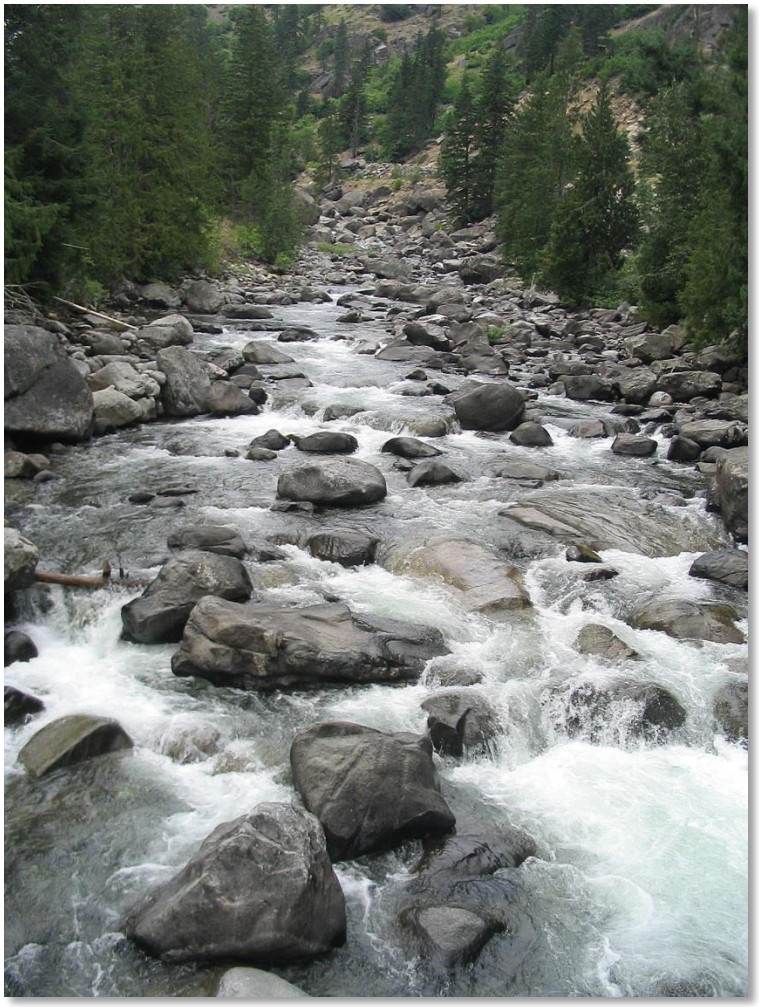
U.S. Fish and Wildlife Service

Summary of Icicle Creek Temperature Monitoring, 2015



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***On the cover**: Icicle Creek upstream of the Leavenworth National Fish Hatchery. USFWS.*

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SUMMARY OF ICICLE CREEK TEMPERATURE MONITORING, 2015

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SUMMARY OF ICICLE TEMPERATURE MONITORING, 2015

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Executive Summary– Record low winter snowpack and above average air temperatures in June resulted in the warmest high 7DADMax water temperatures recorded in Icicle Creek since monitoring began. The Mid-Columbia River Fisheries Resource Office began monitoring water temperature in Icicle Creek in 2005 to evaluate the impact of Leavenworth National Fish Hatchery (NFH) operations on stream temperatures. In 2015 temperature loggers were deployed at 13 sites in Icicle Creek upstream, adjacent to, and downstream of the Leavenworth NFH. During the warm summer months Icicle Creek water warmed as it moves downstream, with two exceptions; the Snow Creek confluence and the Leavenworth NFH spillway pool. Snow Creek received water from a diversion that withdraws water from the bottom of Snow Lake during the summer months and water in Snow Creek had a high 7DADMax 1.1°C cooler than water temperatures recorded 0.1 km upstream in Icicle Creek prior to supplementation. However, immediately after supplementation began water temperatures in Snow Creek dropped and the difference between Snow Creek and Icicle Creek 0.1 km downstream increased to 2.8°C. Snow Creek water temperatures continued to drop throughout the period of supplementation. The largest water temperature difference between Snow Creek and Icicle Creek 0.1 km downstream was 6.1°C and occurred on August 1, 2015. The spillway pool at Leavenworth NFH receives hatchery effluent river water mixed with well water making an off-channel pool with a high 7DADMax that was 2.2°C cooler than in Icicle Creek directly upstream of the Leavenworth NFH. At both locations Icicle Creek water temperatures were reduced by Leavenworth NFH operations. In 2015, air temperatures were higher than average, especially during June when air temperatures were on average 4.7°C (0.9–8.8°C) warmer than the long-term mean.

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Introduction

Water temperature is extremely influential in the life history of fishes (Coutant 1987; Magnuson et al. 1979; Olden and Naiman 2010). Icicle Creek is home to ESA-listed Bull Trout *Salvelinus confluentus*, anadromous Rainbow Trout *Oncorhynchus mykiss* (steelhead) and spring Chinook Salmon *Oncorhynchus tshawytscha*. These fish are considered coldwater species and have upper thermal limits for rearing, spawning and adult survival (Brett 1952; Bell 1986; Fraley and Shepard 1989; Eaton and Scheller 1996; Rieman and Chandler 1999; Myrick and Cech 2001; Dunham and Chandler 2001; Selong et al. 2001; WDOE 2006). Monitoring water temperature in Icicle Creek is used to determine whether Leavenworth NFH operations alter Icicle Creek water temperatures which may degrade the thermal habitat for ESA-listed fish species.

This report summarizes water temperature data collected by the Mid-Columbia River Fisheries Resource Office in Icicle Creek and tributaries upstream, adjacent to, and downstream of the Leavenworth National Fish Hatchery (NFH) in 2015. Water temperature monitoring sites were unchanged from the previous years and span the lower Icicle Creek from river km 0.8–9.3. Temperature data in this report encompassed January 01–October 29 of 2015, however the focus was on the period of the warmest water temperatures which occurred during the summer months.

Study Area

The Icicle Creek watershed drains 55,426 hectares of forested uplands on the eastern slope of the Cascade Mountain range in North Central Washington State. Icicle Creek is 50.8 km long from its headwaters at Lake Josephine at an elevation 1423 m to its confluence with the Wenatchee River at an elevation of 340 m (WRWSC 1998). Upstream of river kilometer (rkm) 6.0 Icicle Creek watershed is characterized by high basin relief, glaciated cirques, and steep headwalls, with batholithic geology. Downstream from rkm 6.0 to the mouth of Icicle Creek the watershed forms a shallow gradient basin filled with sand-and-gravel based glacial deposits. Approximately 87% of the watershed is publically owned and maintained by the U.S. Forest Service with 74% of the watershed residing within the Alpine Lakes Wilderness (USFS 1994).

The Icicle Creek watershed receives 305 cm of precipitation at the highest elevations, and 50.8 cm in the lower elevations. Mullen et al. (1992) reported that there were 14 glaciers and 102 lakes in the watershed that store most of the available precipitation, with glacial melt estimated to generate 21% of Icicle Creek flow during the summer months. The size of the glaciers and subsequently the percent of flow attributed to glacial melt may have changed since Mullan et al. (1992) was published. Stream discharge was recorded by the U.S. Geological Survey (#12458000) located at rkm 9.4 and upstream of all major water diversions. Mean base flow from 1937–2014 was 291cfs. The minimum mean daily discharge was 44 cfs and occurred on November 30, 1936; the maximum mean daily discharge was 19,800 cfs and occurred on November 29, 1995.

Icicle Creek has two major water diversions that impact in-stream flow and water temperature (Figure 1). Both diversions occur near the confluence of Snow Creek and each diversion supplies two user groups. Upstream of the Snow Creek confluence at rkm 9.3, the Icicle Peshastin Irrigation District (IPID) withdraws 60–103 cfs of water from April through September, and the City of Leavenworth withdraws 2 cfs year-round (Montgomery Water Group, Inc. 2004).

Downstream of Snow Creek at rkm 7.2, the Cascades Orchard Irrigation Company (COIC) withdraws 7 cfs from May– September, and the Leavenworth NFH uses 20–40 cfs year-round. The total amount of water diverted by all users from Icicle Creek during the summer months of June, July, and August, is about 140 cfs, while in the winter months it is about 42 cfs. (Montgomery Water Group, Inc. 2004).

Snow Creek is a major tributary of Icicle Creek, joining at rkm 9.2. Snow Creek drains a series of high mountain lakes; Upper Snow Lake is the largest by volume at approximately 12,450 acre-feet at full capacity (Anchor QEA 2010). In 1939, the U.S. Bureau of Reclamation installed a valve near the bottom of Upper Snow Lake to drain the lake at a controlled rate and supplement Icicle Creek during low-flow periods. Water diverted from the valve on Upper Snow Lake flows directly into Nada Lake which then flows into Snow Creek. Leavenworth NFH has rights to 16,000 acre-feet of water per year from Upper Snow Lake. The valve is typically opened in late July delivering up to 60 cfs of water to Snow Creek, and is closed in October (Table 1). During some low-flow periods, supplemented Snow Creek water represents the majority of in-stream flow in Icicle Creek after the IPID diversion.

The Leavenworth NFH occupies land adjacent to Icicle Creek from approximately rkm 4.1 to rkm 6.1. The Icicle Creek watershed transitions from a steep canyon to a broad valley at rkm 6.1. Downstream of the Leavenworth NFH, Icicle Creek meanders for 4.0 rkm through a broad valley of mixed residential and agricultural properties before its confluence with the Wenatchee River.

The Leavenworth NFH water intake is located in Icicle Creek at the shared COIC/LNFH diversion at rkm 7.2, and water is transported to the hatchery via underground piping. In addition to river water, Leavenworth NFH has water rights for up to 14.9 cfs of well water however average use is about 4–5 cfs (T. Collier, LNFH, personal communication). Well water temperatures are between 7–9°C year-round and are used to cool incubation racks and rearing water in the summer and warm them in the winter (USFWS 2006).

The Leavenworth NFH returns water to Icicle Creek in two locations: 1) the adult fish ladder outfall at rkm 4.3, which drains the adult and juvenile rearing ponds, and 2) the pollution abatement pond at rkm 4.2. More than >95% of the water that Leavenworth NFH uses is returned to Icicle Creek via the adult fish ladder outfall. Water is released from the pollution abatement pond at a rate of approximately 1 cfs with a daily pulse of about 3 cfs for a few hours during routine juvenile pond cleaning (Hall 2013). In 2011, Leavenworth NFH began using a new abatement pond (AB2) while the old pond (AB1) was refurbished. Since 2014 both ponds have been used simultaneously, receive equal flow, and water temperatures were recorded in both ponds.

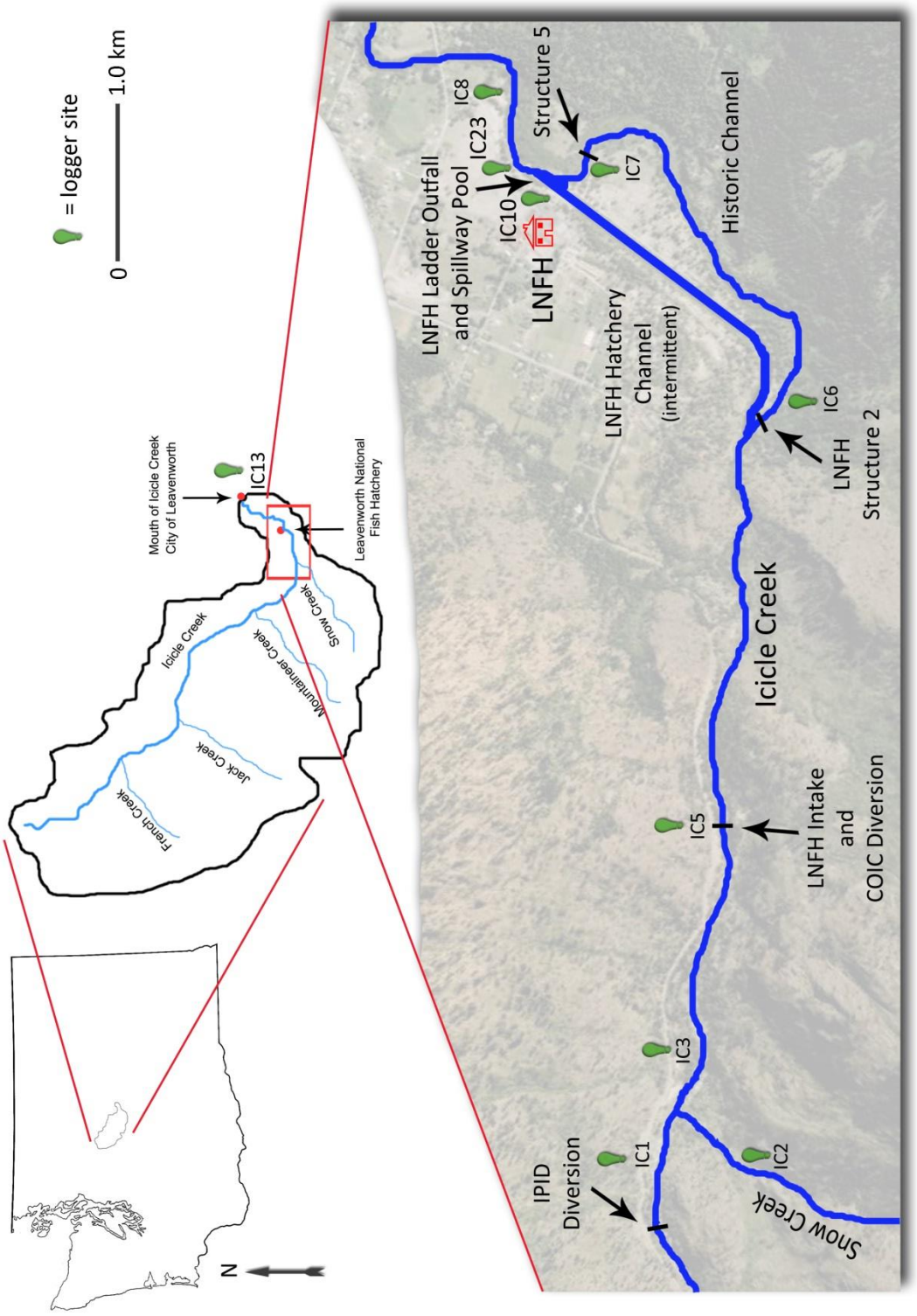

FIGURE 1.—Map of Icicle Creek drainage with *selected* water temperature monitoring sites and structures.

TABLE 1.— Snow Lake valve openings, adjustments, closures, and discharge into Snow Creek, 2006–2015.

Year	Date	Action	Discharge[1]
2015	1-Jul	Valve Opened	42 cfs
	28-Jul	Adjustment	increased to 50 cfs
	2-Oct	Valve Closed	
2014	31-Jul	Valve opened	50 cfs
	24-Aug	Adjustment	increased to 55 cfs
	2-Oct	Valve Closed	
2013	25-Jul	Valve opened	40 cfs
	31-Aug	Adjustment	increased approx. 15 cfs
	3-Oct	Valve closed	
2012	31-Jul	Valve opened	25 cfs
	10-Aug	Adjustment	increased to 50 cfs
	28-Aug	Adjustment	opened from 45 to 53 degrees
	2-Oct	Valve closed	
2011	3-Aug	Valve opened	20 cfs
	12-Aug	Adjustment	opened to 30+ degrees
	31-Aug	Adjustment	opened to 47 degrees
	3-Oct	Valve closed	
2010	2-Aug	Valve opened	32 cfs
	13-Aug	Adjustment	increased to 53 cfs
	27-Aug	Adjustment	increased to 60 cfs
	4-Oct	Valve closed	
2009	23-Jul	Valve opened	14 cfs
	27-Jul	Adjustment	increased to 32 cfs
	10-Aug	Adjustment	increased to 52 cfs
	10-Sep	Adjustment	increased to 60 cfs
	6-Oct	Valve closed	
2008	29-Jul	Valve opened	25 cfs
	12-Aug	Adjustment	increased to 60 cfs
	3-Oct	Valve closed	
2007	23-Jul	Valve opened	53 cfs
	3-Oct	Valve closed	
2006	26-Jul	Valve opened	18 cfs
	16-Aug	Adjustment	increased to 56 cfs
	5-Oct	Valve closed	

[1]Discharge is a function of both valve opening and head pressure (level of the lake). If the valve is left in the same position, discharge will decrease as head pressure decreases (Wurster 2009).

Methods

Water Temperature

In 2015, water temperature monitoring continued throughout the year at the same 13 sites as previous years and an additional site was added in the second abatement pond (Appendix A). Water temperature at all sites was recorded with Hobo Water Temp Pro V2 temperature loggers. All loggers were programmed to record water temperatures hourly.

In 2015, all water temperature monitoring sites were visited three times to download data and perform routine maintenance. On March 19, 2015, all of the loggers were downloaded in the field and replaced with new loggers. All of the new loggers were tested and calibrated before being deployed (Appendix B). On June 29, August 7 and October 31, data were downloaded in the field and the loggers were not removed. During each visit the housing and loggers were cleaned and the cables were inspected for integrity.

Water temperature comparisons between sites and across the summer season were done using a 7-day average of the daily maximum temperatures (high 7DADMax). The high 7DADMax is the mean of seven consecutive daily maximum temperatures calculated using the day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after. For example the high 7DADMax for August 6 would be the mean of the daily maximum temperatures for August 3–9. The high 7DADMax is considered a better metric to evaluate stream water temperature than daily max temperatures because it is not overly influenced by a single high daily temperature rather it describes the fishes exposure to a week-long average high temperatures (USEPA 2003).

In 2014, IC3 located on Icicle Creek directly below the confluence with Snow Creek wasn't recovered after two attempts to retrieve it. A new temperature logger was deployed at IC3 when spring flows came down on April 25, 2015. The new logger was destroyed sometime during July 6–Aug 6 so data for that period were not recorded. A new logger was deployed on Aug 7. IC6, located in Icicle Creek 10 m downstream of structure 2, was found out of the water when it was retrieved for downloading on June 29. The data showed that the logger was removed from the water on June 12 so data from June 12–29 were lost. Data were lost from IC7, located in Icicle Creek 0.2 m upstream from the spillway pool, due to equipment failure sometime during the March 19–June 29 period. Data were lost due to equipment failure from IC 6, 7, 10 and 11 from August 17–September 2.

Air Temperature

Air temperature data were downloaded from the Washington Department of Ecology "River and Stream Flow Monitoring" website (https:/fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp, station ID: 45B070, "Icicle Cr. Near Leavenworth"). Prior to 2012, air temperature data were recorded at the Mid-Columbia River Fisheries Resource Office (rkm 5.0), using Hobo Water Temp Pro V2 temperature loggers.

Results

Water Temperature

In 2015, water temperatures in Icicle Creek were the highest since monitoring began in 2005. Similar to previous years, water temperatures in Icicle Creek varied temporally and spatially (Figure 2; Table 2). Downstream monitoring sites in Icicle Creek were warmer than more upstream sites with the exception of two locations; immediately downstream of the Snow Creek confluence at rkm 8.7 and 7.1 (IC3 and IC5) and the spillway pool at rkm 4.3 (IC10 and IC11). IC3 recorded the lowest temperatures because of the Snow Creek influence, the high 7DADMax was 20.6°C. The warmest site on Icicle Creek was IC13 located at the mouth and had a high 7DADMax of 21.5°C and a daily high of 21.9°C.

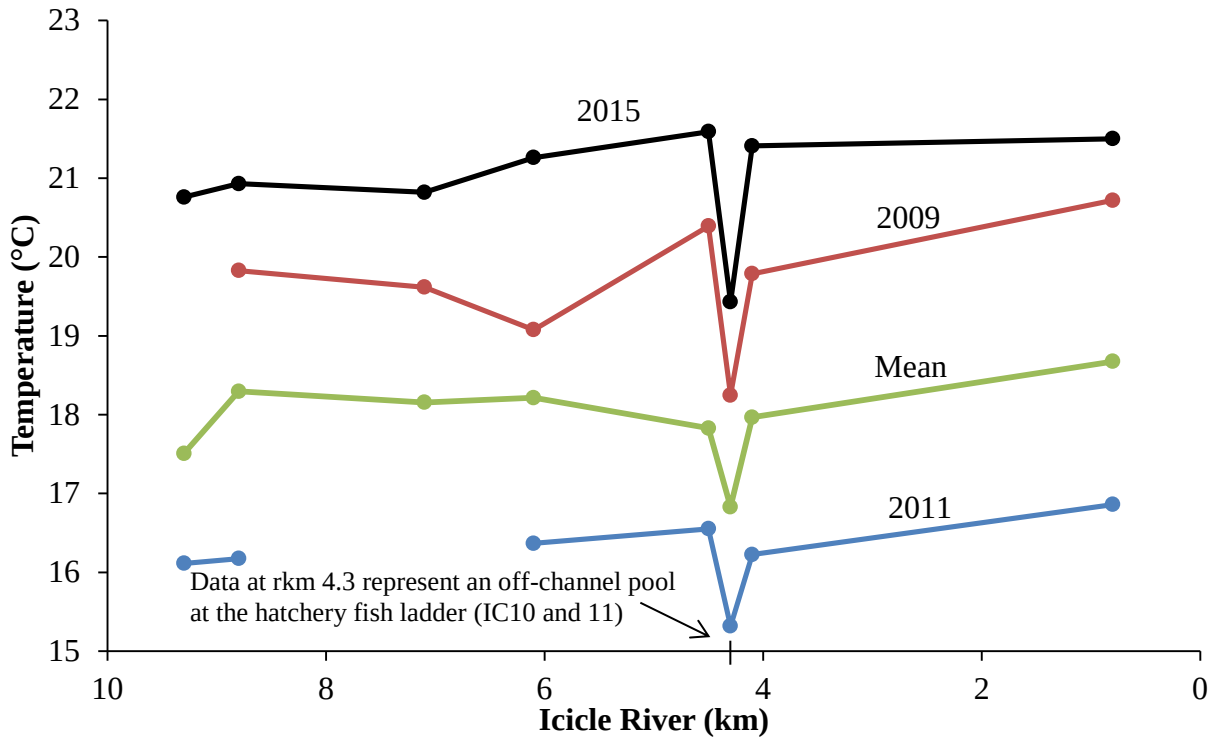

FIGURE 2.—Water temperature profile of Icicle Creek from river kilometer (rkm) 9.3 downstream to the mouth (rkm 0). The high 7DADMax for 2015 (black) compared to the mean high 7DADMax from 2005–2014 (green), 2009 (red) and 2011 (blue), respectively, the warmest (prior to 2015) and coolest year since monitoring began in 2005.

TABLE 2.— High 7DADMax water temperatures recorded at each site, the date the temperatures were recorded and the river kilometer (rkm) of each site.

Site	Description	Elevation (m)	rkm	Date	High 7DADMax (°C)
IC19	Upstream of IPID @ USGS gauge	435	9.3	7/1	20.8
IC1	Upstream of Snow Creek	410	8.8	7/1	20.9
IC2	Snow Creek	398	- -	6/30	19.8
IC3	Icicle Creek downstream of Snow Creek	390	8.7	6/30	20.6
IC5	LNFH intake	356	7.1	7/1	20.8
IC6	LNFH headgate (structure 2)	350	6.1	7/2	21.3
IC7	Downstream of structure 5	340	4.5	7/3	21.6
IC10	LNFH spillway pool	340	4.3	7/1	19.4
IC11	LNFH spillway pool	340	4.3	7/1	19.4
IC23	Abatement pond	339	4.2	8/3	16.4[1]
IC24	Abatement pond	339	4.2	7/2	20.3
IC8	Icicle downstream of LNFH	339	4.1	7/1	21.4
IC13	Icicle Mouth	334	0.8	7/2	21.5

1) Data were unavailable prior to 8/2, which excluded the warmest time of the year in early July.

Snow Creek Supplementation

Supplementation of Snow Creek from Upper Snow Lake began on July 1 which was a month earlier than past years (2006–2014). On July 1, 2015 the valve at Snow Lakes was opened to provide 42 cfs of flow, when flows in Icicle Creek above the Snow Creek confluence were 273 cfs (Figure 3). On July 28, 2015 the valve was opened further to provide 50 cfs when Icicle Creek flows were at 128 cfs. The valve was closed on October 2, 2015. Leavenworth NFH has water rights to 42 cfs from Icicle Creek at rkm 7.1.

Prior to supplementation water temperatures in Snow Creek had a high 7DADMax of 19.8°C which was 1.1°C cooler than the main-stem Icicle Creek 0.1 rkm upstream from the confluence (Table 2). After supplementation began water temperatures in Snow Creek immediately began to drop and the temperature difference between Snow Creek and Icicle Creek immediately increased to 2.8°C. Snow Creek temperatures decreased continuously for the remainder of the year, the largest difference was 6.1°C on August 1 (Figure 4). The continued decrease in Snow Creek temperatures was consistent with data from previous years.

In 2015, the effect of Snow Lakes supplementation was highlighted by comparing high 7DADMax water temperatures recorded at IC1 to both IC3 and IC5 (Figure 2). IC1 is located in Icicle Creek 0.1 rkm upstream of IC3 and the confluence of Snow Creek occurs between IC3 and IC1. IC5 is located 1.7 rkm downstream of IC1. In 2015 during Snow Creek supplementation Icicle Creek high 7DADMax temperatures were reduced on average by 2.2°C (0.6–2.9°C) at IC5 and 2.1°C (0.1–3.7°C) at IC3. IC3 is the ideal location to demonstrate the effect of Snow Creek supplementation due to its proximity to the confluence however; data were not available 7/4–8/9 at IC3. IC5 was on average 0.95°C (0.5–1.1°C) warmer than IC5 8/10–8/31. To reconstruct

missing IC3 values I added 0.95°C to IC5 water temperatures and recalculated the average difference at IC3 which increased to 2.5°C (0.1–3.8°C).

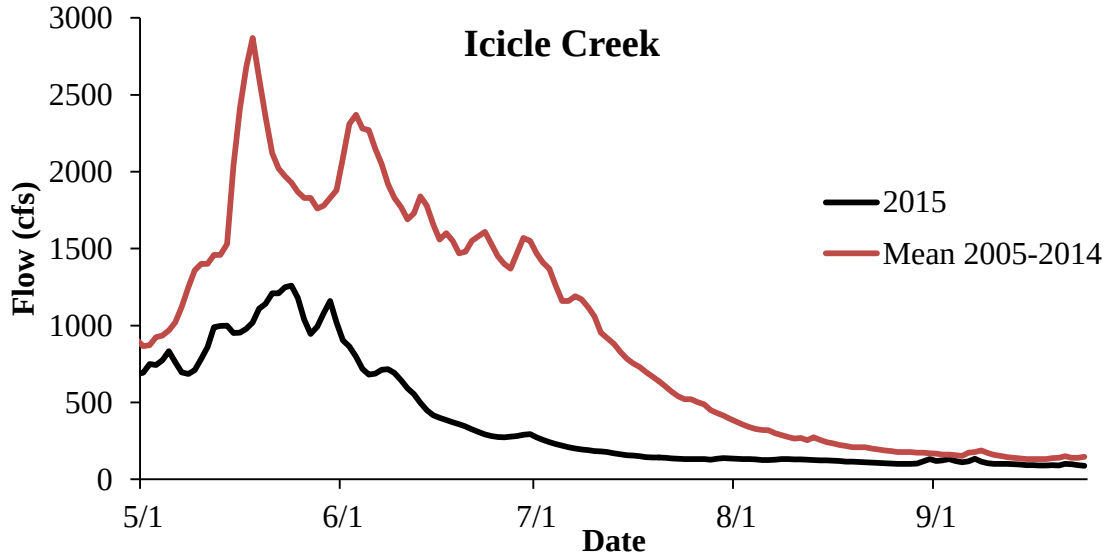

FIGURE 3.—Mean daily flow in Icicle Creek from May 1–September 24, 2015 measured at the U.S. Geological Survey gauge #12458000, upstream of the Snow Creek confluence.

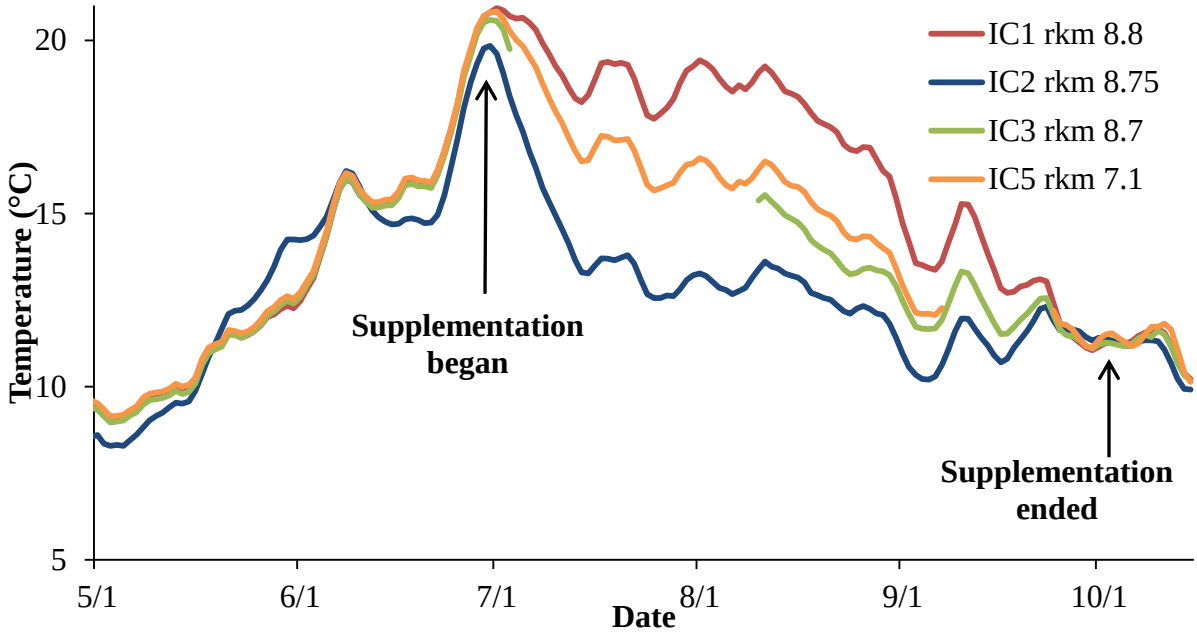

FIGURE 4.—High 7DADMax daily water temperature of Snow Creek (IC2), Icicle Creek upstream (IC1) and downstream (IC3 and IC5) of Snow Creek May 1–October 15, 2015 demonstrating the cooling effects of supplementation water from Snow Lakes. IC3 data were not available 7/4–8/9.

Spillway Pool and Ladder Outfall

The Leavenworth NFH spillway pool is an off-channel pool located at the downstream end of the hatchery channel and the outflow of the adult fish ladder (Figure 1). More than 95% of the water that Leavenworth NFH returns to Icicle Creek enters at the spillway pool. Returned river water was often mixed with well water, which is between 7–9°C. Water temperature sites IC10 and IC11 represent different locations within the spillway pool. IC11 is directly under the Leavenworth NFH adult ladder drain on river left, while IC10 is on the opposite side of the pool.

In 2015, IC10 and IC11 recorded the lowest high 7DADMax of all the monitoring sites at 19.4°C and 19.4°C, respectively. Since water temperature monitoring began in Icicle Creek high 7DADMax temperatures at the spillway pool have been the lowest among the sites. During the peak summer water temperatures in 2015 and when data were available (7/3–8/16), spillway pool high 7DADMax temperatures were on average 2.9°C (1.8–4.2°C), cooler than IC7 which is located immediately upstream (Figure 2). IC10 and IC11 recorded lower temperatures than sites upstream which demonstrated that Leavenworth NFH operations reduced Icicle Creek during summer months. The temperature reduction in Icicle Creek from the spillway pool was demonstrated by comparing IC7 located upstream of the spillway pool to IC8 which is located downstream of the spillway pool (Figure 5). In 2015 during July IC8 is up to 2.4°C cooler than IC7. In contrast, during the winter, the well water increased the temperature of discharged water from Leavenworth NFH by up to 2.9°C when compared with IC7 (Hall and Kelly-Ringel 2011). The summer cooling and winter warming was directly attributed to the operational influence of the Leavenworth NFH. During periods of low flow, Icicle Creek flows primarily in the historic channel and the hatchery channel is dry. In low flows the spillway pool was distinctly separated from the thalweg of Icicle Creek and mixing occurred downstream of the spillway pool. During high flows, Icicle Creek flows in both the historic channel and the hatchery channel which resulted in water mixing further upstream than during periods of low flow.

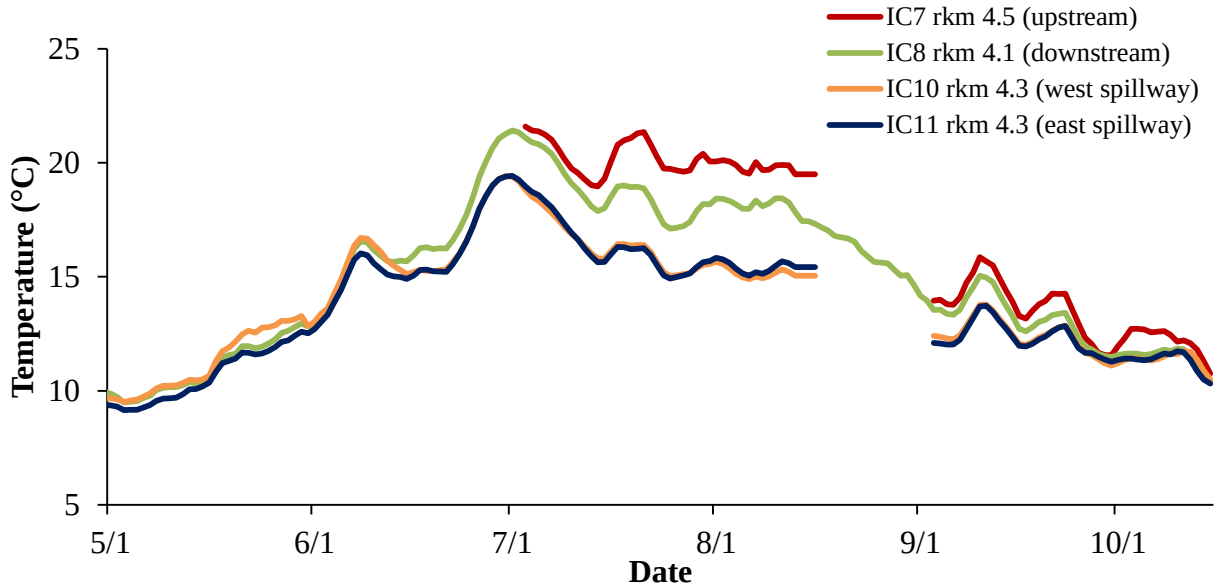

FIGURE 5.—High 7DADMax daily water temperatures in Icicle Creek upstream (IC7), downstream (IC8) and in the Leavenworth NFH spillway pool (IC10 and IC11) May 1–October 15, 2015 demonstrating the cooling effects of Leavenworth NFH operations. Data for IC7, IC10 and IC11 were not available 8/17–9/2.

Abatement Pond

Leavenworth NFH returned about 1cfs of water to Icicle Creek from the abatement ponds during most of the year with the exception of a few hours each day when cleaning activities increased the flow to approximately 3 cfs (Hall 2013). Both IC23 and IC24 are located in the abatement ponds however data were unavailable from IC23 during the warmest time of the year due to equipment failure. The ponds were used simultaneously with equal flow moving through them (T. Collier, LNFH, personal communication). Additionally, when water temperature data were available from both probes the difference in the mean high 7DADMax was 0.3°C and not substantially different, therefore IC24 will be used from here on to describe the water temperature regime in the abatements ponds. In 2015, the high 7DADMax was 20.3°C, and the daily max was 20.7°C. Discharge from the abatement pond was warmer than the nearest upstream Icicle Creek sites, IC10 and IC11which are both located in the spillway pool. However, a comparison to IC10 and IC11 is misleading because water in the spillway pool was tempered with well water. When compared to Icicle Creek water temperatures above Leavenworth NFH (IC6 and IC7) the abatement discharge was cooler because it receives effluent from the hatchery that was tempered by well water which offset the solar heating in the abatement pond. Additionally, the contribution from the abatement pond was small (~1 cfs). The high 7DADMax of 20.3°C in 2015 was slightly above the mean high 7DADMax from 2006–2014 of 18.9°C.

Air Temperature

In 2015, mean daily air temperatures in Icicle Creek were generally within +/- 1 standard deviation (2006–2014) with the exception of the month of June (Figure 6). June air temperatures exceeded the long-term mean by more than 1 standard deviation. In 2015, the mean summer air temperature was 21.9°C; the high 7DADMax was 39.7°C and occurred on July 28 (Table 3).

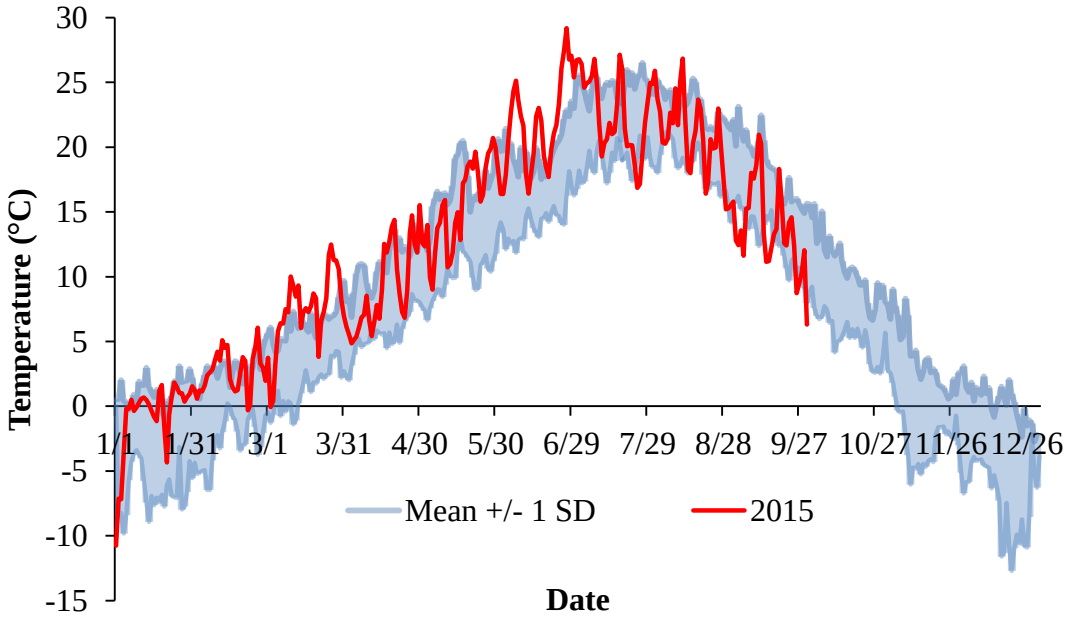

FIGURE 6.— Mean daily air temperature for 2015 (red line) and +/- 1 standard deviation for the mean daily air temperature from 2006–2014 (grey area). Data for October –December of 2015 were not available at the time of this report.

TABLE 3.— Mean air temperature for July–August and high 7DADMax air temperature for 2006–2015.

Year	Mean (°C)	High 7DADMax (°C)
2006	22.0	37.9
2007	20.5	33.6
2008	21.0	38.3
2009	22.7	41.0
2010	20.9	38.7
2011	20.2	38.9
2012	21.0	35.3
2013	21.3	36.1
2014	21.9	37.3
2015	21.9	39.7

Discussion

Record low winter snow pack and above average air temperatures in June resulted in the warmest high 7DADMax water temperatures recorded in Icicle Creek since monitoring began in 2005. Water temperature monitoring across 9.3 rkm in lower Icicle Creek during the warm summer months indicated a downstream warming trend with the exception of two locations; downstream of the Snow Creek confluence (IC3 and IC5) and the Leavenworth NFH spillway pool (IC10 and IC11). Both locations recorded lower water temperatures than sites immediately upstream.

In 2015, the influence from Snow Creek supplementation (July 1–October 2) provided up to 50 cfs of water that had a high 7DADMax of 2.8–6.1°C cooler than Icicle Creek immediately upstream. Snow Creek supplementation occurred during the warmest time of year when water temperature in Icicle Creek was increasing and flow was decreasing. The cooling influence of Snow Creek water supplementation increased throughout the summer months as flow in Icicle Creek decreased and water temperatures increased. Declining flow throughout the summer resulted in a higher percentage of Icicle Creek flow composed of cooler water from Snow Creek supplementation. Additionally, water temperatures in Snow Creek decreased throughout the period of supplementation, most likely due to the constant cooling of Nada Lake through the input of cool water from the bottom and Snow Lake and because of decreasing air temperatures at higher elevations from July 1 onward. Nada Lake resides directly below Snow Lake and receives supplementation water before discharging into Snow Creek.

Well water used by Leavenworth NFH to temper adult holding, rearing, and incubation of spring Chinook Salmon resulted in cooler water temperatures in Icicle Creek during the warm summer months. The cooling effects of well water use were demonstrated by decreased water temperatures in the spillway pool that were out of sync with the general downstream warming trend observed in Icicle Creek. The only identified source of increased water temperatures

connected to hatchery operations during the warm summer months was the warm water discharged from the abatement ponds. However, the abatement pond discharges 0.1 rkm downstream of the Leavenworth NFH spillway pool which is known to have a cooling effect on Icicle Creek. When compared to Icicle Creek water temperatures upstream of the Leavenworth NFH spillway pool, the abatement pond discharge was cooler. Regardless of the water temperature in the abatement pond the impact of discharge from the abatement pond was most likely negligible because flows were low, on average 1 cfs.

In general, during Snow Creek supplementation (July 1–October 2) Leavenworth NFH operations did not substantially reduce flow in Icicle Creek during the summer months. Snow Creek supplementation of 42–50 cfs enters Icicle Creek 1.7 rkm upstream of the Leavenworth NFH in-take. The hatchery has rights to 42 cfs therefore the flow in Icicle Creek below the hatchery in-take should have closely represented the natural flow of Icicle Creek. Without Snow Creek supplementation Leavenworth NFH removes water from Icicle Creek at the in-take which does reduce flow in Icicle Creek for 2.8 km. This reduction in flow may impact water temperatures and result in Icicle Creek being more susceptible to diurnal fluctuations in air temperature and ice formation in the winter. However the flow reduction does not occur during the warmest time of year when the native coldwater fishes in Icicle Creek are most susceptible to lethal water temperatures.

The life histories of ESA-listed Bull Trout, steelhead and spring Chinook Salmon are known to be impacted by water temperatures. Each species has upper thermal limits for rearing, spawning and adult survival therefore reducing water temperatures should not negatively impact stream conditions for these coldwater species (Appendix C). Water temperatures recorded in 2015 indicated that Icicle Creek may not be thermally suitable for some life history stages of these species, and lethal water temperatures for some species were recorded. Bull Trout water temperature requirements are cooler than those of steelhead and Chinook Salmon (WDOE 2006). The Washington State Department of Ecology criterion for Bull Trout rearing is a high 7DADMax of 12°C (WDOE 2006). Juvenile Bull Trout are uncommon where water temperatures exceed 15°C for extended periods of time and adult Bull Trout prefer 9–13°C (Fraley and Shepard 1989; Rieman and Chandler 1999; Dunham and Chandler 2001; Selong et al. 2001; WDOE 2006). WDOE (2006) water temperature criteria were not always met indicating that Icicle Creek may not be thermally suitable for some life history stages of Bull Trout. Selong et all (2001) determined the upper lethal limit to adult Bull Trout a high 7DADMax of 23.5°C and was not recorded in Icicle Creek during 2015. Nelson et al. (2011) suggested that the spillway pool, which was cooled by Leavenworth NFH discharge, may serve as a thermal refuge for Bull Trout in Icicle Creek when water temperatures are high. The high 7DADMax WDOE criteria for rearing of salmonid spawning, rearing, and migration is 17.5°C (WDOE 2006). In 2015, Icicle Creek water temperatures exceeded this criterion at all monitoring sites. Studies have shown the upper thermal limit for Chinook Salmon is a high 7DADMax between 24.0–25.1°C (Brett 1952; Bell 1986; Eaton and Scheller 1996; Myrick and Cech 2001). The upper thermal limit for Chinook Salmon was never reached in 2015. Water temperatures lethal to steelhead have been documented as a high 7DADMax of 21.0–23.9°C (Bell 1986; USEPA 1999). Water temperatures lethal to steelhead were recorded at some monitoring sites in Icicle Creek in 2015. However, water temperatures would have been warmer and more widespread throughout lower Icicle Creek were it not for the cooling effects of Leavenworth

NFH. In warm water years with low flows such as 2015 the reduction in water temperatures from Leavenworth NFH operations may help to avoid lethal water temperatures for coldwater fish species.

In conclusion, Icicle Creek water temperatures downstream of rkm 9.3 in 2015 were the highest observed since monitoring began in 2005. Icicle Creek is occupied by coldwater species such as Bull Trout, Chinook Salmon, steelhead and other native fishes that all can be detrimentally impacted by warm water. Water temperature data in 2015 indicated that water temperatures in Icicle Creek were lower in some areas during the warmest time of the year as a result of Leavenworth NFH operations. Cooler water temperatures may benefit native coldwater fishes especially in warm water years when the natural thermal regime may reach lethal temperatures. Additionally, in warmer water years the Leavenworth NFH spillway pool may provide thermal refuge for native fishes.

Literature Cited

Anchor QEA, LLC. 2010. Draft Wenatchee River Basin Water Storage Report-Snow Lakes. 811 Kirkland Ave. Suite 200. Kirkland, Washington 98033

Bell, M.C. 1986. Fisheries handbook of engineering requirements and biological criteria. Fish Passage Development and Evaluation Program. U.S. Army Corps of Engineers. 209pp.

Brett, J. R. 1952. Temperature Tolerance in Young Pacific Salmon, Genus Oncorhynchus. Pacific Biological Station, and Department of Zoology, University of Toronto. J. Fish Res. Board Can. 9(6): 265–308 + appendices.

Coutant, C. C. 1987. Thermal Preference - When does an asset become a liability? Environmental Biology of Fishes 18(3):161–172.

Dunham, J. B., G. Chandler. 2001. Models to predict suitable habitat for juvenile bull trout in Washington State. Final Report to USDI Fish and Wildlife Service. U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 75 p.

Eaton J. G., and R. M. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. Limnol Oceanogr 4l:109–1115.

Fraley, J. J., and B. B. Shepard. 1989. Life history, ecology, and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and River system, Montana. Northwest Science 63:133–143.

Hall, M. R. 2013. Summary of Icicle Creek Temperature Monitoring, 2012. U.S. Fish and Wildlife Service, Leavenworth, WA.

Hall, M. R., and B. M. Kelly-Ringel. 2011. Summary of Icicle Creek Temperature Monitoring, 2005–2009. U.S. Fish and Wildlife Service, Leavenworth WA.

Magnuson, J. J., L. B. Crowder, and P. A. Medvick. 1979. Temperature as an ecological resource. American Zoologist 19(1):331–343.

Montgomery Water Group, Inc. 2004. Water management plan for Leavenworth National Fish Hatchery. Kirkland, Washington. 17 p.

Mullan, J. W., K. R. Williams, G. Rhodus, T.W. Hillman, and J.D. McIntyre. 1992. Production and habitat of salmonids in Mid-Columbia River tributary streams. U.S. Fish and Wildlife Service, Monograph 1, Leavenworth, Washington.

Myrick C.A., and J.J. Cech. 2001. Temperature Effects on Chinook Salmon and Steelhead: a Review Focusing on California's Central Valley Populations. Bay-Delta Modeling Forum. Technical Publication 01-1. 57pp

Nelson, M. C., A. Johnsen, and R. D. Nelle. 2011. Seasonal movements of adult fluvial bull trout and redd surveys in Icicle Creek, 2009 Annual Report. U.S. Fish and Wildlife Service, Leavenworth, Washington.

Olden, J. D., and R. J. Naiman. 2010. Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshwater Biology 55(1):86–107.

Rieman, B. E., and G. L. Chandler. 1999. Empirical evaluation of temperature effects on bull trout distribution in the Northwest. Final report to U.S. Environmental Protection Agency, Boise, Idaho.

Selong, J. H., T. E. McMahon, A. V. Zale, and F. T. Barrows. 2001. Effect of temperature on growth and survival of bull trout with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society. 130(6):1026–1037.

WDOE (Washington Department of Ecology). 2006. Water quality standards for the surface waters of the state of Washington Chapter 173-201A WAC. Amended November 20, 2006. Publication number 06-10-091.

U.S. Environmental Protection Agency (USEPA). 1999. A review and synthesis of effects of alternation to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. Region 10, Seattle, WA. EPA 910-R-99-010. 279pp.

U.S. Environmental Protection Agency (USEPA). 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, Washington.

USFS (U.S. Forest Service). 1994. Icicle Creek stream survey report. Leavenworth Ranger District, Leavenworth, Washington

USFWS (U. S. Fish and Wildlife Service). 2006. Fish production review of the Leavenworth National Fish Hatchery Complex, 2005. Prepared by M. Cooper. Mid-Columbia River Fishery Resource Office, Leavenworth, Washington. 99 p. http://www.fws.gov/midcolumbiariverfro/pdf/Fish%20Production%20Review%20of%20the%20Leavenworth%20NFH%20Complex,%202005.pdf

Ward, W. J. 2003. Continuous Temperature Sampling Protocols for the Environmental Monitoring and Trends Section. Washington State Department of Ecology, Publication 03-03-052, Olympia, Washington

WRWSC (Wenatchee River Watershed Steering Committee). 1998. Wenatchee River watershed action plan: a plan containing nonpoint pollution source control and implementation strategies. Chelan County Conservation District, Wenatchee, Washington.

Wurster F. 2009. Technical Memos:2005–2008 Upper Snow Lake Data Review. USFWS, Portland, Oregon.

Personal Communications

Collier, Travis. 2015. Leavenworth National Fish Hatchery. Conversation with Gregory Fraser. November 17, 2015

Appendix A: Table A1: Site Descriptions, elevation, High 7DADMax (°C), Daily Max Temperature (°C), and Date of first occurrence.

Site	Description	rkm	Elevation (m)	Year	High 7DADMax	7DADMax week ending	Daily Max Temperature	Date of Daily Max Temperature
IC15	Wenatchee River	n/a	339	2015				
				2014	19.8	2-Aug	20.9	16-Aug
				2013	no data	no data	no data	no data
				2012	19.7	20-Aug	20.2	19-Aug
				2011	17.9	30-Aug	18.1	27-Aug
IC13	Icicle Mouth	0.8	334	2015				
				2014	18.8	2-Aug	19.7	2-Aug
				2013	19.2	11-Aug	20.4	10-Aug
				2012	18.2	19-Aug	18.7	8-Aug
				2011	16.8	29-Aug	17.2	29-Aug
				2010	18.1	18-Aug	18.7	17-Aug
				2009	20.7	3-Aug	21.3	1-Aug
				2008	18.7	19-Aug	19.4	16-Aug
				2007	18.8	29-Jul	19.4	26-Jul
IC23	Abatement Pond outfall	4.2	339	2015	16.5	8-Aug	17.4	31-July
				2014	18.4	2-Aug	19.1	2-Aug
				2013	17.9	12-Aug	19.6	11-Aug
				2012	16.5	9-Aug	17.5	8-Aug
				2011	20.2	7-Jul	22.7	5-Jul
				2010	no data	no data	no data	no data
				2009	22	2-Aug	23	29-Jul
				2008	19.4	19-Aug	20.5	19-Aug
				2007	18	15-Jul	19	4-Aug
IC8	d/s of LNFH	4.1	339	2015	21.4	4-July	21.7	2-July
				2014	18.3	2-Aug	19.0	2-Aug
				2013	18.5	27-Jul	19.6	10-Aug
				2012	no data	no data	no data	no data
				2011	16.2	29-Aug	16.5	29-Aug
				2010	no data	no data	no data	no data
				2009	19.8	3-Aug	20.3	28-Jul
				2008	no data	no data	no data	no data
				2007	19.4	26-Jul	18.5	26-Jul
				2006	18.9	27-Jul	19.8	23-Jul
				2005	19.6	31-Jul	20	28-Jul

Appendix A: Table A1: Site Descriptions, elevation, High 7DADMax (°C), Daily Max Temperature (°C), and Date of first occurrence (cont'd).

IC11	LNFH at Ladder outfall	4.3	340	2015	19.4	4-July	19.9	29-Jun
				2014	17.5	2-Aug	18.0	2-Aug
				2013	17.1	27-Jul	17.9	10-Aug
				2012	16.6	9-Aug	17.3	5-Aug
				2011	15.3	29-Aug	15.4	25-Aug
				2010	no data	no data	no data	no data
				2009	18.2	2-Aug	18.7	28-Jul
				2008	16.3	19-Aug	17	16-Aug
				2007	16.3	29-Jul	16.8	26-Jul
IC10	LNFH Spillway pool	4.3	340	2015	19.4	4-July	20.1	29-Jun
				2014	no data	no data	no data	no data
				2013	no data	no data	no data	no data
				2012	16.4	18-Aug	17.3	8-Aug
				2011	15.2	29-Aug	15.4	23-Aug
				2010	no data	no data	no data	no data
				2009	18.3	2-Aug	18.7	28-Jul
				2008	16.2	19-Aug	16.8	16-Aug
				2007	16.2	30-Jul	16.8	26-Jul
				2006	no data	no data	no data	no data
				2005	16.9	11-Aug	17.7	31-Jul
IC7	d/s of Structure 5	4.5	340	2015	21.6	4-July	23.0	20-July
				2014	18.6	2-Aug	19.3	2-Aug
				2013	18.8	11-Aug	19.8	10-Aug
				2012	17.7	19-Aug	18.3	14-Aug
				2011	16.6	29-Aug	16.8	29-Aug
				2010	no data	no data	no data	no data
				2009	20.4	3-Aug	20.9	1-Aug
				2008	18.2	19-Aug	19.2	16-Aug
				2007	19.3	29-Jul	20.2	28-Jul
				2006	19.4	28-Jul	20.2	23-Jul
				2005	no data	no data	no data	no data
IC6	at LNFH Headgate	6.1	350	2015	21.3	4-July	21.8	29-Jun
				2014	18.4	2-Aug	19.2	2-Aug
				2013	18.4	27-Jul	19.4	10-Aug
				2012	17.5	18-Aug	18.2	8-Aug
				2011	16.4	29-Aug	16.5	23-Aug
				2010	17.3	18-Aug	17.7	17-Aug
				2009	19.1	2-Aug	19.6	28-Jul

Appendix A: Table A1: Site Descriptions, elevation, High 7DADMax (°C), Daily Max Temperature (°C), and Date of first occurrence (cont'd).

				2008	17.6	18-Aug	18.6	16-Aug
				2007	17.9	30-Jul	18.8	26-Jul
				2006	19.2	28-Jul	20.2	23-Jul
				2005	20.3	21-Aug	21	16-Aug
IC5	LNFH Intake	7.1	356	2015	20.8	4-July	19.0	29-Jun
				2014	18.3	2-Aug	19.0	2-Aug
				2013	18.1	26-Jul	19.8	10-Aug
				2012	17.1	19-Aug	17.8	5-Aug
				2011	no data	no data	no data	no data
				2010	no data	no data	no data	no data
				2009	19.6	2-Aug	20.1	28-Jul
IC3	d/s of Snow Creek	8.7	392	2015	20.6	4-July	21.2	29-Jun
				2014	no data	no data	no data	no data
				2013	no data	no data	no data	no data
				2012	17	19-Aug	17.7	5-Aug
				2011	16	29-Aug	16.2	25-Aug
				2010	16.4	18-Aug	16.8	17-Aug
				2009	19.5	2-Aug	20	28-Jul
				2008	no data	no data	no data	no data
				2007	17.2	30-Jul	18.2	26-Jul
				2006	no data	no data	no data	no data
				2005	18.1	31-Jul	18.6	29-Jul
IC2	in Snow Creek	n/a	398	2015	19.8	4-July	20.8	29-Jun
				2014	16.3	2-Aug	18.9	2-Aug
				2013	17.1	23-Jul	18.4	2-Jul
				2012	18	19-Jul	18.5	19-Jul
				2011	15.6	8-Aug	16.4	4-Aug
				2010	17.4	30-Jul	18.3	28-Jul
				2009	18	28-Jul	18.7	27-Jul
				2008	15.9	26-Jul	16.7	9-Jul
				2007	18.5	16-Jul	19.7	13-Jul
				2006	17.5	14-Jul	19	14-Jul
				2005	16.6	23-Jul	17.4	18-Jul
IC1	u/s of Snow Creek	8.8	410	2015	20.9	4-July	21.3	2-July
				2014	18.0	2-Aug	18.8	9-Aug
				2013	18.3	11-Aug	19.1	10-Aug
				2012	17.6	20-Aug	18.2	14-Aug
				2011	16.2	29-Aug	16.4	25-Aug
				2010	17.4	18-Aug	18	17-Aug

Appendix A: Table A1: Site Descriptions, elevation, High 7DADMax (°C), Daily Max Temperature (°C), and Date of first occurrence (cont'd).

				2009	19.8	2-Aug	20.2	28-Jul
				2008	18.3	19-Aug	19.3	16-Aug
				2007	17.9	29-Jul	18.7	2-Aug
				2006	18.6	27-Jul	19.5	23-Jul
				2005	18.9	31-Jul	19.5	6-Aug
IC19	u/s of IPID at USGS gauge	9.3	435	2015	20.8	4-July	21.1	2-July
				2014	18.0	9-Aug	18.7	9-Aug
				2013	18.3	10-Aug	18.9	10-Aug
				2012	17.7	19-Aug	18.2	14-Aug
				2011	16.1	29-Aug	16.4	25-Aug

Appendix B: Temperature Logger Calibration Protocol

Temperature Logger Calibration/ Testing
Kendall Henry

Prior to deployment temperature loggers were tested and calibrated. Temperature loggers were tested in two water baths representing the potential extremes temperatures of their monitoring conditions, as per Ward (2003).

Water baths were made in coolers and used either an aquarium powerhead or air pump/stone added to mix the water and maintain a uniform temperature. Temperature loggers were weighted in the coolers with the same nuts and bolts used in the field. Temperature loggers were acclimated to the water baths for at least 30 minutes before temperature monitoring began. To validate the temperatures we used a NIST certified thermometer and an YSI sonde. Temperature loggers were set to record temp at five minute intervals and the YSI and NIST temperatures were recorded at the same interval.

The room-temperature water bath was made by filling a cooler and allowing it to stabilize to room temperature (approx. 21 °C). The ice-water bath was made with tap water and ten trays of ice cubes. The lid was placed over the cooler except for 1 inch on the side to allow insertion of the thermometer and the power cord for the pump. The ice-water bath sat for at least one hour to allow it to stabilize and become uniform throughout.

After the tests concluded the data were analyzed. Temperature loggers were retested if an absolute value recorded differed by more than +/- 0.2 °C. If the second test of a temperature logger showed similar results that logger was not used during this study.

Appendix C: Table C1: Upper thermal water temperature criteria for Char and Salmonids

Category	Highest 7DADMax °C
Char Spawning[1]	9.0
Char Spawning and Rearing[1]	12.0
Salmon and Trout Spawning[1]	13.0
Core Summer Salmonid Habitat[1]	16.0
Salmonid Spawning, Rearing, and Migration[1]	17.5
Salmonid Rearing and Migration **Only**[1]	17.5
Upper Lethal Limit Bull Trout[2]	23.5
Upper Lethal Limit Steelhead[3]	21.0–23.9
Upper Lethal Limit Chinook Salmon[4]	24.0–25.1

1) WDOE 2006
2) Selong et al. 2001
3) Bell 1986; USEPA 1999
4) Brett 1952; Bell 1986; Eaton and Scheller 1996; Myrick and Cech 2001

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