Skagit and Sauk Tributary Stream Temperature Monitoring: 2008-2013 Results and Interpretation

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This report is available online at: http://www.skagitcoop.org/index.php/documents/

Table of Contents

List of Figures

List of Tables

1. Stream Temperatures and Skagit Salmonids

Stream temperature is an important water quality component, known to strongly affect aquatic life and stream health. Salmon and trout face limitations in Skagit River tributaries during mid-summer, when habitat availability is reduced by low flows and high stream temperatures. Previous research, summarized in several comprehensive reviews, indicates that stream temperature is a significant factor that affects distribution and health of salmonids (Bjornn and Reisner, 1991; McCullough, 1999; and Hicks, 2001).

The direct effect of high temperatures on physiological functions of salmon is reasonably well understood and has been documented in laboratory settings. Water temperature is also important for regulating biological and physiological processes in other parts of the aquatic system that may indirectly affect salmon through loss of food supply, spread of disease and other factors. High temperatures may alter migration rates for spawning and rearing and promote growth of competing species (Beschta *et al*., 1987). Potentially lethal temperature-related limitations including reduced metabolic energy, reduced food supply, and competition from warm water species, can indirectly lead to fish mortality (Pollock *et al*., 2009). In general, the preferred temperature range for salmon is 12˚C to 14˚C with most at risk of mortality when temperatures exceed 20˚C, although the exact lethal limit temperature depends on species, life-stage of development and the temperature that the fish is acclimated to (Hicks, 2001). Table 1 contains the approximate temperature ranges for modes of thermally-induced mortality.

Table 1. Temperature ranges for modes of thermally-induced mortality of cold-water fish species (adapted from DOE, 2004)

Modes of thermally-induced mortality for cold-water fish species	Temperature range (˚C)	Time to mortality
Instantaneous Lethal Limit - leads to direct mortality	> 32	Instantaneous
Incipient Lethal Limit - breakdown of physiological regulation of vital bodily processes including respiration and circulation	21 - 25	hours to days
Sub-Lethal Limit - conditions that: 1) cause decreased metabolic energy for growth, feeding, or reproduction; and 2) encourage increased exposure to pathogens, decrease food supply and increase competition from warm-water species.	20 - 23	weeks to months

Summer maximum stream temperatures vary widely based on many site-specific factors including: air temperature; shade; groundwater influx; hyporheic exchange; flow volume; channel depth and gradient; elevation; and other factors (Adams and Sullivan, 1989). Land-use history and mass wasting events may influence temperatures when they alter these drivers (Beschta and Taylor, 1988; Johnson and Jones, 2000).

Temperature Conditions in Skagit Tributaries

Data collected by the Skagit County stream temperature monitoring program indicates that some streams in the lower Skagit River Basin, located in mostly non-forested environments, experienced maximum summer temperatures high enough to stress or kill salmonids while others did not (Skagit County, 2014). The Washington Department of Ecology (DOE) includes several lower Skagit tributaries on the 303(d) list (the state list of impaired waters) for not meeting state water quality standards for temperature in summer low flow periods (DOE, 2008).

The previous report from the SRSC Temperature Monitoring program (Phillips *et al.*, 2011) reported on data from 2008 and 2009, the latter a very hot summer. Critically warm temperatures were generally limited to the largest streams (Finney and Day Creeks) and sites shortly downstream of lakes, both scenarios with maximum solar exposure. Temperature regimes in smaller streams were variable but mostly within a more favorable range for salmonids. Although this report highlighted temperature sensitive reaches and temperatures resulting from an unusually hot summer, data were not collected over a long enough period to evaluate temporal patterns.

1.1. Objectives

The primary objectives of the SRSC monitoring program are to: 1) Improve knowledge of the extent of potentially harmful maximum summer temperatures in Skagit tributaries from basins actively managed for timber; 2) Identify tributary channels that may be important for providing thermal refugia during periods of high temperature; 3) Describe observations of stream temperature patterns and discuss possible relevant factors. This report focuses specifically on streams used by anadromous fish harvested by tribes.

This report presents stream temperature monitoring data collected by SRSC between the years 2008 and 2013, as well as other unpublished data collected at comparable sites and dates by state, non-profit and other tribal organizations. The availability of data from six summers allows greater consideration of temporal patterns than the previous progress report (i.e. Phillips *et al.*, 2011).

Although this report compares temperatures to water quality standards, the intent is not to indicate which streams are "impaired" by land use or other impacts. This is because stream temperatures are naturally variable and maxima can exceed standards even in natural conditions. Therefore a standard temperature requirement isn't necessarily applicable to all stream systems. Still, Washington temperature standards are based on salmonid use, so are a relevant metric for interpreting our data.

2. Study Area and Sampling Methods

The Skagit River is the second largest river (after Fraser River) draining to the Salish Sea (Puget Sound and adjacent water in British Columbia). It is located in the northwestern Cascade Mountains of Washington State. The climate is temperate with mild, dry summers and cool, wet winters and abundant precipitation the majority of which falls as rain at lower elevations. High stream temperatures typically occur in late July and August when extended periods of hot, sunny days coincide with low summer flows.

The Skagit River basin, consisting of the mainstem Skagit (including tributaries, sloughs and estuaries) and four secondary river basins (Baker, Cascade, Sauk, and Suiattle) contains essential habitat for anadromous salmonids, including several species that are listed as threatened under the Endangered Species Act (DOE, 2008). Five species of salmon (Chinook, coho, pink, chum and sockeye), two char species (Dolly Varden and bull trout) as well as steelhead and cutthroat trout exist in the basin (SRSC and WDFW, 2005). The Skagit has the largest run of Chinook and the second largest wild run of coho in the Puget Sound (DOE, 2008).

The uplands of the Skagit basin (aside from high elevation federal lands) have been managed for over a century for timber harvest. Historically, harvest has occurred in clearcuts; however, beginning in the 1970's and increasing in the 1990's, many riparian areas and unstable slopes have been left un-harvested as buffers in part to protect fish habitat and maintain healthy stream temperatures. The lowlands of the basin, where most of the anadromous habitat is located, are dominated by small farms and rural residential development. The land use is a mix of agriculture, urban, suburban, rural and forestry. Many of the water bodies in the lowlands have been modified in the form of diking or channelization.

Lower elevation forests, where monitoring sites are located, are in the Western Hemlock Climax Zone (Franklin and Dyrness, 1973). Western hemlock, Douglas-fir, western red cedar are the dominant conifer species and red alder, black cottonwood, and big leaf maple are the most common deciduous species. Riparian stands are almost entirely less than 100 years old due to logging and/or channel disturbance.

2.1. Sampling Locations

Stream temperature data were collected at thirty-four sites over the course of six years (2008-2013). The tributary basin areas range from 0.1 to 50.8 mi^2 (Appendix 3). The sites are located throughout the central and lower Skagit and Sauk River basins in Water Resource Inventory Areas 3 & 4 (Figure 1). All basins get primarily rain but also significant snow during winter months; none include any glacial melt. In an effort to compliment the temperature monitoring being conducted by Skagit County[1] in agricultural and urban areas in the lower Skagit basin, we have focused data collection and this report on available, currently unreported data from the central Skagit and Sauk basin tributaries where forestry is concentrated.

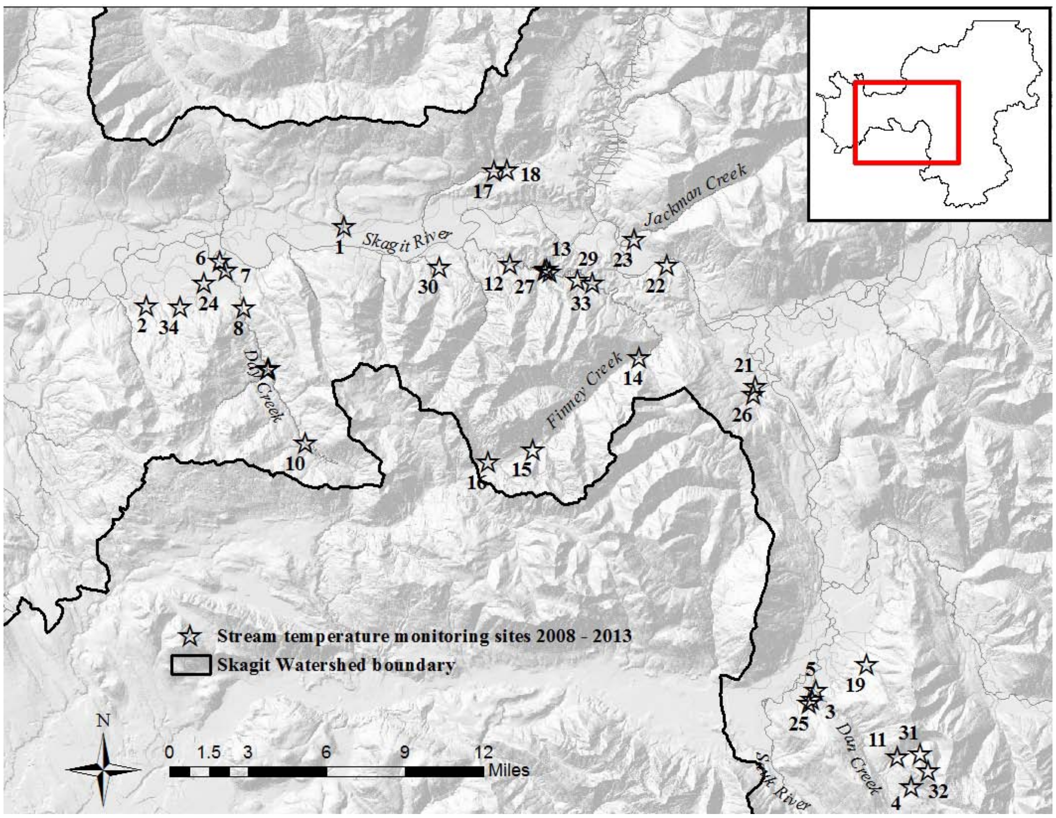

Figure 1. Skagit basin study area map showing the location of stream temperature monitoring sites. Site numbers correspond with those in Table 2 below.

This report represents a collaborative effort utilizing data collected by several organizations including: the Skagit River System Cooperative (SRSC); Sauk-Suiattle Indian Tribe (SSIT); Skagit Fisheries Enhancement Group (SFEG); and the Washington Department of Ecology (DOE) (Table 2). The data from SFEG and DOE sites were downloaded from the Environmental Information Management (EIM) database which is maintained by DOE[2].

[1] Skagit County monitoring data are summarized in annual reports (e.g. Skagit County, 2014) and is not included in this report because sites were not located on forest land.
[2] The EIM database may be found at: http://www.ecy.wa.gov/eim/

Table 2. Summary of stream temperature monitoring sites for 2008-2013. Stream attributes are listed in Appendix 1.

Site #	Stream Name	Location	Organization*	Missing Years
1	Alder Creek	Cape Horn Rd	SRSC	
2	Anderson Creek	upstream of South Skagit Hwy	SRSC	
3	Bob Lewis Creek	upstream of Sauk Prairie Rd	SSIT	
4	Conn Creek	USFS 2430 Rd	SSIT	
5	Dan Creek	upstream of Sauk Prairie Rd	SSIT	2011
6	Day Creek	river mile 0.2	SFEG	2008, 2013
7	Day Creek	river mile 0.7	SFEG	2008, 2012
8	Day Creek	river mile 2.5	SFEG	2008, 2012, 2013
9	Day Creek	near Rocky Creek Confluence	SRSC	2008
10	Day Creek	Day Lake outlet	SFEG	2008, 2012, 2013
11	Decline Creek	USFS 2430 Rd	SSIT	2010
12	Finney Creek	river mile 2.4	SFEG	
13	Finney Creek	downstream of Quartz Creek	SRSC	
14	Finney Creek	river mile 13	SFEG	
15	Finney Creek	river mile 18	SFEG	
16	Finney Creek	river mile 21	SFEG	
17	Grandy Creek	downstream of East Fork trib	SRSC	
18	Grandy Creek	Grandy Lake outlet trib	SRSC	2008
19	Gravel Creek	USFS 2140 Rd	SSIT	
20	Hatchery Creek	Lower Finney Rd	SRSC	
21	Hobbit Creek	upstrm of Concrete-Sauk Vly Rd	SRSC	2008
22	Hooper Creek	upstrm of Concrete-Sauk Vly Rd	SRSC	
23	Jackman Creek	upstream of Hwy 20	SRSC	
24	Morgan Creek	upstream of South Skagit Hwy	SRSC	2009
25	Mouse Creek	upstream of Sauk Prairie Rd	SSIT	
26	Osterman Creek	upstrm of Concrete-Sauk Vly Rd	SRSC	2008
27	Quartz Creek	downstream of Lower Finney Rd	SRSC	
28	Rocky Creek	near Day Creek confluence	SRSC	2008
29	Ruxall Creek	downstream of Lower Finney Rd	SRSC	
30	Savage Creek	Weyco 4400 Rd	SRSC	
31	Unnamed Decline Trib	USFS 2430 Rd	SSIT	
32	Unnamed Decline Trib	USFS 2435 Rd	SSIT	
33	Unnamed Finney trib	small tributary to Finney Creek	SRSC	
34	Winters Creek	tributary to Morgan Creek	SRSC	2008

* Source Organizations: Skagit River System Cooperative (SRSC), Sauk-Suiattle Indian Tribe (SSIT), Skagit Fisheries Enhancement Group (SFEG)

2.2. Data Collection

Temperature data were collected using submersible Onset HOBO data loggers that documented hourly stream temperatures throughout the summer season. All the organizations involved indicated that data collection followed protocols and procedures developed in the Timber Fish and Wildlife (TFW) Stream temperature Survey Manual (Schuett-Hames *et al*., 1999) and Department of Ecology standards (DOE, 2003).

Monitoring protocols specify that sites are to be located in areas where there is a relatively homogeneous reach upstream in terms of stream and riparian conditions so that stream temperature is at equilibrium. The length of stream necessary to reach equilibrium varies but a rule-of-thumb is a distance of 2,000 feet (Schuett-Hames *et al*., 1999). Sites are also to be located in areas of sufficient mixing within the main channel (Schuett-Hames *et al*., 1999).

Site parameters such as gradient, bankfull width and canopy closure were collected in the field at the time of installation. Gradient was measured with a clinometer. Bankfull width was measured at probe locations; some were approximated due to high stream discharge that precluded direct measurement. Percent canopy closure above the instrument was measured using a concave spherical densitometer. Several monitoring locations shifted a short distance between years because of morphological channel changes (i.e. new channel debris, altered pools, small bank failures).

Other site parameters such as elevation, basin size and upstream land cover were derived using ArcGIS raster data and aerial photography. A coarse categorization of the upstream riparian land cover yielded three categories: 1) forested buffer – if there was a typical Forest Practices Rules riparian buffer or equivalent; 2) mixed – if there was a mix of forested buffer and open; and 3) lake – if there was a lake upstream, regardless of whether or not there was a buffer around it. The majority of sites were located in streams that have forested riparian buffers, largely on industrial and other private forest lands regulated by the Washington Forest Practices Rules. Others, including a group of sites located on the Sauk Prairie and in the Dan Creek watershed, were on private residential and US Forest Service managed lands (Figure 1).

2.3 Data Quality and Duration

Data logger calibration was conducted in accordance with the procedures developed in the TFW Stream Temperature Survey Manual (Schuett-Hames *et al*., 1999). To meet the protocol, the accuracy of each probe is verified with pre-deployment calibration checks which require that the mean absolute value difference is less than 0.2 C˚ (Schuett-Hames *et al*., 1999). All SRSC and SSIT instruments were lab-checked at the beginning of each monitoring season.

Although the span for most sites is from 2008 through 2013, several sites have less than six summers of data (Table 2) for various reasons. Ten of these became established in 2009. Other sites included in the 2011 report were terminated (e.g. several SFEG Day Creek sites) and some long-term sites had years excluded because they were identified as dry at some point (e.g. Morgan Creek 2009, Decline Creek 2010 and Dan Creek 2011). These seasons were excluded because of the potential that peak temperatures were actually air temperatures when the probe was not submerged. They were identified either by field observations of a dry channel or data with unusually high temperature spikes and/or uncharacteristically large diurnal ranges. In addition, data from several sites were not recovered due to equipment loss, vandalism or equipment malfunction.

2.4 Temperature Metrics

In this report, two widely-used metrics are reported to represent peak summer temperatures. The 7-Day Average Daily Maximum (7-DADM) temperature is the peak of a moving average that is used because it reduces the effect of short periods of abnormally hot temperatures to evaluate biological effects. The 7-DADM values are used for comparison to state temperature standards. The Seasonal Maximum Hourly Temperature (SMHT) is another standard metric that corresponds to the single highest temperature that fish and biota must withstand.

Daily or diurnal temperature fluctuation is another common metric used to interpret stream temperature and its effects on aquatic life. Diurnal fluctuations can affect fish growth, metabolic rate and survival and large amplitudes can be a threat to the fish community (McCullough, 1999). Higher temperature differences can be the result of disturbances such as channel widening or canopy removal and it has been shown that sites in clearcuts have significantly higher ranges than those in forested or buffered streams (Johnson and Jones, 2000; Veldhuisen and Couvelier, 2006). Diurnal ranges were calculated by averaging the daily ranges (maximum minus minimum) over the 7-day period for which the 7-DADM was recorded.

3. Results and Discussion

Generally most sites peaked sometime between late July and late August, though every year there were a few outlier sites that had peak dates outside this range. Peak dates for all sites can be found in Appendix 1. The year 2013 was unusual as almost a third of the sites peaked in early July and the rest were scattered from July 9th through September 12th.

The magnitude and timing of peaks for both 7-DADM and SMHT varied considerably by site and by year. Site differences are presented below in Section 3.1, while Section 3.2 covers inter-annual differences.

3.1 Differences between sites

Average 7-DADM figures were calculated for each site over the six-year period. Figure 2 shows basic spatial differences. The sites that have the highest 7-DADM temperatures on average (above 20˚C) are located on lower Day Creek (Sites 6, 7 and 8), Finney Creek (Sites 12 and13) and the two sites below lake outlets (Site 18 at Grandy Creek and Site 10 at Day Creek). Sites with low average peak temperatures (below 16˚C) are dispersed throughout the basin and don’t display a discernible spatial pattern. These include Winters, Alder, Savage, Grandy, Hooper, Upper Finney, Osterman, Hobbit, Gravel Creeks and the upper Sauk basin sites. Site specific attributes that contribute to the variable temperatures are discussed in Section 3.1.2.

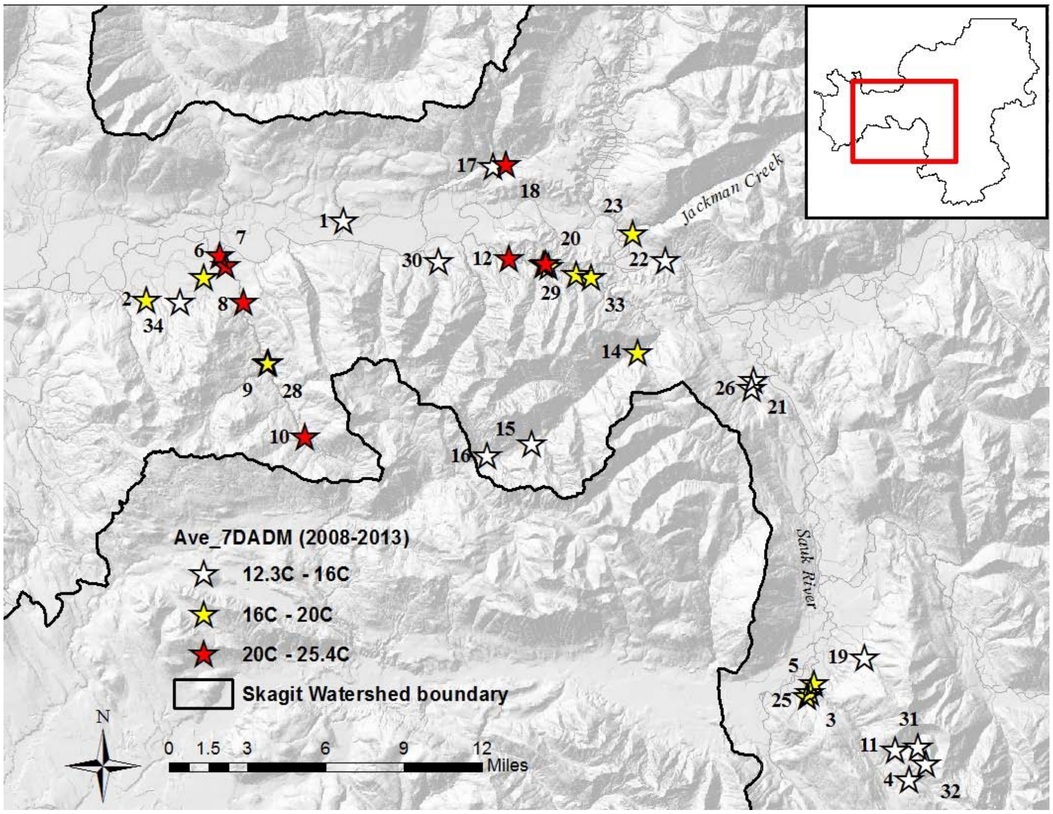

Figure 2: Study area map of 6-year 7-DADM temperature averages.

3.1.1. Diurnal Fluctuations

Some studies suggest that a fluctuating thermal regime of several degrees has beneficial effects on certain juvenile salmon species, such as an increased metabolic rate (Beauregard *et al.*, 2013). However, the effects of fluctuating temperatures also depends on the rate of heating, rate of acclimation to temperature variation, species, life stage and other factors that weren't assessed in this report (McCullough, 1999). The 7-DADM ranges for each site were calculated as explained in Section 2.4. Site specific values can be found in Appendix 2.

Lower Finney Creek (Site 12) exhibited the widest diurnal ranges during all six years. Annual figures range from 5˚C in 2011 to 7.5˚C in 2010. Other sites that had a diurnal amplitude of 5˚C or greater during at least one of the six years were Day Creek (Sites 6 and 7) and another Finney Creek site (# 13). All other sites had 7-DADM ranges between 0.7˚C and 4.9˚C. Sites with low diurnal fluctuations may be buffered by greater shade and/or groundwater inputs that moderate stream temperature extremes (Moore *et al.*, 2005). For example, sites like Hobbit and Savage Creeks displayed low diurnal ranges (1.2˚ and 1.5˚C respectively). The relatively stable temperature time series of both sites indicates groundwater influence (Phillips *et al.*, 2011). Approximately 44% of all sites had average diurnal temperature ranges that were less than 2˚C (Appendix 2). Many of the sites with narrow ranges have high canopy cover, which is consistent with studies elsewhere (Appendix 3) (Johnson, 2004).

The 7-DADM temperatures at each site corresponded positively with 7-DADM daily ranges ($p < .01$). Additionally, the sites that display higher diurnal fluctuations also experienced more inter-annual variability. Sites like lower Day and Finney creeks received greater solar radiation input due to their wide channels, minimal shade and greater upstream length. These characteristics presumably contribute to higher diurnal ranges (McCullough, 1999).

3.1.2 Site-specific Variables

Though atmospheric heat exchange drives stream temperatures, other parameters such as gradient, stream size, elevation, shade, land use and geology influence resulting stream temperatures as well (Johnson, 2004; Beschta and Taylor, 1988; Moore *et al.*, 2005). Rates of groundwater flow and surface discharge can also affect water temperature (Bogan *et al.*, 2003).

Site-specific attributes including bankfull width, gradient and canopy closure were recorded for SRSC and SSIT sites and elevation was derived for all sites. Although this project was not designed to rigorously evaluate the effects of these variables, Figure 5 provides scatter plots for visual review. Bankfull width, channel gradient and elevation are all somewhat correlated with average 7-DADM temperatures. Gradient and elevation are inversely related to 7-DADM, while higher bankfull widths are associated with higher temperature (Figure 3). The poor correlation between shade and stream temperatures likely reflects the inability of the single-site shade measurements to characterize shade effects across a broader range of upstream reaches. Sites that are higher in elevation have lower peaks because of cooler average air and water inputs. Streams higher in gradient and smaller in size are generally cooler likely because they are less exposed to sunlight (Beschta *et al.,* 1987; Johnson, 2004).

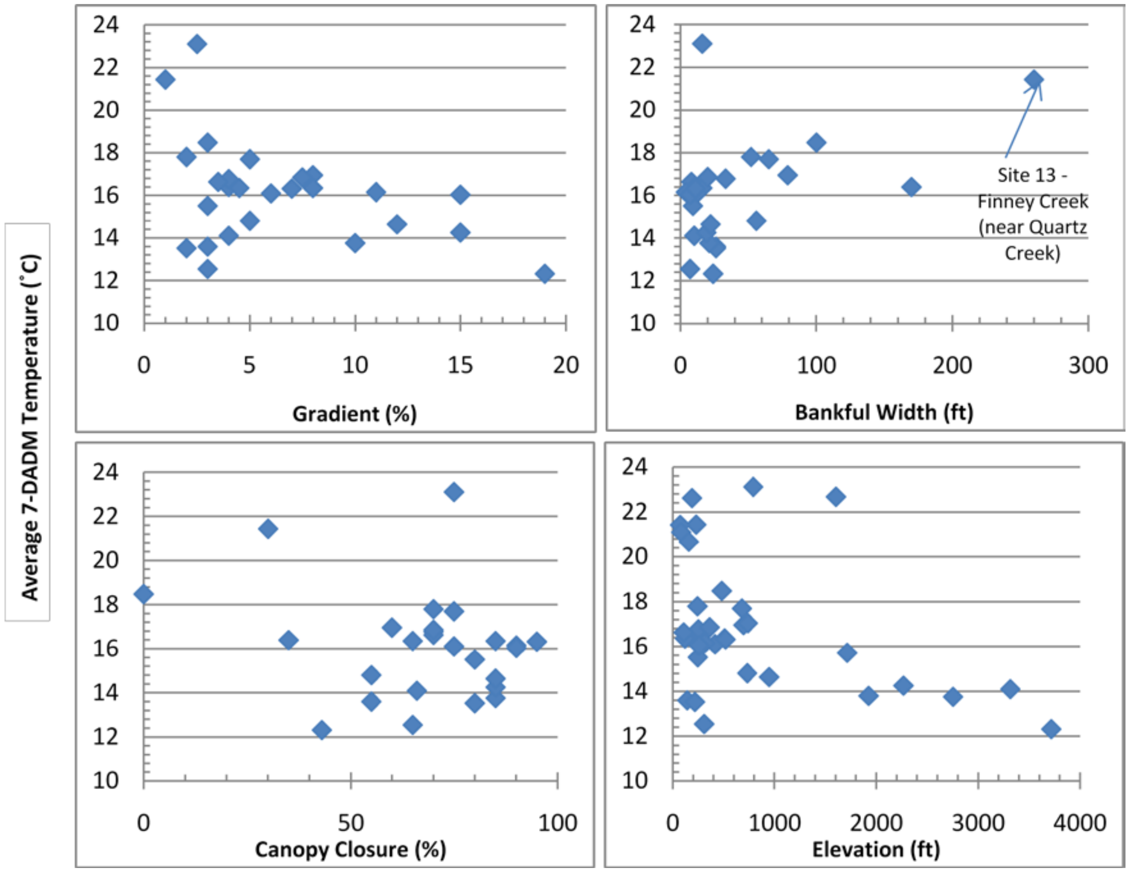

Figure 3. Scatter plots of average 7-DADM temperature and gradient, bankfull width, canopy closure and elevation.

Several other stream temperature factors were discussed in the 2008-2009 SRSC Stream Temperature Monitoring Report, such as contribution of groundwater, basin size and upstream land cover that can also explain some of these dynamics (Phillips *et al.*, 2011).

Relative basin size was assessed to show that in general, sites with greater drainage areas tend to exhibit higher 7-DADM temperatures. This is especially true for Finney and Day Creeks, which are both larger systems than any other creeks monitored (Appendix 3). Like other large streams with wide channel widths, both Finney and Day Creeks have little to no shade in the middle, open portions of the channels. Additionally, the monitoring sites are located well downstream from the headwaters, allowing for more exposure to heat input over time. As already mentioned, the low gradients and elevation of these sites can contribute to warmer temperatures as well.

Several sites have temperatures that reflect local hydrologic influences. For instance, measurement sites below both Day and Grandy Lakes exhibited higher temperatures throughout all six years (greater than 20˚C on average), which reflects the outflow of warm water from the lakes' surfaces. Ground water inputs also affect stream temperatures, as discussed in the previous monitoring report (Phillips *et al.*, 2011). Ground water is typically cooler than stream water in summer during daytime and can moderate seasonal and diurnal temperature variations (Moore *et al.*, 2005). Sites like Hobbit Creek (Site 21) and Savage Creek (Site 30) have temperature time-series that are very cool and stable, indicative of groundwater influence.

3.2. Comparison with State Water Quality Standards

This section compares our results to water quality standards, though such comparisons have important limitations. Stream temperatures are variable in both disturbed and undisturbed systems, and some streams exceed standards even in natural conditions. Therefore this criterion is used here for basic comparison purposes, and not for reporting compliance.

In 2006, Washington adopted 16 C˚ as the 7-DADM standard for waters designated as "Core Summer Salmonid Habitat" (DOE, 2008). The key identifying characteristics of this use are summer (June 15 – September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and subadult native char (DOE, 2011). This criterion was lowered from a previous value of 18 C˚ and is identical to the criterion that Environmental Protection Agency (EPA) recommended in its temperature guidance for salmon and trout core juvenile rearing. Washington State water quality standards are defined in Chapter 173-201A of the Washington Administrative Code (WAC)[3]. All of the streams monitored are subject to the core summer salmonid habitat standard of 16˚ C as defined in the state water quality standards for temperature (Chapter 173-201A Washington Administrative Code).

Of the thirty four sites subject to the Core Summer standard, close to 90% recorded temperatures that exceeded state standards in one or more year. In 2008 42% of the sites had temperatures that were in exceedance, 85% in 2009, 67% in 2010, 33% in 2011, 48% in 2012 and 52% in 2013. Site specific results are listed in Appendix 4. Sites that were especially warm and exceeded state standards over 50% of the installation period for all recorded years are: Day Creek (Sites 6,7 and 8) and Finney Creek (Sites 12 and 13).

In addition to the Core Summer salmonid standard, some locations (specified in Appendix 4) have an additional requirement of 13˚ C during specific time periods based on supplemental spawning and incubation criteria that are required to ensure protection for the incubation of salmon, trout, and char[4]. Eleven sites are subject to the 13˚ C temperature requirement – Alder Creek (Site 1), Dan Creek (Site 5), Day Creek (Sites 6 - 9), Finney Creek (Sites 12 and 13), Jackman Creek (Site 23), Hatchery Creek (Site 20) and Quartz Creek (Site 27). Ten of these sites exceeded standards during at least one of the six years. Day Creek at river mile 2.5 (Site 8) is not shown to exceed the standard because the installation period did not coincide with the 13˚ C requirement period

[3] Chapter 173-201A of the WAC may be found at: http://www.ecy.wa.gov/biblio/wac173201a.html

[4] A map of the supplemental spawning and incubation criteria for the Lower Skagit (WRIA 3) may be found at: http://www.ecy.wa.gov/pubs/0610038/spawning3.pdf and for the Upper Skagit (WRIA 4) at: http://www.ecy.wa.gov/pubs/0610038/spawning4.pdf

(February 15th – June 15th). Alder Creek (Site 1) exceeded standards only during one year (2009) for five days.

The start and end dates of the monitoring period vary by site. The total number of days over the temperature standard may not be complete at all sites, particularly those where temperatures were over standards nearly the entire duration. The majority of sites had 7-DADM temperatures under the 20˚C stress limit (Figure 4). Since 2009 was the warmest summer, 30% of the sites had 7-DADM temperatures above 20˚C and 6% of the sites in 2011, the coolest summer season, had temperatures above 20˚C. The two sites that are consistently above the 20˚C stress limit are lake outlets - Day Creek (Site 10) and Grandy Creek (Site 18). The rest are located on Day Creek (Sites 6, 7 and 10) and Finney Creek (Sites 12 and 13).

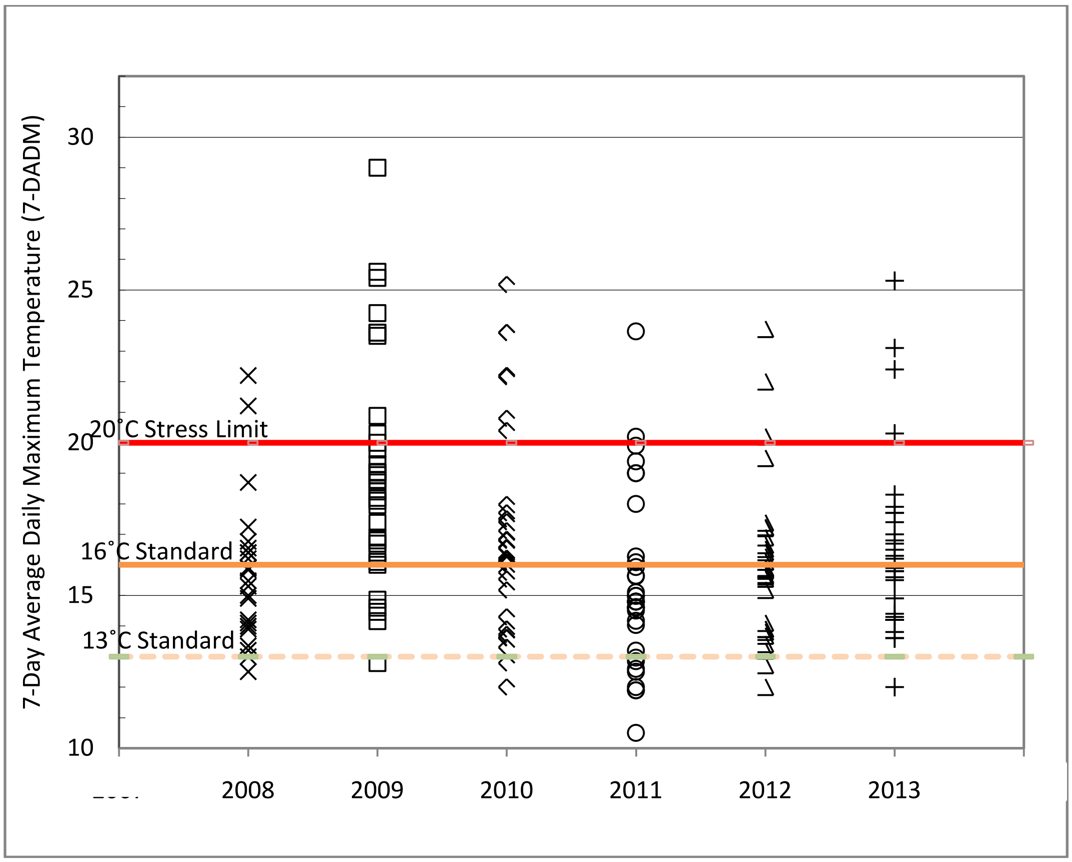

Figure 4: 6-year 7-DADM temperature values compared to the state standards and the 20˚C stress limit.

Nearly two thirds of all sites throughout the six years of monitoring (with the exception of 2009) exceeded standards 10 days or less during the installation period (Figure 5). Because 2009 was the warmest year on record, more than half of all sites had more days of exceedance (> 10 days over standard) in 2009 than all other years. Each year there were certain sites that consistently exceeded standards for more than 30 days, specifically the wide channels of Finney and Day Creek and the lake outlet sites on Grandy and Day Creeks. The relatively warm years of 2009, 2010 and 2013 had the most sites where standards were exceeded for more than 30 days (Figure 5), as discussed further in section 3.3.2 below.

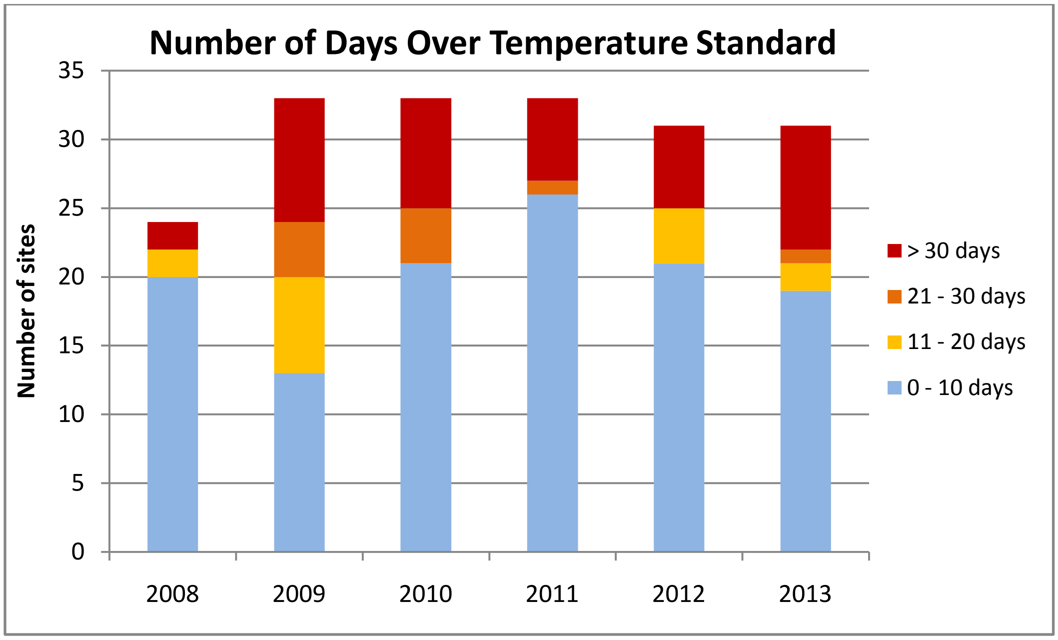

Figure 5: Sites categorized by the number of days in the summer installation period during which temperatures were above the standard.

3.3. Inter-annual Differences and Trends

Having data from six consecutive summers allows an initial exploration of inter-annual trends. Long-term changes are of interest because they are potentially indicative of climate change and/or the effectiveness of buffers located upstream of the study sites.

Temporal trends and 7-DADM inter-annual ranges were evaluated using only information from sites that had a minimum of five years of data. Four sites from Day Creek were dropped from these analyses (Sites 6, 7, 8 and 10) as they only have 3 to 4 years of data. Inter-annual variability was also evaluated relative to air temperature conditions and other site-specific factors.

The mean 7-DADM temperature values by year range from 15.3˚C in 2011 to 19.1˚C in 2009. The mean SMHT for each of the six years was slightly warmer, from 16˚C to 19.7˚C. The minimum, maximum and mean temperature data for all years are listed in Appendix 1 and 2. Median values for 7-DADM and SMHT are slightly cooler than averages (Figure 6).

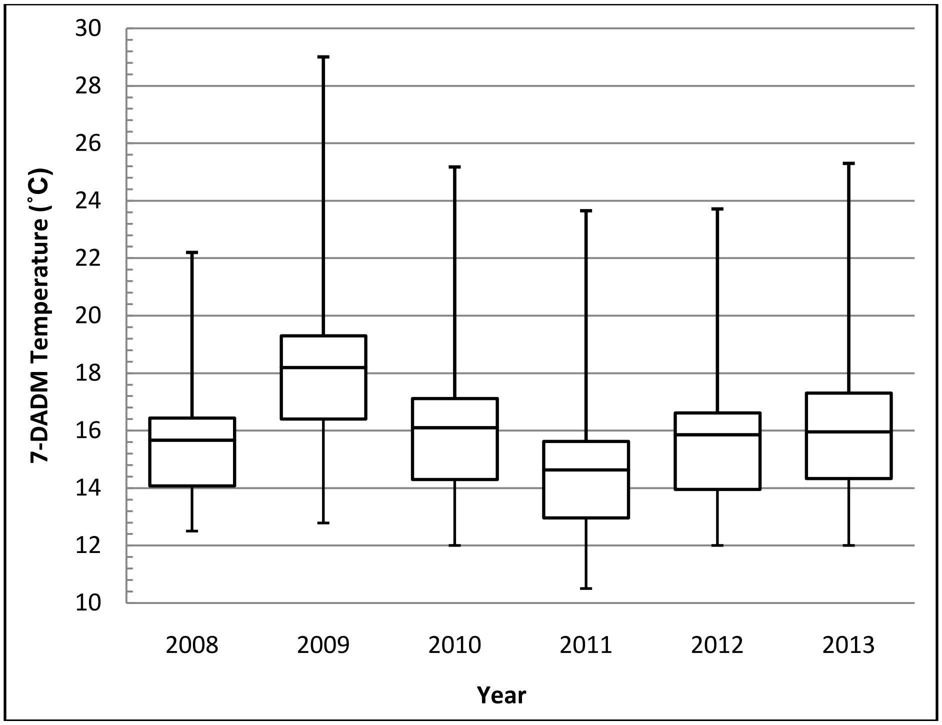

Figure 6: Box plots over the 6-year monitoring period showing inter-annual temperature differences. Outer whisker tips represent the minimum and maximum temperatures among sites. The box is the 25%-75% range of temperatures and the middle divider is the median.

No trend was evident for inter-annual mean temperature variability amongst the thirty sites in either an increasing or decreasing direction (Figure 6), nor was it statistically significant (regression p-value = 0.60). Additional years of data will be needed to discern or rule out any long-term temporal trend with more confidence.

3.3.1. Inter-annual Range

The sites with the greatest range of peaks across monitoring years were Grandy Lake Outlet (Site 18) and Finney Creek (Site 12). Sites that had a relatively high inter-annual temperature range (>4.5˚C) also had higher 7-DADM temperatures (>20˚C) (Figure 7). There are some outliers such as Quartz Creek (Site 27), Decline Tributary (Site 31) and Rocky Creek (Site 28) that had mild 7-DADM temperatures, but high inter-annual temperature variation. Sites with the least inter-annual variation (≤ 2.5˚C) included Savage Creek (Site 30), Morgan Creek (Site 24), Alder Creek (Site 1), upper Finney RM 18 (Site 15) and Hobbit Creek (Site 21). Temperature ranges for all sites are listed in Appendix 2.

This information allows the identification of sites that are more responsive to above average heating conditions, both daily and seasonally. Streams with higher average stream temperatures are likely to exhibit even warmer temperatures on above average years. This information can help prioritize which streams need more shade through the protection, and regulation of mature forest buffers.

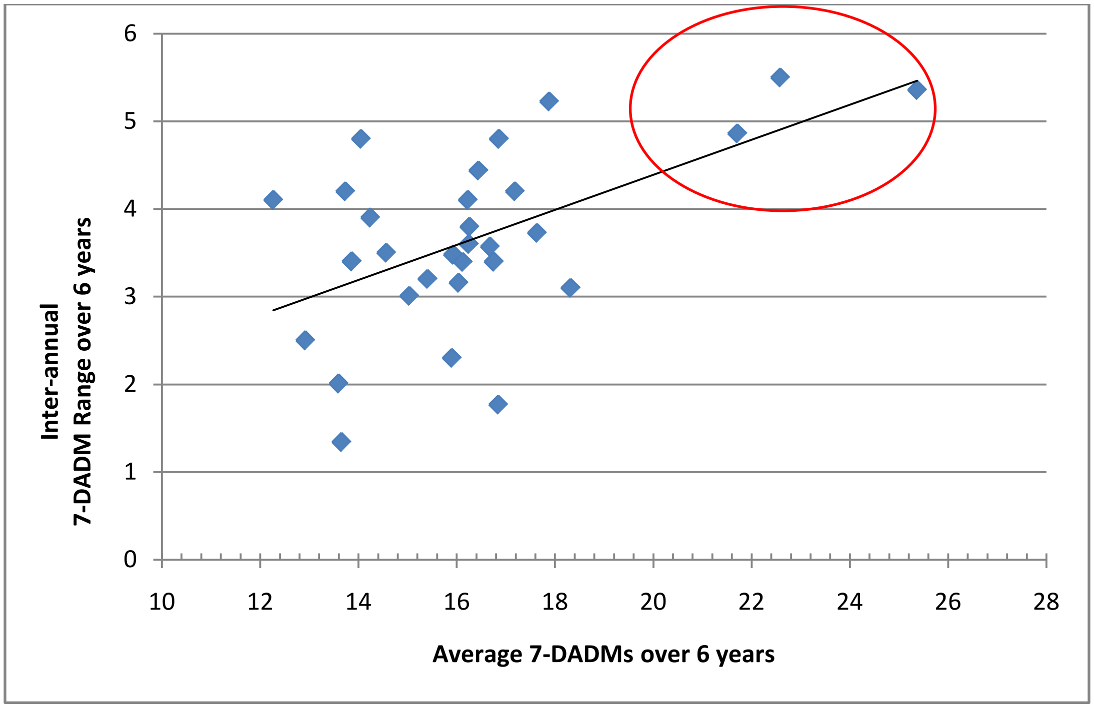

Figure 7: Plot of average 7-DADM temperature for all six years and corresponding inter-annual temperature range. Sites with 7-DADM temperatures above 20˚C (circled in red) also have high differences between summers of varying weather conditions. Inter-annual range on the y-axis represents the highest minus the lowest 7-DADM temperature for each site over the 6-year record.

3.3.2. Weather Conditions

Because peak temperatures of individual streams are known to vary between years due to differing weather and flow conditions (Jackson *et al.*, 2001), we explored inter-annual weather differences. Although a wide range of factors likely play contributing roles, this section focuses only on summer air temperatures, which are available for several key locations in the study area[5]. This is not to suggest that warm air temperatures are the physical cause of high stream temperatures, because warm air is not very efficient at transferring heat into the water surface (Brown, 1969). Instead, high air temperatures are indicative of broader weather conditions (typically extended dry weather with offshore air flow) when solar radiation, low flows and other transfer mechanisms can have the greatest cumulative effect. Warm air and water temperatures coincide because both air and stream temperatures are responding to the same temporal multi-day fluctuations (Johnson, 2004).

We compared daily air temperature peaks from Sedro Woolley, Concrete and Darrington weather stations with peak stream temperature dates to assess the degree of correlation. The peak dates for all three weather stations are listed in Appendix 5. The majority of stream sites tended to peak either on the air temperature peak date or within several days of it. For instance, the hottest day of the 2009 season was July 30th and all but two of the seasonal maxima fell between July 28th and August 1st. In contrast, the summer of 2013

[5] Western Region Climate Center website: http://www.wrcc.dri.edu/summary/climsmwa.html

was anomalous in that 23 out of the 31 stream sites did not coincide with air temperature peak dates, perhaps because peak air temperatures did not coincide with lowest flows.

Monthly average air temperatures (daily means and maxima) at the three weather stations were compared with long-term averages to determine which summers were warmer or cooler than average (Appendix 6). Summer index values were established to classify average departures from mean long-term values. Results indicated that air temperatures in the summer of 2009 and 2013 were warmer than average and 2008, 2011 and 2012 were all cooler than average (Figure 4). Summer 2010 was closest to the average values. When compared to mean 7-DADM water temperatures for each year, air temperature indices generally agreed (Figure 4). The only exception is the year 2013 that had above-average air temperatures, but peak stream temperatures were surprisingly similar to 2010 when air temperatures were considered 'average'. Despite the exception of 2013, data from the bulk of monitoring years confirms that seasonal weather conditions are a major driver in the variation observed.

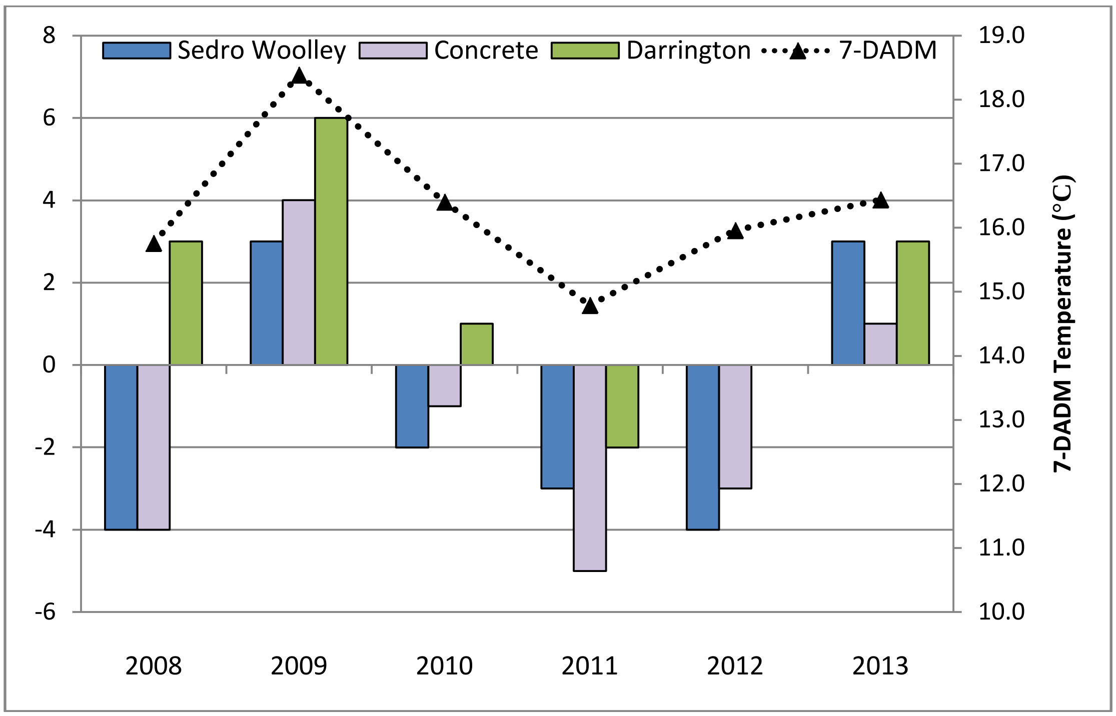

Figure 8. Air temperature index values (bars) during summers (June – August) of stream temperature monitoring. Index values (left-hand Y-axis) are average departures of daily maxima from long-term averages; positive values indicate generally warmer than average conditions (e.g. 2009), negative were relatively cooler (e.g. 2011). Monthly departures provided in Appendix 4. Mean 7-DADM values (triangles and dotted line) are averages from stream temperature sites (right-hand Y-axis).

Appendix 6 contains air temperatures during the summer months of June to September compared with long-term averages for the three weather stations. June and July 2009 air temperatures were much warmer than average (>mean + standard deviation) as were Darrington and Sedro Woolley August data. Temperatures in 2013 were much warmer than average in Sedro Woolley and Darrington stations in July and warmer than average in August. The cool July temperatures in 2011 explain the cooler 7-DADM and SMHT stream temperatures that year, since July and August are usually the warmest summer months. Stream temperatures were also relatively cooler in 2008 and this is consistent with air temperatures in Sedro Woolley and Concrete that were either average or cooler than average during all months. Darrington temperatures in 2008 were warmer in July and much warmer in August and September, but since there is a lot of data missing for this station, the accuracy of these averages may be lower. Throughout the study period, average air temperatures in Darrington (green bars in Figure 8) were generally warmer (relative to long term) than the other local stations.

4. Conclusions

Based on summer stream temperature data from 34 tributaries monitored over six summers (2008 – 2013):

- Temperature maxima varied considerably between sites and by years, extending the pattern identified in the previous progress report (Phillips *et al.*, 2011). Sites that had the highest stream temperatures are located on lower Day and Finney Creeks and below the outlets of Day and Grandy Lakes. All are channels too wide to be shaded by existing forest canopy and have slow water velocities that allow extended warming from direct sunlight.

- Monitoring sites with the highest seasonal maxima (commonly 20-25˚C, see Figure 4) also showed higher sensitivity over both shorter (i.e, diurnal) and longer time scales (i.e. inter-annual range). This suggests that streams with high average temperatures are also those prone to greater increases during particularly warm summers. Buffers and perhaps shade enhancement actions are particularly valuable on these sensitive streams to avoid exacerbating this pattern, as described further below.

- Site-scale factors such as channel width, low channel gradient and low elevation were all correlated with the highest peak stream temperatures. The previous report (Phillips *et al.*, 2011) further noted that drainage area, groundwater input, and upstream land cover were correlated with site-scale stream temperatures as well. All of these results are consistent with the regional scientific literature.

- Many of our sites exceeded the Washington state water quality standards for temperature. In 2009, the warmest summer, 85% of sites exceeded standards at some point in the summer, many for a number of days (Figure 5). Even in the coolest summer of the study (2011), 33% of sites exceeded standards. Peak temperatures (7-DADM) in several streams reached the sub-lethal range (>20˚C) in multiple summers (Table 1). In 2009, 30% of sites exceeded the stress limit for salmonids.

- There wasn't any directional trend evident in year-to-year temperature variation over the six-year period. Instead, maxima were closely correlated to year-to-year weather differences (Figure 8). Temperatures were warmest in 2009, an unusually warm summer, and coolest in 2011. Summer monthly index values at three local climate stations showed that the summer of 2009 was much warmer than average and that 2008, 2011 and 2012 were cooler than average (Figure 8).

- Most stream temperature peak dates aligned with air temperature peaks, with the notable exception of 2013. This correlation suggests that heat input over both daily and monthly time scales influences stream temperature maxima.

- Despite the presence of potentially harmful temperatures in larger Skagit tributaries, other nearby streams remained within the optimal range, peaking in the mid-teens. These strong and consistent differences among streams should be factored into assessments of fisheries impacts or watershed monitoring, protection and restoration priorities.

4.1 Management Implications

Knowing stream and site-specific temperature dynamics can inform a variety of riparian management approaches and actions. This includes assessing forest practice activities that take place in riparian buffers, such as hardwood conversions and thinning of overstocked stands. This information can also guide restoration priorities to mitigate temperature issues through riparian vegetation management.

Knowledge of existing temperature conditions could also aid in developing further monitoring studies that address specific drivers and temperature effects. These could include more focused studies involving land-use effects on temperatures or monitoring actively managed buffers and restoration sites. Other studies could also examine refugia opportunities in warm streams such as Finney and Day Creeks, that could include cold-water pockets, hyporheic exchange areas, thermally stratified pools and other small tributaries.

The Washington Department of Ecology has identified that meeting water temperature standards will require the conservation of existing riparian forests and implementation of vegetation restoration projects that increase shade and improve the health of riparian forests (DOE, 2008). Similar efforts on tributary channels may be important for ameliorating temperature increases and potentially providing thermal refugia for fish during periods of high temperature in larger tributaries like Finney or Day Creeks. Throughout the study area, forested buffers are required on all fish-bearing streams by Washington Forest Practices Rules and county Critical Areas Ordinances.

Most riparian zones in Skagit timberlands are densely forested though many, including Finney Creek, are now dominated by hardwood trees such as red alder and bigleaf maple as a result of land use changes (Haight, 2002). This can have long-term limitations for stream temperatures. Although these deciduous species grow rapidly and produce dense shade in summer, their canopy heights seldom exceed 120 feet (Haight, 2002). In contrast, native conifers such as western redcedar and western hemlock can exceed twice that height, resulting in greater shade to the larger channels found to be most temperature sensitive. Various silvicultural techniques can enhance conifer reestablishment, including riparian planting and preventing dominance by exotic and native competitors. The long-term stand composition of riparian forests similar to SRSC's monitored sites would ideally include large conifers over 100 years old intermixed with various native deciduous species. This will maximize shade and other riparian functions.

In addition, continuing efforts should focus on reducing landslide potential on hillslopes that can deliver massive sediment volumes to streams (Lyons and Beschta, 1983; Nichols and Ketcheson, 2013). In past decades, sediment from landslides has caused channel widening and destroyed riparian vegetation which exacerbates temperature problems until channels recover (Collins *et al.*, 1994). On forest lands, mitigation efforts include buffering of potentially unstable slopes and riparian areas and upgrading roads to current Road Maintenance and Abandonment Plan (RMAP) standards. These actions are particularly crucial upslope from streams with warm temperatures identified above.

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Appendix 1: Summary of SMHT temperatures and SMHT dates for the years 2008-2013. Temperatures between 16˚C and 20˚C are highlighted in yellow and those above 20˚C are highlighted in orange.

		2008		2009		2010		2011		2012		2013	
Site #	Stream name	SMHT (˚ C)	SMHT Date	SMHT (˚ C)	SMHT Date	SMHT (˚ C)	SMHT Date	SMHT (˚ C)	SMHT Date	SMHT (˚ C)	SMHT Date	SMHT (˚ C)	SMHT Date
1	Alder Creek	14.0	8/16/08	15.1	7/28/09	14.4	7/9/10	13.1	8/6/11	13.9	8/5/12	14.4	7/1/2013
2	Anderson Creek	16.8	8/16/08	19.8	7/30/09	17.2	8/16/10	15.8	8/26/11	16.8	8/17/12	16.4	9/12/2013
3	Bob Lewis Creek	17.3	8/15/08	19.3	7/29/09	16.8	8/17/10	15.0	8/26/11	16.4	8/17/12	16.1	7/1/2013
4	Conn Creek	15.3	8/17/08	16.5	7/28/09	14.1	8/16/10	12.5	8/26/11	14.3	8/5/12	14.3	8/10/2013
5	Dan Creek	21.2	8/16/08	20.6	7/29/09	18.4	8/17/10	-	-	17.7	8/17/12	18.0	8/10/2013
6	Day Creek (river mile .2)	-	-	24.1	7/30/09	24.1	7/24/10	20.1	8/25/11	21.0	8/5/12	-	-
7	Day Creek (river mile .7)	-	-	24.1	7/29/09	21.6	8/15/10	19.9	8/25/11	-	-	20.7	8/5/2013
8	Day Creek (river mile 2.5)	-	-	24.4	7/30/09	21.3	8/15/10	18.9	8/26/11	-	-	-	-
9	Day Creek (near Rocky Creek)	-	-	20.8	7/30/09	17.8	7/9/10	16.9	8/26/11	18.5	8/5/12	18.7	7/1/2013
10	Day Lake Outlet	-	-	26.5	7/30/09	23	7/27/10	21	8/21/11	-	-	-	-
11	Decline Creek	15.2	8/17/08	16.7	7/30/09	-	-	13	8/26/11	14.4	8/5/12	15	8/10/2013
12	Finney Creek (river mile 2.4)	23.9	8/16/08	26.4	7/29/09	24.2	8/15/10	21	8/26/11	23.0	8/5/12	22.9	7/24/2013
13	Finney Creek (near Quartz Creek)	22.9	8/16/08	25.2	7/29/09	23.0	8/15/10	20.4	8/26/11	22.0	8/5/12	23.4	8/5/2013
14	Finney Creek (river mile 13)	17.5	8/16/08	19.6	7/30/09	18.2	8/16/10	15.7	8/26/11	17.3	8/17/12	22.6	7/23/2013
15	Finney Creek (river mile 18)	16	8/16/08	17.3	8/1/09	16.5	8/16/10	15	8/25/11	16.6	8/5/12	17.2	8/10/2013
16	Finney Creek (river mile 21)	14	8/17/08	16.2	8/1/09	14.3	8/16/10	13	8/26/11	14.3	8/17/12	14.6	8/10/2013
17	Grandy Creek	14.4	7/12/08	15.2	7/3/09	16.4	7/9/10	14.7	7/24/11	16.9	8/5/12	18.3	7/9/2013
18	Grandy Creek (lake outlet trib)	-	-	30.3	7/29/09	26.3	8/15/10	24.4	8/25/11	25.2	8/5/12	25.8	7/19/2013
19	Gravel Creek	16.3	8/17/08	17.2	7/28/09	15.2	8/16/10	13.8	9/11/11	15.0	8/17/12	14.7	8/10/2013
20	Hatchery Creek	17.4	8/16/08	19.7	7/29/09	17.6	8/16/10	18.3	9/11/11	17.3	8/17/12	16.8	7/1/2013
21	Hobbit Creek	-	-	13.7	8/11/09	13.5	9/19/10	12.1	8/6/11	13.1	7/19/12	14.8	8/29/2013
22	Hooper Creek	16.1	8/16/08	18.3	7/29/09	16.2	8/16/10	14.7	8/26/11	15.8	8/17/12	15.6	9/11/2013
23	Jackman Creek	17.2	8/16/08	19.4	7/29/09	17.5	8/16/10	15.1	8/26/11	16.5	8/17/12	17.3	8/10/2013
24	Morgan Creek	16.9	8/17/08	-	-	18.2	8/16/10	17.1	9/23/11	17.5	8/5/12	18.2	8/28/2013
25	Mouse Creek	17	8/17/08	18.8	7/29/09	16.8	8/17/10	15.3	8/26/11	16.7	8/17/12	16.1	8/10/2013
26	Osterman Creek	-	-	18.7	7/29/09	16.7	8/16/10	15.3	8/26/11	16.2	8/17/12	16.4	7/1/2013
27	Quartz Creek	18.5	8/16/08	21.7	7/29/09	18.7	8/15/10	16.5	8/26/11	18.1	8/17/12	18.7	8/10/2013
28	Rocky Creek	-	-	20.6	7/30/09	17.3	8/5/10	15.6	8/26/11	17.6	8/5/12	17.2	8/10/2013
29	Ruxall Creek	17.6	8/17/08	19.7	7/29/09	17.2	8/16/10	16.2	8/26/11	17.0	8/5/12	17.3	7/1/2013
30	Savage Creek	13.5	8/16/08	14.3	7/29/09	13.9	8/16/10	13.3	8/26/11	14.0	8/5/12	14.5	9/7/2013
31	Unnamed Decline trib. (USFS 2430 Rd.)	15	8/16/08	17	7/31/09	14.6	8/5/10	12.5	8/26/11	14.7	8/5/12	14.6	8/10/2013
32	Unnamed Decline trib. (USFS 2435 Rd.)	13.6	8/17/08	14.8	7/31/09	12.8	8/5/10	10.8	8/26/11	12.9	8/5/12	12.7	8/10/2013
33	Unnamed Finney trib (small Fin)	16.4	8/17/08	19.0	7/29/09	16.7	8/16/10	15.3	8/26/11	16.5	8/5/12	16.6	7/1/2013
34	Winters Creek	-	-	19.1	7/29/09	16.5	8/15/10	15.1	8/26/11	16.5	8/17/12	16.1	7/1/2013
	Minimum	13.5		13.7		12.8		10.8		12.9		12.7	
	Maximum	23.9		30.3		26.3		24.4		25.2		25.8	
	Mean	16.8		19.7		17.8		16.0		16.9		17.3	

Appendix 2: Summary of 7-DADM temperatures and 7-DADM Ranges. Six year averages are included as well as the 6-year 7-DADM range. Temperatures between 16˚C and 20˚C are highlighted in yellow and those above 20˚C are highlighted in orange.

		2008		2009		2010		2011		2012		2013				
Site #	Stream name	7DADM (˚C)	7DADM Range	7DADM (˚C)	7DADM Range	7DADM (˚C)	7DADM Range	7DADM (˚C)	7DADM Range	7DADM (˚C)	7DADM Range	7DADM (˚C)	7DADM Range	Average 7DADM	Average Ranges	6-year 7DADM Range
1	Alder Creek	13.3	2.6	14.9	3.1	13.7	3.0	12.9	2.8	13.2	2.7	13.6	2.9	13.6	2.9	2.0
2	Anderson Creek	15.9	1.7	18.8	2.4	16.2	2.2	15.0	1.7	15.9	1.9	15.8	1.4	16.3	1.9	3.8
3	Bob Lewis Creek	16.4	1.6	18.7	2.3	16.2	2.1	14.6	1.4	15.9	1.6	15.6	1.3	16.2	1.7	4.1
4	Conn Creek	14.1	1.5	16.1	1.8	13.3	1.5	11.9	1.6	13.4	1.5	13.6	1.5	13.7	1.6	4.2
5	Dan Creek	18.7	4.2	20.3	4.0	17.7	3.6	-	-	17.2	2.8	17.7	3.5	18.3	3.6	3.1
6	Day Creek (river mile .2)	-	-	23.6	5.7	23.6	6.7	19	4.6	19.5	4.4	-	-	21.4	5.4	4.6
7	Day Creek (river mile .7)	-	-	23.5	5.0	20.8	4.9	19	4.1	-	-	20.3	4.9	20.9	4.7	4.5
8	Day Creek (river mile 2.5)	-	-	23.6	5.5	20.4	5.2	18	3.4	-	-	-	-	20.7	4.7	5.6
9	Day Creek (near Rocky Creek)	-	-	20.0	2.2	17.1	2.2	16.3	1.9	17.4	2.4	17.4	2.3	17.6	2.2	3.7
10	Day Lake Outlet	-	-	25.6	2.8	22.2	3.1	20.2	2.3	-	-	-	-	22.7	2.7	5.4
11	Decline Creek	14.2	1.6	16.4	2.1	-	-	12.5	1.7	13.9	1.7	14.2	1.8	14.2	1.8	3.9
12	Finney Creek (river mile 2.4)	22.2	6.3	25.4	6.7	23.6	7.5	19.9	5.0	22.0	6.0	22.4	6.0	22.6	6.3	5.5
13	Finney Creek (near Quartz Creek)	21.2	5.1	24.2	5.1	22.2	5.6	19.4	4.2	20.2	3.9	23.1	3.6	21.7	4.6	4.9
14	Finney Creek (river mile 13)	16.4	2.5	19.3	2.6	17.5	3.6	15.1	2.5	16.9	3.0	17.9	3.9	17.2	3.0	4.2
15	Finney Creek (river mile 18)	15	3.5	16.9	1.2	16	3.4	14.6	3.5	16.1	3.7	16.8	3.7	15.9	3.2	2.3
16	Finney Creek (river mile 21)	13	1.4	16.0	2.0	13.6	1.8	12.6	2	13.8	2.0	14.2	2.0	13.9	1.9	3.4
17	Grandy Creek (downstream East Fork trib)	14.0	4.2	14.5	1.9	15.2	3.4	14.0	3.1	15.5	2.6	17.0	3.6	15.0	3.1	3.0
18	Grandy Creek (lake outlet trib)	-	-	29.0	4.8	25.2	4.5	23.7	4.3	23.7	2.0	25.3	4.3	25.4	4.0	5.4
19	Gravel Creek	14.9	1.8	16.7	2.2	14.3	1.8	13.2	1.4	14.1	1.8	14.2	1.7	14.6	1.8	3.5
20	Hatchery Creek	15.5	2.0	19.0	3.0	16.8	2.8	16.1	3.3	16.4	2.2	16.2	2.3	16.7	2.6	3.6
21	Hobbit Creek	-	-	12.8	1.2	12.8	0.8	11.9	1.2	12.7	1.0	14.4	1.2	12.9	1.1	2.5
22	Hooper Creek	15.3	1.7	17.4	2.3	15.5	2.1	14.2	1.7	15.2	2.0	14.9	1.4	15.4	1.9	3.2
23	Jackman Creek	15.9	2.6	18.9	3.7	16.8	3.2	14.5	2.7	15.8	2.9	16.7	3.5	16.4	3.1	4.4
24	Morgan Creek	16.5	0.7	-	-	17.4	1.4	15.9	3.3	16.6	1.8	17.7	1.3	16.8	1.7	1.8
25	Mouse Creek	16.2	1.3	18.4	1.9	16.1	1.8	14.8	1.4	16.1	1.7	15.9	1.7	16.3	1.6	3.6
26	Osterman Creek	-	-	18.0	1.9	16.0	1.9	14.8	1.4	15.6	1.3	15.8	1.6	16.0	1.6	3.2
27	Quartz Creek	17.2	2.7	20.9	4.4	18.0	4.0	15.7	2.9	17.2	3.3	18.3	4.6	17.9	3.7	5.2
28	Rocky Creek	-	-	19.8	2.2	16.5	1.8	15.0	1.5	16.5	1.9	16.5	1.9	16.9	1.9	4.8
29	Ruxall Creek	16.8	2.2	19.0	2.6	16.6	2.4	15.6	2.2	16.3	2.2	16.3	2.4	16.8	2.3	3.4
30	Savage Creek	13.2	0.8	14.2	1.5	13.6	1.4	13.0	1.2	13.7	1.3	14.3	1.2	13.7	1.2	1.3
31	Unnamed Decline tributary (USFS 2430 Rd.)	13.9	2.2	16.8	3.4	13.9	3.1	12.0	2.5	13.9	2.7	13.8	4	14.1	3.0	4.8
32	Unnamed Decline tributary (USFS 2435 Rd.)	12.5	1.8	14.6	2.4	12	2.1	10.5	2	12.0	2	12.0	3.2	12.3	2.3	4.1
33	Unnamed Finney trib (small Fin)	15.8	1.2	18.2	1.8	16.1	1.9	14.8	1.4	15.8	1.5	16.0	1.5	16.1	1.6	3.4
34	Winters Creek	-	-	18.1	1.7	15.8	1.4	14.6	0.9	15.7	1.3	15.5	0.8	15.9	1.2	3.5
	Maximum	22.2	6.3	29.0	6.7	25.2	7.5	23.7	5.0	23.7	6.0	25.3	6.0	25.4	6.3	5.6
	Minimum	12.5	0.7	12.8	1.2	12.0	0.8	10.5	0.9	12.0	1.0	12.0	0.8	12.3	1.1	1.3
	Mean	15.8	2.4	19.1	3.0	17.1	3.0	15.3	2.5	16.1	2.4	16.6	2.6	16.9	2.7	3.8

Appendix 3: Summary of site information and parameters measured.

Site #	Stream Name	Gradient (%)	*Canopy Closure (%)	*Bankful (feet)	Elevation (feet)	Upstream Category	Basin Area (mi^2)
1	Alder Creek	3	55	26	139	Mixed	11.9
2	Anderson Creek	4.5	65	16	117	Forested Buffer	2.2
3	Bob Lewis Creek	8	85*	10	508	Forested Buffer	0.3
4	Conn Creek	10	85	21	2752	Forested Buffer	1.6
5	Dan Creek	3	0*	100*	481	Forested Buffer	16.4
6	Day Creek (river mile .2)	N/A	N/A	N/A	72	Mixed	35.0
7	Day Creek (river mile .7)	N/A	N/A	N/A	81	Mixed	33.8
8	Day Creek (river mile 2.5)	N/A	N/A	N/A	156	Forested Buffer	32.6
9	Day Creek (near Rocky Creek)	5	75	65*	677	Forested Buffer	26.0
10	Day Lake Outlet	N/A	N/A	N/A	1605	Lake	6.5
11	Decline Creek	15	85	19	2268	Forested Buffer	3.2
12	Finney Creek (river mile 2.4)	N/A	N/A	N/A	187	Forested Buffer	50.8
13	Finney Creek (near Quartz Creek)	1	30	260*	229	Forested Buffer	45.0
14	Finney Creek (river mile 13)	N/A	N/A	N/A	738	Forested Buffer	30.1
15	Finney Creek (river mile 18)	N/A	N/A	N/A	1715	Forested Buffer	7.3
16	Finney Creek (river mile 21)	N/A	N/A	N/A	1925	Forested Buffer	3.1
17	Grandy Creek (downstream E. Fork trib)	5	55	56	730	Forested Buffer	9.9
18	Grandy Creek (lake outlet trib)	2.5	75	16	790	Lake	5.3
19	Gravel Creek	12	85	22	948	Forested Buffer	2.1
20	Hatchery Creek	4	70	33	250	Forested Buffer	1.8
21	Hobbit Creek	3	65	7	308	Forested Buffer	0.9
22	Hooper Creek	3	80	9	243	Forested Buffer	0.5
23	Jackman Creek	4	35	170*	232	Forested Buffer	24.0
24	Morgan Creek	3.5	70	8	107	Mixed	2.5
25	Mouse Creek	7	95	11	516	Forested Buffer	0.5
26	Osterman Creek	6	75	12	414	Mixed	1.1
27	Quartz Creek	2	70	52	242	Forested Buffer	4.1
28	Rocky Creek	8	60	79*	694	Forested Buffer	8.2
29	Ruxall Creek	7.5	70	20	361	Forested Buffer	1.8
30	Savage Creek	2	80	26	217	Forested Buffer	1.8
31	Unnamed Decline tributary (USFS 2430)	4	66	10	3315	Forested Buffer	0.7
32	Unnamed Decline tributary (USFS 2435)	19	43	24	3717	Forested Buffer	0.3
33	Unnamed Finney trib (small Fin)	11	90*	4	314	Forested Buffer	0.1
34	Winters Creek	15	90	7	257	Mixed	0.3

* Measurements are approximate

Appendix 4: Summary of period of installation and comparison with state standards for 2008 -2013.

Site #	Stream name	2008			2009			2010			2011			2012			2013		
		# of Days Over		% Days Over	# of Days Over		% Days Over	# of Days Over		% Days Over	# of Days Over		% Days Over	# of Days Over		% Days Over	# of Days Over		% Days Over
		13° C	16° C		13° C	16° C		13° C	16° C		13° C	16° C		13° C	16° C		13° C	16° C	
1	Alder Creek	0	0	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0	0
2	Anderson Creek	-	0	0	-	13	11	-	3	3	-	0	0	-	0	0	-	0	0
3	Bob Lewis Creek	-	5	5	-	16	9	-	3	3	-	0	0	-	0	0	-	0	0
4	Conn Creek	-	0	0	-	1	1	-	0	0	-	0	0	-	0	0	-	0	0
5	Dan Creek	19	15	32	42	36	44	23	30	51	-	-	-	25	18	33	37	39	59
6	Day Creek (river mile .2)	-	-	-	26	62	100	22	68	100	22	38	79	22	54	100	-	-	-
7	Day Creek (river mile .7)	-	-	-	26	62	100	21	61	92	22	42	84	-	-	-	20	61	100
8	Day Creek (river mile 2.5)	-	-	-	-	72	82	-	52	58	-	26	70	-	-	-	-	-	-
9	Day Creek (near Rocky Creek)	-	-	-	6	23	25	0	25	25	0	5	5	-	35	38	0	70	60
10	Day Lake Outlet	-	-	-	-	78	85	-	77	88	-	72	87	-	-	-	-	-	-
11	Decline Creek	-	0	0	-	4	3	-	-	-	-	0	0	-	0	0	-	0	0
12	Finney Creek (river mile 2.4)	16	41	92	26	63	100	21	59	93	21	38	91	21	54	100	20	59	100
13	Finney Creek (near Quartz Creek)	30	36	65	43	63	90	20	58	80	28	37	54	0	38	25	23	65	81
14	Finney Creek (river mile 13)	-	4	6	-	21	22	-	27	31	-	0	0	-	16	19	-	38	47
15	Finney Creek (river mile 18)	-	0	0	-	8	8	-	1	1	-	0	0	-	3	4	-	18	22
16	Finney Creek (river mile 21)	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0
17	Grandy Creek (downstream E. Fork trib)	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	11	11
18	Grandy Creek (lake outlet trib)	-	-	-	-	101	93	-	92	100	-	112	89	-	112	78	-	90	93
19	Gravel Creek	-	0	0	-	5	3	-	0	0	-	0	0	-	0	0	-	0	0
20	Hatchery Creek	7	4	11	30	22	43	13	6	20	23	0	19	19	6	16	17	6	27
21	Hobbit Creek	-	-	-	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0
22	Hooper Creek	-	0	0	-	9	7	-	0	0	-	0	0	-	0	0	-	0	0
23	Jackman Creek	0	0	0	23	19	36	6	6	13	14	0	14	13	0	11	19	8	28
24	Morgan Creek	-	17	17	-	-	-	-	26	26	-	0	0	-	15	10	-	52	46
25	Mouse Creek	-	3	3	-	13	7	-	2	4	-	0	0	-	5	4	-	0	0
26	Osterman Creek	-	-	-	-	11	11	-	1	1	-	0	0	-	0	0	-	0	0
27	Quartz Creek	6	6	12	25	32	48	13	23	37	24	0	20	24	17	27	21	47	62
28	Rocky Creek	-	-	-	-	21	18	-	10	10	-	0	0	-	11	12	-	22	17
29	Ruxall Creek	-	6	5	-	20	17	-	5	5	-	0	0	-	5	3	-	7	6
30	Savage Creek	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0
31	Unnamed Decline trib (USFS 2430 Rd.)	-	0	0	-	6	5	-	0	0	-	0	0	-	0	0	-	0	0
32	Unnamed Decline trib (USFS 2435 Rd.)	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0	0
33	Unnamed Finney trib (small Fin)	-	0	0	-	12	10	-	2	2	-	0	0	-	0	0	-	1	1
34	Winters Creek	-	-	-	-	10	10	-	0	0	-	0	0	-	0	0	-	0	0
	Maximum	30	41	92	43	101	100	23	92	100	28	112	91	25	112	100	37	90	100
	Minimum	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Mean	11	6	10	25	24	30	14	19	26	17	11	19	16	13	15	17	19	25
	% Sites Over Standard			41.67%			84.85%			66.67%			33.33%			48.39%			51.61%

Appendix 5: Chart comparing peak air temperature dates for Concrete, Darrington and Sedro Woolley during 6 summer seasons (2008-2013) with stream temperature peak dates.

		Air Maximum Temperature Dates			**Stream Temperature Peak Dates**						
		Concrete	**Darrington**	**Sedro Woolley**							
2008	**Peak Date**	8/16/2008	Data Missing	8/16/2008	**Dates**	8/15/2008	8/16/2008	8/17/2008	Other		
	Next Peak*	6/29/2008		6/30/2008	**Number of Sites**	1	13	9	1		
2009	**Peak Date**	7/30/2009	7/30/2009	7/30/2009	**Dates**	7/28/2009	7/29/2009	7/30/2009	7/31/2009	8/1/2009	Other
	Next Peak				**Number of Sites**	3	16	8	2	2	2
2010	**Peak Date**	8/16/2010	8/16/2010	8/16/2010	**Dates**	7/9/2010	8/15/2010	8/16/2010	8/17/2010	8/5/2010	Other
	Next Peak	7/9/2010	7/9/2010	7/10/2010	**Number of Sites**	3	7	14	3	3	3
2011	**Peak Date**	9/8/2011	8/21/2011	8/22/2011	**Dates**	8/6/2011	8/25/2011	8/26/2011	9/11/2011	Other	
	Next Peak	8/21/2011	7/25/2011	8/21/2011	**Number of Sites**	2	4	22	2	3	
2012	**Peak Date**	8/6/2012	8/6/2012	8/7/2012	**Dates**	8/5/2012	8/17/2012	Other			
	Next Peak	8/17/2012	8/17/2012	8/18/2012	**Number of Sites**	17	13	1			
2013	**Peak Date**	7/1/2013	7/1/2013	7/17/2013	**Dates**	7/1/2013	8/5/2013	8/10/2013	Other		
	Next Peak	9/12/2013		7/1/2013	**Number of Sites**	8	2	12	9		

* Next peak is the next day with a naximum air temperatures that was within 2 degrees of the maximum temperature recorded on the peak date.

Source: Western Regional Climate Center web site: http://www.wrcc.dri.edu/summary/climsmwa.html

Appendix 6: Comparisons of monthly average daily mean (average of daily average temperatures) and max (average of daily maximum temperatures) air temperatures for 2008-2013 to long-term averages at selected regional monitoring stations in the Skagit basin.

Method: Monthly average values for daily mean and max during study were compared to long term averages for station and placed into one of five categories described below:

Air Temperature category:	**Symbol**
much cooler (<mean - standard deviation) than average	-- --
cooler than average (between 0 and -- -- category)	--
near (within +/- 1oC) average	0
warmer than average (between 0 and + + category)	+
much warmer (>mean + standard deviation) than average	+ +

Location	Statistic	June	July	August	September
			2008		
Sedro Woolley	mean	-- --	0	+	--
	max	-- --	--	--	-- --
Concrete	mean	-- --	--	0	--
	max	-- --	--	--	--
Darrington	mean	--	+	+ +	+ +
	max	0	+	+ +	+ +
			2009		
Sedro Woolley	mean	+ +	+ +	+ +	+ +
	max	+	+ +	0	+ +
Concrete***	mean	+	+ +	+	+
	max	+ +	+ +	0	0
Darrington***	mean	+ +	+ +	+ +	-- --
	max	+ +	+ +	+ +	-- --
			2010		
Sedro Woolley	mean	0	+	+	+ +
	max	-- --	0	0	--
Concrete	mean	--	0	0	-- --
	max	-- --	0	0	-- --
Darrington	mean	0	+ +	+	0
	max	--	+	+	--
			2011		
Sedro Woolley	mean	0	0	0	+ +
	max	--	-- --	0	+ +
Concrete	mean	--	-- --	+	+
	max	-- --	-- --	-	0
Darrington	mean	0	--	+	+ +
	max	--	-- --	+	+

			2012		
Sedro Woolley	mean	-- --	-- --	ND	ND
	max	-- --	-- --	0	+
Concrete	mean	-- --	--	0	+ +
	max	-- --	--	0	+ +
Darrington	mean	--	+	+ +	+ +
	max	-- --	0	+ +	+
			2013		
Sedro Woolley	mean	ND	+ +	+ +	-- --
	max	0	+ +	+	-- --
Concrete	mean	0	0	+	+
	max	--	+	+	0
Darrington	mean	+	+ +	+	+
	max	+	+ +	0	0

* Mean is the average of daily average temperatures ** Max is the average of daily maximum temperatures

ND = No Data

2008 data missing: July = 1 (Sedro Woolley); June = 12, July = 8, August = 12, September = 12 (Darrington)

2009 data missing: July = 1 (Sedro Woolley); August = 10, September = 8 (Darrington)

2010 data missing: None

2011 data missing: September = 2 (Sedro Woolley)

2012 data missing: June= 10, July = 10 (Sedro Woolley)

2013 data missing: June = 20, August = 8, September = 8 (Sedro Woolley); August = 6 (Darrington)

Source: Western Regional Climate Center web site: http://www.wrcc.dri.edu/summary/climsmwa.html

***2009 Concrete, Darrington data for June obtained from NOAA http://www.ncdc.noaa.gov/cdo-web/quickdata