Floating Treatment Wetlands: an Innovative Option for Stormwater Quality Applications

T. R. Headley*, C.C. Tanner**

ABSTRACT
Floating Treatment Wetlands (FTWs) are an innovative variant of the more traditional constructed wetland and pond technologies that offer great potential for treatment of urban stormwaters. FTWs employ rooted, emergent macrophytes (similar to those used in surface and subsurface flow wetlands) growing on a mat floating on the surface of the water rather than rooted in the sediments. Thus, they can tolerate the wide water depth fluctuations typical in stormwater systems, without the risk of the plants becoming inundated and stressed. In many aspects, FTWs are a hybrid between a pond and a wetland; they behave hydraulically similar to a stormwater detention pond, whilst imparting similar treatment processes to that of a wetland. The plant roots hang beneath the floating mat and provide a large surface area for biofilm growth which forms an important part of the treatment reactor. This paper provides a review of the FTW concept, structure and function, and discusses some of the potential advantages of this emerging technology for stormwater applications.

Keywords Construction; floating treatment wetland; hydroperiod; urban drainage; structure; pond.

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INTRODUCTION
Ponds and wetlands have become widely accepted as urban stormwater treatment devices over the past two decades and are increasingly being integrated into water sensitive urban design practices. This growing popularity has been largely due to the fact that pond and wetland based systems offer the advantages of providing a relatively passive, low-maintenance and operationally simple treatment solution whilst potentially enhancing habitat and aesthetic values within the urban landscape. However, a number of limitations have emerged with the application of wetland and pond systems for stormwater treatment. For example, although ponds are generally effective at attenuating hydraulics and removing coarse suspended sediments, they are less effective at removing finer particulates and dissolved contaminants (ARC, 2004; USEPA, 2008; Revitt *et al.*, 2008; Scholes *et al.*, 2008). To enhance treatment capabilities, wetlands are often used in combination with ponds. Wetland systems with surface flow have been most commonly used for stormwater treatment. However, sediment-rooted wetland vegetation can tolerate only relatively shallow water depths (ca. 30 cm) and can be susceptible to chronic die-back if inundated too frequently or for excessive periods (Greenway *et al.*, 2007; Jenkins and Greenway, 2007; Somes and Wong, 1997).

Floating Treatment Wetlands (FTWs) are an emerging variant of constructed wetland technology which consist of emergent wetland plants growing hydroponically on structures floating on the surface of a pond-like basin. They represent a means of potentially improving the treatment performance of conventional pond systems by integrating the beneficial aspects of emergent macrophytes without being constrained by the requirement for shallow water depth. Despite the potential advantages of FTWs for the treatment of stormwater and other wastewaters, there has been very little information published to date about their design, construction and performance. It is therefore the aim of this paper to provide a review of the FTW concept and aspects of structure and design, in light of the potential application of the technology for treatment of urban stormwater.

CONCEPTUAL CLASSIFICATION OF FTWs: WETLAND OR POND?
Within the spectrum of natural treatment technologies, FTWs sit somewhere between conventional wetland systems and ponds, sharing aspects of both system types. Owing to their mimicry of natural processes, water quality improvement is achieved in a relatively passive and solar-powered manner with minimal technical maintenance required. A pond is essentially an open water body, one to two metres deep and dominated by phytoplanktonic communities rather than higher plants such as emergent macrophytes (Kadlec, 2005). By contrast, a treatment wetland is characterized by partial to complete coverage of macrophytic vegetation normally growing rooted in a water-logged substrate. Conventional treatment wetlands typically involve flow of contaminated

water amongst the shoots (surface-flow or free-water surface) or root-zone (subsurface-flow or submerged bed) of emergent species of sedges, rushes and reeds. A third approach has also been used for wastewater treatment, involving the use of free-floating aquatic plants which float either as a thin layer on the water surface (e.g., duckweed and azolla) or have specially-adapted buoyant leaf-bases (e.g., water hyacinth, water lettuce and salvinia). Floating treatment wetlands (FTWs) are in many ways a hybridisation of all of these systems, employing rooted emergent plants (similar to those used in surface and subsurface flow applications) growing on a mat floating on the surface of a pond-like water body rather than rooted in the sediments (Figure 1).

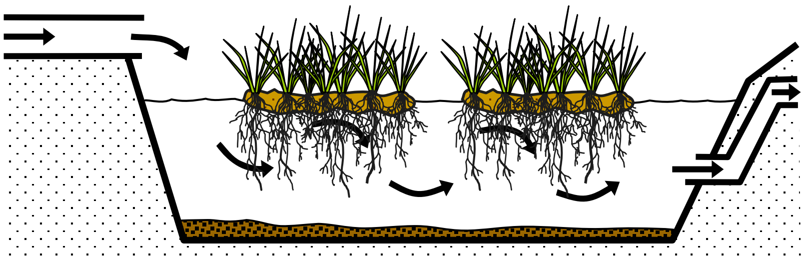

Figure 1. Schematic longitudinal cross-sections of: a typical floating treatment wetland. Note that the water depth can vary without compromising plant health.

In this paper we distinguish FTWs from free-floating macrophyte systems by the fact that FTWs utilize larger wetland plant species that are normally classified as emergent (e.g. rushes, reeds and sedges) growing on a somewhat consolidated floating mat, as opposed to an unconsolidated mass of small, individual buoyant plants lacking any significant mat.

APPLICATION OF FTWs TO DATE

Artificially created floating wetlands have been used with varying success for a number of applications to date, such as water quality improvement, habitat enhancement (e.g., Burgess and Hirons, 1992) and aesthetic purposes in ornamental ponds. In terms of water quality improvement, the main applications of FTWs reported to date have been for the treatment of:

- Stormwater (e.g., Headley and Tanner, 2007; Kerr-Upal *et al.,* 2000; Revitt *et al.,* 1997).
- Combined stormwater-sewer overflow (e.g., Van Acker *et al.,* 2005).
- Sewage (e.g., Ash and Truong, 2003; Ayaz and Saygin, 1996; Todd *et al.,* 2003).
- Acid mine drainage (e.g., Smith and Kalin, 2000).
- Piggery effluent (e.g., Hubbard *et al.,* 2004; Ash and Truong, 2003).
- Poultry processing wastewater (e.g., Todd *et al.,* 2003).
- Water supply reservoirs (e.g., Garbutt, 2004).

Naturally occurring floating wetland ecosystems also occur in many parts of the world, ranging from large floating marshes covering thousands of hectares in Louisiana, USA (e.g. Sasser *et al.,* 1991), to smaller floating mires in The Netherlands (e.g. van Diggelen *et al.,* 1996). Many insights into the likely long-term structure and dynamics of FTWs can be gained from these natural systems.

FTW STRUCTURE AND FUNCTION

A FTW consists of emergent wetland vegetation growing on a mat or structure floating on the surface of a pond-like water body. The plant stems remain above the water level, while their roots grow down through the buoyant structure and into the water column. In this way, the plants grow in a hydroponic manner, taking their nutrition directly from the water column in the absence of soil. Beneath the floating mat, a hanging network of roots, rhizomes and attached biofilms is formed. This hanging root-biofilm network provides a biologically active surface area for biochemical processes as well as physical processes such as filtering and entrapment. Thus, a general FTW design objective is to maximize the contact between the root-biofilm network and the polluted water passing through the system.

Surface Coverage and Shading

The coverage of pond surface provided by the floating mat minimises light penetration into the water column, thereby limiting the potential for algae growth. This will also have an impact on the composition of the biofilm community that develops within the network of roots under the floating mat. With the exception of the edges of the floating mats where there will be some light penetration, biofilms will be composed predominantly of non-photosynthetic bacterial communities. This will have an effect on the physico-chemical conditions that develop in the water column (e.g. dissolved oxygen and pH) and some of biogeochemical processes affecting treatment within the FTW (e.g. the role played by algae in nutrient and element cycling).

Water Depth

The water depth in a FTW system can vary, but it is recommended that a minimum water depth of 0.8 – 1.0 m should be maintained to prevent the macrophyte roots from attaching to the benthic substrate. If the roots attach to the basin bottom, there will be a risk that the floating mat will remain anchored and become submerged when water levels rise again. This could potentially lead to the death of the macrophytes and significant damage to the floating structure.

Buoyancy

In an artificially created FTW, the plants can float or be supported on the surface of the water by:

1. A buoyant raft or frame supporting a net or mesh holding soil or media (e.g. coco-peat) on which the plants grow, as in Figure 2;
2. An artificial mat or matrix with integral buoyancy into which the plants grow directly, as in Figure 3;
3. A rigid frame suspended close to the water surface and supporting the growth of plants (Figure 4). Such a system requires a consistent water depth to be maintained and is therefore not ideally suited for stormwater applications;
4. Cables suspended above the water surface which support plant containers from where the plants can spread laterally, as in Figure 5. Such a system generally has limited capability for adjusting to variable water depths and is therefore not particularly suitable for stormwater applications; or
5. Formation of a self-buoyant endogenous mat of intertwined roots, rhizomes, plant litter and organic matter, as in a natural floating wetland. Buoyancy is maintained naturally as a result of air contained in hollow or spongy roots and rhizomes, and entrapment within the mat of gas bubbles (such as methane) liberated from the sediments (Hogg and Wein, 1988). In such cases, self-buoyancy must be initiated by provision of small buoyant structures or suspended cables, from where the mat of plant roots and organic matter can develop and spread to cover the water surface.

Figure 2. Floating wetland created by joining buoyant sub-units to create a floating frame to support plant growth ("Eco-Islands" by A.G.A. Group).

Figure 3. Aerial view of a polyester floating mat (~2.3 m^2), produced by Floating Islands International (Montana, USA), with integral buoyancy provided by injected patches of marine polystyrene.

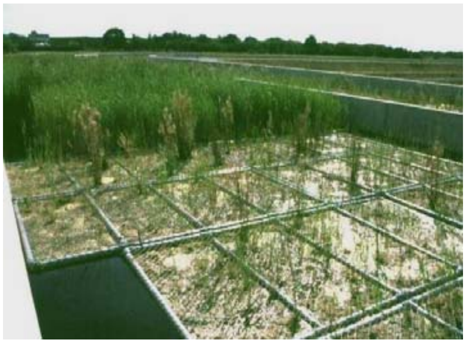

Figure 4. FTW constructed using rigid frames supported at the water surface, Heathrow Airport, UK.

Figure 5. Plants supported at the water surface by cables suspended across the pond (source: LIFE02 ENV/E/182, 2005).

ADVANTAGES OF FTWs FOR STORMWATER TREATMENT

Tolerance of variable water depths

One of the main advantages of FTWs over conventional sediment-rooted wetlands is their ability to cope with the variable water depths that are typical of event-driven stormwater systems (Kerr-Upal *et al.,* 2000). Because they float on the water surface, the plants in a FTW are not affected by fluctuations in water levels that may submerse and adversely stress bottom-rooted plants in stormwater systems. This also allows for the FTW to be designed to operate as an extended detention basin so that large runoff events can be captured and slowly released over several days, thereby increasing the proportion of storm flow that receives treatment.

Increased areal efficiency?

By deepening the wetland, the effective volume of the treatment system is increased (compared to conventional wetland systems), thereby lengthening the amount of time that water spends within the system (i.e. the hydraulic retention time) without necessarily increasing its footprint. For many pollutants, particularly those involving time dependent chemical or biological reactions, the retention time plays an important role in determining the level of treatment. Compared to ponds, FTWs have the advantage of the additional surface area provided by the floating mat and root network for the establishment of attached growth microbes (biofilms) that are responsible for many of the desirable treatment processes. The ability of floating treatment wetlands to operate at greater water depths than conventional wetlands may mean that they are capable of achieving a higher level of treatment per unit surface area (increased areal efficiency) for certain pollutants.

Long-term management of accumulated solids and sludge

In surface flow and subsurface flow wetlands the accumulation of solids and sludge occurs integrally within the plant-substrate matrix where it can not easily be removed, and therefore imposes a design and dimensioning limitation. By comparison, the ultimate long-term sink for solids in a FTW is in the sediments on the bottom of the underlying basin, segregated from the floating mat and associated plants. Thus, there is greater potential for this accumulated sediment to be excavated from the system without substantially disturbing or damaging the system (assuming the entire water surface is not covered with floating mat).

Plant uptake

It is conceivable that plant assimilation of nutrients and other elements, such as metals, may be higher in a floating wetland system compared to a sediment-rooted wetland, as the roots hanging beneath the floating mat are in direct contact with the stormwater to be treated. Furthermore, the plant roots are not in contact with the bottom sediments or soil and only have access to nutrients contained within the floating mat and in the water column, much like a hydroponic cultivation system.

Flexible modular construction

Depending on the materials and structure used, floating wetlands are particularly suitable for modular applications, where the number (and % coverage) of floating wetlands can be easily increased in order to improve treatment performance if necessary (providing sufficient basin area is available). It should also be possible to have an influence over the ambient physico-chemical conditions that develop in the water column by varying the percentage of water surface that is covered and the configuration of this cover (i.e. continuous cover versus a patchwork of open water and cover). For example, open water zones provide greater opportunity for air diffusion and phytoplanktonic photosynthesis, both of which effect the DO concentration and pH of the water column and may be used to promote or inhibit certain treatment processes. Conversely, excessive coverage of FTW can lead to de-oxygenation of the water column which may have negative impacts on downstream biota or possibly lead to release of phosphorus from anaerobic sediments.

Aesthetic enhancement of ponds

Floating wetlands may be perceived to enhance the aesthetic values of a stormwater treatment pond, depending on the shape, structure and vegetation used. There may also be some additional benefits in terms of provision of habitat for wildlife, such as birds. A floating wetland can provide protection for birds against some predators. However, the attraction of wildlife may also have deleterious effects on water quality through the introduction of faecal material, nutrients and disturbance. Excessive bird numbers can also lead to vegetation decline due to overgrazing and trampling and make it difficult to initially establish plants on the floating structure.

CONCEPTUAL STORMWATER SYSTEM DESIGN

A conceptual design of a stormwater treatment train incorporating a FTW with more conventional sedimentation basin and surface flow wetland components is presented in Figure 6. The FTW component should be designed to operate as an extended detention basin in order to maximize the proportion of storm flow that is retained and exposed to treatment.

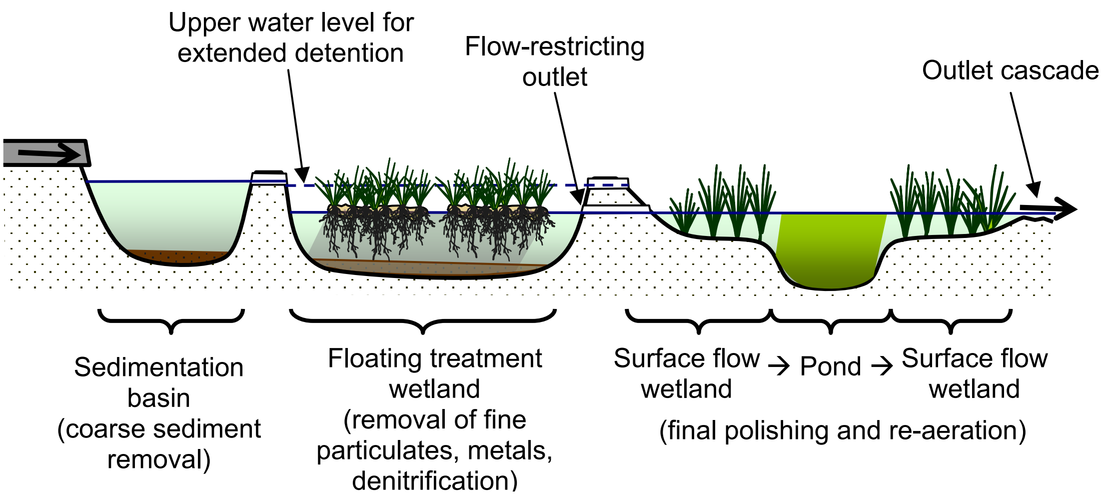

Figure 6. Conceptual longitudinal cross-section through a “newly designed” stormwater treatment system incorporating floating wetlands, ponds and surface flow wetlands (not to scale).

CONCLUSIONS

Floating Treatment Wetlands are a relatively novel and innovative variant of treatment wetland and pond technology that offer great potential for treatment of stormwater and other contaminated waters. They have the key advantage, in terms of stormwater management, of being able to accommodate variable water depths. Further work is required to assess the long-term performance and process dynamics of full-scale systems under field conditions and to develop robust sizing and system design approaches to optimise the desired treatment processes and reliably achieve water quality objectives. In this regard, it will be particularly important to gain a more thorough understanding of the degree of passive aeration that can be achieved by manipulating the ratio of open water to floating mat coverage. It is envisaged that FTWs will become a useful component of stormwater treatment trains integrated with other pond and wetland technologies and will also provide an important option for upgrading existing pond-based treatment systems.

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