Supplementary Information

1 Design

In the nutrient removal *P-k-C** model, each wetland cell is taken to behave hydraulically as a number, *N*, of tanks in series (TIS). A higher *N* value corresponds to a well-designed wetland with a narrower range of residence times, and thus a closer approximation to ideal plug flow, with lower output concentrations. A low *N* value corresponds to a poorly-designed wetland with channelling and/or poor mixing, leading to a larger range of outputs, with a generally higher mean. The value of *N* is determined in practice using tracer measurements through the wetland. To reflect the weathering of a particular contaminant as it flows through the cell and the subsequent change in removal rates, a value termed the *P*TIS is used as a an effective value for *N*, thus accounting for both hydraulics and contaminant removal. Kadlec and Wallace provide a methodology for estimating *P*TIS for a given wetland.[1]

Values for *k* and *C** for different contaminants in FWS wetlands were taken from the compiled data in the work of Kadlec and Wallace, using median values in the reported frequency distributions for phosphorus and nitrogen removal.[1] No precipitation, evapotranspiration, infiltration or transpiration were included when generating results, making these conservative estimates (i.e. without contaminant removal through transpiration and infiltration, or dilution of contaminants through precipitation). For BOD removal, the mean *k*-value of the super, primary, secondary, and tertiary wetland categories (defined by Kadlec and Wallace[1]) was used. The background concentration, *C**, was linearly scaled with the BOD input concentration for input BOD concentrations above 15 mg/L, using the function: $BOD_{output} = 0.0593*(BOD_{input}-15) + 2$. For input BOD concentrations below 15 mg/L, *C** was set to 2 mg/L.

When sizing wetlands for treatment of Acid Mine Drainage, removal rate ranges for the zero-order model were sourced from literature, shown in Table S1.

Table S1: Assumed Wetland Acidity and Metal Removal Rate Ranges.

Wetland Type	Removal Rate ($g/m^2/day$)	Sources
FWS	Fe: 10-20 Mn: 0.5-2	[2–5]
HSSF	Acidity: 3.5-10	[3,4,6]
VF	Acidity: 15-30	[3,6–8]

2 Comparison of Nutrient Removal Costs With Conventional Costs

Costs of nutrient removal using constructed wetland were compared to those of conventional technologies reported in literature, and used to construct Fig. 3. Full data is provided in Table S2.

Table S2: Comparison of Conventional Nutrient Removal Costs From Literature With Calculated Costs for Wetland Nutrient Removal.

Inputs/Influent Type	Outputs/Treatment Level	Reported Costs ($/m^3)	This Study ($/m^3)	Wetland Area (ha)	Source
8,000-36,000 m^3/d Municipal Wastewater	Secondary (conventional activated sludge)	0.19-0.25	0.10-0.12	22.8-100	[9]
2,000-15,000 m^3/d Municipal Wastewater	Secondary (extended aeration activated sludge with mechanical dewatering)	0.17-0.28	0.10-0.15	6.00-42.4	[9]
310-15,000 m^3/d Municipal Wastewater	Secondary (extended aeration activated sludge with air drying)	0.13-0.31	0.11-0.21	0.955-42.4	[9]
4800 m^3/d 130 mg/L BOD, 25 mg/L NH_3, 3 mg/L org-N, 8 mg/L P	Secondary extended aeration activated sludge with mechanical dewatering)	0.67	0.10	11.4	[10]
	Secondary (Conventional Activated Sludge)	0.49	0.10	11.4	[10]
	8 mg/L BOD, 10 mg/L TN, 1 mg/L TP	0.61	0.36	52.8	[10]
10,000-50,000 m^3/d Municipal Wastewater	25 mg/L BOD	0.17-0.28	0.10-0.12	30.8-149	[11]
	10 mg/L BOD	0.21-0.24	0.15-0.18	43.7-211	[11]
	10 mg/L BOD, NH_4-N < 5 mg/L	0.23-0.28	0.24-0.27	83.9-413	[11]
400-10,000 m^3/d Municipal Wastewater (assumed)	Secondary (unstated)	0.57-2.97	0.11-0.20	1.36-28.6	[12]
	Tertiary (unstated)	0.57-2.97	0.36-0.53	5.03-114	[12]
10-50 m^3/d Municipal Wastewater	40 mg/L BOD, 15 mg/L NH_4-N, 10 mg/L P	0.62-1.87	0.32-0.45	0.054-0.269	[13]
2,700-59,000 m^3/d Municipal with rare industrial discharge	Secondary	0.16-1.29, mean: 0.47	0.11-0.17	9.81-200	[14]
3,000-10,000 m^3/d Post-activated sludge effluent (post-secondary treatment), 4.09 mg/L phosphorus	0.1 mg/L phosphorus	0.14-0.24	0.55-0.62	53.0-172	[15]
	0.5 mg/L phosphorus	0.08-0.19	0.34-0.39	33.3-108	[15]
	1 mg/L phosphorus	0.01-0.07	0.26-0.29	24.8-81.2	[15]
45,000 m^3/d Post-Secondary Treatment	TN < 3mg/L	0.11	0.43	668	[16]
	TP < 0.1 mg/L	0.15	0.52	823	[16]

	TN < 3mg/L, TP < 0.1 mg/L	0.24	0.52	823	[16]
100-400 m^3/d Domestic Wastewater	BOD < 30 mg/L, NH_4 < 0.5 mg/L, P < 0.5 mg/L, TN < 15 mg/L	1.18-3.04	0.75-0.95	1.70-6.59	[17]
	BOD < 30 mg/L, NH_3 < 1 mg/L, P < 0.5 mg/L	1.15-2.97	0.65-0.82	1.49-5.74	[17]
	BOD < 30 mg/L, NH_3 < 1 mg/L	1.09-2.81	0.65-0.82	1.49-5.74	[17]
	BOD < 30 mg/L	1.04-2.73	0.20-0.26	0.319-1.23	[17]
4,500-45,500 m^3/d 174 mg/L BOD, 7.5 mg/L TP	22 mg/L BOD, 5.86 mg/L TP	0.62-1.29	0.11-0.15	15.2-152	[18]
	10 mg/L BOD, 1 mg/L TP	0.80-1.51	0.29-0.36	48.2-468	[18]
	7.5 mg/L BOD, 0.325 mg/L TP	0.84-1.57	0.42-0.51	67.9-665	[18]
23,000 m^3/d Municipal Wastewater, 239 mg/L BOD, 5.7 mg/L TP, 26.8 mg/L NH_4-N, 15.5 mg/L org-N	1.02 mg/L phosphorus	0.47	0.28	212	[19]
	1.02 mg/L phosphorus, 0.08 mg/L NH_4-N, 0.8 mg/L BOD, 7.01 mg/L NO_x-N	0.47	0.62	469	[19]
	0.05 mg/L phosphorus, 1.04 mg/L NH_4-N, 0.62 mg/L BOD, 7.23 mg/L NO_x-N	0.51	0.63	487	[19]
18-455 m^3/d Municipal Wastewater	12 mg/L TN	1.33-7.75	0.37-0.68	0.163-4.11	[20]
	6 mg/L TN	1.47-11.54	0.52-0.95	0.249-5.43	[20]

Secondary treatment standards were considered to be 30 mg/L BOD. Tertiary treatment standards were considered to be 10 mg/L BOD, 1 mg/L phosphorus and 5 mg/L ammonia. One population equivalent was taken to signify 200 L/d. Municipal and domestic wastewater were taken to contain 200 mg/L BOD and 9.5 mg/L phosphorus, 22.9 mg/L NH_4-N, and 15.6 mg/L org-N. Municipal with rare industrial discharge was taken to contain 350 mg/L BOD, 45 mg/L NH_4-N, 15 mg/L org-N, and 15 mg/L P. Post-secondary treatment influent was taken to contain 30 mg/L BOD, 5.9 mg/L P, and 25 mg/L TN (half org-N and NH_4-N). Treatment plant lifetime was taken to be 20 years.

*BOD not achievable due to minimum background concentrations of 2 mg/L. However, all other levels were achieved, with the focus of the referenced study being phosphorus removal rather than BOD removal.

3 Cost of Nitrogen Removal As a Function Of Number of Cells

Fig. S1 shows the effects of varying the number of cells on overall costs and areas for nitrogen removal, for varying input concentrations and fixed output concentrations, at a flow rate of 5,000 m^3/d.

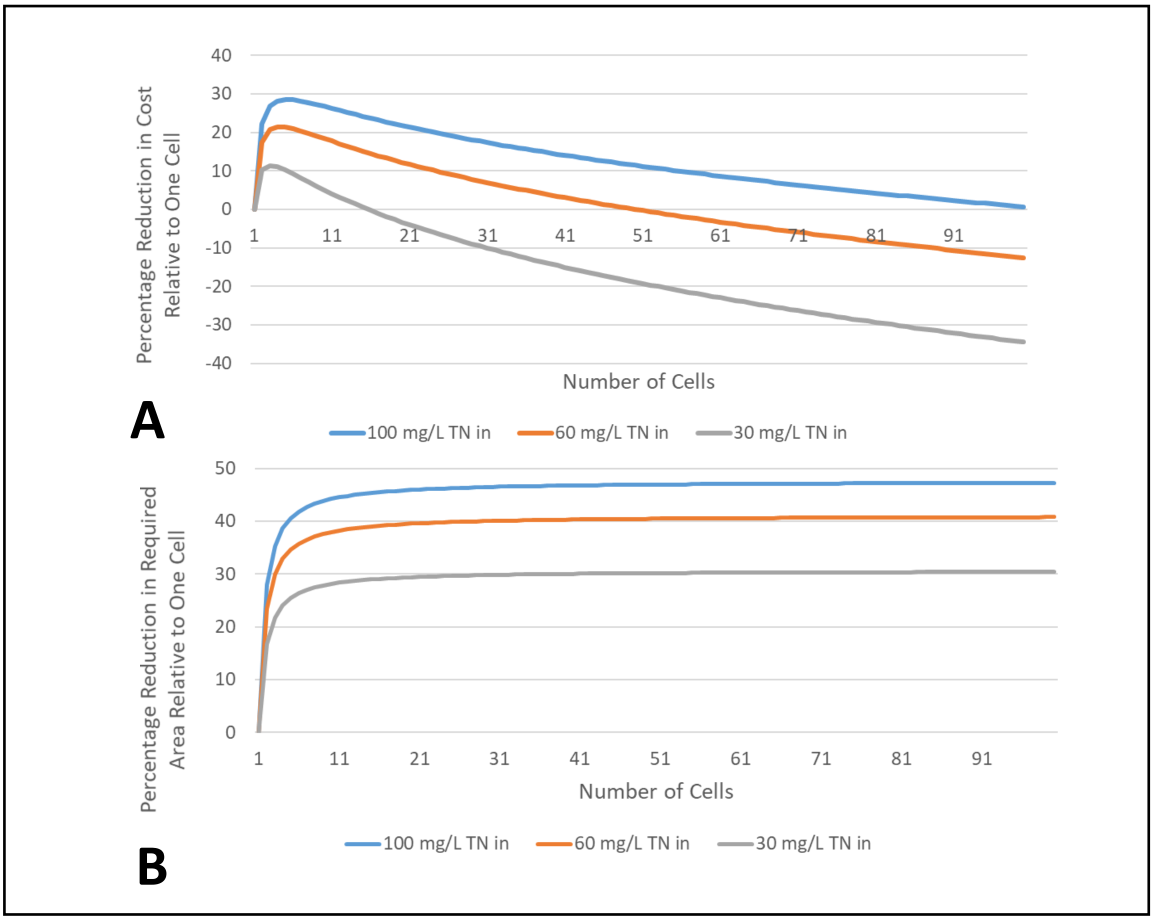

Figure S1: Effect of varying the number of wetland cells on required overall area and treatment costs for Nitrogen Removal. All plots are for 5,000 m^3/d of varying Total Nitrogen (TN) input concentrations, with an output concentration of 5 mg/L. Plots are A: Reduction in total cost, B: Reduction in required area.

4 Cost of Nutrient Removal Per Unit Mass of Contaminant Removed

Fig. S2 shows the costs of nutrient removal using constructed wetlands, per unit mass of contaminant removed.

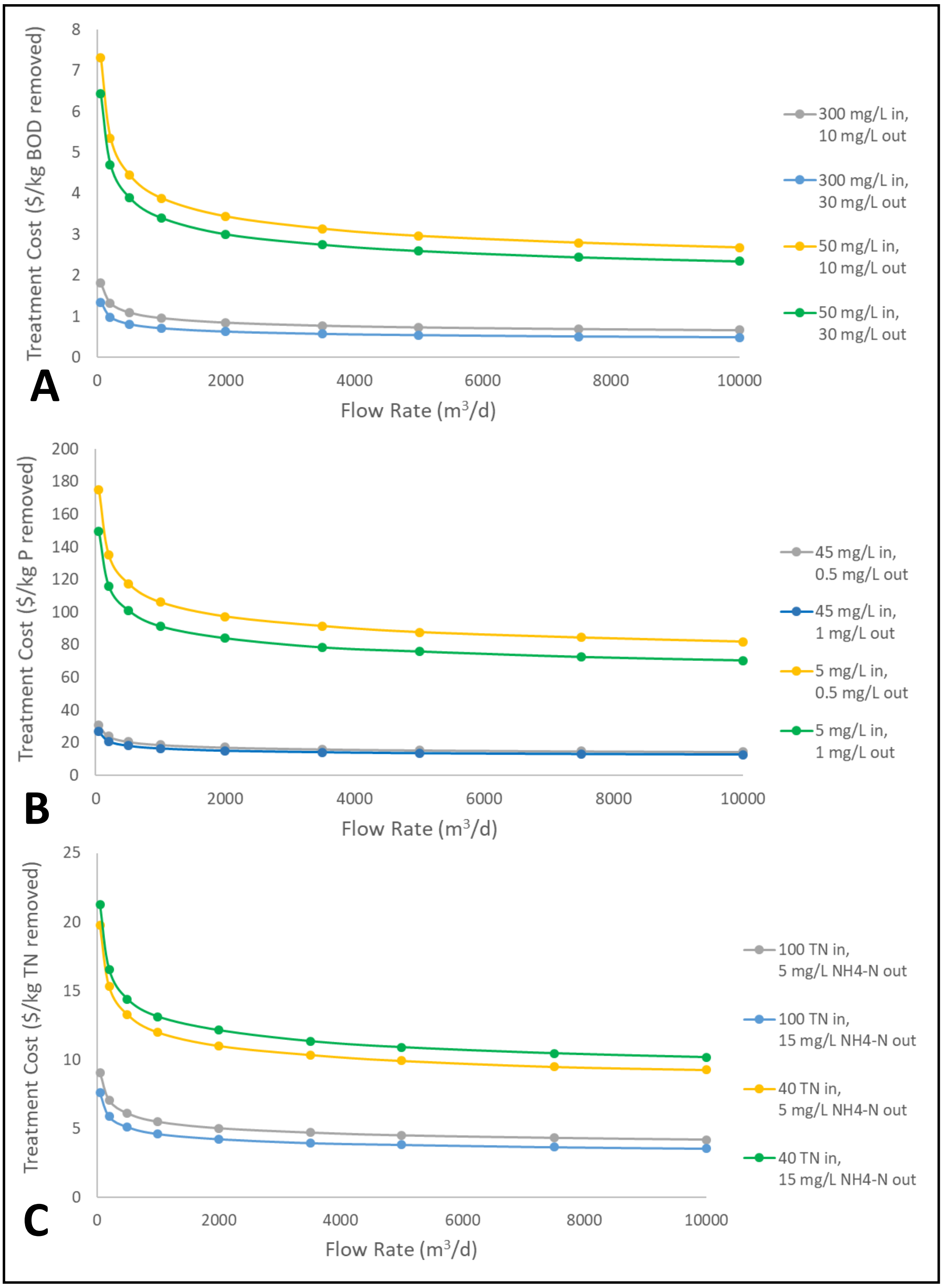

Figure S2: Costs of nutrient removal using constructed wetlands per unit mass of contaminant removed, for a range of input and output conditions. Plots are A: biochemical oxygen demand (BOD) removal, B: phosphorus (P) removal, C: total nitrogen (TN) removal, assuming input nitrogen made up of 50% organic nitrogen and 50% ammonia nitrogen (NH_4-N).

5 Full Contour Plots for Cost of Nutrient Removal

BOD Removal

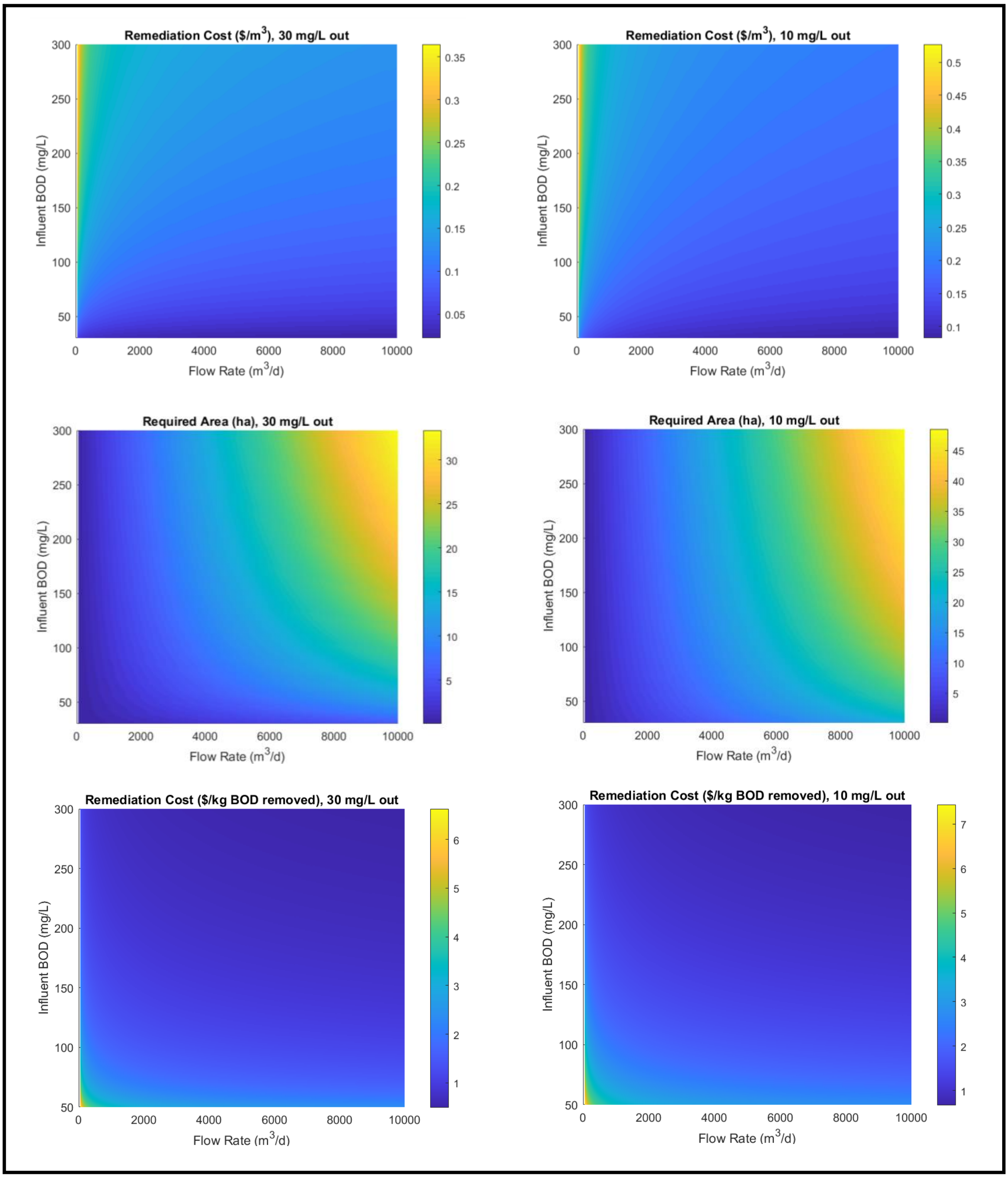

Figure S3: Remediation costs and required wetland areas for BOD removal, varying with flow rate and influent concentration, for two different effluent concentrations.

Phosphorus Removal

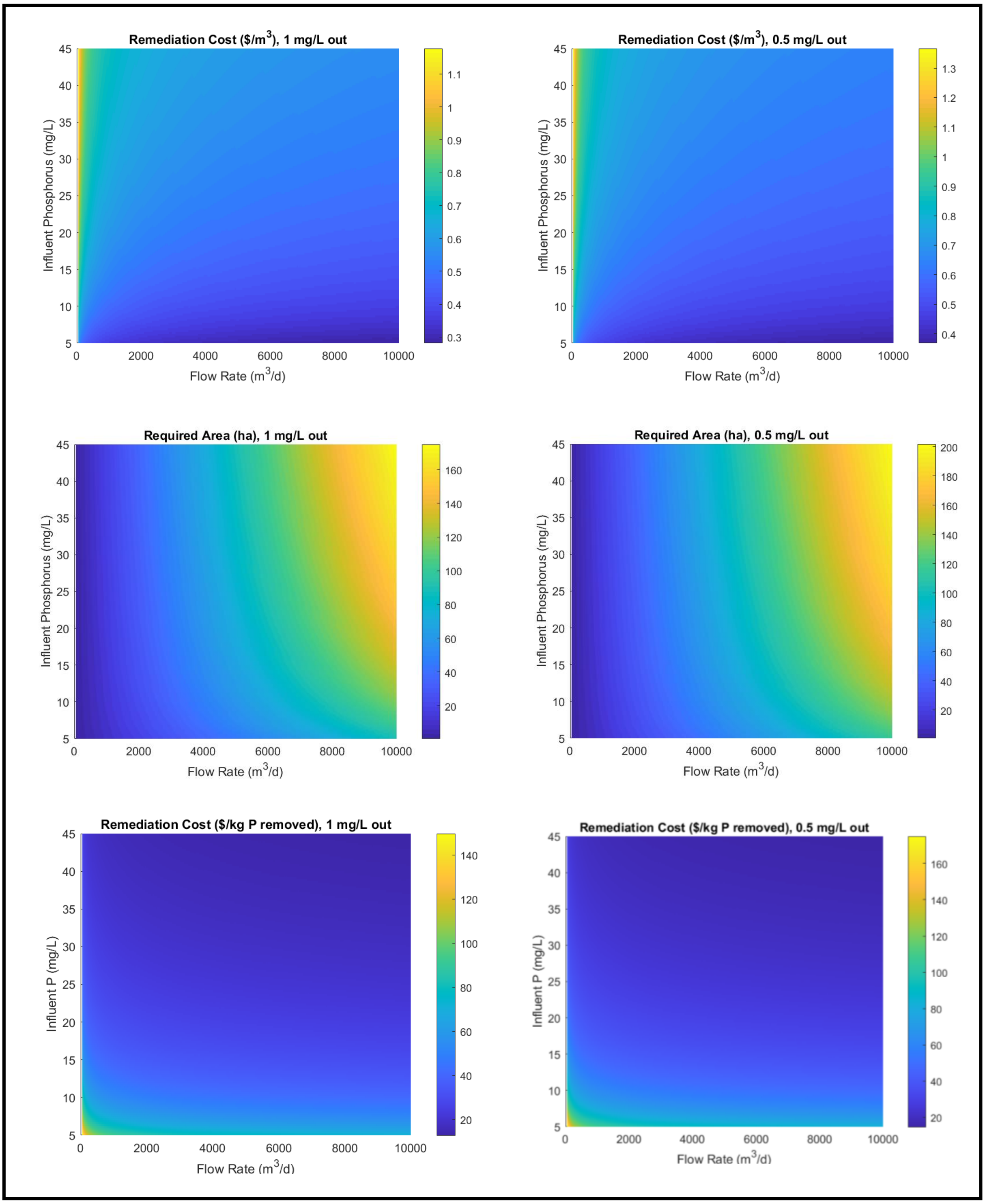

Figure S4: Remediation costs and required wetland areas for phosphorus removal, varying with flow rate and influent concentration, for two different effluent concentrations.

Nitrogen Removal

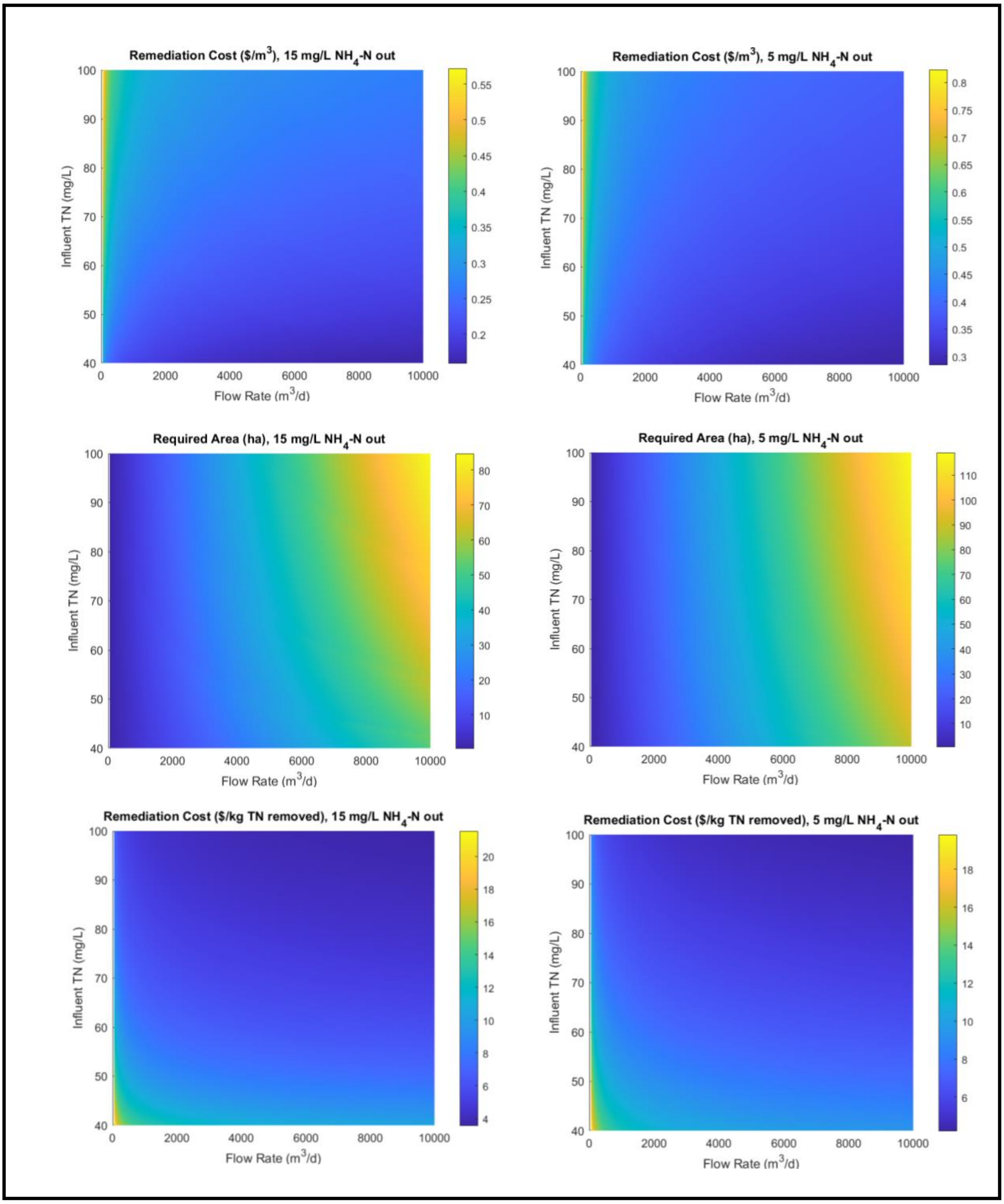

Figure S5: Remediation costs and required wetland areas for nitrogen removal, varying with flow rate and influent concentration, for two different ammonia nitrogen effluent concentrations. Input nitrogen assumed to be made up of 50% organic nitrogen and 50% ammonia nitrogen (NH_4-N).

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