Effects of Inline Ponds on Stream Temperatures in the Johnson Creek Watershed

Author: Katie Holzer, City of Gresham
Publication Date: June 25, 2020
Other Data Contributors: Johnson Creek Watershed Council, United States Geological Survey, City of Portland

1. Summary

Streams that have been altered by urban and agricultural activities are often too warm for some native aquatic species. Johnson Creek and its tributaries in the Portland, Oregon metropolitan area often exceed the summer instream temperature standard for salmonid rearing and migration. There are dozens of inline ponds in the watershed and their effects on stream temperature have been largely unknown. This study examined hourly data collected from upstream and downstream of 25 inline ponds from 2008-2019 to examine the effects of the ponds on stream temperatures. The ponds were comprised of a variety of sizes, locations, and outlet structures. Most ponds were found to substantially raise the stream temperature by several degrees Celsius in the summer months and to increase the amount of time that a stream segment exceeded the temperature standard by several weeks each year. The few ponds which decreased summer stream temperatures were all formed either by beaver dams or by an outlet structure which pulled water from below the pond surface. The effect that each pond had on stream temperature varied greatly and was associated with several factors. Stream temperature increases were greater where upstream temperatures were cooler, where pond surface areas were larger, and where ponds were formed with flow-over dams with outlet structures which released water from the surface of the ponds. These finding demonstrate that inline ponds add substantial heat to stream sections throughout the Johnson Creek watershed and that removal, off-lining, or retrofitting of inline ponds could substantially cool those sections. These actions would likely have larger effects when prioritizing large ponds with surface outlets in areas where the upstream flow is still cool.

2. Background

Human activity can increase stream temperatures through a variety of mechanisms. These include removal of trees shading the streams, construction of field tile drains and impervious surfaces such as buildings and pavement which prevent groundwater recharge, and impounding water in inline ponds which increase the residence time that water is exposed to solar radiation. Johnson Creek in the Portland metropolitan area has been altered by human activity in all of these ways, and the current summer temperatures are often warmer than the optima for many native species, including federally listed salmon. The creek has a Total Maximum Daily Load (TMDL) for temperature administered by the Oregon Department of Environmental Quality (DEQ). Local jurisdictions are working to understand the major sources of heat in the creek and to implement projects which reduce temperatures.

The Johnson Creek Inter-Jurisdictional Committee (IJC) is a group of scientists and land managers formed in 1995 who work together to coordinate monitoring and restoration projects in the watershed. The group has been conducting temperature monitoring in the creek since 1998 with widespread continuous monitoring beginning in 2008. Early efforts showed that the mainstem of the creek generally exceeded DEQ's instream temperature standard for salmon migration and rearing for much of the summer throughout its entire length, and that only a few highly forested tributaries stayed cool enough to meet the standard all summer.

The temperature TMDL strategy in the watershed focuses primarily on riparian tree plantings to increase shade. Cities and counties in the watershed have been implementing widespread planting efforts as part of their TMDL Implementation Plans, and the watershed council and soil and water conservation districts have been successfully conducting riparian restoration on the properties of willing landowners. There are still public and private riparian properties in need of tree planting, but stream temperature reduction through shading will also require time as the vegetation grows.

In 2015 the Johnson Creek Watershed Council (JCWC) conducted a pond inventory of the watershed using aerial images and discovered around 70 likely inline ponds. These ponds were hypothesized to increase stream temperatures, but the exact effects were unknown. From 2008-2019 members of the IJC collected continuous summer stream temperature data upstream and downstream of accessible inline ponds throughout the watershed. The results of these efforts are summarized in this study.

3. Methods

3.1 Site Selection

Temperature monitoring locations were discussed and chosen by the IJC (Fig. 1). Sites focused on known inline ponds with access to upstream and downstream locations for placing temperature loggers. Logger locations were generally selected as close as reasonable to ponds to avoid other influences to stream temperature. Loggers were generally placed a few inches above the streambed in a location where they were likely to remain submerged throughout the summer. Instantaneous investigations in several sections demonstrated that temperatures were generally consistent across a stream cross-section with the exception of pools being cooler at the bottom. Some inaccuracies may exist due to the microclimate of the logger location, but there are no biases expected which would be unique to upstream or downstream locations.

A total of 22 ponds in the Johnson Creek watershed were monitored. Most of these ponds were monitored for a single summer (16) while the remaining six were monitored for two or three summers. Three nearby ponds outside of the watershed are also included in this analysis. These ponds are in Gresham and were included because they represent gaps in the Johnson Creek data in terms of pond size and because they provide multiple years of data (3-6 summers each). These ponds were on Beaver, Kelly, and Fairview Creeks. The first is similar in size and summer flow to the Johnson Creek mainstem while the others are similar to major Johnson Creek tributaries.

Most of the ponds were formed by dams constructed by humans (16) while the remaining nine were formed by beaver dams. Most of the human dams had flow-over outlet structures that discharged water off the surface of the pond (15) while one had a subsurface outlet structure which released water from below the pond surface. Beaver dams were porous and released water from throughout the pond water column. Most of the ponds were located on tributaries (17) while the remaining eight were on the mainstem.

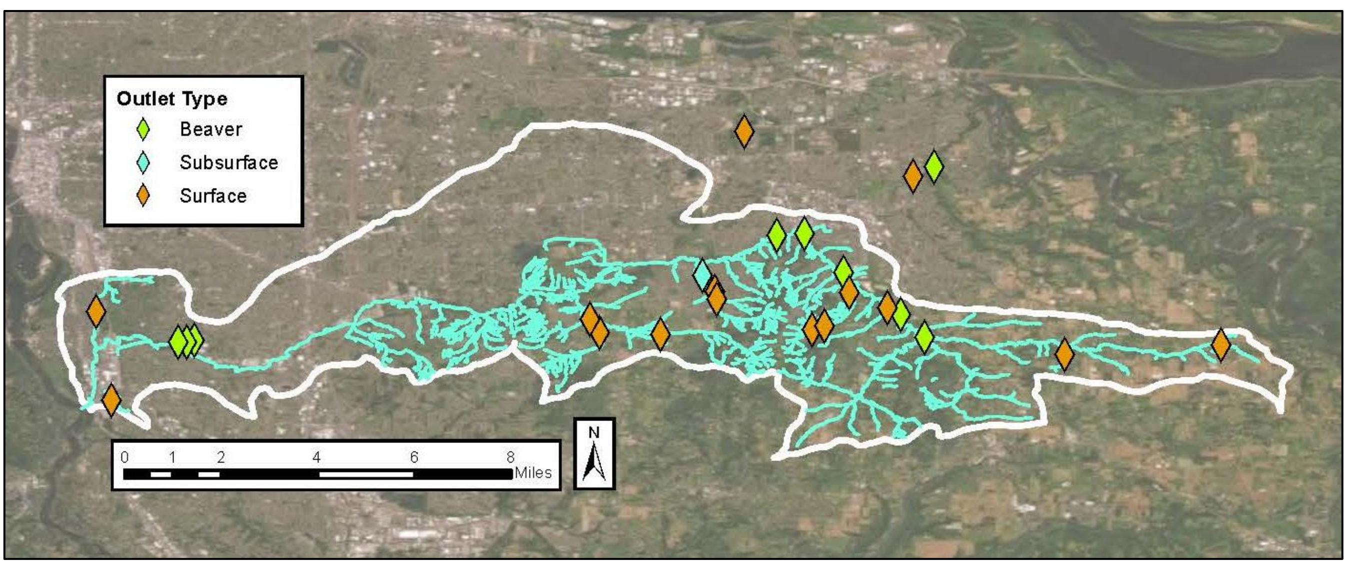

Figure 1 Map of 25 ponds examined in current study. All but three ponds were located in the Johnson Creek watershed which is shown in the white outline.

3.2 Data Collection

Continuous temperature data were collected with Hobo Tidbit temperature loggers (Onset Corp.) set to collect data at least hourly. Temperature loggers were generally deployed from May through October of a given year. Several sites were already exceeding the instream temperature standard when the loggers were deployed in the spring, so some additional exceedances were likely missed in the early season for those sites. Additionally, a few loggers were out of the water for small portions of the summer, so some mid-summer exceedances are also missing for those sites. Surface areas of ponds were estimated using aerial imagery.

3.3 Analysis

We calculated the 7-day moving average of the daily maximum (7DADM) for each site. From this we calculated the maximum 7DADM for the entire summer and the number of days that the 7DADM exceeded the instream temperature standard of 18 °C. To examine the effect of each pond on stream temperature we calculated the change in the maximum 7DADM for the entire summer, the maximum change in the 7DADM for a given day, and the change in the number of exceedances from the upstream site to the downstream site. For ponds with multiple years of data we summarized the average of these changes across years.

We examined several local factors which may affect the influence of the ponds: temperature at the upstream site, surface area, and outlet structure type. To explore the relationship between these factors and the influence of the pond on stream temperature we conducted simple linear regressions for continuous variables (upstream temperature and surface area) and a Mann-Whitney U test for the categorical variable (outlet structure type). Surface areas were log-transformed prior to analysis to fit the assumptions of normality. We also created a generalized linear model to determine which of these factors were most useful in predicting the effect of the ponds on stream temperature. For model selection we used minimization of the Akaike Information Criterion with a 2nd order correction for use with small sample sizes (AICc).

3.4 Modelled Additional Exceedances

To obtain an estimate of additional exceedances that were missed by the temperature loggers we employed a simple linear regression model constructed from the sites with complete data. This model was built by relating the maximum 7DADM temperature to the number of exceedances for each site with complete data (R^2=0.80). The resulting regression equation was applied to sites with missing data. Both the raw and modelled exceedances are reported.

Twelve of the upstream locations and 17 of the downstream locations likely had additional exceedances of the temperature standard that were not captured by the temperature loggers. The estimates for six of the upstream sites and four of the downstream sites were the same or lower than the observed number of exceedances. Each of these sites had datasets that started with 7DADM values very close to the temperature standard, so there were likely to be few, if any, additional exceedances. For those sites, summary statistics are reported with the observed number of exceedances.

4. Results

4.1 Summary

Most inline ponds (20 out of 25) increased summer stream temperatures (Fig. 2). The average increase in maximum 7DADM temperature was 2.1 °C (range: -2.3 – 8.7 °C). The average increase in 7DADM for a given day was 3.0 °C (range: -1.1 – 9.7 °C). The average increase in the number of days of exceedances of the temperature standard was 26 days (range: -23 – 112 days) for sites with complete data and 35 days when including modelled estimates for sites with incomplete data (range: -27 – 134 days). These measures were all highly correlated (Fig. 3; all $p < 0.001$, all $R^2 \geq 0.77$). The increase in the maximum 7DADM was the most informative of these three measures for factor analyses and did not require any estimations, so it was therefore used as the dependent variable for factor analyses.

Upstream maximum 7DADM temperatures averaged 20.9 °C (range: 16.7 – 25.3 °C) and downstream maximum 7DADM temperatures averaged 23.0 °C (range: 17.9 – 28.3 °C). Exceedances at upstream sites averaged 51 days for sites with complete data (range: 0 – 116 days) and 58 days when including modelled estimates for sites with incomplete data (range: 0 – 116 days). Exceedances at downstream sites averaged 79 days for sites with complete data (range: 0 – 132) and 93 days when including modelled estimates for sites with incomplete data (range: 0 – 162 days). Four of the upstream sites stayed below the temperature standard for the entire summer while all but one downstream site had exceedances. The sites without exceedances were all on small headwater streams: Hogan Creek, Spring Creek, Errol Springs Creek, and the headwaters of the Johnson Creek mainstem. Summary data for each pond are shown in Table 1.

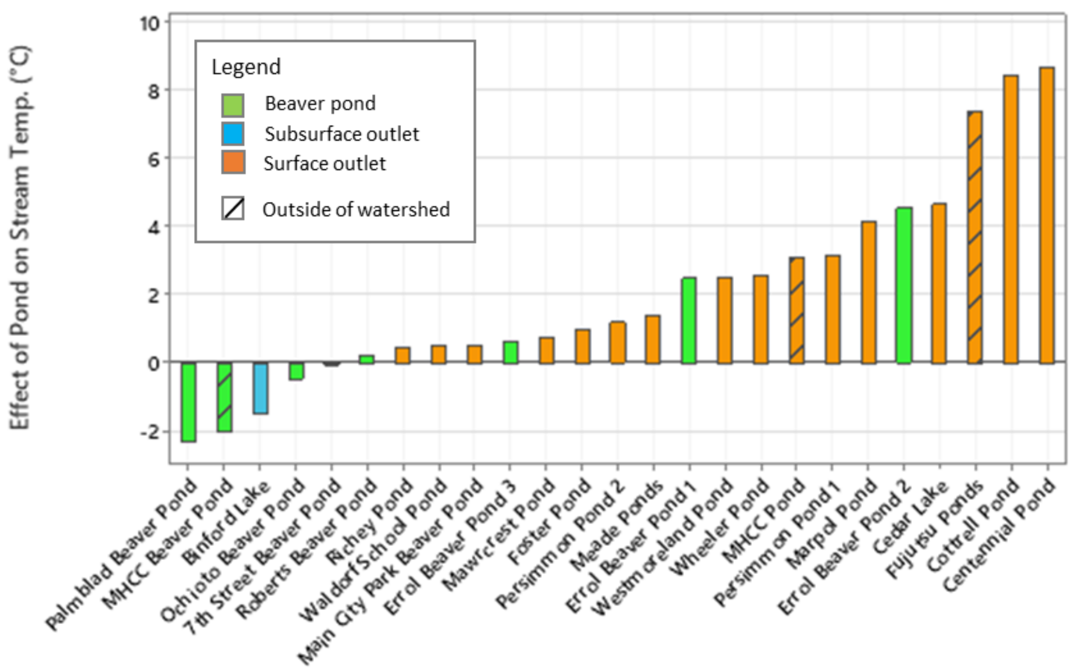

Figure 2 Effect of each pond on stream temperature. The y-axis is the difference in the maximum value of the 7-day average of the daily maximum temperature (7DADM) between the upstream and downstream sampling locations for each pond over the entire summer (values averaged across years for sites with multiple years of data). Ponds are ordered from left to right in by amount of temperature increase they caused. Bars below 0 represent ponds which decreased stream temperature while those above 0 represent ponds which increased stream temperature.

Table 1 List of ponds and major attributes. All temperatures are the maximum 7-day average of the daily maximum (7DADM). Exceedances (ex.) are the number of days that the 7DADM exceeded the instream temperature standard of 18 °C for salmonid rearing and migration. The far-right columns show the increase (Incr.) from the pond in the stream temperature in the number of days of measured or modelled (mod.) exceedances. Numbers which changed with modelling are italicized. Ponds are ordered from highest to lowest in how much they increased stream temperature.

Pond name	**Creek**	**Outlet structure**	**Surf. area (acres)**	**Up-stream temp. (°C)**	**Down-stream temp. (°C)**	**Up-stream ex. (# days)**	**Down-stream ex. (# days)**	**Incr. in temp. (°C)**	**Incr. in daily temp. (°C)**	**Incr. in ex. (# days)**	**Incr. in mod. ex. (# days)**
Centennial Pond	Mitchell Creek	Surface	0.58	19.6	28.3	36	116	8.7	7.3	80	*126*
Cottrell Pond	Johnson Creek	Surface	0.73	17.8	26.2	0	95	8.4	8.5	95	*134*
Fujutsu Ponds	Fairview Creek	Surface	17.82	18.4	25.7	20	132	7.4	9.7	112	112
Cedar Lake	Hogan Creek	Surface	1.74	19.8	24.4	25	95	4.7	2.6	70	*72*
Errol Beaver Pond 2	Errol Springs Creek	Porous	1.25	20.0	24.5	45	116	4.6	5.2	71	71
Marpol Pond	Butler Creek	Surface	1.18	20.5	24.6	55	96	4.1	6.9	41	*61*
Persimmon Pond 1	Hogan Creek	Surface	0.97	16.7	19.8	0	53	3.1	5.0	53	53
Mt. Hood CC Pond	Kelly Creek	Surface	2.02	21.4	24.5	72	102	3.1	4.0	31	*41*
Wheeler Pond	Wheeler Creek	Surface	0.13	17.5	20.1	0	18	2.6	2.7	18	*30*
Westmoreland Pond	Crystal Springs Creek	Surface	2.57	20.2	22.7	50	81	2.5	0.6	28	*35*
Errol Beaver Pond 1	Errol Springs Creek	Porous	1.50	17.5	20.0	0	45	2.5	3.3	45	45
Meade Ponds	Brigman Creek	Surface	0.17	22.9	24.3	83	96	1.4	2.9	13	*29*
Persimmon Pond 2	Hogan Creek	Surface	0.35	19.8	21.0	53	49	1.2	1.3	-4	*9*
Foster Pond	Kelley Creek	Surface	0.10	21.5	22.5	63	67	1.0	2.0	4	4
Mawrcrest Pond	Butler Creek	Surface	0.07	19.9	20.7	35	60	0.8	2.0	25	25
Errol Beaver Pond 3	Errol Springs Creek	Porous	0.15	24.5	25.2	116	124	0.7	1.0	8	8
Main City Park Beaver Pond	Johnson Creek	Porous	0.47	24.4	24.9	34	48	0.5	1.2	14	*8*
Waldorf School Pond	Spring Creek	Surface	0.10	17.4	17.9	0	0	0.5	2.6	0	0
Richey Pond	Kelley Creek	Surface	0.23	22.0	22.5	67	91	0.5	3.0	24	24
Roberts Beaver Pond	Johnson Creek	Porous	0.22	21.4	21.6	80	83	0.2	0.8	3	3
7th Street Beaver Pond	Johnson Creek	Porous	0.39	23.8	23.8	38	39	-0.0	0.4	1	*0*
Ochioto Beaver Pond	Johnson Creek	Porous	0.43	23.1	22.7	89	84	-0.5	0.1	-5	*-6*
Binford Lake	Butler Creek	Sub-surface	1.38	23.0	21.6	97	90	-1.5	2.8	-7	-7
MHCC Beaver Pond	Beaver Creek	Porous	0.08	25.3	23.3	50	40	-2.0	0.1	-10	*-27*
Palmblad Beaver Pond	Johnson Creek	Porous	0.24	25.0	22.7	112	89	-2.3	-1.1	-23	-23
		Min.	0.07	16.7	18.0	0	0	-2.3	-1.1	-23	-27
Summary		**Mean**	1.39	20.9	23.0	49	76	2.1	3.0	27	33
		Max.	17.82	25.3	28.3	116.0	132	8.7	9.7	112	134

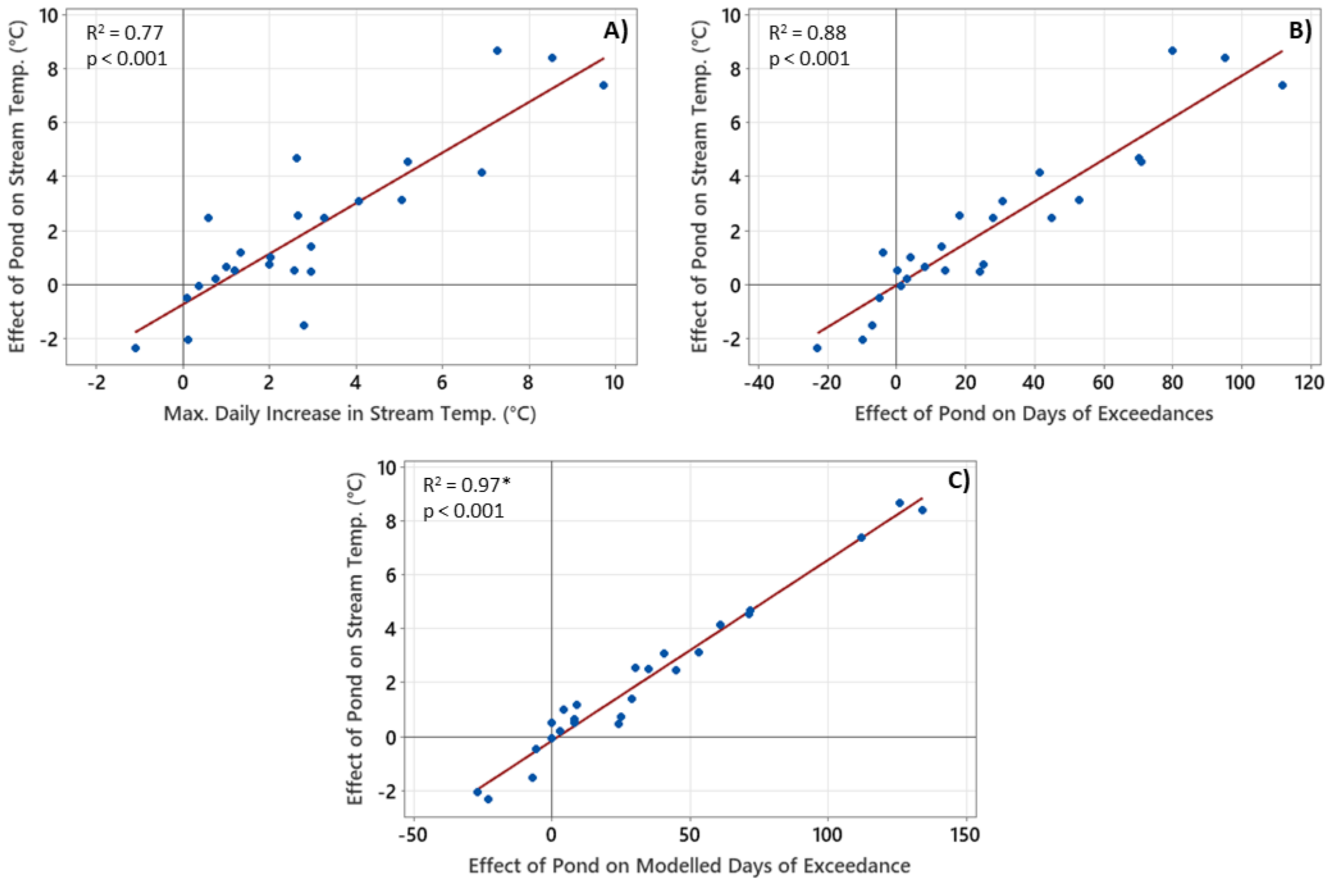

Figure 3 Correlations among measures of increases in stream temperature from the 25 ponds studied. Each point represents one pond (with data averaged for those with multiple years). Most ponds increased stream temperature for all three measures, and the measures were highly correlated. The y-axis for each graph is the increase in the maximum of the 7-day average of the daily maximum temperature (7DADM) over the entire summer. The x-axes are as follow: A) the maximum increase in the 7DADM on a given day, B) the raw data for the increase in the number of days of exceedances of the instream water quality standard of 18 °C for salmonid migration and rearing, and C) is the modelled increase in the number of days of exceedances of that standard for sites with missing data. *The R^2 value in C) is artificially inflated because the modelled data use the y values to predict the x values.

4.2 Factors Affecting Pond Influence on Stream Temperature

Simple regressions showed significant relationships between increase in maximum 7DADM temperature and several local factors (Fig. 4). Generalized linear models indicated that the top model included all three factors examined: upstream temperature, surface area, and outlet structure type (AICc weight of full model = 0.47, $p < 0.001$, $R^2 = 0.60$). This indicates that each of these factors explain a significant proportion of the variation in the increase in temperature from a given pond.

Ponds on stream segments with lower upstream temperatures tended to cause more warming (Fig. 3A, T = -4.04, p = 0.001, $R^2 = 0.41$). Ponds with maximum 7DADM upstream temperatures <21 °C generally increased stream temperatures by 2 – 8 °C whereas those with upstream temperatures >21 °C generally increased stream temperatures by <2 °C.

Ponds with larger surface areas tended to cause more warming (Fig. 3B, T = 3.26, p = 0.003, $R^2 = 0.32$). Ponds with surface areas of >0.5 acres generally increased stream temperatures by 2 – 8 °C whereas those <0.5 acres generally increased stream temperatures by <2 °C.

Ponds created by human dams with surface release outlet structures tended to cause more warming than those created by porous beaver dams or by the human dam with a subsurface outlet structure that drew from below the pond surface (Fig. 3C, W = 76.0, p = 0.003). On average, ponds with surface release structures warmed stream segments by 3.3 °C (range: 0.5 – 8.7 °C) while those with porous or subsurface release warmed stream segments by 0.1 °C (range: -2.5 – 4.6 °C).

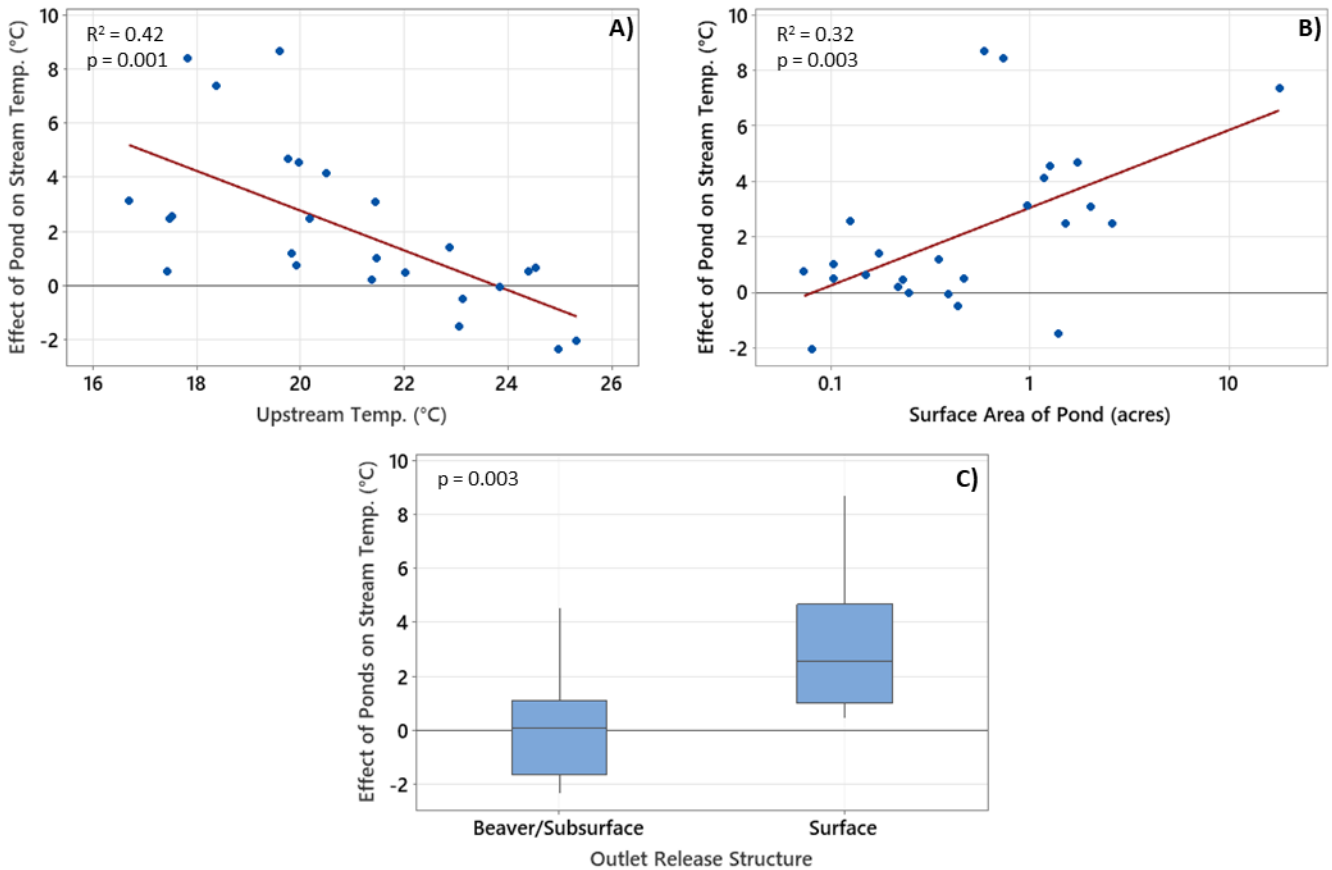

Figure 4 Correlation of pond features with increases in stream temperatures. Three local pond features were correlated with amount of stream warming. A) Ponds located on cold stream segments tended to warm the stream more than those on segments where the stream was already warm. B) Ponds with larger surface areas tended to warm stream sections more than smaller ponds. C) Ponds with flow-over outlet structures tended to warm stream sections more than ponds created by porous beaver dams or by a dam with a subsurface release structure. The y-axis for each graph is the increase in the maximum of the 7-day average of the daily maximum temperature (7DADM) over the entire summer (values averaged across years for sites with multiple years of data). The x-axis in A) is the maximum 7DADM at the upstream location.

5. Discussion

Inline ponds generally increased stream temperatures in the Johnson Creek watershed. The effects of individual ponds varied depending on several factors, but the majority of ponds increased summer stream temperatures by several degrees Celsius. These ponds generally caused stream segments to exceed the instream temperature standard for salmon rearing and migration by several additional weeks each summer. Most stream segments were already exceeding the temperature standard for a portion of the summer before they encountered inline ponds, and these ponds increased this issue.

Several factors were shown to be correlated with a pond's effect on stream temperature: upstream temperature, surface area, and outlet structure type. Cooler streams tended to experience more warming than streams that were already relatively warm. This indicates that efforts targeting ponds on cool streams, such as tributaries and headwater areas, may have the greatest impact on cooling stream temperatures. Ponds with larger surface areas tended to warm streams more than those with smaller surface areas. Therefore, larger ponds may be prioritized for retrofit or removal. We did not examine depth, streamflow, or shade in this study which likely have substantial effects of the amount of warming though stratification and attenuation of solar radiation.

Outlet structures appear to have a strong effect on the amount of warming. Flow-over structures which skimmed the hottest water from the surface of ponds tended to increase stream temperatures much more than those which drew cooler water from below the pond surface. Observations of the beaver dams indicated that generally no water spilled over the tops of the dams during the summer months and that water was percolating through the entire structure, presumably drawing from the entire water column. Instantaneous observations taken in several ponds (human and beaver) during the hottest part of the summer in 2017 and 2019 showed that most ponds >2' deep possessed some thermal stratification. Therefore, targeting dams with surface outlet structures is more likely to reduce stream temperatures addressing than those with other structures. Additionally, retrofitting ponds to be porous or have subsurface release structures may be a cost-efficient and worthwhile option for reducing stream temperatures where pond removal is not desired and where fish passage is not a concern.

The factors identified work together to explain the increases in stream temperature from a given pond. One clear example of this is with the beaver ponds. Most beaver ponds in this study had little effect on downstream temperatures, and these tended to be deep, narrow, shaded ponds on the mainstem of the creek which was already warm. Conversely, two beaver ponds increased stream temperature substantially, with one being among the top ponds in the watershed for increase, and these were large, shallow, sunny ponds on a small, cool, spring-fed stream. Although beaver ponds tended to increase stream temperatures less than human ponds of similar sizes and upstream temperatures, they had a wide variety of impacts dependent on the specifics of the pond.

The factors identified in this study can contribute to prioritization for pond removal or retrofit. There are additional factors that could also be considered such as overall thermal loading, potential rearing habitat provided by the pond, the willingness of the landowner for change, and the feasibility and cost of a project. The Johnson Creek Watershed Council has already been using this information to target ponds for removal and retrofit. By the writing of this report the pond showing the largest increase in stream temperature (Centennial Pond) had already been retrofit through a project led by the council and projects for several other ponds were actively in process.

This study examined summary data for measures of temperature maxima and exceedances over the entire summer. There are other aspects of this data which may be biologically relevant, such as daily minima or timing of warming. Fig. 5 shows example raw data from six ponds which show very different patterns. Additionally, this study examined stream temperatures immediately upstream and downstream of ponds, but it did not look at the legacy effects of these ponds on the stream. Changes in stream temperature may be sustained far downstream or may attenuate in a short distance dependent on factors such as flow rate, shade, and microclimate. This is a substantial gap in the knowledge of the effects of inline ponds on stream temperatures in Johnson Creek and warrants more study.

This study indicates that many inline ponds increase stream temperatures throughout Johnson Creek and its tributaries. Therefore, removing or retrofitting ponds would likely reduce thermal loading and be an important part of working towards meeting the instream water quality temperature standard. Individual ponds showed large differences in how much they increased stream temperature. Efforts to reduce temperature impacts could prioritize ponds on cool stream sections, those with large surface areas, and those which draw water off the surface of the pond. The results of this study may also be useful in other watersheds with inline ponds where temperature reduction is desired.

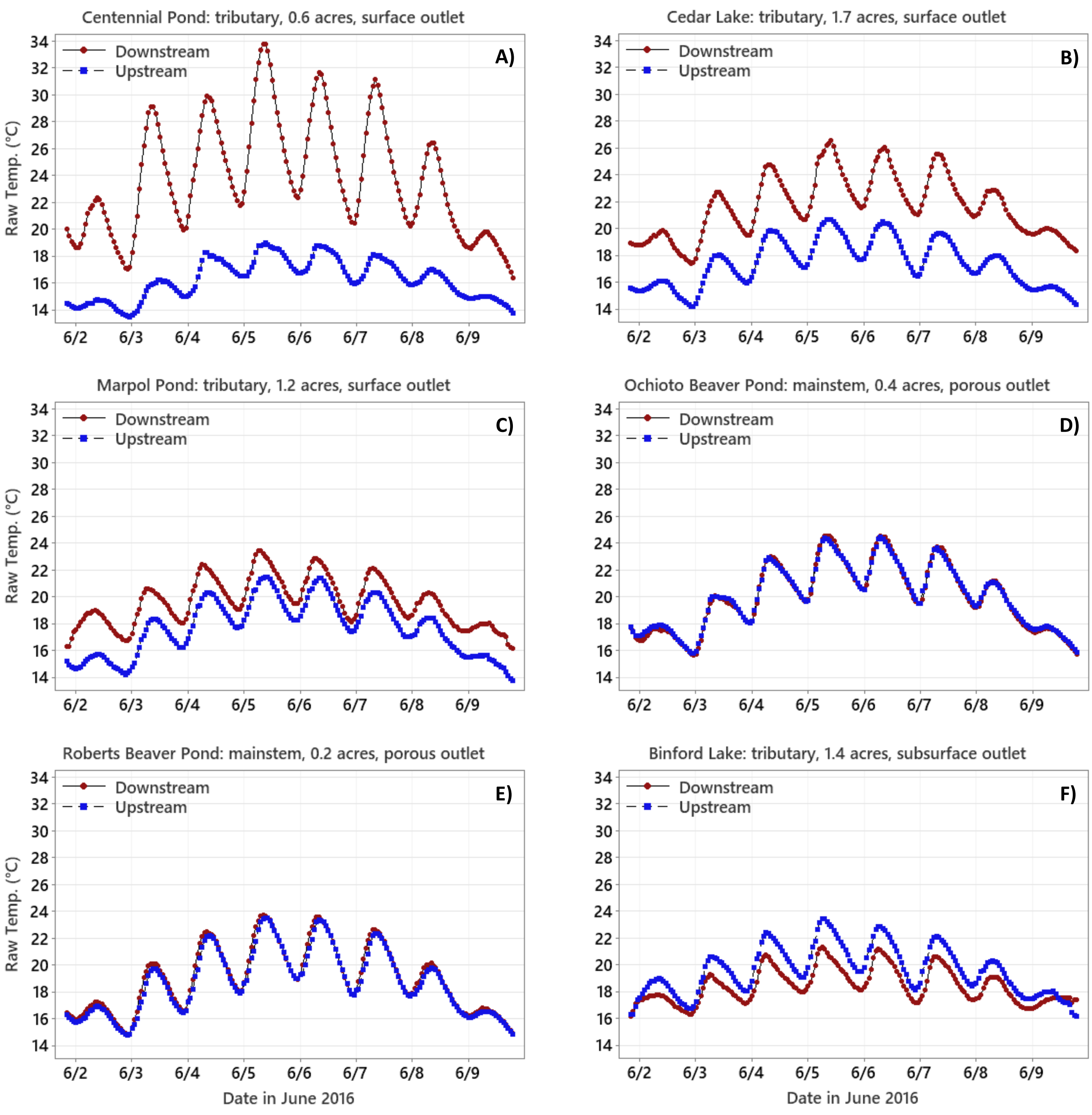

Figure 5 Raw data from six representative ponds during a warm week in 2016. The raw hourly data from these six example ponds demonstrate how various factors contribute to stream warming and how patterns of temperature effects differ among ponds. Ponds A-C warmed the stream, ponds D-E had no significant effect, and pond F cooled the stream. Pond names and major measured factors are described at the top of each graph.