Water Quality with a Grain of Salt

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INTRODUCTION

- Urbanization and population growth have increased water demand.
- Polluted stormwater runoff from impervious surfaces can cause ecological problems (such as algal blooms and the urban stream syndrome), flooding, and negative human health impacts.
- Biofilters are a low-energy and low-impact option to capture, treat, and reuse stormwater.
- Melbourne, Australia has successfully implemented biofilters to help fight drought and improve the quality of stormwater runoff.

Figure 1. Unplanted biofilter.

Figure 2. Planted biofilter.

RESEARCH QUESTION

Can we use chemical engineering reactor theory to design and size biofilters for pollutant removal?

RESEARCH APPROACH

Salt breakthrough curves (BTCs) were used to determine biofilter design parameters.

METHODS

- Six biofilters were constructed, three planted with *Carex appressa* (B,D,F) and three unplanted (A,C,E).
- A salt pulse was added to each column under saturated and constant head conditions and outflow water was sampled for four hours.
- Sample conductivity was measured and used to generate salt BTCs.
- Mass balance was performed to confirm salt acted as a conservative tracer.
- Salt BTCs were fit to a Gaussian transport model using a Generalized Likelihood Uncertainty Estimation (GLUE) framework.
- From these results, biofilter design parameters (dispersivity and porosity) were obtained.

RESULTS

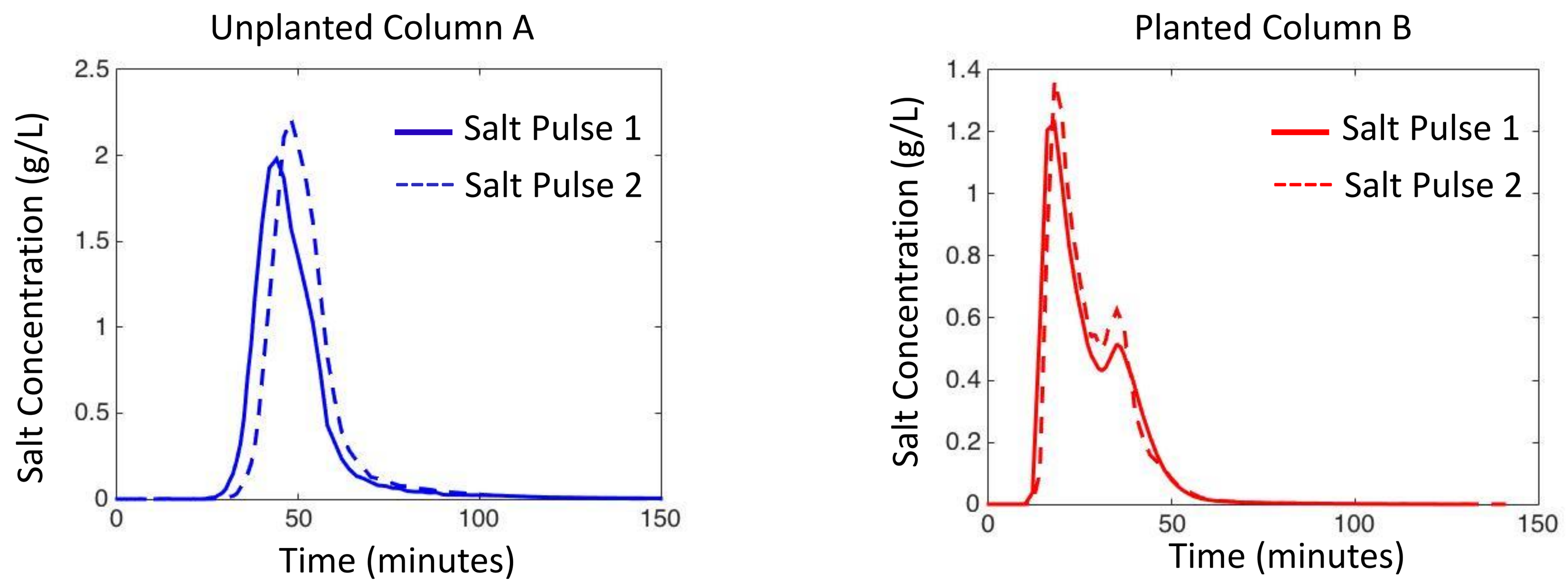

Figure 3. Salt BTCs for unplanted (Column A) and planted (Column B) biofilters.

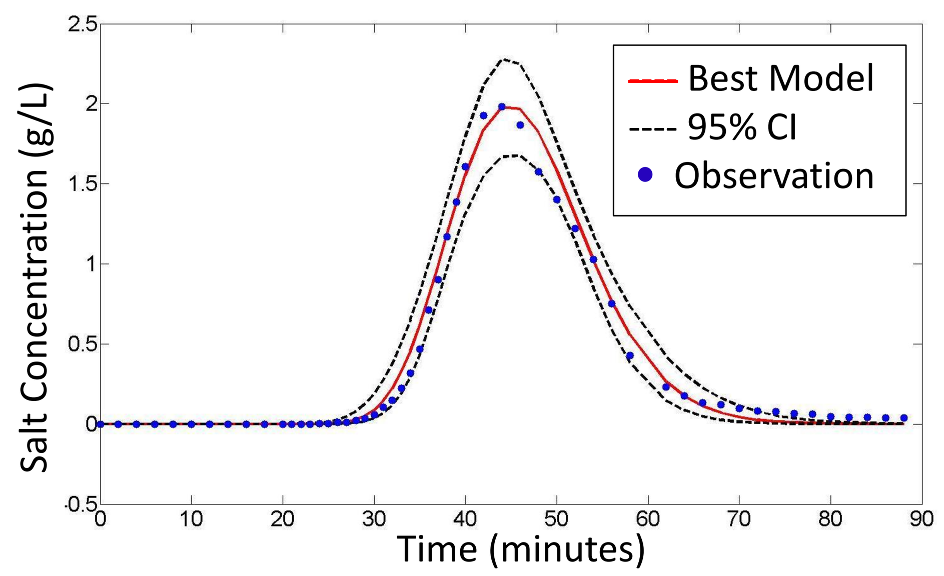

Figure 4. Gaussian transport model fit to salt BTC from Column A (unplanted).

- Salt mass recovery was slightly over 100% (Table 1).
- Single peak (unplanted) or double peak (planted) BTCs were observed (Fig. 3).
- Apart from the double peak, salt BTCs generally conform to a Gaussian model (Fig. 4).

Table 1. Properties of biofilters with (green) and without (white) plants for Salt Pulse 1 and 2.

	Column	Mass Recovery (%)	Dispersion Coeff. (m^2/s)	Porosity (unitless)	Superficial Velocity (m/s)	Dispersivity (m)	Residence time (min)
Salt Pulse 1	A	103.67	3.27E-06	0.345	3.03E-04	1.08E-02	45.4
	C	105.26	5.10E-06	0.36	3.49E-04	1.46E-02	39.37
	E	106.66	5.27E-06	0.355	3.54E-04	1.49E-02	38.86
	B	103.63	4.87E-05	0.293	6.25E-04	7.78E-02	21.99
	D	103.91	1.99E-05	0.33	4.40E-04	4.53E-02	31.24
	F	107.84	1.42E-05	0.321	3.95E-04	3.60E-02	34.82
Salt Pulse 2	A	106.17	2.16E-05	0.371	2.80E-04	7.74E-03	49.15
	C	107.38	4.02E-06	0.372	3.39E-04	1.19E-02	40.57
	E	105.6	4.63E-06	0.361	3.51E-04	1.32E-02	39.18
	B	104.77	3.66E-05	0.308	5.94E-04	6.16E-02	23.13
	D	104.75	4.13E-05	0.335	5.85E-04	7.06E-02	23.5
	F	104.78	1.99E-05	0.322	4.19E-04	4.75E-02	32.78

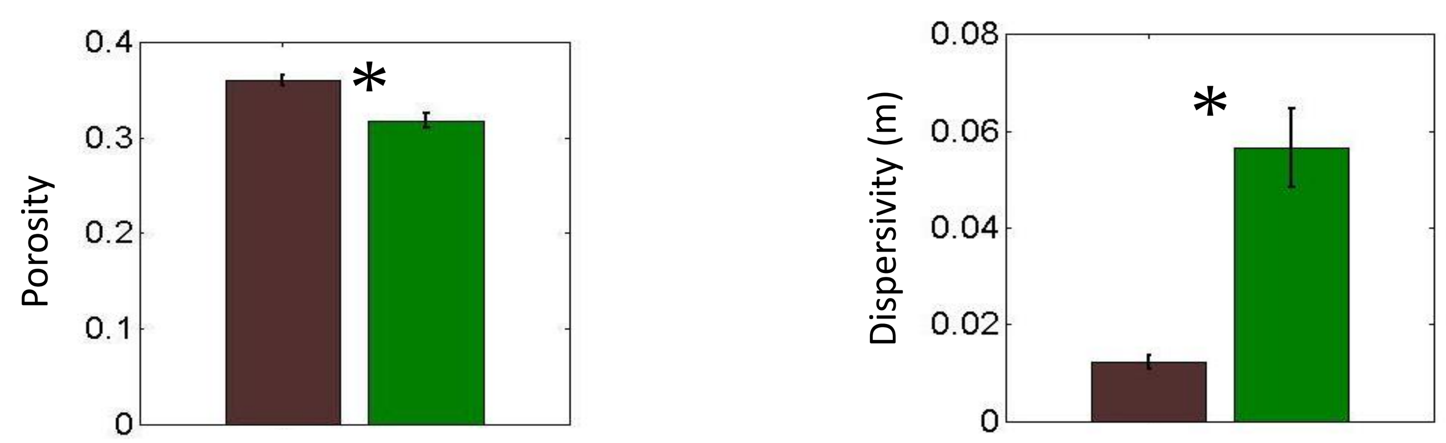

Figure 5. Average porosities and dispersivities for unplanted (brown) and planted (green) columns. Error bars indicate standard deviations. Significance determined using a t-test (*p < 0.05).

- Planted biofiters have significantly (p<0.05) lower porosities and higher dispersivities than unplanted biofilters (Fig. 5).

DISCUSSION

- Mass recovery was slightly higher than 100% in all biofilters and across both salt pulses. This effect could be due to measurement error and/or leaching of previously accumulated salts.
- Plant roots appear to decrease effective porosity and increase dispersive mixing in the biofilters.
- Thus, plants may affect pollutant removal efficiency by changing the residence time distribution.
- Some features of the salt BTCs are not well-captured by a Gaussian transport model.
- Data analysis could be improved by adopting biofilter transport models that explicitly account for media heterogeneity (within and across layers) and the presence of plant roots.

CONCLUSION AND FUTURE DIRECTIONS

- Plants affect salt BTCs in several important ways: 1) introduce multiple peaks, perhaps reflecting slow and fast transport through the biofilter, 2) decrease effective porosity, and 3) increase dispersive mixing.
- These data are essential for designing field-scale biofilters using chemical engineering reactor theory, as will be illustrated in two companion posters.

ACKNOWLEDGEMENTS

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Barking UPP the Right Tree: A Biofilter Design for Aldrich Park

Belen Cairo, Nicole Cuevas, Minna Ho, Andy Hwang, Shalini Kannan, Allison Khoe, Jimmy Luong, Isabella Mariano, Nikole Meade, Charlotte Papp, Andrew Price, Oliver Saeby

Introduction

- Both engineering and social constraints need to be considered to successfully integrate stormwater biofilters into California's landscape.
- Engineering analysis can provide guidance about the physical and biological characteristics (dimensions, flow rates, filter media, planted/unplanted) needed to achieve pollutant removal targets.
- Social science sheds light on what is likely to be accepted in practice (e.g., based on user perceptions) and co-benefits beyond the stated design goals.

Research Question

Drawing on Melbourne's experience with the Millennium Drought, how can we design an optimally functioning biofilter in Aldrich Park that will fit the needs of the surrounding community?

Methods

Engineering Approach

- Utilized the design results presented in the Fecal Indicator Bacteria (FIB) poster.

Social Science Approach

- 179 surveys were administered in Melbourne's Royal Botanic Gardens to better understand how park visitors perceive urban green spaces.
- Survey responses were assigned numerical values: 1: strongly disagree to 5: strongly agree or coded based on keyword analysis
- Responses were evaluated based on their relevance to the following topics: I) Environmental Concerns, II) Greenspace Co-Benefits, III) Educational Value and IV) Willingness to Fund Green Spaces

Results

Engineering Approach

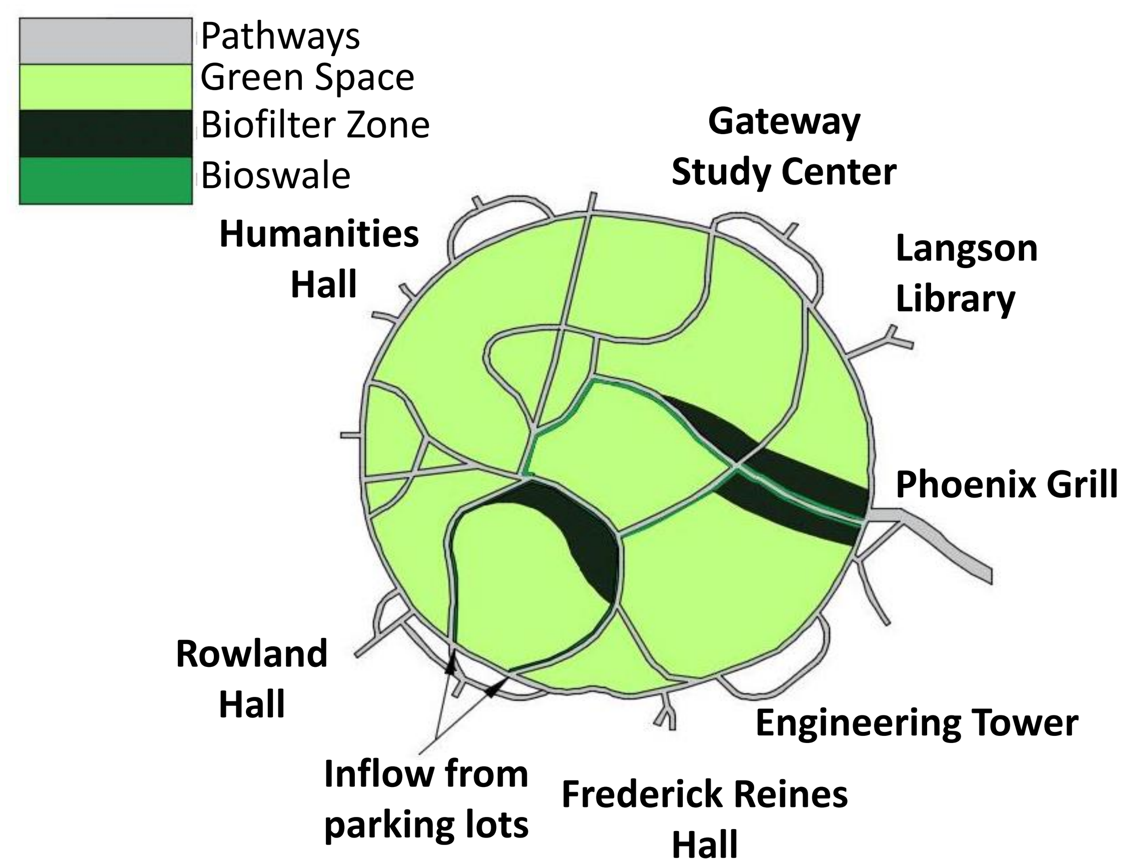

Figure 1. Proposed biofilter design for Aldrich Park assuming a 1-hour, 25-year design storm. Total area: 4,881 m^2

I. Environmental Concerns

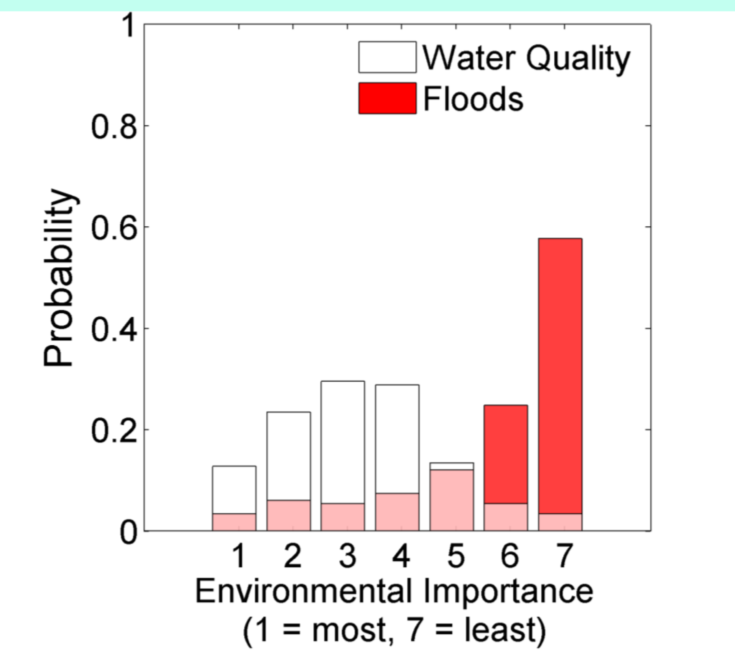

Figure 2. Societal importance of water quality (white) and floods (red)

- In order of concern: water quality > drought > bush fire > floods.

II. Green Space Co-Benefits

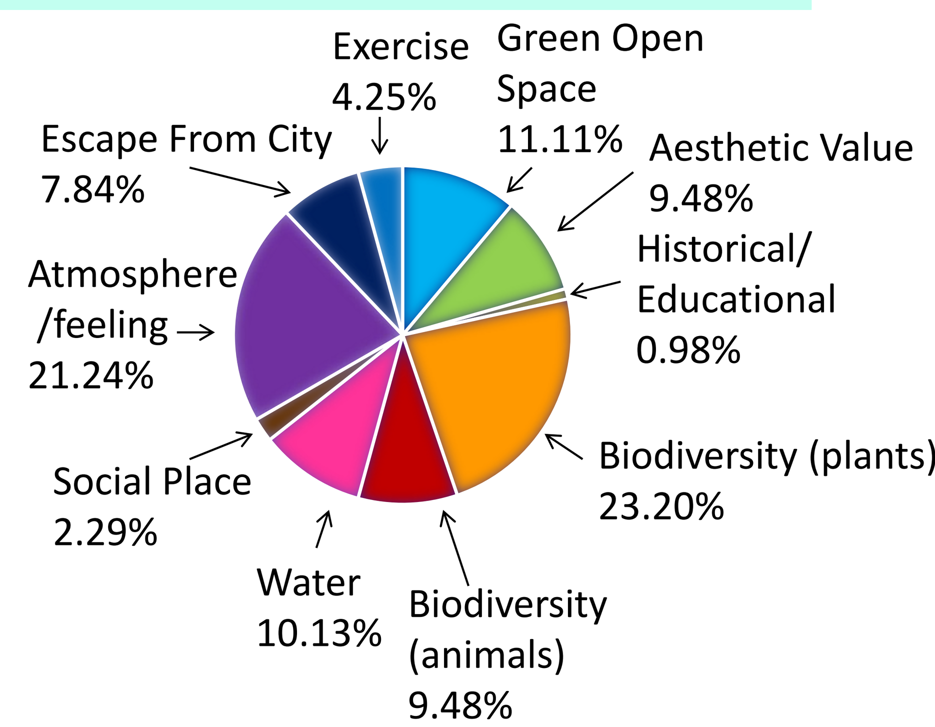

Figure 3. Depicts the aspects of the park that are most important to survey participants.

- Important green space co-benefits include plant biodiversity and atmosphere/feeling.
- Historical/educational worth was the least important co-benefit.

III. Educational Value

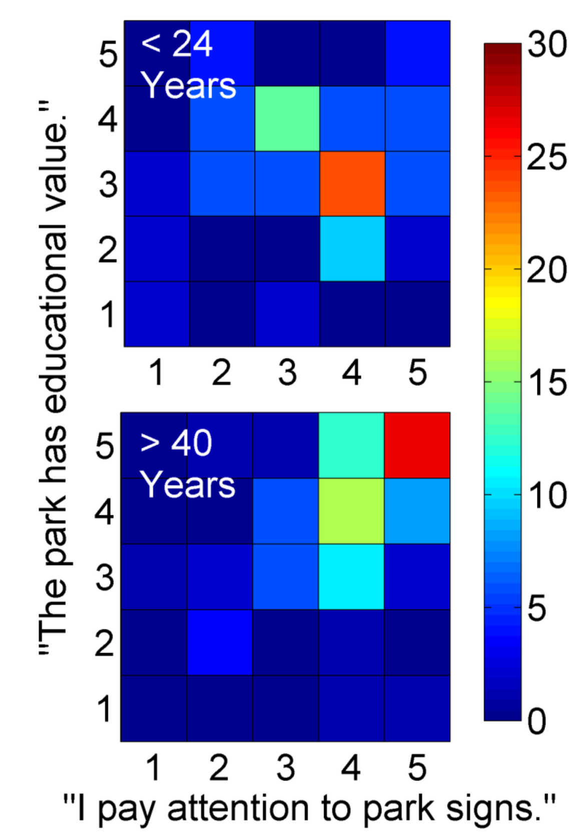

Figure 4. Correlation between sign use and park educational value (colorbar is response percent).

- Educational value is positively correlated with park sign use only for people over 24 years of age.

< 24 years: r = 0.05; > 40 years: r = 0.47

IV. Willingness to Fund Green Spaces

- The commitment to fund greenspaces increases with age, but is similarly low for the youngest age groups: < 24 years of age and 25-39 years of age (r = 0.95; average values used)

Discussion

- Engineering design is necessary to ensure FIB removal, but must be balanced with social science constraints to create an acceptable green space.
- Survey results show that people are concerned about water quality, thus our Aldrich Park biofilter design (which removes 2-log FIB) meets both engineering and important societal goals.
- To incorporate co-benefits beyond storm water treatment, green spaces should foster a peaceful atmosphere and have high plant diversity. This is consistent with our choice of a planted rather than unplanted biofilter design.
- The educational value of green spaces (and sign usage) is higher for older age groups. To support youth interest and educational investment in Aldrich Park, alternative educational approaches are warranted.
- Our findings suggest that green space implementation and maintenance cannot rely solely upon funding from youth. Alternative funding sources will likely be required.

Final Design Recommendations

- A planted biofilter with an area of at least 4,881 m^2 is required to achieve water quality goals (2-log FIB removal).
- The biofilter should be vegetated with diverse plant-life and should be set in a peaceful location (trees can be used to reduce noise pollution and benches added to encourage use and social interaction).
- Interactive art and science installments (e.g., community-painted murals, binocular stations for wildlife viewing) should be used to promote youth involvement/education.
- A long-term funding plan must be established that does not rely solely on youth financial investment.

Acknowledgements

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Water Quality Ain't No FIB:

Sizing Stormwater Biofilters for Fecal Indicator Bacteria Removal

Introduction

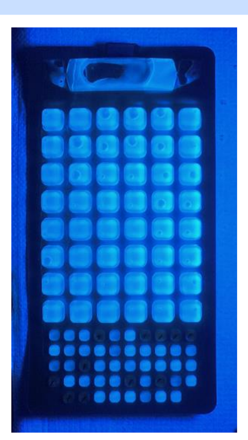
Urban stormwater runoff poses a two-fold problem: 1) it is underused for water supply, and 2) it threatens human and waterway health. Biofilters are a low-energy solution to these problems, and were widely adopted in Southeastern Australia during the Millennium Drought. Our study aims to determine rate constants for the removal of fecal indicator bacteria (FIB) in biofilters. FIB are a common stormwater contaminant and a proxy for the presence of human sewage.

Experimental Hypothesis

FIB removal in biofilters depends on the presence or absence of plants, and FIB group (*Escherichia coli* (EC), *Enterococcus* (ENT) bacteria).

Experimental Methods

- Six biofilter columns (three planted with *Carex appresa*, and three unplanted) were constructed.
- Pulses of secondary-treated sewage effluent were added under saturated and constant head conditions.
- Outflow water samples were collected for three hours and used to create breakthrough curves (BTCs) for FIB (EC & ENT, quantified using IDEXX Colilert and Enterolert).
- The FIB BTCs were fit to a reactive Gaussian transport model to obtain first-order removal rate constants (k).
- The last step was carried out using Generalized Likelihood Uncertainty Estimation (GLUE) and dispersivity and porosity values determined previously (see salt poster).




Experimental Results

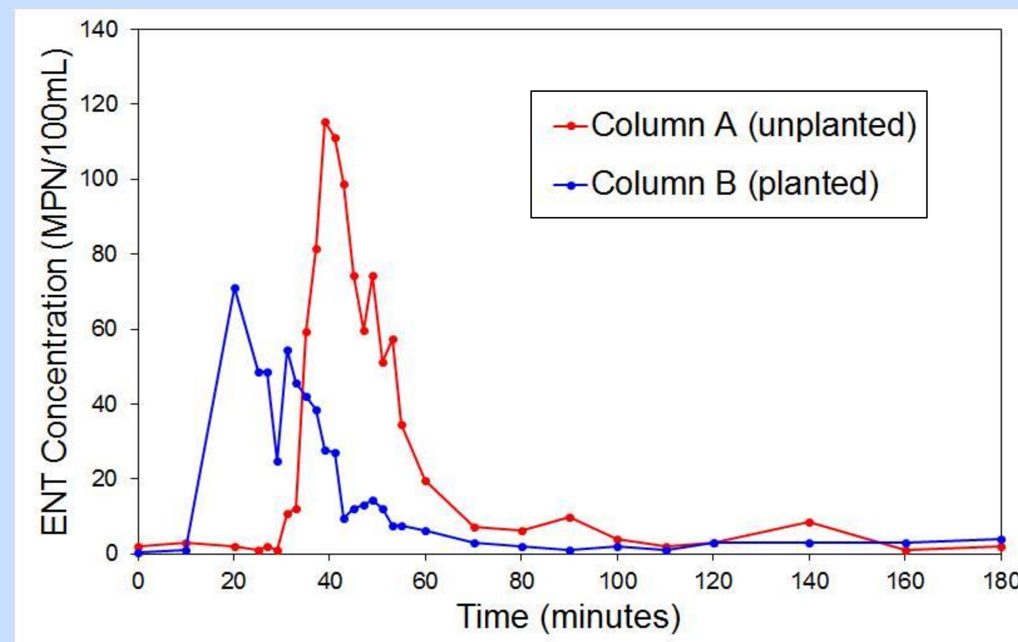


Figure 1. ENT BTCs for an unplanted (red, Column A) and planted (blue, Column B) biofilter.

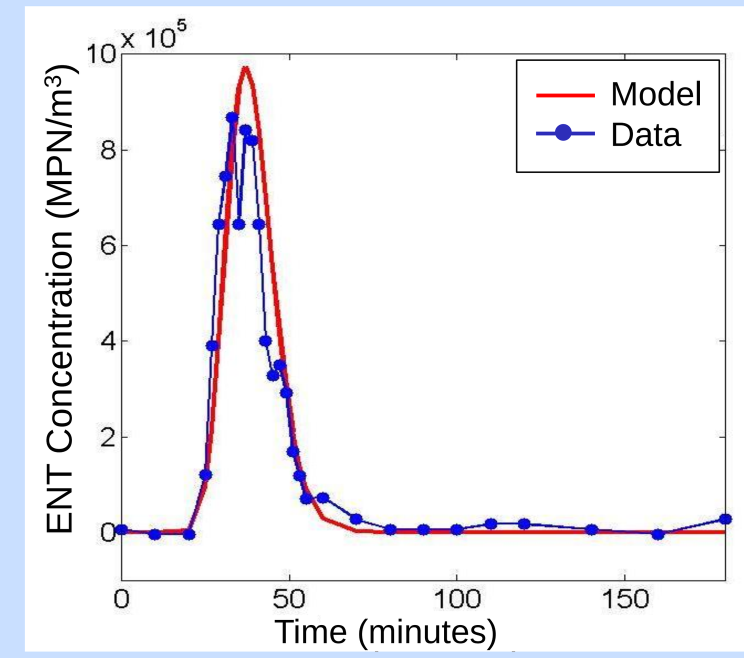


Figure 2. Reactive Gaussian transport model fit to ENT BTC from Column C (unplanted).

Table 1. Average and standard deviation of log-removal and optimal removal rate constants (k).

AVERAGE LOG-REMOVAL AND OPTIMAL K VALUES				
	Planted		Unplanted	
	EC	ENT	EC	ENT
Average log-removal	0.477	0.724	0.606	0.799
Std-dev log-removal	0.0761	0.0956	0.0931	0.0807
Average optimal k	6.54E-04	6.70E-04	8.01E-04	7.42E-04
Std-dev optimal k	2.26E-04	3.54E-05	1.16E-04	1.28E-04

Table 2. Significance tests for log-removal and optimal k within and across biofilter treatments.

COMPARISON		t-VALUE FOR LOG-REMOVAL	t-VALUE FOR OPTIMAL K
Does FIB (EC & ENT) removal or reaction vary significantly within a treatment?	planted	2.33	1.13
	unplanted	1.20	0.80
Does FIB removal or reaction vary significantly across treatments (planted & unplanted)?	EC	6.21**	0.11
	ENT	4.01*	0.79

**p-value is marginally significant (<0.06), ** p-value is significant (<0.05)*

Experimental Conclusion

- FIB breakthrough occurred earlier in planted biofilters, possibly due to super diffusion along root channels.
- Log FIB removal was significantly higher in unplanted columns, but k values were not significantly different.
- No significant difference in k values or log FIB removal was found between EC and ENT.

Design Implications

- Assigned task of designing large-scale biofilter to achieve 2-log FIB removal.
- To accomplish this, we assumed: 1) steady-state operation, 2) dispersivity and porosity values from salt BTCs (see salt poster), 3) removal rate constants from FIB BTCs, 4) site characteristics including impervious runoff coefficient (0.95), impervious area draining to biofilter (67,679.63 m^2), and biofilter depth (2.5 m), and 5) the following design equation:

$$\frac{C}{C_o} = \frac{Q}{A}\int_0^\infty \frac{e^{-\frac{\left(L-\frac{Q\tau}{A\theta}\right)^2}{4D\tau}-k\tau}}{\sqrt{4\pi D\tau}}\,d\tau$$

Figure 3. Biofilter design equation

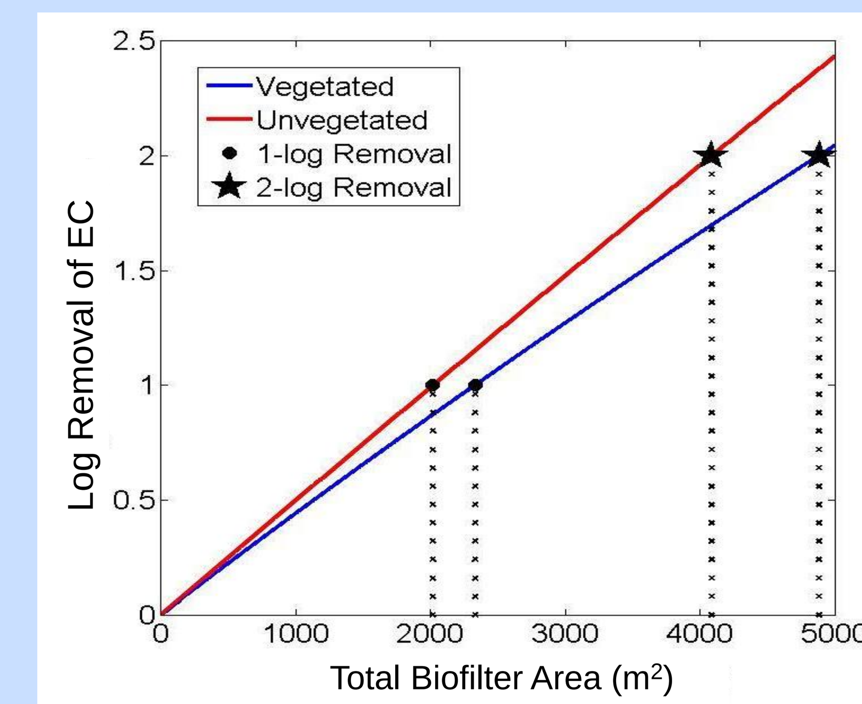


Figure 4. Plot depicting log removal of EC over increasing biofilter area.

- 2-log removal of EC is achieved with a biofilter area of 4881 m^2 (planted) or 4081 m^2 (unplanted).
- 2-log removal of ENT is achieved with a biofilter area of 3980 m^2 (planted) or 3687 m^2 (unplanted).
- Unplanted biofilters can perform FIB removal using a significantly smaller area than planted biofilters.
- However, due to aesthetics, unplanted biofilters may not gain public acceptance. Thus, other factors must be considered for implementation (see social science poster).

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