Subsurface horizontal-flow gravel wetlands in Vermont – permitting, performance, and chloride concerns

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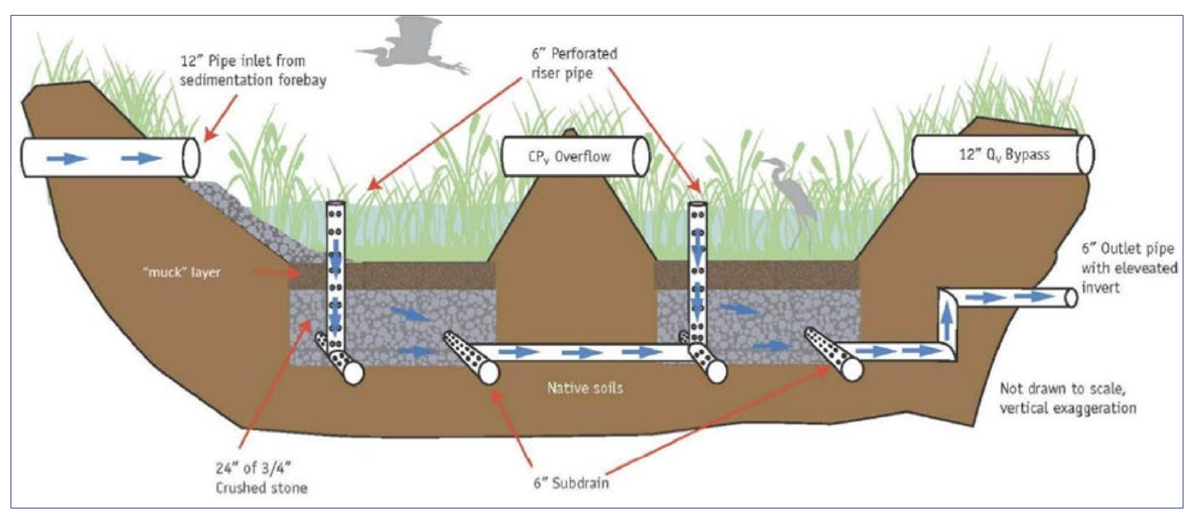
BACKGROUND

Subsurface horizontal-flow gravel wetlands (SHGW) are water treatment practices that use a saturated bed of gravel and wetland vegetation to filter incoming water and remove pollutants. Their modeled capacity to remove fine particles and nutrients of concern indicates that they have one of the highest capacities for phosphorus (P) removal of any passive stormwater treatment practice (Ballestero et al., 2016; Roseen et al., 2009). With the promise of impressive phosphorus (P) removal, the implementation of SHGWs has proliferated among Vermont municipalities to meet impending P control requirements under state stormwater permit applications. However, the SHGW design specifications outlined in the 2017 Vermont Stormwater Management Manual (VSMM) are vague. The impact of these design nuances on practice performance is not well researched and poses concerns about P and chloride impacts on surface waters in the Lake Champlain Basin.



Cross sectional depiction of a subsurface gravel wetland. (Image adapted from: Stormwater Report: Water Environment Federation.)

The impact of chloride on natural waters and roadside soils raises questions on the impact of road salt-laden runoff entering vegetated treatment practices that rely on the consistent hydraulic capacity of a soil and gravel media coupled with a robust plant community for pollutant removal performance (Kakuturu and Clark, 2015). In areas where salt application is significant (such as highways and state roadways), chloride loading to stormwater practices may dramatically change the hydraulic conductivity and/or vegetation health and survival – rendering practice performance different than what models predict (Hintz and Relyea, 2019; Richburg et al., 2001; White and Broadley, 2001).

Two SHGW systems located in Burlington and Essex Junction, VT are being monitored over a two-year period to evaluate SHGW hydraulic performance, P capture, and chloride dynamics during individual storm events. Year 1 of the monitoring study was completed in the Fall of 2020. Year 2 of the study will begin in June 2021.

OBJECTIVES

Part 1 – SHGW Hydraulics and Phosphorus Capture

- Determine if SHGWs permitted under the VSMM perform as expected for flow attenuation and phosphorus capture.
- Identify differences in performance between monitored practices.

Part 2 – Effects of Road Salt on SHGW Systems

- Investigate how chloride (Cl-) moves through and is stored within SHGWs.
- Determine if plants are taking up and storing chloride in above ground biomass.

Findings of this preliminary phase of research are intended to inform the Vermont stormwater regulatory community and permittees' decisions regarding SHGW design. This work will support accurate SHGW performance expectations that can provide greater precision in Vermont's effort to predict environmental outcomes associated with stormwater mitigation efforts.

MATERIALS & METHODS

Field Sampling

- A storm event that qualified for flow monitoring demonstrated at least 0.3 inches of total rainfall accumulation. On-site rain gauges logged rainfall every sixty seconds for the duration of the storm event.
- Flow-weighted composite sampling was completed for 16 storm events using automated sampling units at the inlet and outlet locations of both SHGW systems to compare TSS, TP, TDP, and Cl- concentrations between the inlet and outlet.
- Continuous flow rate and volume was measured using pressure-based water level loggers or automatic sampler-connected flow modules.
- Multi-parameter probes were installed at the inlet, outlet, and center of each SHGW for continuous monitoring of chloride, dissolved oxygen, temperature, and specific conductivity.

Laboratory Analyses of Field Samples

Analyte	Substrate	Laboratory Methdology
TSS	Surface water	SM2540 D-97
TP	Surface water	SM20 4500 P-F
TDP	Surface water	SM20 4500 P-F
Cl^-	Surface water	EPA 300.0
Electrical Conductivity	Soil/ Pore water	APHA 2510
Cl^-	Soil/ Pore water	EPA 9251
Cl^-	Vegetation	EPA 9251 (after $CaSO_4$ extraction)

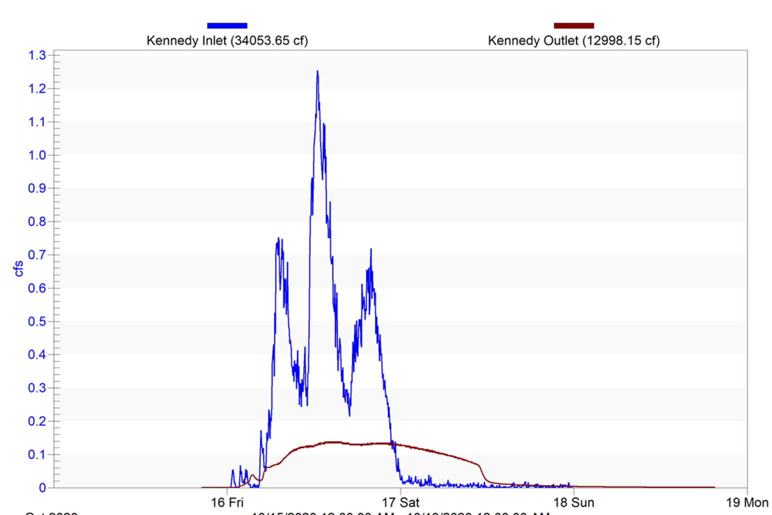
Statistical Analyses of Field Samples

Analyte	Substrate
Flow	Measured peak flow comparison to modeled values
TSS, TP, TDP, Cl^-	Paired t-test (influent – effluent)

DATA HIGHLIGHTS

Flow Volume

Total flow volume was calculated in cubic feet at the primary inlet and outlet locations over individual storm events. Below are two hydrographs that represent one heavy storm (Storm Event 14) and one moderate storm (Storm Event 15) at the Kennedy SHGW system.



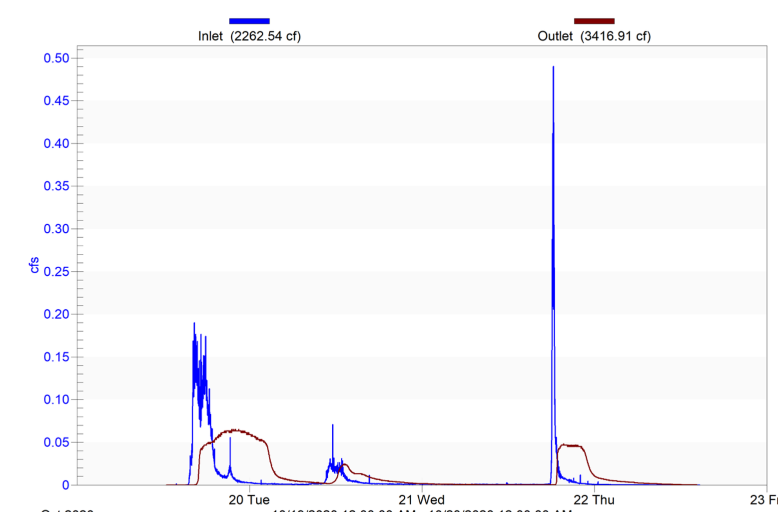
Storm Event 14

Storm Date: October 16-17, 2020
Total Rainfall: 0.86 inches

Total Discharge In: 34,054 CF
Total Discharge Out: 12,998 CF

TP In: 0.0482 kg
TP Out: 0.0478 kg

TP loading decreased by 1%



Storm Event 15

Storm Date: October 19-22, 2020
Total Rainfall: 0.47 inches

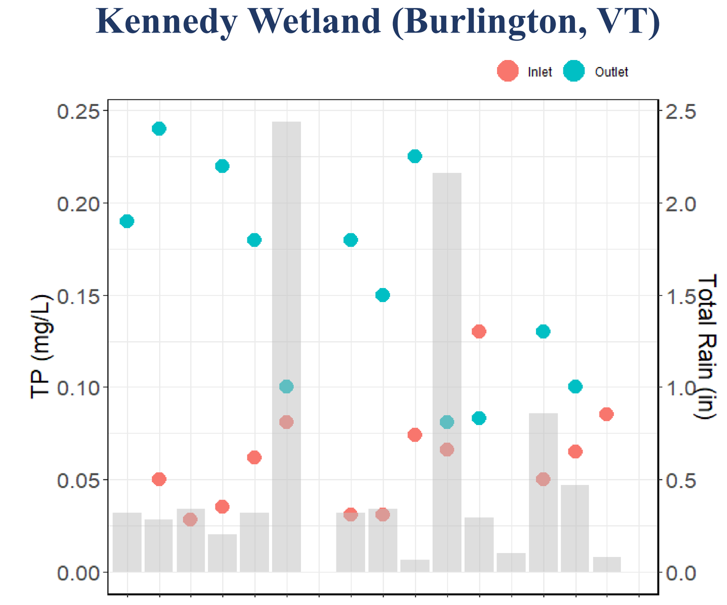
Total Discharge In: 2,263 CF
Total Discharge Out: 3,417 CF

TP In: 0.004 kg
TP Out: 0.010 kg

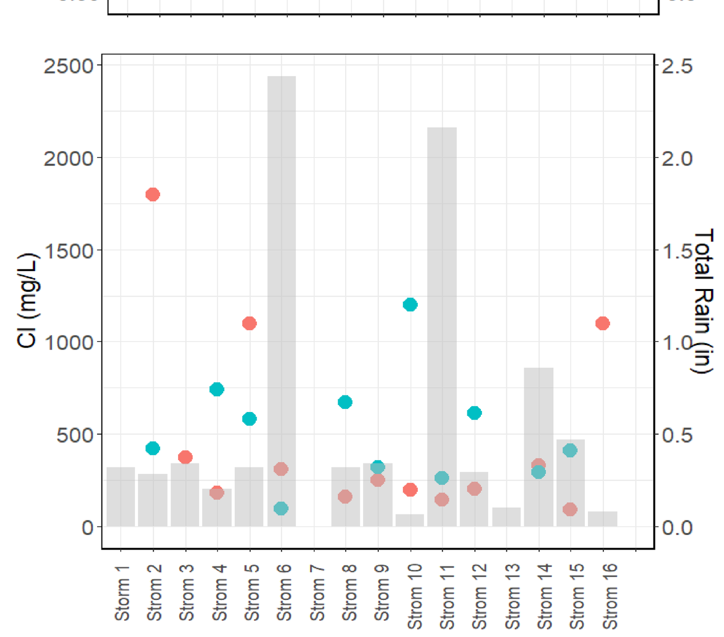
TP loading increased by 150%

Water Quality Results – Total Phosphorus and Chloride

Kennedy Wetland (Burlington, VT)

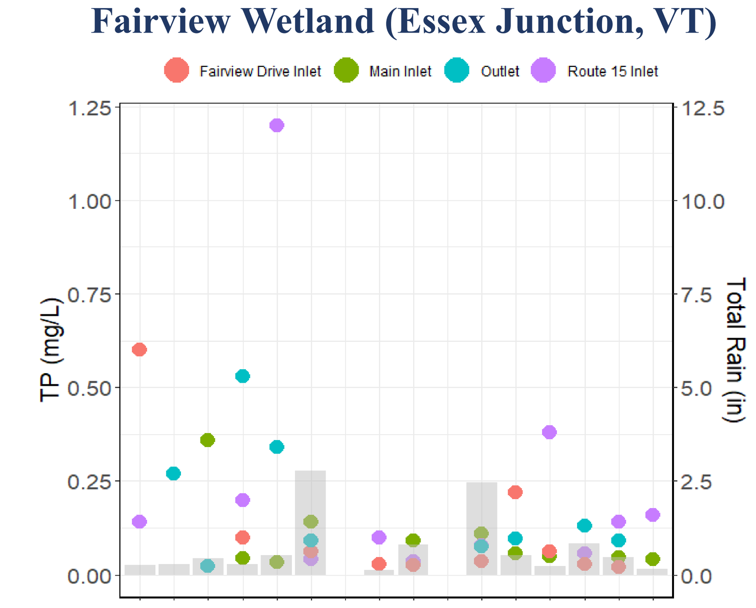


The primary inlet demonstrated an average TP concentration of 0.061 mg/L and the primary outlet demonstrated an average TP concentration of 0.154 mg/L. A paired, two-tail t-test produced a p-value of 0.0028.

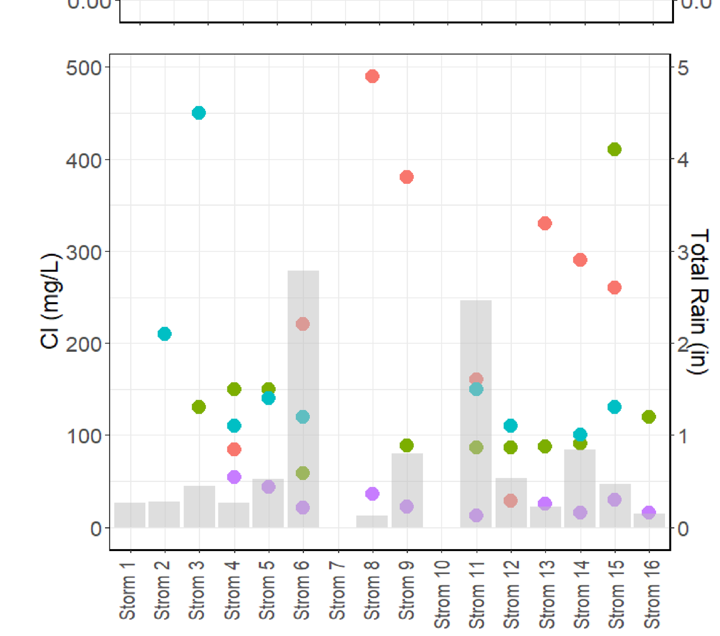


The primary inlet demonstrated an average Cl- concentration of 432 mg/L and the primary outlet demonstrated an average Cl- concentration of 508 mg/L. A paired, two-tail t-test produced a p-value of 0.67.

Fairview Wetland (Essex Junction, VT)



The primary inlet (green) demonstrated an average TP concentration of 0.106 mg/L and the primary outlet (blue) demonstrated an average TP concentration of 0.172 mg/L. A paired, two-tail t-test produced a p-value of 0.47.



The primary inlet demonstrated an average Cl- concentration of 133 mg/L and the primary outlet demonstrated an average Cl- concentration of 205 mg/L. A paired, two-tail t-test produced a p-value of 0.70.

YEAR 1 FINDINGS

Hydrological Trends:

Kennedy Wetland

- A baseflow component exists during dry and wet weather, resulting in a combined baseflow + stormflow outflow volume.
- Peak discharge of storm events is attenuated as expected by the outlet control orifice.

Fairview Wetland

- In heavy storm events (>0.5 in), storm volume bypasses the main inflow path by flowing through stone, resulting in greater measured outflow than inflow volume.
- Storms with a total accumulation between 0.1-0.3 inches can be fully captured with no discharge exiting the system.

Water Quality Trends:

Phosphorus

- There is a variable relationship between influent and effluent TP concentrations in the Kennedy and Fairview SHGW systems.
- Parameters such as elevated hydraulic conductivity and high water extractable phosphorus concentration may cause unestablished vegetation.

Chloride

- Kennedy receives acute levels of chloride from influent. There is a variable relationship between influent and effluent chloride concentration in both SHGWs.
- Fairview receives variable chloride levels at the influent. Variable relationship when the 3 inlets are averaged and compared to the single effluent.
- Chloride may inhibit vegetation growth, particularly at Kennedy.

REFERENCES

Ballestero, T., Houle, J., and Puls, T., 2016. Breaking Through UNH Stormwater Center 2016 Report. https://scholars.unh.edu/stormwater/2

Hintz, W.D., and Relyea, R.A., 2019. A review of the species, community, and ecosystem impacts of road salt salinization in fresh waters. Freshwater Biology 64:1081-1097.

Kakuturu, S.P., and Clark, S.E., 2015. Clogging mechanism of stormwater filter media by NaCl as a Deicing Salt. Environmental Engineering Science 32:141-152.

Richburg, J.A., Patterson, W.A., and Lowenstein, F., 2001. Effects of road salt and Phragmites australis invasion on the vegetation of a Western Massachusetts calcareous lake-basin fen. Wetlands 21: 247-255.

Roseen, R., Ballestero, T., Houle, J., Avelleneda, P., Briggs, J., Fowler, G., and Wildey, R., 2009. Seasonal Performance Variations for Storm-Water Management Systems in Cold Climate Conditions. Journal of Environmental Engineering 135:128-137

White, P.J., and Broadley, M.R., 2001. Chloride in Soils and its Uptake and Movement within the Plant: A Review. Annals of Botany 88:967-988.

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