U.S. Fish and Wildlife Service

Summary of Icicle Creek Temperature Monitoring, 2011

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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, 2011

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Abstract- Icicle Creek temperature monitoring began in 2005. ONSET Hobo Water Temp Pro V2 temperature loggers are deployed to 13 Icicle Creek sites upstream, adjacent to, and downstream of the Leavenworth National Fish Hatchery (LNFH). Water temperatures are recorded hourly. The year 2011 was cooler than average, with a mean summer air temperature of 20.2^{o}C. In Icicle Creek, the expected downstream warming occurs, with two exceptions within the operational influence of the LNFH: 1) At the Snow Creek confluence, summer supplementation of water from Snow Lake cools Icicle Creeks mean high 7DADmax by 0.2^{o}C. 2) At the LNFH spillway pool, returned river water is mixed with well water creating an off-channel pool with a high 7DADmax that is, on average, 1.4^{o}C cooler than immediately upstream. This cooling effect is a result of hatchery related operations, and in 2011, was less than in previous years.

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Introduction

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 (LNFH) in 2011. All loggers were calibrated in the spring of 2011, and new housings were constructed and deployed. Most sites are unchanged from previous years. Two sites have been added and one site has been removed.

Study Area

The Icicle Creek watershed drains 55,426 hectares of forested uplands on the eastern flank of the Cascade Mountain range in North Central Washington State. Icicle Creek is 50.8 km long from its headwaters at Lake Josephine (elevation 1423m) to its confluence with the Wenatchee River (elevation 340m) (WRWSC 1998). The upper drainage (approximately upstream of rkm 6.0) is characterized by high basin relief, glaciated cirques, and steep headwalls, with batholithic geology that has little water storage capacity. The lower drainage forms a low sloping 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 its highest elevations, and 50.8 cm in its lower elevations. There are 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 (Mullen et al. 1992). Stream discharge has been recorded by the U.S. Geological Survey (Gage Station 12458000 at rkm 9.4[1]) from 1936 to 1971 and from 1993 to the present. The average discharge for the period of record is 614 cfs. The minimum and maximum discharges are 44 cfs (November 30, 1936) and 19,800 cfs (November 29, 1995), respectively (USGS 2009).

Icicle Creek has two major water diversions, supplying four user groups, which affect in-stream flow and water temperature (Figure 1). Both diversions occur near the confluence of Snow Creek. At rkm 9.3, just upstream of the Snow Creek confluence, the Icicle Peshastin Irrigation District (IPID) withdraws from 60 to 103 cfs of water from April through September, and the City of Leavenworth withdraws about 2 cfs year around (Montgomery Water Group, Inc. 2004). At rkm 7.2, the Cascades Orchard Irrigation Company (COIC) withdraws 7 cfs from May through September, and the Leavenworth National Fish Hatchery (LNFH) uses 20 to 40 cfs year around. The total amount of water diverted 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 being the largest by volume at approximately 12,450 acre-ft at

[1] All river kilometers (rkm) are approximate.

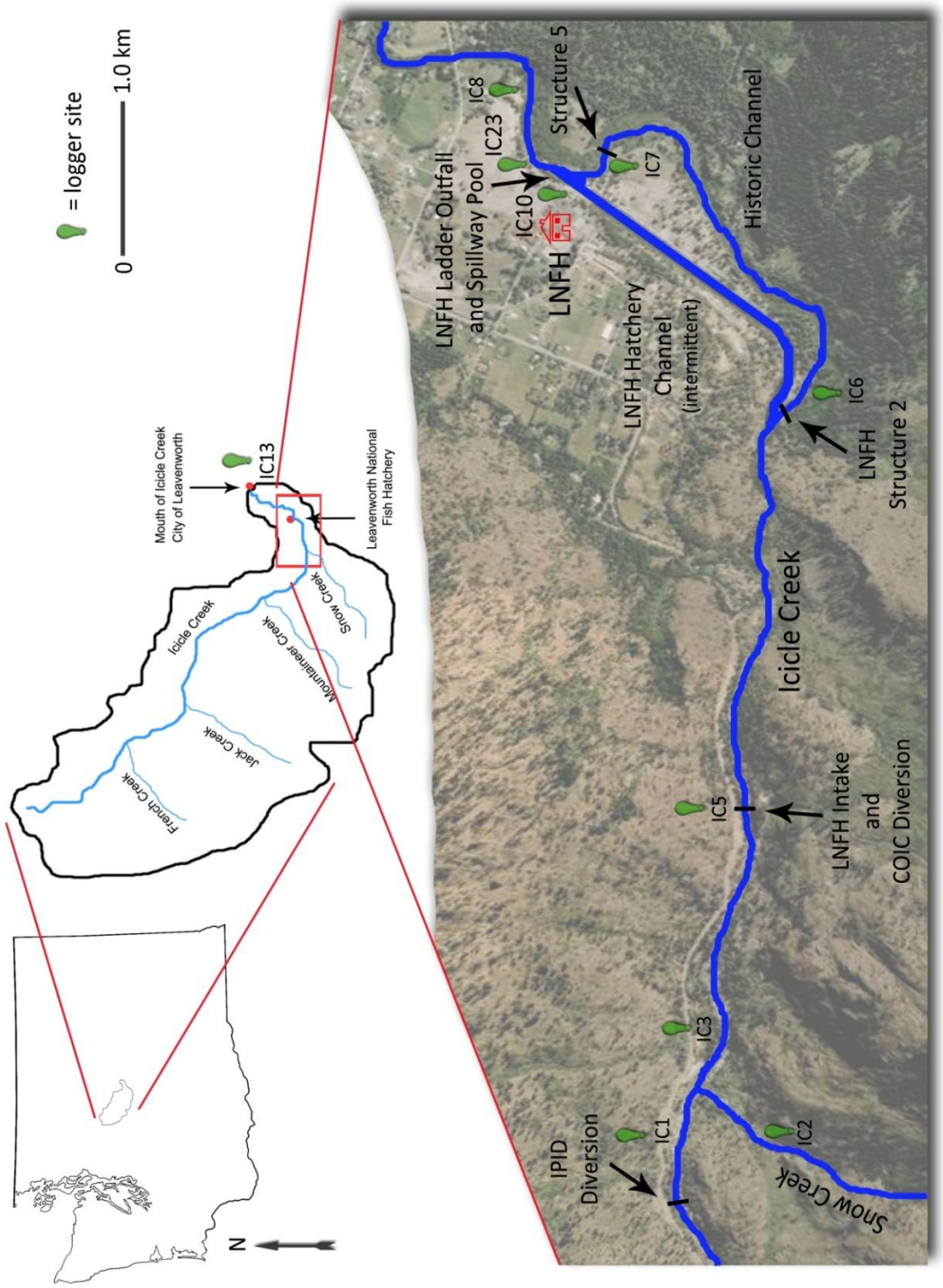

Figure 1. Map of Icicle Creek drainage with *selected* temperature monitoring sites and structures.

full capacity (Anchor QEA 2010). In 1939, the U.S. Bureau of Reclamation installed a valve in the bottom ofUpper Snow Lake, allowing the lake to be drained at a controlled rate, and its water to be used to supplement Icicle Creek during low-flow periods. The LNFH has rights to 16,000 acre-ft of water per year from Upper Snow Lake. In a typical year, the valve is opened on July 28 (average 2006-2011) (Table 1), delivering up to 60 cfs. of water to Snow Creek, and is closed in October. During some low flow periods, supplemented Snow Creek water represents the majority of in-stream flow in Icicle Creek after the IPID diversion.

Table 1. Snow Lake valve openings, adjustments, and closures, and discharge into Snow Creek during those periods, 2006-2011[1,2].

Year	Date	Action	Discharge
2006	26-Jul	Valve Opened	18 cfs
	16-Aug	Adjustment	Increased to 56 cfs
	5-Oct	Valve Closed	
2007	23-Jul	Valve Opened	53 cfs
	3-Oct	Valve closed	
2008	29-Jul	Valve opened	25 cfs
	12-Aug	Adjustment	Increased to 60 cfs
	3-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	
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	
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	

[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. From Fred Wurster memos (2009) and Al Jensen, LNFH, pers. comm.
[2] Estimated based on valve opening.

The LNFH occupies land adjacent to Icicle Creek from approx. rkm 6.1 to rkm 4.1. At rkm 6.1, the Icicle Creek watershed transitions from a steep canyon to a broad valley. Channel classification transitions from B1 upstream of the LNFH Structure 2 to C4 downstream to the mouth (Rosgen 1996).

The LNFH 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. The LNFH also uses up to 14.4 cfs of well water to

supplement its river supply, and to cool its incubation and rearing water in the summer and warm it in the winter (USFWS 2006).

The LNFH returns water to Icicle Creek in two locations: the adult ladder outfall at rkm 4.3, which drains the adult and juvenile rearing ponds, and the pollution abatement pond at rkm 4.2, which is used to collect and settle effluent from pond cleaning before returning the water to Icicle Creek. The adult ladder outfall represents >95% of the water returned to Icicle Creek from the LNFH. Water release from the pollution abatement pond consists of a "leakage" rate of approx. 1 cfs, and a pulse of about 3 cfs for a few hours per day during routine juvenile pond cleaning (Steve Croci, LNFH, pers. comm.).

Downstream of the LNFH, Icicle Creek meanders for 4.0 rkm through a broad valley of mixed residential and agricultural properties before emptying into the Wenatchee River.

Methods

In May of 2011, the ONSET Hobo Water Temp Pro V2 temperature loggers that have been deployed In Icicle Creek for temperature monitoring were gathered from the field sites and brought back to the MCRFRO. The loggers were tested for accuracy, and those which met ONSET's reported accuracy of +/- 0.2 ^{o}C were selected (see Appendix A). A PVC housing was developed and constructed to meet the demands of logger accuracy, housing durability, and downloading ease. The loggers and housings were deployed to 14 sites in Icicle Creek. The monitoring sites were selected to represent baseline conditions and as a means to assess the effects of water diversions and hatchery operations (Appendix B). All loggers recorded the temperature hourly when deployed. The data was downloaded via the Hobo Waterproof shuttle 2-4 times per year. Air temperature was recorded at the Mid-Columbia Fisheries Resource Office (rkm 5.0).

During this monitoring effort, IC5's battery failed, resulting in a gap in data at this site from 11-July to 27-Sept. Also during this year, IC14 was removed from the monitoring program. We concluded that because IC14 and IC13 are very close in proximity, ground water exchange between the two sites was resulting in temperature readings within 0.5^{o}C of each other. This does not reflect the actual differences occurring between the broader Wenatchee River and Icicle Creek. Anticipating this action, a site was established approx. 2 rkm upstream from IC14 and designated as IC15. As well, a site designated IC19 was established at the USGS gauge on Icicle Creek, giving us temperature data from Icicle Creek before it encounters any diversions or structures.

The raw data was imported into the HOBOware Pro V2x software to calculate daily minimums, maximums, and means. A 7-Day Average Daily Maximum (7DADmax) was calculated for each site and day using the running average of the previous 7 days. Distances between loggers were measured on USGS maps using Maptech, and elevation was estimated using Google Earth.

Results and Discussion

All of the raw data collected from this project is available upon request. Results in this report focus on summer highs, as these are of the most interest to the water users and regulatory agencies. The summer season includes the period of Snow Creek supplementation (beginning 3-Aug in 2011), and the results presented here reflect this effect, unless otherwise noted. For 2011, the maximum temperature reached (High Max.), maximum 7 day average daily maximum (High 7DADmax), and dates of occurrence for each site is given in Appendix B. Note that because IC5 is missing data from the critical summer period, High Max. and High 7DADmax were not calculated. Overall, 2011 was cooler than recent years for both air and water temperature.

Air Temperature

Mean summer and High 7DADmax air temperature for the years 2005-2011 are given in Figure 2. Note that there is no data for mean summer temperature for 2005. In 2011, the mean summer temperature (July/August) was 20.2^{o}C. This is the coolest summer mean of the years monitored. The High 7DADmax was 38.9^{o}C, which occurred on 12-Sept. This was among the higher 7DADmax's of the years monitored. A cool spring and early summer pulled down the average temperature overall, however a late, contracted warm period brought the peak summer highs up to levels comparable to previous years (Figure 3).

Icicle Creek

A longitudinal temperature profile for Icicle Creek within the operational influence of the LNFH, using the High 7DADmax for 2011, 2009, and 2007, is displayed in Figure 4. The years 2007 and 2009 are used as comparison because they are the (previously) coolest and warmest years recently monitored. This profile demonstrates the condition of Icicle Creek during the warmest period of the years monitored. Note that IC10 is located in the off-channel LNFH spillway pool.

In 2011, Icicle Creek experienced the expected downstream warming, with IC13, at the mouth, being the warmest site within the creek, with a High 7DADmax of 16.8^{o}C and a High Max. of 17.2^{o}C. The coolest site within the *main channel* of Icicle Creek was IC3, downstream of the Snow Creek supplementation. At 16.0^{o}C, this site was slightly cooler than IC19, the uppermost site on Icicle Creek.

Snow Creek Supplementation

Supplementation of Snow Lakes water into Icicle Creek via Snow Creek began on 3-Aug. This is considerably later than the previous average opening date of 25-July (2005-2010), and reflects the cool spring and summer conditions, allowing the snowpack to linger and Icicle Creek flows to remain robust into the summer months. IC2, located in Snow Creek, had a High 7DADmax of 15.6^{o}C, and a High Max. of 16.4^{o}C. Both of these readings occurred in early August, before supplemented Snow Lakes water reached the site. After supplementation begins, Snow Creek temperatures decrease continuously for the remainder of the year. This is commensurate with findings from previous years.

IC3, located in Icicle Creek immediately downstream of the Snow Creek confluence, reflects Snow Creek supplementation, with a High 7DADmax and High Max. that is cooler than that of IC1, immediately

upstream of the confluence. The Snow Lake supplementation cooled Icicle Creek's high 7DADmax by 0.2°C in 2011 (Figure 4). This is below the average cooling of 0.7°C (range 0.3°C to 1.0°C) for years 2005 to 2010. The modest cooling is likely explained by considering the overall cool temperatures experienced in Icicle Creek in 2011.

Spillway Pool and Ladder Outfall

The LNFH spillway pool is an off-channel pool formed by the intermittent use of the Hatchery Canal and the adult ladder outfall, which constitutes >95% of the water returned to Icicle Creek. The returned river water is mixed with well water, which is between 7°C and 9°C, depending on which well is used. The IC10 and IC11 sites represent different locations within the LNFH spillway pool. IC11 is directly under the LNFH Ladder drain, while IC10 is on the opposite side of the pool. The temperatures recorded at these two sites have historically been nearly identical, with the average difference of 0.1°C, less than the stated accuracy of the loggers. This trend continues in 2011, and as such, IC10 will be used to represent this site.

IC10 had a high 7DADmax of 15.2°C and a High Max. of 15.4°C. These are the coolest temperatures monitored *overall* in this program, and reflect the cooling effect of the LNFH return water/well water mixture. In 2011, IC10's high 7DADmax and High Max. were 1.4°C cooler than the nearby, upstream IC7 site (Figure 4). This is less cooling than the average of 2.4°C from 2007 to 2010, and is likely explained by considering the overall cool temperatures experienced in Icicle Creek in 2011.

During the winter, the well water warms the discharged mix by up to 2.9°C when compared with IC7 (Hall and Kelly-Ringel 2011). The summer cooling and winter warming can be directly attributed to the operational influence of the LNFH. During periods of low flow, the spillway pool is distinctly separated from the thalweg of Icicle Creek, and the water mixes slowly. During high flow events, the thalweg of Icicle Creek overcomes its bank- full channel and readily mixes with the spillway pool.

Abatement Pond

The LNFH abatement pond returns about 1cfs of water to Icicle Creek during most of the year. For up to a few hours each day, cleaning activities increase this contribution to no more than 3 cfs (Steve Croci, LNFH pers. com.). The abatement pond return water is expected to be warmer than Icicle Creek due to solar heating over its large surface area, however its flow contribution is small.

In 2011, the LNFH began using a new abatement pond constructed next to the old pond. It will be used while the old pond is refurbished. In the future, both ponds will be available, though only one is expected to be used at a time.

Site IC23 is located at the outfall of the new abatement pond, and in 2011, the high 7DADmax was 20.2°C, and the High Max. was 22.7°C. Both of these events occurred in early July. These temperatures are slightly higher than the averages from 2007 to 2010 (19.8°C and 20.8°C, respectively). This was unexpected, given the otherwise cool temperatures at other Icicle Creek sites.

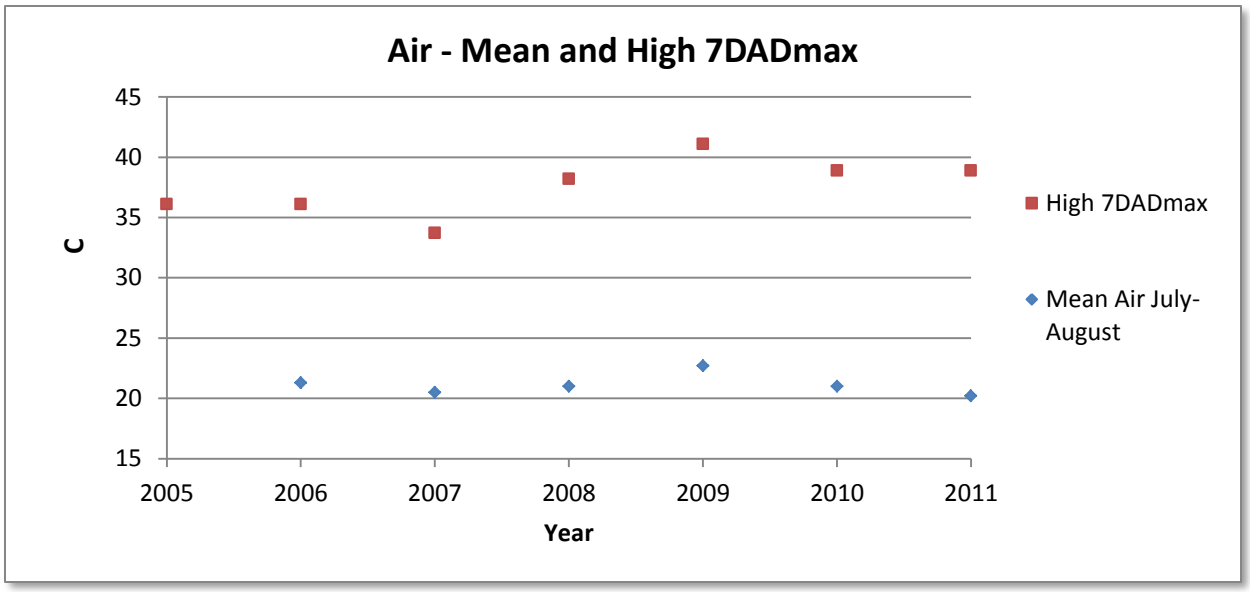

Figure 2. Mean summer and High 7DADmax air temperature for years 2005-2011

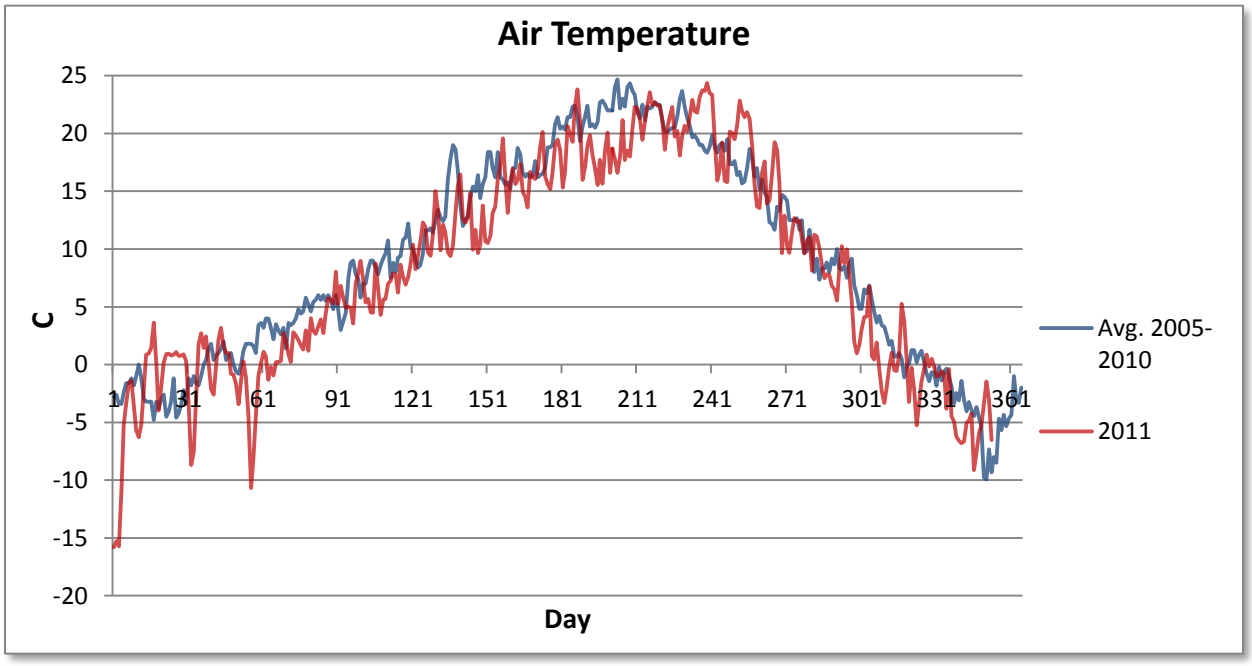

Figure 3. Air temperature, average 2005-2010 and 2011

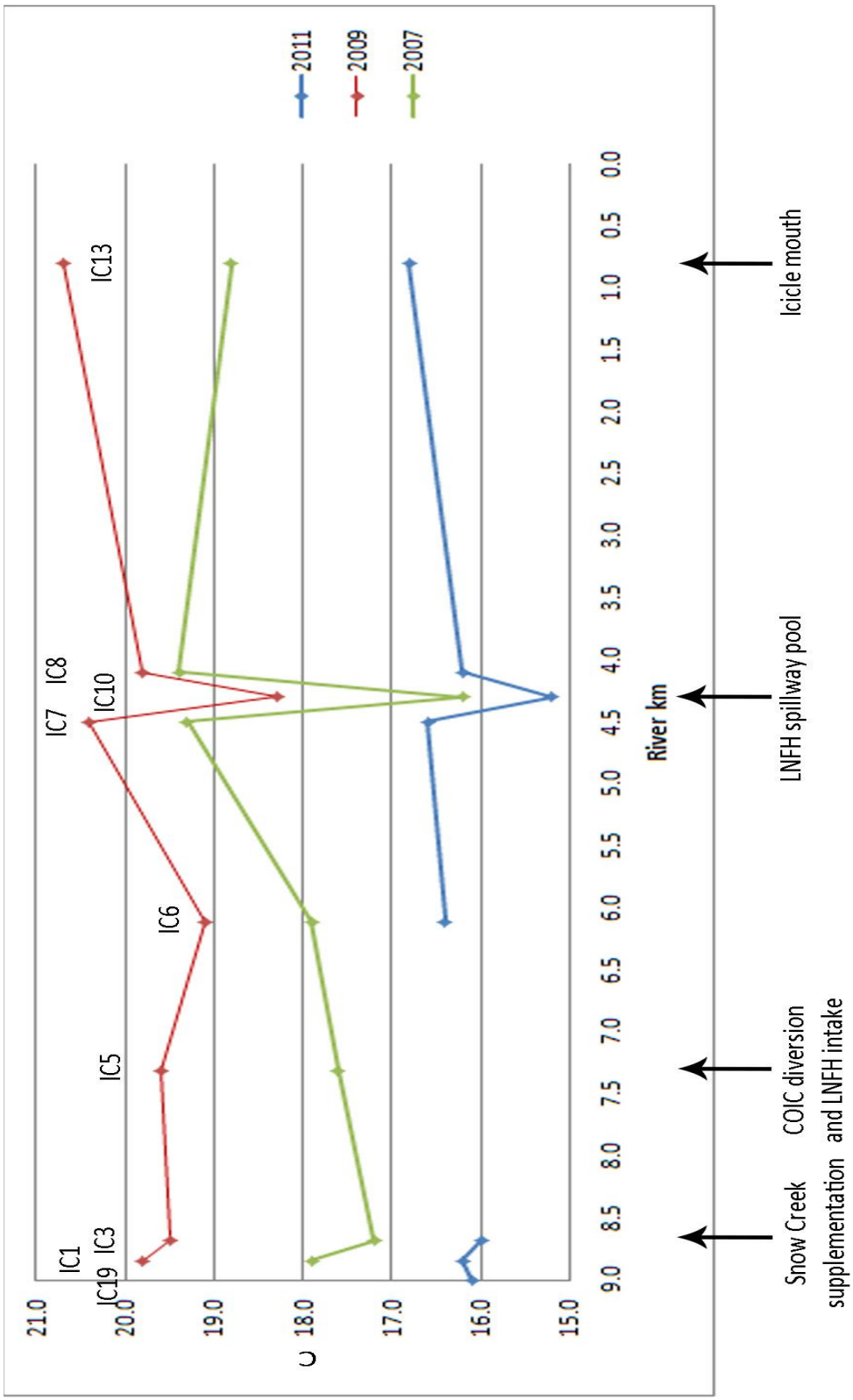

Figure 4. Longitudinal temperature profile for a portion of Icicle Creek using High 7DADmax for years 2011, 2007 (previous coolest year), and 2009 (warmest year).

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Appendix A: Temperature Logger Calibration Protocol

Temperature Logger Calibration/ Testing
Kendall Henry

Prior to deployment, all temperature loggers were tested in two temperature baths representing the extremes of their monitoring conditions, as per Ward 2003.

The baths were made in coolers and had either an aquarium powerhead or air pump/stone added to mix the water and maintain a uniform temperature. The loggers were weighed down by putting the same nuts and bolts that will be used in the field through the hole. The loggers were acclimated to the baths for at least 1/2 hour before temp monitoring began. We used a NIST certified thermometer and a YSI sonde to measure temperature. The loggers were launched to record temp at 5 minute intervals and the YSI and NIST temperatures were noted at the same 5 minute intervals.

The room temperature bath was made by filling a cooler and allowing it to stabilize to room temperature (about 21 C). The ice bath was made using the coldest tap water and 10 ice cube trays of ice. The lid was placed over this cooler except for 1 inch on the side to allow insertion of the thermometer. The ice bath sat for at least 1 hour to allow it to stabilize and become uniform throughout.

After the calibration tests were concluded, the data was downloaded to hobo software and exported to Excel for comparison with the reference thermometer. If the mean absolute value of the difference was greater than 0.2 ° C the thermometers were tested again. If the mean difference was still more than +- 0.2 ° C they were not used in the sampling.

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

Appendix B: Site Descriptions, High 7DADmax, High Max, and Dates.

Site ID	Description	River km	Elevation (m)	Years	High 7DADmax (C)	7DADmax-week ending*	High max (C)	High max date*
IC15	Wenatchee River	n/a	339	2011	17.9	30-Aug	18.1	27-Aug
IC13	Icicle Mouth	0.8	334	2007	18.8	29-Jul	19.4	26-Jul
				2008	18.7	19-Aug	19.4	16-Aug
				2009	20.7	3-Aug	21.3	1-Aug
				2010	18.1	18-Aug	18.7	17-Aug
				2011	16.8	29-Aug	17.2	29-Aug
IC23	Abatement Pond outfall	4.2	339	2007	18.0	15-Jul	19.0	4-Aug
				2008	19.4	19-Aug	20.5	19-Aug
				2009	22.0	2-Aug	23.0	29-Jul
				2010	no data	no data	no data	no data
				2011	20.2	7-Jul	22.7	5-Jul
IC8	d/s of LNFH	4.1	339	2005	19.6	31-Jul	20.0	28-Jul
				2006	18.9	27-Jul	19.8	23-Jul
				2007	19.4	26-Jul	18.5	26-Jul
				2008	no data	no data	no data	no data
				2009	19.8	3-Aug	20.3	28-Jul
				2010	no data	no data	no data	no data
				2011	16.2	29-Aug	16.5	29-Aug
IC11	LNFH at Ladder outfall	4.3	340	2007	16.3	29-Jul	16.8	26-Jul
				2008	16.3	19-Aug	17.0	16-Aug
				2009	18.2	2-Aug	18.7	28-Jul
				2010	no data	no data	no data	no data
				2011	15.3	29-Aug	15.4	25-Aug
IC10	LNFH Spillway pool	4.3	340	2005	16.9	11-Aug	17.7	31-Jul
				2006	no data	no data	no data	no data
				2007	16.2	30-Jul	16.8	26-Jul
				2008	16.2	19-Aug	16.8	16-Aug
				2009	18.3	2-Aug	18.7	28-Jul
				2010	no data	no data	no data	no data
				2011	15.2	29-Aug	15.4	23-Aug
IC7	d/s of Structure 5	4.5	340	2005	no data	no data	no data	no data
				2006	19.4	28-Jul	20.2	23-Jul
				2007	19.3	29-Jul	20.2	28-Jul
				2008	18.2	19-Aug	19.2	16-Aug
				2009	20.4	3-Aug	20.9	1-Aug
				2010	no data	no data	no data	no data

				2011	16.6	29-Aug	16.8	29-Aug
IC6	at LNFH Headgate	6.1	350	2005	20.3	21-Aug	21.0	16-Aug
				2006	19.2	28-Jul	20.2	23-Jul
				2007	17.9	30-Jul	18.8	26-Jul
				2008	17.6	18-Aug	18.6	16-Aug
				2009	19.1	2-Aug	19.6	28-Jul
				2010	17.3	18-Aug	17.7	17-Aug
				2011	16.4	29-Aug	16.5	23-Aug
IC5	LNFH Intake	7.1	356	2011	no data	no data	no data	no data
IC3	d/s of Snow Creek	8.7	392	2005	18.1	31-Jul	18.6	29-Jul
				2006	no data	no data	no data	no data
				2007	17.2	30-Jul	18.2	26-Jul
				2008	no data	no data	no data	no data
				2009	19.5	2-Aug	20.0	28-Jul
				2010	16.4	18-Aug	16.8	17-Aug
				2011	16.0	29-Aug	16.2	25-Aug
IC2	in Snow Creek	n/a	398	2005	16.6	23-Jul	17.4	18-Jul
				2006	17.5	14-Jul	19.0	14-Jul
				2007	18.5	16-Jul	19.7	13-Jul
				2008	15.9	26-Jul	16.7	9-Jul
				2009	18.0	28-Jul	18.7	27-Jul
				2010	17.4	30-Jul	18.3	28-Jul
				2011	15.6	8-Aug	16.4	4-Aug
IC1	u/s of Snow Creek	8.8	410	2005	18.9	31-Jul	19.5	6-Aug
				2006	18.6	27-Jul	19.5	23-Jul
				2007	17.9	29-Jul	18.7	2-Aug
				2008	18.3	19-Aug	19.3	16-Aug
				2009	19.8	2-Aug	20.2	28-Jul
				2010	17.4	18-Aug	18.0	17-Aug
				2011	16.2	29-Aug	16.4	25-Aug
IC19	u/s of IPID at USGS gauge	9.3	435	2011	16.1	29-Aug	16.4	25-Aug

*date of first occurrence

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