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# Evaluation of small-scale constructed wetland for water quality and Hg transformation

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**Abstract**

Elevated concentrations of nutrients and mercury (Hg) make Steamboat Creek (SBC) the most polluted tributary of the Truckee River. Since wetlands are considered cost-effective, reliable, and potential sites for methylmercury (MeHg) production, a small-scale wetland system was constructed and monitored for several years in order to quantify both nutrient removal and transformation of mercury. Results indicated seasonal variations in nutrient removal with 40–75% of total nitrogen and 30–60% of total phosphorus being removed with highest removals during summer and lowest removals during winter. The wetland system behaved as a sink for MeHg during the winter months and as a source for MeHg during summer months.


*Keywords:* Water quality; Constructed wetland; Truckee River; Mercury

## 1. Introduction

Steamboat Creek (SBC), Washoe County, Nevada, USA is typical of many urban watersheds in that it is contaminated by agricultural and urban storm water runoff, and land management practices which all contribute to nutrient pollution [1]. Steamboat Creek is considered to be the most polluted tributary of the Truckee River and a major source of nonpoint pollution, annually contributing around 70,000 kg of nitrogen, 15,000 kg of phosphorus, 900,000 kg of total suspended solids (TSS), and 9 kg of total mercury [2]. Research has shown that constructed wetlands can be used to improve water quality by removing nutrients (nitrogen, phosphorus), heavy metals, and suspended solids [3,4]. Therefore, the construction of a large-scale wetland system at the confluence of the Truckee River and Steamboat Creek has been proposed as a component of a regional watershed restoration plan developed by the Cities of Reno and Sparks and the Army Corps of Engineers (Codega and WESTEC, Inc., 1998). To quantify anticipated nutrient removal within such a system, a small-scale wetlands system was constructed near the confluence of SBC and the Truckee River at the Truckee Meadows Water Reclamation Facility (TMWRF) in Sparks, Nevada [2]. SBC also has high concentrations of mercury in both water and sediments [5]. Mercury in the creek water is derived primarily from mine wastes that have been distributed down the creek from the headwaters since the late 1800s. Since wetlands are known to be sites of methylmercury (MeHg) production [6], a constructed wetland could affect MeHg concentrations in the lower Truckee River. Truckee River supplies water to the terminal Pyramid Lake, home to two fish species listed by U.S. Fish and Wildlife Service (i.e., endangered cui-ui (USFWS, 1967) and threatened Lahontan cutthroat trout (USFWS, 1975)). Since fish consumption is the main pathway for human exposure to MeHg there is a great concern about the effect of constructed wetland in the SBC watershed to MeHg production. The main objective of this study was to quantify the ability of constructed wetlands to reduce loadings of total nitrogen, total phosphorus and MeHg production in a small-scale surface flow wetland system.

## 2. Materials and methods

### 2.1. Experimental design

The small-scale wetlands system was a free-water flow surface wetlands similar to a natural marsh and characterized by a

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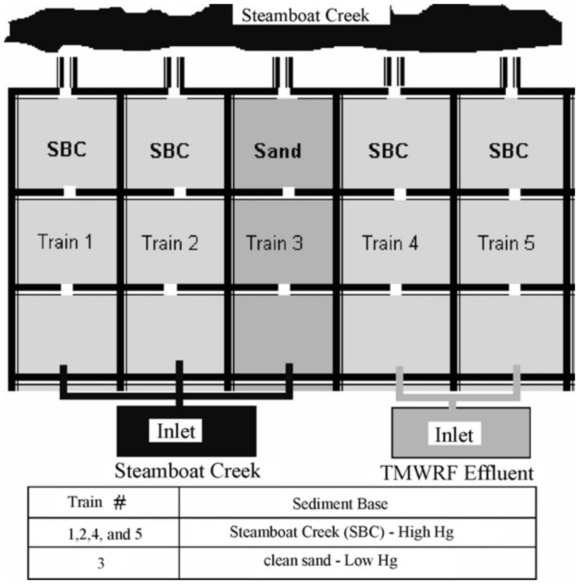


Fig. 1. Experimental design for the small-scale surface flow wetland system.

soil bottom, emergent vegetation, and a water surface exposed to the atmosphere. The wetlands were designed to enable easy water quality sampling and were divided into the five parallel trains. Each train was 1.8 m wide, 9 m long, and 0.6 m deep. Water depths varied from approximately 5–20 cm. A base layer of 20 cm of aggregate and sand, autochthonous SBC sediments ($0.86 \pm 0.52$ μg Hg/g) were used in Trains 1, 2, 4, and 5. Train 3 was filled with aggregate and sand (mixed 80% sand and 20% aggregate by volume, low in heavy metals and toxins, $0.09 \pm 0.03$ μg Hg/g). Water from SBC (25–318 ng Hg/L) was pumped to Trains 1–3 while Trains 4 and 5 received treated wastewater effluent from TMWRF (4–16 ng Hg/L), an advanced wastewater treatment facility. Combination of these sediment base and waters provided us with three different designs: (1) SBC sediments and SBC water, (2) clean aggregate and sand and SBC water, and (3) SBC sediments and TMWRF effluent. Before collecting sampling all trains were allowed to equilibrate for 6–12 months. All of the trains were densely vegetated with cattails (*Typha* sp.), rushes (*Juncus* sp.), tall white top (*Lepidium latifolium*), and duckweed (*Lemna* sp.). A schematic of the wetlands system is shown in Fig. 1.

### 2.2. Sample collection and analytical procedures

#### 2.2.1. Water quality analyses

The water quality of the influent and effluent flows for the wetland system was monitored to quantify the removal of the nutrients and suspended solids. Samples were collected biweekly (January 2001–July 2003) and analyzed in laboratory for nutrients (i.e., nitrogen and phosphorus), TSS, and total organic carbon (TOC). Other parameters that were also monitored in field included temperature, pH, dissolved oxygen, electrical conductivity, and flow. All field instruments were calibrated in the laboratory before each sampling period. Temperature, nutrients, electrical conductivity, pH, $NO_3^-$, TSS, and $SO_4^{2-}$ were analyzed using the methods described in Standard Methods (APHA, 1995) [7]. Typical water quality of the influent flows to the wetland system is summarized in Table 1.

#### 2.2.2. Mercury analyses

The concentrations of total mercury (THg) and MeHg were monitored bimonthly from January 2002 to July 2003 by collecting water samples of the influent and effluent from each train in acid washed Teflon® bottles [8] using clean hands/dirty hands protocols [9]. MeHg was determined using the distillation-ethylation procedure [10] followed by acidic bromide/methyl chloride extraction. THg was determined by bromine monochloride oxidation followed by stannous chloride reduction and purging of elemental mercury from solutions onto gold-coated quartz sand traps [11]. Mercury on traps was determined using cold vapor atomic fluorescence spectrometry (CVAFS) [12]. Detection limits (three standard deviations of reagent blanks) were 5 pg/L ($n = 12$) for MeHg and 0.1 ng per 100 mL ($n = 15$) for THg.

#### 2.2.3. Statistical analyses

Statistical analyses were performed using StatView 14.0. The strength of relationship between was evaluated using linear regression analyses. Results were considered statistically significant at $p < 0.05$. Means are reported ± standard deviation, unless otherwise noted.

## 3. Results and discussion

### 3.1. Water quality (nutrients)

Most water quality parameters for SBC water and TMWRF effluent differed significantly, except for temperature and dissolved oxygen which behaved similarly in all five trains and exhibited seasonality (Table 1). Temperature variation was observed from winter to late summer and ranged from 2.1 °C to 29.1 °C, respectively. Dissolved oxygen decreased from 14.5 mg $O_2$/L in winter to 3.5 mg $O_2$/L in late summer. Average pH of

Table 1
Steamboat Creek (SBC) water and Truckee Meadows Water Reclamation Facility (TMWRF) effluent: temperature ($T$) range in °C, pH and average concentration (mg/L) of inorganic nitrogen ($NO_3^- + NO_2^-$), organic nitrogen (as TKN), total phosphorus (TP), total suspended solids (TSS), total organic carbon (TOC), and dissolved oxygen (DO)

| | TKN[a] | $NO_3^- + NO_2^{-*}$ | TP | TSS[a] | TOC[a] | DO | $T$ | pH[a] | $PO_4$ |
|---|---|---|---|---|---|---|---|---|---|
| SBC water | 0.9 ± 0.3 | 0.5 ± 0.2 | 0.28 ± 0.1 | 25 ± 15 | 5.0 ± 1.5 | 98 ± 66 | 2.1–29.1 | 8.1 ± 0.5 | 0.1 ± 0.06 |
| TMWRF effluent | 1.6 ± 0.6 | 0.1 ± 0.1 | 0.15 ± 0.1 | 7 ± 3 | 9.5 ± 4.0 | 73 ± 53 | 84–26.4 | 7.6 ± 0.4 | 0.09 ± 0.05 |

[a] Two sample $t$-test indicated significant ($p < 0.001$) differences between SBC water and TMWRF effluent for these parameters.

Table 2
Average removal efficiencies (%) for water quality parameters within the wetland system during the period of January 2001–July 2003

| Parameter | Average (%) removal, Trains 1–3 (SBC water) | Average (%) removal, Trains 4 and 5 (TMWRF effluent) |
|---|---|---|
| Total nitrogen | 71.9 ± 27.4 | 68.8 ± 25.9 |
| Inorganic nitrogen | 63.5 ± 18.2 | 37.4 ± 17.5 |
| Total phosphorus | 40.9 ± 8.3 | 27.4 ± 14.8 |
| Orthophosphate | 39.6 ± 9.1 | 15.7 ± 7.4 |
| TSS | 72.16 ± 182 | 36.2 ± 25.8 |
| TOC | 11.0 ± 7.6 | 5.1 ± 4.4 |

SBC water was significantly higher than the pH of TMWRF effluent ($p < 0.001$, degree of freedom (d.f.) = 30). The results of water quality monitoring over the period 2001–2003 are summarized in Table 2.

Total nitrogen in SBC water and TMWRF effluent were not significantly different ($p = 0.408$, d.f. = 30). Organic nitrogen, measured as total Kjeldahl nitrogen (TKN), in TMWRF effluent was consistently higher than in SBC water ($p < 0.001$, $T = -3.94$, d.f. = 37). However, inorganic nitrogen ($NO_3^- + NO_2^-$) in SBC water was significantly higher than in TMWRF effluent ($p < 0.0001$, d.f. = 49). A seasonal variation in $NO_3^- + NO_2^-$ concentrations was observed for SBC water while TMWRF effluent showed no seasonal variation. The average removal efficiency for inorganic nitrogen in Trains 1 and 2 was 51 ± 11% and 74 ± 26% in Train 3. In Trains 4 and 5, the average removal of inorganic nitrogen was 37 ± 17%. Similar observations were reported by Comín et al. [13]. The average removal efficiency of TN was observed in the wetland system was 72 ± 28%. Slightly higher TN removal efficiency (84–98%) was observed by Comín et al. [13] in constructed surface flow wetland. Bratli et al. [14] observed a similar seasonal variation in TN removal efficiency with 50–80% removal in the summer period, while during the winter only 30% was retained.

Concentrations of orthophosphate ($PO_4^-$) and total phosphorus (TP) in SBC water and TMWRF effluent showed little seasonal variability. The average concentrations of $PO_4^-$ and TP in SBC were 0.21 ± 0.09 mg/L and 0.28 ± 0.10 mg/L, respectively. The average removal efficiencies of $PO_4^-$ and TP in Trains 1–3 were 39 ± 9% and 41 ± 8%, respectively. TMWRF effluent had concentrations of $PO_4^-$ and TP of 0.07 ± 0.05 mg/L and 0.15 ± 0.5, respectively. The average removal efficiencies of $PO_4^-$ and TP in Trains 4 and 5 were 15 ± 7% and 27 ± 15%, respectively.

The creek water had higher TSS concentrations ($p < 0.001$, d.f. = 39) than TMWRF effluent. Overall, the average removal efficiency of TSS in Trains 1–3 was 72 ± 18%. The removal efficiency of TSS in Trains 4 and 5 was highly variable and was sometimes negative (i.e., TSS was exported from the wetlands). This was likely due to the low concentrations of TSS in TMWRF effluent. TMWRF uses dual media filtration to enhance the removal of TSS [15]. Total organic carbon concentrations in SBC water were lower than in TMWRF effluent ($p < 0.001$, d.f. = 39). The annual average removal efficiency was 07 ± 6% in all five trains.

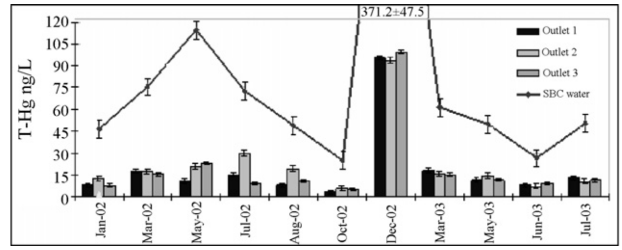


Fig. 2. Influent and effluent total Hg concentrations in Trains 1–3 receiving the Steamboat Creek water (SBC). Error bars represent standard deviation of three replicates.

### 3.2. Mercury in wetland system

In Trains 1–3 fed by SBC water, the average removal of THg ranged from 78.2 ± 7.5% (Fig. 2). Higher THg removal was attributed to higher TSS removal since most of the THg was in particulate form. Similar behavior was observed in boreal forest catchments containing different types of wetlands at the Experimental Lakes Area (ELA) in northwestern Ontario [16], retaining 30–80% of THg inputs. The concentrations of THg in SBC water varied from 25 to 318 ng/L. This range was similar to those observed in earlier studies along SBC where concentrations were 24–84 ng/L [17] and 83–419 ng/L [5]. These concentrations were higher than the typical range of 2–35 ng/L reported for rivers in the western United States [9]. Wetland trains receiving TMWRF effluent were significant sources of THg at the beginning of monitoring and continued to function as sources of THg throughout monitoring period, except for Train 4 in March and July 2003 (Fig. 3). For Trains 4 and 5 THg export decreased over the course of the sampling period, this could have been due to sediment flushing. During December

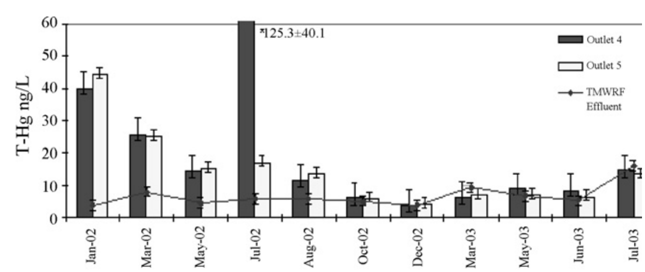


Fig. 3. Influent and effluent total Hg (THg) concentrations in Trains 4 and 5 receiving Truckee Meadows Water Reclamation Facility (TMWRF) effluent. *Outflow four in July 2002 was probably elevated due to sediment disturbance by wildlife. Error bars represent standard deviation of three replicates.

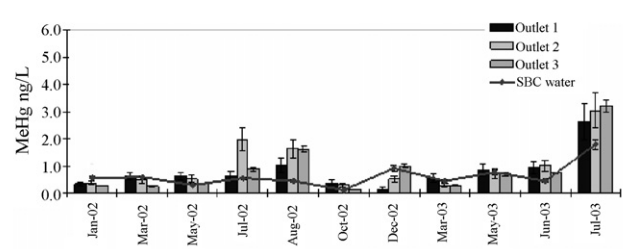


Fig. 4. Methylmercury (MeHg) concentrations in Steamboat Creek (SBC) water and outflows from Trains 1–3. Error bars represent standard deviation of three replicates.

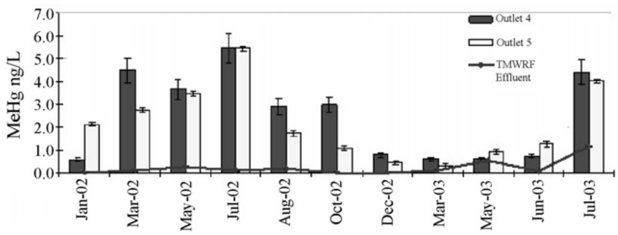


Fig. 5. Methylmercury (MeHg) concentrations in Truckee Meadows Water Reclamation Facility (TMWRF) effluent and outflows from Trains 4 and 5. Error bars represent standard deviation of three replicates.

2002 sampling, THg in influent and effluent was high due to repair work performed on liner was being at inlet and within trains.

### 3.3. Methylmercury in wetland system

Seasonality was observed in net MeHg output in all five trains (Figs. 4 and 5). Although MeHg concentrations in TMWRF effluent were on average 38% of the concentrations in SBC water, Trains 4 and 5 (fed by TMWRF effluent) produced 3–5 times more MeHg on average than Trains 1–3 (Fig. 4). Some of the possible explanations for the observed discrepancy might be wetland age, pH, mercury concentration, nutrient availability, and sulfate concentrations. Trains 1–3 exhibited seasonal variations in MeHg concentrations, functioning as sources of MeHg during summer and as sinks of MeHg during winter (Fig. 4).

Although trains fed by TMWRF effluent exhibited some seasonality in MeHg, they functioned as sources of MeHg year round, with outflow concentrations being 10–200 times higher than the inflow (Fig. 5). Higher MeHg concentrations in summer are attributed to increased microbial activity, when higher temperatures and plant exudates stimulate sulfate reducing bacteria [18], while lower temperatures and senescent vegetation during winter may lower overall microbial activity and reduce methylation [19]. It has been shown that the nitrate ion ($NO_3^-$) inhibits methylation [20]. The trains receiving TMWRF effluent had significantly lower nitrate concentrations than trains receiving SBC water (Table 1). In addition to differences in nutrient concentrations, SBC water had significantly higher TSS concentrations (Table 1). Particulate matter has been shown to strongly suppress methylation [21]. Although the pH of SBC water was higher than the pH of TMWRF effluent (Table 2), neither was as near pH 5, which is reportedly ideal for methylation [18].

## 4. Conclusions

Based on results from this study, the construction of a large-scale wetland at the confluence of the Truckee River and SBC could potentially have a significant impact on the downstream water quality. Even though the proposed large-scale wetland system would enhance water quality through the removal of nutrients and suspended solids, it could increase the loading of methylmercury (MeHg) from SBC into the Truckee River. However, the wetland could also function as a significant sink of total mercury (THg). The removal efficiency of nitrate and nitrite-nitrogen in trains fed with SBC water varied seasonally from around 70% during warmer months and around 30% during winter months. Large variations in the removal efficiency of nitrate and nitrite-nitrogen were observed in trains fed with TMWRF effluent. Organic nitrogen was not retained by the wetland system. Data indicated average removal efficiencies of total phosphorus of 28% for trains receiving SBC water and 10% for trains receiving TMWRF effluent. Results indicated an average removal efficiency of TSS of 75% in the trains receiving SBC water, while large variations in TSS removal were observed in the trains receiving TMWRF effluent.

In the small-scale wetlands system, net MeHg production was observed during the spring, summer, and fall months in wetland trains receiving SBC water. However, in the winter months, these wetlands acted as sinks for MeHg. Wetland trains receiving TMWRF effluent functioned as sources of MeHg all year, with outflow concentrations being 10–200 times higher than inflow concentrations. The SBC water had higher pH and higher concentrations of inorganic nitrogen and total suspended solids. All of these factors could have influenced the production of MeHg resulting in the observed discrepancies in MeHg exported from various wetland trains. Information gained from this study will help watershed managers in decision-making process regarding the incorporation of wetlands into flood control and watershed restoration projects along the Truckee River. In addition, this information will be transferable to other wetland settings across the arid West where Hg is a common contaminant, and where nutrient loading is of significant concern.

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