

## Evaluating water quality improvements in grassed, wetland, and unvegetated swales treating highway runoff

Évaluation de l'amélioration de la qualité de l'eau dans les fossés engazonnés, les zones humides et les fossés non végétalisés servant au traitement des eaux de ruissellement des autoroutes

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### RÉSUMÉ

La quantité et la qualité des eaux pluviales ont été mesurées dans trois fossés contigus présentant différents types de végétation (herbé, zone humide végétalisée et zone humide dépourvue de végétation) le long d'un tronçon de la route nationale américaine 23, près d'Upper Sandusky, dans l'Ohio. La présence de zones humides dans les fossés routiers est souvent accidentelle ; un entretien périodique est donc effectué pour éliminer la végétation hydrophile et les sédiments accumulés, ce qui permet de retrouver des zones humides dépourvues de végétation (ou « asséchées »). Entre juillet 2023 et juillet 2024, des échantillonneurs automatiques ISCO 6712 ont collecté des échantillons de ruissellement à débit constant et établi des hydrogrammes afin de calculer les charges polluantes annuelles (kg/ha/an) et les hauteurs de ruissellement par bassin versant (mm) pour chaque type de traitement. Un total de 760 mm de précipitations a été enregistré durant la période de suivi. Parmi tous les traitements de végétation, la zone humide non végétalisée a transporté les plus importantes quantités annuelles de sédiments (583 kg/ha/an), de phosphore total (PT ; 0,96 kg/ha/an), d'azote total (4,52 kg/ha/an) et la plus grande hauteur de ruissellement (283 mm par bassin versant). Ceci est probablement dû à l'exposition des eaux de ruissellement aux sols nus et à la réduction de la rugosité du chenal suite au dragage du fossé. À l'inverse, la zone humide végétalisée a transporté une hauteur de ruissellement inférieure (13,25 mm par bassin versant) à celle du fossé non végétalisé, ainsi que les plus faibles charges en sédiments, PT et phosphore dissous. La présence involontaire de zones humides dans les fossés routiers contribue à réduire le volume de ruissellement et à hyperaccumuler les sédiments et les nutriments. Les fossés routiers aménagés en zones humides constituent une solution rentable pour réduire la charge polluante.

### ABSTRACT

Stormwater quantity and quality within 3 co-located swales with different vegetative conditions (grassed, vegetated wetland, and unvegetated wetland) were monitored along a stretch of US highway 23 near Upper Sandusky, Ohio. Wetland conditions occurring within roadside swales are often unintended; therefore, periodic maintenance may be done to remove hydrophytic vegetation and accumulated sediment from the swale, resulting in unvegetated (i.e., "dipped out") wetland conditions. Between July 2023 to July 2024, ISCO 6712 automated samplers collected flow-paced runoff samples and runoff hydrographs used to calculate annual pollutant loading rates (kg/ha/yr) and watershed runoff depths (watershed-mm) for each treatment. A total of 760 mm of rainfall occurred during the monitoring period. The unvegetated wetland condition conveyed the greatest annual sediment (583 kg/ha/yr), total phosphorus (TP; 0.96 kg/ha/yr), total nitrogen (4.52 kg/ha/yr), and runoff depth (283 watershed-mm) of all vegetation treatments. This is likely driven by the exposure of runoff to bare soils and reduced channel roughness following wetland swale dredging. In contrast, the vegetated wetland condition conveyed a lower runoff depth (13.25 watershed-mm) than the unvegetated wetland swale along with the lowest sediment, TP, and dissolved phosphorus loading rates amongst all treatments. Unintended wetland conditions within roadside swales serve to reduce runoff volume as well as hyperaccumulate sediment and nutrients from runoff. Wetland roadside swales provide a cost-effective means to reduce pollutant loads.

### KEYWORDS

Ditches, Maintenance, Nutrient Load, Swales, Wetland

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## 1 INTRODUCTION

Roadways are an essential piece of infrastructure, with greater than 6.3 million km of roads in use daily across the United States. The U.S. state of Ohio has the nations 5th largest interstate system at nearly 13,000 lane km. To ensure driver safety during storm events, roadside swales (or ditches) are often used to convey stormwater to a nearby outfall. Roadside swales are designed to drain roadways in the most hydraulically efficient way; therefore, sediment and nutrients removal in the swale are often not optimized. Since highways were identified by Clary et al. (2020) as the land use with the highest runoff pollutant concentrations and given recurrent algal blooms in Ohio's lakes, management strategies to improve swale water quality performance are needed.

Roadside swales are usually trapezoidal, triangular, or parabolic in cross-section and are most often vegetated with a mix of herbaceous grasses and weeds. However, obligate wetland vegetation may also predominate in roadside swales constructed in regions with shallow water tables and low slopes. These accidental conditions are not credited with additional pollutant removal in Ohio but may provide further nutrient reduction. TSS removal ranges from 45-81% in grassed roadside swales. TN (5 to 72%) and TP (-26% to 36%) reductions provided by grassed swales vary widely. Unintended wetland swales have been noted to occur occasionally in roadside swales for decades, however little research has been dedicated to determining their effect on roadside runoff quality. Winston et al. (2012) noted that TN concentrations were lower by 0.4 mg/L in effluent from wetland swales compared to nearby grassed swales. Another experiment implemented a constructed wetland in a highway swale and found that it reduced TSS concentrations by 93-97%, which is higher than typical grassed swale sediment removal rates (Qian et al. 2022).

Vegetated roadside swales have been shown to be extremely effective at removing TSS in stormwater but may accumulate sediment at rates that warrant maintenance to restore the shape of the swale (Schneider and Johnson 2019). There are very few studies on the effects of roadside swale maintenance (which typically consists of removal of vegetation and accumulated sediment, often without taking action to revegetate the channel). However, vegetation establishment has been identified as the primary solution to minimize soil loss and filter out contaminants from recently cleaned swale during storm events.

This study was designed to compare three vegetation treatments within roadside swales: grassed, vegetated wetland, and unvegetated wetland conditions. The ultimate goal was to determine the effects of this design variable on runoff volumes and water quality treatment. This was done by instrumenting research sites near Upper Sandusky, Ohio over a period of one year.

## 2 METHODS

To understand the effects of wetland, grassed, and unvegetated wetland conditions on effluent water quality and runoff hydrology from swales, co-located sites were sought out in Northwest Ohio (where nutrient-fed algal blooms are common). Candidate wetland swales were vetted based on the presence of Broadleaf Cattail to reflect a typical swale that would require maintenance to stay hydraulically functional due to accumulation of sediment and organic matter. Once a nearby wetland roadside swale was selected for maintenance (i.e., "dipping out" accumulated sediment), and a second nearby grassed swale was selected, three co-located swales were established that represented the typical grassed, wetland, and unvegetated wetland roadside swale conditions. The wetland swale was 814 m long and 1.5 m wide at the channel base and contained primarily narrow-leaved and hybrid cattail. The unvegetated wetland swale was 1,027 m long and 2.7 m wide at the bottom of the channel. The grassed swale was 650 m long with a bottom swale width of 0.33 m and located 1.6 km from the wetland swales. Watersheds draining to each swale were delineated using ArcGIS and consisted mainly of roadway with ancillary drainage from adjacent farmland.

A manual rain gauge and an automated 0.25 mm interval tipping-bucket rain gauge were located at the research site to assess rainfall timing and depth. The depth of rainfall was determined using the manual rain gauge, and the tipping-bucket rain gauge was used for further analysis of hyetograph timing, antecedent dry period, and rainfall intensity. To measure the runoff hydrograph at the outlet of each swale, 30 cm tall h-flumes were installed in the thalweg of the channels. The flow depth in each flume was measured every minute using a bubbler flow module attached to an ISCO 6712 automated sampler (Teledyne ISCO). Flow was directed to the flumes by attaching plywood wing-walls at 45-degree angles upstream of the opening of the flume. Wing walls were installed to a height of 30 cm to match the height of the flume. Level data were converted to flow rate using known relationships between level and flow rate for a 30 cm tall h-flume (Teledyne ISCO, 2024). Hydrographs

were analyzed for key features including runoff volume, peak flow rate, and timing. During storm events, flow-volume proportional, composite samples were obtained from the flumes to characterize sediment and nutrient concentrations. Each stormwater sample was assessed for concentrations of total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP) and dissolved N and P species ( $PO_4$ ,  $NO_2$ - $NO_3$ ,  $NH_3$ , and  $NO_2$ ).

A series of nonparametric two-sample t-tests were used to assess the effect of each vegetative condition on runoff quality. Comparisons between 2 groups were done using the Mann-Whitney test if data were independent and the Wilcoxon signed-rank test if data were paired. Significant differences between the 3 conditions were tested for using the Kruskal-Wallis k-sample test. Nutrient loading rates were calculated for each swale vegetative condition by multiplying the measured event mean concentration (EMC) of each pollutant by the runoff volume and dividing by watershed area (kg/ha). Annual loading rates (kg/ha/yr) for each vegetation treatment were then calculated by summing the total nutrient load across all sampled events and multiplying by the ratio of the typical annual precipitation to sampled precipitation.

### 3 RESULTS AND DISCUSSION

Sixty-four storm events over 2.5 mm occurred during the stormwater sampling periods from July 1 - December 1, 2023, and March 12-July 11, 2024. A total of 20 paired samples were collected at the wetland and unvegetated wetland swales and 6 were collected from the grassed swale (due to lack of runoff generation from this swale and equipment malfunctions).  $PO_4$  concentrations (mg/L) in the effluent from the grassed swale were significantly greater than for the unvegetated and wetland swale. Median TP in effluent from the grassed swale was greater than the other two swale vegetation treatments, but not significantly so (Figure 1). Conversely,  $NO_2$ - $NO_3$  concentrations were significantly higher in the effluent from the unvegetated wetland and wetland swales compared to the grassed swale. TSS and turbidity were both significantly greater in the grassed swale compared to the unvegetated wetland and wetland swales, indicating that dredged wetland swales in low topography regions may not serve as a significant source of sediment to receiving waters.

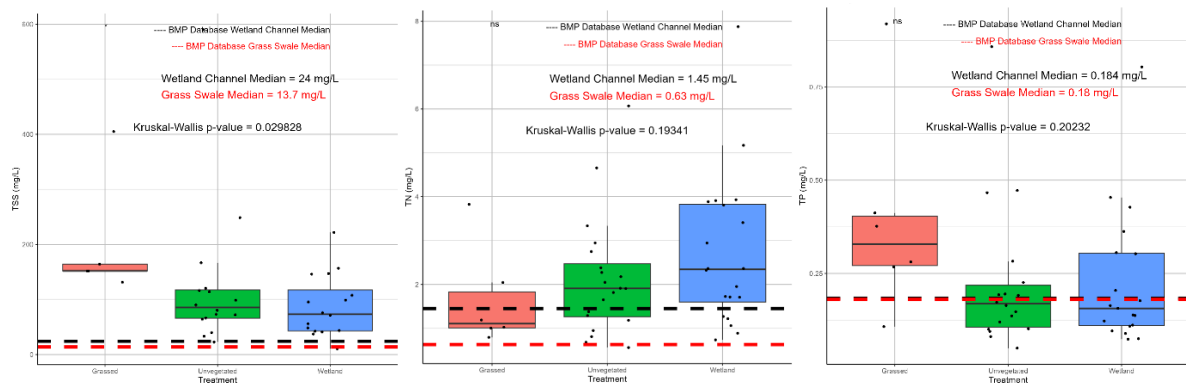


Table 1: TSS (left), TN (middle), and TP (right) effluent concentrations from the swale vegetation treatments.

Swale effluent pollutant concentrations from this study were compared to results from the International Stormwater BMP Database (ISBMP Database), which houses data from previous monitoring studies focused on urban stormwater controls (Clary et al., 2020 ; Figure 1). Similar to this study, the ISBMP Database TP and  $PO_4$  concentrations were higher in grassed swales compared to wetland channels, while TN and  $NO_2+NO_3$  median concentrations were greater in wetland swales compared to grassed swales. Overall, the differences in N and P concentrations between wetland and grassed swales in this study were reflective of those seen in the ISBMP Database. However, the grassed swale’s TSS EMCs herein were nearly 10x larger than those in the ISBMP Database and are likely an outlier compared to typical grassed roadside swale treatment, perhaps due to the relatively large rainfall depths required to produce flow from this swale.

The unvegetated wetland swale generated the greatest amount of runoff at 283 watershed mm annually followed by the wetland swale (133 watershed mm) and the grassed swale (118 watershed mm). In terms of annual pollutant loads, the unvegetated wetland swale produced the greatest TP (0.86 kg/ha/yr), TSS (583 kg/ha/yr),  $NO_2+NO_3$  (1.93 kg/ha/yr) and TN (4.53 kg/ha/yr) compared to the grassed and wetland swale pollutant loads (Table 1). The unvegetated wetland swale produced a TSS load greater than the grassed swale while the wetland swale conveyed less than half as much TSS downstream compared to the other swale vegetation treatments. The grassed swale conveyed the greatest annual  $PO_4$  load (0.35 lbs/ac/yr), while the wetland swale’s

annual PO<sub>4</sub> was 2-3x less than both the unvegetated wetland and grassed swales.

When compared to previous studies of highway runoff pollutant loads, all swales fell below the averages established for all pollutants except sediment. The TSS loading rate for the unvegetated wetland swale was similar to a number of previous studies that established annual highway sediment loading rates. Overall, unvegetated wetland swales conveyed greater sediment and P than a typical grassed roadside swale. However, the grassed swale conveyed a greater PO<sub>4</sub> load annually than unvegetated wetland and wetland swales. Therefore, steps should be taken to ensure that the swale revegetates rapidly back to a wetland condition to optimize sediment and PO<sub>4</sub> load reduction. Implementing simple changes to roadside swales to temporarily increase the hydraulic retention time of roadside runoff has the two-fold potential to encourage wetland vegetation as well as sedimentation.

Table 1: Total outflow and pollutant loads for swale vegetation treatments.

Swale Vegetation Treatment	Total Outflow (watershed-mm)	TP (kg/ha/yr)	PO <sub>4</sub> (kg/ha/yr)	NO <sub>2+3</sub> (kg/ha/yr)	TN (kg/ha/yr)	TSS (kg/ha/yr)
Grassed	118	0.45	0.35	0.47	2.14	374
Unvegetated Wetland	283	0.96	0.22	1.93	4.53	583
Wetland	133	0.36	0.10	1.77	2.97	149

## 4 CONCLUSIONS

We evaluated the effects of roadside swale vegetation on hydrologic and water quality treatment performance. This was done by monitoring three swales located within 1.6 km of each other for a calendar year and collecting hydrologic data and runoff samples at each swale outlet. Wetland conditions in highway swales are a potential stormwater treatment option that can accumulate sediment as well as reduce PO<sub>4</sub> and TP more effectively than traditional grassed swales during storm events. Wetland roadside swales had >50% lower TSS and PO<sub>4</sub> load as both grassed and unvegetated wetland conditions and serve as a sink of sediment and nutrients. In this study, the unvegetated roadside swale contributed the greatest annual load of sediment and TP compared to a typical grassed roadside swale and a wetland swale. However, the grassed swale conveyed the highest annual PO<sub>4</sub> load of the three vegetation treatments. Significant reductions in swale effluent sediment and nutrient concentrations are possible through the strategic use of low-cost retrofits (e.g., check dams) to create linear wetland systems for water quality benefits. Simple swale management changes have the potential to turn roadside swales into significant sinks of sediment and P. With better management practices to quickly return unvegetated wetland swales back to wetland conditions, there is potential to utilize the wetland swale maintenance cycle as an effective BMP for reducing sediment and P in roadside swales.

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