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Beaver activity improves pollutant reduction in a constructed stormwater wetland

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ABSTRACT

Urban water bodies often receive pollution from stormwater runoff. Beaver activity can have varying effects on water quality, but the impact on urban systems is not well understood. This study evaluates pollutant reduction in a constructed stormwater wetland facility with and without beaver activity. The concentration of urban pollutants was measured in runoff at the inlet and outlet of the facility during storms: seven when beavers were absent and seven when beavers were present. Percent reductions of many pollutants, especially heavy metals and sediment, were significantly higher when beavers were present. None of the pollutants were significantly reduced in the facility when beavers were absent, while several were significantly reduced when beavers were present, including copper, mercury, lead, zinc, total phosphorus, and suspended solids. However, orthophosphate increased with beaver activity. There was evidence that organic compounds such as phthalates, herbicides, and preservatives may be reduced. The vast majority of applicable water quality standards were met at the facility outlet when beavers were both absent and present. Beaver dams in the facility appeared to allow for sediment settling and filtration of the water through the dam matrix of sticks, roots, and mud. Results for nutrients and sediment were similar to what has been found with beaver activity in other systems, and the results for heavy metals are encouraging as there are few studies on those pollutants. Coexistence devices like culvert protectors and pond levelers were constructed to allow beavers to remain in the facility without negative impacts to human maintenance efforts.

1. Introduction

1.1. Urban stream degradation

Streams in urban areas have been degraded through a variety of processes. Impervious areas such as roads, roofs, and parking lots cause rain to run off and create sudden influxes of stormwater in streams leading to flashy stream flows, erosion, and incision (Dietz and Clausen, 2008; Allmendinger et al., 2007). Runoff from pavement, lawns, and other surfaces contains fertilizers, herbicides, hydrocarbons, heavy metals, tire particles, and other pollutants. Many streams throughout North America and Eurasia are additionally degraded because the key species which were historically responsible for engineering those systems, beavers, have often been greatly reduced in population, if not removed entirely (Bailey et al., 2018; Halley and Rosell, 2002). North American beavers (*Castor canadensis*) and Eurasian beavers (*Castor fiber*) were nearly ubiquitous in their respective regions until a few hundred years ago when they were trapped to near extinction (Wilson and Reeder, 2005). Beaver presence has been shown to improve ecosystem functions, with particular impact on aquatic habitats and channel structure (Bylak and Kukuła, 2020; Di Lorenzo et al., 2024; Butler and Malanson, 2005). In their absence, many of these urban streams are now dealing with a lack of beavers as their natural regulating agent in addition to flashy flows and a cocktail of pollutants (Bailey et al., 2018).

1.2. Stormwater mitigation

The field of stormwater science has developed over the past several decades to address urban stream degradation by reducing the harm from runoff and restoring ecological functions. Green stormwater infrastructure facilities such as rain gardens, ponds, and constructed wetlands are often built in new developments and sometimes as retrofits in existing urban areas to infiltrate, detain, and treat runoff (EPA (Environmental Protection Agency), 2025; Koucka et al., 2025; Winston et al., 2010;

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Castleton et al., 2010). These facilities reduce flashy flows by either infiltrating runoff or detaining water during storms and releasing it slowly over time. They clean the water through physical settling and filtration, chemical sorption and transformation, and biological uptake and degradation (Taguchi et al., 2020). For example, average reductions of 10–44% have been observed for various nutrients and heavy metals in constructed stormwater wetlands (Clary et al., 2020). Hydrocarbon reduction in constructed wetlands has also been observed, with effluent concentrations 50–95% lower than the influent and often below detection limits (Walaszek et al., 2018; Tromp et al., 2012).

In addition to detaining and cleaning water, stormwater facilities can contribute to ecological uplift by replicating wetland habitats that were lost through draining or filling during conversion to urban or agricultural use. Wildlife species including birds (Knight et al., 2001), amphibians (Scheffers and Paszkowski, 2013; Knight et al., 2001), and dragonflies (Perron and Pick, 2020) use these facilities as habitat. In heavily urbanized areas, stormwater facilities can represent the majority of available habitat where most natural wetlands have often been filled or drained, and some species are more commonly found in these facilities than in the remaining natural habitats (Ferzoco and McCauley, 2024; Holzer, 2014). Beavers have also colonized some larger stormwater facilities, creating both a challenge for human maintenance at the same time as an opportunity for more natural urban hydrology regulation (Bailey et al., 2018).

1.3. Beavers and water quality

Beaver activity has been shown to improve some water quality measures in streams including dissolved oxygen (DO) (Bylak et al., 2024; Stevenson et al., 2022; Dewey et al., 2022), sediment (Bylak and Kukuła, 2022; Smith et al., 2025; White et al., 2025), *E. coli* (White et al., 2025), nitrogen (Cooper et al., 2025; Wąs et al., 2025; Murray et al., 2023), phosphorus (Cooper et al., 2025; Wąs et al., 2025; Law et al., 2016), and the heavy metals zinc, copper, cadmium, and lead (Belova et al., 2025; Murray et al., 2021; Shepherd and Nairn, 2020). It has also been shown to reduce flashiness of stream discharge by slowing water and reconnecting streams to their floodplains (Smith et al., 2020; Thompson et al., 2021). Increased microbial activity in beaver ponds can improve pollutant degradation in addition to beaver dams acting as sinks for contaminants via sediment deposition and filtering the water as it flows through them (White et al., 2025; Murray et al., 2023;). However, there is a lack of published information on the effect of beaver activity on urban pollutants such as heavy metals, hydrocarbons, or pesticides within an urban system.

Most studies on beaver activity in urban systems are focused on mitigating negative impacts of beavers such as clogging of inlets and outlets, felling trees, flooding of parking lots and roadways, etc. (Portugal et al., 2015; Hoyt and Brown, 2005; Sobieraj et al., 2022). Bailey et al. (2018) describes the general benefits of beaver dam building and subsequent wetland expansion in improving urban hydrology in wetland complexes in Seattle, but no analytical data was collected. To our knowledge, there are no studies on the impact to water quality from beaver activity in stormwater facilities. Beaver activity may increase pollutant reduction in these facilities through sediment settling, increased microbial activity, and filtration, as observed in stream studies (Cooper et al., 2025; Smith et al., 2025). Alternately, since facilities are designed to specific standards to optimize pollutant removal (EPA (Environmental Protection Agency), 2021), beaver activity may have the potential to negatively impact pollutant reduction efficiency due to changes in flow paths and vegetation from damming and ponding (Bylak and Kukuła, 2020; Di Lorenzo et al., 2024).

Beaver population increases have been noted in urban areas throughout North America and Eurasia as the species rebound (Halley and Rosell, 2002; Butler and Malanson, 2005; Bailey et al., 2018). Beavers exist in a wide variety of habitats, and often inhabit flat, lowland streams; therefore, many present-day urban centers likely contained beaver wetland complexes before extensive trapping, indicating that some cities may be readily recolonized (Larsen et al., 2021; Rosell and Campbell-Palmer, 2022). While the beavers' return may afford significant opportunities to reduce anthropogenic stream degradation, their interaction with human infrastructure often leads to substantial conflicts which must be addressed for humans to tolerate their presence (Portugal et al., 2015; Hoyt and Brown, 2005; Sobieraj et al., 2022).

1.4. Research aims and hypotheses

Although there is extensive research on both constructed stormwater facilities and beaver activity, to our knowledge, this is the first study to evaluate the impact of beaver activity on pollutant reduction in a stormwater facility. Our research question is: Do beavers increase pollutant reduction in this constructed stormwater facility? We hypothesize that beaver activity will increase pollutant reduction, with our null hypothesis that pollutant reduction will not be impacted by beaver activity. To evaluate pollutant reduction due to the presence of beavers, water quality samples were collected at the inlet and outlet of a constructed stormwater wetland facility during storm events with and without beaver activity and analyzed for typical urban stormwater pollutants.

2. Materials and methods

2.1. Site description

Beavers colonized a constructed stormwater wetland several years after it was built and substantially altered the way the facility functioned. This presented an opportunity to examine the impacts of beaver activity on the treatment of urban stormwater runoff. The study area is a 6-ha (15-acre) site containing a 3.6-ha (9-acre) constructed stormwater treatment wetland facility (hereafter: facility) located in Gresham, Oregon, USA in the Pacific Northwest region of North America. The facility was constructed in 2008 as a retrofit to treat stormwater runoff from 387 ha (956 acres) of urban area dominated by industrial and commercial retail land use (Fig. 1). Water enters the facility through two large stormwater pipes which directly drain impervious surfaces. It then passes through sedimentation forebays which are designed to slow the water to settle out sediment and are dredged every few years. The water then enters the main wetland area of the facility where it was designed to flow through a series of sinuous terraced channels separated by rock cascades (Fig. 2, top image). The treated water leaves the facility through a single pipe at the outlet structure where it is discharged to the Columbia Slough. The outlet structure contains a flow control device with a series of orifices engineered to detain water before release.

The facility is managed by the City of Gresham local government. It was generally built to specifications in the City of Gresham's Stormwater Management Manual (City of Gresham, 2025); however, since it was a retrofit, it was built to accommodate as much water as feasible and did not fully meet the sizing criteria used for new developments. It was designed to maximize the flow path and residence time of water in the limited space with a series of terraced channels separated by berms. Channels were designed to be vegetated with emergent aquatic vegetation to help slow the water and provide treatment. After construction, background water levels in the facility were higher than anticipated, likely due to constant inputs of groundwater from the inlet pipes. This constant flowing water was typically ~0.5–1 m deep (~1.6–3.3 ft) and limited the establishment of emergent vegetation.

Beaver activity was first noticed in the facility in the summer of 2014 when substantially altered flow paths and ponding depths were observed. Beavers built dams on the rock cascades where the water flow is constricted, creating ponds on the terraces (Fig. 2, bottom image). The dams extended along the berms separating the terraces, which increased ponding depth. The dams within the main facility were ~ 0.5–2 m

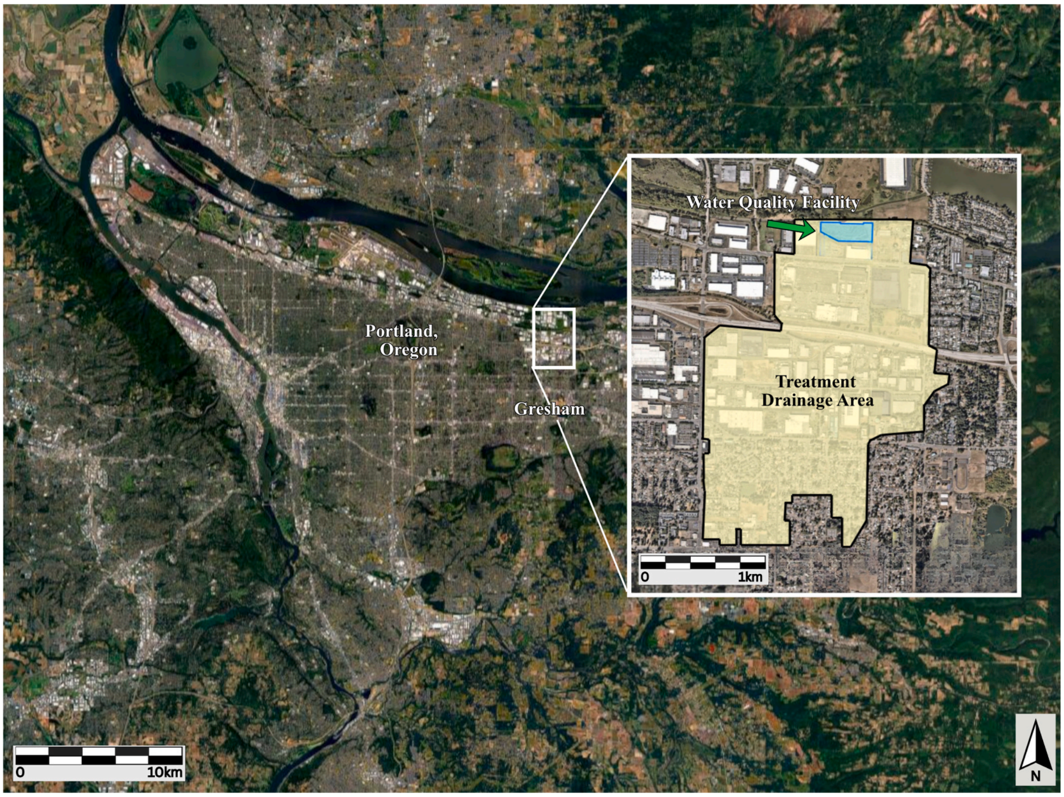

Fig. 1. Map of constructed stormwater wetland facility location and its treatment drainage area.

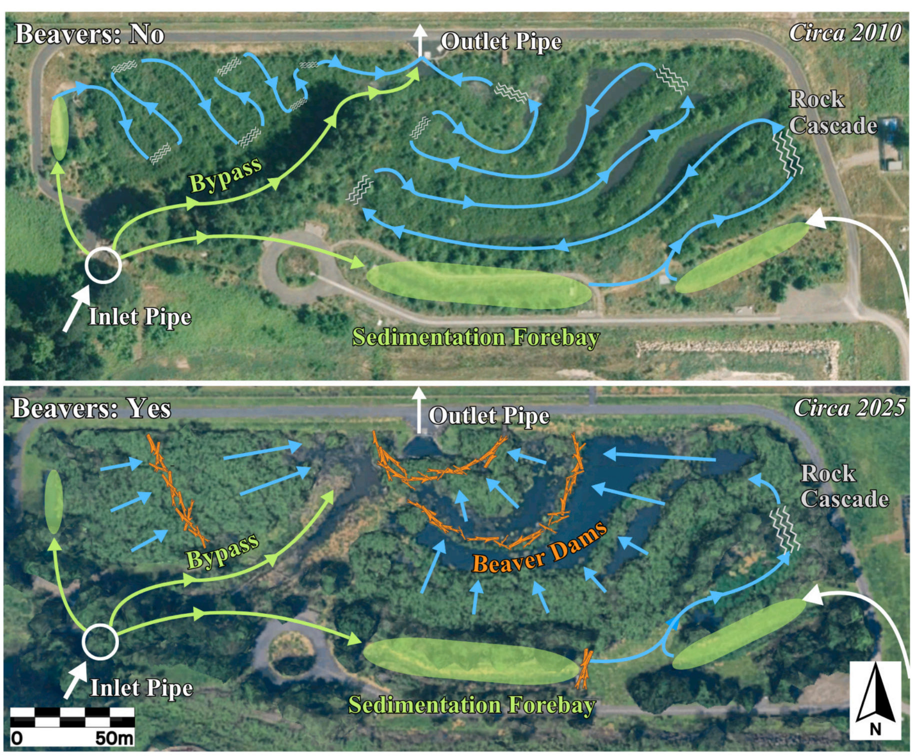

Fig. 2. Aerials of the constructed stormwater wetland facility. The top image shows the water flow path (blue arrows) as designed and constructed and the bottom image shows the flow path with beaver activity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(~1.6–6.6 ft) high and ~ 40–100 m (~131–328 ft) long. This slowed the flow of water and increased the depth to ~1–2 m deep (~3.3–6.6 ft) throughout much of the facility. Vegetated shallows emerged on the sloped edges which were now under water. Two lodges were constructed in the middle of the facility. An additional dam was built in the weir structure at the downstream end of one of the sedimentation forebays. Dam sizes and locations were consistent across storms sampled with beaver presence. The beavers and their dams were removed from the facility in fall 2015. Beaver activity was absent from the facility for several months during which time the flow paths and ponding depths returned to design specifications. Beavers recolonized the facility in winter 2016 and resumed dam building in the same locations for the duration of the study.

After the beavers returned to the facility, several beaver coexistence devices were constructed to reduce conflict with human maintenance. These included a culvert protection fence at a sedimentation forebay outlet, tree protection fencing around some large trees, and a pond-leveler placed in the tallest dam to ensure it did not reach more than ~2 m (~6.6 ft) in height (Fig. 3).

2.2. Stormwater sampling

Water quality samples were collected during 15 storms at the two inlets and the single outlet of the facility from 2011 to 2025. Storms were targeted for sampling when there was a minimum of 24 h without rain prior to the storm and 8–25 mm (0.3–1.0 in) of rain was forecast in a 24-h period, which is typical of a frequent runoff-producing storm in this region (Washington State Department of Ecology, 2012). One storm produced much more rain than forecast at 43 mm (1.7 in) with outlying inlet concentrations of pollutants and it was therefore excluded from the analysis. The remaining 14 storms averaged 12 mm (0.47 in) in 24 h. Neither storm size nor inlet concentrations of any pollutants differed significantly for the storms when beavers were absent vs. present using a Mann-Whitney *U* test (storm size: W = 49.50, $p = 0.749$; inlet concentrations: W = 27–62, $p = 0.097$–1.00). This indicates that storm size and initial pollutant concentrations were comparable for storms with and without beaver activity and that pollutant reductions can be compared between these two conditions.

Seven storms were analyzed when beaver activity was absent during two time periods (fall 2011 – spring 2014 before beavers arrived and fall 2015 after beavers and dams were removed), and seven storms were analyzed when beaver activity was present during two time periods (winter/spring 2015 after the beavers initially arrived and winter 2016 – fall 2025 after beavers recolonized). A minimum of three sub-samples were collected during each storm to capture the beginning, middle, and end of the storm, representing the rising limb, peak, and falling limb of the hydrograph. During a subset of storms, observations were noted on whether the dams were overtopped or breached when a given sub-sample was collected. However, these observations were not consistently collected and were therefore not statistically analyzed.

Fig. 3. Beaver dam and beaver coexistence devices in the constructed stormwater wetland facility. Top: main dam near the outlet of the facility as seen during willow leaf-off season. The dam is ~2 m tall and extends along the berms to the right and left for ~100 m. Water can be seen filtering through the dam rather than flowing over it. Middle left: trapezoidal culvert-protector fence. Middle right: tree protection fence. Bottom: pond leveler installed in main dam.

2.3. Water quality analysis

Twenty-one water quality parameters were measured for all 14 storms, including heavy metals, nutrients, suspended solids, biochemical oxygen demand (BOD), and *E. coli*. Nine storms were additionally analyzed for chlorinated herbicides and pesticides, eight storms for polycyclic aromatic hydrocarbons (PAHs) and phthalates, and one storm for the newly described tire chemical 6PPD-quinone (Tian et al., 2021). Temperature, pH, dissolved oxygen, and conductivity were measured in the field with a YSI Professional Plus field probe and turbidity was measured in the field by a Hach turbidimeter. Sample bottles were filled and transported to a laboratory facility on ice where the following parameters were measured with methods approved by the United States Environmental Protection Agency (EPA (Environmental Protection Agency), 2003): heavy metals (total mercury and total and dissolved copper, lead, and zinc), nutrients (total Kjeldahl nitrogen, total phosphorus, ammonia, nitrate, and ortho-phosphate), total suspended solids, BOD, *E. coli*, PAHs, phthalates, and chlorinated herbicides and pesticides (see Supplemental Material 1 for a full list of parameters, lab methods, and detection limits). Parameters which were below detection limits were estimated to be one half of the detection limit for statistical analysis (Kayhanian et al., 2002).

2.4. Statistical analysis

Sub-samples within a storm for a given location were averaged for statistical analysis to provide one composite inlet and outlet value for each pollutant for each storm. Values from the two inlets were combined according to their relative contributing area to give an overall inlet value for each parameter during each storm (hereafter: inlet). The west inlet drained twice as much area as the east inlet, and the overall inlet concentration was calculated as two times the west inlet concentration plus the east inlet concentration, divided by three. Non-parametric statistics were used due to the relatively small sample sizes. This is typical for storm-based water quality studies due to the rarity of storms which meet sampling criteria for consistency, but may lead to increased Type 1 and Type 2 errors (Helsel and Hirsch, 2002; Clary et al., 2020).

Average inlet and outlet values were compared between storms when beavers were present vs. absent using the Mann-Whitney *U* test with $\alpha = 0.05$ to determine if inlet or outlet concentrations differed between these conditions. Statistical analyses were not performed for organic compounds in storms without beaver activity due to the lack of data. Pollutant reduction percentages were calculated for each parameter during each storm by subtracting the outlet concentration from the inlet concentration, dividing it by the inlet concentration, and multiplying by 100. Percent reductions were compared between storms with and without beaver activity for each parameter using the Mann-Whitney U test with $\alpha = 0.05$ to determine if reductions were higher when beavers were present. Average values for each water quality parameter for each storm were compared between the inlet and outlet using the Wilcoxon signed rank test with $\alpha = 0.05$ to determine if values increased significantly through the facility with beaver activity.

Results were compared to relevant state water quality regulatory values: the Oregon Department of Environmental Quality's (ODEQ) instream water quality standards for aquatic life and for human health via fish consumption (OAR 340–041). The instream water quality standards for ammonia and some metals vary based on hardness, pH, and other parameters. Average values of these parameters were determined from the City of Gresham's 20-year dataset for instream water quality samples.

3. Results

Overall, beaver activity appeared to improve pollutant reduction from urban runoff in this constructed stormwater treatment wetland. Details on individual pollutant results are described in Sections 3.1–3.4 below. Average percent reduction of pollutants was higher when beavers were present than when they were absent for most pollutants measured (Table 1, Figs. 4 & 5). For example, heavy metals were reduced by an average of 0–35% when beavers were absent and by an average of 27–58% when beavers were present, and reductions for mercury, lead, zinc, phosphorus, and total suspended solids were all significantly higher when beavers were present than when they were absent ($p = 0.008$–0.037). During storms where beavers were absent in the facility, none of the parameters studied were significantly reduced; however, during storms where the beavers were present several parameters were significantly reduced, including most heavy metals as well as phosphorus, sediment, and BOD (Table 1). Several parameters exceeded water quality standards when entering the facility but met the standards upon leaving the facility when beaver activity was both absent and present (Figs. 6-8). Although pollutant reductions were higher for many parameters when beaver activity was present, outlet concentrations did not differ significantly in storms with and without beavers (W = 35–66, $p = 0.097$–0.943; Figs. 6–8). This may be due to limitations of further reducing pollutants at low concentrations where maximum reductions may have been reached for several pollutants in the facility (Drapper et al., 2022; Clary et al., 2020).

3.1. Field parameters

None of the field parameters were significantly different between the facility inlet and outlet when beavers were absent (Fig. 6; W = 7–17, $p = 0.059$–1.000). However, when beavers were present conductivity increased (W = 1, $p = 0.035$) and dissolved oxygen decreased (W = 28, $p = 0.022$), while pH and temperature did not change significantly (Fig. 6).

3.2. Heavy metals

Heavy metals were generally reduced in the facility when beavers

Table 1
Pollutant reduction percentages for the constructed stormwater treatment facility with and without beaver activity present. Percent reduction (% red) are average values across seven storms for each condition. *P*-values for "Inlet vs. Outlet" are from Wilcoxon signed rank tests comparing inlet values to outlet values during those storms, and *p*-values for "% red No Beavers vs. Beavers" are for Mann-Whitney *U* tests of percent reductions in storms with and without beavers. Significance at $\alpha = 0.05$ is shown with "*".

Parameter		No Beavers		Beavers		p-value
Type	Individual	% red	p-value Inlet vs. Outlet	% red	p-value Inlet vs. Outlet	% red No Beavers vs. Beavers
Heavy Metals	Total copper	21	0.052	42	0.022*	0.080
	Total mercury	20	0.106	50	0.022*	0.027*
	Total lead	34	0.272	45	0.052	0.037*
	Total zinc	27	0.108	58	0.022*	0.015*
	Dissolved copper	6	0.800	27	0.035*	0.063
	Dissolved lead	0	0.590	50	0.036*	0.071
	Dissolved zinc	35	0.151	47	0.022*	0.037*
Nutrients, Sediment, and Biological	Total Kjeldahl nitrogen	3	0.554	24	0.076	0.101
	Ammonia	29	0.151	21	0.108	0.551
	Nitrate	−40	0.272	−73	0.052	0.841
	Total phosphorus	−6	0.554	19	0.022*	0.037*
	Orthophosphate	−61	0.142	−18	0.022*	0.449
	Total suspended solids	−57	0.529	61	0.022*	0.008*
	Biochemical oxygen demand	0	0.787	46	0.035*	0.063
	E. coli	−23	0.554	18	0.800	0.125

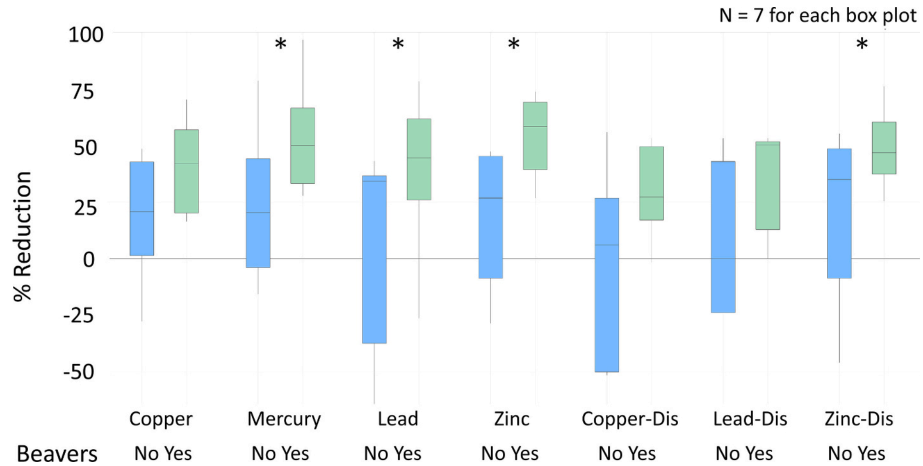

Fig. 4. Percent reductions in total and dissolved metals in a constructed stormwater wetland facility when beavers were absent and present. "Tot" indicates total and "Dis" indicates dissolved forms of the metal. An "*" indicates significance of a Mann-Whitney *U* Test at $p = 0.05$. There was one outlier which is not shown on this figure (dissolved lead without beaver activity at −155%) to increase visibility of remaining data.

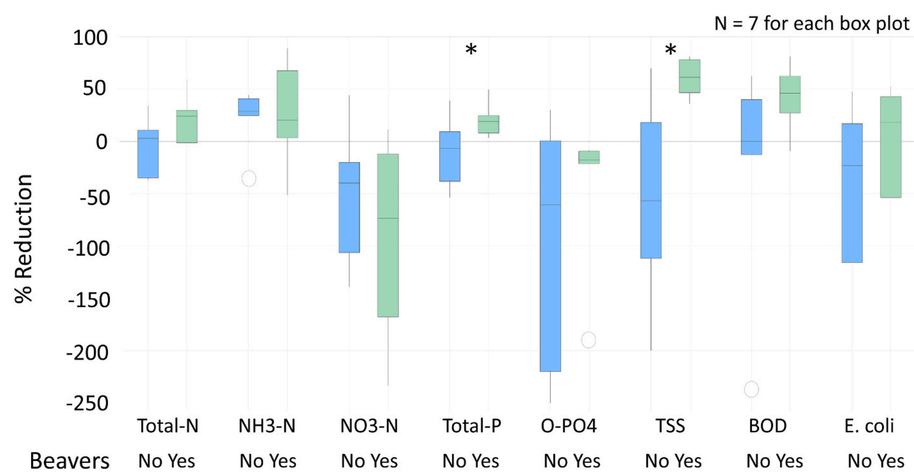

Fig. 5. Percent reductions in nutrients, sediment, and biological parameters in a constructed stormwater wetland facility when beavers were absent and present. An "*" indicates significance of a Mann-Whitney *U* Test at $p = 0.05$. Outliers are indicated with an open circle. Two outliers are not shown on the figure (*E. coli* without beaver at −789% and *E. coli* with beaver at −598%) to increase visibility of remaining data.

were present and were not reduced when beavers were absent (Fig. 4, Fig. 7). Reductions were significantly higher in storms with beavers than without for total mercury, total lead, total zinc, and dissolved zinc ($p =$ 0.015–0.037). The facility did not significantly reduce concentrations of any of the heavy metals measured when beavers were absent; however, when beavers were present almost all metals measured were reduced significantly by an average of 27–58% (Table 1, p = 0.022–0.036). The only metal which was not shown to be significantly reduced when beaver activity was present was total lead ($p = 0.052$), which may be partially due to many samples that were below detection limits at both the inlet and outlet. Concentrations of copper, lead, and zinc were generally below relevant instream water quality standards both with and without beaver activity (Fig. 7). There were a handful of exceedances of water quality standards for metals, but no exceedances occurred in the outlet samples when beaver activity was present.

3.3. Nutrients, sediment, and biological parameters

Reduction of sediment was higher when beaver dams were present than when they were absent ($p = 0.008$), but reduction results were mixed for nutrient and biological parameters (Fig. 5, Fig. 8). When beavers were absent, none of the parameters studied changed significantly between the inlet and outlet ($p =$ 0.142–0.554). However, when beavers were present, total phosphorus decreased significantly by an average of 19% ($p = 0.027$), orthophosphate increased by an average of 18% (p = 0.022), total suspended solids (TSS) decreased by an average of 61% (p = 0.022), and biochemical oxygen demand (BOD) decreased by an average of 46% (Table 1, p = 0.035). TKN, ammonia, nitrate, and *E. coli* were not significantly changed when beavers were present ($p =$ 0.052–0.800). Values were generally below water quality standards both with and without beavers (Fig. 8).

3.4. Organic compounds

During the sampled storms, most of the measured organic pollutant compounds were below detection limits at the inlets and outlets when beavers were both absent and present. The twelve compounds which had detections in at least half of the storms sampled were: the PAHs benzo(a) pyrene, benzo(b) fluoranthene, benzo(ghi) perylene, chrysene, fluoranthene, indeno(1,2,3-cd) pyrene, phenanthrene, and pyrene, the phthalate di(2-ethylhexyl) phthalate (DEHP), the pesticides 2,4-D and pentachlorophenol, and the tire anti-ozonate chemical 6PPD-quinone.

PAHs and phthalates were only measured in two storms without beavers and six storms with beavers; pesticides were only measured in

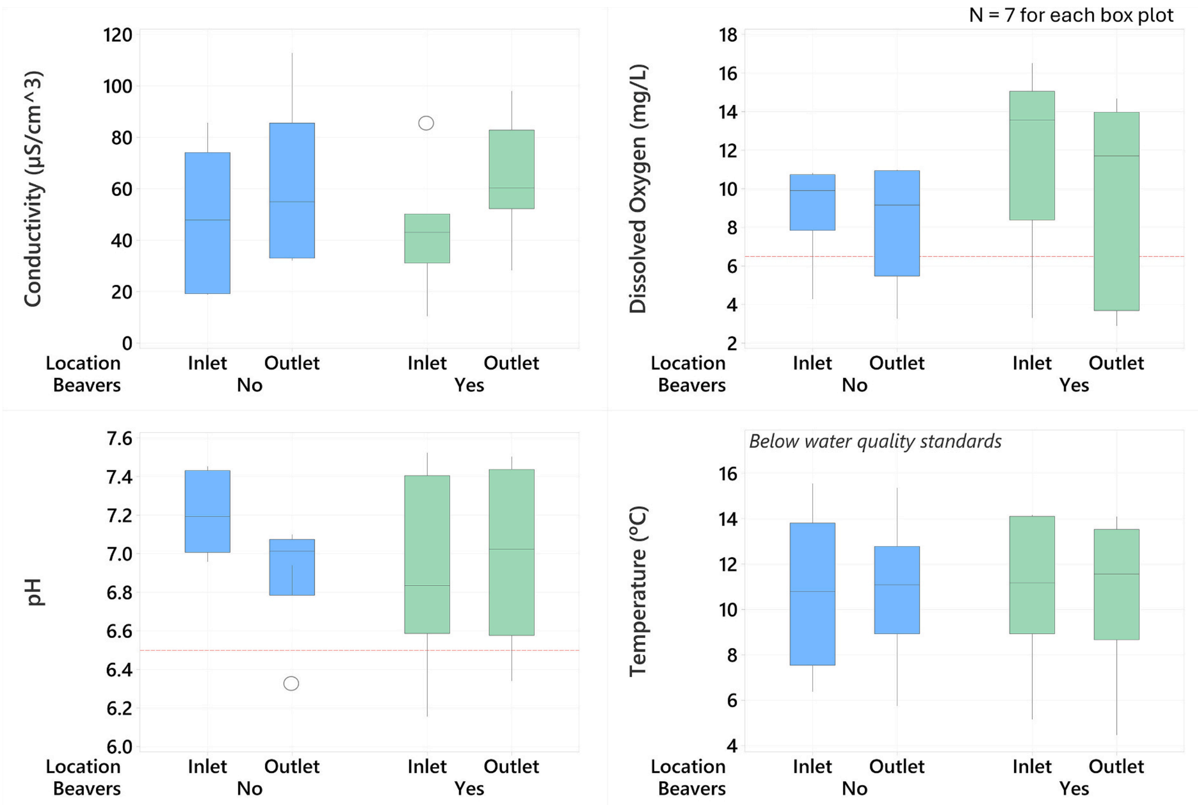

Fig. 6. Field parameters at the inlet and outlet of the facility when beavers were absent and present. Red dashed lines indicate applicable water quality standards. For these parameters they represent minimum values for various aquatic species. No parameters were significantly different with a Wilcoxon signed rank test at p = 0.05. Outliers are indicated with an open circle. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

two storms without beavers and seven storms with beavers, and 6PPD-quinone was only measured in one storm with beavers. Due to the low sample size, statistics were not performed for organic pollutants when beavers were absent or on 6PPD-quinone; however, most of these compounds trended towards being lower at the outlet than the inlet when beavers were both absent and present (Table 2).

Most of the PAHs and DEHP were reduced to at or near detection limits in the facility both when beavers were absent and present (Table 2). Several of these were significantly reduced when beavers were present: benzo(ghi) perylene ($p = 0.025$), fluoranthene ($p = 0.050$), phenanthrene ($p = 0.026$), pyrene ($p = 0.005$), and DEHP ($p = 0.004$). Concentrations of 2,4-D and pentachlorophenol were generally higher in the inlet samples than in the outlet samples but did not reduce to near detection limits at the outlet as the other organic contaminants did (Table 2). All of the 2,4-D concentrations and most of the pentachlorophenol concentrations were below the human health criteria for consumption. Concentrations of pyrene were below human health criteria for consumption of water and aquatic organisms. Concentrations of benzo(*a*)pyrene were above these criteria at the inlets and not able to be assessed at the outlet because the detection limit of 5 ng/L was above the criterion of 1.3 ng/L. The emerging pollutant 6PPD-quinone was only sampled in one storm, and no applicable water quality standard has yet been implemented, but the preliminary results showed that inlet concentrations were above the lethal concentration for 50% of individuals (LC_{50}) for adult coho salmon of 95 ng/L (Tian et al., 2022), while outlet concentrations were below that level (Table 2).

3.5. Observations of facility function during storms

During storms when beaver activity was absent, water generally flowed along the channels in the designed sinuous path (Fig. 2). Little filtration through vegetation was observed as little emergent vegetation was present. During the peaks of large storms, the water level sometimes increased such that the berms were under water and the entire facility basin filled for several hours before draining down slowly.

During the storms when beaver dams were present, water generally flowed through several large ponds and beaver dams (Fig. 2). The water level often increased higher than when beavers were absent as the dams slowed and backed up the water. Water was generally observed flowing through the dams, although during the peak of storms the dams were often over topped or breached with water flowing over or around them. When examining the subset of observations which noted the condition of the water in relation to the dams, it was generally observed that pollutant removal was higher and outlet concentrations were lower when the beaver dams were intact and the water was flowing through the dams than when the dams were topped or breached.

4. Discussion

Our results indicate that beaver activity appears to increase pollutant removal of urban pollutants in this constructed wetland facility, especially for heavy metals and sediment. The results may also have implications for streams degraded by urbanization or other human activity in addition to stormwater treatment facilities due to the ability of beavers to improve water quality in a highly polluted system. Increased ponding was observed when beaver activity was present in the facility, and water was generally seen to flow through the dam matrix. These conditions may have led to increased wetland dynamics in the facility, slowing of water flow, more sedimentation, and increased filtration of the water through the dams.

4.1. Water quality parameters

Beaver dams have been shown to increase the presence of wetland

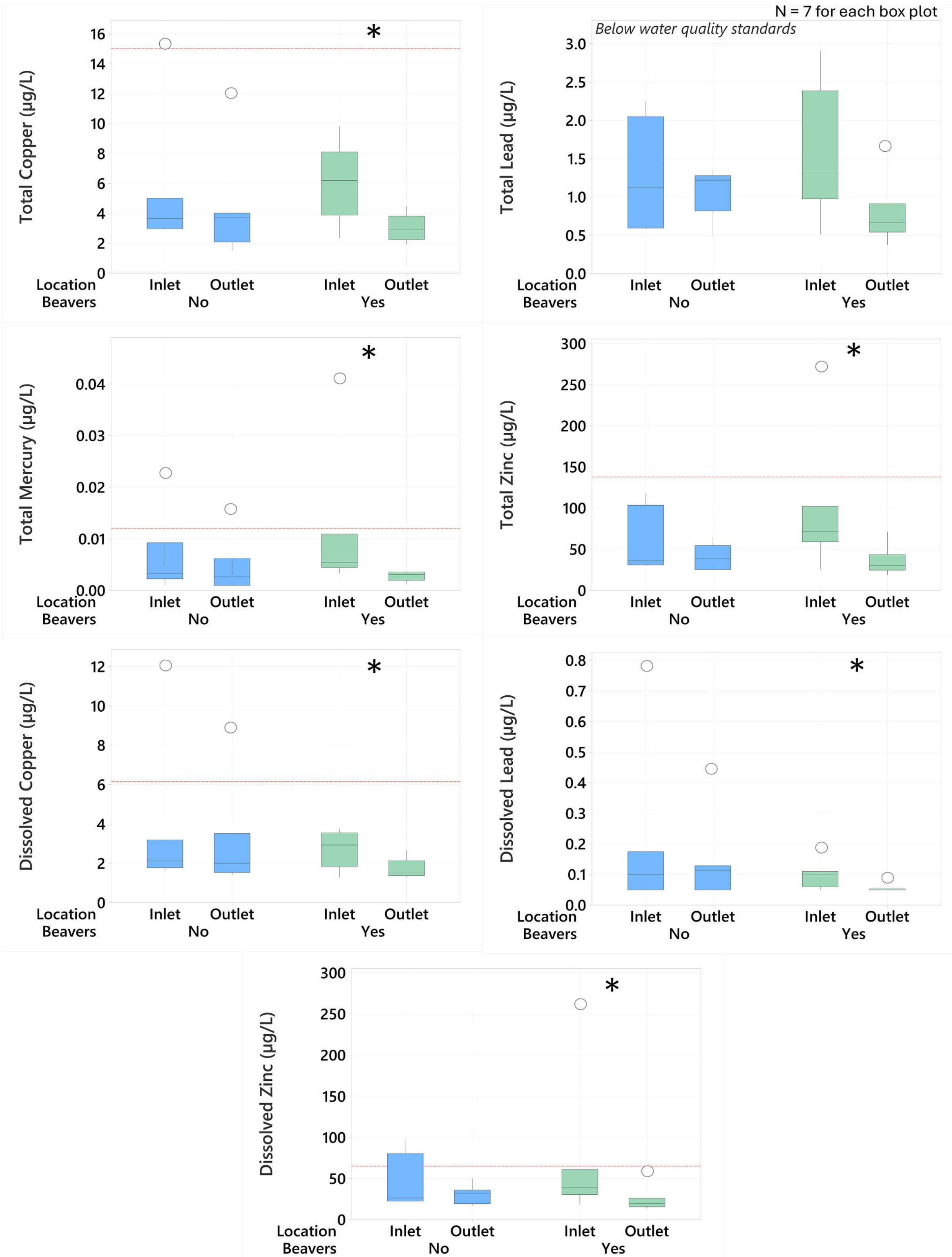

Fig. 7. Heavy metal concentrations at the inlet and outlet of the facility when beavers were absent and present. Red dashed lines indicate applicable water quality standards. For these parameters they represent maximum values. An "*" indicates significance of a Wilcoxon signed rank test at p = 0.05. Outliers are indicated with an open circle. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

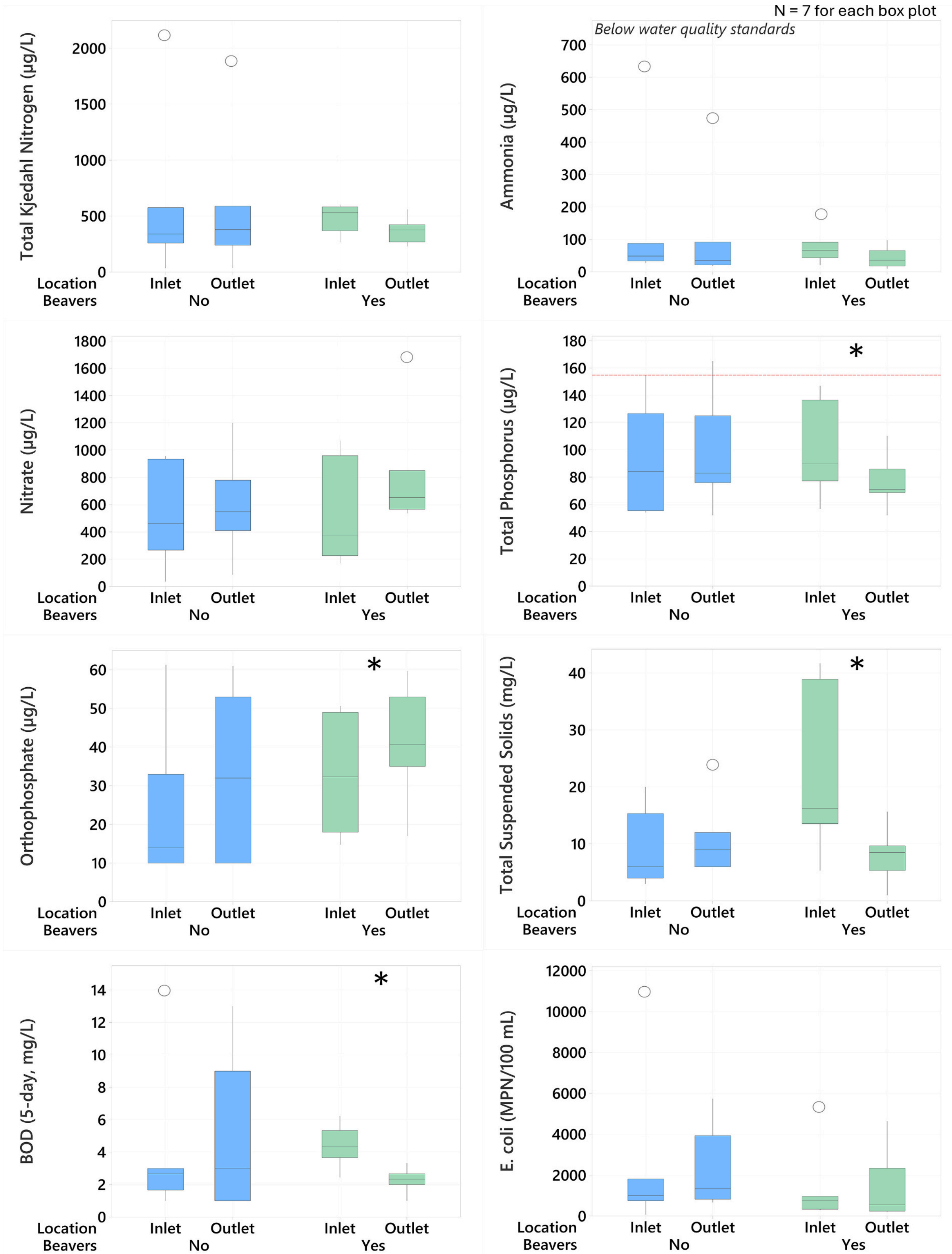

Fig. 8. Nutrient, sediment, and biological parameter concentrations at the inlet and outlet of the facility when beavers were absent and present. BOD stands for biochemical oxygen demand and MPN stands for maximum probably number of colonies. Red dashed lines indicate applicable water quality standards. For these parameters they represent maximum values. An "*" indicates significance of a Wilcoxon signed rank test at $p = 0.05$. Outliers are indicated with an open circle. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Concentrations of organic pollutants at the inlet and outlet of the constructed stormwater facility when beavers were absent and present.

Beaver Activity		No	Yes	No	Yes	No	Yes	No	Yes
Parameter Type	Parameter	Ave. inlet conc. (ng/L)		Ave. outlet conc. (ng/L)		# of events samples		% detection at outlet	
Polycyclic aromatic hydrocarbon (PAH)	Benzo(a) pyrene	12	8	5	5	2	6	0	0
	Benzo(b) fluoranthene	23	13	11	6	2	6	100	33
	Benzo(ghi) perylene	25	26	12	12	2	6	50	33
	Chrysene	22	13	11	5	2	6	100	17
	Fluoranthene	32	27	15	8	2	6	100	50
	Indeno(1,2,3-cd) pyrene	12	8	5	5	2	6	0	0
	Phenanthrene	38	30	21	12	2	6	100	17
	Pyrene	48	62	29	27	2	6	50	67
Phthalate	Di(2-ethylhexyl) phthalate	1267	1493	500	500	2	7	0	0
Pesticide	2.4-D	156	195	112	137	2	7	50	43
	Pentachlorophenol	110	116	70	61	2	7	100	71
Anti-ozonate	6PPD-quinone	NA	140	NA	66	0	1	NA	100

dynamics in flowing water systems, including increased microbial activity (Błędzki et al., 2011; Grudzinski et al., 2022). This may have contributed to the observed changes in nutrient and biological parameters. Increased ponding created by the beaver dams, which traps and provides more time to decompose organic matter, may have led to the observed decrease in dissolved oxygen when beavers were present (Smith et al., 2025). Although low dissolved oxygen is detrimental to many aquatic species who require it for metabolism (Saari et al., 2018), the average outlet value of 11.7 mg/L was still relatively high and is above the instream water quality standard applicable to this receiving water body of 6.5 mg/L for cool-water aquatic life. Constructed stormwater wetlands typically have lower dissolved oxygen concentrations compared to natural ponds due to pollutant degradation, although this varies depending on the time of year (Struck et al., 2008). A decrease in dissolved oxygen has also been observed in beaver ponds (Stevenson et al., 2022; Smith et al., 2025; Smith et al., 2020), which may be due to the water slowing as a result of the dams, although other studies have shown supersaturation of oxygen due to algae and macrophytes in the beaver pond (Bylak et al., 2014). Constructed stormwater wetlands in urban areas often do not have large numbers of macrophytes or algae, particularly during storm events when water is flowing through the wetland, and thus may not have this source of oxygen.

It may be surprising that there were no differences in temperature when beavers were present because dams have been shown to sometimes have large effects on temperature (Jordan and Fairfax, 2022; Stevenson et al., 2022; Błędzki et al., 2011). The difference is likely related to locations and timing of the studies. Most studies on the effects of beaver activity on temperature have taken place in stream systems in the summer with ambient background flows. The current study was conducted in a stormwater runoff system during storm events in the winter rainy season. During these winter storms, the air and water were relatively cool and the sky was cloudy, so there was little solar radiation to create warming that might occur in the system during other times. Additionally, the clay soil underlying the facility may reduce hyporheic exchange with groundwater which has been shown to contribute to cooling in some beaver stream systems (Dittbrenner et al., 2022).

Our study did not show any clear patterns of changes in nitrogen concentrations or species, which points to the complex nitrogen dynamics in wetlands. Changes in nitrogen composition have been found to be variable both for constructed wetlands (Clary et al., 2020; Schmitt et al., 2015) and for beaver ponds (Grudzinski et al., 2022; Puttock et al., 2017; Bason et al., 2017). Using the International Stormwater BMP Database, Clary et al. (2020) indicates there was no significant difference in the influent and effluent of constructed wetlands for total nitrogen and TKN, but reductions in nitrate and ammonia occurred for 14 different studies. However, Schmitt et al. (2015) observed 79% reduction of total nitrogen, and Birch et al. (2004) observed 16% reduction of total nitrogen and 9% reduction of TKN. This is similar to the results observed in beaver ponds where 3 out of 6 studies indicated no difference in total nitrogen, 6 out of 17 studies (35%) indicated no difference in nitrate, and 5 out of 12 studies (42%) indicated no difference in ammonia concentrations (Grudzinski et al., 2022). Some studies have shown decreases in nitrate and ammonia in beaver ponds (Błędzki et al., 2011), but others have shown an increase (Bollinger and Conklin, 2012; Bason et al., 2017). Variability may be due to additional sources of nitrogen from upstream catchments (Puttock et al., 2018) or leaching from soils rich in nutrients such as compost. Nutrients can leach from compost and it has been identified as a significant source of nutrients in the effluent of passive stormwater systems (Mullane et al., 2015; Hurley et al., 2017). The amount of organic matter and dissolved oxygen may also affect ammonia concentrations; aerobic biodegradation of organic matter can occur preferentially to nitrification due to heterotrophic bacteria out-competing nitrifying bacteria (Strauss and Lamberti, 2002). If large amounts of organic matter are present and oxygen levels are low, nitrification may slow or not occur at all.

Total phosphorus was decreased only when beavers were present, although ortho-phosphate increased. Other studies of constructed wetlands also showed a significant decrease in total phosphorus (Clary et al., 2020; Birch et al., 2004; Schmitt et al., 2015), but no significant changes in ortho-phosphate (Clary et al., 2020). Results have been more variable in beaver ponds where 5 out of 10 studies indicated no difference in total phosphorus concentrations (Grudzinski et al., 2022). Some studies on beaver ponds have shown a reduction in ortho-phosphate and total phosphorus (Puttock et al., 2017; Law et al., 2016) whereas others have shown an increase in ortho-phosphate concentrations (Błędzki et al., 2011). The variability may be due to the amount of suspended solids in the stormwater and reduction efficiencies of the facility; suspended solids are typically a source of phosphorus in both beaver ponds and constructed wetlands (Maret et al., 1987).

Our study did not find significant differences in *E. coli* concentrations at the inlets vs. outlets when beavers were either absent or present. The results indicate that there may not be any trends; however, the high spatial and temporal variability of this parameter may be masking potential trends. *E. coli* concentrations in wetlands can be highly variable as wetland dynamics shift bacteriological compositions. The majority of the samples were above the Oregon instream water quality standard, which was developed for human swimming areas receiving runoff from combined sewer systems and was intended to target *E. coli* from human sources (Urban Water Resources Council, 2014). This facility does not receive any runoff from combined sewer systems, and the runoff does not contain any known human waste sources. Additionally, genetic source tracking conducted by the City of Gresham in nearby stream and stormwater systems has shown no detections of human sources and indicated wildlife and domestic dogs as the primary waste sources (City of Gresham, 2016). Abundant wildlife lives in the facility including wetland birds, amphibians, deer, coyotes, and, of course, beavers. Constructed wetlands have been shown to significantly reduce *E. coli* in stormwater in the absence of wildlife (Clary et al., 2020; Birch et al., 2004), while beaver ponds have been shown to be a source of *E. coli* due to the beavers themselves and other wildlife (White et al., 2025). It is likely that this wildlife contributes *E. coli* to the water in the facility, even if some *E. coli* is being filtered out. Beavers have generally increased wildlife use of the facility (City of Gresham, 2019), which may increase *E. coli*, but would still be consistent with the overall goals of the facility.

Beaver dams have been shown to reduce sediment in flowing water by slowing the water and allowing particles to settle out in addition to filtering the water through the dams (Bradbury et al., 2026; Bylak and Kukuła, 2022; Puttock et al., 2017; Fletcher et al., 2019; Bollinger and Conklin, 2012). In our study, total suspended solids were decreased only when beaver dams were present, indicating that beaver dams increased sedimentation in this facility. In a study on sediment dynamics, Bradbury et al. (2026) observed that accumulation occurred during lower intensity storms of <12 mm/h (<0.47 in/h), with erosion occurring in some beaver ponds during larger storms. The peak rainfall intensity of the sampled storms in this study averaged 4.5 mm/h (0.18 in/h) and was always <12 mm/h (0.47 in/h). Therefore, our results are consistent in showing that beaver activity reduced particles in turbid runoff during sampled storm events. Other pollutants such as heavy metals may also have been bound to particles in the water which settled out with sediment behind the dams.

It was somewhat surprising that the facility did not reduce sediment when beavers were absent because the facility was designed to remove sediment and other studies have demonstrated that constructed wetlands often do remove sediment (Birch et al., 2004; Clary et al., 2020; Schmitt et al., 2015). Observations did show some sediment accumulation in the facility when beavers were absent, and also resuspension of some of that sediment during larger storms. When beavers were absent, it is possible that the facility did remove sediment throughout the year during smaller storms with some of it being resuspended during sampled storms. Additionally, the facility was relatively small compared to the drainage area (~1%) because it is a retrofit designed to utilize available space, and the emergent aquatic vegetation originally planted did not establish due to high background water levels (City of Gresham, 2016; City of Gresham, 2019; City of Gresham, 2025). These conditions may have led to lowered performance compared to other facilities which were built to standard storm event sizing criteria (~6–10%) and which effectively established emergent vegetation (Clary et al., 2020).

Beaver dams have been shown to physically filter water as it flows through them, which may also allow for chemical sorption (Shepherd and Nairn, 2020; Belova et al., 2025; Murray et al., 2021). The observation that pollutants had higher reductions during sub-samples where water was flowing through rather than over or around the dams indicates that they may be filtering some of the pollutants. These varying flow paths are similar to those observed by Ronnquist and Westbrook (2021) where water generally travelled through the dam except when the ponds was ~95% full. This facility has high water level variability due to the large drainage area, and water levels often rise and fall >2 m (6.6 ft) during a given storm. Systems where a greater proportion of water flows through beaver dams, such as less flashy systems or those with large, established dams, may experience higher pollutant reductions.

Filtration through the dams may have contributed to reductions in heavy metals and organic pollutants in this facility as they are physically filtered or chemically sorbed to soil particles and organic matter (Shepherd and Nairn, 2020; Belova et al., 2025; Murray et al., 2021). The majority of heavy metals measured were reduced by >40% when beaver dams were present (42–58%). Pollutant reduction rates were similar to what has been observed in constructed wetland studies (Birch et al., 2004; Clary et al., 2020; Walaszek et al., 2018). In beaver ponds, Bollinger and Conklin (2012) observed a decrease in copper and zinc, and Shepherd and Nairn (2020) observed a decrease in lead and zinc at the outlet of a beaver pond, but results were not statistically significant. In general, heavy metals are often removed in soil via the positively charged metal ions sorbing to the negatively-charged soil (Yu et al., 2023). The act of stormwater moving through the soil matrix within the beaver dams in the constructed wetland likely contributed to the reduced concentrations.

The facility appeared to reduce the concentration of most organic pollutants, and did so significantly when beavers were present. However, due to the small sample size, limited data when beavers were absent, and variation in concentrations, a conclusion cannot be drawn whether beaver activity improves pollutant reduction of these parameters. These results are encouraging for the potential of constructed facilities and beaver activity to reduce organic pollutants in urban waterways but more study is needed. Constructed wetlands have been shown to reduce concentrations of organic pollutants which often sorb to organic matter and can be degraded by wetland microbial activity (Birch et al., 2004; Tromp et al., 2012; Walaszek et al., 2018). Our results suggest that this trend may be present in this facility, but the sample size was too small to determine if beavers played a role. Beaver dams are often constructed with organic matter such as sticks, mud, and leaves, which may provide binding sites to sorb organic pollutants (Brazier et al., 2021). The tire chemical 6PPD-quinone in particular is known to bind readily to organic matter and therefore may be removed in constructed wetlands in general and with filtration through beaver dams in particular (Hildebrandt et al., 2024; Sanganyado, 2025). More research is needed that can verify the ability of both constructed wetlands and beaver dams to reduce 6PPD-quinone concentration in stormwater and in streams. If a similar pattern holds, then beaver activity may be a way to lessen the impact of this chemical on endangered salmon and other aquatic life.

Overall, beaver activity appeared to increase pollutant reduction in this facility, especially for heavy metals and sediment, while results for nutrients and biological parameters were more mixed. Possible mechanisms for this include increased wetland dynamics, slowing of water flow, increased sedimentation, and filtration through the dam matrix. These potential pathways were observed in the facility during this study but were not measured directly. Further research on these mechanisms would help to inform how beaver engineering can help reduce urban runoff pollutants in receiving water bodies. Additionally, future studies including information on hydrologic measures such as flow and retention time would allow evaluation of pollutant load reductions in addition to reductions in concentrations.

4.2. Implications for constructed wetland design with beavers in mind

The results of this study indicate that beaver activity in this facility improved urban runoff pollutant reduction. Therefore, it is desirable to determine how to retain beavers at this site and coexist with them such that human operations and maintenance is not compromised. It has long been known that filtering stormwater through soil, such as that in a dam, is an effective way to reduce many pollutants; this is the basis for stormwater technologies like rain gardens, bioretention cells, and infiltration basins (Hunt et al., 2012; Davis et al., 2006). The major reason that large facilities such as the one in this study are not designed with soil filters is because the large volume of water moving through the facility would likely create breeches and washouts of soil berms. Maintenance crews would frequently need to repair the facility to retain flow paths and prevent water from short-circuiting to the outlet without treatment. However, this is exactly what the beavers are doing in this facility, like a free night crew constantly repairing the dams. When large storms create breaches, they immediately seek them out and meticulously patch them up, maintaining the filter.

Food and water levels are likely the most important factors for retaining beavers in this facility. They seem to feed largely on the Sitka willow (*Salix sitchensis*) which were planted during construction. Beavers are often referred to as a “choosey generalist” due to their ability to eat many species but prefer poplars and willows, including the *Salix* sp. (Gerwing et al., 2013; Juhász et al., 2023; Vorel et al., 2015). Roughly

1000 willow stakes were planted over the 9-acre wetland. It appears that this initial planting in conjunction with natural reseeding and regenerative coppicing of the willows after beaver damage is sufficient to sustain at least one family of beavers in the facility. This facility receives constant flow because groundwater infiltrates into the stormwater pipes which feed the wetland allowing year-round water access for the beavers. The shape of the facility allows for ponded areas to create underwater entrances to bank dens and lodges which provide needed safety for the beavers.

For constructed wetlands to be attractive to beavers, it is likely beneficial to have an abundance of food available (e.g. willow, ash, or cottonwood), year-round flow, and room for water levels to rise. Additionally, designs should limit reliance on soil berms, dikes, or levees which may be compromised if beavers create slides or burrow through them to connect areas of the wetlands (Taylor et al., 2017). If beavers are not desired at a constructed wetland, designs should limit plants desirable to beavers as well as constrictions where running water creates an attractive location for a small dam to create a large pond.

Of note, when beavers were absent, this facility was underperforming when compared to other constructed wetlands (Birch et al., 2004; Clary et al., 2020; Schmitt et al., 2015). This is likely due to the relatively small size of the facility compared to the drainage area (~1%) and the lack of established emergent aquatic vegetation. Our results indicate that beaver activity may be able to increase performance of undersized or otherwise constrained constructed wetlands. It is also possible that constructed wetland facilities could benefit from designs which mimic beaver activity. Designs which slow and filter the water in a similar way to beaver dams, and structures such as beaver dam analogs may provide similar benefits (Wohl and Inamdar, 2025). However, more research into the underlying mechanisms of pollutant reduction is warranted to understand how best to design, construct, and maintain such systems to benefit water quality.

The sedimentation forebays in the facility have generally been quite effective at removing sediment and are relatively easy to dredge and maintain. Including these structures in facility design likely supports the efficiency of many stormwater treatment wetlands (EPA (Environmental Protection Agency), 2021). If included in facilities where beaver activity is suspected, constrictions should be avoided or exclusion fences installed to reduce clogging.

4.3. Conflicts and coexistence with beavers at constructed wetlands

Although beaver activity improved pollutant reduction in the facility, it also created challenges for human operations and maintenance. A dam at the weir structure of the outlet to a sedimentation forebay had caused the forebay to overflow, defeating its purpose and washing out an access road. The largest dam in the main wetland became so high that the resulting pond occupied most of the area designed for storm detention, leaving less room for water to accumulate during storms without overtopping the entire facility and bypassing the flow control structure. Additionally, beaver-chewed trees have fallen on power lines, roads, and washed up against outlet grates, blocking flow.

Each of these issues has been greatly reduced by hiring a contractor to build beaver coexistence devices (Fig. 3; Project Beaver, 2025). The forebay outlet was retrofitted with trapezoidal fence (also called a “culvert protector”) which allow the beavers to build up against the fence close to the outlet while allowing water to flow freely through the far side. The largest dam in the main wetland was outfitted with a “pond-leveler” pipe through the dam which has a sunken intake at the bottom of the pond. This allows the dam to persist, but not beyond a predetermined height. Additionally, tree-protection fencing was constructed around certain trees identified as being desirable to retain and therefore preventing beavers from chewing on those trees. Before these coexistence structures were in place, City operations crews were checking this facility every two weeks for beaver-related issues and often needed to remove dams or debris. As of the writing of this paper, the structures have been in place for almost five years and City crews have not needed to conduct beaver-related maintenance in the facility since their installation.

Flow devices for controlling pond level, culvert protectors, and exclusion fencing are the most common methods for coexistence with beavers (Bailey et al., 2018; Portugal et al., 2015; Taylor et al., 2017). In addition to pond-levelers used in the current study, flow devices such as corrugated or flexible pipes in conjunction with exclusion fencing can help maintain water flow, and repellants have also been used to discourage chewing of vegetation (Taylor et al., 2017). Overplanting of vegetation to allow some browsing has also been suggested (Bailey et al., 2018). Although not technically a coexistence device, beavers are also sometimes live-trapped and relocated to a more suitable location (Project Beaver, 2025; Taylor et al., 2017; Bailey et al., 2018). These methods can ensure coexistence with beavers in urban settings, particularly for stormwater systems where beaver activity can improve water quality.

5. Conclusion

This study shows that beaver activity can improve pollutant reduction from urban stormwater runoff in a constructed wetland facility. Copper, mercury, lead, zinc, phosphorus, suspended solids, and BOD were all significantly reduced when beavers were present but not when they were absent. There was also evidence for potential reduction of several organic pollutants such as phthalates, PAHs, herbicides, and the tire chemical 6PPD-quinone. Pollutants were generally reduced by >40% when beavers dams were present. Higher pollutant reduction occurred when water flowed through the dams; lower reductions occurred during the peak of storms when the dams were often overtopped or breached with water flowing over or around them. Although this study indicates that beaver dams are likely to increase pollutant reduction of urban stormwater pollutants, the mechanisms for the reductions were not studied. Future research into understanding these mechanisms would be valuable to increase understanding of how beaver engineering benefits water quality.

This study indicates that it may be beneficial for downstream water quality to support beaver activity in constructed wetlands, but the beaver activity must be compatible with human access and maintenance activities in order to be tolerated. Consideration for beavers can occur during the planning and design of constructed wetland facilities including plant selection, assessment of constriction points for dam building, and room for additional ponding. Coexistence devices such as culvert protectors, pond levelers, and tree fencing can be useful technologies to allow beavers to persist while reducing operations and maintenance burden.

The ability of beaver dams and ponds to filter and settle urban pollutants may also apply to urban stream and river systems. Recolonization and allowed persistence of beavers in watersheds where they historically occurred may be useful tools for mitigating negative impacts of urbanization on urban water quality.

CRediT authorship contribution statement

Katie Holzer: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Cara J. Poor:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis.

Declaration of competing interest

The authors declare no conflicts of interest. The funders had no role in the design of the study, in the collection, analysis, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoleng.2026.108057.

Data availability

Data are available through the Oregon Department of Environmental Quality's Ambient Water Quality Management System database: https://www.oregon.gov/deq/wq/pages/wqdata.aspx (accessed on 16 July 2025).

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