A Hybrid Constructed Wetland System for Decentralized Wastewater Treatment

C. Kinsley¹, A. Crolla¹, J. Rode¹,², R. Zytner²
¹ Ontario Rural Wastewater Centre, Université de Guelph-Campus d’Alfred
² School of Engineering, University of Guelph

**Introduction**

Constructed wetland technology has been widely applied around the world to treat domestic wastewaters from the single family home to small communities. Constructed wetlands can be classified as either surface flow wetlands (similar to natural wetlands) or subsurface flow wetlands, where the wastewater flows through a media. Subsurface flow constructed wetlands can either be horizontal flow systems (HW), where the media (typically gravel) is saturated with effluent flowing horizontally through the bed or vertical flow systems (VW) where the wastewater trickles through an unsaturated media (typically sand).

All constructed wetland systems are designed to remove organic matter and suspended solids. However, nutrient removal is increasingly being required; nitrogen reduction to reduce nitrate loading to groundwater and phosphorus reduction to control eutrophication of surface water bodies. Pathogen reduction is often required for surface discharge or for reuse applications.

This study evaluates the use of a hybrid wetland system consisting of a HW incorporating a reactive P barrier followed by a VW. The HW is efficient at removing both organic matter and solids with a low risk of clogging, while the VW is efficient at nitrification; the conversion of ammonia to nitrate. The nitrified effluent is recycled back to the inlet of the HW, to complete denitrification, the conversion of nitrate to N₂ gas, which requires an anoxic environment and a source of carbon (from incoming wastewater). Recycling nitrified effluent back to the inlet of an HW can reduce total nitrogen by up to 70% [1].

In order to remove phosphorus, a reactive P barrier was installed at the end of the HW. The only proven mechanism for dissolved phosphorus removal is chemical bonding to cations such as iron, calcium or aluminium. Much work has been done on testing various P adsorption media with blast furnace slag providing some of the most promising results [2].

Pathogen reduction in wetland systems is thought to be due to a combination of mechanisms including: filtration, adsorption, predation and natural die off. Removal rates are similar in both horizontal and vertical flow constructed wetlands with 1-3 log E.coli reduction observed depending on the system loading rate, configuration and retention time [3].

The objective of this study was to develop a hybrid wetland technology to treat domestic wastewater under Canadian climatic conditions.

**System Design**

A hybrid constructed wetland technology was designed and installed at the Ontario Rural Wastewater Centre’s Onsite Wastewater Testing Facility located at the Université de Guelph-Campus d’Alfred, in Eastern Ontario, Canada (45.6°N 74.9°W). The system has a design flowrate is 2.8 m³/d, which would serve two single family homes and is described in Figure 1. Two parallel systems were constructed to study the effect of flowrate and recycle rate on system performance. The pilot wetlands are dosed with raw domestic wastewater pumped from the Alfred municipal sewer line.
A - Septic Tank

The septic tank was sized with an operating volume of 5.6 m³ (2X daily design flow). The septic tank provides primary treatment removing settleable solids as well as oil and grease.

B - Horizontal Flow Wetland

The HW was sized for BOD₅ reduction following first order plug flow kinetics at the winter operating condition of 5°C [4]. The dimensions of the HW cells are 5.0 x 9.0 x 0.7 m with an operating depth of 0.55 m. A 30 mil PVC liner was used. Coarse washed gravel (25-50 mm) was placed in the first 1.0 m of the wetland with medium washed gravel (13-20 mm) in the remainder of the cell. The wetland cell has a hydraulic retention time (HRT) of 4.5 days at the design flow (2.8 m³/d). The header pipe is a 10 cm perforated PVC pipe laid across the width of the wetland. The HWs were planted in common reeds (*Phragmites australis*) at 9 seedlings/m² with the last 2.0 m planted in hybrid sandbar willow at 1 cutting/m².

C - Phosphorus Filter

Blast furnace (BF) slag was selected as the media for the phosphorus filter based upon promising lab-scale results [5]. The dimensions of the slag filters are 5.0 x 2.5 x 0.7 m with an operating depth of 0.55 m to provide a 1d design HRT. The slag (25-50 mm) was purchased from the IVACO rolling mill in L’Orignal, Ontario, screened, washed and placed directly after the gravel in the HW wetland cells.

A 2.5 cm perforated PVC footer with a 0.55 m standpipe was installed at the outlet of the slag filter to control the water level in the HW. The outlet pipe flows to a pump chamber dosing the VW.
D - Vertical Flow Wetland

The VW was sized to nitrify ammonia and is based upon the oxygen transfer rate for nitrifying tertiary treatment vertical wetlands [6], while the filter design is based upon a single pass sand filter [7]. A peat layer was incorporated into the design to neutralize the high pH of the effluent from the slag filter. The dimensions of the VW are 2.5 x 2.5 x 0.8 m. The filter is comprised from top to bottom of: a 0.2 m layer of Sphagnum peat moss, a 0.4 m layer of 1-5 mm washed sand, a 0.2 m drainage layer of 13-20 mm washed gravel and a 30 mil PVC liner. The dosing array consists of 6 lines of 38 mm PVC dosing pipe spaced every 50 cm with a 7.5 mm orifice spaced every 50 cm. A float controlled pump delivers 28 L/dose to the filter. The filters were planted in Phragmites Australis at 9 seedlings/m². Effluent drains through 3 x 10 cm perforated PVC pipes connected to a footer line flowing to a pump chamber.

A recycle pump in the effluent pump chamber recycles part of the treated effluent back to the HW inlet.

System Performance

Two experiments were conducted with the pilot wetlands. In the first wetland, the hydraulic loading rate (HLR) was varied from 2.8 to 8.4 m³/d, with no recycle. In the second wetland, the recycle rate was varied from 100 to 300% at a constant HLR of 2.8 m³/d. Summer temperatures averaged 19.5 ± 1.4 °C, while winter temperatures averaged 4.9 ± 2.0°C.

Organic Matter and Solids

The effect of season and HLR on organic matter and solids are presented in Figures 2 and 3, respectively. During the summer, the combined HW-VW system reduced cBOD₅ concentrations to non-detect levels (<2 mg/L) at all HLRs. However, during the winter, VW effluent concentrations increased from 3 to 9 mg/L with increasing HLR. Average TSS varied between 8-12 mg/L during the summer and between 11-18 mg/L during the winter, with no significant differences between the HW and VW values. Increasing HLR appears to have no effect on TSS values.

These results suggest that the combined HW-VW system can maintain cBOD₅ < 10 mg/L and TSS < 15 mg/L at a HLR of 5.6 m³/d during both summer and winter operating conditions.

Fig. 2. cBOD₅ with Season and HLR (Q=2.8 m³/d)
Nitrogen

Total nitrogen (TN) data is presented in Figure 5. Without recycle, TN was reduced by only 19 and 24 % during summer and winter, respectively. With recycle, outlet TN ranged between 9.6-11.8 mg/L with no significant differences observed either between seasons or with increasing recycle ratio. However, there is a clear trend of increasing TKN and decreasing NO$_3$ with increased recycle ratio as well as between summer and winter. This indicates that the VW is becoming saturated with increased flow, which is reducing oxygen transfer and decreasing nitrification. Similarly, during winter, snow and ice cover could act to reduce oxygen transfer; however, the cold temperatures would also likely inhibit the nitrifying bacteria. Total nitrogen reduction varied from 73-78% during summer and 66% during winter. These results indicate that recycling effluent significantly increases TN removal and that there is no additional benefit to increasing the recycle ratio beyond 100%.

Phosphorus

Phosphorus and pH results are presented in Figure 4. Total phosphorus (TP) is almost entirely in the dissolved reactive form (O-PO$_4^{3-}$). Phosphorus was reduced to below 1.0 mg/L for the first 18 months of the study, after which P concentrations increased. During this time pH at the HW outlet remained above pH 10. This strongly suggests that the phosphorus removal mechanism is precipitation under a high pH environment. The peat layer in the VF filter was effective at balancing the pH, maintaining effluent pH between 7-8 for the duration of the study. These results suggest that once the readily dissolvable calcium is released from the BF slag surface, the phosphorus attenuation capacity of the material declines rapidly.
E. coli data are presented in Figure 6. No apparent effect of HLR was observed on E. coli reduction in summer, with a slight reduction in VW removal in winter at 3Q. During summer, a total of 3.4 log were removed, while during winter a total of 2.3 logs were removed. As typical irrigation standards call for \( E. coli < 10^3 \) CFU/100mL, a further disinfection step would be required such as UV or chlorination if reuse applications were to be considered.

![Graph showing E. coli with Season and HLR (Q=2.8 m³/d)](image)

### Summary

A hybrid wetland technology comprising a septic tank, a horizontal flow wetland, a slag phosphorus filter and a vertical flow wetland has been shown to perform well in a cold climate with consistent high effluent quality of less than 10 mg/L cBOD₅ and 15 mg/L TSS in all seasons at a HLR of 5.6 m³/d, which corresponds to an HRT in the HW of only 2.3 days. Total nitrogen reduction of 65-75% can be achieved with 100% recycle rate in both summer and winter, with no benefit accrued by increasing the recycle rate beyond 100%. The BF slag filter performed well for 18 months, after which outlet phosphorus concentrations increased. The combined HW and VW system was effective at reducing 3.4 log \( E. coli \) during summer and 2.3 log \( E. coli \) during winter.

### References


### Acknowledgements

Financial support for this research project was provided by:
- Canada Mortgage and Housing Corporation
- Canadian Water Network
- Ontario Ministry of Agriculture, Food and Rural Affairs.

For further information contact: ckinsley@uoguelph.ca

Copies may be found at: www.orwc.uoguelph.ca

---

Ontario Rural Wastewater Centre
© 2014