribution the spillway is making to the mainstem, the following method was used:

The sum of:

- Calories contributed by the spillway = (Grams of water) X (calories per gram) for the spillway
- Calories contributed by the South Fork above the confluence = (Grams of water) X (calories per gram) for South Fork
- Calories contributed by the dam valve channel = (Grams of water) X (calories per gram) for the dam valve channel

Compared to:

- (Grams of water) X (calories per gram) for the mainstem below the confluence

In other words,

(South Fork calories) + (Spillway temp calories) + (Dam Valve Channel calories) should approximate (Mainstem calories)

Assumptions:

- There is no significant groundwater input.
- The sum of the heat contained in the flow above the confluence should approximate the heat (calories) in the mainstem below the confluence.
- In addition, cooling due to evaporation is an unknown variable.

Flow measurements were taken at the same measured cross-sections several times during the summer of 2013. The cross-sections were at the same location as the temperature probes, with the exception of the South Fork Rock Creek. The flow measurements were done at four locations, three above the confluence of the North and South Fork Rock Creek, and one in the mainstem below the confluence. The locations are: 1) the South Fork Rock Creek above the confluence with the mainstem Rock Creek, 2) the dam valve drainage channel, 3) the spillway channel below the end of the spillway, and 4) the mainstem Rock Creek below the confluence.

The probe that was placed above the confluence in the South Fork Rock Creek was set to take temperatures every minute, rather than every hour. As a result, the memory chip was at capacity within a couple of weeks. The data from the probe that was deployed up upstream at the trashrack above the intake was used as a substitute. Data from both sites was compared for 2012 to see how much difference in temperature there was between the two sites (Figure 20). During the early summer, the difference ranges from 0 to 1 degrees F.

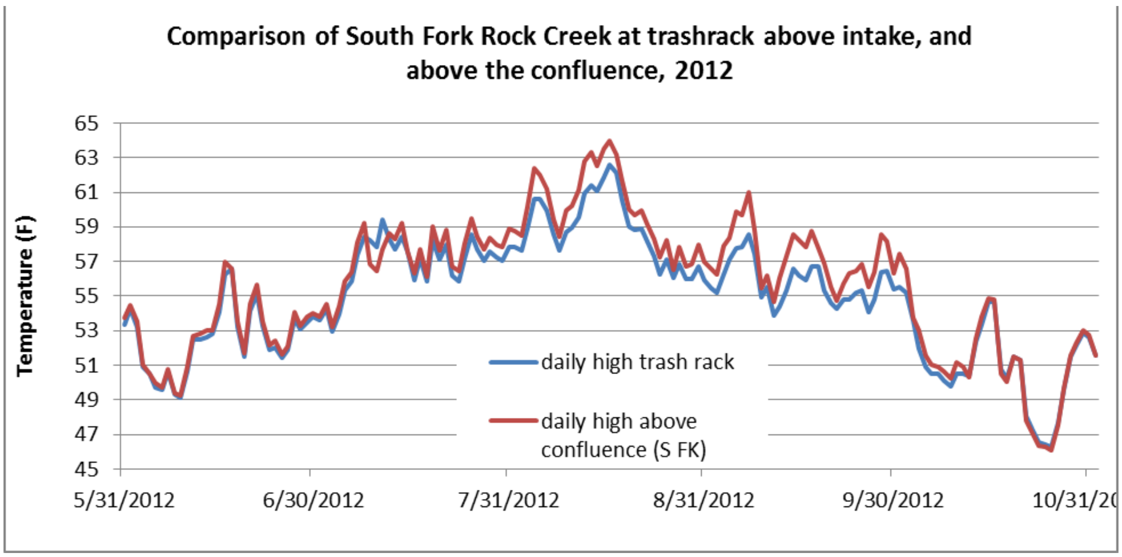


Figure 20: Comparison of the daily high temperatures during the summer of 2012 for the two sites on the South Fork Rock Creek.

Flow data

In addition to the closely bracketed temperature data around the dam and confluence of the North and South Forks of Rock Creek, stream flow data was collected in the three channels above the confluence and just downstream of the confluence in the mainstem of Rock Creek in 2013. The combination of the streamflow data and the relative temperatures above and below the confluence allow for a better analysis of the heat contribution from the spillway.

Stream flows were measured along the same cross-sections several times during the summer. The flow measurements were taken at the same places where temperature probes had been placed, using a Marsh-McBirney flowmeter. Table 5 and Figures 21, 22 and 23 show the dates and results of the flow measurements.

Table 3: Stream flows measured through the summer in cubic feet per second (CFS).

Site	Flow May 14 (CFS)	Flow June 4 (CFS)	flow July 9 (CFS)	Flow July 15 (CFS)	Flow July 26 (CFS)
Mainstem Rock Creek below confluence	10.12	15.74	5.9	4.52	3.94
South Fork Rock Creek above confluence	6.17	9.35	5.7	4.64	4.09
Lower Spillway cross-section	3.05	3.51	0.92	0.55	0
Dam Valve channel			0.52	0.38	0.35
Ratio of lower spillway to mainstem flow	*0.30*	*0.22*	*0.16*	*0.12*	*0.00*

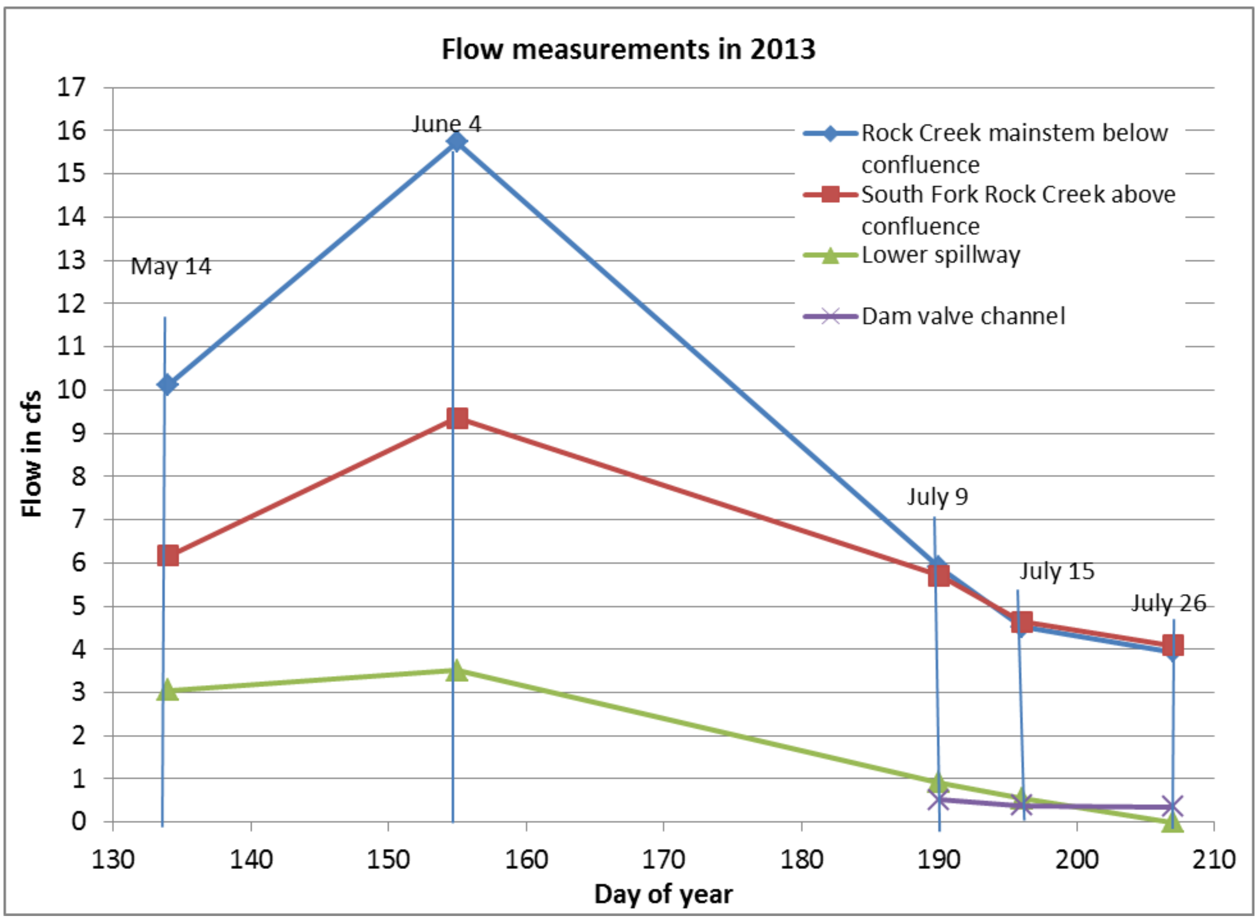


Figure 21: Line graph comparing flows measured around the confluence when the spillway was flowing.

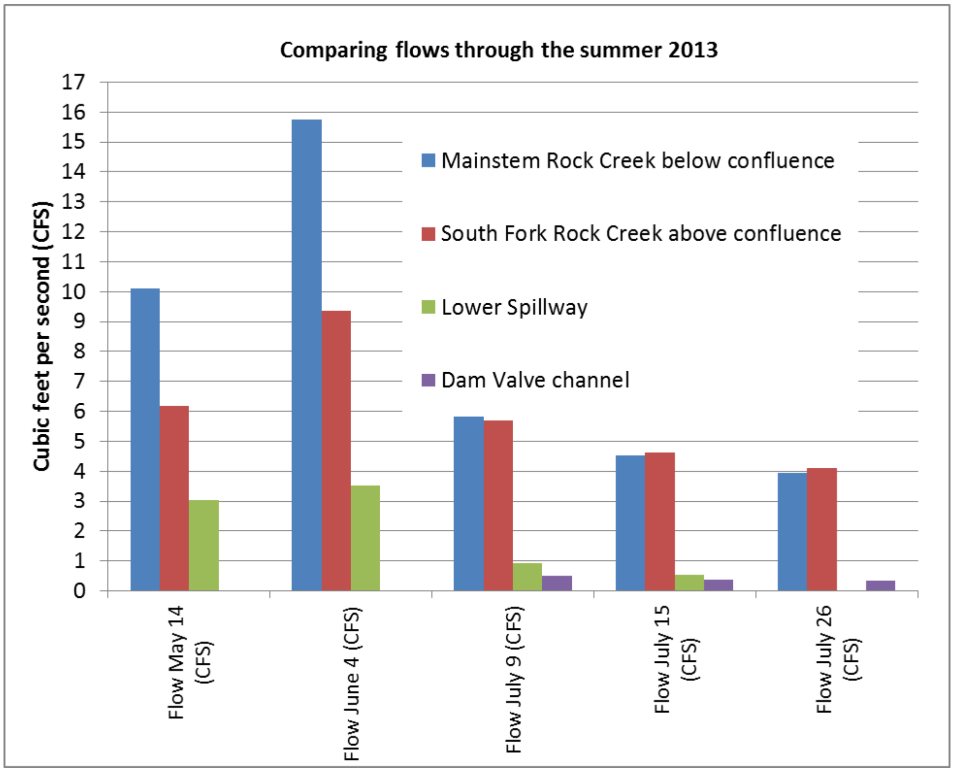


Figure 22: Comparison of flows above and below the North and South Fork Rock Creek confluence. The spillway stopped flowing on July 26. The dam valve channel has a relatively consistent flow through the summer.

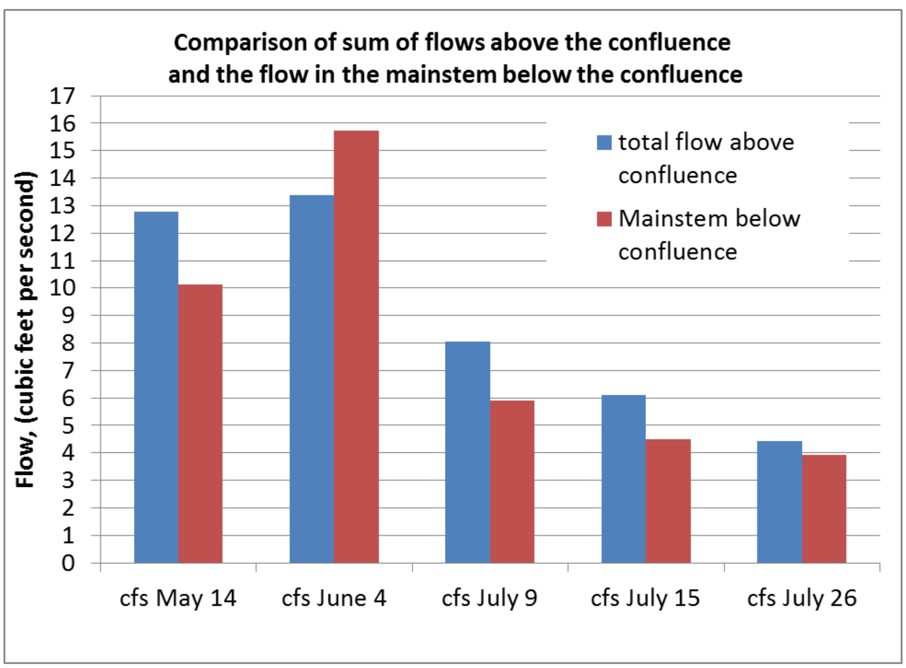


Figure 23: Comparison of the sum of the flows in the three channels above the confluence with the mainstem below the confluence.

When the weather was dry in prior to late May, and also during June and July, flow measured in the mainstem was less than the sum of flows above the confluence. This discrepancy may suggest that below the confluence, the mainstem is contributing to groundwater and hyporheic flow, rather than receiving input from groundwater. After two weeks of rainy weather, the shallow surface hillslope contribution was probably recharged and contributing water to the downstream mainstem.

After a dry spring, the latter half of May was rainy (Figure 24). As a result, stream flows increased between May 14 and June 4.

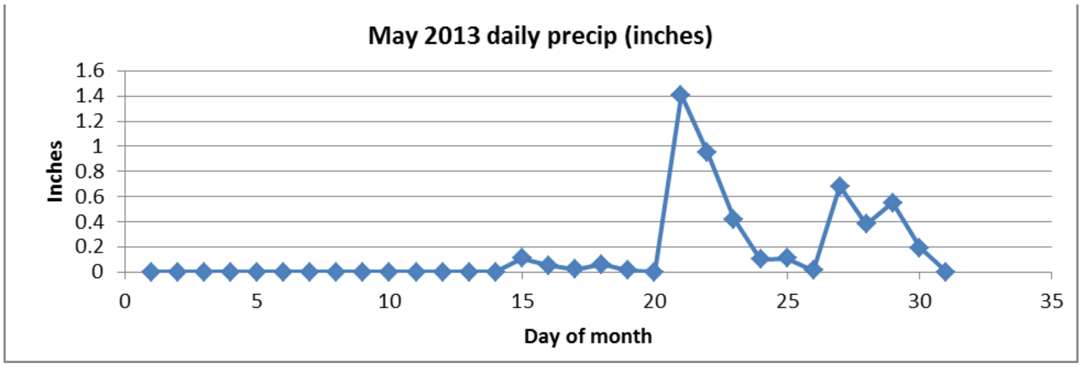


Figure 24: Precipitation at Wilkinson Ridge RAWS station for May, 2013

Figure 25 shows the daily maximum temperatures on the dates that the flow measurements were taken. The flow and the daily high water temperature were used to compare the heat contained in the streams.

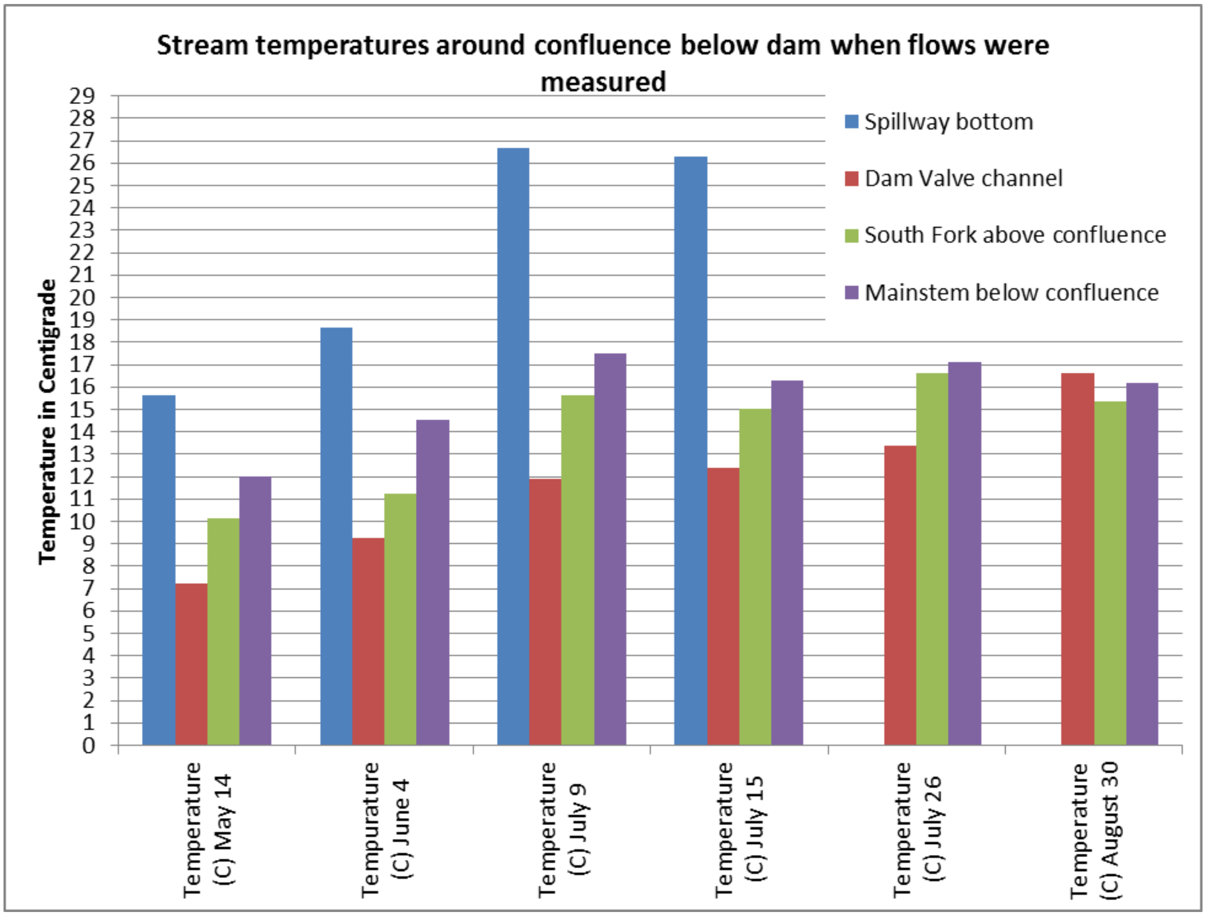


Figure 25. Stream temperatures on the dates that the flows were measured. Note that the dam valve channel temperatures steadily increases through the summer (red bar). On August 30, it is warmer than the mainstem.

Table 6 shows an example of the data used for one of the days when flow was measured.

Table 6: Flows, temperatures in centigrade, and calories for sites around the confluence used in the calculations.

May 14, 2013

Site	Flow (cfs) May 14	convert cfs to cc	convert to grams	Temp C May 14	calories May 14 2013
Spillway bottom	3.05	86366.38335	86343.06443	15.63	1349542.097
Dam Valve channel	0.52	14724.76044	14720.78475	7.22	106284.0659
South Fork above confluence	6.17	174714.946	174667.773	10.14	1771131.218
Mainstem below confluence	10.12	286566.4916	286489.1187	12.03	3446464.098
Totals above confluence	9.74		275731.6221		3226957.381

June 4, 2013

Site	Flow (cfs)	convert cfs to cc	convert tograms	Temp C	calories June 4 2013
Spillway bottom	3.51	99392.13297	99365.29709	18.65	1853162.791
Dam Valve channel	0.52	14724.76044	14720.78475	9.24	136020.0511
South Fork above confluence	9.35	264762.5195	264691.0336	12.32	1224180.460
Mainstem below confluence	15.74	445707.1718	445586.8308	14.51	6465464.916
Totals above confluence	13.38		378777.115		4425424.593

July 9, 2013

Site	cfs	convert cfs to cc	convert tograms	Temp C	calories july 9 2013
Spillway bottom	0.92	26051.49924	26044.46534	26.67	694605.8905
Dam Valve channel	0.52	14724.76044	14720.78475	11.91	175324.5464
South Fork above confluence	5.7	161406.0279	161362.4483	15.63	2522095.066
Mainstem below confluence	5.9	167069.3973	167024.2886	17.51	2924595.293
Totals above confluence	7.14		202127.69		3392025.503

July 15, 2013

Site	cfs	convert cfs to cc	convert to grams	Temp C	calories july 15
Spillway bottom	0.55	15574.26585	15570.0608	26.28	409181.1978
Dam Valve channel	0.38	10760.40186	10757.49655	12.41	133500.5322
South Fork above confluence	4.64	131390.1701	131354.6947	15.03	1974261.062
Mainstem below confluence	4.52	127992.1484	127957.5906	16.29	2084429.15
Totals above confluence	5.57		157682.25		2516942.792

July 26, 2013

Site	cfs	convert cfs to cc	convert to grams	Temp C	calories july 26
Spillway bottom	0	0	0	0	0
Dam Valve channel	0.35	9910.89645	9908.220508	13.4	132770.1548
South Fork above confluence	4.09	115815.9042	115784.6339	16.63	1925498.462
Mainstem below confluence	3.94	111568.3772	111538.2537	17.13	1910650.286
Totals above confluence	4.44		125692.85		2058268.617

August 30, 2013

Site	cfs	convert cfs to cc	convert to grams	Temp C	calories August 30
Spillway bottom	0	0	0	0	0
Dam Valve channel	0.34	9627.72798	9625.128493	16.61	159873.3843

South Fork above confluence	1.7	48138.6399	48125.64247	15.37	739691.1247
Mainstem below confluence	2.71	76738.65537	76717.93593	16.18	1241296.203
Totals above confluence	2.04		57750.771		899564.509

A comparison of the calories in the contributing channels above the confluence and the mainstem below the confluence is shown in Figure 26.

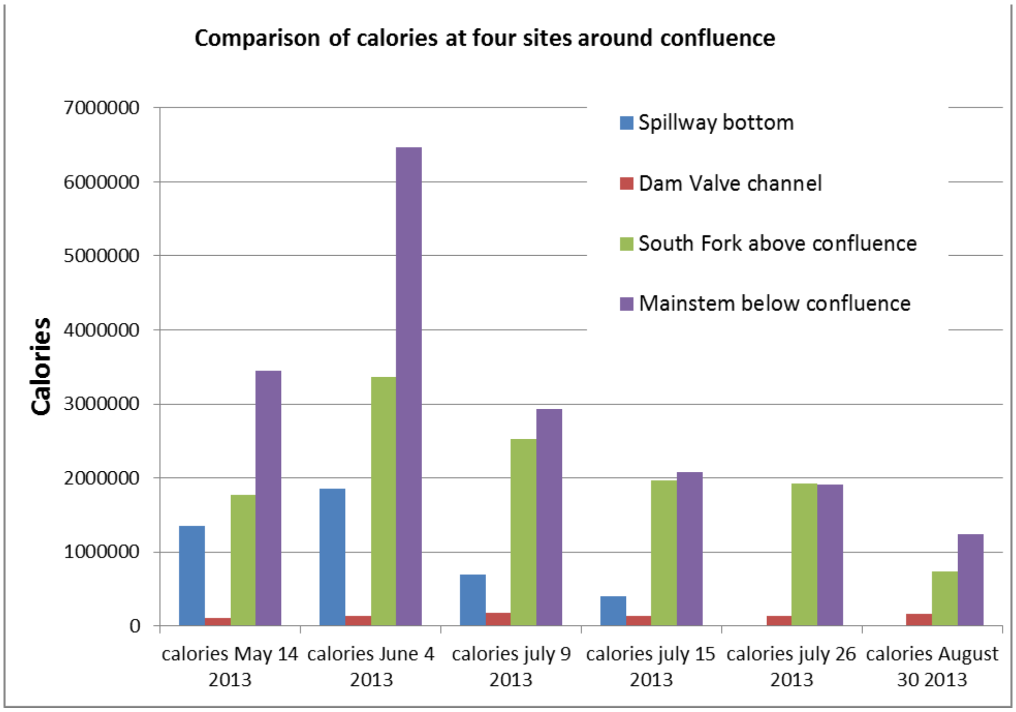


Figure 26a. Comparison of calories at four individual sites around the confluence below the dam.

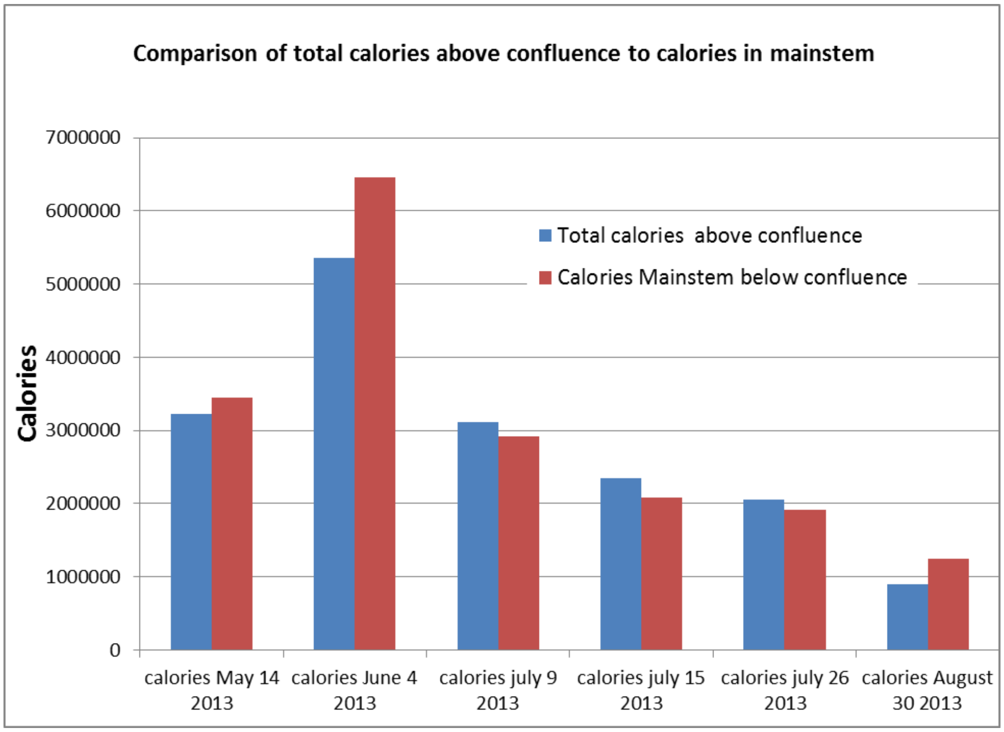


Figure 26b: Graphs showing the comparison of caloric content in the sum of the channels above the confluence and the mainstem below the confluence.

How much of the temperature in the Rock Creek mainstem can be attributed to the spillway contribution of heat?

To calculate how much of the temperature downstream in the mainstem can be attributed to the spillway, "what if" calculations can be made to theoretically eliminate the effects of the spillway.

First, what if the spillway channel was the same temperature as the South Fork of Rock Creek? The temperature data included the May flow date, so this set of data was used for one scenario. The temperature data for the South Fork Rock Creek is substituted for the temperatures in the spillway.

Second, what if the temperature from the spillway was the same as the North Fork? This scenario assumes the temperature at the spillway would be close to the temperatures measured just above the reservoir if the dam wasn't present. The temperature data from the North Fork Rock Creek is substituted for the temperatures in the spillway.

Third, what if the spillway channel was the same temperature as the dam valve channel, which is very close to the bottom of the reservoir. In other words, for the second scenario, what if all the water released by the dam was coming from the bottom of the reservoir? The temperature data from the dam valve channel is substituted for the temperatures in the spillway.

Scenario 1: What if the spillway was the same temperature as the South Fork?

Step 1: Comparison of calories in water at different sites through the summer:

Site	calories May 14 2013,	calories June 4 2013	calories july 9 2013	calories july 15
Spillway bottom (Assume the spillway bottom is the same temperature as the South Fork)	875518.6733	1224180.46	407074.9932	234018.0138
Dam Valve channel	106284.06	136020.051	175324.54	133500.53
South Fork above confluence	1771131.21	2969833.39	2522095.06	1974261.06
Mainstem below confluence	3446464.09	6465464.91	2924595.29	2084429.15

Step 2: What is the difference in calories in the water above the confluence through the summer when the spillway is flowing?

	May 14, 2013	July 4, 2013	July 9, 2013	July 15, 2013
Total calories above confluence if Spillway and South Fork are same temperature	2752933.95	4330033.90	3104494.60	2341779.60
Total calories above confluence with actual measured flows and temperatures in 2013	3226957.38	4959016.23	3392025.50	2516942.79
DIFFERENCE in calories between actual measurements and scenario 1	474023.42	628982.33	287530.89	175163.18

Step 3: What is the total flow above the confluence?

	May 14, 2013	July 4, 2013	July 9, 2013	July 15, 2013
Total flow measured above confluence (grams)	275731.62	378777.11	202127.69	157682.25

Step 4: Divide the difference in calories by the total flow above the confluence to find the different in temperature (Centigrade) above the confluence if the spillway was the same temperature as the South Fork.

DIFFERENCE in temperature in centigrade (divide the difference in calories by the flow (in grams) above the confluence	1.72	1.66	1.42	1.11

Step 5: How much difference would Scenario 1 make in the mainstem directly downstream? Subtract the difference in temperature from step 4 from the actual measured temperature through the summer.

Actual measured temperature (C) downstream at mainstem	12.03	14.51	17.51	16.29
What the mainstem temperature would be if the spillway temperature were the same as the South Fork:	10.31	12.85	16.09	15.18

Step 6: Convert to Fahrenheit.

	May 14, 2013	July 4, 2013	July 9, 2013	July 15, 2013
Actual measured temperature (F) downstream at mainstem	53.65	58.12	63.52	61.32
What the mainstem temperature (F) would be if the spillway temperature were the same as the South Fork:	**50.56**	**55.11**	**60.96**	**59.32**
Temperature Difference in Fahrenheit	**3.09**	**3.01**	**2.56**	**1.99**
Actual 7-day average maximum, Rock Creek mainstem below confluence		58.16	61.6	60.49

Scenario2: What if the spillway was the same temperature as the North Fork Rock Creek?

Step 1: Comparison of calories in water at different sites through the summer:

Site	calories May 14 2013,	calories June 4 2013	calories july 9 2013	calories july 15
Assume the spillway bottom is the same temperature as the North Fork	875518.67	1319571.15	411242.10	236664.92
Dam Valve channel	106284.06	136020.05	175324.54	133500.53
South Fork above confluence	1771131.22	2969833.39	2522095.06	1974261.06
Mainstem below confluence	3446464.09	6465464.91	2924595.29	2084429.15

Step 2: What is the difference in calories in the water above the confluence through the summer when the spillway is flowing?

Total calories above confluence if Spillway and North Fork are same temperature	2752933.95	4425424.59	3104494.61	2341779.61
Total calories above confluence with actual measured flows and temperatures	3226957.38	4959016.24	3392025.50	2516942.79
DIFFERENCE in calories between actual measurements and scenario 2	474023.42	533591.65	287530.89	175163.18

Step 3: What is the total flow above the confluence?

Total flow measured above confluence (grams)	275731.62	378777.11	202127.69	157682.25

Step 4: Divide the difference in calories by the total flow above the confluence to find the different in temperature (Centigrade) above the confluence if the spillway was the same temperature as the North Fork.

DIFFERENCE in temperature in centigrade (divide the difference in calories by the flow in grams in the mainstem	1.72	1.41	1.42	1.11

Step 5: How much difference would Scenario 1 make in the mainstem directly downstream? Subtract the difference in temperature from step 4 from the actual measured temperature through the summer.

Actual measured temperature (C) downstream at mainstem	12.03	14.51	17.51	16.29
What the mainstem temperature would be if the spillway temperature were the same as the North Fork:	10.316	13.10	16.089	15.18

Step 6: Convert to Fahrenheit.

	May 14, 2013	July 4, 2013	July 9, 2013	July 15, 2013
Convert temperatures to Fahrenheit				
Actual measured temperature (F) downstream at mainstem	53.65	58.12	63.52	61.32
What the mainstem temperature (F) would be if the spillway temperature were the same as the North Fork:	**50.56**	**55.41**	**60.94**	**59.32**
Temperature Difference in Fahrenheit	3.09	2.71	2.58	2

Scenario3: What if the spillway was the same temperature as the dam valve channel (reservoir bottom)?

Step 1: Comparison of calories in water at different sites through the summer:

Site	calories May 14 2013,	calories June 4 2013	calories July 9 2013	calories July 15
Assume the spillway bottom is the same temperature as the dam valve channel	875518.67	1114878.63	407074.99	234018.01
Dam Valve channel	106284.06	136020.05	175324.54	133500.53
South Fork above confluence	1771131.21	2969833.39	2522095.06	1974261.06
Mainstem below confluence	3446464.09	6465464.91	2924595.29	2084429.15

Step 2: What is the difference in calories in the water above the confluence through the summer when the spillway is flowing?

	May 14, 2013	June 4, 2013	July 9, 2013	July 15, 2013
Totals above confluence if Spillway and dam valve channel are same temperature	2752933.95	4220732.08	3104494.61	2341779.61
Totals above confluence with actual measured flows and temperatures	3226957.38	4959016.24	3392025.50	2516942.79
DIFFERENCE in Calories between scenario 2 and actual measurements:	474023.42	738284.16	287530.89	175163.18

Step 3: What is the total flow above the confluence?

Total flow measured above confluence (grams)	275731.62	378777.1	202127.69	157682.25

Step 4: Divide the difference in calories by the total flow above the confluence to fine the difference in temperature (Centigrade) above the confluence if the spillway was the same temperature as the dam valve channel.

DIFFERENCE in temperature in centigrade (divide the difference in calories by the flow in grams in the mainstem	1.72	1.95	1.42	1.11

Step 5: How much difference would Scenario 3 make in the mainstem directly downstream? Subtract the difference in themperature found in step 4 from the actual measured temperature through the summer:

Actual measured temperature (C) downstream at mainstem	12.03	14.51	17.51	16.29
What the mainstem temperature would be if the spillway temperature were the same as the dam valve channel:	10.31	12.56	16.09	15.18

Step 6: Convert to Fahrenheit:

	May 14, 2013	June 4, 2013	July 9, 2013	July 15, 2013
Actual measured temperature (F) downstream at mainstem	53.65	58.12	63.52	61.32
What the mainstem temperature would be if the spillway temperature were the same as the dam valve channel:	**50.56**	**54.61**	**60.96**	**59.32**
Temperature Difference in Fahrenheit	**3.09**	**3.51**	**2.56**	**1.99**
7-day average maximum, Rock Creek mainstem below confluence		58.16	61.6	60.49

The results of the scenarios are almost identical. Although the spillway appears to be responsible for a maximum of 3.5 degrees (F) of the measured temperature downstream when the spillway is at its highest flow rate in early summer (Scenario 3), temperatures downstream are below 60 degrees F, and the 7-day average maximum of 58.16F, when the spillway has maximum flow and effect, is well below the state standard of 64F.

The calculated temperature differences also lessen through the summer as the spillway flow diminishes through the summer. Even though the spillway stops flowing on July 26, 2013, there is still a difference in temperature between the South Fork and the mainstem that ranges between 0.3 and 2.2 degrees F during August and September (Figure 5).

In addition, the same downward trend in temperature differences between the South Fork Rock Creek and the mainstem of Rock Creek is present in 2013 as it was in 2012 (Figure 29). This downward trend in temperature differences reflects the diminishing spillway flow through the first part of the summer.

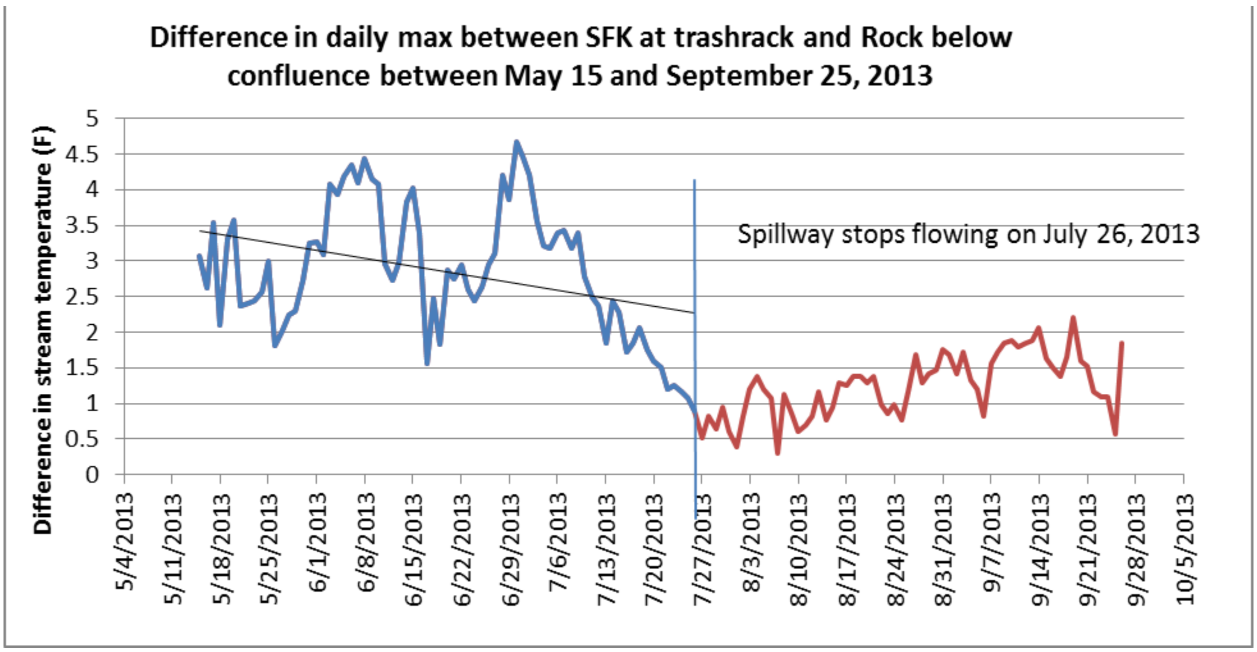
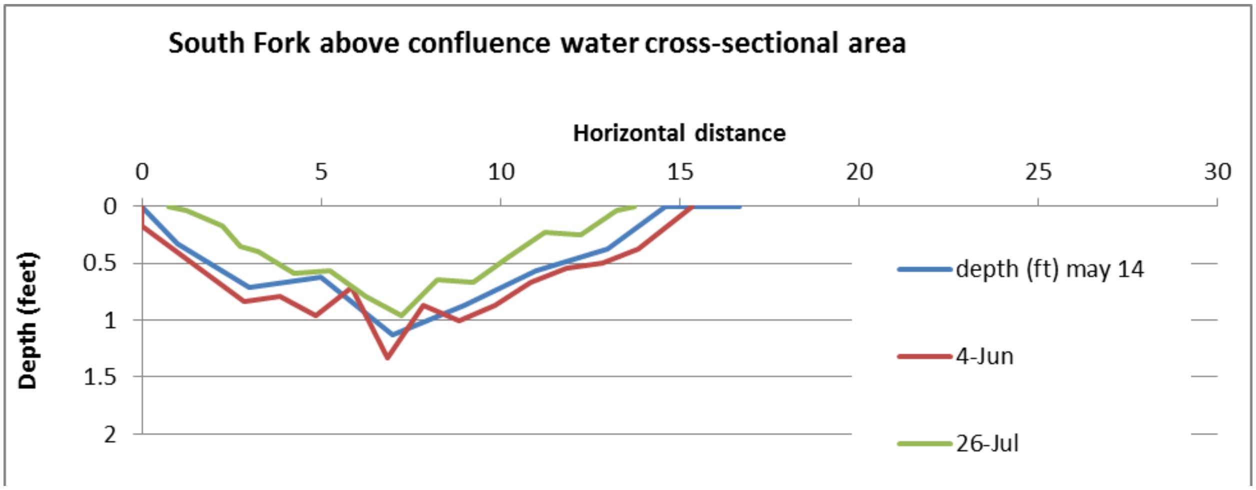


Figure 29. Difference in daily maximum temperatures between the South Fork Rock Creek and the mainstem Rock Creek below the confluence. The black line is the trend line.

An additional factor that could explain the warmer temperatures downstream:

Cross-sections of the water flow at the South Fork above the confluence and the mainstem below the confluence show that the width of the stream relative to its depth is greater below the confluence. In other words, the mainstem is wider and shallower than the South Fork. The mainstem has more water surface relative to depth exposed to air temperatures. This greater opportunity for interaction between the water surface and air temperatures is probably a factor in the higher stream temperatures below the confluence. The cross-sections of the water flow in these two channels are shown in Figure 30, and the dimensions are shown in Tables 7 and 8.



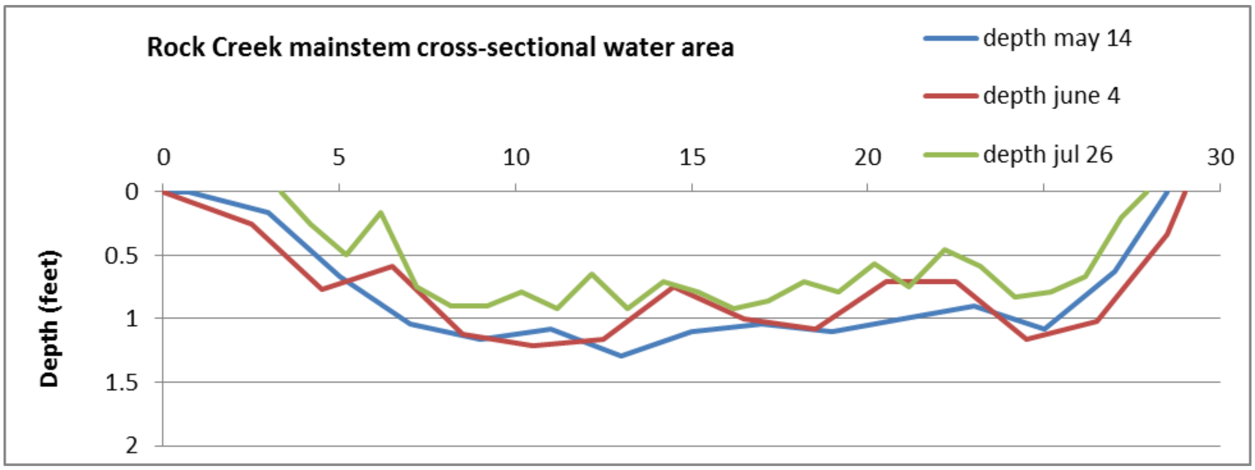


Figure 30: Graphs showing the cross-sectional area of the water flow in the South Fork above the Confluence and the Rock Creek mainstem below the confluence. Note the difference in width between the two sites.

Table 7: South Fork dimensions of flow cross-section, summer 2013

date	width	average depth	max depth	width depth ratio using max depth
14-May	14.585	0.66	1.13	12.96
4-Jun	15.34	0.74	1.33	11.53
26-Jul	13.75	0.44	0.96	14.35

Table 8: Mainstem Rock Creek dimensions of flow cross-section, summer 2013

date	width	average depth	max depth	width/depth ratio using max depth
14-May	27.75	0.94391	1.29	21.51163
4-Jun	29	0.848214	1.2	24.16667
26-Jul	24.59	0.681424	0.9166	26.82741

Conclusions

- Temperature, precipitation and stream flow are variable from year to year, and this variability influences stream temperature. Therefore, conclusions about trends in stream temperature cannot be based on only a couple of years of data.
- Air temperatures in 2012 and 2013 were similar; however, flows were lower in 2013. Maximum stream temperatures were similar, but more days in 2013 were above the state standard of 64F for the 7-day average of the daily maximum temperatures. The lower stream flows were probably a factor.
- The tributaries all met the state water quality standards. The mainstem was above 64F for the 7-day average of the daily maximum temperature, but most sites were less than a degree or two above the standard.
- The bottom of the reservoir was warmer in 2013 by 2 to 5 degrees F, compared to 2012. By mid-August, the bottom of the reservoir was the same temperature or slightly warmer than the mainstem of Rock Creek below the confluence.
- Flow data was collected during the summer, and combined with stream temperatures to calculate the effect of the reservoir on stream temperatures immediately downstream in the mainstem of Rock Creek. While the spillway was flowing, an increase of approximately 2.5 to 3 degrees F could be attributed to the spillway. The effect was more noticeable in the spring and early summer when the spillway had more flow. The effect was reduced as the spillway flow diminished. By mid-July, the spillway flow was 16% of the flow in the mainstem below the confluence. Stream temperatures in the late spring to mid-summer were relatively cool when the spillway flow was higher.