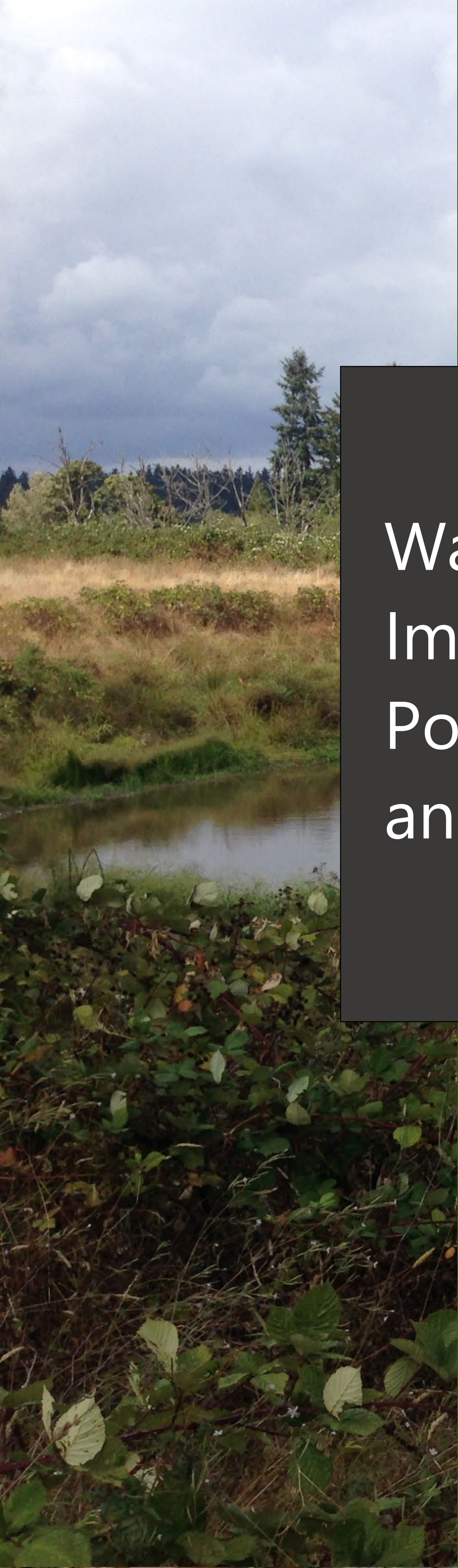

Water Temperature Impacts From In-Channel Ponds in Portland Metro and Northwest Region

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Abstract

This project represents Phase 1 of a potential two-phase study of in-channel ponds (ICPs) in Oregon. In Phase 1, DEQ staff compiled, analyzed, and summarized data acquired to date from local monitoring organizations to address, for internal DEQ purposes, the critical question: "Are in-channel ponds linked to in-stream water temperature increases in Oregon?" Several sub-questions exist regarding the magnitudes, patterns, consistency, and regulatory aspects of any temperature increases. Phase 1 results and remaining gaps are presented in this context.

Data from 26 ICPs were analyzed, representing 19 anthropogenic – human constructed – ponds and seven beaver ponds (Fig. 1, Tbl. 1). All ICPs were in the Portland metro area (DEQ's Northwest Region), with 22 in the Johnson Creek (including six beaver ponds), three in the Sandy River (including one beaver pond), and one in the Columbia Slough watersheds. Over 400,000 pairs of upstream-downstream temperature data provided by local entities were aggregated into hourly and seven-day average daily maximum (7DADM) summary data for analysis. Interpretation focused on 7DADM values (n=6838) given their time integration and relevance to water quality standards.

Across the 19 studied ICPs, the median and mean hourly-based upstream-downstream temperature increases ("T_{Gain}") were 1.55°C and 1.86°C, respectively. Corresponding median and mean 7DADM T_{Gain} were 1.74°C and 2.43°C, respectively (Tbl. 4). The range of median 7DADM T_{Gain} for individual ICPs was 0.09-6.0°C (Fig. 2, Tbl. 3). Among 15 ICPs with surface outlets, 14 had statistically significant 7DADM T_{Gain} (Tbl. 3, i.e., $p<0.05$ by Generalized Estimating Equation method) and the median 7DADM T_{Gain} among individual ICPs was 1.55. Thirteen of these surface-outlet ICPs had median 7DADM T_{Gain} ≥0.5°C (Tbl. 3).

Three ICPs had significantly negative 7DADM T_{Gains} (median range: $^{(-)}$0.85- $^{(-)}$0.40°C). The two ICPs with subsurface outlets did not show significant 7DADM T_{Gain}, suggesting that outlet modification may reduce ICP discharge temperature vs. surface outlets; such modification may however increase in-pond temperature (not studied). On a monthly basis, ICPs had median 7DADM T_{Gain} ≥2.0°C from May-August, with the greatest 7DADM downstream temperatures occurring in July-August (median >20°C) (Fig. 4).

Among beaver ponds, two had significant median 7DADM T_{Gains} (0.31, 0.5), three had insignificant changes, and two had significant decreases (-1.1, -0.15); thus, among beaver ponds with significant 7DADM temperature changes, the median and mean 7DADM T_{Gain} was 0.08 and 0.04, respectively (°C, Tbl. 3).

Conclusions: Generally and as previously reported by local entities,[1,2] human-built ICPs showed strong trends of raising downstream temperatures in the study area. Fourteen of 17 ICPs (82%) with surface or porous outlets showed significant T_{Gain}. Remaining questions or study limitations pertain to:

A. In-channel pond impacts on water temperature beyond the studied basins (i.e., statewide) and time periods.
B. Which factors most influence ICP temperature impacts, e.g., pond, watershed, climatic, hydrologic parameters.
C. If other environmental factors influence water temperature more strongly than ICPs, e.g., watershed land use, shading.
D. This report did not focus on beaver dams or beaver dam analogues. Focused literature review or additional monitoring may be required to draw related conclusions.

Recommendations: Alongside the existing evidence of ICP water temperature impacts and identified gaps, DEQ's interest in and potential uses of ICP impact information should drive decision-making on if and how to conduct additional study (Phase 2); this suggests management discussion beyond the scope of this report. Based on this report, however, DEQ might consider (a) recommending denial of ICP water right permits through the Oregon Water Resources Department unless applicants provide evidence that water temperature impacts are unlikely, or (b) supporting removal of ICPs as a generally effective practice to reduce water temperature impacts. If DEQ requires more specific or deep-rooted evidence (e.g., to (c) compel landowners to remove ICPs or defend decisions in court), then additional, more refined analysis across important geographic, watershed, and design conditions, and/or critical time periods is warranted.

Introduction

In-channel ponds include constructed impoundments built between a stream channel's banks for a range of human uses (e.g., irrigation, livestock, aesthetics, recreation, nurseries); ICPs also form behind beaver dams. Although ICP designs vary, they commonly include dams that retain water until overflow. Recent Johnson Creek Watershed-based studies reported that ICPs with surface overflow (i.e., "surface outlet") dams increase downstream water temperatures when water is released, and suggested causative mechanisms (e.g., that warmer water overflows first; slow-moving pond water absorbs more sunlight).[1,2] However, a comprehensive aggregation and analysis of these data has not been completed.

Despite a general understanding that ICPs often act as a downstream heat source in Oregon[1,2] and other (potentially less relevant) conditions,[3–7] their installation and permitting continues in Oregon. This is partly due to complicating regulatory factors. For one, rules enacted in the 2000s were intended for retroactive approval of smaller existing ponds (dam ht.<10', area <9.2 ac-ft) for water rights (WR) permits, but not as a solution for subsequently installed ponds. Yet, ICPs are routinely built without prior regulatory permits, reviews, inspections, approvals, or other documentation unless a post-installation complaint or other situation triggers such and/or requires a water right permit application. When reviewing water right applications, it is difficult for DEQ staff to recommend conditions to reduce water temperature impacts of an already-constructed ICP.

Except for two recent Portland-area reports that showed significant water temperature impacts of surface-outlet ICPs,[1,2] the few published studies of in-stream water temperature effects of small dams and impoundments do not generally reflect watershed characteristics relevant to much of Oregon.[3,4,7–10] Several such studies, however, reported that small dams increased downstream water temperatures in their study areas (e.g., MA, MI, PA, and France)[3–5,9], and that dam removal[4] or modification[11] can mitigate these impacts. Conversely, reports of beaver dam and beaver-dam analogue temperature impacts vary;[12,13] some recent studies in Oregon and adjacent states indicate a general lack of negative impacts[14–16] and/or positive water temperature benefits for cold-water species.[17,18] Yet, a recent study of eight beaver dams in the Umpqua River Basin reported significant downstream monthly mean daily maximum water temperature gains (1.9°C) that attenuated with downstream distance; this study suggested caution or further study when considering beaver dam analogues for water quality management.[12]

This project phase was targeted to address the primary question: "Are ICPs linked to in-stream water temperature increases in Oregon?" A few tangential questions were also considered. Although much of the studied dataset was previously reported and analyzed,[1,2] DEQ opted to analyze a somewhat broader dataset to understand the data, confirm initial results, expand the (group-wise) statistical analysis, and determine if and what further steps (e.g., new monitoring data collection, existing information mining) may be warranted to aid potential DEQ decision-making.

Methods

Scope

In Phase 1, DEQ staff compiled, processed, verified, analyzed, and summarized ICP water temperature data provided by the Interjurisdictional Committee for Johnson Creek member organizations, several of whom were responding to DEQ requests for data. We reviewed existing reports by the members and conducted an academic literature search and review. Phase 1 would conclude when the analysis indicated answers (e.g., "yes", "no", "insufficient information") to the following questions:

1. Are ICPs linked to in-stream water temperature increases in Oregon?
    a. If yes, how are these effects characterized? For example, in terms of size, consistency, time periods, downstream and geographical extent.
    b. If yes, what are the causative factors and which are most important? For example, various mechanisms, situational conditions, and design parameters.

2. Can DEQ make regulatory recommendations for ICPs now? If "yes", what and what applicability?

The Phase 1 goal was to (a) determine if we can answer the above questions and (b) answer them as feasible. If gaps prevent this (and if DEQ wants the questions answered), this report would recommend a Phase 2 process to address this, which could include additional data collection or analysis. The Phase 1 deliverable is this summary report that (i) compiles, analyzes, and summarizes available Oregon ICP water temperature data, (ii) addresses the two primary questions, (iii) identifies new or remaining knowledge gaps, and (iv) outlines an optional strategy to address them.

Study sites and data

To facilitate data aggregation and comparisons, DEQ only analyzed ICPs with water temperature data reported at ≤2-hr intervals for ≥3 months each year. Monitoring typically occurred from May to October. The earliest date was March and the latest date was December. Fourteen ICPs had one year and 12 had ≥2 years of data. Continuous water temperature sensors were deployed a few inches above the streambed. A previous report[1] details the typical sensor placement and QA/QC.

The analyzed dataset represents twenty-six individual ICPs with previously collected upstream (T_{US}) and downstream (T_{DS}) water temperature data (Fig. 1, Tbl. 1). All analyzed ICP data were provided by the City of Gresham and the Johnson Creek Watershed Council.[1,2] Twenty-two of approximately 70 total ICPs identified in the Johnson Creek Watershed were monitored[1] along with three ICPs in the Sandy River Basin and one in the Columbia Slough Watershed. Nineteen ICPs were classified “anthropogenic”, meaning that their dam structure or “footprint” (ponding area) were a product of human development. Note that DEQ categorized two of the three Errol Springs Creek ICPs as human-and beaver-influenced, while a previous analysis categorized them as beaver ponds.[1] DEQ made this distinction because while Errol 1 & 2 are currently flooded by beaver dams, they were originally developed as trout-rearing ponds and their physical footprints reflect human-caused disturbance (e.g., they are relatively large with little to no shading). Thus, for analysis and interpretation, Errol 1 & 2 are categorized as “anthropogenic”, while Errol 3 Beaver is categorized as “beaver”.

The studied ICPs reflects different flow outlet structure types (i.e., surface, subsurface, and porous (beaver)) and a range of dimensions and *in situ* conditions such as location, surface area (177-10,400 m^2), elevation (80-632 feet above mean sea level) and shading (qualitatively/visually assessed) (Tbl. 1). A Certificate of Water Right was found for eight of the anthropogenic ICPs at the OWRD online search page.

Data processing and analysis

For each ICP, all temporally paired water temperature data (i.e., simultaneous T_{US} and T_{DS} data) were extracted; this yielded ~400,000 data pairs. The variable “T_{Gain}” was then calculated for each pair as: $T_{Gain} = T_{DS} - T_{US}$. T_{US}, T_{DS}; and T_{Gain} data were summarized as rolling seven-day average daily maximums (7DADMs) (n=6838) and included as response variables of interest in statistical models (Generalized Estimating Equations). Predictor variables included ICP ID, type (beaver or anthropogenic), outlet type, T_{US}, and water temperature date. Because multivariate statistical modeling should be completed with single versus multiple models and due to insufficient data, additional descriptors (e.g., ICP dimensions, flows, shading) were not included in the final model or analyzed separately. Statistical analysis was conducted on numerical and ranked outcome data, and results of multiple methods (i.e., Generalized Linear Mixed Models, Repeated Measures ANOVA) were assessed to support GEE analysis. Discussion focuses on T_{Gain} as this most directly addresses the critical question of this report.

Results and discussion

Statistical analysis (GEE) of the ICP water temperature data confirmed that (a) for the ICP group, $T_{DS}>T_{US}$ (i.e., T_{Gain} was significant, $p<0.01$, Tbl. 2). The respective median and mean upstream-downstream 7DADM T_{Gains} were 1.74 and 2.43°C (Tbl. 4). The following discussion focuses on median values as they are more resistant than means to outlier effects and skewed distributions, and thus represent a more conservative estimate of central tendency.

Statistical analysis also confirmed that most (14 of 17, 82%) ICPs with surface or porous outlets had significant positive median T_{Gains} (Tbl. 3). T_{Gain} was insignificant for one of these (Waldorf) and significantly negative for two (Persimmon 2 and Kelley Cr 1). The remaining ICPs (Kelly Cr. and Binford Lk., with subsurface outlets) showed respectively insignificant and significantly negative (-0.40°C) median T_{Gain}, suggesting that outlet modification may prevent downstream T_{Gain}; yet, further assessment may be required to determine if such modifications increase in-pond water temperatures to an important extent. The range of median T_{Gains} (°C) for individual surface-outlet ICPs was $^{(-)}$0.85-$^{(+)}$6.0 (median: 1.55; Tbl. 3); The corresponding 25th and 75th percentiles were 0.45 and 3.0, respectively. Together, this shows that ≥75% of the calculated 7DADM T_{Gains} at each of ≥75% of anthropogenic surface-outlet ICPs were ≥0.45°C.

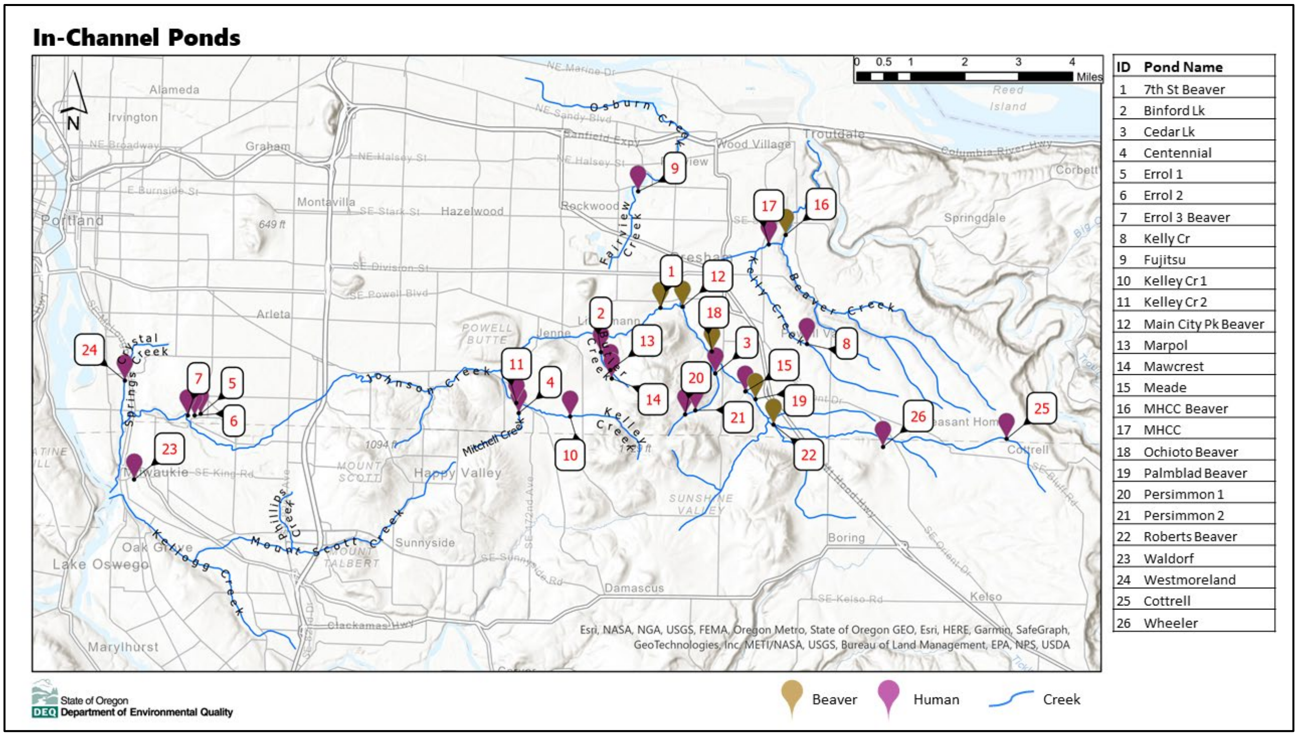

Figure 1: Map of monitored ICPs.

The implications for water temperature standard exceedance associated with these T_{Gains} are potentially major. Figures 2 and 3 show the complete distributions and summary data (i.e., medians, 25th & 75th percentiles, maxima, minima) of 7DADM T_{Gain}, T_{US}, and T_{DS} for each ICP; 13 of the 19 ICPs had median T_{DS}'s above the 18°C summer standard for salmonid rearing and migration, and two more had median T_{DS}'s (i.e., ≥17.4°C) approaching it. Anthropogenic ICPs with subsurface outlets (n=2) and beaver ICPs (n=7) show comparatively small to insignificant or negative T_{Gains} from upstream to downstream monitoring locations (e.g., median T_{Gain} (°C) was ≥0.5 for only one beaver ICP, and for two others was 0.31 and 0.36; Fig. 2, Tbls. 1, 3, 4). These results should be interpreted with caution, however, given divergent results reported in other beaver dam and beaver dam analogue studies.[12–21]

Table 1. Analyzed ICP information

ICP ID	Water Right Cert # (if present)	Lat.[1]	Long.[1]	Elev.[1] (ft)	Shaded[2] (None, L, M, H)	Stream	Watershed	Type	Outlet Structure[3]	Pond S.A. (m^2)[3]	Data Year(s)[3]
7th St Beaver	N/A	45.4954	-122.4382	269	L/M	Johnson Cr.	Johnson Cr.	Beaver	Porous	1563	2018
Binford Lk	28265	45.4831	-122.4606	297	L	Butler Cr.	Johnson Cr.	Human	Subsurface	5605	2013, '16, '17
Cedar Lk	84789	45.4781	-122.4166	344	L	Hogan Cr.	Johnson Cr.	Human	Surface	7046	2008, '16
Centennial	None found	45.4662	-122.4913	326	N	Mitchell Cr.	Johnson Cr.	Human	Surface	2365	2014-16
Centennial No Dam	N/A	45.4662	-122.4913	326	N	Mitchell Cr.	Johnson Cr.	Human	None	N/A	2019-21
Errol 1	N/A/None	45.4639	-122.6127	96	L	Errol Springs Cr.	Johnson Cr.	Human/Beaver	Porous	6070	2018
Errol 2	N/A/None	45.4634	-122.6150	89	N	Errol Springs Cr.	Johnson Cr.	Human/Beaver	Porous	5059	2018
Errol 3 Beaver	N/A/None	45.4634	-122.6176	80	M	Errol Springs Cr.	Johnson Cr.	Beaver	Porous	607	2018
Fujitsu Ponds	None found; 4 Lg ICPs	45.5264	-122.4478	192	N	Fairview Cr.	Columbia Slough	Human	Surface	72123	2011, '13, '14, '16, '17, '19
Kelley Cr. 1	86731	45.4656	-122.4717	342	L/M	Kelley Cr.	Johnson Cr.	Human	Surface	436	2018
Kelley Cr. 2	None found	45.4689	-122.4923	300	M	Kelley Cr.	Johnson Cr.	Human	Surface	177	2018, '20
Kelley Cr. 2 No Dam	N/A	45.4689	-122.4923	300	M	Kelley Cr.	Johnson Cr.	Human	None	N/A	2021
Main City Pk Beaver	N/A	45.4958	-122.4298	276	L/M	Johnson Cr.	Johnson Cr.	Beaver	Porous	1884	2018
Marpol	28128	45.4784	-122.4568	354	N	Butler Cr.	Johnson Cr.	Human	Surface	4779	2016-18
Mawcrest	None found	45.4761	-122.4562	373	M	Butler Cr.	Johnson Cr.	Human	Surface	296	2016-17
Meade	None found	45.4734	-122.4051	344	H	Brigman Cr.	Johnson Cr.	Human	Surface	701	2015-16
MHCC Beaver	N/A	45.5157	-122.3910	259	H	Beaver Cr.	Sandy R.	Beaver	Porous	322	2018
MHCC	89068	45.5130	-122.3974	271	L/M	Kelly Cr.	Sandy R.	Human	Surface	8161	2011, '13, '15, '16, '17, '19
Ochioto Beaver	N/A	45.4840	-122.4181	304	M	Johnson Cr.	Johnson Cr.	Beaver	Porous	1754	2016
Palmblad Beaver	N/A	45.4715	-122.4012	354	M	Johnson Cr.	Johnson Cr.	Beaver	Porous	988	2016, '17
Persimmon 1	87865	45.4669	-122.4278	556	M	Hogan Cr.	Johnson Cr.	Human	Surface	3923	2018
Persimmon 2	87865	45.4681	-122.4239	527	L	Hogan Cr.	Johnson Cr.	Human	Surface	1409	2018
Roberts Beaver	N/A	45.4647	-122.3940	384	M	Johnson Cr.	Johnson Cr.	Beaver	Porous	880	2016
Waldorf	12103	45.4458	-122.6374	56	H	Spring Cr.	Johnson Cr.	Human	Surface	418	2012
Westmoreland	None found	45.4723	-122.6420	36	N	Crystal Springs Cr.	Johnson Cr.	Human	Surface	10400	2012
Cottrell	None found	45.4623	-122.3050	632	L	Johnson Cr.	Johnson Cr.	Human	Surface	2965	2018
Wheeler	None found	45.4594	-122.3521	494	H	Wheeler Cr.	Johnson Cr.	Human	Surface	506	2018
Kelly Cr.	N/A	45.4866	-122.3820	385	H	Kelly Cr.	Sandy R.	Human	Subsurface	471	2011, '13

[1] Source: Google Earth

[2] Qualitative (visual) assessment of Google Earth imagery

[3] Source: see bibliography[1,2]

Table 2. Statistical results and significance

Model Information	Summary Data					Tests of Model Effects[1]				
	N	Mean	Std. Dev.	Min	Max	df	Rank-based	Sig.	Value-based	p
(Intercept)						1	660.5	**<0.01**	*N/A*	*0.32*
Response: T_{Gain} (°C), 7DADM	6502	2.11	2.85	-3.27	12.45	1	1072	**<0.01**	369.0	**<0.001**
Covariate: T_{US} (°C), 7DADM	6502	17.10	2.68	9.82	32.36	1	8.744	**0.003**	4.216	**0.040**
Correlated Data Summary										
Pond ID (Subject Effect), # of Levels	26	# of Meas./Subject, Min			75	Probability Dist.			Normal	
Date (W/in-Subject Effect): # of Levels	1660	# of Meas./Subject, Max			871	Link Function			Identity	
Subjects, #	26	Correl. Matrix Dimension			1660	Working Correl. Matrix Structure			Independent	

[1] Method: Generalized Estimating Equation modeling, repeated on numeric & ranked values for QA/QC. Wald Chi-Square scores presented (Type III).

Figure 2. Boxplots of 7DADM T_{Gain} (°C) data by ICP.

Beaver ponds (n=7) are on the right. The horizontal lines represent no change (black), 0.5°C gain (purple), and 1°C gain (red), respectively.

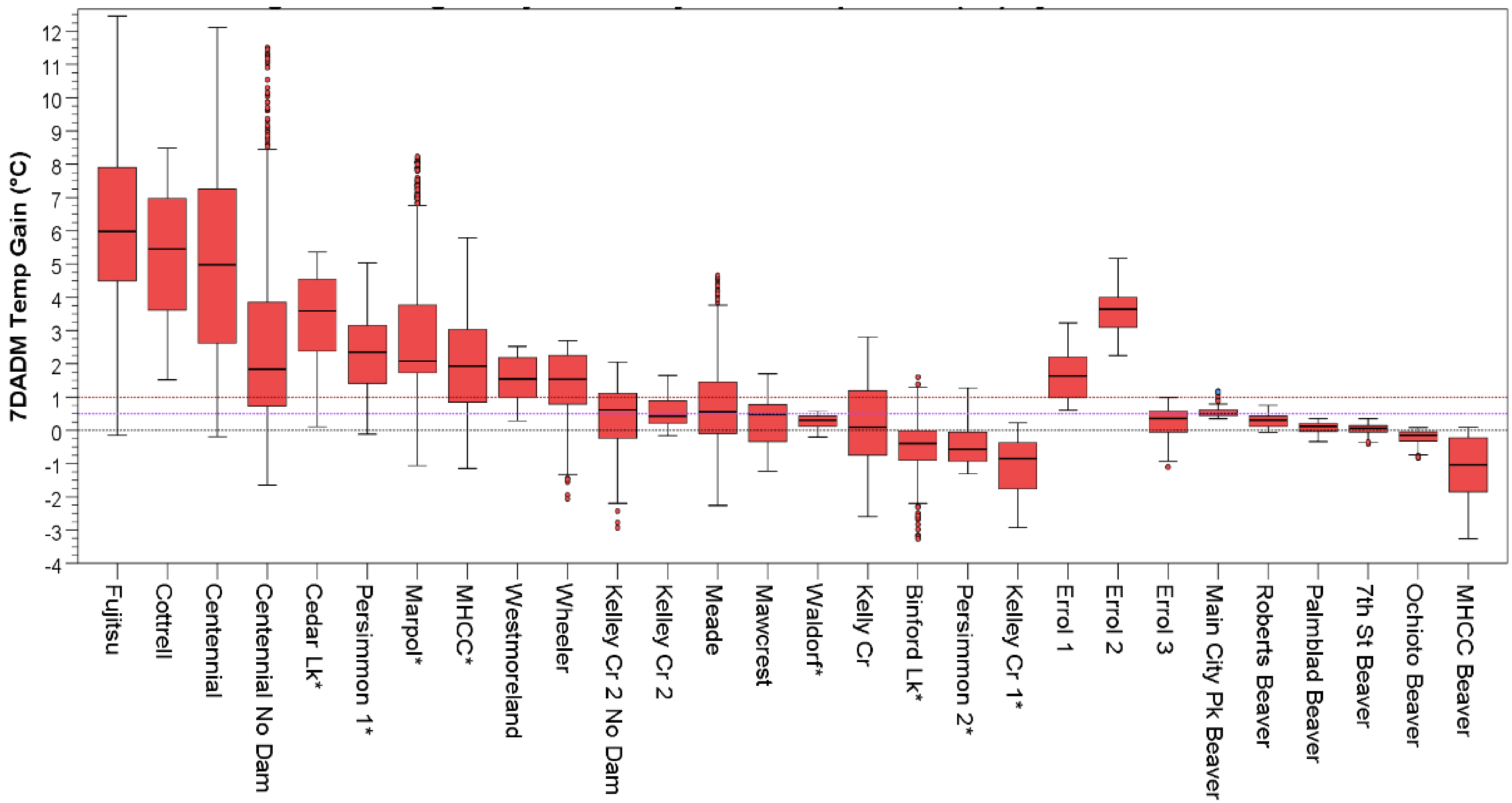

Figure 3. Boxplots of 7DADM TUS, TDS, and TGain data (°C) by ICP.

Beaver ponds (n=7) are on the right. The horizontal lines represent no change (black) and 1°C gain (red), respectively.

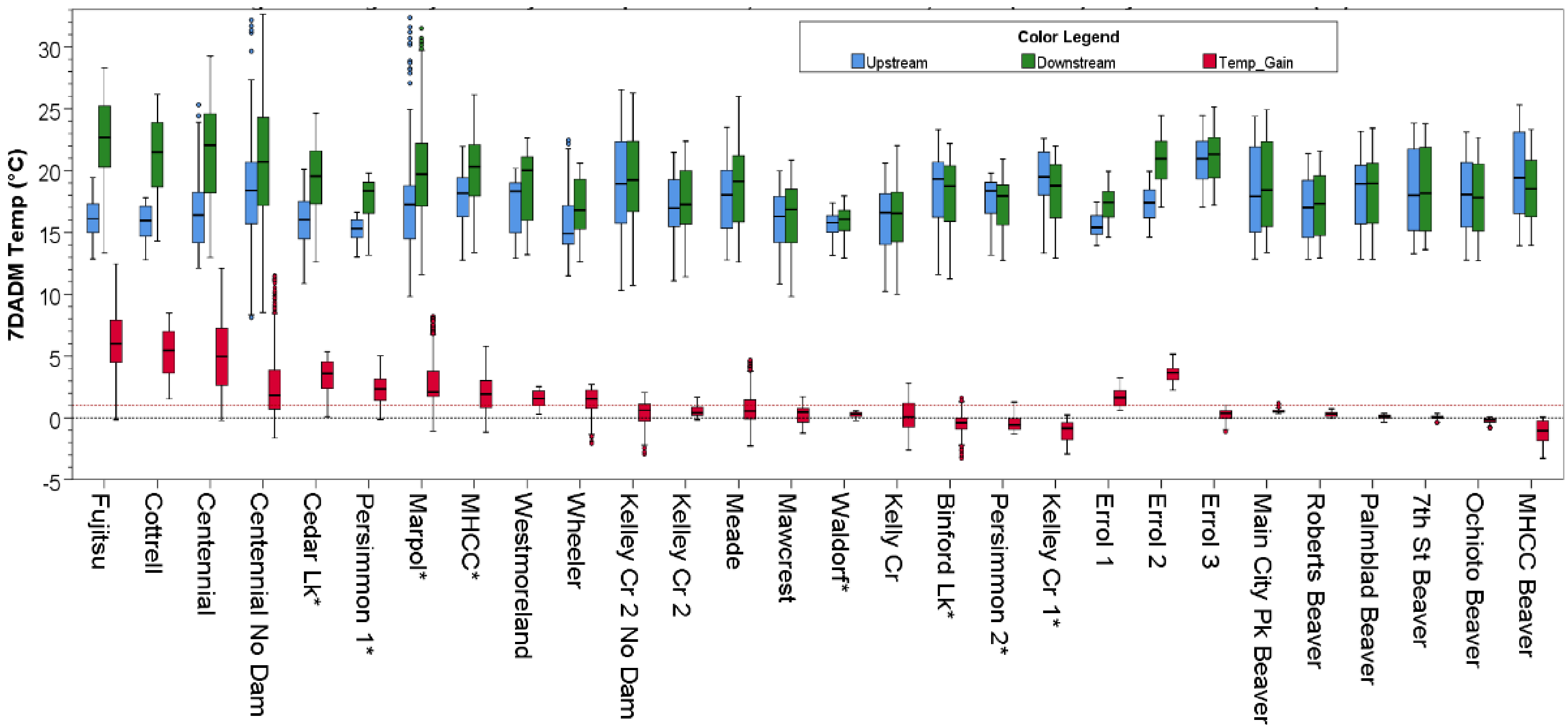

Table 3. Summary Data: Change in 7DADM WT (°C) for individual ICPs.

Median TGain with p<0.05 were considered significantly different than 0 (°C), which is roughly equivalent to <5% probability of a false positive (or false negative) difference.

ICP	Mean T_{Gain} (°C)	Median T_{Gain} (°C)	LCL95	UCL95	n	p	ICP	Mean T_{Gain} (°C)	Median T_{Gain} (°C)	LCL95	UCL95	n	p
Fujitsu	6.24	**5.98**	5.83	6.14	925	**<0.001**	Kelly Cr	0.21	0.09	-0.13	0.27	362	0.080
Cottrell	5.29	**5.46**	4.93	6.46	127	**<0.001**	Binford Lk*	-0.52	**-0.40**	-0.45	-0.35	476	**<0.001**
Centennial	4.97	**4.97**	4.54	5.36	522	**<0.001**	Persimmon 2*	-0.42	**-0.57**	-0.63	-0.45	105	**0.003**
Cedar Lk*	3.30	**3.60**	3.33	3.75	277	**<0.001**	Kelley Cr 1*	-1.06	**-0.85**	-0.98	-0.71	126	**<0.001**
Persimmon 1*	2.34	**2.34**	2.03	2.62	105	**<0.001**	Errol 2	3.59	**3.65**	3.48	3.77	140	**<0.001**
Marpol*	2.95	**2.09**	1.97	2.19	455	**<0.001**	Errol 1	1.67	**1.63**	1.40	1.78	146	**0.032**
MHCC*	2.07	**1.92**	1.79	2.14	823	**<0.001**	Errol 3	0.23	0.35	0.29	0.44	140	0.106
Westmoreland	1.53	**1.55**	1.34	1.88	88	**<0.001**	Main City Pk Beaver	0.57	**0.50**	0.47	0.57	81	**0.041**
Wheeler	1.24	**1.54**	1.16	1.74	127	**<0.001**	Roberts Beaver	0.29	**0.31**	0.27	0.35	176	**0.038**
Meade	0.79	**0.56**	0.46	0.75	334	**<0.001**	Palmblad Beaver	0.09	0.11	0.08	0.15	312	0.062
Mawcrest	0.26	**0.47**	0.33	0.57	326	**<0.001**	7th St Beaver	0.03	0.05	0.00	0.10	81	0.091
Kelley Cr 2	0.52	**0.42**	0.34	0.51	178	**<0.001**	Ochioto Beaver	-0.22	**-0.15**	-0.20	-0.13	176	**0.011**
Waldorf*	0.26	0.30	0.28	0.32	149	0.076	MHCC Beaver	-1.18	**-1.05**	-1.30	-0.80	81	**<0.001**

* ICP was linked to a WR permit. **Bold values** = statistically significant means (family-wise error rate <0.05). Red font = negative values.
CI = confidence interval (around the mean); SEM = standard error of the mean.
Light gray fill = anthropogenic ICPs, dark gray fill = beaver ICPs, medium gray fill = anthropogenically & beaver-affected ICPs.

Table 4. Mean 7DADM TGain (°C) of ICPs by type and dam outlet type.

Pond Type	Mean	Median	Median, LCL95	Median, UCL95	n
Anthropogenic	2.43	1.74	1.62	1.81	5931
Beaver	0.00	0.07	0.05	0.10	907
Dam Outlet Type					
Surface	2.97	2.26	2.17	2.38	4667
Subsurface	-0.20	-0.28	-0.36	-0.23	838
Porous	0.58	0.21	0.19	0.23	1333

Table 5. Summary 7DADM WT (°C), two ICPs with pre-/post-ICP dam removal data.

Location	Years	n	$T_{US,}$ DADM	$T_{DS,}$ 7DADM	$T_{Gain,}$ 7DADM
Centennial Pre	2014-16	504	16.42	22.07	4.97
Centennial Post	2019-21	544	18.26	19.99	1.21
Kelley 2 Pre	2018, 2020 (May-June)	296	17.24	17.60	0.47
Kelley 2 Post	2020, 2021 (Aug-Nov)	266	17.53	18.77	0.85

Literature comparisons:

As previously discussed, limited directly relevant information is available regarding water temperature impacts of ICPs similar to those assessed herein.[3,4,7–10] Nevertheless, our results agree with small dam studies in other regions (e.g., that most small surface-outlet impoundments increase summer water temperatures up to several degrees Celsius).[3,4,8,9] Likewise, previous studies of many sites included herein reported that anthropogenic ICPs increased the average 7DADM by 2.1°C and the average number of summer days with water temperature standard exceedances by 35 days/year, from 58 to 93 days.[1,2] For beaver ICPs, this analysis aligns with Oregon reports that beaver dams show water temperature effects ranging from benefits (reductions) to no or modest increases,[17–19] while other reports suggest water temperature impacts and the need for further study.[12,13,20,21]

Critical questions

Based on this and related studies, some answers to the project's critical question and sub-questions are possible.

1. **Are human-constructed ICPs linked to in-stream water temperature increases in Oregon?**

   Yes, based on standard statistical hypothesis test interpretations, this is highly probable for ICPs with surface outlets in this study area (>95% confidence). In contrast, two of seven beaver ICPs showed significant T_{Gain}, and the two ICPs with subsurface outlets showed significant water temperature *decreases* (Tbl. 3, Fig. 2)

   a. **If yes, what is the nature and extent of these effects?**

Focusing on surface-outlet ICPs across monitoring seasons, 12 of 15 showed significant 7DADM T_{Gain}. Among these 12 ICPs, the median 7DADM T_{Gain} was 2.0°C (Fig. 2, Tbl. 3) and nine had median 7DADM T_{Gain} >1°C. Among this ICP type, only Kelley Cr 1 and Persimmon 2 had significant negative median T_{Gain}. Additionally, two ICPs with porous outlets (Errol 1 & 2) had significant T_{Gain} (respective medians: 1.63 and 3.65°C; Tbl. 3).

All but one surface-outlet ICP (i.e., Waldorf) had 7DADM T_{DS} data that exceeded the 18°C temperature standard. Across ICPs, T_{DS} exceedances were more frequent and drastic than T_{US}; indeed, T_{US} at four never exceeded the 7DADM standard (Fig 2.) 7DADM T_{Gains} were greatest in summer (Fig. 4). e.g., across all ICPs in July and August, respective median T_{US} and T_{DS} (°C) were ~18.3 and ~20.8, representing ~2.5°C T_{Gain}.

Although strong effects were evident in this study area, we cannot say if or how these results may extend to other Oregon regions and watersheds. Alongside broad geographic- and landscape-based variation, this study's mainly metropolitan extent suggests that effects of riparian shading and other potentially influential stream and watershed characteristics would require additional study. Nevertheless, our results indicate that the water temperature effects of surface outlet ICPs should be of concern.

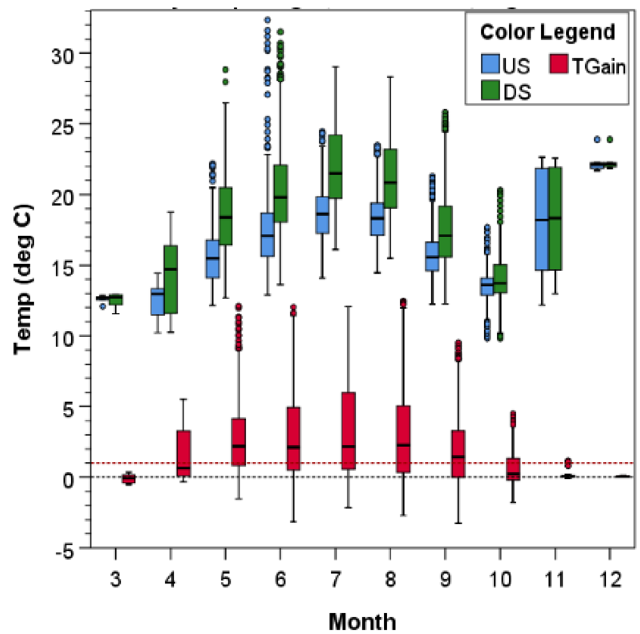

Figure 4. Boxplots of 7DADM T_{US}, T_{DS}, and T_{Gain} data (°C) by month.

b. If yes, what are the causative factors and which are most important? *e.g., influential conditions, design parameters, mechanisms.*

This question was not comprehensively or quantitatively addressed herein. A related study by City of Gresham reported a significant correlation between ICP surface area and T_{Gain},[1] which corresponded with suggestions that a primary ICP T_{Gain} mechanism is when ponded water receives additional sunlight due to reduced shading and increased water retention times.[3,4,12] Further study would likely be required to confirm. This may be possible with the current ICP water temperature data if additional catchment and ICP information were collected. If confirmed, this mechanism may also explain why subsurface outlets did not show significant T_{Gain} in this study. Summer thermal stratification was observed even in shallow ICPs,[1,2] meaning that subsurface outlets would draw deeper, colder water versus surface outlets.

2. Can we make regulatory recommendations for ICPs now?

This is ultimately a DEQ policy and management decision beyond the purview of this report, which may be determined best by a policy-technical group. That said, several *options* are initially evident based on Phase 1. Further study (Phase 2) may however be advisable to support certain options.

a. If yes, what are the recommendations and applicability? The following are example *potential* options:

- Continue to support OWRD efforts to obtain water right permits for ICPs.
- Recommend ICP water right permit denial unless permittee provides evidence that water temperature impacts are unlikely.

- Support voluntary ICP removal as a generally effective best management practice to reduce water temperature. Anecdotal evidence suggests that ICP dam removal or modification is a feasible, effective, and landowner-acceptable solution that also benefits fish passage. DEQ should consider promoting this.
- If new monitoring or modeling is planned, recommend forming a technical group to design the study (e.g., goals, roles, resource needs, data objectives, analysis methods) and to potentially review progress and output.

Recommendations for future work

- The downstream extent of water temperature increases was not assessed. Methods to assess this include temperature modeling and/or additional monitoring locations. *Note: the monitoring organizations typically used professional judgment to pre-select "well-mixed" downstream monitoring points, so we can assume the water temperature changes apply at least that far.*
- The broader geographic applicability (representation) of ICP water temperature effects was not assessed. The geographic applicability could be extended through desktop modeling (potential discussion topic) or new monitoring areas (e.g., different river basins, regions, etc.).
- "Control" sites (comparable sites without ICPs) in Oregon have not been extensively addressed. The water temperature data provided by local partners did include some data for two sites collected before and after ICP removal that provide a preliminary view (Tbl. 5). At the location with more data (Centennial), the median pre- and post-removal 7DADM T_{Gains} are notably different (5.0 and 1.2°C, respectively). The (more limited) Kelley Creek pre- and post- data (0.47 and 0.85°C, respectively) appear to show less of a dam removal effect.
    - *Note:* Hypothesis testing was not completed on these data as pre- and post- periods were different and could not be analyzed as matched pairs. Because some upstream-downstream T_{Gain} is likely even where ICPs are not present (due to increased sunlight exposure with downstream travel time and other factors),[3] it would be beneficial to collect and analyze additional, better matched "with-" and "without-dam" data to better-characterize the effects of ICP dam removal or modification.

Further study would likely be required to address the above considerations. This may be possible with the existing data if additional catchment and ICP information were collected. Local partners have expressed inclination to conduct such work. New monitoring sites and actions with a refined design may facilitate more robust analyses of potential influences. If this is pursued, it would be beneficial to engage in team-based design or prototype monitoring.

Conclusion

Overall, most studied human-constructed ICPs (14 of 17, omitting two ICPs with subsurface outlets) exerted significant water temperature effects at magnitudes of probable downstream concern. The significant T_{Gains} occurred during sensitive time periods, increased in the hottest months, and resulted in water temperature standard exceedances or exacerbations thereof. Among ICPs without significant median T_{Gain} (n=5), two had subsurface outlets (Kelly Cr., Binford Lk.) and two had among the highest median T_{US} of the study; note that increased T_{US} was reportedly linked to reduced ICP T_{Gain} effects.[1,4] From the current data and analysis, DEQ cannot yet conclude if similar effects occur in other regions and watersheds, and if so what are the major patterns and influences. However, direct solar radiation likely increases the temperature of ponded water in all areas of the state. DEQ also cannot say how far the downstream effects of a given ICP may persist.

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