Modelling and real time control of pathogen dynamics in a stormwater constructed wetland

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Highlights

- A coupled hydrodynamic-microorganism model was developed for stormwater wetlands.
- Modelling results showed that this model can capture flow and *E. coli* dynamics in a field-scale stormwater wetland.
- Real-time control can enhance stormwater constructed wetland *E. coli* removal performance.

Introduction

Pathogens from stormwater are a potential threat to water quality and public health risks. Stormwater constructed wetlands have been widely adopted to treat stormwater, and highly variable pathogen removal performance was observed under different scenarios (Meng et al., 2018).

Modelling is a critical tool to understand the microbial removal mechanism in stormwater wetlands, therefore supporting design, maintenance and optimization. In the past, first-order models were widely used to model *E. coli* dynamics in constructed wetlands under steady inflow conditions (Khatiwada and Polprasert, 1999; Kadlec and Wallace, 2008). Adaptive neuro-fuzzy inference systems in constructed wetlands have been proven to perform better than the first-order model (Hamaamin et al., 2014), however it only has been tested in a lab-scale wetland under pulse loading conditions.

This study aims to develop a robust model to capture the pathogen dynamics in the field-scale stormwater wetlands. *Escherichia coli (E. coli)* was selected as the faecal indicator organism in the presence of pathogens. Troups creek wetland, which is a surface-flow stormwater wetland, located in Melbourne, Australia has been selected as the case study. In addition, a lab-scale stormwater wetland experiment has been performed, used to collect data for further validation of the model as well as test how can real-time control (RTC) technology enhance wetland pathogen removal performance.

Methodology

Model setup

TUFLOW FV, a numerical hydrodynamic model tool is used in this study (BMT, 2020). As Troups creek wetland is a shallow water system, strong vertical stratification is not expected, therefore a two-dimensional model was built in this stormwater wetland. The Aquatic EcoDynamics (AED2) modelling library (Hipsey et al., 2013)was applied to simulate *E. coli* dynamics by coupling with TUFLOW-FV. This stormwater wetland microbe model is based on a generic, process-based microbe dynamic model in aquatic systems (Hipsey et al., 2008) and a tested *E. coli* model in an urban estuary using TUFLOW FV-AED2 framework (Jovanovic, 2018). This model simulates the transport and fate of *E. coli* including microbe advection, dispersion, die-off, settling and resuspension. A suspended sediment model adopted from an urban estuary (Jovanovic, 2018) has been incorporated into the microbe model to account for interactions between sediments and microbes. All parameters were adopted based on literature without calibration.

Model assessment

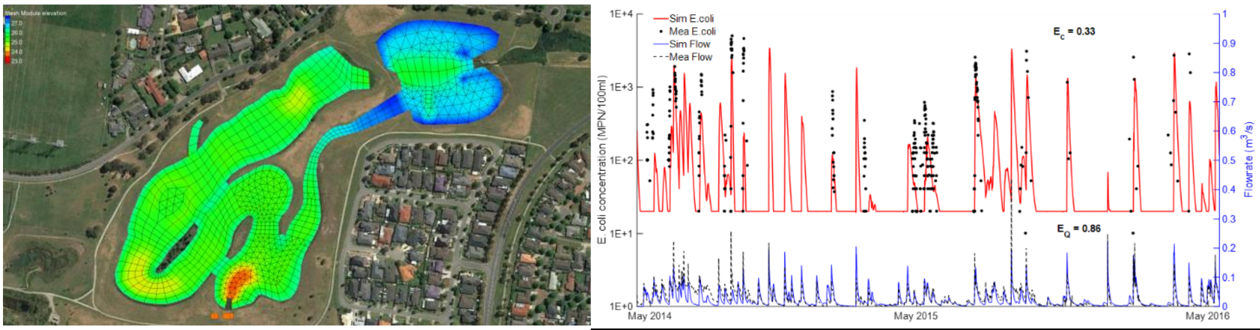
Two-year 6-min timestep flow data and event-based measured microbe data were used to validate the model. Nash-Sutcliffe Efficiency (NSE) was used as the assessment metric (Nash and Sutcliffe, 1970). The hydrodynamic model performance was evaluated by comparing simulated against the measured flow rate in the outlet weir. The microbe model performance was evaluated by comparing measured versus simulated log-transformed *E. coli* concentrations in the wetland outlet.

Laboratory experiment

Six wetland mesocosms were established in the greenhouse of the living lab, Monash University. All wetlands are in the same configuration, 3 acts as RTC and 3 as non-RTC. Semi-natural stormwater was used for dosing, including laboratory-grade chemicals, *E. coli*, and sediment collected from a local stormwater wetland (Chandrasena *et al.*, 2017; Shen *et al.*, 2020). Large (17.68mm), medium (6mm) and small (4.16mm) event sizes were selected to test wetland *E. coli* removal performance. Two RTC strategies were tested in this study: (1) RTC strategy 1(Minimum 24hour): close outlet for 24 hours since rainfall event start and open outlet after 24 hours; (2) RTC strategy 2 (Pre-drain): pre-drain 30% of the wetland natural water level before the rainfall event, based on the weather forecast. Composite inflow and outflow samples were collected during the whole retention time and for enumeration of *E. coli* using the Colilert method™ (IDEXX-Laboratories, 2007). Event mean concentrations (EMCs) were calculated for each dosing/sampling event for the wetland outlet. These EMCs were then used to calculate the log reduction of *E. coli*.

Results and discussion

The model domain consists of a sediment pond, macrophyte zone and bypass channel of Troups creek wetland. The mesh construction is shown in Figure 1. The wetland hydrodynamic model was tested using a two-year database from May 15, 2014 to May 15, 2016. For the whole two-year period, the overall simulated outflow rate was consistent with the measured flowrate ($E_Q = 0.86$), which formed a reliable base to be coupled with the microbe model. Overall, the microbe model performed well, achieving $E_C = 0.33$ during the two years.



(1) (2)

Figure 1. Flexible mesh of Troups creek wetland used in this study (left). The elevation was divided into 10 bars, ranges from 23 to 27 m AHD (Australian Height Datum). The mesh covered the sediment pond, macrophyte zone and bypass channel. Hydrodynamic and microbe model results for two-year simulation (right). Measured (black dash line) and simulated (blue line) outflow rate in outlet v-notch weir was compared for the hydrodynamic model, measured (black dots) and simulated (red line) *E. coli* concentration was compared for microbe model.

For lab study, non-RTC wetlands have 0.5 - 3 log *E. coli* EMC reduction across all tested events, while RTC wetlands have 1 - 4 log *E. coli* EMC reduction. Therefore, RTC wetlands have at least 1 log *E. coli* EMC reduction higher compared to non-RTC wetlands (Figure 2). This proved the effectiveness of implementing real-time control to enhance the stormwater wetland pathogen removal.

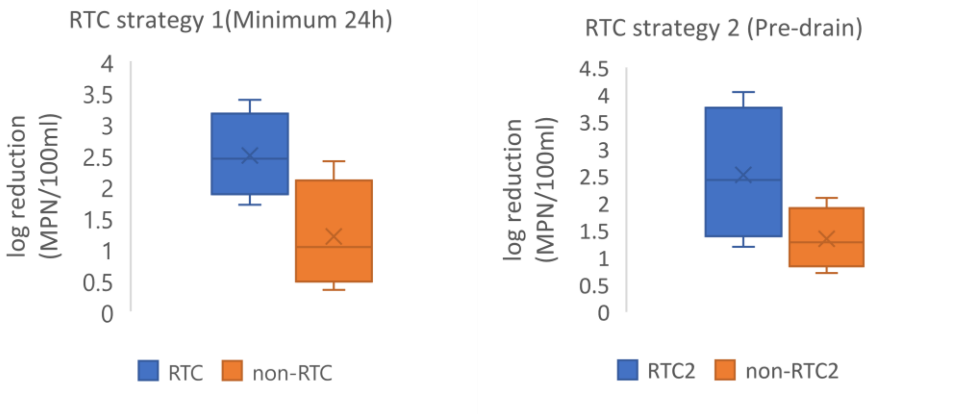


Figure 2. *E. coli* EMC log reduction for RTC strategy 1 and strategy 2 compared to non-RTC strategy.

Conclusions and future work

Conclusions:

1. The model successfully predicted flowrate (NSE = 0.86), which is considered good for a two-year simulation in a 6-min timestep.
2. The microbe model was capable of capturing *E. coli* dynamics validated from 22 wet weather events (NSE = 0.33).
3. RTC can enhance pathogen removal in stormwater constructed wetlands.

Future work:

1. This model could be potentially used to support real-time decision-making for Troups creek wetland RTC retrofit.
2. The lab experiment data could be used to further validate the model.
3. The plant function in pathogen removal should be included in the model and considered in RTC strategy development.

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