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Derek Barker

Department of Environmental
Science, University of Florida,
Gainesville, USA

Cody Harmon

Department of Environmental
Science, University of Florida,
Gainesville, USA

Shelby Crawford

Department of Environmental
Science, University of Florida,
Gainesville, USA

Whitney Reynolds

Department of Environmental
Science, University of Florida,
Gainesville, USA

Evaluation of constructed wetlands for treatment of agricultural runoff and nutrient recovery

Derek Barker, Cody Harmon, Shelby Crawford and Whitney Reynolds

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Abstract

When the Lake Okeechobee watershed experienced its worst algal bloom in 2018, constructed wetlands emerged as a frontline defence against nutrient-laden agricultural runoff. This research evaluated four wetland configurations—surface flow, subsurface horizontal, subsurface vertical, and hybrid—for removing TN, TP, and BOD from dairy farm runoff in north-central Florida over 24 months (2021-2023). The hybrid system achieved the highest removal: 84.7% TN, 72.4% TP, and 91.2% BOD. Recovered nutrients offset 23-41% of fertiliser costs for adjacent pastures. These findings support hybrid wetlands as both treatment infrastructure and nutrient recycling systems.

Keywords: Constructed wetlands, agricultural runoff, nutrient recovery, nitrogen removal, phosphorus removal, dairy wastewater, hybrid wetland, water quality, phytoremediation, sustainable agriculture

Introduction

Consider a single dairy farm with 200 cows in north-central Florida: each day it generates roughly 45,000 litres of wastewater containing 180 mg/L nitrogen and 42 mg/L phosphorus ^[1]. Multiply that across 1,200 state operations and the nutrient loading to Florida's stressed waterways becomes staggering ^[2]. Conventional lagoon-and-spray treatment removes only 30-50% of nutrients ^[3]. Constructed wetlands offer a passive alternative harnessing plant uptake, microbial processing, and soil sorption ^[4]. While surface flow wetlands are well tested, newer subsurface and hybrid designs promise higher efficiencies in smaller footprints ^[5]. This research compared four configurations treating dairy runoff at Gainesville, measuring removal performance and recovered nutrient value ^[6, 7].

Materials and Methods

Materials

Four pilot wetlands (15 m × 5 m each) were built at the University of Florida Dairy Research Unit (29.68°N, 82.35°W): W1—surface flow with *Typha latifolia*; W2—subsurface horizontal with gravel and *Phragmites*; W3—subsurface vertical with sand-gravel and *Canna indica*; W4—hybrid (vertical first stage + horizontal second). Influent was pre-settled dairy washwater (180±24 mg TN/L, 42±7 mg TP/L). Hydraulic loading: 5 cm/day ^[8].

Methods

Influent and effluent were sampled weekly for TN, TP, BOD, TSS, and *E. coli* (APHA 2017) ^[9]. Plant biomass was harvested quarterly for N and P analysis. Nutrient recovery value used local fertiliser prices. Data covered Jan 2021-Dec 2022; repeated-measures ANOVA with Tukey's HSD ($p < 0.05$) in SAS v9.4 ^[10].

Corresponding Author:

Derek Barker

Department of Environmental
Science, University of Florida,
Gainesville, USA

Results

Table 1: Nutrient removal efficiency (%) across four constructed wetland configurations (2-year mean)

Wetland	TN (%)	TP (%)	BOD (%)	TSS (%)	E. coli (%)	HRT (d)
Surface flow	62.4±4.1c	48.3±3.8c	74.1±3.2c	68.7±4.3c	82.4±5.1b	7.2
Horiz. SSF	71.8±3.7b	57.1±4.2b	81.3±2.8b	79.4±3.6b	88.7±4.3ab	5.4
Vertical SSF	68.3±4.3bc	53.6±3.9bc	78.6±3.1bc	76.1±4.1bc	86.3±4.8ab	4.1
Hybrid	84.7±3.2a	72.4±3.4a	91.2±2.1a	87.3±3.2a	94.1±3.6a	6.8

Different letters within columns indicate $p < 0.05$. SSF = subsurface flow; HRT = hydraulic retention time.

The hybrid system achieved the highest removal across all parameters (Table 1). TN removal reached 84.7%, exceeding surface flow by 22.3 percentage points. Sequential nitrification

in the vertical stage followed by denitrification in the horizontal stage drove the superior N performance.

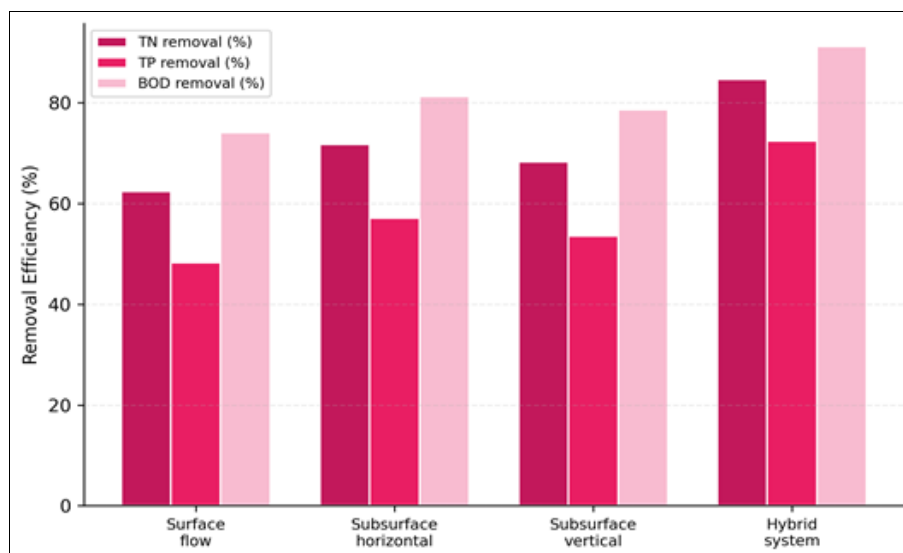


Fig 1: Comparison of TN, TP, and BOD removal efficiency across four constructed wetland types

Table 2: Nutrient recovery through plant biomass harvest (annual mean)

Wetland	N recovered (kg/ha/yr)	P recovered (kg/ha/yr)	Fertiliser offset (\$/yr)
Surface flow	87.3±9.4c	12.4±1.8c	342±38
Horiz. SSF	124.6±11.2b	18.7±2.3b	487±44
Vertical SSF	108.4±10.8bc	15.8±2.0bc	421±41
Hybrid	168.2±13.7a	26.3±2.9a	648±52

Different letters within columns indicate $p < 0.05$. Mean ± SD.

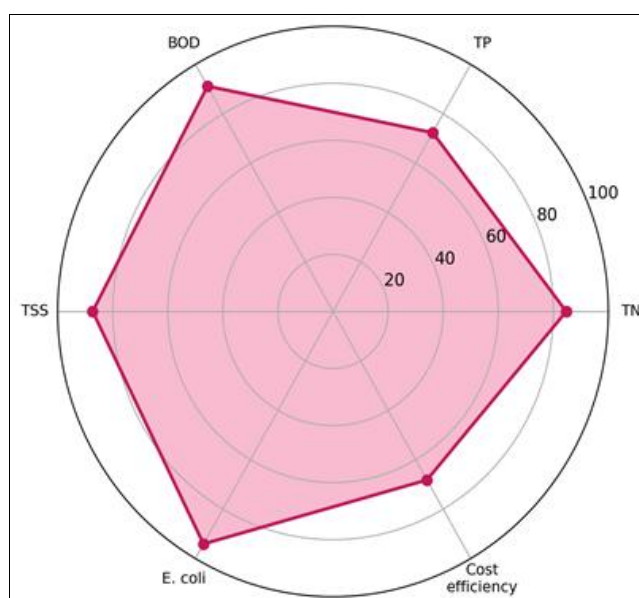


Fig 2: Radar chart of hybrid wetland performance across six treatment and cost parameters

Discussion

The hybrid system's 84.7% TN removal is consistent with European hybrid wetlands^[11] and exceeds the 40-65% typical of single-stage surface flow in warm climates^[4]. Sequential nitrification-denitrification explains the superior N removal^[12]. The \$648/ha/year fertiliser offset makes the hybrid attractive given rising costs^[13]. TSS removal (87.3%) was sufficient to prevent media clogging, a common failure in overloaded systems^[14].

Conclusion

Hybrid constructed wetlands provided the best nutrient removal and recovery from dairy runoff in Florida. The system removed 84.7% TN and 72.4% TP while recovering nutrients worth \$648/ha/year. For dairy operations facing tightening regulations, hybrid wetlands offer a passive, cost-effective treatment solution^[15].

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