

Impact of Small Dam Removal on Water Quality in Temple Stream, Farmington, Maine

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Site of the former Walton's Mill Dam



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Introduction

Despite the restoration efforts of numerous groups since the 1970s, the population size of Atlantic salmon (*Salmo salar*) in Maine has remained low (USASAC 2020). According to the 2018 recovery plan for Gulf of Maine Atlantic salmon, habitat connectivity is the primary action needed to restore populations ([USFWS and NMFS 2018](#)). Although the main stem of the Kennebec River has dams downstream of the Sandy River blocking access for sea-run fish, the Sandy River watershed remains highly productive for salmon, largely due to the trap-and-truck translocation of adults by the Maine Department of Marine Resources (MDMR). In July 2022, the Atlantic Salmon Federation (ASF) removed Walton's Mill Dam, the only dam on Temple Stream, a tributary to the Sandy River in Farmington. The 6 m tall dam, originally built in 1820, blocked all fish passage and impounded approximately one mile of stream (more than 19 acres). Removal of small, surface-spill dams typically results in increased resiliency to the effects of climate change, including improvements in water quality such as decreased temperatures and increased dissolved oxygen concentrations (Abbott et al. 2022; Paukert et al. 2021; Poff et al. 2002; Zaidel 2018; Zaidel et al. 2021). The natural ledge waterfall at the dam site creates a bedrock sill that may maintain a natural impoundment in the stream within the former impoundment. Environmental monitoring of the stream before, during, and after dam removal was conducted as a multi-partner collaboration between the University of Maine at Farmington, US Fish and Wildlife Service, MDMR, ASF, and Maine Department of Environmental Protection (MDEP). This report characterizes changes in stream water quality following dam removal.

Methods

Study Location

Temple Stream is a tributary to the Sandy River (originally called Anmessokkanti, [UMF 2022](#)), within the homeland of the Nanrantsouak (Norridgewock) Tribe of Wabanaki ([Native Land Digital, 2022](#)). The stream and its tributaries are assigned the Statutory Class of B under Maine's Water Classification Program ([38 M.R.S. §§ 464](#)).

For a description of the watershed and land uses, see [Zimmermann 2022](#). MDMR has been planting salmon eggs upstream of the dam for 13 years and conducting electrofishing surveys to determine average relative abundance of parr (using the catch per unit effort metric of how many parr were captured every minute of fishing). Since removal of the dam, average relative abundance of salmon in Temple Stream is 0.11 parr/minute (MDMR data from 2023-2025). In 2023, 5 redds from wild spawning were found above the former dam (MDMR data). Three locations in Temple Stream were monitored for water quality (Fig. 1): upstream of the Rt.43 crossing, in a deep section of the former impoundment approximately 380 m above the former dam, and approximately 500 m downstream of the former dam. A biological monitoring site 320 m further downstream was sampled in 2020. The dam gates were opened April 28, 2022, and the dam was fully breached July 21, 2022 (see [time lapse photos](#) of the breach and removal).

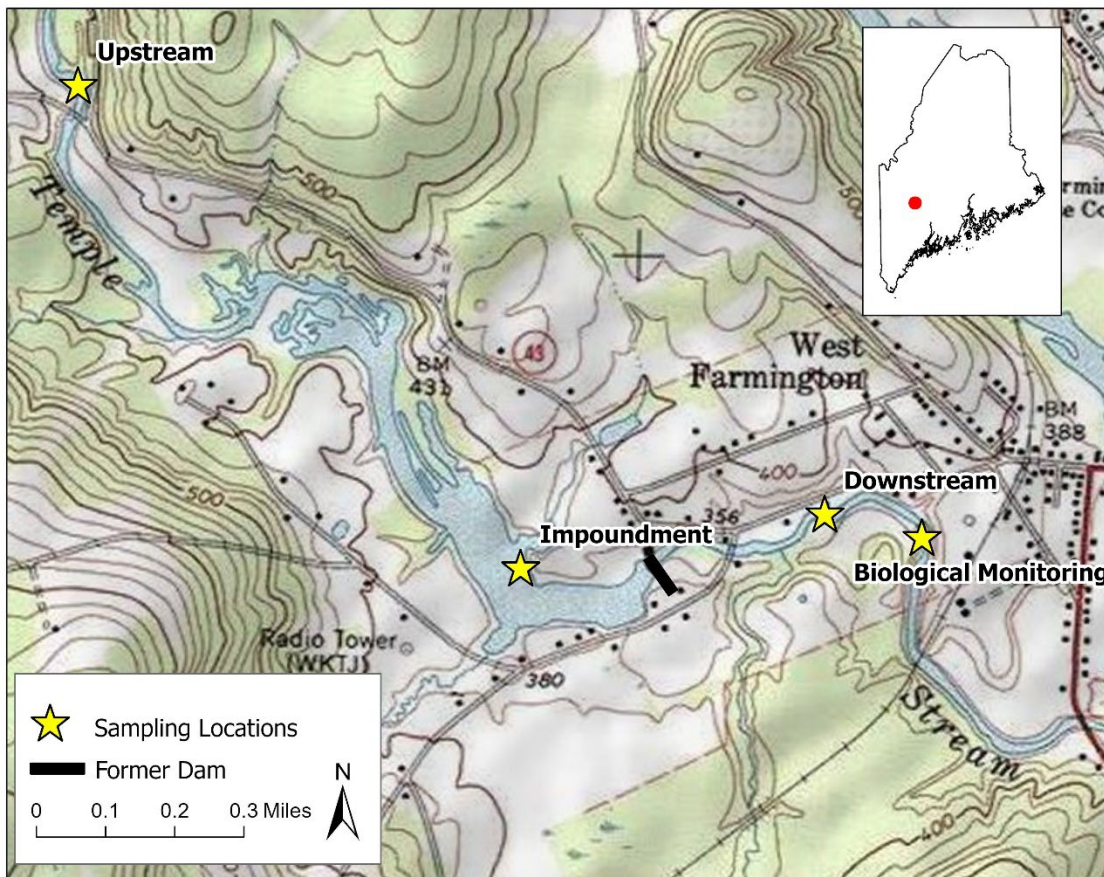


Figure 1. Map of the sampling locations on Temple Stream.

Water Quality

All water quality monitoring activities followed the U.S. Environmental Protection Agency (EPA)-approved Salmon Habitat Monitoring Program Quality Assurance Project Plan (MDEP 2021). Continuous monitoring devices were deployed to collect water quality data (temperature, dissolved oxygen, pH, and specific conductance) every half hour at the upstream and downstream sites from April to October 2021-2023 and every 15 minutes within the impoundment until May 1, when the equipment was buried and lost under the sand (see [Zimmermann 2022](#) for detailed methods). Turbidity was only measured at the downstream site. Continuous data were corrected as needed based on quality control procedures as described in MDEP (2016) and using a sonde as a reference field meter (Eureka Manta2 Sub2 or Eureka Manta+ 20). Surface grab samples for total phosphorus, total Kjeldahl nitrogen (TKN), and nitrate + nitrite as nitrogen were collected in April, August, and October every year from each sample location, following the methods in [Zimmermann \(2018\)](#). In addition, dissolved organic carbon (DOC) was collected in August every year. Macroinvertebrate samples were collected in 2020 at the furthest downstream site and in 2023 at the site below the former dam using rock bags following the Maine Department of Environmental Protection (MDEP) Biological Monitoring Program sampling methods (MDEP 2014).

Data Visualization and Analysis

Water quality data were analyzed using the Water Resources Database (WRDB) 8.0.0.20 (Wilson Engineering 2025) and R 4.4.1 (R Core Team 2024). Figure 6 was created in WRDB. All other figures were created in R using the *ggplot2* package (Wickham 2009). All data are presented as mean \pm standard deviation (SD). Linear mixed models from the *lme4* package were used to test statistical significance with an α level of 0.05, and estimated marginal means *emmeans* package with Tukey post-hoc adjustment for multiple comparisons (Bates et al. 2015; Lenth 2023). Durations of stressful events, based on thresholds for the protection of salmon and other aquatic life, were calculated based on how many consecutive data points exceeded the water quality threshold before recovery.

Quality control issues in 2023, such as from damage or burial by sediments and debris from storm flows, caused rejection of 2% of specific conductance data (6.8 cumulative days), 3% of pH data (7 cumulative days) and 14% of DO data (1.7 cumulative months, not including the burial and resulting loss of equipment in the former impoundment following the May storm). Data flagged due to equipment malfunctions, primarily due to the sensor wiper getting jammed with debris, included 26% of turbidity data (3.3 cumulative months). Data flagged due to corrections included 2% of specific conductance data (7.3 cumulative days), 3% of temperature data (10 cumulative days), 8% of pH data (1 cumulative month) and 19% of DO data (2.5 cumulative months). For quality control issues in the first two years of the study, see the prior reports ([Zimmermann 2022](#), [2023](#)). For any non-detect data, reporting limits were used in analysis.

Results and Discussion

Weather

The first two years of the study were characterized by warm, dry winters and abnormally dry conditions from June through September, escalating to moderate (2022) to severe (2021) drought in July and August (NOAA 2023; U.S. Drought Monitor 2023). In contrast, 2023 was wetter than normal, with more than twice as much rain as the prior two years (0.6 m in 2021, 0.7 m in 2022, and 1.3 m in 2023), including a large flood event on May 1 of 5 inches of rain in 24 hours (Fig. 2; Weather Underground, 2023). Increased rain may have eased some of the potentially stressful conditions for salmonids and other fishes caused by low flow, such as improving access to cold water refuges.

Stream Temperature

Salmon prefer cold waters (Stanley and Trial 1995). The temperature threshold for optimal growth is less than 20°C (Jonsson et al. 2001; [USEPA 1986](#)). Salmon experience physiological stress (e.g., stop feeding) and seek cold water when temperatures are above 22°C (Cunjak et al. 2005; Elliott and Elliott 2010; Lund et al. 2002). Maximum temperature for the survival of adults occurs at 26-27°C (Shepard

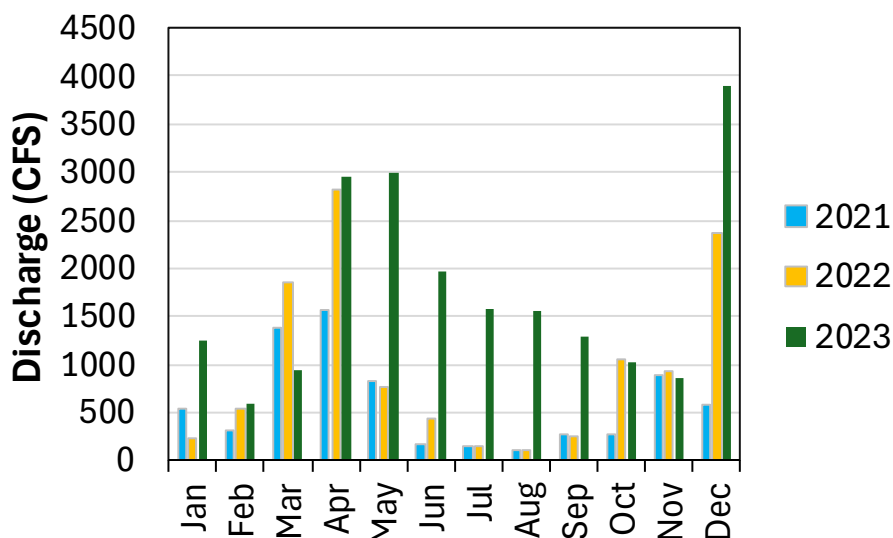


Figure 2. Average monthly streamflow discharge of the Sandy River at Mercer, Maine, approximately 28 km downstream from the confluence with Temple Stream. Data from USGS monitoring station 01048000 (USGS 2023).

1995 as cited in Frechette et al. 2018) and for parr at 28-29°C (Elliott 1991 as cited in Stanley and Trial 1995; Garside 1973 as cited in Lund et al. 2002; Grande and Andersen 1991 as cited in Elliott and Elliott 2010).

Surface water temperature significantly decreased with each year of the study at all sample sites (see Appendix II table II-1, and in [Zimmermann 2022](#), [2023](#)). The warmest temperatures occurred at the downstream site, however downstream warming was significantly reduced following dam removal (as compared to the upastream site; $1.50 \pm 1.26^{\circ}\text{C}$ in 2021, excluding Oct. 2021 when it was warmer at the upstream site; $0.76 \pm 1.31^{\circ}\text{C}$ in 2022; $0.26 \pm 0.62^{\circ}\text{C}$ in 2023; Fig. 3). Warmer than optimal temperatures ($>20^{\circ}\text{C}$) became less common with each year of the study (56% of the study duration in 2021, excluding the thermally stratified cooler bottom waters of the impoundment; 35% in 2022; 13% in 2023), as did exceedances of the stress threshold of 22°C (25% of the study duration in 2021; 19% in 2022; 3.4% in 2023, Fig. 4; Appendix II Table II-3, and in [Zimmermann 2022](#), [2023](#)). Unlike prior years, neither the maximum temperature for survival of adults ($26\text{-}27^{\circ}\text{C}$) nor for parr ($28\text{-}29^{\circ}\text{C}$) were exceeded in 2023.

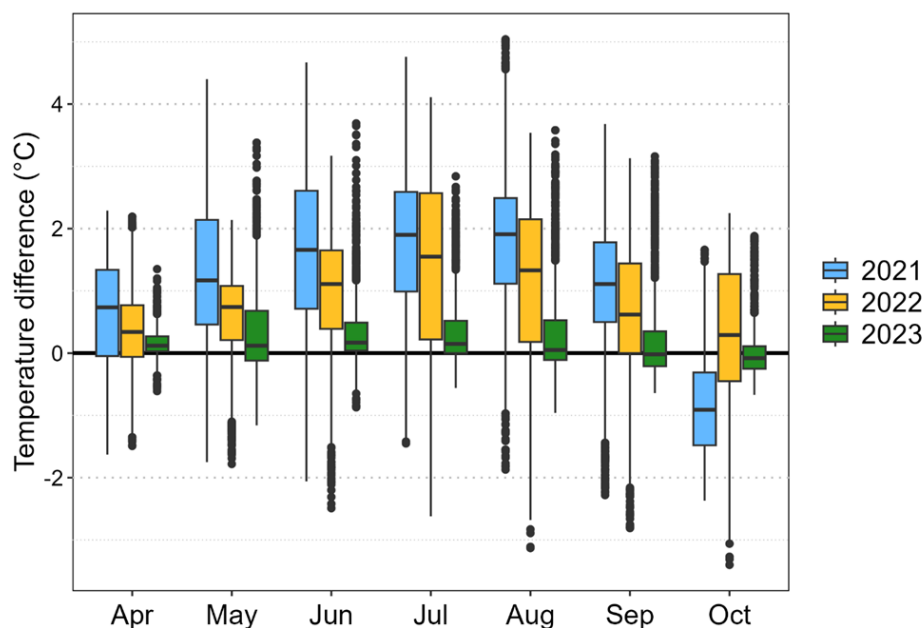


Figure 3. Temperature difference between the upstream and downstream sites, from paired measurements collected every 15-30 minutes, April through October.

Cooler temperatures in 2023 resulted in shorter durations of stressful periods ($>22^{\circ}\text{C}$) compared to the prior year (3 hours shorter upstream and 17 hours downstream). Resiliency to warm temperatures improved, with a maximum duration of stressful temperatures 3.7 days shorter than the prior year at both upstream and downstream sites. Following dam removal, the downstream site had slightly higher diel variability ($3.60 \pm 1.93^{\circ}\text{C}$) than upstream ($2.64 \pm 1.22^{\circ}\text{C}$). In contrast, when the dam was present, the impoundment dampened the downstream diel variability ($2.46 \pm 1.18^{\circ}\text{C}$) compared to the upstream site ($4.16 \pm 2.00^{\circ}\text{C}$). In relation to water temperature-based fish communities, average summer temperatures in 2023 were low enough that both the upstream and downstream sites cooled from the transition zone between coldwater and warmwater to coldwater (Beauchene et al. 2014). The largest temperature change was observed at the downstream site, cooling from warmwater to coldwater. Although the colder season and increased flows from rainfall in 2023 explain much of the reduction in stressful thermal conditions, greater cooling was observed at the downstream site compared to upstream, indicating that dam removal improved thermal suitability for coldwater fish.

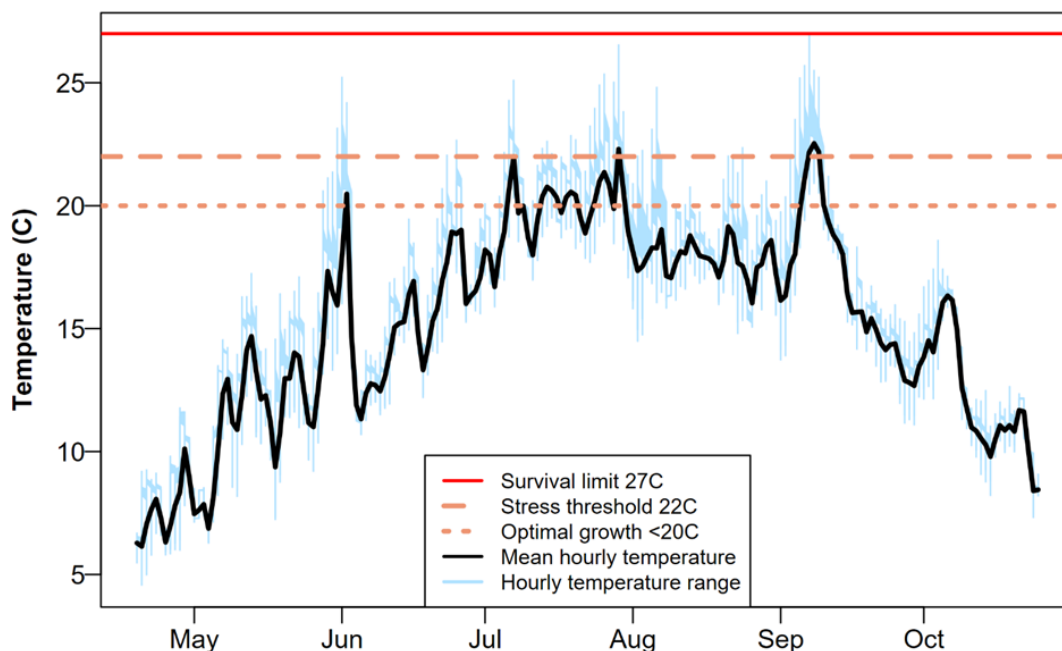


Figure 4. Mean hourly water temperature, May through October 2023 for all sites combined. Optimal growth limit from Jonsson et al. 2001 and [USEPA 1986](#). Stress threshold from Cunjak et al. 2005; Elliott and Elliott 2010; Lund et al. 2002. Survival limit for adult salmon from Shepard 1995 as cited in Frechette et al. 2018.

Conditions at the former impoundment transitioned from deep with slow flow to shallow with faster flow during this study (Appendix I Table I-I). Following dam removal, thermal stratification occurred less frequently, including not at all during 2023 (Fig. 5). Diel fluctuations in the former impoundment remained slightly greater than when the dam was present ($2.71 \pm 1.34^{\circ}\text{C}$ in 2023 vs. $2.1 \pm 1.0^{\circ}\text{C}$ in 2021). In relation to water temperature-based fish communities, the surface waters of the impoundment changed from warmwater to the transition zone between coldwater and warmwater (Beauchene et al. 2014). Thermal stratification may still occur during abnormally dry summer conditions due to low flows, the low stream gradient and the bathymetry at the study site, including the natural bedrock sill at the former dam site. However, no stratification occurred during 2023 in a 1.7-meter-deep pool approximately 117 meters downstream from the study site within the former impoundment, suggesting that the increased flows throughout the reach following dam removal may be sufficient to prevent stratification even in the deeper pools.

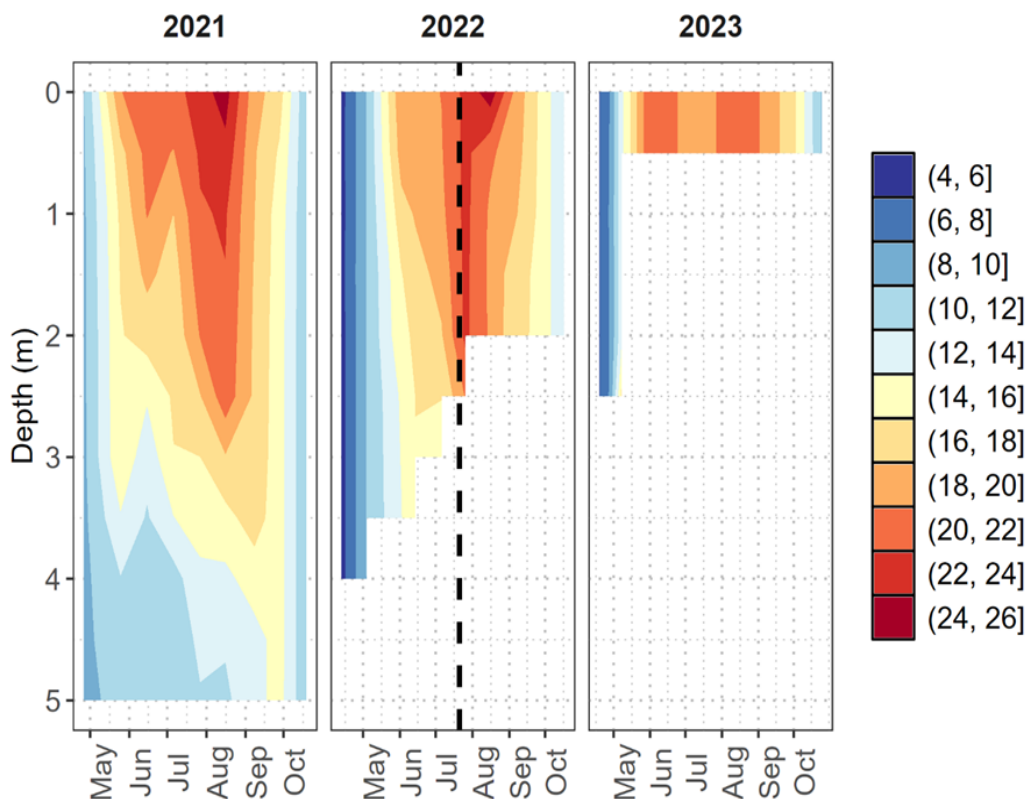


Figure 5. Impoundment temperature-depth profiles collected every three weeks April through October. Blue to yellow represents optimal growth for salmon ($<20^{\circ}\text{C}$; Jonsson et al. 2001; [USEPA 1986](#)). Orange to red represents stressful conditions ($>22^{\circ}\text{C}$; Cunjak et al. 2005; Elliott and Elliott 2010; Lund et al. 2002). Dam breached July 21, 2022, indicated by the vertical dashed line.

In the study area, high temperatures likely cause sublethal stress and reduced growth in salmon during the warmest months. The cooler temperatures and higher flows experienced in 2023 contributed to improved habitat suitability for aquatic life, however dam removal also decreased temperature differences between the upstream and downstream sites, increasing the amount of cool-water habitat available for fish in Temple Stream (Beauchene et al. 2014; Velinsky et al. 2001; Zaidel et al. 2021). The change from impoundment to free-flowing stream may have contributed to a slight increase in diel fluctuations both at the surface of the former impoundment and downstream, providing a greater chance for nightly thermal refugia (Bushaw-Newton et al. 2002; Dripps and Granger 2013; Poole and Berman 2001). Further cooling may be

observed as the former impoundment revegetates with a resilient riparian zone that provides shade from solar radiation, which may take years (Lawrence et al. 2014; Poole and Berman 2001; Zaidel et al. 2021).

Dissolved Oxygen (DO)

Salmon prefer well oxygenated waters with DO concentrations above the Maine Water Quality Standard minimum criterion value of 7 mg/L ([38 M.R.S. §§ 465.2.B](#); Stanley and Trial 1995). Within riverine impoundments that thermally stratify, such as Temple Stream during the warmest summer months, DO data within 0.5 m of the bottom or below the thermocline (a temperature change of $\geq 1^{\circ}\text{C}$ per meter of depth) are not used for compliance purposes, however salmon are likely to avoid areas below 7 mg/L ([38 M.R.S. §§ 464.13.B](#); Stanley and Trial 1995). Salmon experience acute physiological and behavioral stress below 5 mg/L ([USEPA 1986](#)).

DO increased with each year of the study at all sample sites (see Appendix II table II-1, and in [Zimmermann 2022, 2023](#)). DO remained within a healthy range for fish (>7 mg/L) for 100% of the study period in 2023 (Fig. 6.; as compared to 94% in 2022 and 93% in 2021). In all years of the study, the upstream site had the highest DO (0.56 ± 0.50 mg/L higher than downstream, and 1.01 ± 0.81 mg/L higher than the surface of the impoundment), however the sites were much more similar to each other in 2023, likely due to the increased flow from rain.

The surface waters of the former impoundment experienced more time in the optimal range (>7 mg/L) with each year of the study, increasing from 86% in 2021, to 89% in 2022, to 100% in 2023. The longest durations below optimal DO levels in the surface waters of the former impoundment occurred in 2022 (5 hours on average, with a maximum of 4 days in early August, after the dam was removed; [Zimmermann 2023](#)). Unlike the two prior years, in 2023 there were no exceedances of MDEP's consolidated assessment and listing methodology associated with the Integrated Water Quality Monitoring and Assessment Report ([MDEP 2024](#), p. 50-55). This assessment methodology is used by MDEP to determine if streams are impaired for aquatic life criteria. In the bottom waters of the former impoundment, increases in DO were likely caused by increased mixing and decreased hydrological residence time due to the

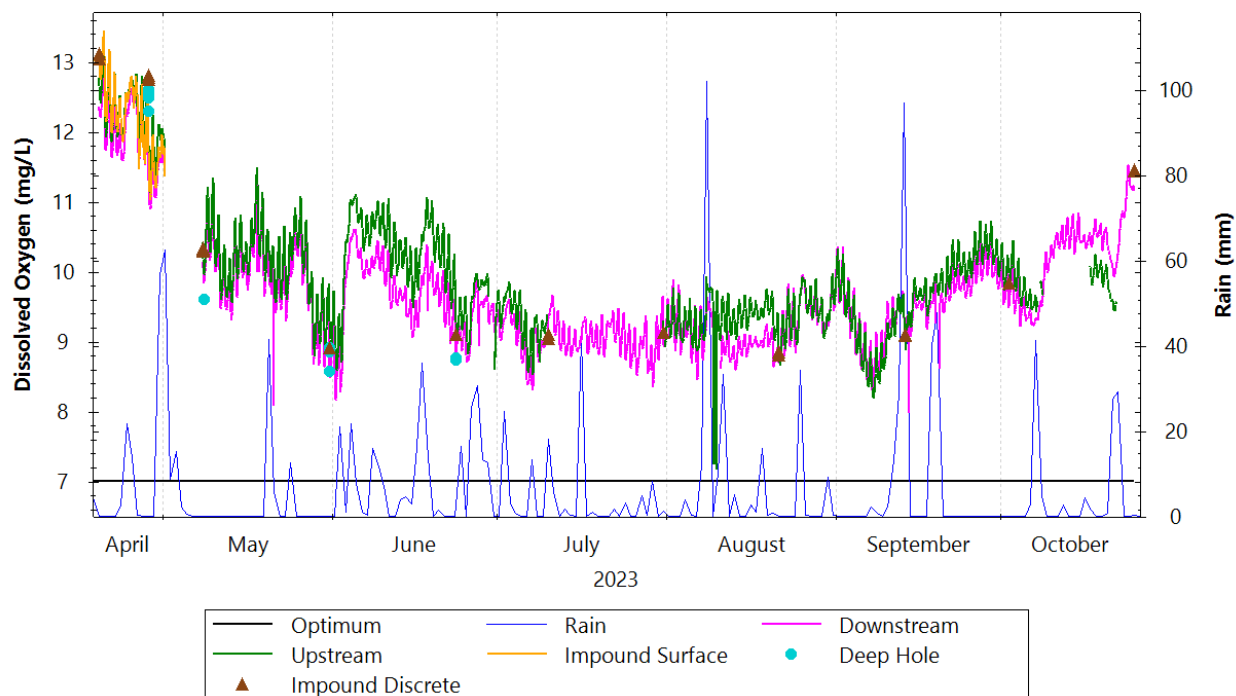


Figure 6. Dissolved oxygen and local rainfall April through October 2023. In the former impoundment (Impound Surface), the logger was 0.5 m from the surface until burial by the early May storm event. Deep hole measurements were collected 110 m downstream from the impoundment site. Optimum threshold from Stanley and Trial 1995 and [38 M.R.S. §§ 465.2.B](#). Stress threshold from [USEPA 1986](#). Rainfall data from Weather Underground station KMEFARMI35.

higher flows, resulting in reduced sediment and nutrient trapping (Fig. 7; Abbott et al. 2022; Bednarek 2001). Acute stress (<5 mg/L) decreased in each year of the study and did not occur at any site in 2023 (71% of the study period in 2021 and 24% in 2022). Similarly, hypoxic conditions (<2 mg/L, Rounds et al. 2013) decreased each year and did not occur in 2023 (65% of the study period, lasting 2.2 days in 2021 and 16% in 2022, lasting on average 7 hours). Summer DO stratification also decreased each year of the study, with no stratification observed in 2023 even in the deepest part of the former impoundment (average depth 1.7 m, approximately 110 m downstream of the study site; Fig. 7).

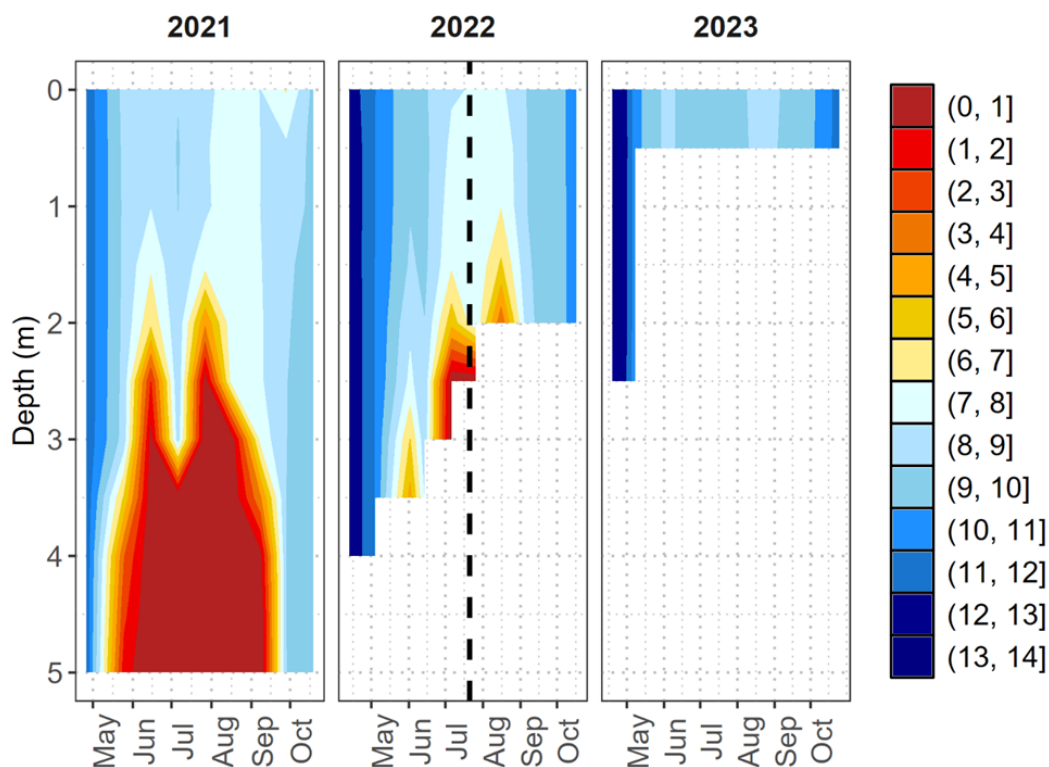


Figure 7. Impoundment dissolved oxygen-depth profiles collected every three weeks April through October. Red represents hypoxic conditions (<math><2\text{ mg/L}</math>; Rounds et al. 2013); orange represents acute stressful conditions (<math><5\text{ mg/L}</math>; USEPA 1986); yellow represents suboptimal conditions (<math><7\text{ mg/L}</math>); and blue represents optimal conditions (>7 mg/L; 38 M.R.S. §§ 465.2.B; Stanley and Trial 1995). Dam breached July 21, 2022, indicated by the vertical dashed line.

Periods of low DO in the surface waters of the former impoundment coupled with warm temperatures likely caused stress to salmon and other aquatic life (Maxted et al. 2005; Remen et al. 2012). Opening the dam gates, followed by complete dam removal, resulted in more stream-like conditions with well-mixed water, reducing the frequency of stratification and decreasing the occurrence of summer hypoxia in the former impoundment (Abbott et al. 2022; Bushaw-Newton et al. 2002; Zaidel 2018). In the year after dam removal, the bottom meter of the former impoundment likely did not support aquatic life during summer low flows in a dry year, possibly due to the maintenance of a natural, smaller impoundment by the bedrock sill at the former dam site, however during the following rainy year no stressful conditions were observed. As seen in prior studies,

the downstream site was not significantly impacted by the low DO from the impoundment, suggesting the water became reaerated during its passage downstream, regardless of dam presence (Abbott et al. 2022; Lessard and Hayes 2003; Velinsky et al. 2006; Zaidel 2018). Within a year of dam removal, the former impoundment became more stream-like and DO concentrations improved to optimal levels for aquatic life, similar to the upstream site.

pH

Salmon prefer pH values that are circumneutral (6.5-7.5), rather than acidic (<6.5). The impacts of acidity depend on 1.) duration, magnitude, and frequency of the episode, 2.) the ability of the fish to avoid adverse water quality conditions, 3.) the concentration of exchangeable aluminum (Al_x), 4.) the buffering capacity of the water (i.e., ANC and calcium), and 5.) life stage (see [Zimmermann 2018](#) for overview). pH thresholds used in this analysis are estimates of anticipated impacts to salmon populations and do not include a detailed analysis of the impact of other factors.

No significant changes were observed between the years of sampling nor following the dam breach at either the upstream or downstream site. pH was generally neutral (grand mean 6.97 ± 0.22), staying above the threshold of 6.5, an optimal minimum pH for the protection of the most sensitive salmon life stages (alevins and smolts), for the majority of the study duration (98%; Fig. 8; Appendix II Table II-1; Kroglund and Staurnes 1999; Kroglund et al. 2008). The lowest pH of the study (5.82) occurred at the upstream site in 2023. While lower than the optimal pH for salmon, the minima was well above the critical stress threshold of 5.5, above which no adverse impacts to salmon populations are expected (Haines et al. 1990; Stanley and Trial 1995). Across all years of the study, rain-driven depressions between May and October lasted on average 5 hours at the upstream site (maximum 2.9 days in 2022) and 2.7 hours at the downstream site (maximum 20 hours in 2022). Wider daily ranges of pH were experienced at the upstream site compared to the downstream site (0.4 ± 0.2 vs. 0.2 ± 0.1), possibly driven by increased productivity (Nimick et al. 2011).

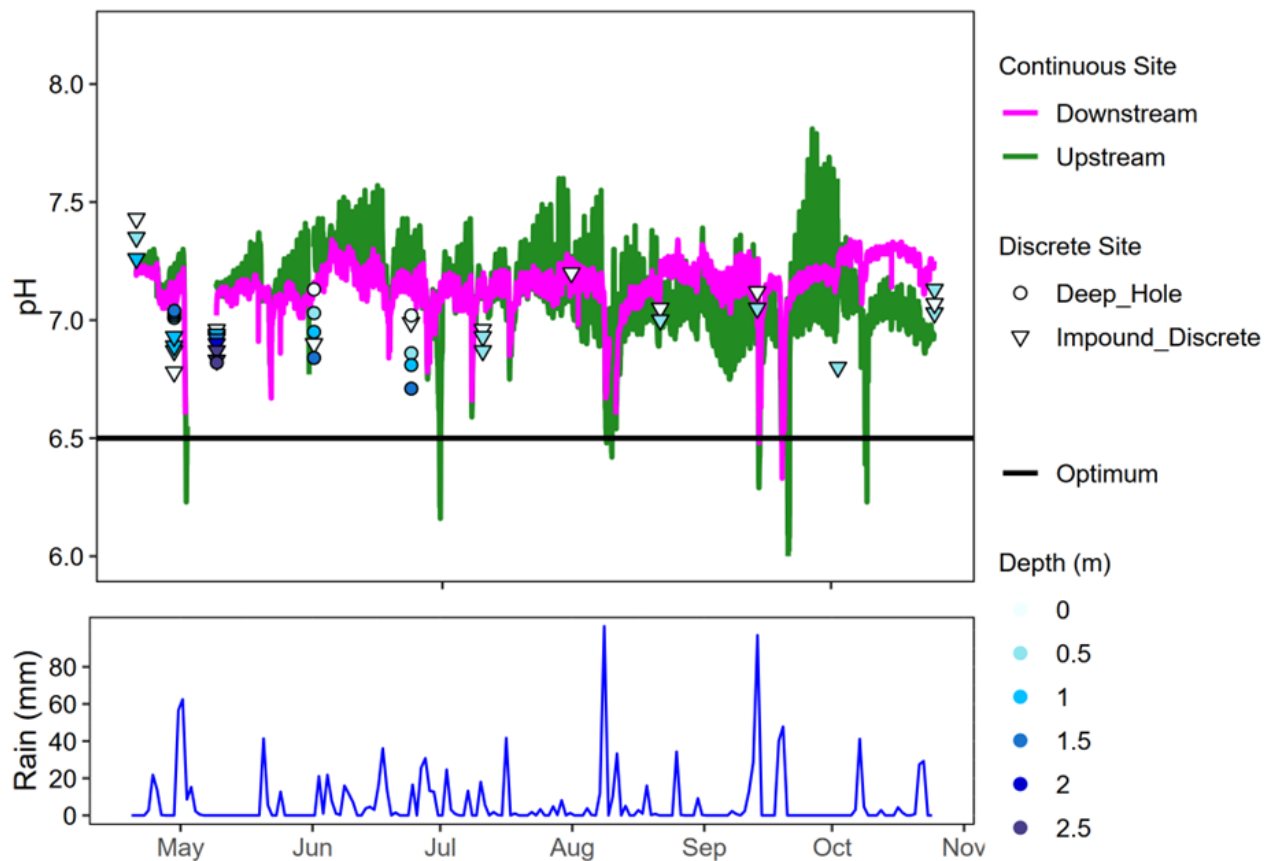


Figure 8. Continuous and discrete pH and local rainfall in 2023. Optimum pH from Kroglund and Staurnes 1999 and Kroglund et al. 2008. Rainfall data from Weather Underground station KMEFARMI35.

In the prior years of the study, when the impoundment stratified (June-September), low pH occurred below 2 m, with a minimum pH of 6.1 observed at 3-3.5 m, possibly caused by the production of carbon dioxide by anaerobic respiration (Fig. 9). After the dam was breached, pH at the former impoundment remained above 6.5 for 97% of the time, compared with 68% before the breach. Increased mixing following dam removal increased the minimum pH from 6.1 to 6.4. While pH in the study area is not expected to have negative impacts on salmon at the population level, dam removal has decreased the occurrence of suboptimal conditions at depth in the former impoundment by reducing stratification.

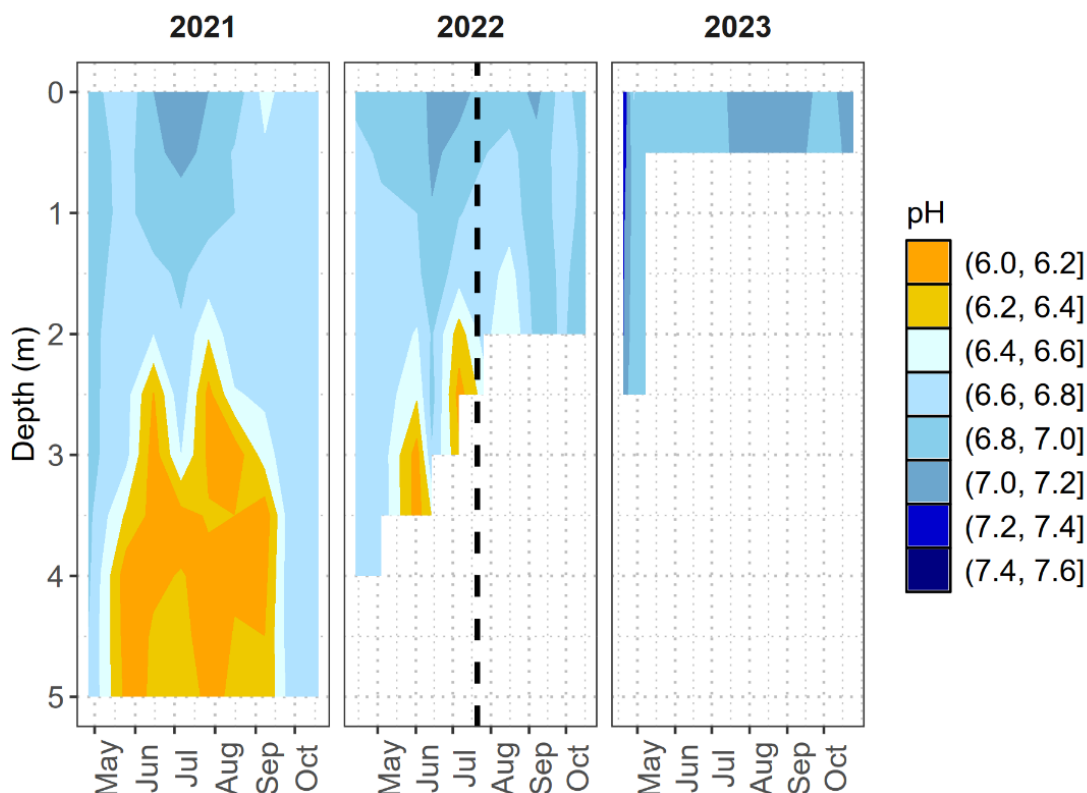


Figure 9. Impoundment pH-depth profiles collected every three weeks April through October at the former impoundment. Dam breached July 21, 2022 (dashed line). Orange to yellow represents potentially stressful pH (<6.5). Blue represents optimal pH (>6.5, from Kroglund and Staurnes 1999; Kroglund et al. 2008).

Specific Conductance

Specific conductance (SPC) is a measure of the concentration of ions in the water, or the ability of water to conduct electricity. SPC was similar at all sites, with a grand mean of $45 \pm 8 \mu\text{S}/\text{cm}$ in 2023, slightly lower than the two prior years ($61 \pm 14 \mu\text{S}/\text{cm}$ in 2022 and $58 \pm 11 \mu\text{S}/\text{cm}$ in 2021; Fig. 10; Appendix II Table II-1). Slightly higher SPC downstream may be due to the influence of winter de-icing salts washed off roads. No adverse impacts due to specific conductance are expected at any of the study sites.

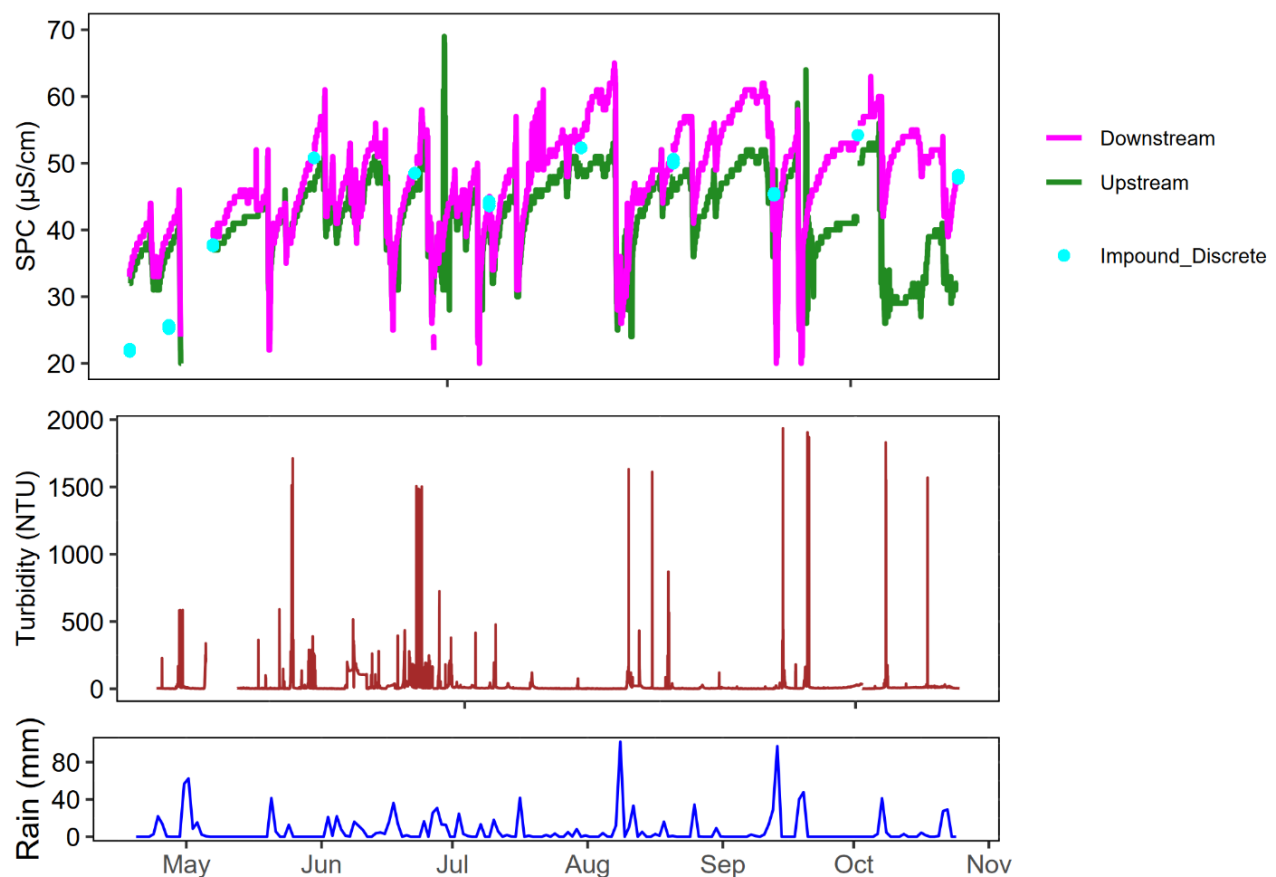


Figure 10. Specific conductance (SPC), turbidity and local rainfall in 2023. Turbidity was only measured at the downstream sampling site. Rainfall data from Weather Underground station KMEFARMI35.

Turbidity

Turbidity is a measure of the relative cloudiness of the water based on the amount of light scattered by suspended or dissolved material including clay, silt, and organic materials. When turbidity increases above ambient background levels by more than even 10 NTU, potential negative impacts include decreasing primary production (such as from siltation or scouring), increasing stress (e.g., in fish, physiologically such as gill trauma, behaviorally such as reduced foraging effectiveness), and altering habitat (such as from siltation and embeddedness; Bash et al. 2001; Carlson et al. 2017; Kjelland et al. 2015). Chronically high turbidity has stronger negative impacts to aquatic life than short high pulses (Stanley and Trial 1995). Turbidity, only measured at the

downstream site, was higher in 2023 than in 2022 (21.2 ± 91.9 NTU vs. 6.0 ± 18.9 NTU). Dam deconstruction activities coincided with the highest turbidity concentrations in 2022, but rain events coincided with the highest spikes in 2023, lasting 5.3 hours on average and remaining above ambient background levels (~ 10 NTU) for a maximum of 4.6 days (Figure 10). Dam removal exposed fine sediments through the drawdown of the former impoundment, where the substrate is glaciomarine silt and clay, which is easily suspended in the water column (MGS 2003). Large flood events in 2023 mobilized large amounts of sediment in the watershed, at times burying the monitoring equipment. Pulses of increased turbidity from storm events may have had short-term negative impacts on downstream habitat and aquatic life (Bednarek 2001; Carlson et al. 2017; Gray and Ward 1982; Kjelland et al. 2015; Schofield et al. 2004; Zuellig et al. 2002). However, turbidity remained low for most of the study period, indicating clear background water conditions outside of episodic disturbances from dam deconstruction and stormflows.

Dissolved Organic Carbon (DOC)

DOC has been shown to be a strong determinant of fish mortality in brook trout due to its buffering capacity (Baldigo and Murdoch 2007). The grand mean of DOC across all study sites during baseflow was 3.0 ± 0.6 mg/L, similar to other streams with clear water, including Orbeton Stream, another tributary to the Sandy River ([Zimmermann 2021](#)). Temple Stream has very low organic content, high pH and high calcium ([Zimmermann 2022](#)), indicating a well-buffered system. Dam removal had no measurable impact on the buffering capacity of the stream.

Nutrients

Biologically available nitrogen (nitrate + nitrite as nitrogen) levels were low at all sites, comparable to other tributaries to the Sandy River (grand mean 0.019 ± 0.010 mg/L; Appendix II Table II-2; [Zimmermann 2021](#)). There were no statistically significant differences within each site pre- and post-dam removal, however prior to dam removal, biologically available nitrogen concentrations were lower in the impoundment, as compared to the upstream and downstream sites. Increased flows following the breach and removal of the dam likely reduced the potential for denitrification at the sediment-

water interface as oxygen concentrations in the bottom waters increased and as hydrological residence time in the former impoundment decreased (Bushaw-Newton et al. 2002, Fairchild and Velinsky 2006; Saunders and Kalff 2001; Stanley and Doyle 2002). Total Kjeldahl nitrogen (TKN) concentrations were similar in 2023 to baseline concentrations (grand mean 0.26 ± 0.07 mg/L; Appendix II Table II-2). In contrast, concentrations were almost twice as high in 2022, possibly in part due to the fresh erosion of organic deposits from the banks of the former impoundment. However, TKN concentrations were also high upstream of the impoundment in 2022, and the banks were still actively eroding during high flow events in 2023.

Total phosphorus was lower in 2023 than during the prior two years, with a grand mean of 6.7 ± 2.0 μ g/L (Appendix II Table II-2; [Zimmermann 2021](#)). As in prior years, concentrations were lower upstream compared to the other sites (5.0 ± 0.1 μ g/L), suggesting phosphorus retention in the former impoundment may not have contributed significantly to phosphorus flux (Bushaw-Newton et al. 2002). Although not statistically significant, the downstream phosphorus concentration decreased with dam removal, possibly due to the increased retention of phosphorus in the shifting sediments of the free-flowing former impoundment (Ahearn and Dahlgren 2005; Fairchild and Velinsky 2006; Lei et al. 2023; Stanley and Doyle 2002). The similarity in nutrient levels between sites indicates that water chemistry in the former impoundment was dominated by inflow from upstream, rather than the biological reactions (e.g., plant uptake, nitrification, denitrification) typical in larger impoundments, possibly due to the relatively short hydrological residence time (Bushaw-Newton et al. 2002). Nutrient levels were typical of natural, minimally disturbed streams in Maine.

Biological Data

The water quality of Temple Stream supports a robust macroinvertebrate community that attains Maine's highest aquatic life water quality classification (Appendix III, [38 M.R.S. §§ 465](#); [Davies et al. 2016](#)). Mean abundance and generic richness both decreased significantly following dam removal (from 429 to 235 mean abundance, and from 49 to 35 generic richness; Appendix II Table II-3), however it may take 1-7 years or more for macroinvertebrates to recover from large pulse flows and the resulting

changes in sediment transport and physical benthic habitat (e.g., Bushaw-Newton et al. 2002; Carlson et al. 2017; Collier and Quinn 2003; Hansen and Hayes 2012; Orr et al. 2008; Thomson et al. 2005). Variation in the biological community may also be due to differences in the physical and chemical properties at the sampling sites (the 2020 samples were collected 300 m downstream from the 2023 samples (Fig. 1). The proportion of the macroinvertebrate community represented by EPT taxa (mayflies, stoneflies, and caddisflies) remained unchanged following dam removal (around 48%), comparable to reference sites in Baxter State Park.

Following dam removal, and the large flood event of May 2023, net-spinning caddisflies (*Hydropsyche*) and blackflies (*Simulium*) were the dominant taxa, as seen in other studies (Stanley et al. 2002, Zuellig et al. 2002). Moderately sensitive (*Baetis*, *Tricorythodes*) and sensitive (*Ephemerella*) mayfly species were still among the most dominant taxa, however they comprised almost 12% less of the community than the pre-removal mayflies (*Maccaffertium* and *Isonychia*), possibly indicating a decline in water quality and/or physical habitat (Bushaw-Newton et al. 2002). The abundance of stoneflies, which are very sensitive, remained relatively low following dam removal, however their presence is an indicator of excellent water quality. The Shannon-Wiener diversity index remained quite high (3.83 pre- dam removal and 3.87 post- dam removal, compared to a max of 4.6), indicating a stable, natural community. Prior to dam removal the Hilsenhoff Index was relatively low (4.23) compared to reference streams and it was even lower following dam removal (3.73), indicating higher sensitivity to nutrient pollution. As the geomorphology of Temple Stream stabilizes following dam removal, it is expected that the macroinvertebrate community will establish a new baseline in association with the new sediment transport regime of the free-flowing stream (Orr et al. 2008; Stanley et al. 2002).

Variation in the algal community composition was observed between the two samples (Appendix III). The 2023 algal assemblage, collected 500m below the former dam, attained Maine's highest aquatic life classification and contained significantly more intolerant algae species that are sensitive to disturbances from pollution, nutrients, and sedimentation (Appendix II Table II-4; (Appendix III, [38 M.R.S. §§ 465](#)). Abundance of tolerant algae, as well as the richness of motile diatoms and nutrient-tolerant diatoms

were lower. Further downstream, the 2020 algal assemblage only attained a class C determination and had a larger proportion of motile diatoms and nutrient tolerant diatoms, possibly due to the fine silts and clay in that stream reach ([38 M.R.S. §§ 465; Zimmermann 2022](#)). In contrast, following dam removal and the flooding events of 2023, the site closer to the dam was dominated by cobble, gravel and sand. The Shannon-Wiener diversity index was higher at the site closer to the dam (3.03 vs. 2.42). Following removal of small dams, immediate decreases in the benthic community often occur due to silt deposition and scouring, followed by variable recovery speeds, often reaching a relatively stable equilibrium with a changed composition after months to years (Orr et al. 2008; Thomson et al. 2005). Due to the change in sample location, no conclusions can be drawn regarding the potential impact of dam removal to algae in Temple Stream, however the water quality at the site closer to the dam supports a more diverse and robust algal community than the site further downstream.

Conclusion

Temple Stream has become more suitable for salmon and other aquatic life with the removal of the Walton's Mill dam, particularly within the former impoundment. Downstream warming was significantly reduced from 1.5°C to 0.3°C as has been observed at other small dams (Zaidel et al. 2021). At all study sites, high summer water temperatures exacerbated by summer drought conditions could lead to sub-lethal stress or avoidance behavior in salmon, however the most sensitive life stages of salmon (from hatch to swim up and smolts) are not present during the summer when most temperature maxima occur. Stratification in the former impoundment was significantly reduced, resulting in greater diel temperature fluctuations which could provide a greater chance for nightly thermal refuge, and higher dissolved oxygen. The transition to more stream-like conditions following dam removal reduced the frequency of stratification and decreased the occurrence of summer hypoxia in the former impoundment, improving pH and eliminating stressful DO conditions altogether during a rainy year. Increased sediment transport during stormflows of 2023, partly due to the fine sediments exposed in the former impoundment, may have had short-term negative impacts on downstream habitat and aquatic life (Bushaw-Newton et al. 2002; Carlson et al. 2017).

With the predicted 2°C increase in air temperatures in Maine by 2040 (Fernandez et al. 2020), protecting and enhancing cool water habitat, such as limiting the influence of dammed impoundments, is essential for the protection of aquatic life (Paukert et al. 2021). Removal of small dams, such as Walton's Mill dam, helps buffer the negative effects of climate change on streams, such as warming temperatures, by increasing flow through the former impounded area, narrowing the channel, increasing shade from restored riparian vegetation, as well as reconnecting aquatic resources to more resilient stream habitat upstream (Foley et al. 2017; Lawrence et al. 2014; Poole and Berman 2001; Zaidel et al. 2021). As stream-like conditions in the former impoundment stabilize, water quality is expected to continue to improve due to decreased water temperatures and reduced disturbance from sediment mobilization, creating more resilient aquatic habitat for Atlantic salmon.

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Appendix I – Stream Characteristics

Table I-1. Study site locations and watershed characteristics. Wetted stream width measured for channel sampled, with full multichannel width in parentheses. Mean stream depth was measured every three weeks while sondes were deployed. For watershed and substrate characteristics, see Appendix I Table I-1 in [Zimmermann 2022](#).

Site	Site Code	Latitude	Longitude	Year	Wetted stream width (m)	Mean stream depth (cm)
Upstream	KSDTE29	44.67001	-70.18253	2021	3.4 (15.5)	26
Upstream	KSDTE29	44.67001	-70.18253	2022	5.8 (17.6)	31
Upstream	KSDTE29	44.67001	-70.18253	2023	6.73	43
Impoundment	KSDTE17	44.66005	-70.16934	2021	27.2 (122)	480
Impoundment	KSDTE17	44.66005	-70.16934	2022	15.4 (113)	314
Impoundment	KSDTE17	44.66005	-70.16934	2023	15.4	87
Downstream	KSDTE12	44.66127	-70.16044	2021	10.7 (25)	36
Downstream	KSDTE12	44.66127	-70.16044	2022	11.7 (25)	44
Downstream	KSDTE12	44.66127	-70.16044	2023	9.8	50

Appendix II – Summary Data Tables

Table II-1. Continuous 2023 Data Summary. Summary statistics (mean, standard deviation (SD), minimum and maximum) of measurements from YSI 6000 series sondes and Onset Hobo U26 dissolved oxygen loggers (KSDTE17), April to October 2023 (n ~ 9,000). Data at KSDTE17 from Eureka Manta2 Sub2 field meter (n ~ 9). Only 4 of the 7 sample events at KSDTE17 had sufficient depth for multiple samples, with an average depth offset between surface and bottom of 1m (range 0.57 - 2.58m).

Site Code	pH	pH Min	pH Max	Temperature (Temp; °C)	Temp Min	Temp Max	Specific Conductance (SPC; µS/cm)	SPC Min	SPC Max	Dissolved Oxygen (DO; mg/L)	DO Min	DO Max
KSDTE29	7.11 ± 0.18	5.98	7.81	15.50 ± 3.95	4.57	24.16	42 ± 7	17	69	9.96 ± 0.90	7.16	13.17
KSDTE17 – TOP	7.02 ± 0.19	6.78	7.43	15.86 ± 5.63	5.90	21.59	43 ± 11	22	54	10.15 ± 1.57	8.81	13.04
KSDTE17 – BOTTOM	7.01 ± 0.15	6.83	7.26	13.79 ± 5.95	5.91	21.29	38 ± 14	16	51	10.66 ± 1.80	8.86	13.12
KSDTE12	7.15 ± 0.10	6.33	7.34	15.76 ± 4.16	4.70	26.95	48 ± 8	16	65	9.97 ± 0.90	7.16	13.17

Table II-2. Discrete 2023 Data Summary. Summary statistics (mean, SD, minimum and maximum) from grab samples collected April 30, Aug. 21, and Oct. 25. n = 3 except for DOC where n =1. Samples in the former impoundment (KSDTE17) were collected from surface waters.

Site Code	Dissolved Organic Carbon (mg/L)	Nitrate + Nitrite as Nitrogen (N+N; mg/L)	N+N Min	N+N Max	Total Kjeldahl Nitrogen (TKN; mg/L)	TKN Min	TKN Max	Total Phosphorus (TP; µg/L)	TP Min	TP Max
KSDTE29	3.3	0.017 ± 0.011	0.005	0.027	0.25 ± 0.07	0.21	0.33	5 ± 0.1	4	5
KSDTE17	3.4	0.018 ± 0.011	0.006	0.028	0.21 ± 0.03	0.18	0.23	7 ± 2	6	9
KSDTE12	3.7	0.021 ± 0.013	0.008	0.034	0.32 ± 0.08	0.25	0.40	8 ± 2	7	10

Table II-3. Exceedances Pre- and Post-dam Removal.

Site Code	Dam removal status	% >22 deg C	% <7 mg/L
KSDTE29	PRE	14.4	0
KSDTE29	POST	9.1	0
KSDTE17 – TOP	PRE	22.0	11.0
KSDTE17 – TOP	POST	21.3	14.5
KSDTE17 - BOTTOM	PRE	<0.1	67.0
KSDTE17 - BOTTOM	POST	17.0	40.8
KSDTE12	PRE	25.6	0.8
KSDTE12	POST	13.5	1.5

Table II-4. Macroinvertebrate (MI) and Algae Summary. Samples were collected 800m downstream of the former dam in 2020 and 500m downstream in 2023, following the Biological Monitoring Unit’s protocol (MDEP 2014) and analyzed by a certified taxonomist to the lowest possible level (species).

Station ID	MI Log #	Algae Bottle #	Year Sampled	Total Mean Abundance	Generic Richness	EPT Generic Richness	Relative Ephemeroptera Abundance	Intolerant Algae % Species	Tolerant Algae % Abundance	Nutrient-tolerant Diatom Richness	Motile Diatom Richness
S-1183	2816	1945	2020	429	49	23	54%	6	3	5	18
S-1242	3064	2180	2023	235	35	17	39%	39	0	2	1

Appendix III – Biological Monitoring Program Reports

Macroinvertebrates

[Temple Stream – Station 1183](#) URL

https://www.maine.gov/dep/gis/datamaps/lawb_biomonitoring/station_web/S-1183M.html

[Temple Stream – Station 1242](#) URL

https://www.maine.gov/dep/gis/datamaps/lawb_biomonitoring/station_web/S-1242M.html

Algae

[Temple Stream – Station 1183](#) URL

https://www.maine.gov/dep/gis/datamaps/lawb_biomonitoring/station_web/S-1183A.html

[Temple Stream – Station 1242](#) URL

https://www.maine.gov/dep/gis/datamaps/lawb_biomonitoring/station_web/S-1242A.html