CONSTRUCTION, OPTIMIZATION, AND COST-BENEFIT ANALYSIS OF FLOATING AQUATIC TREATMENT WETLANDS FOR PHYTOREMEDIATION PRE-TREATMENT OF MUNICIPAL LANDFILL LEACHATE EMPLOYING SALINE-TOLERANT PLANTS

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Abstract

Leachate treatment is a cost-intensive process for most municipal landfills because it carries excessively high concentrations of ammonia, metals, and other dissolved solids which can disrupt the function of contemporary water treatment plants. To compensate for potential disruption, wastewater treatment plants require payment based on the volume and concentration of multiple substances in leachate. Some of the substances are: chemical oxygen demand, ammonium, phosphate, nitrate, and nitrite. Dr. Ashley Danley-Thomson's lab at the U.A. Whitaker College of Engineering at Florida Gulf Coast University tested the ability of multiple native Florida, saline-tolerant plant species to survive in leachate. After a few species (mangrove spider lily, giant leather fern, white mangrove, red mangrove, and black mangrove among others) were identified to survive in leachate and remove some contaminants, those species were suspended in dilutions of 25%, 50%, 75%, and 100% concentrations of leachate to test their ability to survive in it without soil and to treat it. Different floating wetland designs were also tested to determine the most efficient design for reduction of chemical oxygen demand, ammonium, phosphate, nitrate, and nitrite in the leachate. Once trials were conducted to examine the efficiency of different plants and designs to treat leachate, a cost-benefit analysis was done to determine the extent to which floating wetlands could be used to minimize costs for municipal landfills. The analysis determined some plant species which were more efficient at removing chemical oxygen demand and some which were more efficient at removing ammonium. The appropriate species for optimal removal depends on initial concentrations within the target leachate and the specific contaminant regulations which must be met for treatment. Other factors may be used to optimize the system including aeration and pH adjustment.

Figure 1 (below). Photo of all floating wetland designs in test phase. Each design was tested to determine buoyancy, ability to sustain plant growth, and durability.

Figure 2 (above). Photo of most economical design by cost per gram of biomass supported. The 8' x 4' floating wetland cost $185.47 and is estimated to support 250 kilograms based on the volume of 4" PVC and the weight of the apparatus. The design may also support a soil component if necessary.

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Hinkley Center for Solid and Hazardous Waste Management

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Results

Results indicate that black mangrove is the most efficient remover of chemical oxygen demand and sea oxeye is the most efficient remover of ammonium.

	mg COD Removed/ g of Biomass	
Plant	75%	100%
MSL	301.13	78.27
GLF	153.40	113.42
SG	30.07	3.43
SO	168.21	152.00
BM	536.49	420.38
WM	51.30	41.48
RM	135.93	39.80

Table 1. (Left) Final total chemical oxygen demand removed for each plant at 75% and 100% leachate dilution.

Table 2. (Right) Final total ammonium removed for effective plants at 75% and 100% leachate dilution.

	mg Ammonium Removed/ g of Biomass	
Plant	75%	100%
SG	NE	10.86
SO	160.72	147.51
RM	43.32	52.90

Figure 3 (above). Mangrove spider lily in 100% leachate dilution bioreactor.

Calculations

Leachate Pond Volume: 11,356,235 Liters (3 million gallons)
Leachate Pond Surface Area: 51,200 Square feet
Device Surface Area: 32 Square feet
COD Removed/ g Sea Oxeye (100%): 80.23 mg/g
Ammonium Removed/ g Sea Oxeye (100%): 77.86 mg/g

Average Leachate COD (mg/L): 4,500
Average Leachate Ammonium (mg/L): 4,000

Available COD: 11,356,235 L x 4,500 mg/L /1,000,000 mg/kg = 51,103 kg
Available Ammonium: 11,356,235 L x 4,000 mg/L /1,000,000 mg/kg = 45,425 kg
Biomass Available: 51,200 ft^2 / (32 ft^2 /Device x 2 (Spacing factor)) x 51 kg/Device = 40,800 kg biomass available

Ammonium Removed: 40,800,000 g biomass x 52.9 mg Removed/g biomass/ 1,000,000 kg/mg = 2,158 kg removed
Percentage Removed: 2,158 kg/ 45,425 kg = 4.8%

COD Removed: 40,800,000 kg biomass x 420 mg Removed/g biomass x /1,000,000 mg/kg = 17,136 kg removed
Percentage Removed: 17,136 kg/ 51,103 kg = 33%

Figure 4 (above). Close- up of four floating wetlands designs. (Top-left: BeeMat, Top-right: mattress pad, Bottom-left: BioHaven, Bottom-right: PVC)

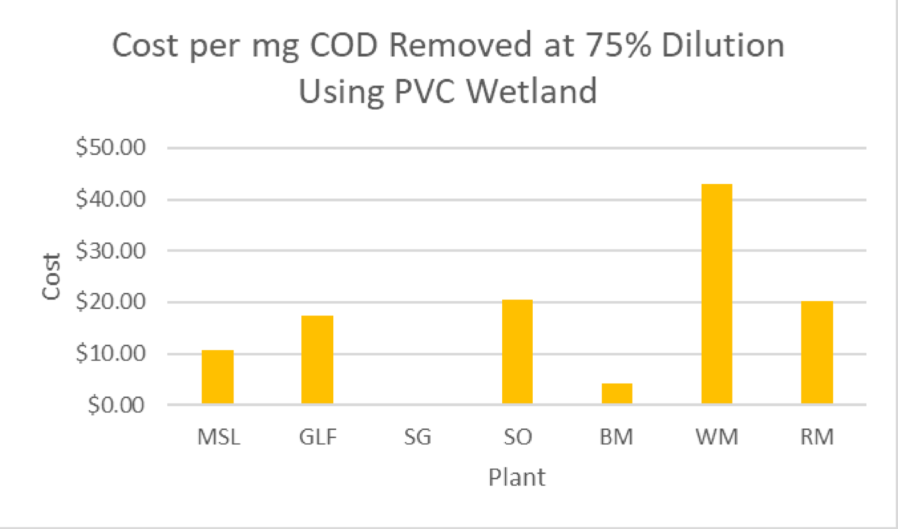

Figure 5. The cost of removal for 1 kilogram of chemical oxygen demand is shown for each native plant at the 75% leachate dilution. Black mangrove is the most effective plant at removing chemical oxygen demand at this dilution.

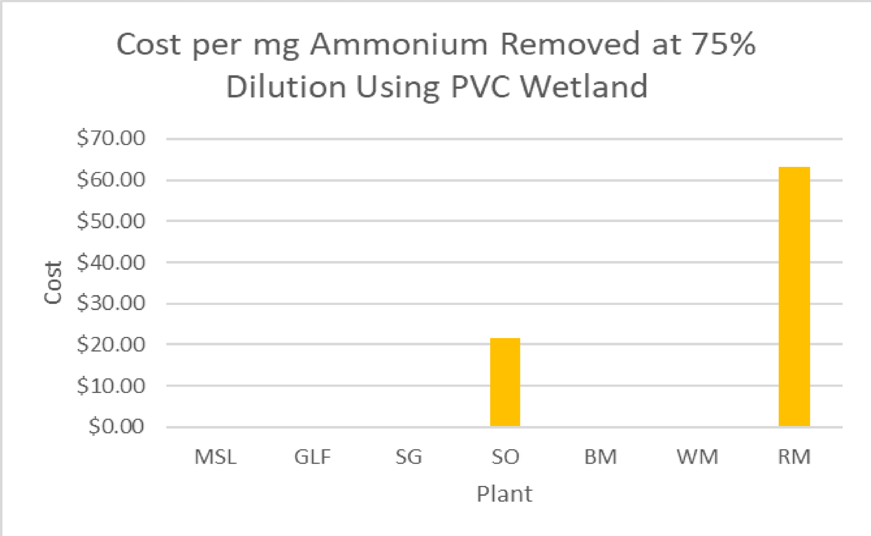

Figure 6. The cost of removal for 1 kilogram of ammonium is shown for each native plant at 75% leachate dilution. The only effective plants at this dilution were the sea oxeye and the red mangrove.

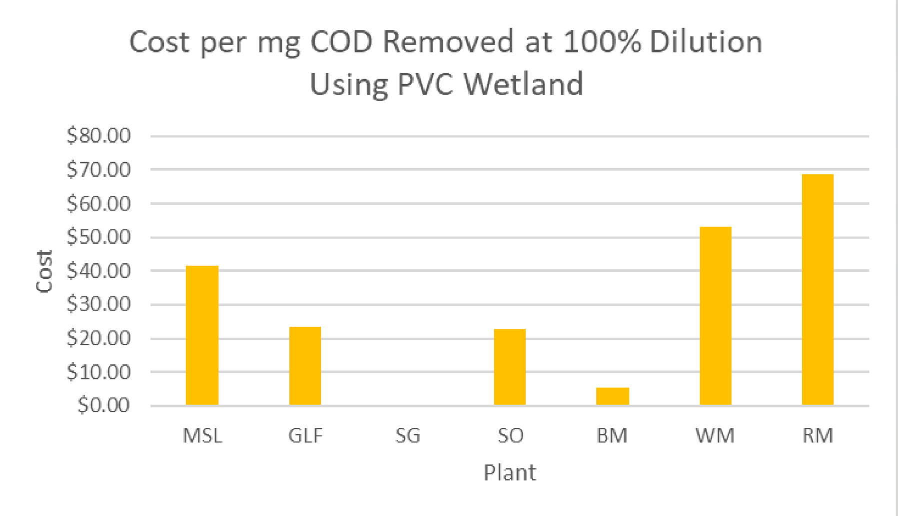

Figure 7. The cost of removal for 1 kilogram of chemical oxygen demand is shown for each native plant at the 100% leachate dilution. Black mangrove is also the most efficient plant at removing chemical oxygen demand at this dilution while sawgrass is ineffective.

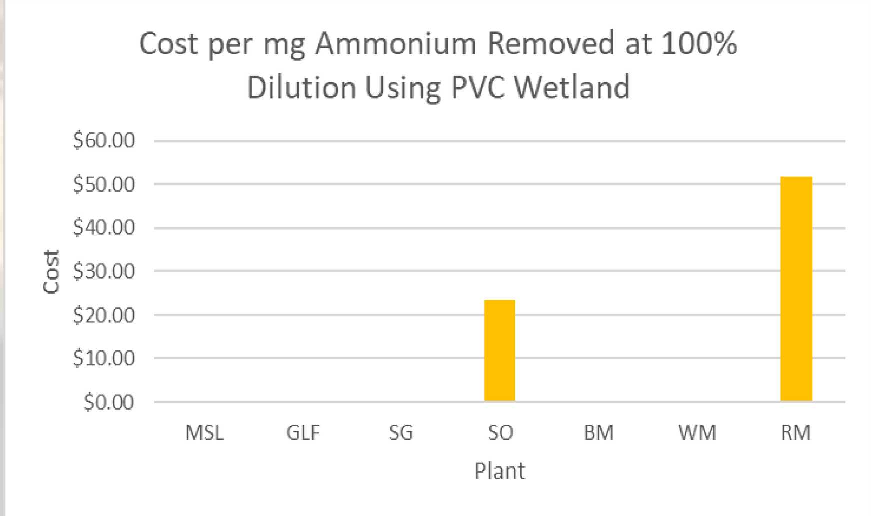

Figure 8. The cost of removal for 1 kilogram of ammonium is shown for each native plant at 100% leachate dilution. The mangrove spider lily, giant leather fern, sawgrass, black mangrove, and white mangrove were not effective at removing ammonium at this dilution.

Methods and Materials

Four floating wetland designs were drafted or identified, then built and evaluated simultaneously as the treatment abilities of seven salt-tolerant native South Florida plants were measured in 8"x8" batch reactors suspended by small floatation devices in 14-day trials. The plants were compared in four 4 liter leachate dilutions: 25%, 50%, 75%, and 100%, and measured for chemical oxygen demand and ammonium according to USEPA Reactor Digestion Method 10212 and Ammonia Salicylate Method 10031. Concentrations of both contaminants were analyzed and compared to actual leachate storage pond surface areas and volumes to determine system feasibility.

Conclusions

Based on the surface area and volume of an average leachate pond in Southwest Florida (Lee County Solid Waste Division), 40,800 kilograms of plant mass could be suspended in the pond while covering 50% of the surface area. The mass of plants (if black mangrove) could remove almost 22,000 kg of chemical oxygen demand (more than 40%) with no dilution. Black mangroves are notorious for being living comfortable in and even creating anaerobic conditions, which could reduce its capacity for treating ammonium. But at 75% dilution sea oxeye could remove up to 6,500 kg (13%) of chemical oxygen demand as well as 6,500 kg (14%) of ammonium. Sea oxeye could be effective at both the 75% and the 100% leachate dilution as seen in **Table 3.** Significant reduction of both chemical oxygen demand and ammonium in leachate is possible with phytoremediation using native salt-tolerant plants, and it could be financially beneficial to the landfill as well as optimal for wastewater treatment plant operators. No analysis has yet been attempted to calculate the cost of operation and maintenance of the floating wetland design. Little to no dilution reduces the ability of the selected plants to survive in landfill leachate.

Figure 9 (left). Aerial of the leachate pond used to estimate the surface area of an average leachate pond. The surface area of the pond was used to estimate the biomass which can fit comfortably on a leachate pond.

Table 3 (below). A comparison of sea oxeye, black mangrove, and red mangrove reduction capabilities in an average full-scale leachate pond. Optimal plant may depend on the local cost of sending high chemical oxygen demand and/or ammonium concentrations to wastewater treatment plants. (NE: not effective)

	Mass Removed (kg)			
	COD		Ammonium	
Plant	75%	100%	75%	100%
MSL	12,286 (24%)	3,193 (6.2%)	NE	NE
GLF	6,259 (12%)	4,628 (9.1%)	NE	NE
SG	1,227 (2.4%)	140 (0.27 %)	NE	443 (0.98%)
SO	6,863 (13%)	6,201 (12%)	6,557 (14.4%)	6,018 (13.2%)
BM	21,889 (43%)	17,151 (34%)	NE	NE
WM	2,093 (4.1%)	1,692 (3.3%)	NE	NE
RM	5,546 (3.2%)	1,624 (3.2%)	1,768 (3.9%)	2,158 (4.8%)