# Potential and Problems of Floating Treatment Wetlands for Mitigating Agricultural Contaminants

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Floating treatments wetlands (FTWs) are a relatively new water treatment technology and are designed to float on top of ponds or other existing water bodies, whereby the submerged root systems of plants aid in removal of nutrients and metals carried in runoff from wastewater, urban, or agricultural sources (Majsztrik et al. 2017; Stewart et al. 2008; Winston et al. 2013). Research documents the efficacy of FTWs to mitigate both metal and nutrient contaminants from runoff (Borne et al. 2014; Lynch et al. 2015; Olguín et al. 2017; Pavlineri et al. 2017). The most recent meta-analysis of published FTW research concluded that biosynthesis, settling and biofilm metabolism are the primary processes driving contaminant removal (Pavlineri et al. 2017). Most FTW studies have focused on quantifying changes to contaminant concentration in water, the mass of contaminant fixed in plant tissues, or plant growth rates as proxies for FTW performance (Olguín et al. 2017; White and Cousins 2013). A few studies have preliminary descriptions of the microbial communities that colonize the roots of plants installed within FTWs (Chang et al. 2012; Zhang et al. 2014). Floating treatment wetlands are being used to mitigate nutrient and metal contaminants in urban stormwater and agricultural runoff, and their rate of adoption will likely continue to increase due to their versatility and function.

The factors most likely to influence FTW performance in agricultural applications include sizing, contaminant loading rate, the consistency or periodicity of hydraulic loading, plant selection, management strategy, wildlife pressure, climate, and geographic region. Adoption of FTWs by agricultural producers to mitigate contaminants is primarily determined by the cost of installation, as well as by the capacity of the technology to integrate within their production system (Lamm et al. 2017b).

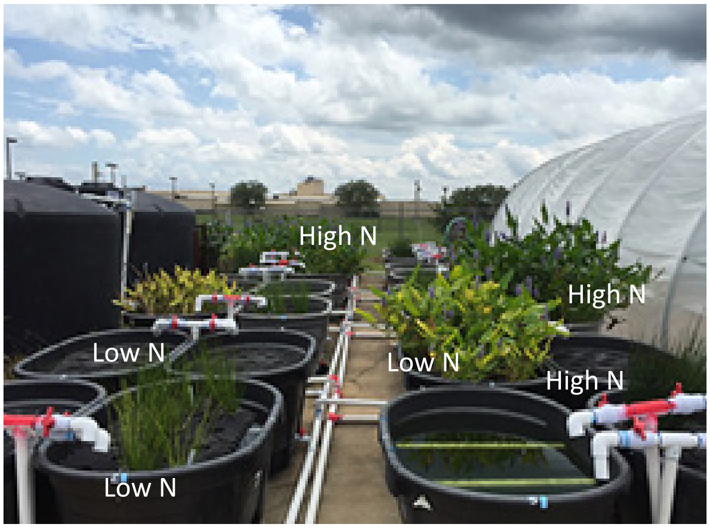
## WATER QUALITY, NUTRIENT LOAD, PLANT SELECTION, AND SIZING

Research on pilot-scale FTWs has been conducted at the Water Treatment Technology Laboratory at the Clemson Water Resources Center since 2008 (Figure 1). Over the last decade, FTW performance as influenced by plant species, nutrient loading rate, percent surface area covered, planting density, aeration, and hydraulic retention time have been evaluated.

Plant selection plays an important role in the performance of floating treatment wetlands (Pavlineri et al. 2017), just as it does within constructed wetlands (Brisson and Chazarenc 2009). Results of the plant screenings indicate that both traditional wetland species (*Agrostis alba*, *Andropogon glomeratus, Canna* ‘Firebird’, *Canna flaccida*, *Carex stricta, Iris ensata, Juncus effusus,* and *Panicum virgatum*; Garcia Chance and White 2017; Garcia et al. 2016; Glenn et al. 2011; White and Cousins 2013; White et al. 2011) and alternative species with enhanced economic value like specialty basil (*Ocimum basilicum*; Van Kampen et al. 2013) and swiss chard (*Beta vulgaris*; Tyrpak et al. 2013) absorb substantial nutrients from the water column, fixing them within their shoots and roots.

Aeration within the ponds on which FTWs are established is thought to enhance removal of nutrients by

FIGURE 1. Mesocosm units in the Water Treatment Technology Laboratory at the Clemson Water Resources Center were assigned treatments (no cover, unplanted FTW mats, or planted FTW mats) to quantify FTW remediation when planted with either *Pontederia cordata* or *Juncus effusus* and exposed to two nutrient loads. The chlorotic plants were in the “low - 3 mg.L-1N” treatments. The healthier plants were in the “high - 12 mg.L-1 N” treatments.



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increasing the volume of water that flows through the plant root system. In a 2018 study, Garcia Chance and White (2018) determined that aeration did not enhance or reduce nutrient remediation efficacy within the water column; rather, nutrient fixation within plant tissues were greater for *Juncus effusus* plants in aerated vs. non-aerated treatments, while *Canna flaccida* plants fixed similar masses of nitrogen and phosphorus in both aerated and non-aerated treatments.

The mass of nutrients in the water flowing into ponds or experimental units established with FTWs influences their remediation efficiency. In some instances, if the concentration of nitrogen and phosphorus within the water column is low, plant growth and survival within the FTW itself is compromised (*personal observation* and *personal communication with Steve Beeman, Beemats LLC*). Therefore, knowing the water quality of the system into which FTWs will be installed is pertinent, as plant selection should be based on whether the water quality of the pond is nutrient-poor or nutrient-rich (Polomski et al. 2008; White et al. 2011).

Planting density is also one factor to consider when establishing FTWs. Garcia Chance and White (2018) reported that planting density was important, and that FTWs established with only half the manufacturer recommended density of plants absorbed 35.9 to 56.6% less nutrients than FTWs established with the recommended density. We also determined that similar masses of nitrogen and phosphorus were remediated by both *Juncus effusus* and *Canna flaccida* when the FTW was established

FIGURE 2. Schematic of nursery where tracer study was conducted. In the nursery schematic (top) irrigation runoff flows from the production area through a vegetated channel and then into pond 1, pond 2 and pond 3, where the v-notch weir and level logger were installed to monitor flow rate. The pond 1 flow rate hydrograph (middle) shows flow rate changes (blue lines) after consecutive irrigation (solid gray vertical lines) and rain events (orange dots) as contrasted with rhodamine detection at the tracer outlet (bottom) after water flows through the FTW in Pond 1.

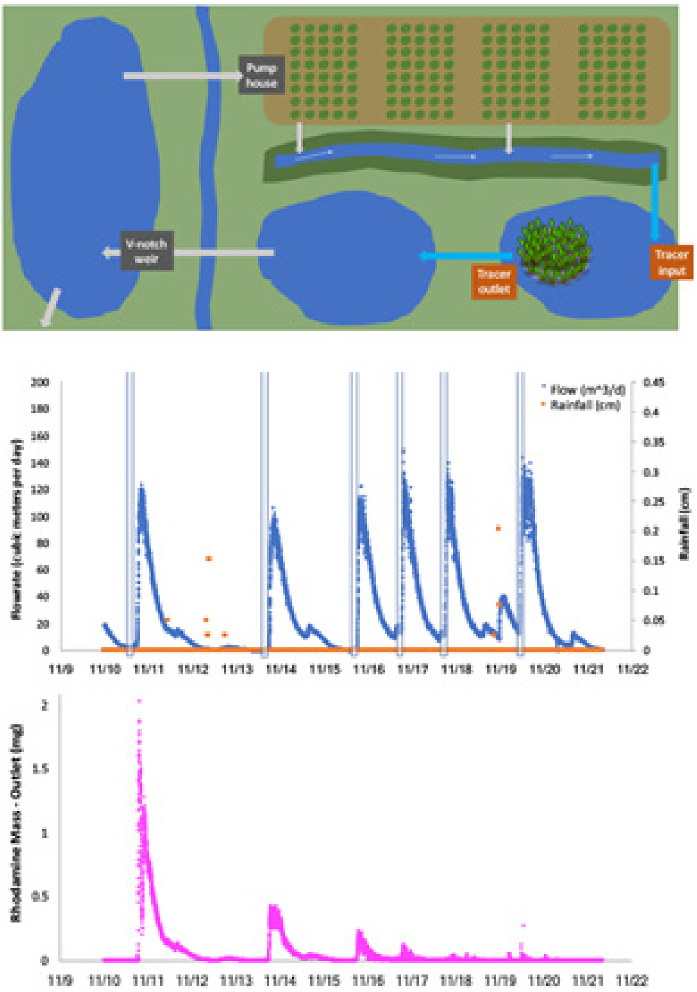
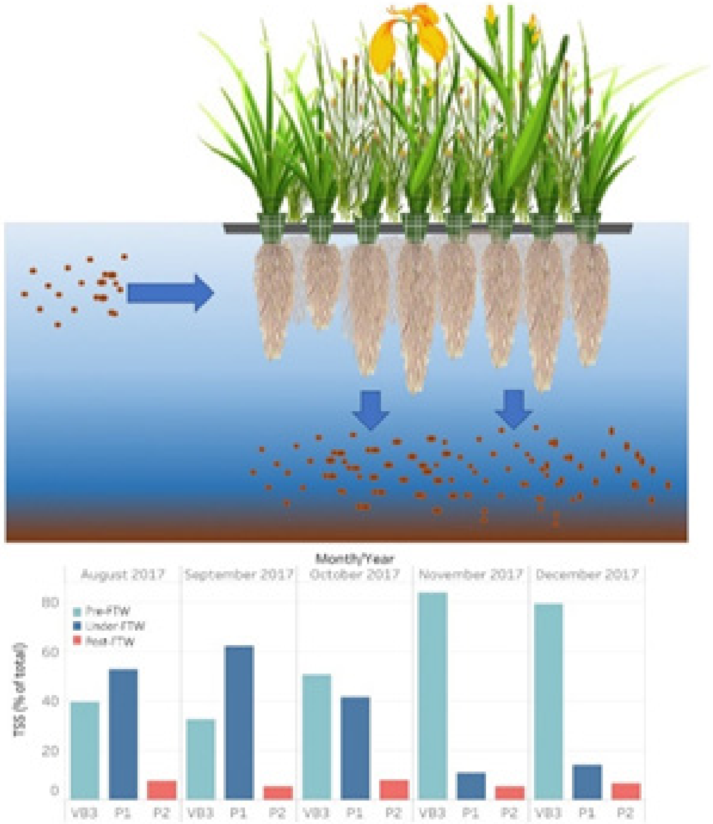


FIGURE 3. Theoretical sedimentation pattern in a pond after a floating treatment wetland (FTW) installation (top image). As water with suspended sediments flows through the roots of plants suspended in the FTW, entrapment and settling of sediment can occur, potentially making sediment settle from the water column below the FTW. We measured total suspended solids pre-FTW (VB-3 = vegetated channel), underneath the FTW (P1 = pond 1), and post-FTW (P2 = pond 2, bottom image) and detected the lowest % of total suspended solids measured in samples collected in pond 2, after the water was filtered by the FTW. In late October, the runoff channel upstream of all sampling points was dredged by the operation to increase flow capacity; thus, the sediment concentrations detected in November and December increased because less vegetation was present to limit erosion.



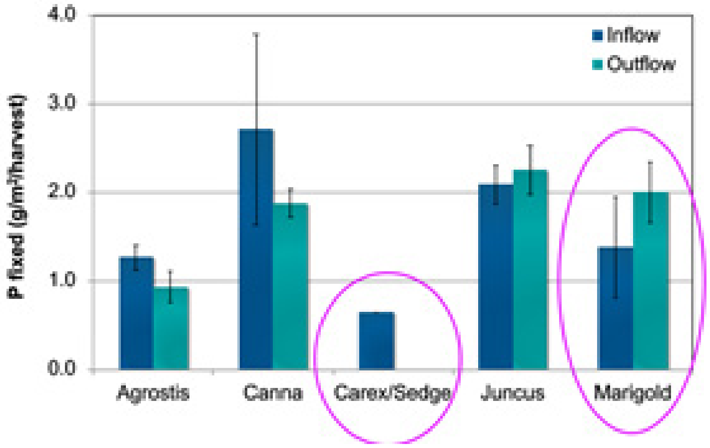
to cover 50 or 100% of the mesocosm surface (Garcia Chance and White 2018). Work by Chang et al. (2012) evaluated 5 and 10% surface-area covered by FTWs; they reported that the most economic sized-FTWs in their outdoor mesocosms were 5%. In 2017, we installed a FTW covering 10% of a 320 $m^2$ pond at a nursery in SC (Figure 2). Data analyses of pre- and post-installation water quality data are ongoing, but initial findings indicate installation of the FTW aided in up to 80% of phosphorus removal from the pond (phosphorus levels reduced to 0.02 $mg \cdot L^{-1}$ from 0.10 $mg \cdot L^{-1}$).

## POND HYDROLOGY & SEDIMENTATION

Ongoing field and laboratory studies are evaluating changes in pond hydrology as influenced by the presence of FTWs. Our first evaluation of FTW influences on pond hydrology were conducted in the pond where we installed a FTW that covered 10% of the pond surface area (Figure 2). We measured physical, chemical, and biological water quality parameters (pH, EC, dissolved oxygen, water temperature, total suspended solids (TSS), mineral nutrients, and the presence of plant pathogens) and hydraulic loading through the system for one year, prior to installing the FTW. We then installed rhodamine sensors on the water quality sondes deployed in the water conveyance structures at the nursery and initiated a tracer study. We also installed a v-notch weir and level logger to constantly monitor flow rate through the system. We wanted to determine (1) if flow through the pond could be characterized as closer to ideal plug flow or completely mixed flow, (2) the actual hydraulic residence time (HRT) of the system (vs. the calculated HRT based on flow rates and pond size alone), and (3) if dead zones were present or if short-circuiting occurred.

Preliminary results of the six tracer runs through the pond and water infrastructure (3 pre- and 3 post-FTW installation) indicate that the presence of FTWs increased mixing in the pond system, but that short-circuiting may also have increased as the HRT was shown to decrease after FTW installation (Figure 2). Recovery of the tracer (rhodamine) was lower (~25% recovery) when the FTWs were present, than when no FTW was present (~125% recovery). It may be possible that the increased mixing caused by the presence of the FTW promoted rhodamine entrapment in dead zones or possible sorption to organic matter, including the roots of the FTW plants. We are repeating this tracer study in Fall 2018 in a more controlled setting to determine if we can better quantify specific effects of FTWs on pond hydrology. Accurate characterization of pond hydrology will allow for more accurate modeling of contaminant removal in FTW systems.

FIGURE 4. Weedy species (circled) that colonized floating treatment wetlands (FTWs) installed at inflow and outflow points of a pond receiving stormwater influent from primarily residential land uses. Nutrient uptake within the weedy marigold was similar to uptake within plants selected for establishing the FTWs.



While evaluating how FTWs influenced pond hydrology, we also began to characterize their contribution to changes in measured TSS (Figure 3). Increasing concentrations of TSS typically correlate with the presence of increasing concentrations of phosphorus or pesticides, as sediment serves as a substrate to which both phosphorus and pesticides bind (Liu et al. 2008). Thus, if we can manage and reduce TSS, we can also reduce the presence of phosphorus and pesticides in the water. The root systems of plants in FTWs serve as living sieves or barriers in the water column that can slow the flow of water through a pond. Slowing water can increase the rate of sedimentation below the FTW, causing TSS to settle below the FTW. Preliminary data from our 2017 field-scale FTW trial at a nursery shows reductions in TSS after water comes into contact with the FTW. More work is needed to clarify where sedimentation occurs after water comes into contact with the FTW and the influence of HRT on sedimentation aided by FTWs.

## MAINTENANCE CONSIDERATIONS

### Weed management

Depending upon where the FTW is installed, weed control may be needed. In agricultural settings, if there are concerns related to weed seeds in irrigation water, control of weedy species colonizing the FTW may be necessary. However, there is also potential for plants that colonize the FTW to become contributors to the total nutrient remediation efficacy, as plants that colonize and survive within FTWs are likely well-adapted to the nutrient conditions within those systems. In a study conducted in 2011 with field-scale installation of FTWs covering 1% of a residen-

FIGURE 5. Evaluation of secondary uses for plants first grown in floating treatment wetlands (FTWs). Five plant species were trialed in mesocosm-scale FTWs and their nutrient remediation efficacy evaluated (top). At harvest, alternate uses for plants were evaluated and included container production for later sale (middle) or direct use as bare root transplants for riparian plantings (bottom).

tial stormwater pond surface area, we found that one of two weedy-species that colonized the FTWs fixed nutrients as well as or better than species initially planted in the island (Figure 4). Garcia Chance and White (2018) also reported that the mass of nitrogen and phosphorus fixed in weedy species that invaded experimental FTWs was lower than that absorbed by either the *Juncus effusus* or *Canna flaccida* used to establish the experiments. Nonetheless, weedy species (e.g., marigold in Figure 4) could be important contributors to total nutrients fixed in FTWs.

## Harvest

The necessity of harvest for optimal nutrient remediation by floating treatment wetlands is a hotly debated topic in the floating wetland / island realm. Some manufacturers state that harvest of plant tissues is not required, as normal plant senescence on floating islands will not increase nutrient loads within the water body where the island is installed. Other manufacturers state that harvest is critical to remove nutrients completely from the pond in which they are installed, to reduce nutrients available for the pond nutrient cycle. Researcher recommendations on this topic are split based on the installation location, FTW scaffold (manufacturer) and the relative feasibility of harvest, and the rationale for FTW installation. If enhancing aesthetics and provision of biological habitat and function are the desired endpoint, harvest may not be required. When remediation of contaminants is the desired endpoint, harvest for removal of nutrients may not be feasible, due to the type of scaffold used to support the plants (Headley and Tanner 2012). Over many years within naturally formed floating wetlands internal nutrient cycling occurs, some of the nutrients are released back into the water column and some are stored within aboveground plant biomass or deposited within or upon the floating mat upon plant senescence. Other researchers note that if nutrient removal from the water column is the desired endpoint (along with the other factors), harvest is needed (Wang et al. 2014), as these treatment technologies need to show remediation benefits after short durations. White and Cousins (2013) reported that nearly half the nitrogen and phosphorus fixed by plants (*Juncus effusus* and *Canna flaccida*) were stored in the roots of the plants, and that there is considerable potential for nutrients to be only temporarily removed from the water column if both the plant roots and shoots are not harvested. When remediation of nutrient contaminants from agricultural runoff is the application for the FTW, whole-plant harvest should be considered.

## ECONOMICS: COSTS AND BENEFITS

Agricultural producers make decisions related to changing production and management practices primarily on the economics of the decision (Lamm et al. 2017a). Documenting the contributions of FTWs to return on investment from both an economic and environmental standpoint would help in this decision-making process. One method proposed by (White 2013) is the use of FTWs as alternative production areas, where producers can clean their water and grow plants that are saleable.

In 2016, we began evaluating the potential of secondary uses for plants first used in FTWs to clean water (Figure 5). We evaluated whether harvested plant material could be planted either into containers or directly into the soil as a riparian planting. Plants transplanted into containers were grown for 6 weeks and their aesthetic appearance evaluated. Four of the five plant species we evaluated grew well in the containers after transplant and would be considered saleable by nursery producers. Bareroot plants transplanted directly into riparian zones, fared less well long-term, as the transplant intervals occurred during the summer when little supplemental rain occurred. So, while some of the plants survived, it is likely that the potential for bareroot transplants to succeed would be predicated on the season in which transplant occurred or the availability of supplemental irrigation at the site where the plants are transplanted. Container production of harvested materials is feasible, and we are finalizing the economic assessment of the 2016 field study. Data derived from the economic cost-benefit analysis will be used to inform growers about the potential for return on investment with FTWs.

## CONCLUSION

FTWs are a viable technology for agricultural producers to clean production runoff. Uncertainty yet remains regarding how FTWs should be sized to best meet the water quality goals of individuals or companies managing water quality in stormwater or production ponds. The economics of harvest are critical - if harvest is not required to manage water quality, then leaving plant materials on the FTW will contribute to long-term nutrient mineralization and fixation, though some nutrients will be contributed to the internal-nutrient cycle of the water body on which they are installed. Developing a secondary use of plants harvested from FTWs will not only allow removal of nutrients fixed by plants from the water, but also allow the grower to have a product that is marketable to another audience (another form of nutrient recycling). We still need information on when to harvest plants from FTWs if harvest is needed, and better methods of selecting plants for use in FTWs based on site-specific remediation goals. All of these gaps are being evaluated, but ensuring the scalability of the research is also critical, as mesocosm trials may over- or under-estimate FTW performance, and economic decisions need to be made on reliable data. ■

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