Chamokane Creek Fish Hatcheries

Temperature and Flow Study

Summer 2016

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State of Washington

Spokane Tribal
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Temperature and Flow Study
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Executive Summary

Water temperature is a critical element of salmonid survival in Chamokane Creek. Significant volumes of relatively cool water discharge from two fish hatcheries into Chamokane Creek. The Department of Ecology (Ecology), the Department of Fish and Wildlife (WDFW), and the Spokane Tribe of Indians (STOI) jointly conducted a study to shade portions of the WDFW run Ford Fish Hatchery and quantified the temperature reduction of hatchery water discharge. Water temperatures were also monitored at the Spokane Tribal Hatchery.

During the summer of 2016, half of the circular raceways and two of the rectangular raceways at the Ford Fish Hatchery were shaded with 90 percent shade cloth. Water flowing through the shaded circular raceways was 2.0 ^{o}C cooler during the hottest days of the summer than the water flowing through the open circular raceways.

Water flowing through the shaded rectangular raceways did not warm up as it passed through the raceways. Water flowing through the open rectangular raceways warmed 0.5 ^{o}C. Shading the entire facility would decrease the temperature of the water leaving the facility by at least 2.5 ^{o}C.

Using a U.S. Forest Service water mixing model, we calculate that a shaded Ford Fish Hatchery would decrease the water temperature in Chamokane Creek proper by an additional 1.4 ^{o}C. This cooler water will improve habitat conditions for fish species in Chamokane Creek.

Benefits of additional shading at the Spokane Tribal Hatchery are not expected to be large due to the increase in flow in Chamokane Creek between it and the upstream Ford Hatchery, negating the mixing benefits of cooler water entering the mainstem of Chamokane Creek.

Mass balance mixing calculations reasonably approximate empirical data, and can be used to estimate benefits.

Background

Chamokane Creek is a stream on the eastern margin of the Spokane Indian Reservation. Water rights in portions of Chamokane Creek basin were adjudicated in *United States v. Anderson 1979*, and oversight of water rights in the basin are within the jurisdiction of the Federal Court.

Water temperature is a critical element of salmonid survival in the creek. Ecology and the Spokane Tribe of Indians (STOI) agree that mitigation of high temperatures in the creek is in our collective interest. This effort to mitigate temperature is one element of a broader strategy to mitigate impacts of small groundwater uses on flows and habitat in the creek.

This specific project, conducted with the full cooperation and partnership of the Washington Department of Fish and Wildlife (WDFW), looks at temperature impacts attributable to the Ford Hatchery. It is designed to assess the water temperature impacts of the hatchery, and evaluate the mitigation potential of shading the open elements (raceways) at WDFW's hatchery operation at Ford, WA.

Synoptic temperature (water and air), discharge, water depth, and regional weather data were collected in the Chamokane Creek valley between the town of Ford and the USGS gage. The project location is illustrated on Figure 1.

Study goals

- Quantify temperature reduction due to shading of raceways within the Ford Hatchery.
- Assess the temperature and flow impact of Ford Hatchery operations on Chamokane Creek.
- Assess the temperature and flow impact of the Spokane Tribal Hatchery on Chamokane Creek.
- Generate data useful to assess and predict temperature benefits from hatchery shading on Chamokane Creek flows downstream from the hatchery.

Objectives

- Collect time-synchronized temperature data from stations established within the Ford Hatchery. Evaluate the data for usability to evaluate variation in raceway temperature between treated (shaded) and untreated (unshaded) raceways.

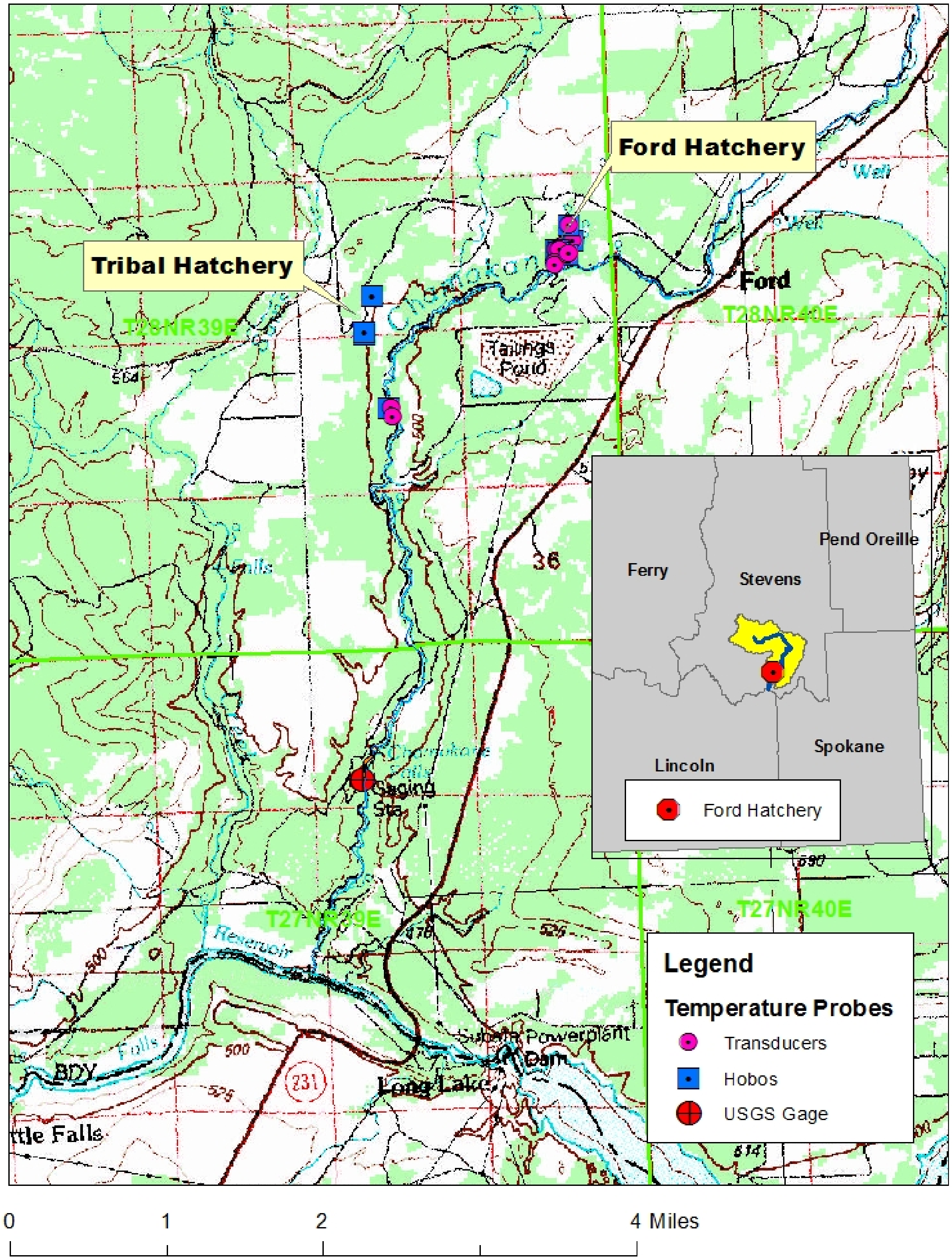

Figure 1. Topographic Map of Project Area

- Compare raceway data with ambient conditions.
- Collect similar datasets from the Spokane Tribal Hatchery.
- Collect temperature and flow data from Chamokane Creek in the reach between Ford and the Chamokane Gaging Station to determine contributions from the hatcheries.
- Assess the temperature and flow data to determine benefits of shading on Chamokane Creek summer temperatures.

Methodology

Data collection

Thirty-one temperature recording devices were deployed in the field over two site visits in the spring of 2016.

On May 16, 2016, 25 devices were installed:
- At the Ford Fish Hatchery;
- In the small tributary creek receiving the Ford Hatchery effluent discharge; and
- In Chamokane Creek above and below the confluence of this tributary creek and Chamokane Creek. (See Figure 2.)

On June 8, 2016, six devices were installed:
- At the Spokane Tribal Hatchery;
- In the tributary creek into which the Spokane Tribal Hatchery effluent discharges; and
- In Chamokane Creek above and below the confluence of the Spokane Tribal Hatchery tributary creek and Chamokane Creek. (See Figure 3.)

All loggers collected synoptic measurements every 15 minutes, beginning at the top of the hour. Temperature loggers deployed at the fish hatcheries were hung on string or rope (with weights added) and tied off to secure the loggers placement at each site. Loggers were weighted down to keep the loggers at the bottom of the water feature they were measuring. We determined GPS field locations of the deployed loggers with a Garmin GPSmap 78s. (See Table 1.)

Graduated staff gages were attached to fence posts driven into the streambed at the stream gaging sites. This allowed us to correlate the miscellaneous streamflow measurements to the continuous head data collected by the pressure transducers secured to those fence posts.

Thirty of the 31 deployed loggers were recovered at the end of the project. One logger, last downloaded on July 7, was gone on our next field visit.

The STOI purchased a quantity of 90 percent shade cloth from International Greenhouse Company to cover a portion of the concrete raceways that serve as fish rearing pens at the Ford Hatchery. On June 8, 2016, we attached the fabric with zip ties to the top of the existing aluminum frame structure over the six eastern circular raceways. The western six circular raceways were left uncovered. We placed fabric over rectangular raceways 3 & 4 in the same manner, covering the sidewalls, top, and southern end of the raceways. The other eight rectangular raceways were left unshaded. (See Figure 4 and Figure 5 for pictures of the deployed fabric. Figure 6 shows the distribution of the shading material at the Ford Hatchery during the summer of 2016.)

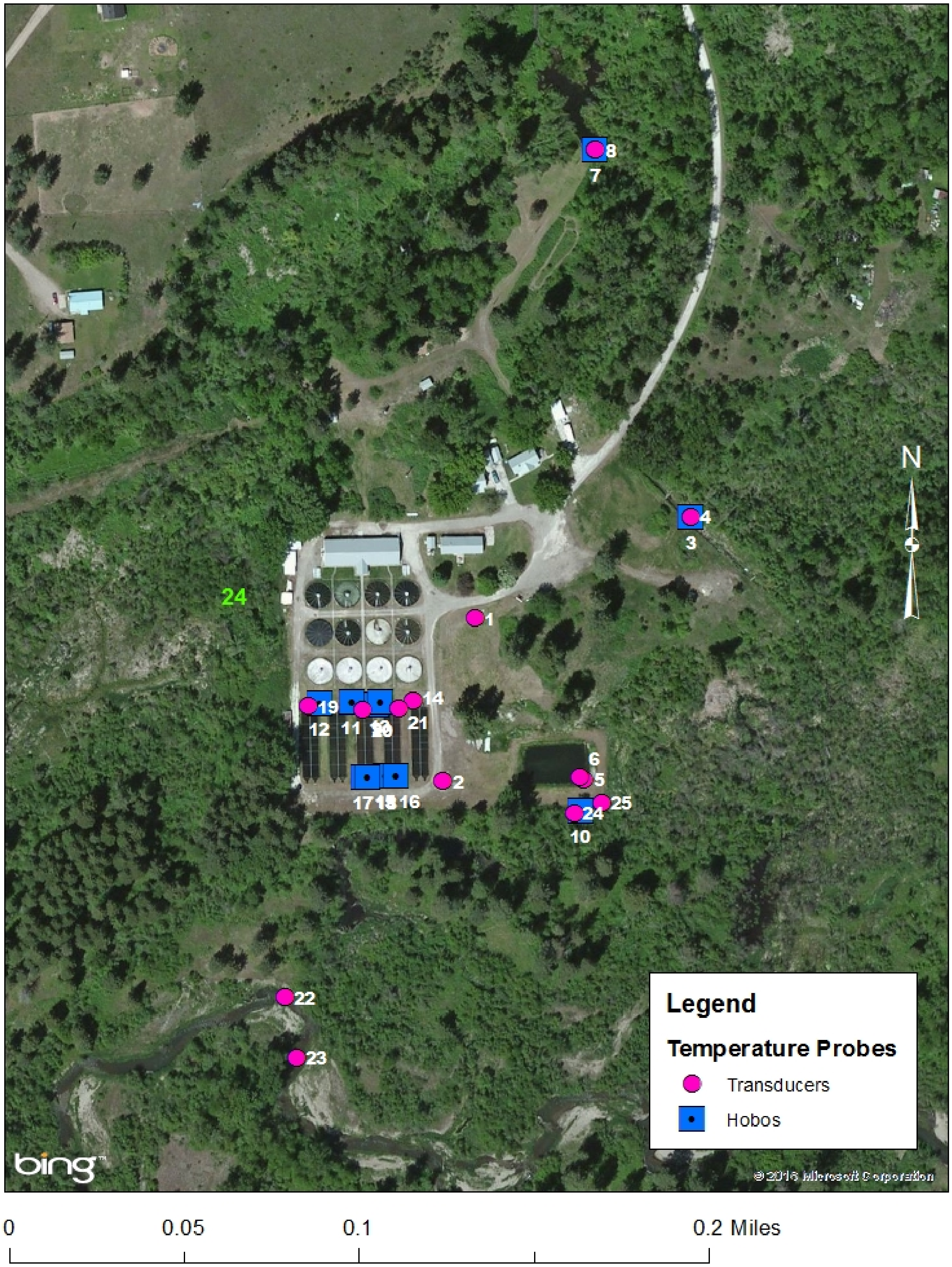

Figure 2. Temperature logger locations at Ford Hatchery

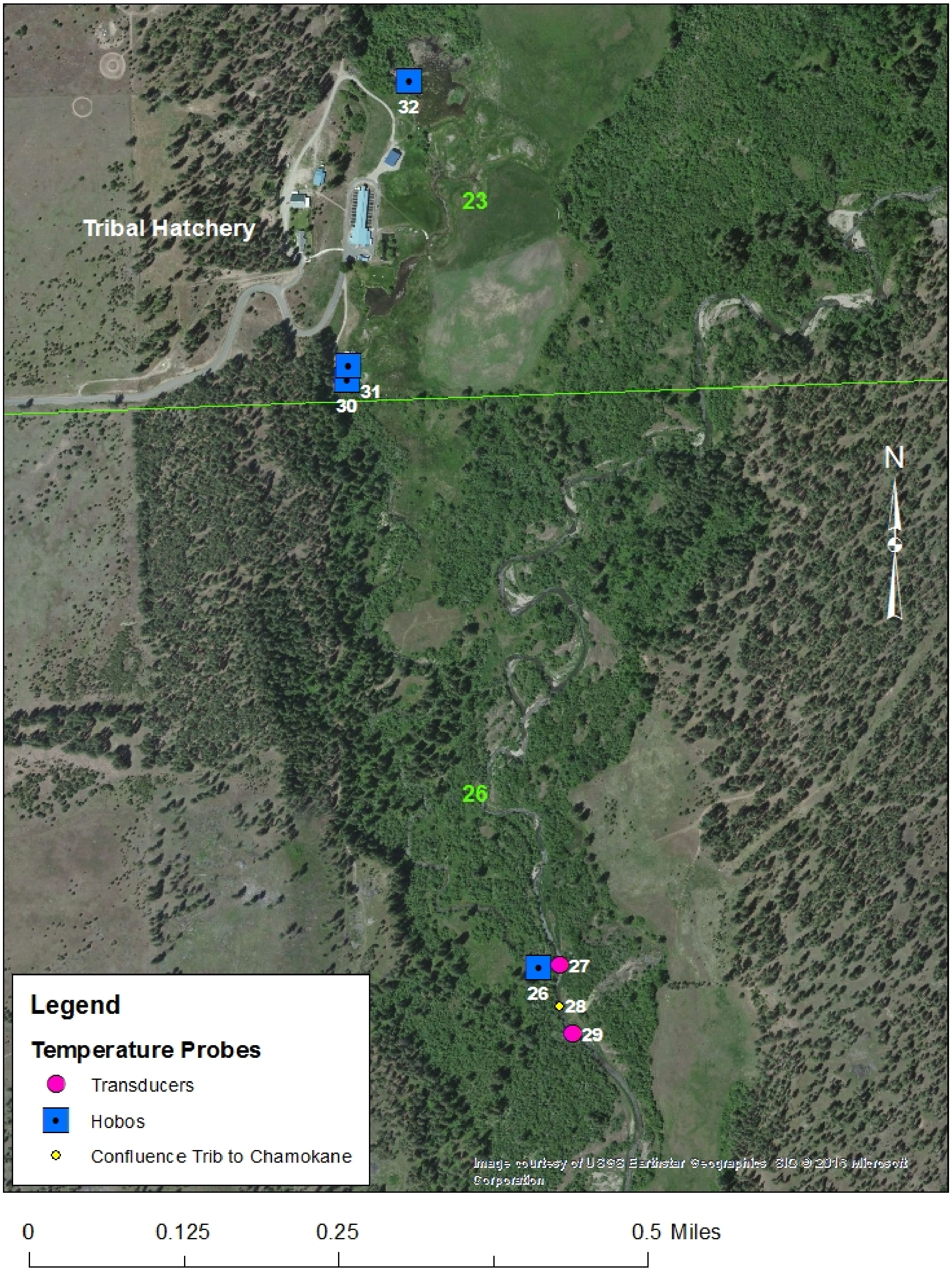

Figure 3. Temperature logger locations at the Spokane Tribal Hatchery

Table 1. Map Index of temperature probes deployed in 2016 along with serial numbers and locational information. (Datum NAD83 Harn)

MapID	Serial Number	Latitude	Longitude	Type	Location
1	D0228	47.91184	-117.82841	P	Shed Barometer
2	S71437	47.91117	-117.82864	P	Manhole
3	H10854920	47.91223	-117.82706	H	Mary's Ditch Intake
4	G3326	47.91223	-117.82706	P	Mary's Ditch intake
5	D8056	47.91116	-117.82777	P	Below Wier-Abatement Pond LOST
6	B4061	47.91117	-117.82780	P	Above Wier-Abatement Pond
7	H10854919	47.91376	-117.82757	H	Main Intake
8	C7184	47.91376	-117.82757	P	Main Intake
9	H10854921	47.91150	-117.82903	H	Collection Trench near A4 Floating at Water Surface
10	H10854922	47.91103	-117.82780	H	Effluent discharge to outlet stream
11	H10587799	47.91151	-117.82918	H	Outfall Box D3
12	H10587791	47.91151	-117.82938	H	Outfall Box D4
13	H10587800	47.91151	-117.82901	H	Outfall Box D2
14	D8036	47.91151	-117.82881	P	Outfall Box D1
15	H10377266	47.91120	-117.82899	H	Downflow end Raceway 4
16	H10587792	47.91120	-117.82893	H	Downflow end Raceway 3
17	H10339541	47.91120	-117.82913	H	Downflow end Raceway 6
18	H10377329	47.91120	-117.82910	H	Downflow end Raceway 5
19	D8045	47.91150	-117.82945	P	Lower intake discharge to A4
20	S71423	47.91148	-117.82912	P	intake box Raceway 6/5
21	S71445	47.91148	-117.82890	P	intake box Raceway 3/4
22	D8043	47.91030	-117.82966	P	Chamokane Ck. Downstream from outlet stream confluence
23	A4602	47.91005	-117.82960	P	Chamokane Ck. Upstream from outlet stream confluence
24	G3373	47.91102	-117.82784	P	Outlet stream below hatchery outfall
25	D8037	47.91106	-117.82767	P	Outlet stream above hatchery outfall
26	H10937952	47.89733	-117.85316	H	Tribal Outfall
27	D6562	47.89735	-117.85280	P	Chamokane Ck Above Tribal Hatchery discharge
28	XX	47.89687	-117.85281		Chamokane Ck at confluence with Tribal Hatchery trib
29	C7187	47.89654	-117.85261	P	Chamokane Ck Below Tribal Hatchery discharge
30	H10937951	47.90427	-117.85614	H	Tribal Hatchery discharge below pumphouse
31	H10937943	47.90444	-117.85610	H	Bottom of wetland at Tribal Hatchery
32	H10937959	47.90774	-117.85489	H	Top of Tribal Hatchery wetland

Type:	P = Pressure Transducer; H = Hobo Probe
MapID 1-25	Ford Hatchery
MapID 26-32	Tribal Hatchery

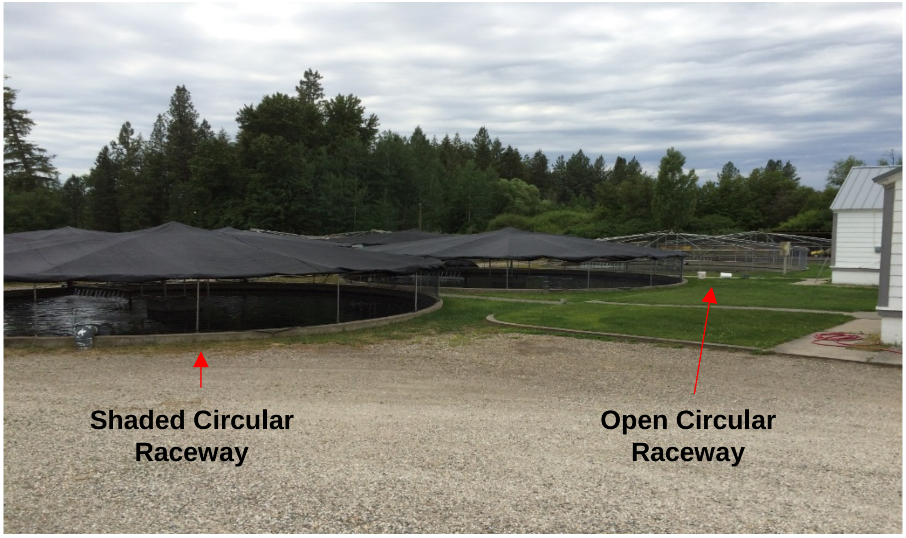

Figure 4. Circular raceways (two shaded in foreground, two unshaded in the distance)

Figure 5. Rectangular raceways 3 and 4 under the black fabric. Unshaded raceways 5 and 6 on the right.

Water flows through the Ford Hatchery from north to south and exits to the southeast corner of the facility (Figure 6). Water flows into the northernmost circular raceway in each column. It discharges from the top circular raceway into the second raceway to the south. From the second raceway it flows into the third circular raceway. Water exits through the Outfall Boxes (D1 through D4) and into the collection trough in the middle of the facility. From there, it flows into individual rectangular raceways (numbered 1 through 10). Water discharging from each rectangular raceway is collected in a buried pipe (measureable at MapID 2, the Outfall Manhole)

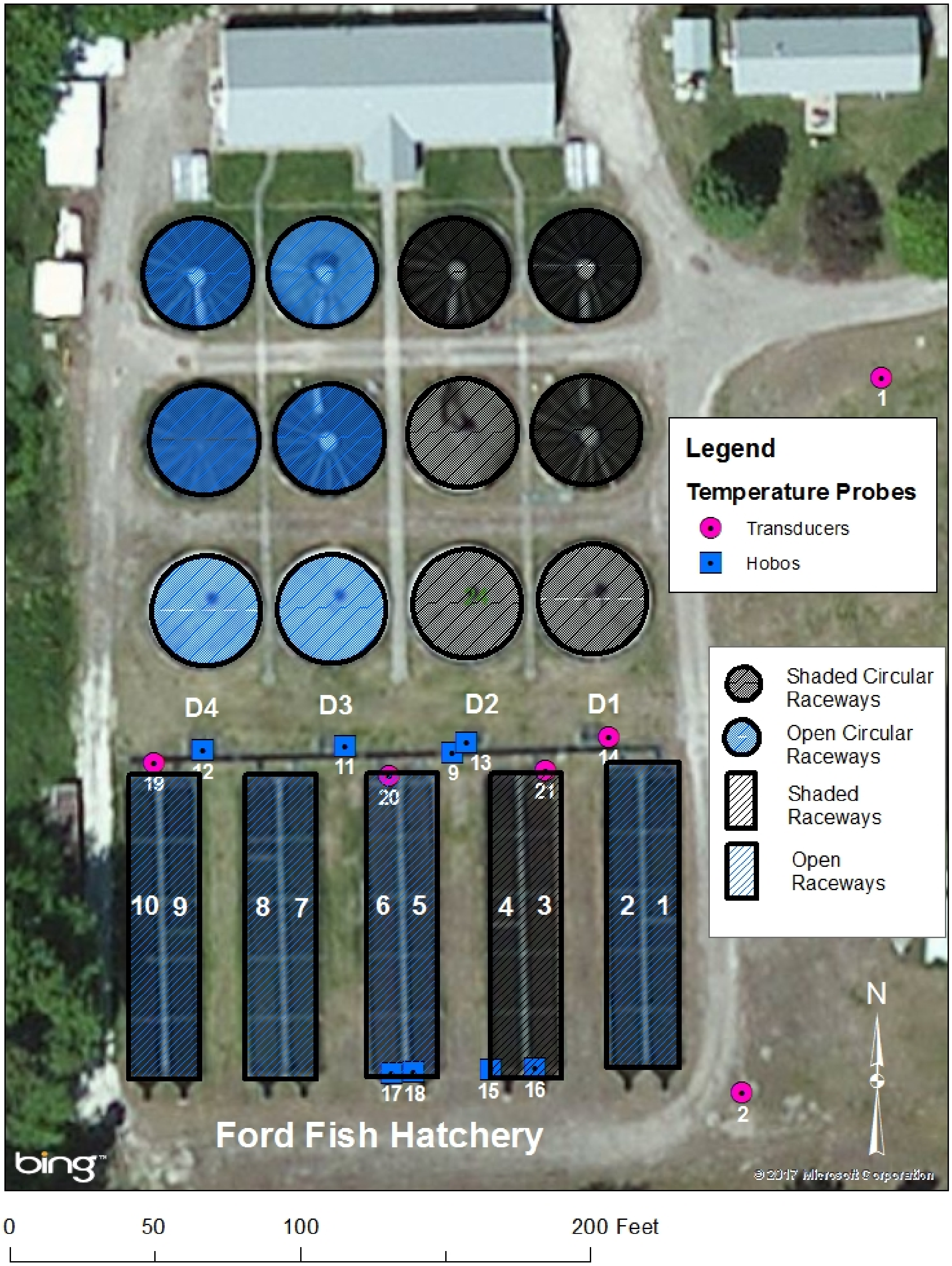

Figure 6. Orthophoto of Ford Hatchery showing shade cloth distribution.

and flows east to discharge to the tributary creek which begins south of the abatement pond. See Figure 2.

Site visits were made on May 27, June 29, July 7, and September 27, 2016. Deployed loggers were downloaded on each site visit. STOI field staff collected streamflow discharge measurements at the tributary and mainstem Chamokane Creek sites on June 13, August 2, and September 27, 2016. Staff gage readings were recorded on each site visit.

Instrument calibration

We deployed 31 dataloggers, as described in Table 2, below. Ecology's Eastern Regional Office supplied the 16 Schlumberger Divers®, which gathered both temperature and water level data. The STOI and WDFW provided the additional 15 Onset Hobo Pro® and Onset Hobo Pro 2® units, which gathered only temperature data. All 31 loggers were factory calibrated.

Table 2. Loggers used for the study

Quantity	Meter	Measurement(s)	Accuracy
16	Schlumberger Diver®	Temperature and Water Level	+/- 0.1 ^{o}C
15	Onset Hobo Pro® or Onset Hobo Pro 2®	Temperature	+/- 0.2 ^{o}C

Each set of loggers were tested prior to deployment by placing them together into a 5 gallon bucket filled with water and simultaneously record the water temperature over time. Readings were then compared between loggers. The Divers were tested for a month prior to deployment. (See Figure 7.) The Hobos were tested for about two days prior to deployment. (See Figure 8.)

After the loggers were pulled, the Divers were retested by placing them all in a bucket of water. (See Figure 9.) The loggers (both Divers and Hobos) displayed very similar temperature measurements for the test plots.

To test between-instrument repeatability (precision), a Diver and a Hobo logger were deployed together at the Main Intake and Mary's Ditch sites. The results demonstrate very close temperature agreement. (See Figure 10.)

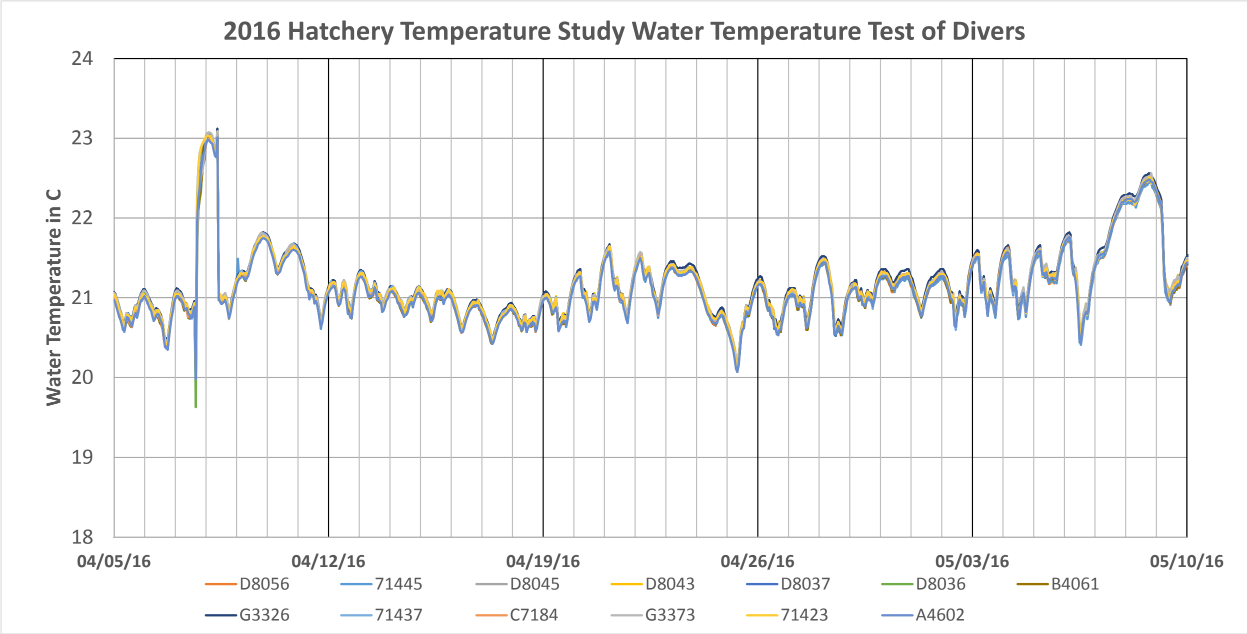

Figure 7. Diver transducer data during pre-deployment testing

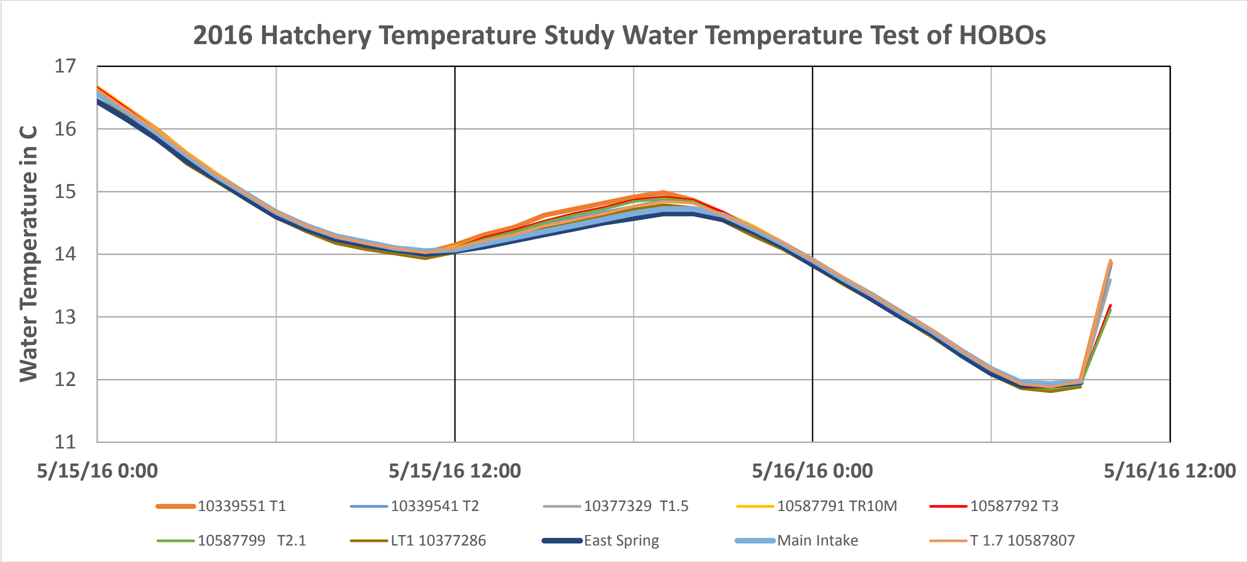

Figure 8. Hobo temperature logger data during pre-deployment testing

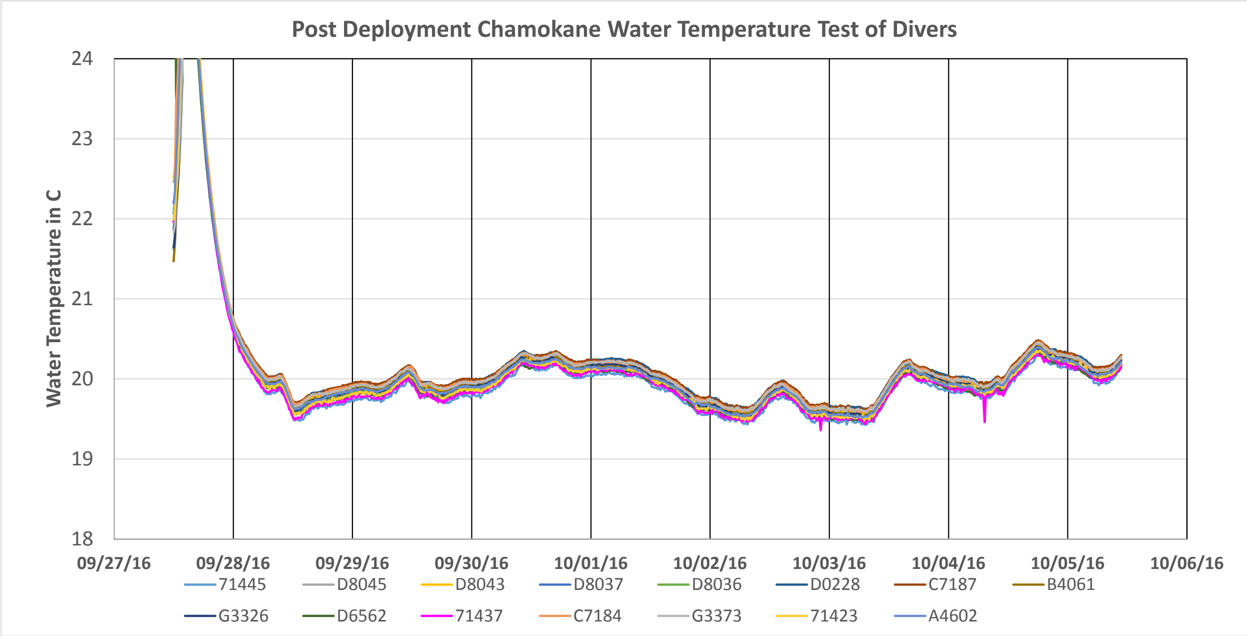

Figure 9. Driver transducer data during post-deployment test

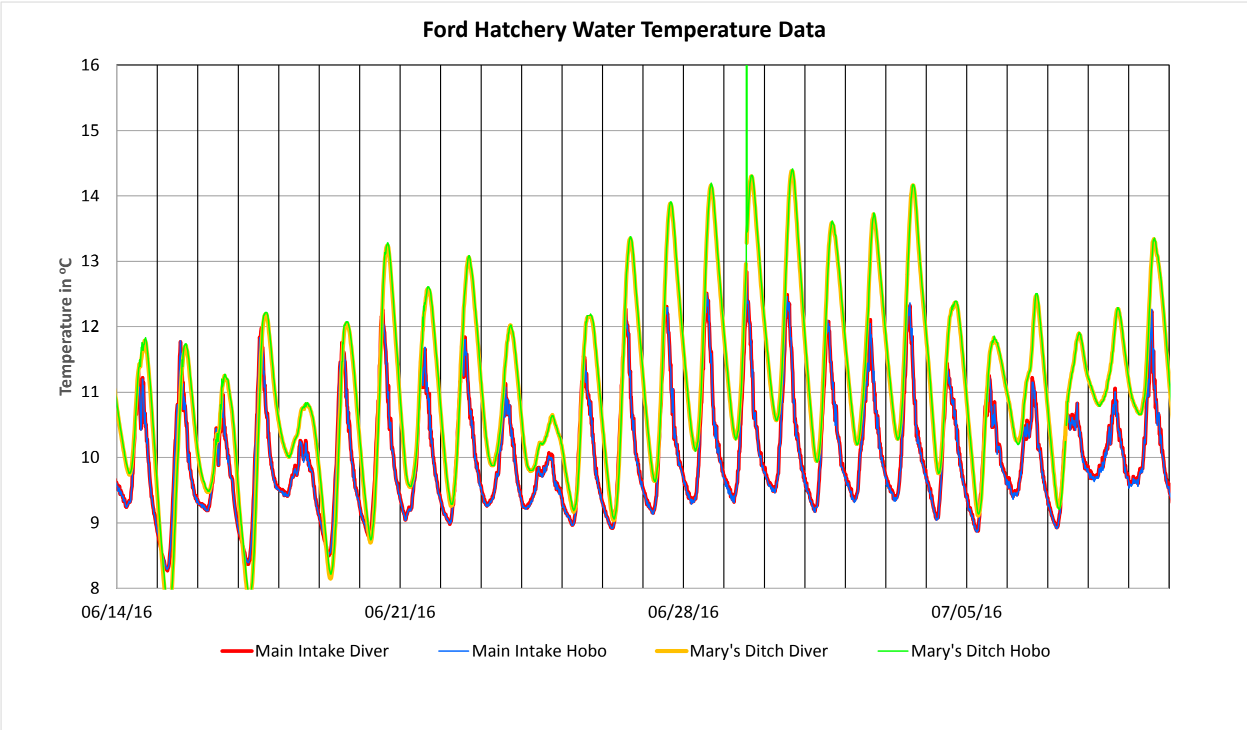

Figure 10. Comparison of Diver and Hobo temperature records at two sites at the Ford Hatchery

Data Analysis and Results

Head data was barometrically corrected for all Diver pressure transducer data utilizing the Diver-Office version 2012.1 Schlumberger Water Services software that is used to download the loggers. Diver temperature and Hobo Probe temperature data don't require any correction. All of the processed head data and raw temperature data was input and arranged in an excel spreadsheet for analysis.[1]

Over the course of any given year, WDFW staff at the Ford Hatchery use different portions of the hatchery infrastructure to rear fish depending on the species present and life stage. During the spring, not all the raceways at the facility are utilized. Some are empty. As summer approaches, staff ultimately fill and use all raceways to manage their stock. Analysis of the data shows that the Ford Hatchery raceways were all full of water and operating in a comparable manner starting June 13, 2016. Operation of the raceways was consistently maintained throughout the remainder of the study period. The period of record for data analysis for this project is June 14th through September 26, 2016.

Air temperature and barometric pressure data (S/N D0228) were collected at the Ford Hatchery (MapID 1). This logger was installed inside the garage that was constructed at the Ford Hatchery this spring. When it was installed, there was no garage door on the structure. In late June, a garage door was installed. With the addition of the door, the air inside the garage stayed warmer than the ambient outside air during most evenings. (See Figure 11.) Consequently, air temperature and solar radiation data collected at an AgriMet Weather Station located within the watershed several miles south of Springdale was incorporated into the dataset. The garage datalogger supplied local barometric data over the entire period of record.

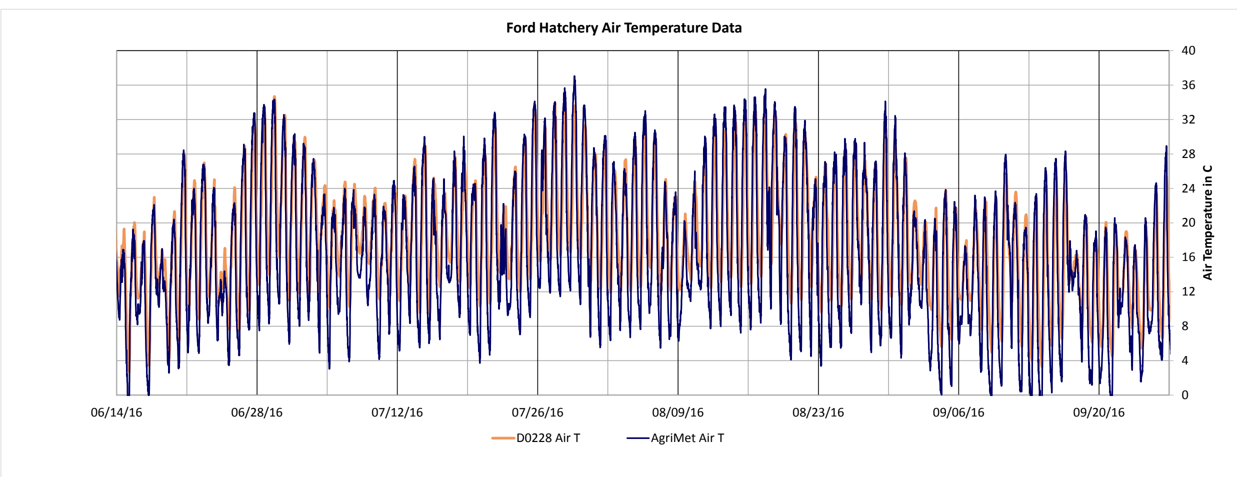

Figure 11. Air temperature records for the Diver logger at the Ford Hatchery (D0228) and at the AgriMet station in near Springdale.

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[1] Anyone interested in larger versions of the figures in this report or details of the data sets they represent should contact John Covert at John.Covert@ecy.wa.gov.

Impacts of solar radiation on water and air temperature

Comparing the solar radiation curve with the air temperature curve demonstrates the familiar lag time between solar radiation peaking at solar noon (13:00 PDT) and daily maximum air temperatures which occur several hours later. (See Figure 12.) This results from the changing relationship between incoming solar radiation and outgoing Earth radiation. It is necessary to consider that thermal energy is radiating continually from the surface of the earth at long wavelengths, while incoming solar (relatively short wave) radiation arrives only when the sun is above the horizon. With the sun below the horizon (night), outgoing radiation allows the surface to cool, and the temperature drops. After sunrise, incoming solar radiation counteracts this loss of heat, but only after a time lag.

The minimum temperature occurs when there is a balance between outgoing radiation (cooling) and incoming radiation (warming). As the sun rides higher in the sky, increasing amounts of short-wave radiation are available to heat the ground, and therefore available to heat the overlying air. Although outgoing, land-based radiation is also increasing, solar heating is dominant.

The temperature rises until several hours past noon (and past the noon solar radiation maximum), when heat loss due to outgoing radiation balances the now declining incoming solar radiation. This always occurs sometime after midday and changes over the course of the year, occurring earlier in the afternoon during the winter and later in the afternoon during the summer.

Comparing the water temperature daily maximums for a number of sites within the project area, two different patterns emerge. The surface water bodies near the hatcheries that are dominated by groundwater discharge show temperature patterns that mimic the solar radiation curve with a peak temperature at the solar noon (13:00 PDT). Surface water bodies that are not as dominated by groundwater discharge have temperature patterns that mimic the air temperature warming lag times with the daily maximum occurring well after midday. (See Figure 13.)

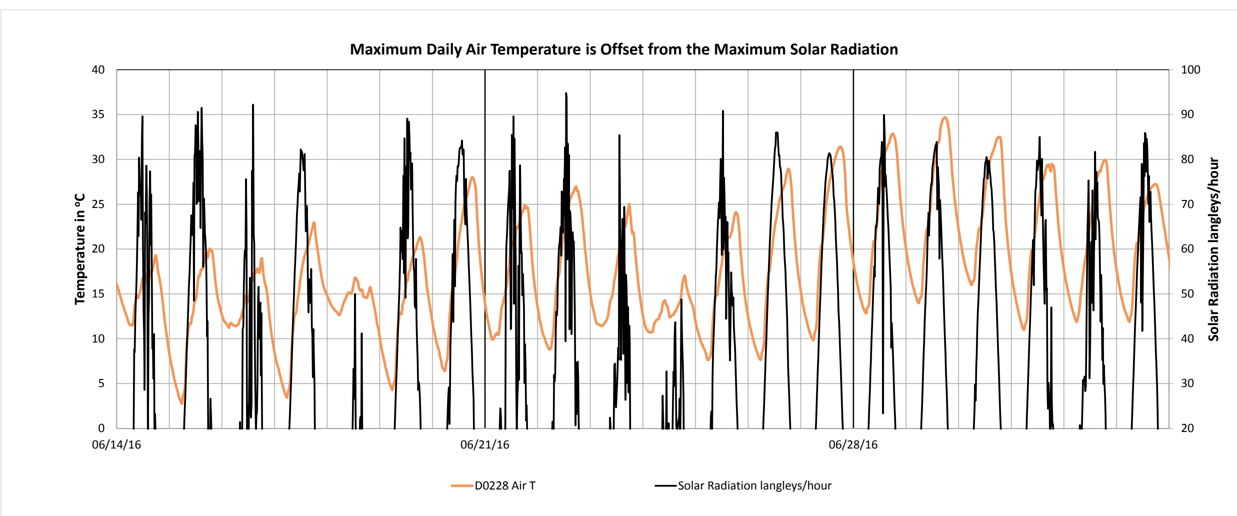

Figure 12. Solar radiation versus air temperature data

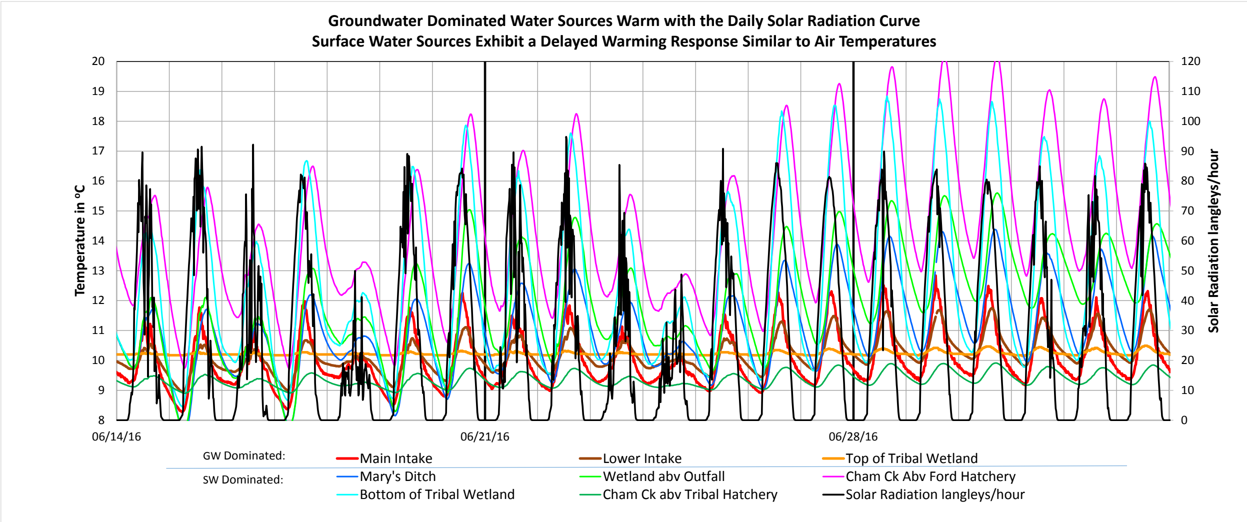

Figure 13. Water temperatures of groundwater dominate sources and surface water dominated sources compared to solar radiation

Streamflow discharge calculations

Rating curves were developed for six sites deployed in stream channels (shown in Figure 2 and Figure 3, on pages 5 and 6):

- Two in Chamokane Creek at the Ford Hatchery, above and below the confluence with the tributary stream that brings the hatchery discharge to the mainstem of Chamokane Creek (MapIDs 23 and 22 respectively);
- One in the wetland discharge channel adjacent to the Ford Hatchery Abatement Pond (MapID 25);
- One in the tributary creek below the outfall of the Ford Hatchery (MapID 24); and
- Two in Chamokane Creek below the Spokane Tribal Hatchery above and below the confluence with the tributary stream that brings the hatchery discharge to the mainstem of Chamokane Creek (MapIDs 27 and 29 respectively).

We collected three miscellaneous discharge measurements at each site along with their respective staff gage values. Flows did not vary much over the duration of the study as it was conducted during the low flow summer months. This makes it difficult to develop a robust rating curve under the best of circumstances. Rating curves were generally noisy and displayed poor coefficients of determination (R^2 values) which can make the conversions from stage to flow unreliable.

At Chamokane Creek near the Ford Hatchery, a beaver began constructing a dam during the month of June that negatively affected the stage/discharge relationships producing rating curves that were not representative of flow in the creek. Water depth at the sites increased without an increase in flow (as a result of the beaver dam construction activity). (See Figure 14.) This resulted in an unusable rating curve between stage and flow. (See Figure 15.)

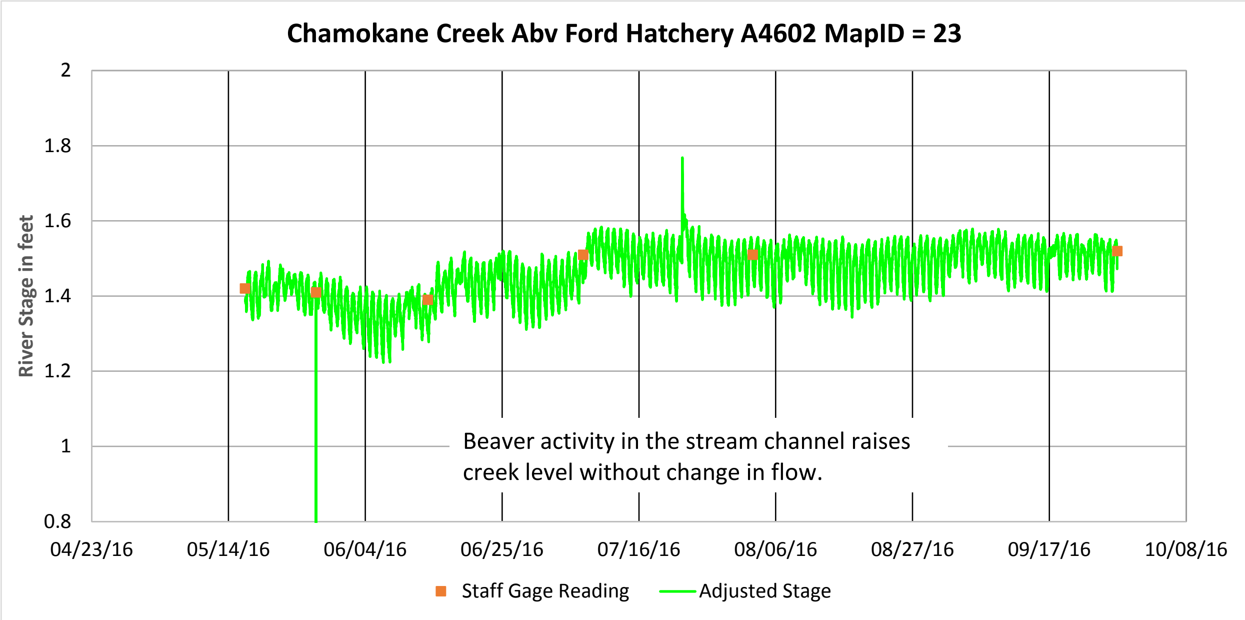

Figure 14. Chamokane Creek stage data at MapID 23

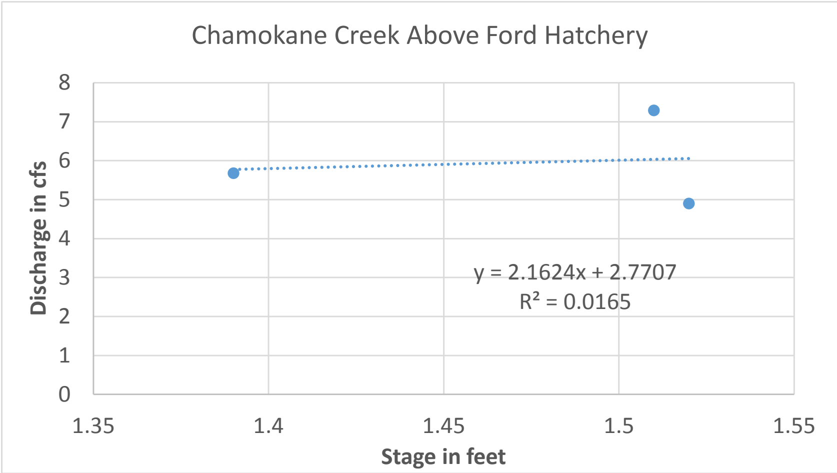

Figure 15. Rating Curve for Chamokane Creek at MapID 23

Real-time flow data collected by the USGS at their stream gaging station (12433200) below Chamokane Falls was incorporated into the dataset to allow a comparison between flow measurements collected both above (MapID 23) and below (MapID 22) the Ford Hatchery and downstream at the USGS gage. The beaver activity in the creek near the hatchery makes the streamflow calculations unreliable at these sites. (See Figure 16.) Water temperature data collected in Chamokane Creek near the Ford Hatchery were still useable as there are no corrections applied to the temperature readings that were disturbed by the beaver activity and a poor rating curve is not relevant to water temperature.

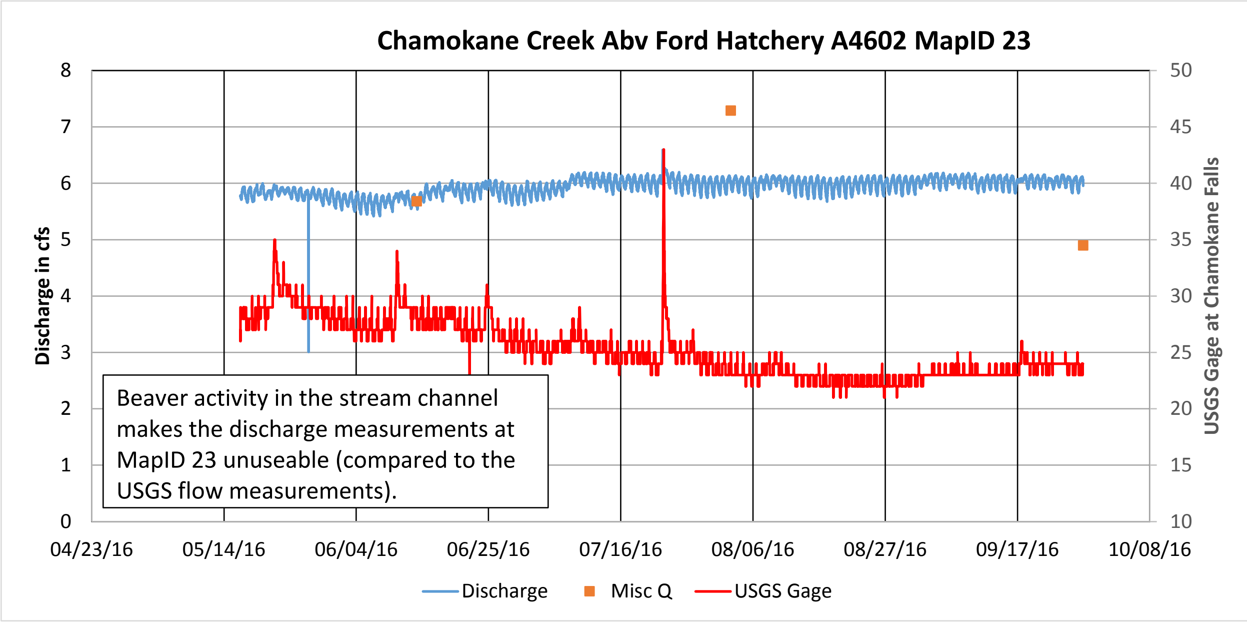

Figure 16. Streamflow data for Chamokane Creek at MapID 23 and at USGS gage 12433200

Discharge coming out of the Ford Hatchery (MapID 24, shown in Figure 2) maintained a very steady flow in the tributary creek that flows from the hatchery towards Chamokane Creek. (See Figure 17.) Flow in this tributary is comprised mostly of discharge coming out of the hatchery and a small volume coming out of the wetlands adjacent to the hatchery (MapID 25, Shown in Figure 2). Discharge coming out of the wetland was measured at less than 0.15 cfs for most of the summer.

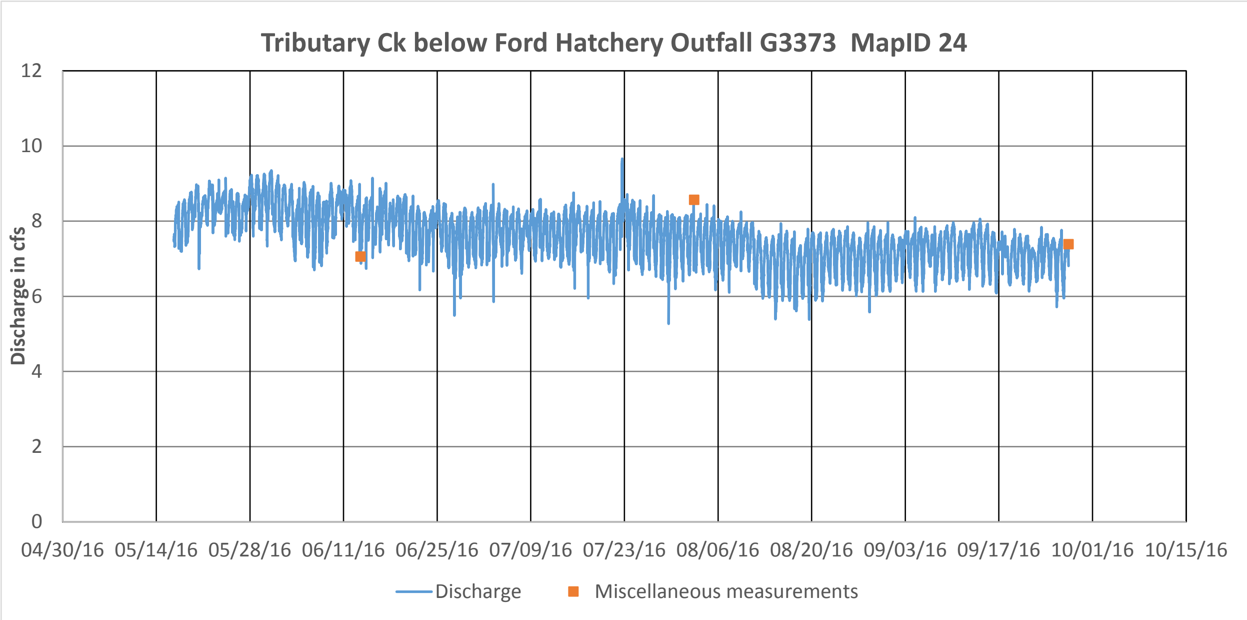

Figure 17. Streamflow data for the tributary receiving outfall from Ford Hatchery

Streamflow data collected at the site above the Spokane Tribal Hatchery (MapID 27, shown in Figure 3) proved to be useful. The rating curve for this site allowed us to calculate discharge data that mimicked the data collected at the USGS gage downstream. (See Figure 18.)

The site on Chamokane Creek below the Spokane Tribal Hatchery inflow (MapID 28, shown in Figure 3) had a very poor rating curve with an R^2 value 0.05 making the rating curve useless. Water temperature data collected in Chamokane Creek near the Spokane Tribal Hatchery were still useable as there are no corrections required for the temperature readings and a poor rating curve is not relevant to temperature data.

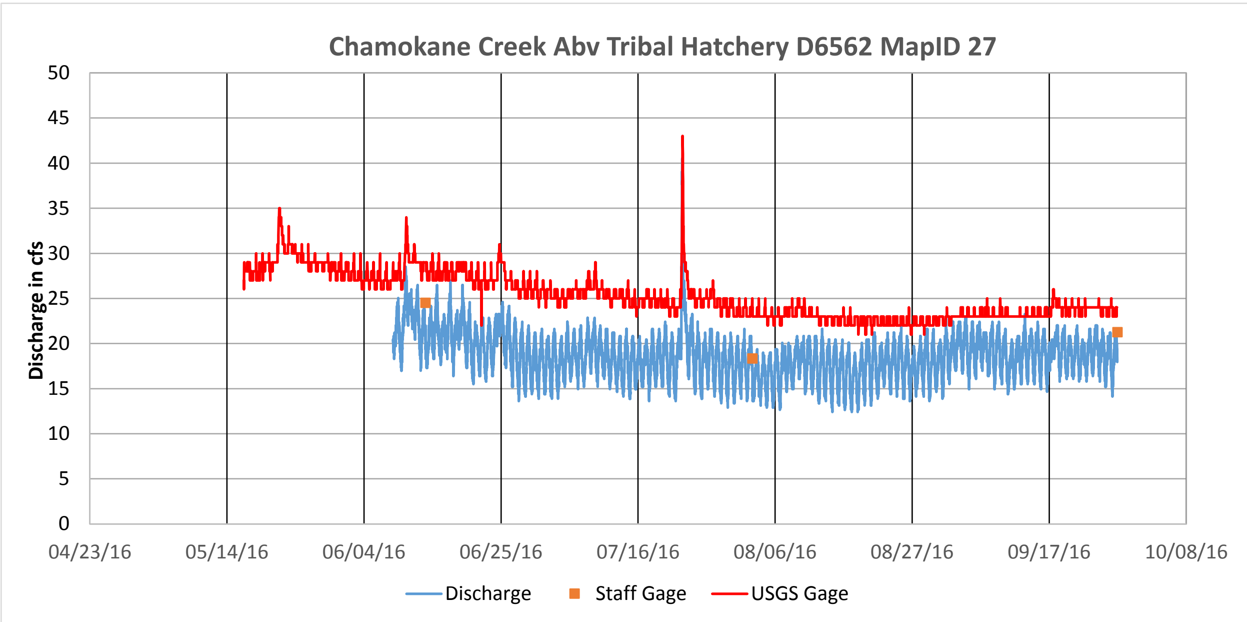

Figure 18. Streamflow data for Chamokane Creek above the Spokane Tribal Hatchery and for USGS Gage 12433200

Water temperature impacts from the Ford Hatchery discharge

Water temperatures in Chamokane Creek were dramatically lowered by the inflow of Ford Hatchery discharge water during the summer of 2016. Water temperatures in Chamokane Creek above the confluence with the Ford Hatchery (MapID 23, see Figure 2) were significantly warmer than at the nearby downstream location below the confluence of the Ford Hatchery tributary creek that brings hatchery outflow to Chamokane Creek (MapID 22, see Figure 2).

During the hottest days of the summer, the hatchery discharge water cooled the water in Chamokane Creek by four to five degrees Celsius. (See Figure 19.) A smaller volume (5.6 cfs) of warm water (20 ^{o}C) is flowing down Chamokane Creek above the Ford Hatchery. It mixes with a larger volume (7.1 cfs) of colder water (~14 ^{o}C) coming out of the Ford Hatchery, thereby reducing the Chamokane Creek water temperature (15.5 ^{o}C) below the hatchery by about 4.5 ^{o}C. (See Figure 20.)

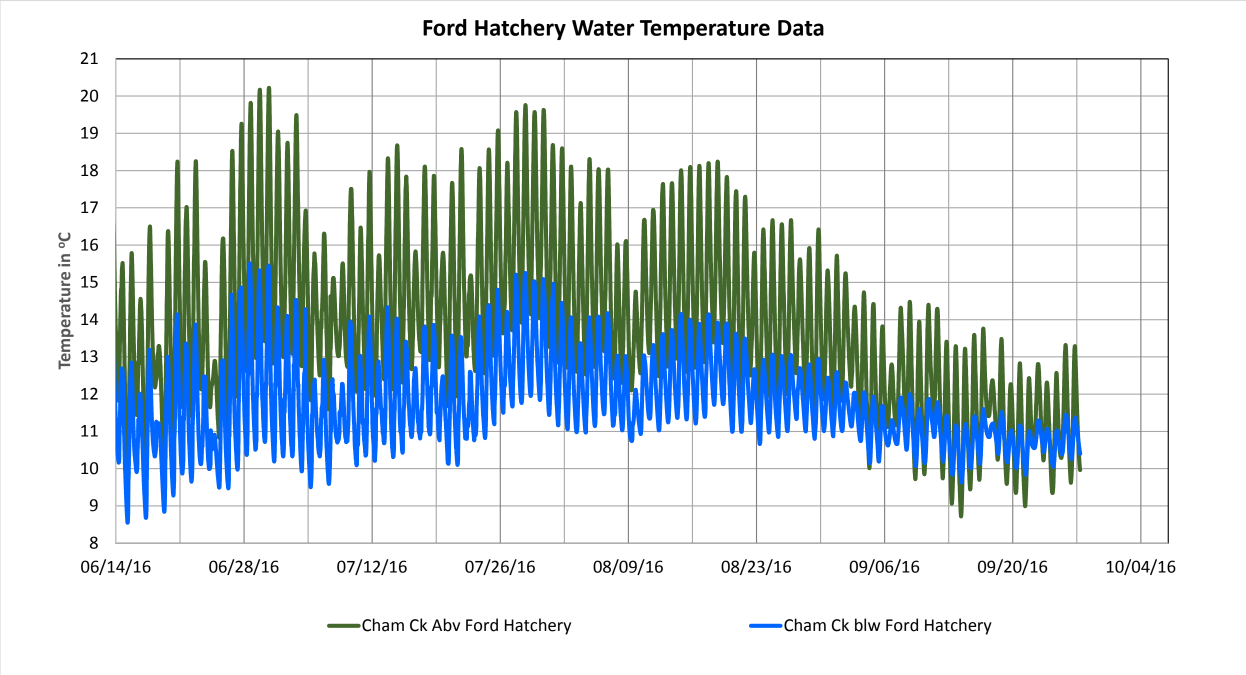

Figure 19. Chamokane Creek water temperatures above and below Ford Hatchery contribution

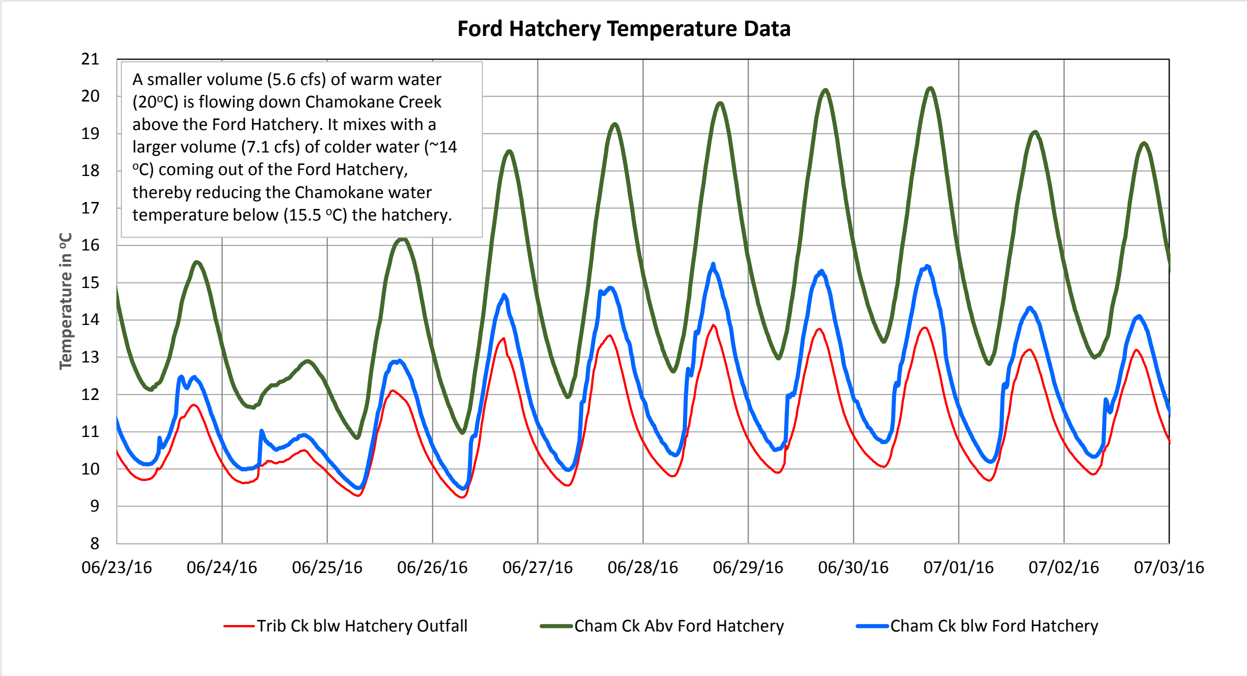

Figure 20. Water temperatures of the tributary creek below the Ford Hatchery outfall, and those in Chamokane Creek above and below confluence with the tributary shows the outfall impacts Chamokane Creek temperatures

Impacts on Water Temperature from Shading Portions of the Ford Hatchery

Shading components of the Ford Hatchery raceways had a measureable and significant impact on reducing the temperature of water flowing through the hatchery infrastructure.

The six eastern circular raceways (see Figure 6 on page 9) were shaded with 90 percent shade cloth. Water temperatures were measured in the four outfall boxes located at the southern end of the four rows of circular raceways. The shaded raceways had water temperatures that were 1 to 2 ºC cooler than the open, unshaded circular raceways. (See Figure 21.)

Diurnal fluctuations in water temperature coming through the circular raceways ranged over 5 ºC. The maximum water temperature recorded each day from the circular raceways is presented in Figure 22. The unshaded, open raceways (D3 and D4) displayed similar maximum daily temperatures, which were warmer than the maximum daily temperatures of the two covered, shaded circular raceways (D1 and D2).

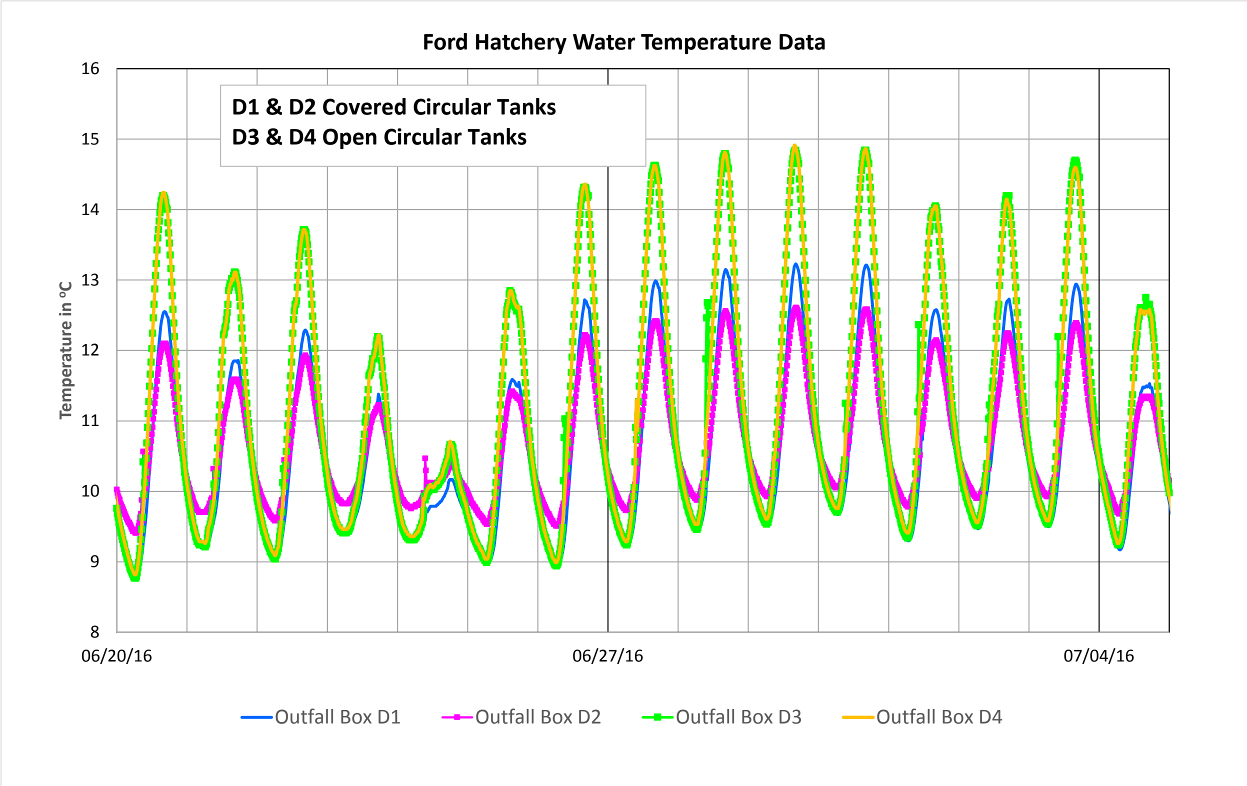

Figure 21. Circular raceway water temperatures for shaded (D1, D2) and unshaded (D3, D4) outfall boxes

Averaging the two shaded and two unshaded maximum daily temperature profiles respectively, and computing the daily difference between the shaded and unshaded raceways results are presented in Figure 23. On the hottest days of the summer, during the hottest part of the afternoon, the shaded circular raceways were 2 ^{o}C cooler than the unshaded circular raceways.

Water exiting the circular raceways mixes in a collection trough in the middle of the facility and then flows into the rectangular raceways to the south. Raceways 3 and 4 were shaded. The other eight raceways remained unshaded (see Figure 6). Water flowing through the unshaded, rectangular raceways was 1 to 2 ^{o}C warmer than the water flowing through the shaded, rectangular raceways. (See Figure 24.) Diurnal fluctuations in water temperature coming from all rectangular raceways ranged over 4 ^{o}C.

Water flowing down the shaded, Rectangular Raceway 3 did not warm as it traversed through the raceway. Water flowing down the unshaded, rectangular Raceway 6 warmed by about 0.5 ^{o}C between its inflow and outflow point. (See Figure 25.)

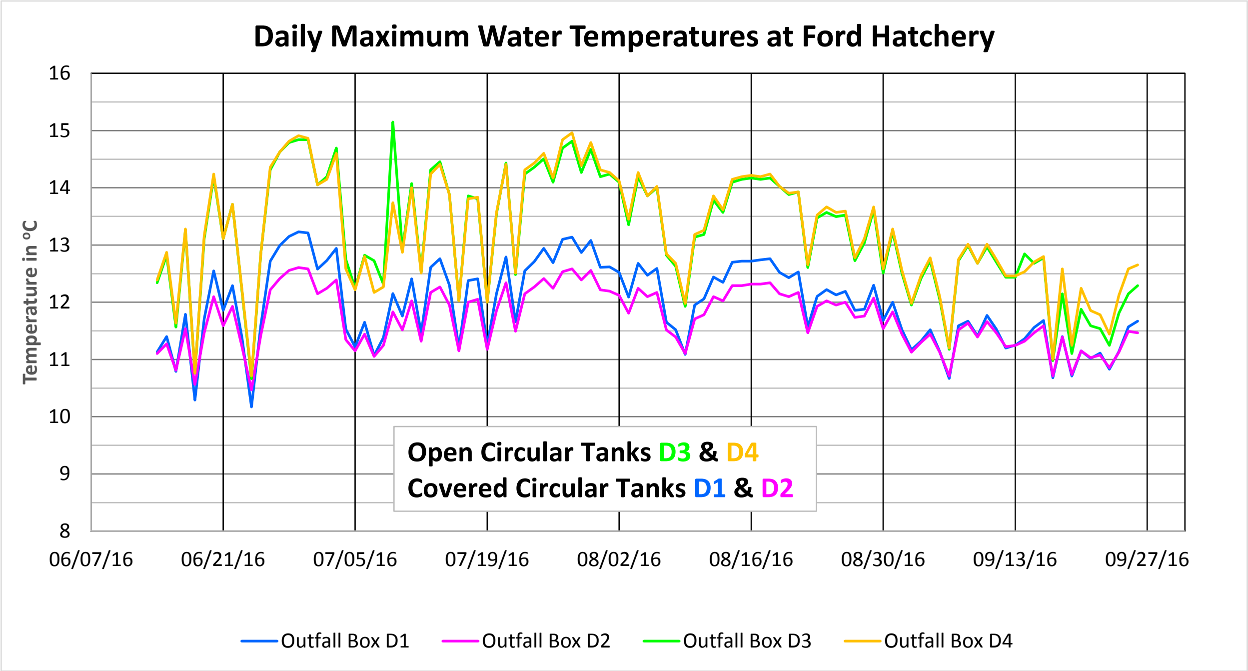

Figure 22. Maximum daily water temperatures for the circular raceways

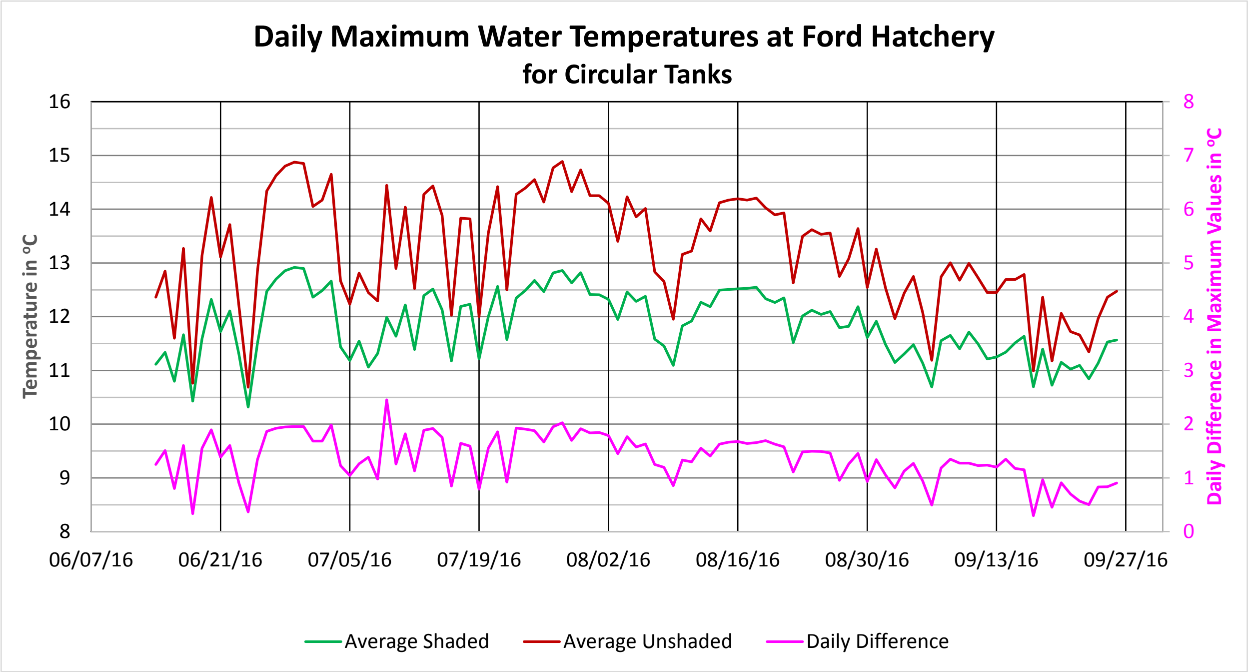

Figure 23. Averaged maximum daily temperatures for the shaded and unshaded circular raceways

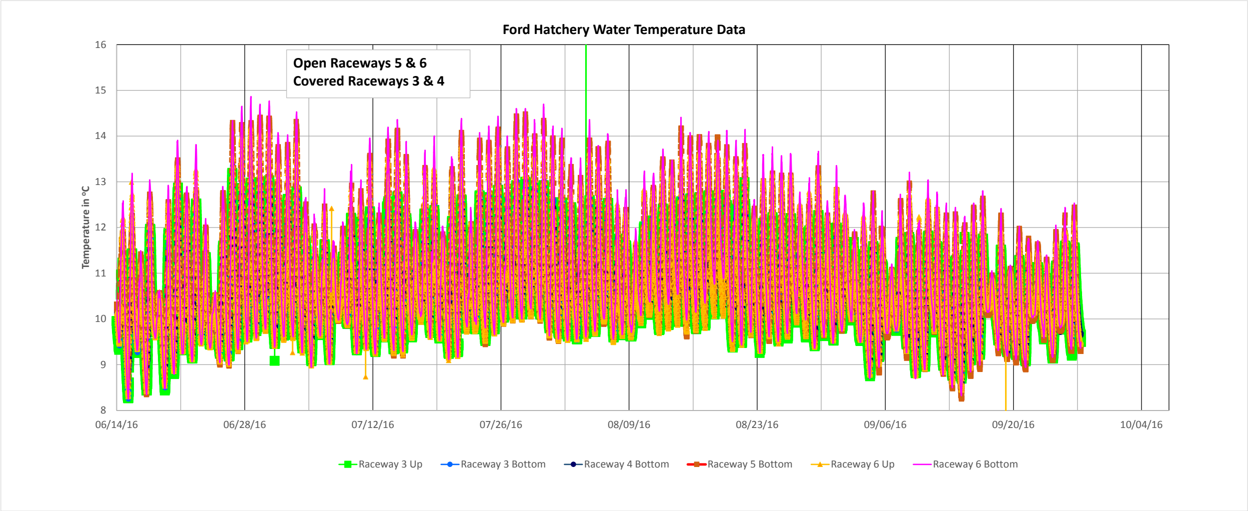

Figure 24. Ford Hatchery rectangular raceway water temperatures

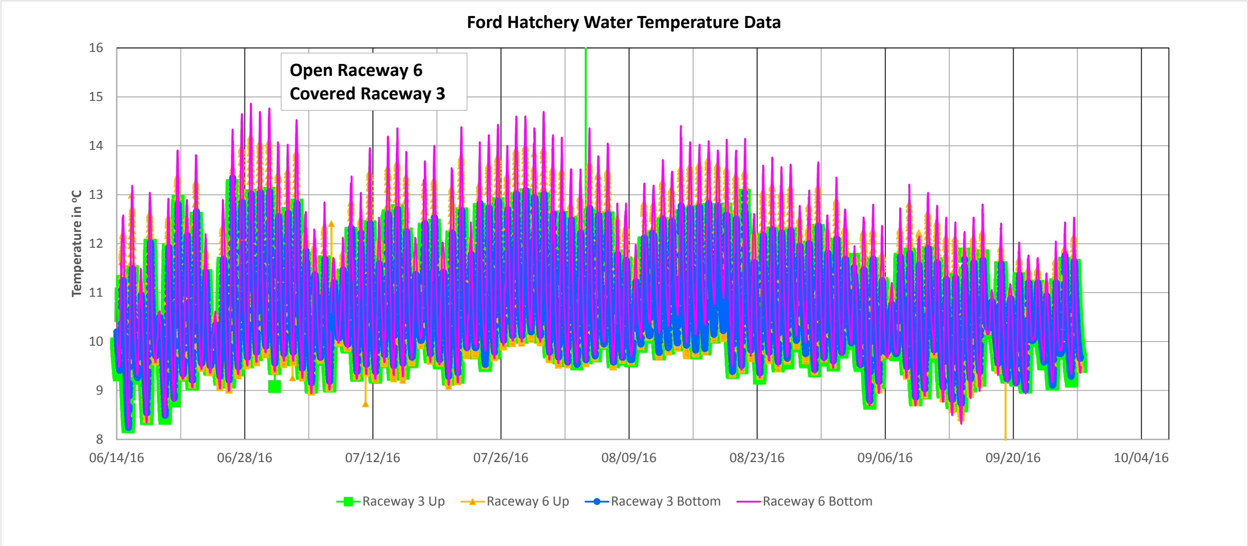

Figure 25. Shaded Rectangular Raceway 3 and unshaded Rectangular Raceway 6 water temperatures at inlet (up) and outlet (bottom) of each raceway

The maximum water temperature recorded each day from the rectangular raceways are presented in Figure 26. The unshaded, open rectangular raceways (5 and 6) displayed similar maximum daily temperatures, which are warmer than the two covered, shaded rectangular raceway (3 and 4) maximum daily temperatures.

Averaging the two shaded and two unshaded maximum daily temperature profiles respectively, and computing the daily difference between the shaded and unshaded raceways is shown in Figure 27. On the hottest days of the summer, during the hottest part of the afternoon, the shaded rectangular raceways were 1.5 °C cooler than the unshaded rectangular raceways.

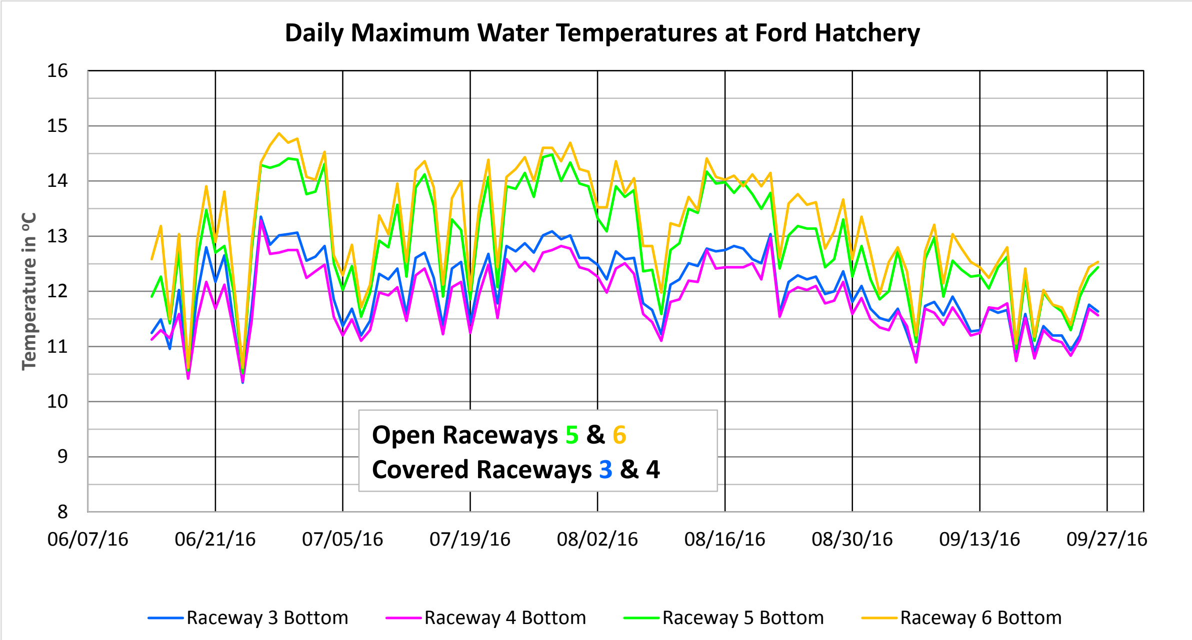

Figure 26. Maximum daily water temperatures for shaded (3, 4) and unshaded (5, 6) rectangular raceways

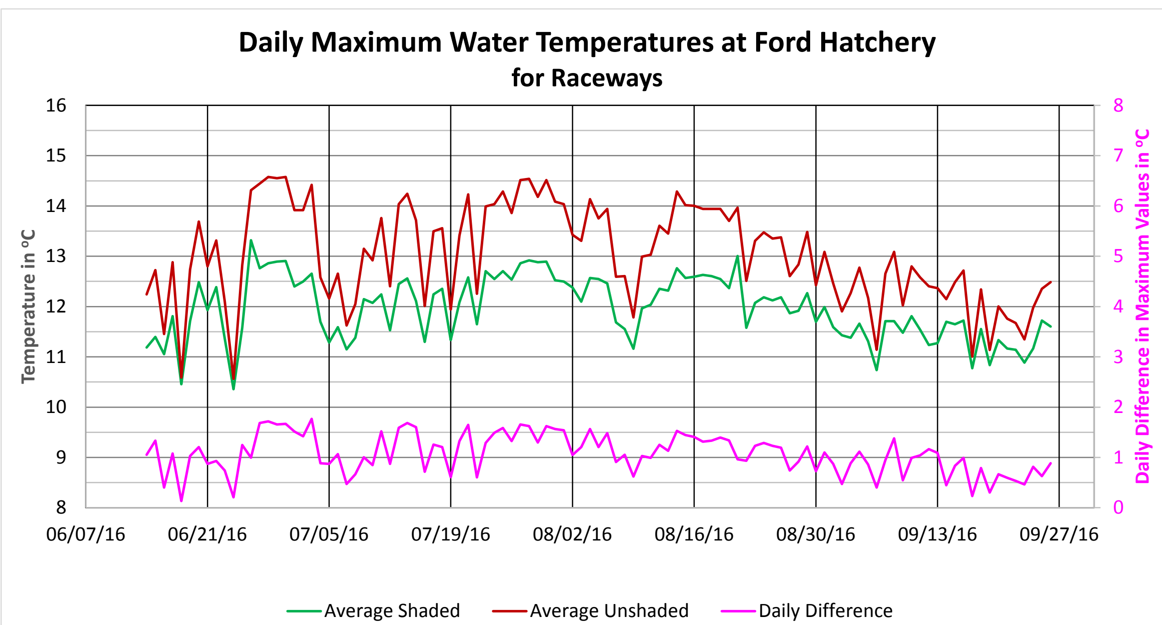

Figure 27. Average maximum daily water temperatures for shaded and unshaded rectangular raceways

Shading half of the hatchery circular raceways resulted in a 2 ^{o}C lowering of the water temperature coming out of the shaded, circular raceways. That cooler water mixed with the warmer water coming through the unshaded circular raceways in the collection trough. That water was supplemented with additional cooler water coming from the Lower Intake on the west side of the facility and with warmer water coming from Mary's Ditch on the east side of the facility. These mixed temperature water sources in the collection trough flowed into the rectangular raceways. Water traveling through the shaded raceways did not gain any additional temperature by the time it reached the bottom of its rectangular raceway. Water traveling through the unshaded, rectangular raceways warmed an additional 0.5 ^{o}C before leaving the facility.

Water temperature impacts associated with the abatement pond

The Ford Hatchery is plumbed so staff can clean infrastructure and divert that flow into an abatement pond located on the southeast side of the facility. (See Figure 28.) Temperature loggers were installed in the pond itself (MapID 6) and in a culvert below the pond (MapID 5) so that the temperature effects of storing water in the abatement pond and of discharging out of the abatement pond into the tributary channel could be examined. (See Figure 29.) The logger in the culvert was the only instrument lost during the project. The last time this logger was downloaded was July 7, 2016. We used the three weeks' of data from this logger to determine the abatement pond's impacts on the system.

Water is flushed into the pond on a daily basis by hatchery personnel as they routinely clean the hatchery's raceways. This diverted water does not travel through the outfall manhole (head in the manhole drops) and head in the abatement culvert surges (head in the culvert increases) while water empties out of the pond. (See Figure 30.) As the water sits in the pond, it warms. Water in the abatement pond had the highest temperatures recorded of any of the sites at the Ford Hatchery.

The pond does not receive cool groundwater discharge on a continuous basis like all of the other components of the hatchery. Consequently it doesn't display the diurnal cooling exhibited by the other sites. (See Figure 31.)

Even though this water is significantly warmer than the rest of the hatchery discharge water, abatement pond discharge water flushing out of the pond has only a negligible effect on temperature in Chamokane Creek below the hatchery, and that only lasts a fraction of a day while the staff are cleaning. (See Figure 30.) When water starts being displaced out of the abatement pond and into the culvert that drains the pond to the tributary capturing hatchery effluent, the water temperature starts out warm. The discharge quickly cools off towards the temperature of the water in the Outfall Manhole, which represents the water temperature leaving the facility. Surprisingly, very little warm abatement pond water actually leaves the pond during cleaning events. The discharge from the pond is mostly cooler, hatchery water. (See Figure 32.)

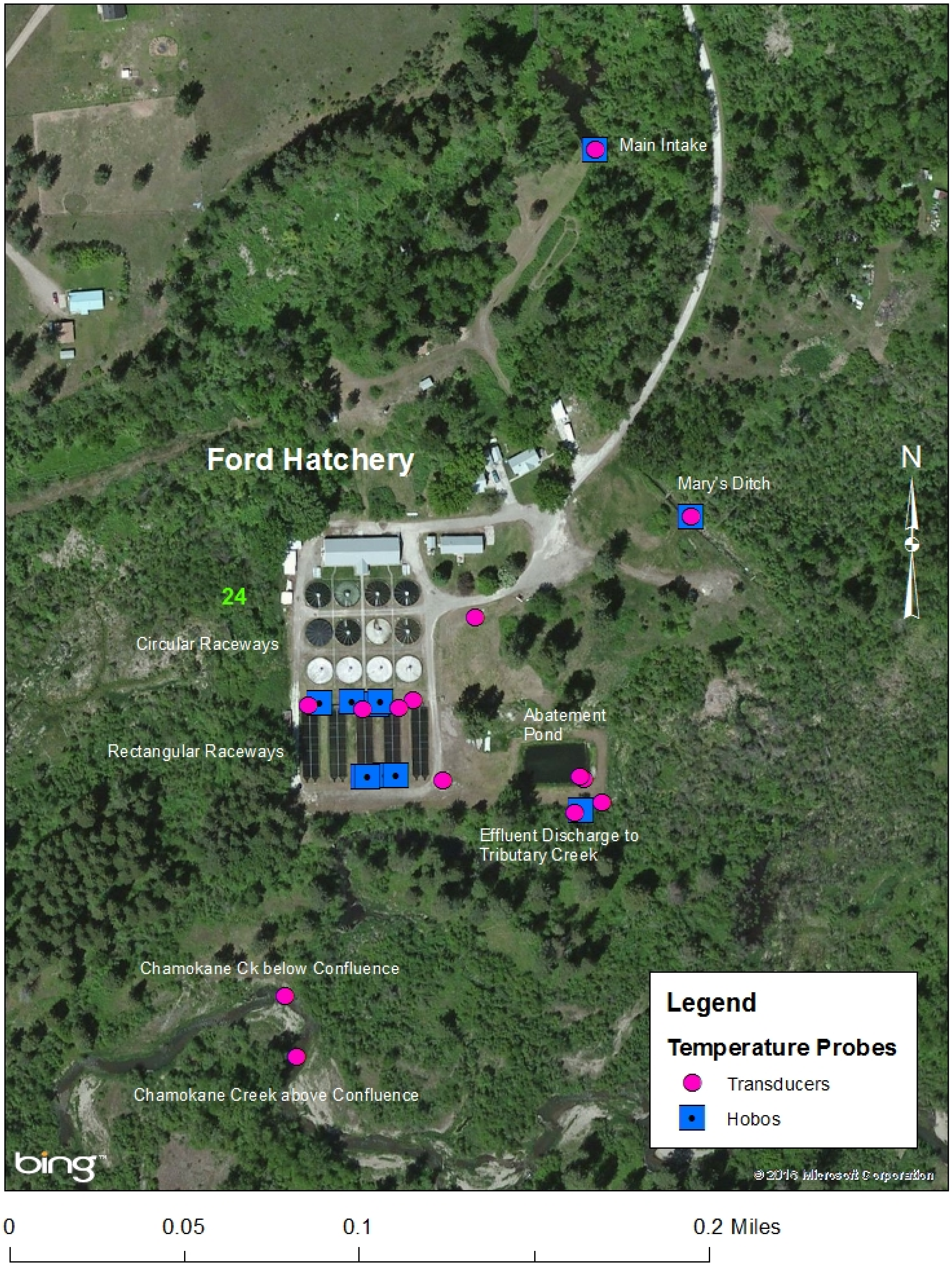

Figure 28. Loggers deployed at the Ford Hatchery

Figure 29. Loggers deployed at the abatement pond at the Ford Hatchery

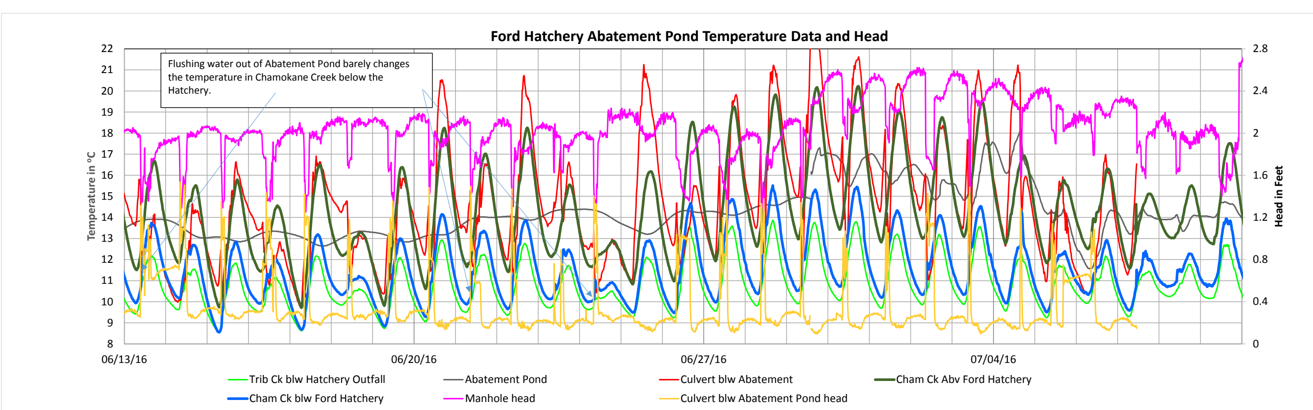

Figure 30. Abatement Pond's discharge effect on water temperature

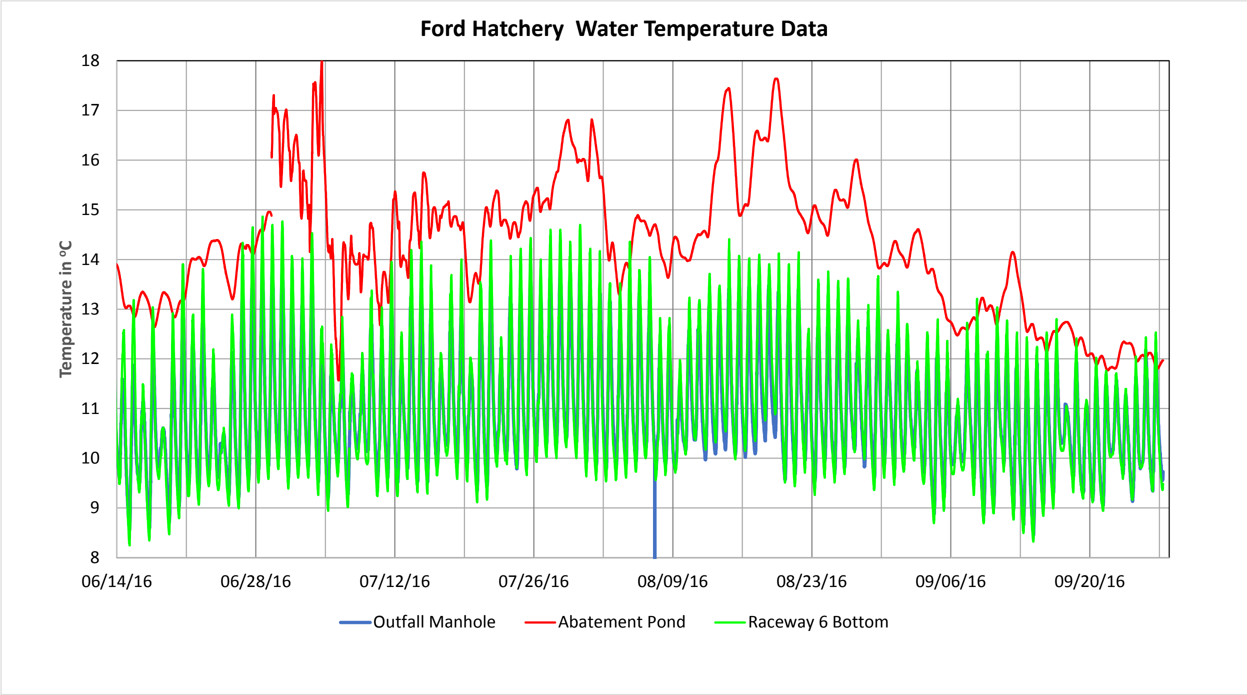

Figure 31. Abatement Pond water temperature does not show diurnal fluctuations like the rest of the Ford Hatchery

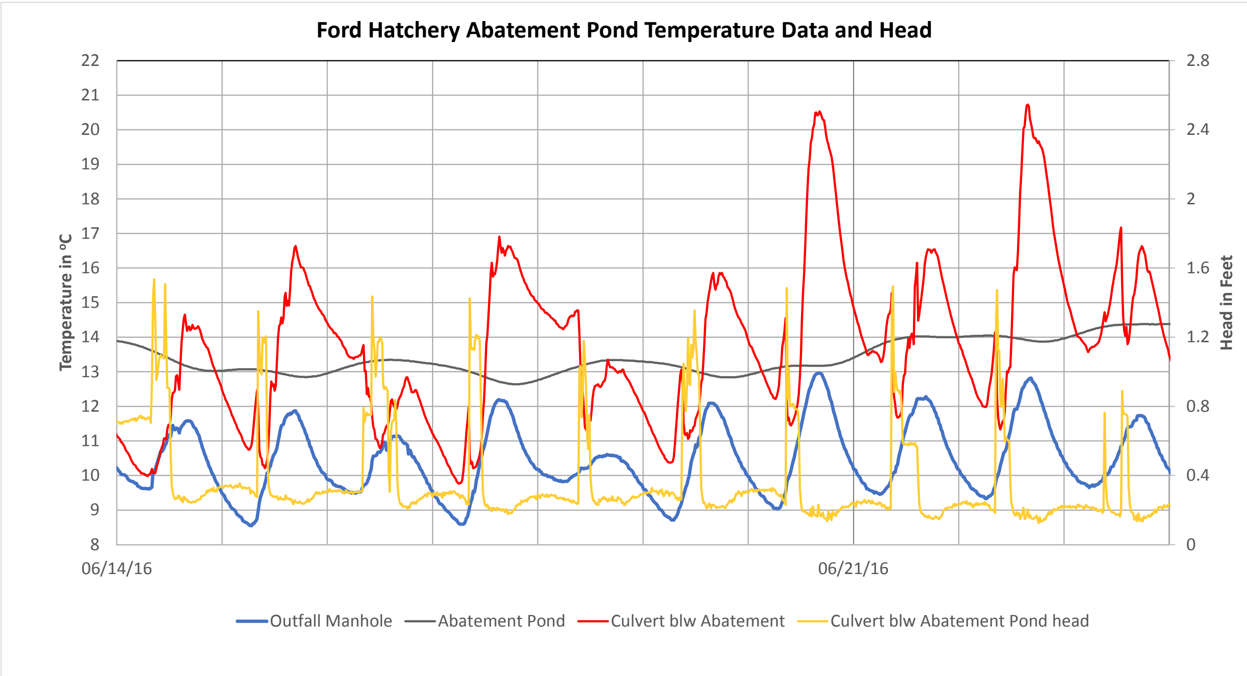

Figure 32. Abatement Pond head and water temperature data

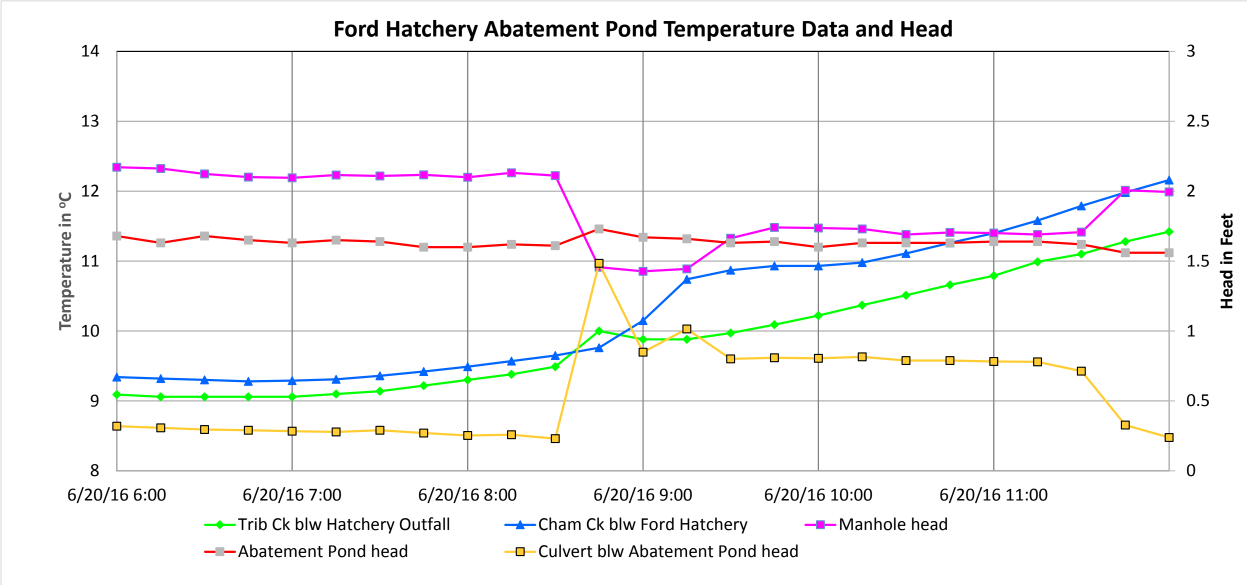

Figure 33. Abatement Pond water temperature and head data for June 20, 2016

On the morning of 6/20/16, hatchery staff started cleaning a raceway between 8:30 and 8:45. (See Figure 33.) The 8:45 readings show the head in the Abatement Pond and the head in the Culvert below the Abatement Pond have jumped up. The head in the Outfall Manhole has dropped (because raceway water has been diverted into the abatement pond and bypassed the Outfall Manhole).

Water temperature in the tributary creek below the hatchery has bumped up 0.5 °C with the influx of warmer abatement pond discharge water. Fifteen minutes later, at the 9:00 reading, the water temperature in Chamokane Creek below the hatchery confluence has bumped up less than 0.3 °C as that discharged warmer water has traveled from the hatchery to Chamokane Creek (from MapID 24 to MapID 22, see Figure 2 for locations). The volume of warm water leaving the abatement pond is not large enough to appreciably change the hatchery effluent temperature nor the temperature of the water in Chamokane Creek proper. We can see a subtle bump but it is minor.

One of our thoughts going into this project was that the abatement pond will likely have warm water sitting in it all summer (and we confirmed that it does); and that we might want to shade it to help decrease water temperature in Chamokane Creek since that warm water discharges to Chamokane when the hatchery staff are cleaning raceways. For this pilot study, we were unable to shade the abatement pond with our available resources. Temperature probes were installed in an unshaded abatement pond. Temperature observations collected throughout the study suggest that spending money to shade the abatement pond would not result in a significant improvement in discharge temperature. The volume of water coming out of the pond is not large enough to measurably influence temperatures in Chamokane Creek.

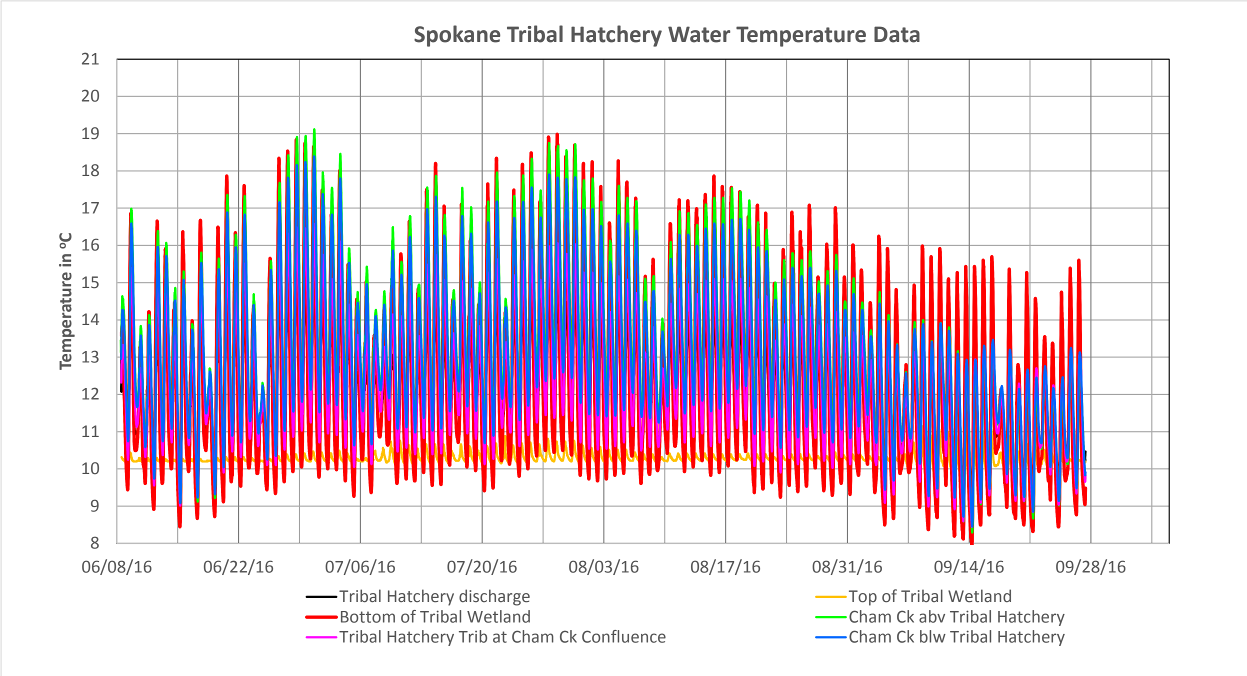

Figure 34. Water temperatures collected at the Spokane Tribal Hatchery

Water temperature results observed at the Spokane Tribal Hatchery

Three temperature probes were installed on the east side of the Spokane Tribal Hatchery and three probes were installed in the vicinity of the confluence of where the Spokane Tribal Hatchery outflow water's tributary enters Chamokane Creek. (See Figure 3.) All of the data collected from these six sites can be seen on Figure 34. The STOI measures water temperature at a number of sites within its facility. That data is not part of this study.

Spring fed water entering into the wetlands (MapID 32) on the east side of the Spokane Tribal Hatchery has a very consistent water temperature of around 10.5 ºC. As that water flows down through the wetlands and exits the Spokane Tribal Hatchery project area (MapID 31), it warms up appreciably, getting as warm as 19 ºC on the hottest days of the summer. Water discharging from the Spokane Tribal Hatchery (MapID 30) has a diurnal temperature range of about 4 ºC. On the warmest days of the summer, the hatchery discharge water has a maximum daily temperature of around 14.8 ºC. (See Figure 35.)

As the water flowing out of the Spokane Tribal Hatchery travels down its tributary towards its confluence with Chamokane Creek, it warms by about 1.5 ºC by the time it gets to MapID26. On the warmest day of the summer, this tributary water had a maximum temperature of around 16.5 ºC. This water mixes with water in Chamokane Creek that has warmed to a maximum of around 19 ºC, resulting in a mixed water temperature of around 18.4 ºC. The reduction in water temperature after mixing the Spokane Tribal Hatchery outflow water with Chamokane Creek water is around 0.6 ºC. (See Figure 36.)

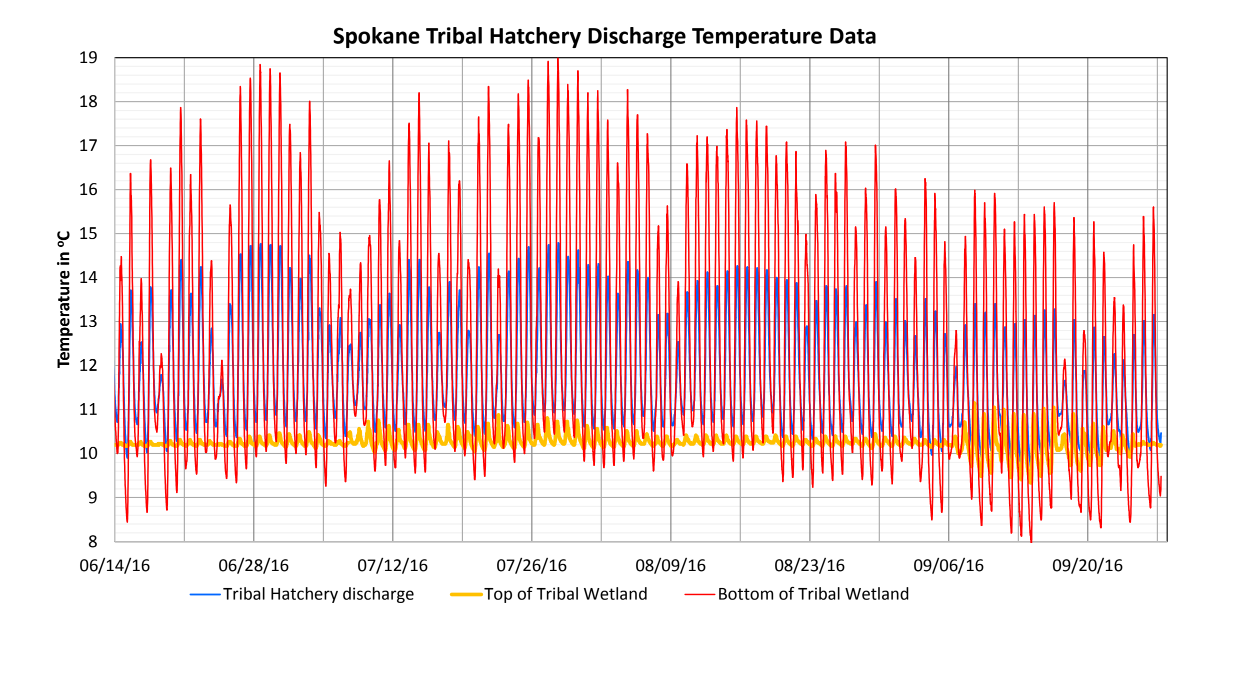

Figure 35. Water temperatures from wetland at the Spokane Tribal Hatchery

The Spokane Tribal Hatchery outflow water has a minimal impact on water temperature in Chamokane Creek because the volume of water flowing down Chamokane at this point in the watershed has increased to over 24 cfs before it mixes with the 8.5 cfs of cooler water joining the creek at its confluence.

A significant portion of the Spokane Tribal Hatchery facilities have already been covered by the construction of their new building and they have plans to cover the remaining portions of their raceways that were unshaded during 2016.

Some portion of the facility's water supply comes from the wetlands on the east side of their facility. As this wetland water exhibited an increase in water temperature from 10.5 °C to 19 °C over its length, there may be some benefit to exploring ways to reduce the wetland's water temperature before it gets to the hatchery's intake structure at MapID 31. They could also explore the feasibility of moving the intake structure closer to the top of the wetland to intake cooler water.

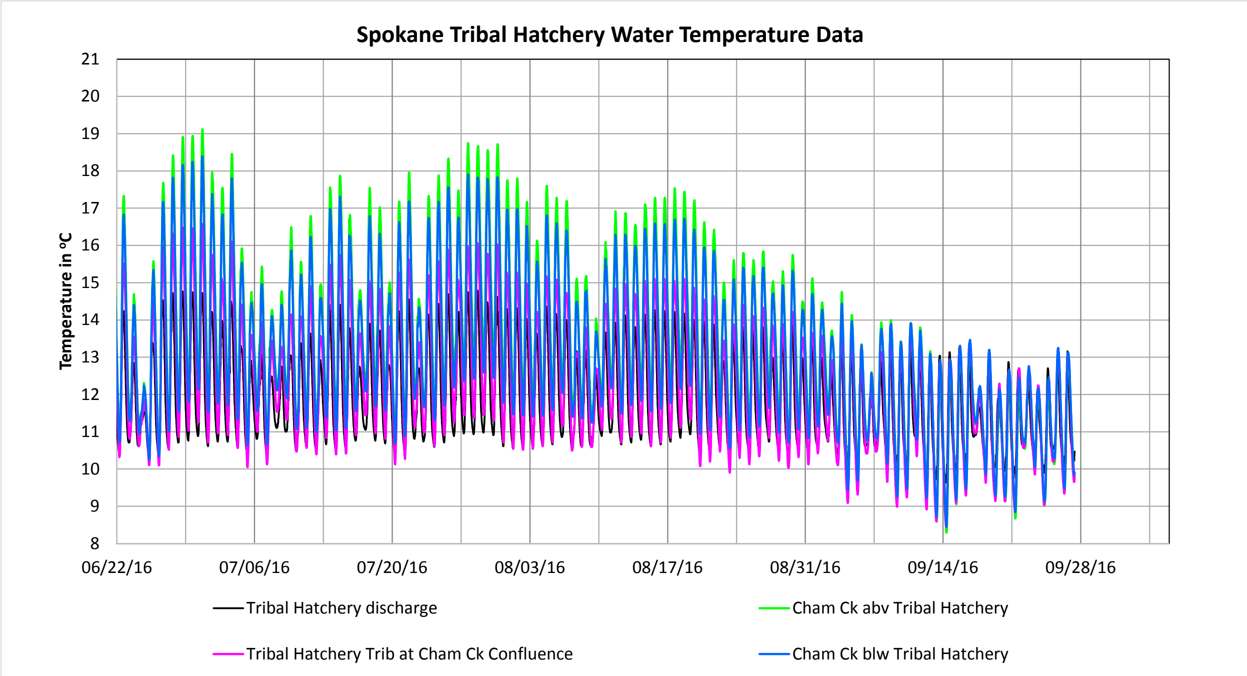

Figure 36. Water temperatures in Chamokane Creek above and below the confluence with Spokane Tribal Hatchery outflow

Water temperature mixing calculations

Shading the raceway portions of the facility (including the collection trough area between the raceways) would clearly lower the temperature of the water leaving the Ford Hatchery at least 2.5 ºC. The discharge of water leaving the facility is more than the discharge coming down Chamokane Creek. Mixing a larger volume of cooler water with a smaller volume of warmer water had a significant impact on the temperature of water in Chamokane Creek. Making all of the hatchery discharge water 2.5 ºC cooler by shading the entire hatchery (except the abatement pond) should lower the creek water temperature by a measureable amount.

We used a simple mixing model approach[2] to calculate the water temperature at a downstream location after two water sources are mixed. The mixing calculation:

$$T_D \frac{(D_M * T_M) + (D_T * T_T)}{D_M + D_T}$$

where:

T_D= temperature of main stream downstream after tributary stream enters the main stream

[2] Used by the United States Forest Service in Chapter 7 of An Approach to Water Resources Evaluation of Non-Point Silvicultural Sources (A Procedural Handbook) (EPA 600/8-80-012, dated August 1980)

D_M discharge in the main stream above the tributary stream

T_M temperature in the main stream above the tributary stream

D_T discharge of the tributary stream

T_T temperature of the tributary stream

To test the equation, we input flow and temperature data measured near the Spokane Tribal Hatchery in Chamokane Creek on June 13, 2016 into the equation:

- Flow in Chamokane above the Spokane Tribal Hatchery was 24.51 cfs (MapID 27).
- The daily high water temperature at that location was 16.07 ^oC.
- Flow in the tributary channel was 8.45 cfs (MapID 28).
- The tributary had a daily high water temperature of 14.75 ^oC.

For Chamokane Creek near the Spokane Tribal Hatchery on June 13, 2016, the equation is:

$$((24.51 \text{ cfs} * 16.07\ ^oC) + (8.45 \text{ cfs} * 14.75\ ^oC))/(24.51 \text{ cfs} + 8.45 \text{ cfs}) = 15.73\ ^oC$$

This results in a calculated water temperature after mixing of 15.73 ^oC. The maximum water temperature recorded on 6/13/16 at the site below the confluence of the Spokane Tribal Hatchery tributary and Chamokane Creek (MapID 29) was 15.72 ^oC. The results of the mixing model equation seems to be very reflective of actual measured conditions.

We can use this mixing equation to determine the effects that shading the Ford Hatchery would have on summer, low flow water temperature conditions in Chamokane Creek. In Chamokane Creek during the heat of the summer, we have 6 cfs of 20 ^oC water coming down Chamokane Creek at a spot above the Ford Hatchery tributary. Discharge of the tributary coming from the Ford Hatchery is around 8 cfs of 14.6 ^oC water on the hottest days. Mixing these two streams results in 14 cfs of 16.9 ^oC water.

If we shade the hatchery facilities and cool the discharge water by 2.5 ^oC, this would result in 8 cfs of 12.1 ^oC water coming down the tributary channel. Mixing this cooler water with the 20 ^oC water results in 14 cfs of 15.5 ^oC water in Chamokane Creek below the confluence of the Ford Hatchery discharge. This represents a 1.4 ^oC decrease in the water temperature in Chamokane Creek directly attributable to the potential shading project as calculated by the field-verified, mixing equation.

Data quality indicators and data limitations

We evaluated the temperature probes being considered for use in this study prior to deployment by comparing real-time water temperature measurements against each other in a controlled environment. This allowed us to eliminate devices whose reading showed the greatest deviation from the group to maximize precision and accuracy.

Dual deployment of different logger types at two site locations helped assure representativeness and comparability.

We lost one temperature probe out of the 31 we deployed. For the entire study, we collected more than 700,000 data points. The lost logger had approximately 8,000 fewer temperature measurements than the rest of the probes for a completeness percentage of almost 99 percent. Valuable data from the lost logger was collected during the first portion of the study. It was last successfully downloaded on July 7, 2016, but was gone on our next site visit.

The results and conclusions are based on one season of temperature data collection. The Spokane Tribe of Indians has collected water temperature readings at their Chamokane Creek monitoring site near Martha Boardman Road for multiple years. (See Figure 37.) Temperature data collected in 2016 is similar in character to the data collected in 2007, 2011, and 2015. During the hottest days of the summer of 2016, water temperatures were slightly lower than those observed in 2007 and 2015, but higher than those observed in 2011. It is likely that hatchery temperature shading effects observed in 2016 would have been similar if this study had been conducted during any of these years.

Weather conditions, particularly air temperature and solar radiation, have a significant impact on the temperature of the water flowing through the hatchery on any given day. The maximum effect from any shading program will vary year-by-year according to that year's specific weather conditions.

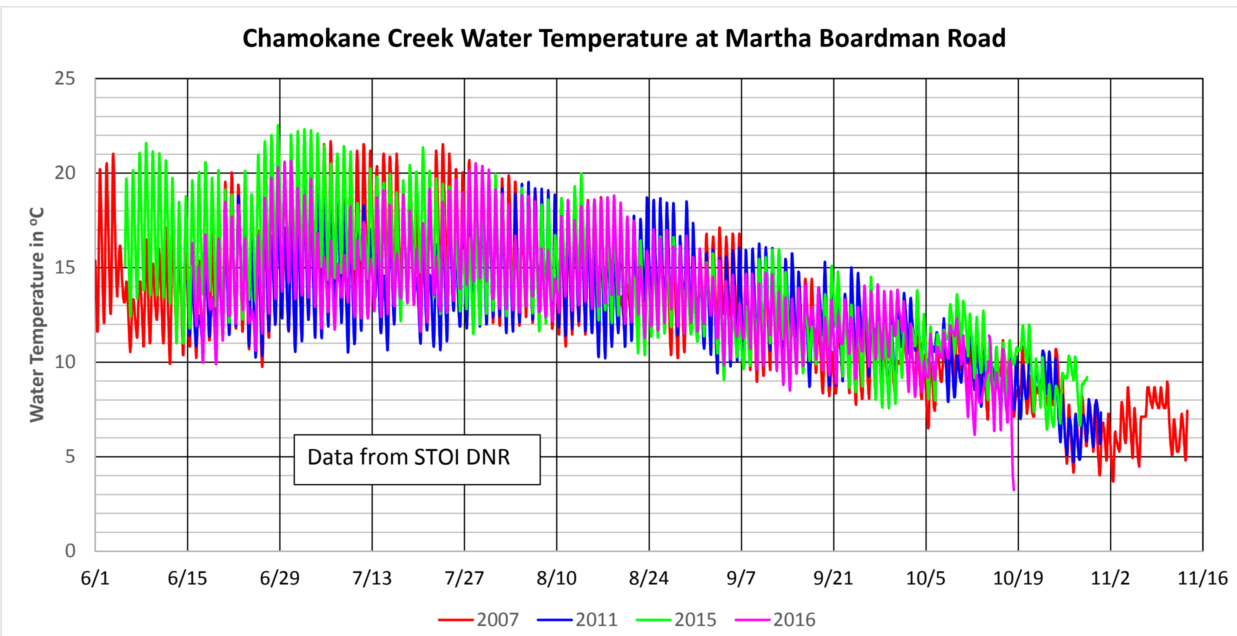

Figure 37. Water temperatures in Chamokane Creek collected over four summers

Conclusions

- The surface water bodies near the hatcheries that are dominated by groundwater discharge show temperature patterns that mimic the solar radiation curve, with peak temperatures at solar noon (13:00 PDT). Surface water bodies that are not dominated by groundwater discharge have temperature patterns that mimic the air temperature warming. Daily maximums occur well after midday.

- Shading of raceways at the Ford Hatchery will decrease the temperature of the discharge to Chamokane Creek. Data indicate a 2.5 ^{o}C temperature benefit within the hatchery, and up to a 1.4 ^{o}C decrease of temperature on the mainstem of Chamokane Creek at the point where the hatchery effluent enters the creek.

- Shading of the abatement pond at the Ford Hatchery will have a negligible effect on temperature of the water discharging to Chamokane Creek.

- Benefits of additional shading at the Spokane Tribal Hatchery are not expected to be large. This is due to the increase in flow in Chamokane Creek between the tribal hatchery and the upstream Ford Hatchery, negating the mixing benefits of cooler water entering the mainstem of Chamokane Creek. A decrease in intake water temperature may be seen by relocation of the existing spring intake.

- Mass balance mixing calculations reasonably approximate empirical data, and can be used to estimate benefits.