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Multi-scale Technoeconomic Analysis of Woodchip Bioreactors

What is a Woodchip Bioreactor?

Woodchip bioreactors are essentially large, lined pits of woodchips that act as a carbon source for denitrifying bacteria. The bacteria work to convert nitrates from incoming tile drainage into harmless nitrogen gas.

Bioreactor Installation

Project Objective

The goal of this project was to evaluate the cost to remove one kg of nitrate-N from multiple scales of bioreactors operated at various Hydraulic Residence Times (HRTs).

Methods

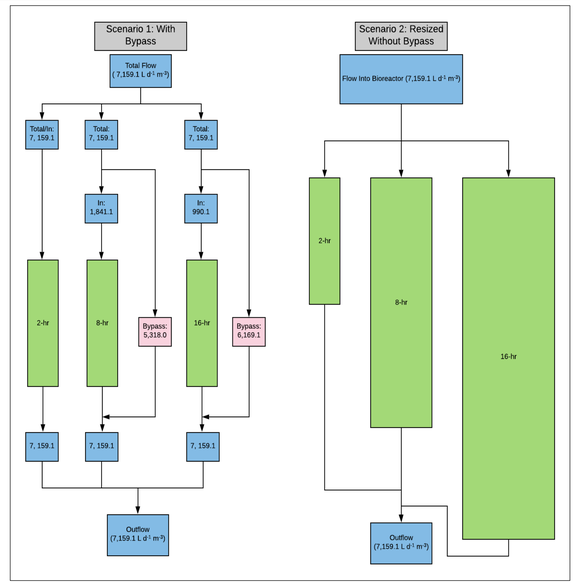
This analysis was conducted using four scales of bioreactors (pilot-, small-, medium-, and large-scale) operated at three HRTs (2-, 8-, and 16-hours). Additionally, two scenarios were evaluated where the bioreactors were operated with or without expected bypass flow.

With Bypass Flow

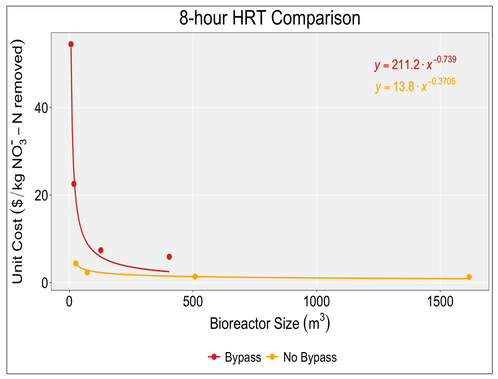
The four scales of bioreactors were operated at an HRT of 2-hours without bypass flow occurring. At HRTs of 8- and 16-hour bypass flow occurred. The size of the pilot-, small-, medium-, and large-scale bioreactors were 6.38, 18, 127, and 404 m^3 respectively. At HRTs of 2-, 8-, and 16-hours, the mass removal was 9.32, 8.52, and 7.67 g NO_3-N m^{-3} d^{-1} with 9.04%, 8.26%, and 7.44% removal respectively.

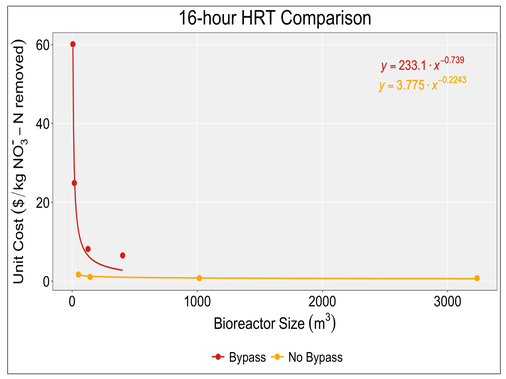
With Low Probability of Bypass Flow

The four scales of bioreactors were operated at an HRT of 2-hours without bypass flow occurring in the original scenario. At HRTs of 8- and 16-hours, the bioreactors were scaled up keeping the length to width ratio constant so that a low probability of the flow was bypassed. The volume of the bioreactors increased by a factor of 4 and 8 from the original size to achieve 8- and 16-hour HRTs respectively. At HRTs of 2-, 8-, and 16-hours, the mass removal was 9.32, 33.13, and 55.44 g NO_3-N m^{-3} d^{-1} with 9.04%, 32.12%, and 53.75% removal respectively.



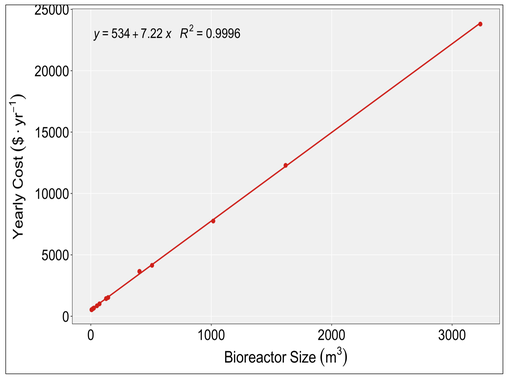
Results





Annualized Cost

As the bioreactor size is increased, the annual cost increases linearly. This analysis considers the bioreactors with or without expected bypass flow.



Comparison of Bypassed vs Non-Bypassed

Without bypass flow, the size of the bioreactor and its capacity to remove nitrates increased while the unit cost for removal of one kg NO_3-N decreases. The unit cost for removal begins to plateau as the size increases.

Acknowledgements

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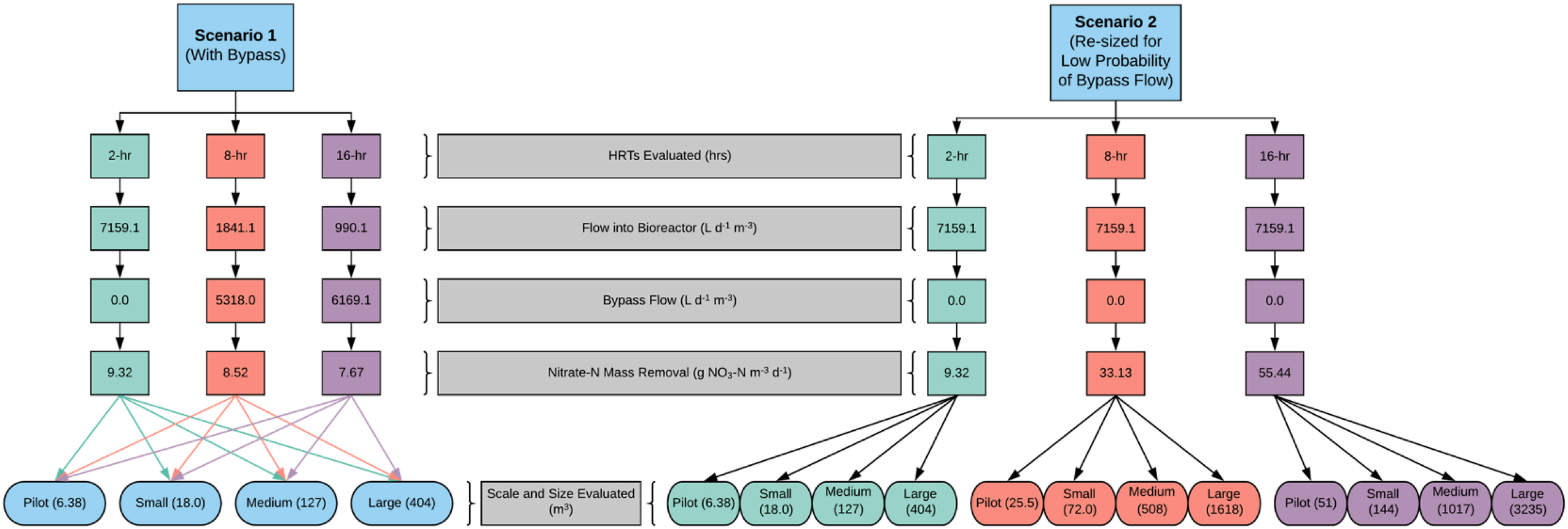
References:

1. Christianson, L., A. Bhandari, M. Helmers, K. Kult, T. Sutphin, and R. Wolf. 2012. "Performance evaluation of four field-scale agricultural drainage denitrification bioreactors in Iowa." *Trans. ASABE* 55 (6) :2163-2174.
2. Martin, E. A., M. P. Davis, T. B. Moorman, T. M. Isenhart, and M. L. Soupir. 2019. "Impact of hydraulic residence time on nitrate removal in pilot-scale woodchip bioreactors." *Journal of Environmental Management* 237:424-432.

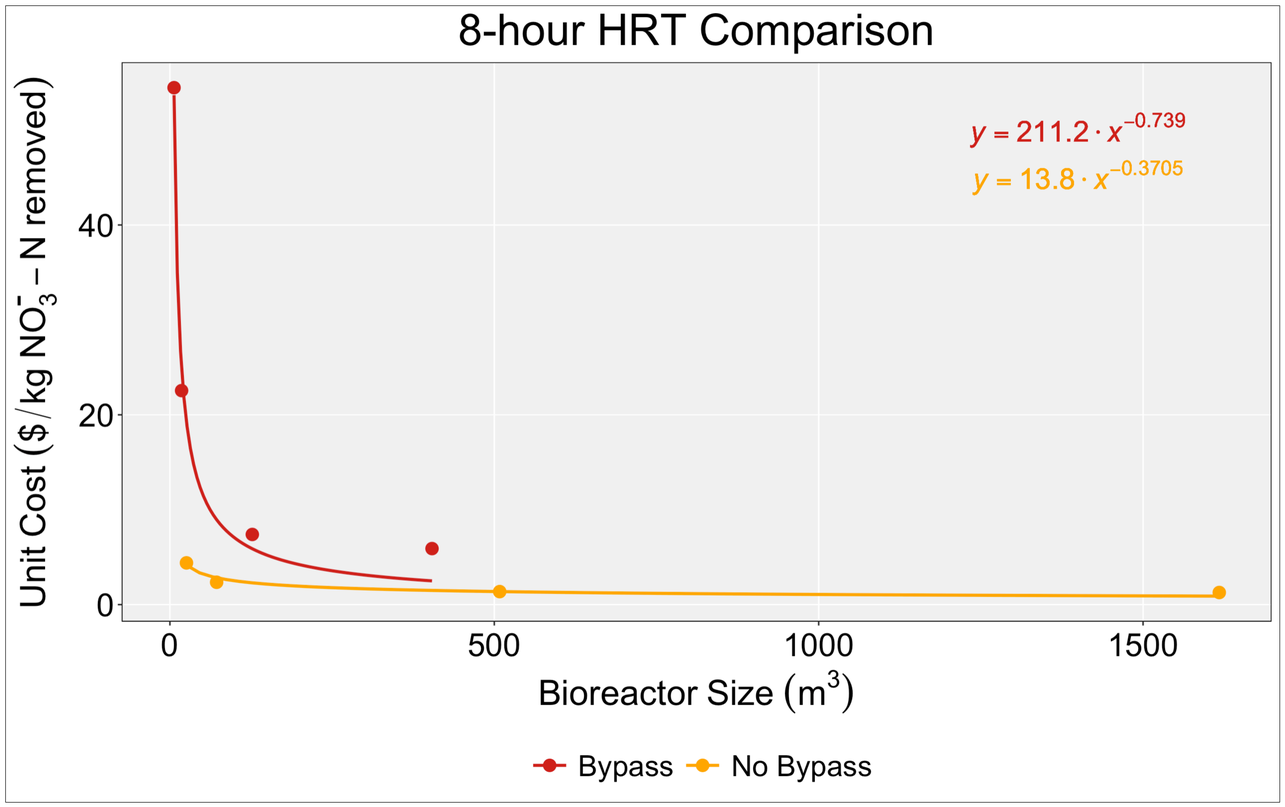
Scenario Explanations

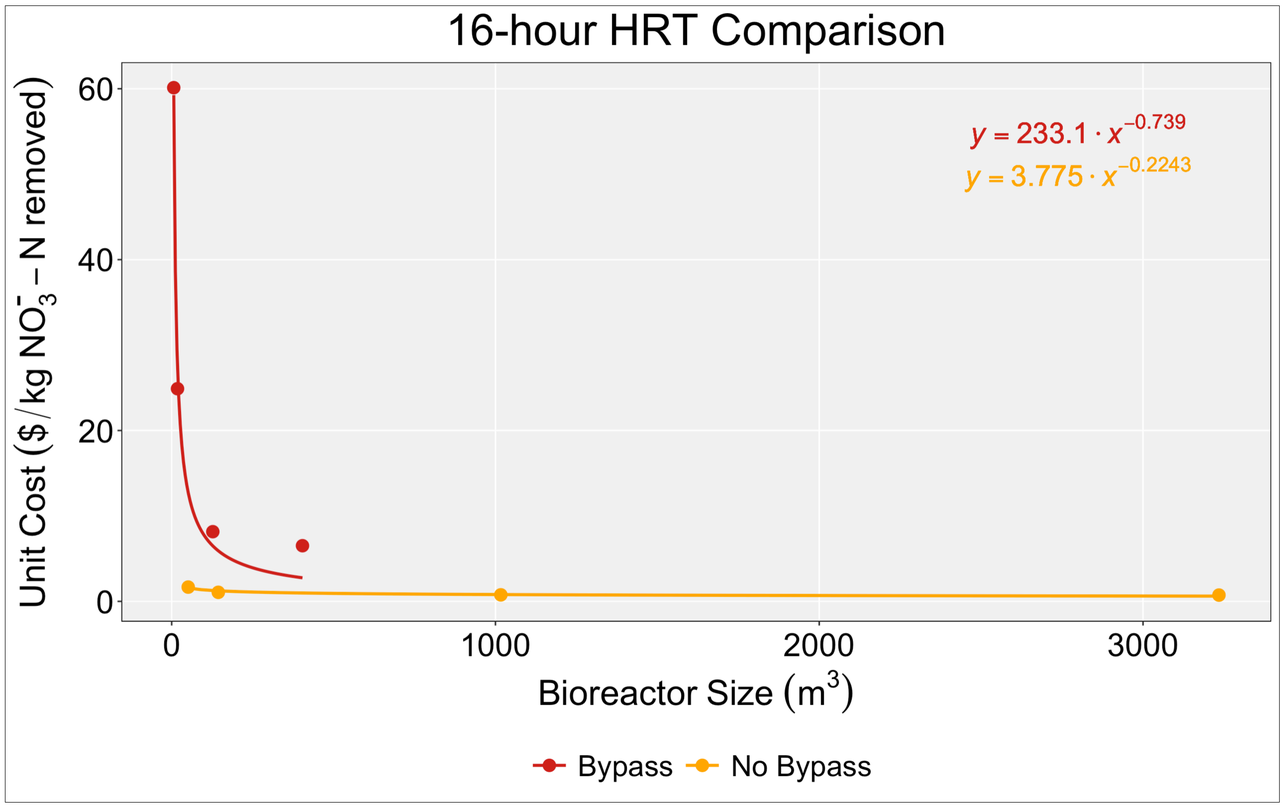


Nutrient Loads and Removals for the Two Scenarios

		With Bypass		Without Bypass	
HRT (h)	Influent NO_3-N Load (g NO_3-N m^{-3} d^{-1})	Percent Removal (%)	Mass Removal (g NO_3-N m^{-3} d^{-1})	Percent Removal (%)	Mass Removal (g NO_3-N m^{-3} d^{-1})
2	103.14	9.04%	9.32	9.04%	9.32
8	103.14	8.26%	8.52	32.12%	33.13
16	103.14	7.44%	7.67	53.75%	55.44

Unit Cost Comparisons





With Bypass

Scale	HRT (h)	Size (m^3)	Bioreactor Total Cost ($)	Annual Cost ($/y)	Unit Cost ($/kg NO_3-N removed)	NO_3-N Removal (kg/y)
Pilot	2	6.38	$2,451	$532	$49.78	10.68
	8				$54.47	9.76
	16				$60.13	8.84
Small	2	18.0	$2,905	$621	$20.61	30.13
	8				$22.55	27.54
	16				$24.89	24.95
Medium	2	127	$7,057	$1,437	$6.75	212.72
	8				$7.39	194.42
	16				$8.16	176.12
Large	2	404	$18,326	$3,651	$5.39	676.91
	8				$5.91	618.68
	16				$6.52	560.45

Low Probability of Bypass

Scale	HRT (h)	Size (m^3)	Bioreactor Total Cost ($)	Annual Cost ($/y)	Unit Cost ($/kg NO_3-N removed)	NO_3-N Removal (kg/y)
Pilot	2	6.38	$2,451	$532	$49.78	10.68
	8	25.52	$3,152	$669	$4.40	152.18
	16	51.04	$4,081	$852	$1.67	509.32
Small	2	18.0	$2,905	$621	$20.61	30.13
	8	72.0	$4,889	$1,011	$2.35	429.35
	16	144.0	$7,509	$1,526	$1.06	1436.95
Medium	2	127.1	$7,057	$1,437	$6.75	212.72
	8	508.3	$20,845	$4,146	$1.37	3030.99
	16	1016.6	$39,211	$7,755	$0.76	10144.20
Large	2	404.4	$18,326	$3,651	$5.39	676.91
	8	1617.5	$62,285	$12, 290	$1.27	9645.13
	16	3234.5	$120,847	$23,798	$0.74	32276.79