Phosphorus accumulation in a bioretention cell in Mississauga, Ontario: Insights from field monitoring and process-based modeling

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Abstract

Bioretention cells are a Low Impact Development (LID) technology that is being promoted as a green solution to attenuate urban stormwater nutrient loadings. Despite extensive implementation of bioretention cells in Canada, the mechanistic understanding of phosphorus (P) cycling in bioretention cells is still limited. We conducted detailed analyses of (geo)chemical and hydrological data coupled to numerical reactive transport modeling to simulate the fate and transport of P in a bioretention cell located in Mississauga (Ontario, Canada) within the Credit River watershed. Our objective is to utilize the model to predictively understand the accumulation and speciation of P in the bioretention cell under long-term field operation. Unlike existing bioretention models, our model incorporates a detailed representation of the biogeochemical processes that control P cycling in the bioretention cell. We further compare the model predictions with data from sequential chemical extractions of P from soil samples taken from the bioretention cell. The model correctly estimates the cumulative TP (total P) and SRP (soluble reactive P) outflow loadings from the bioretention cell, as well as the TP accumulation rate and observed partitioning of P over the different pools in the bioretention cell. The relative importance of various processes controlling P retention are assessed using mass balance calculations and sensitivity analyses of the model. The results show that filtration of fine P-containing particles and slow sorption are the main processes retaining P in the bioretention cell.

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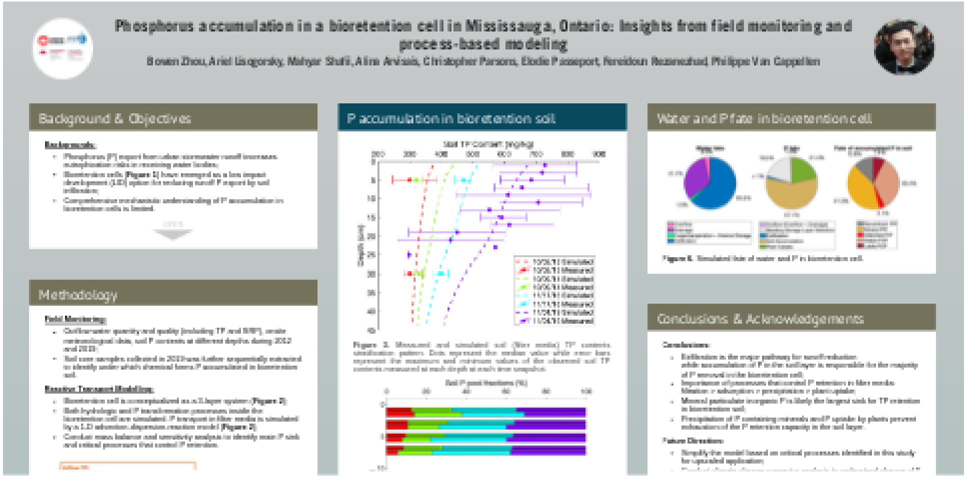

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PRESENTED AT:

BACKGROUND & OBJECTIVES

Backgrounds:

- Phosphorus (P) export from urban stormwater runoff increases eutrophication risks in receiving water bodies;
- Bioretention cells (**Figure 1**) have emerged as a low impact development (LID) option for reducing runoff P export by soil infiltration;
- Comprehensive mechanistic understanding of P accumulation in bioretention cells is limited.

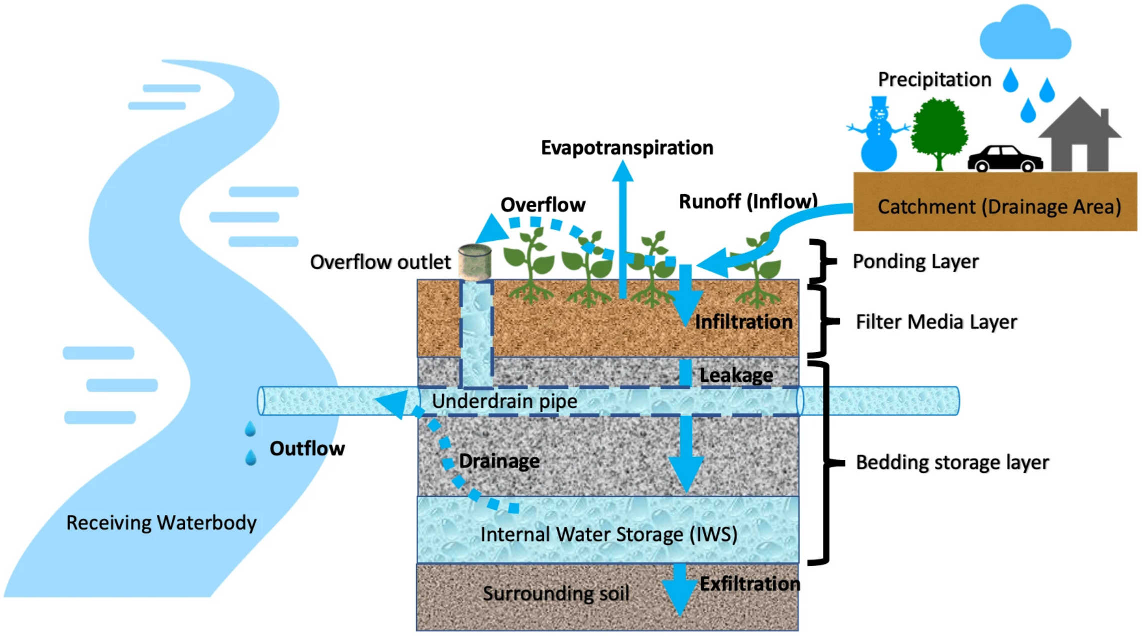

Figure 1. Vertical structure and hydrologic processes of bioretention cell in this study

Objectives:

- Improve understanding of long-term P accumulation mechanisms in bioretention cells;
- Develop a modelling tool that can predict long-term P accumulation in and export from bioretention cell;
- Identify main P sink and critical processes for P retention in bioretention cell.

METHODOLOGY

Field Monitoring:

- Outflow water quantity and quality (including TP and SRP), onsite meteorological data, soil P contents at different depths during 2012 and 2019;
- Soil core samples collected in 2019 was further sequentially extracted to identify under which chemical forms P accumulated in bioretention soil.

Reactive Transport Modelling:

- Bioretention cell is conceptualized as a 3-layer system (**Figure 2**);
- Both hydrologic and P transformation processes inside the bioretention cell are simulated. P transport in filter media is simulated by a 1-D advection-dispersion-reaction model (**Figure 2**);
- Conduct mass balance and sensitivity analysis to identify main P sink and critical processes that control P retention.

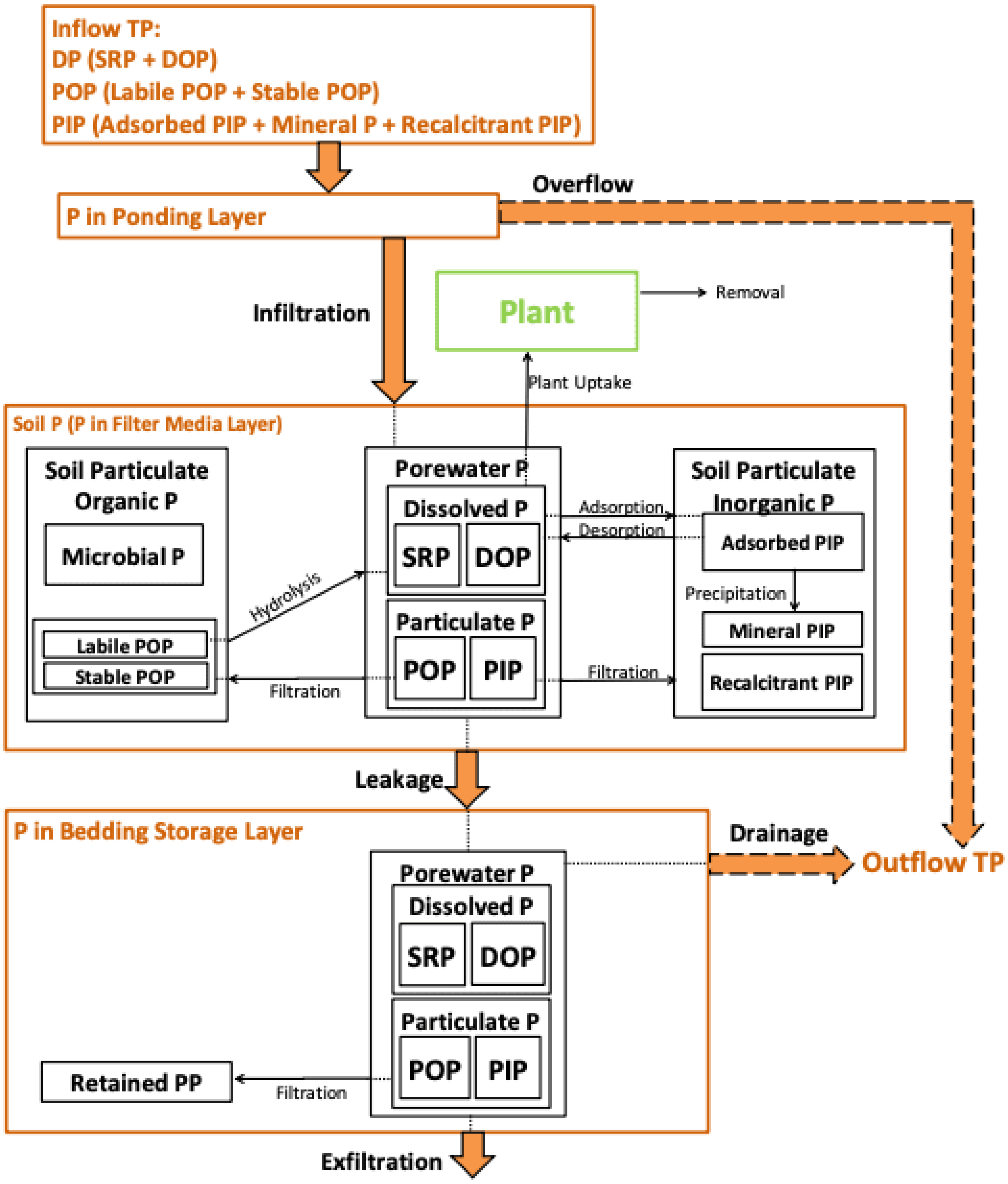

Figure 2. P reactive transport model diagram of bioretention cell.

P ACCUMULATION IN BIORETENTION SOIL

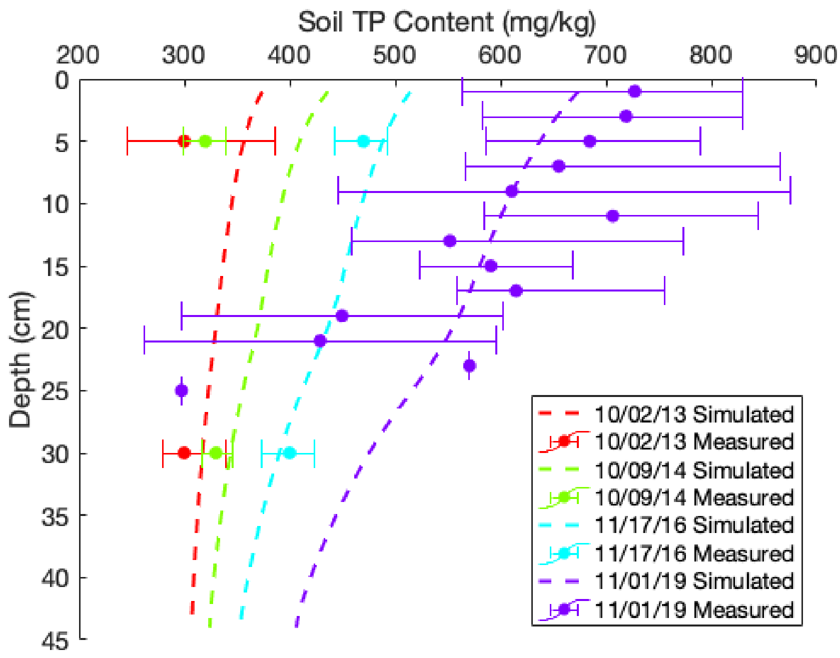

Figure 3. Measured and simulated soil (filter media) TP contents stratification pattern. Dots represent the median value while error bars represent the maximum and minimum values of the observed soil TP contents measured at each depth at each time snapshot.

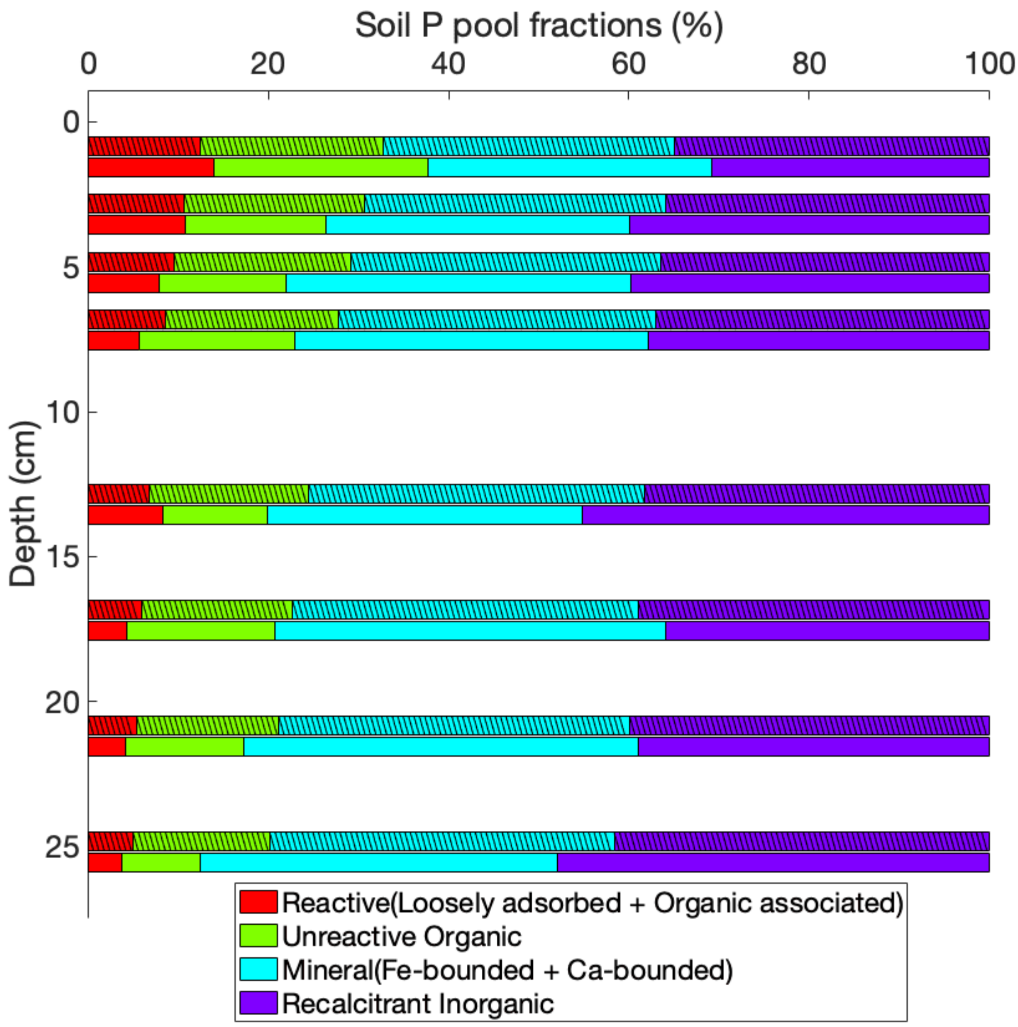

Figure 4. Measured (unshaded bars) and simulated (shaded bars) soil P pool fractions at different depth. Measured results obtained from analyzing core samples collected on 11/01/2019

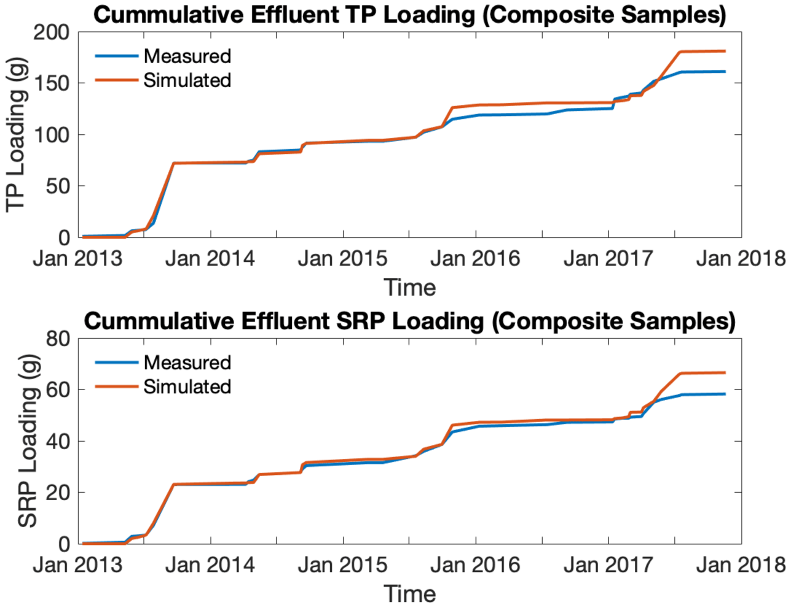

Figure 5. Simulated

cumulative effluent TP and SRP loading for events with EMC TP and SRP monitored

WATER AND P FATE IN BIORETENTION CELL

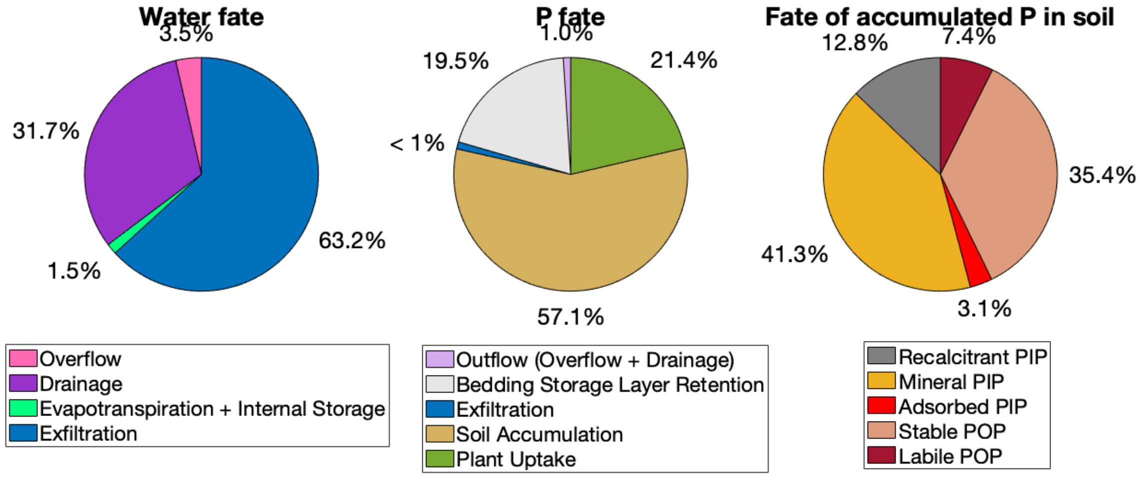

Figure 6. Simulated fate of water and P in bioretention cell.

CONCLUSIONS & ACKNOWLEDGEMENTS

Conclusions:

- Exfiltration is the major pathway for runoff reduction while accumulation of P in the soil layer is responsible for the majority of P removal in the bioretention cell;
- Importance of processes that control P retention in filter media: filtration > adsorption > precipitation > plant uptake;
- Mineral particulate inorganic P is likely the largest sink for TP retention in bioretention soil;
- Precipitation of P containing minerals and P uptake by plants prevent exhaustion of the P retention capacity in the soil layer.

Future Direction:

- Simplify the model based on critical processes identified in this study for upscaled application;
- Conduct climate change scenarios analysis to understand change of P retention performance of bioretention cell under future climate.

Acknowledgements:

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AUTHOR INFORMATION

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ABSTRACT

Phosphorus (P) concentrations in urban stormwater runoff are typically elevated compared to those associated with runoff from natural lands. Urban P export is a leading driver of eutrophication problems in downstream aquatic systems. Low impact development (LID) options such as bioretention cells (Bio-C) have emerged as a green solution for reducing peak discharge and nutrient export from urban areas. Despite the prevalent implementation of Bio-C worldwide, the mechanistic understanding of P cycling in these systems remains limited. This is especially true in cold climate regions where winter-associated processes can play a crucial role in the performance of Bio-C. We conducted data mining and numerical reactive transport modeling to simulate the fate and transport of P in a monitored Bio-C system in the Toronto metropolitan area, Ontario, Canada. Our aim is to utilize the model for predicting the export fluxes and speciation of P from the Bio-C following precipitation events of variable magnitude and duration. Our model development differs from existing models by the incorporation of a more detailed representation of the biogeochemical processes controlling the reactive transport and speciation of P in the Bio-c system. We employ our model to predict temporal variations in the Bio-C's P retention, outflow and exfiltration. the modeling work is paired with the sequential chemical extraction of P from soil samples taken from the Bio-C to characterize different P pools in the cell media. We then use these data to verify the model predicted P accumulation rates. In ongoing work, we are using the improved predictive understanding of P cycling in the Bio-C to analyze how P retention and export may change under the more hydrologically extreme conditions projected for southern Ontario in the coming decades.