Chapter 10
Guide to Floating Treatment Wetlands—A Vietnamese Perspective

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Abstract Constructed floating wetlands (CFWs) have emerged as a promising ecological engineering tool for the restoration of water bodies and have been extensively studied in controlled environments such as mesocosms and laboratories. There is a lack of in situ applications to improve ecosystem health. To address this gap, the project CRRP2021-06MY-Jegatheesan, funded by the Asia-Pacific Network for Global Change Research (APN-GCR), was undertaken. As part of this project, six CFWs were installed in 2022 at Bung Xang Canal in Can Tho City, Vietnam, by the College of Environment and Natural Resources (CENREs) at Can Tho University (CTU). The guide synthesises the knowledge gathered and provides an overview of the operating principles of CFWs. Detailed information on installation, including the official procedure, plant selection, and location, is also included in the guide. Moreover, the guide addresses the challenges that may arise during maintenance and offers recommendations and solutions to ensure the smooth operation of CFWs. The guide is expected to serve as a valuable resource for practitioners and researchers involved in the design, installation, and operation of CFWs for specific water

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resource management purposes and aims to promote the wider implementation of CFWs and contribute to sustainable management and restoration of water bodies.

Keywords Constructed floating wetlands · Eco-friendly technology · Nature-based solutions (NbS) · Sustainable city · Urban landscape · Water management

10.1 Introduction

Constructed Floating Wetlands (CFWs), also termed "planted floating system beds" or "floating treatment wetlands (FTWs)", are a new ecological technology applied for water treatment. In this guidebook, we adopt the term "Constructed Floating Wetlands" (CFWs) since it is the most widely used in the literature. CFWs are man-made structures that provide a medium for aquatic plants to grow above the surface of the water, to grow and develop in waters that are often deep compared to the plants' root systems. The plant roots spread through the floating system and extend down, creating a dense root system with a very large surface area, which creates favourable conditions for microorganisms to adhere and develop (Fig. 10.1).

Constructed floating wetlands (CFWs) are technologies that stand out for their efficiency, ease of installation, and maintenance. The system comprises aquatic macrophytes emerging in a floating structure that keeps the plant roots in direct contact with the effluent regardless of water flow variations over time, allowing the removal of pollutants by various processes (Fig. 10.1). Artificially created floating wetlands have been used with varying success for several applications to date, such as water quality improvement, habitat enhancement, and aesthetic purposes in ornamental ponds (Headley and Tanner 2008).

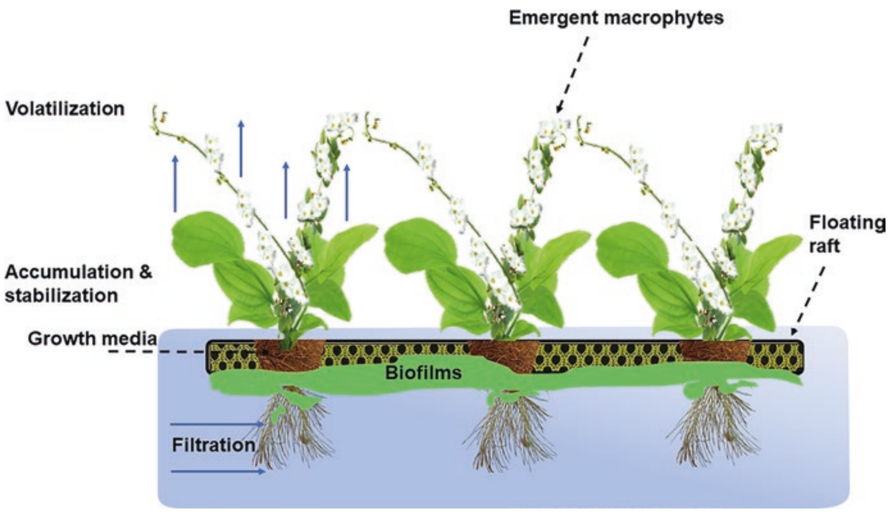


Fig. 10.1 Constructed floating wetlands structure and water purification processes

10.1.1 Applications of CFWs

The application of CFWs to treat wastewater has the advantage of low costs to remove nutrients as well as reducing the cost of maintenance and energy consumption when compared to the conventional centralised treatment of wastewater (Oliveira et al. 2021). Currently, CFWs have been successfully applied to improve water quality (rainwater runoff, domestic wastewater, agricultural wastewater), to improve and provide habitat for wildlife, and to create landscapes in ponds and lakes.

The application of CFWs for domestic wastewater treatment has been widely applied worldwide and is increasingly known in Vietnam. Due to low investment costs, the ease of installation, and low operating and maintenance costs, CFWs offer a sustainable treatment model. Currently, in developing countries, 80% of domestic wastewater from residential areas is discharged directly, without treatment, into receiving water bodies such as urban rivers, lakes, and canals, causing surface water quality to become seriously polluted (World Water Assessment Programme 2009). Therefore, the application of environmentally friendly and low-cost wastewater treatment solutions, for example CFWs, is very necessary for developing countries. A good example of a successfully applied model of CFWs that reduce most organic and inorganic pollutants with a very low treatment cost of US$0.0026/m^3 of domestic and industrial wastewater in Pakistan is provided by Afzal et al. (2019).

A CFWs with five species of ornamental plants was installed for water treatment and landscaping at Bung Xang canal, Can Tho city of Vietnam (Fig. 10.2), which this guidebook outlines with a cost of only 320,000 VND/m^2 for material used (equivalent to US$13.95/m^2, 1 USD = 22,946 VND (currency exchange rate in April 2022).

Fig. 10.2 The application model of CFWs at Bung Xang Canal, Can Tho City of Vietnam

10.1.2 Pros and Cons CFWs Applications

The CFWs for wastewater treatment is an artificial ecosystem that simulates a natural floating habitat system. In the early twentieth century, this system was used to mimic the natural habitat of birds and fish breeding grounds. In the 1980s, German scientists designed the modern eco-floating raft and used it for the first time to filter polluted water (Nakamura and Shimatani 1997).

The CFWs are an eco-friendly and sustainable wastewater treatment technique. Basically, this technology is a hydroponic method using artificial aquarium rafts, in which plants grow and use nutrients and organic matter present in wastewater to produce biomass, thereby helping the water environment to become less polluted in an environmentally friendly way (Sun et al. 2009). Some pros and cons of using CFWs for wastewater treatment are presented in Table 10.1.

Table 10.1 Pros and cons of using CFWs for wastewater treatment

Pros	Cons
1. Offers design flexibility: the floating rafts can be sized to fit into any existing space of water body shape such as pond, lake, or domestic sewage drain. Easy to design and to operate. 2. Provide a sustainable pollutant removal system and provide a natural habitat for animals (aquatic animals, insects, birds etc.). 3. The construction of a submerged floating raft on the surface of the pond creates a barrier against the penetration of light into the water surface, thereby limiting the possibility of algae growth. 4. Improved aesthetics: the CFWs can be used to create urban landscapes. 5. Tidal adaptation: the floating rafts can withstand tidal fluctuations as long as they are anchored at the bottom or fastened to the shore. 6. High treatment efficiency: the natural air movement allows the rafts to move over the water surface and this movement adds oxygen to the water to enhance the treatment efficiency. 7. Sustainability: the seedlings of the plants on the floating rafts grow over time, this process is repeated, making the floating raft systems function effectively continuously without interruption over time, especially in the tropics.	1. Occupies a large area of water (because of the biological filtration process, it requires a large planting area). 2. Some contaminants, such as oils and herbicides in municipal wastewater, can affect vegetation and harm microorganisms. 3. In order to achieve maximum treatment efficiency, plants grown on floating rafts need to be harvested periodically to avoid ageing and death of plants, causing re-pollution. 4. Water level is reduced in the low tide, or high evapotranspiration, or drought causing running out of water in the water body, making the rafts unable to float on the water. 5. Pollution because of salinity (i.e. saline intrusion in the water body), eutrophication causes plant death.

10.1.3 Operating Principles

The principles of operation of the CFWs are very simple: the plants on the floating rafts use the nutrients present in the wastewater to produce biomass. Plants provide oxygen through the root system into the wastewater environment, creating favourable conditions for aerobic microorganisms to develop, which contributes to better treatment efficiency. The pollutant removal processes that occur in CFW systems are biosynthesis, deposition, settling, and biofilm metabolism. Sedimentation occurs by the root system, and uptake by plants is the main process for removing phosphorus from wastewater (Pavlineri et al. 2017).

Plants directly uptake pollutants, especially nutrients, from the water using a process known as bio-sorption or bio-uptake. Microorganisms grow on floating rafts and attach to the root systems of the plants. They decompose and consume organic matter in the water. Root systems filter out sediments and pollutants.

Similar to other constructed wetlands with flora, the root systems of the plants below the floating rafts provide a large surface area for the adhesion and growth of biofilms (Fig. 10.1). This creates favourable conditions for the metabolism of organic substances. Microorganisms, phytoplankton, and higher plants (macrophytes) absorb and transport pollutants into the food chain. The suspended organic matter adhered to the biofilm at the root surface is decomposed, becoming food for plankton, larvae, and fish. Finely dispersed suspended solids are settled or precipitated. Aquatic plants also can store carbon dioxide (through photosynthesis), allowing them to remove and convert nitrate and ammonia into nitrogen. These processes prevent or slow down eutrophication and keep the water in balance (Fig. 10.3).

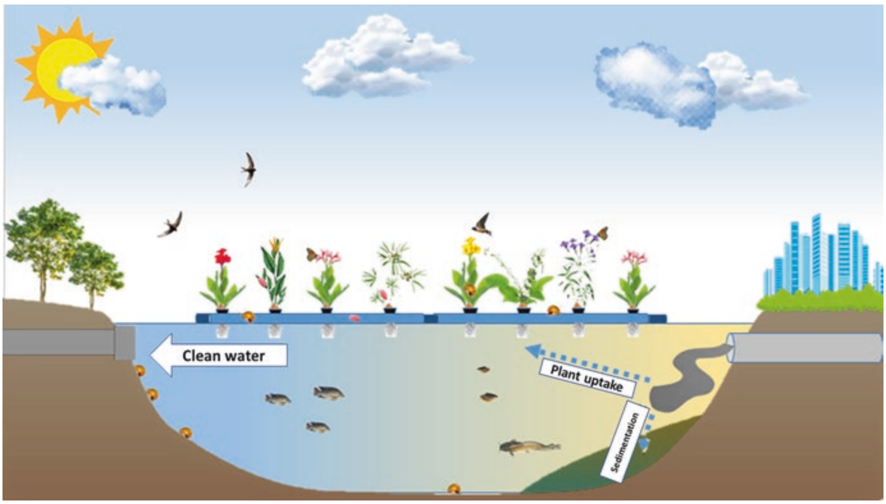


Fig. 10.3 Operating principles of CFWs

10.2 Installation Instructions

10.2.1 Installation Location Survey

10.2.1.1 Surveying the Installation Location of the CFWs

Depending on the purpose of designing the rafts, surveying the location of the raft is conducted accordingly. CFWs for wastewater treatment in urban areas can be applied at the existing ponds, lakes, rivers, and canals in the inner city, for example. Surveying and selecting the placement of the floating rafts is a very important step in the installation process because the appropriate placement of the rafts helps the rafts work more efficiently.

10.2.1.2 Obtaining Permission for Installation of the CFWs

Depending on the location where the floating rafts are to be installed, there will be a specific organisation or agency responsible for the management of the inner-city ponds, lakes, rivers/canals. In urban areas, it is possible that an urban environment company, a Water Supply and Drainage Company, or a Department of Natural Resources and Environment, for example will manage the drainage channels. When agreeing on the location of the rafts, the designer should contact the local authorities for permission of installation of the rafts to be formalised (Fig. 10.4).

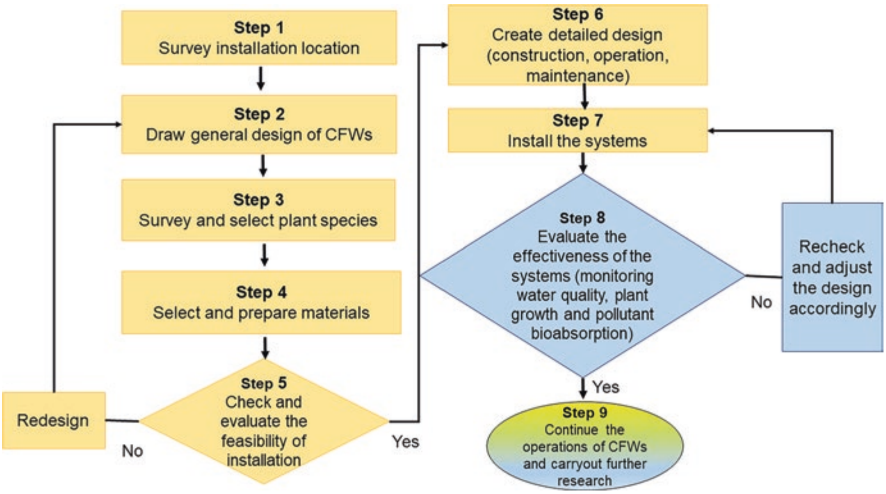


Fig. 10.4 Installation and evaluation steps for the CFWs

10.2.2 Plant Species Selection and Installation Locations

10.2.2.1 Plant Species Selection

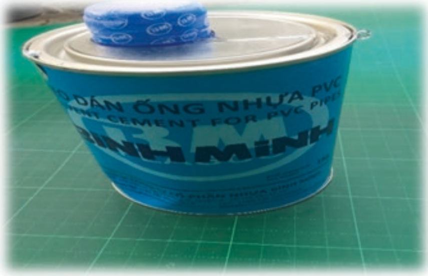
Aquatic macrophytes with emergent growth forms are suitable for selection and growing on the floating rafts. However, it is up to the designer to use the rafts for what purposes they suggest, including the selection of the appropriate species. For example, to create a landscape for the treatment area, choose plants with beautiful flowers or colourful leaves such as *Cyperus alternifolius*, *Canna* sp., *Ruellia tuberosa*, *Heliconia psittacorum*, and *Echinodorus cordifolius* (Table 10.2); if

Table 10.2 Tools and materials used in the design of each floating raft

No.	Tools and materials	Illustrating images
1	The length of a PVC (*polyvinyl chloride)* pipe was l = 2 m, the diameter of the pipe was = 90 mm • Quantity: 07 pipes of 2 m • Function: making frame of floating raft	
2	Plastic trellis mesh size 2 m × 4.5 m, mesh size 1–2 cm • Quantity: 01 grid • Function: fixed stand for planting	
3	Hydroponic baskets: • Quantity: 72 baskets (36 baskets of D57: 65 × 65 × 40 mm; and 36 baskets of 70 × 60 × 40 mm) • Function: support plants standing	

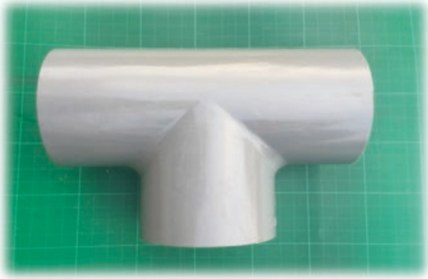
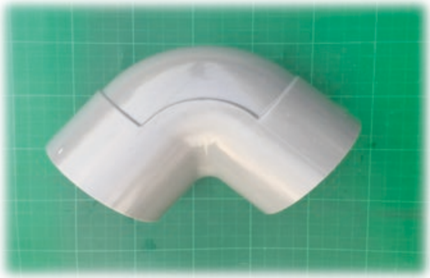
(continued)

Table 10.2 (continued)

No.	Tools and materials	Illustrating images
4	PVC pipe glue • Quantity: 1 jar (0,5 kg) • Function: Fixing PVC pipes and cores	
5	Plastic drawstring 4 T (40 cm) • Quantity: 2 bags • Function: fixing net to the raft frame	
6	Nylon string • Nylon string 3 mm: – Quantity: 2 kg – Function: used to tie the trellis to the PVC pipes • Nylon string 0.5 mm: – Quantity: 0.5 kg – Function: used to tie hydroponic baskets to the net	
7	Pincers, saw, measure • Quantity: one for each • Function: PVC pipe sawing, mesh cutting, nylon string cutting	

(continued)

Table 10.2 (continued)

No.	Tools and materials	Illustrating images
8	Φ90 mm T-shaped PVC core used to connect pipes • Quantity: 2 pieces • Function: connect pipes to form a raft frame	
9	Φ90 mm T-shaped PVC core used to connect pipes • Quantity: 4 pieces • Function: connect pipes to form the raft frame	
10	Coconut coir • Function: used as substrates to fix the plants to the baskets and to support the plants to stand	
11	Aquatic macrophytes • The species (*Cyperus alternifolius*, *Canna* sp., *Ruellia tuberosa*, *Heliconia psittacorum*, *Echinodorus cordifolius*) selected for the design in this guide. • In addition, depending on the purpose of the CFWs application, the designer can choose the appropriate plant species (outlined in Sect. 10.2.2.1)	

choosing plants to collect biomass for reuse as fodder or for composting, choose herbaceous plants such as Vetiver (*Vetiveria zizanioides* or *Chrysopogon zizanioides*), Cattail (*Typha* sp.), Reed (*Phragmites* sp.); or can choose plants that can be harvested and sold, for example *Cyperus alternifolius* (Dell'Osbel et al. 2020). Some designers even choose to plant fruit and vegetable crops such as pumpkin, eggplant, and tomato (Bi et al. 2019).

In addition to the landscape value, it is necessary to pay attention to select plants that have the ability to grow well in wastewater conditions and exhibit a high pollutant treatment efficiency. It should be noted that in order to limit the investment costs to purchase plants and to increase the adaptability of the plants on the CFWs systems, the designer needs to select native species that are available in the area where the CFWs are arranged (Bi et al. 2019). The species (*Cyperus alternifolius*, *Canna* sp., *Ruellia tuberosa*, *Heliconia psittacorum*, *Echinodorus cordifolius*) were selected for the design in this manual based on their common applicability, which were then selected and planted on the floating wetlands in application models. They have been previously applied to treat many types of wastewater and evaluated to be effective in generating high biomass, contributing to the effective treatment of pollution in wastewater (Barco and Borin 2020, Dell'Osbel et al. 2020).

10.2.2.2 Location Selection and CFWs Layout

It is very easy to choose the location to place the CFWs, it can be ponds, lakes, rivers, or canals in the inner city. However, surveying and choosing the location to install the CFWs is a very important step. During the installation process, a suitable installation position will help the CFWs work more efficiently. Selecting the appropriate location to install the CFWs should meet the following criteria:

- The installation location is large enough (note not to obstruct the traffic of boats if the canal serves waterways).
- Near the inlet point of wastewater flowing into the water body (to promote the pollution treatment effectiveness of the plants on the rafts).
- Avoid locations with tree stakes under the water (so that the raft is not entangled at low tide).
- Select locations with full sunlight to ensure photosynthesis of the plants on the rafts.
- If the water body is a river, choose places with weak currents to avoid affecting the rafts.
- It is necessary to pay attention to the concentration of pollutants in the wastewater before placing the rafts (because if the concentration is high, it will affect the vegetation on the raft, thereby affecting the pollution treatment process).
- It is necessary to avoid sources of discharge with herbicide content, which would affect the vegetation on the rafts.

Some locations and placement layouts of rafts in inner-city lakes, ponds, and canals are shown in Fig. 10.5.

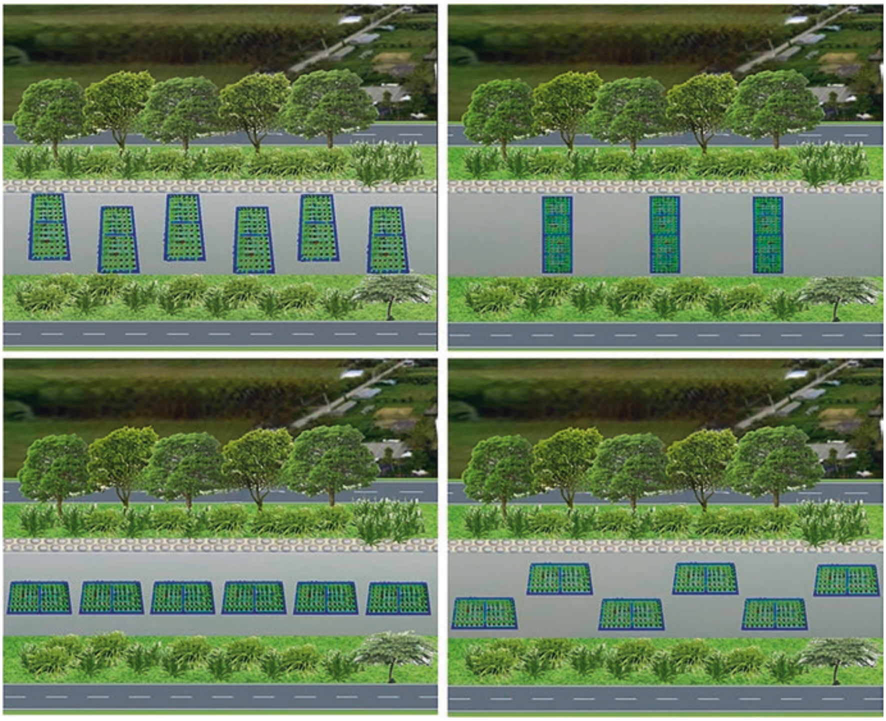


Fig. 10.5 The ways of placing the floating rafts in an urban canal

The depth of the water body selected for installation varies depending on the selected water bodies for treatment and the applied aquatic plant species. The minimum recommended 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 raft 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 (Headley and Tanner 2008). For nutrient-rich water bodies, at a depth of 0.2 m, roots can also be active. However, in nutrient-deficient wastewater such as rainwater, the recommended depth is 0.8–3.0 m because plant roots are capable of growing longer in the absence of nutrients and can grow into lower-bottom sediments.

10.2.3 Design Guidelines

10.2.3.1 Size and Shape of the Floating Rafts

The size and shape and the number of floating rafts do not follow any rigid specifications, depending on the purpose, the location of the installation in the water body, the budget, the available design materials etc. designer may have a suitable CFWs design. Depending on the size of the water body (i.e. water surface area), it is possible to design the appropriate size of the floating rafts, however, it is advisable to arrange the floating rafts with a moderate size for later easy installation and maintenance of the rafts. The recommended raft size in this guide is a length twice the width (Schwammberger et al. 2019), with a length of 4 m and a width of 2 m.

Between 2 PVC pipes of 2 m, there should be a T-shaped PVC core (Fig. 10.6). This divides and supports the PVC pipes when plants' biomass becomes high and heavy.

Materials used to make frames of the floating rafts: There are many types of materials that can be used for the frame of a floating raft for growing aquatic plants as long as it can make the rafts float on the water surface and withstand the weight of the plant throughout their life cycle. The commonly used materials for making floating rafts are: bamboo, foam sheets, plastic bottles/jars, PVC pipes, and coconut coir mats (Sharma et al. 2021) (Table 10.2; Fig. 10.7). However, since the raft is in direct contact with water, it is necessary to choose materials that will not break down when saturated with water. In addition, in tropical climates like in Vietnam, it is important to choose materials with a long life under direct sunlight. There are many commercial products (e.g. carpets) available and floatable; however, PVC pipes or natural floating materials (e.g. bamboo) are reliable and inexpensive alternatives (Pavlineri et al. 2017). The shape of the frame is designed according to the user, it can be rectangular, square, oval, circle, diamond, hexagon, and many other shapes to make it more beautiful.

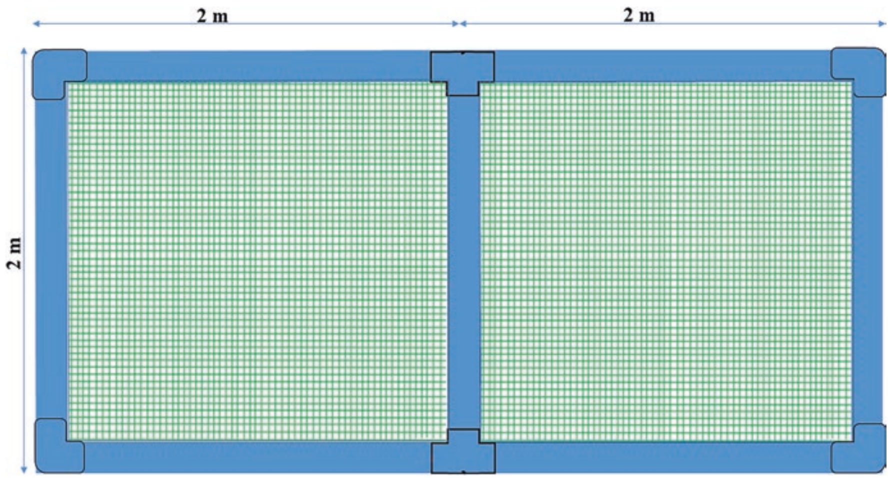


Fig. 10.6 Size of the CFWs with a rectangle shape

Fig. 10.7 Materials that can be used to make the frame of floating rafts

The recommended number of rafts, or total raft area per water surface area, is 5% for optimal nutrient treatment efficiency (Chang et al. 2012). Whereas the density of plants should allow for a total raft coverage of at least 50% (Sharma et al. 2021). In this guideline, the coverage area of the rafts per water surface area was 4.4%, and total plant coverage on each raft was 30% at the initial planting stage, whilst, within 1 month after planting the plant coverage rate increased to 80–90%.

10.2.3.2 Prepare Materials and Tools for Raft Design

The materials used to make the floating raft are presented in Table 10.2. The quantities of materials shown in Table 10.2 were used to design a raft with the dimensions of 4 × 2 m (length × width, respectively) with a total area of 8 m^2.

10.2.3.3 Material Costs for Making a Floating Raft

Materials and cost of materials used to design the floating raft with an area of 4 × 2 m = 8 m^2 are listed in Table 10.3. The total cost of materials used to design the raft was 320,000 VND/m^2 (equivalent to US$13.95/$m^2$, 1 USD = 22,946 VND (currency exchange rate in April 2022).

Table 10.3 Material costs used to design the floating raft (4 × 2 m = 8 m²)

No.	Items/product's name	Unit	Unit price	Quantity	Costs (VND)
1	Ø90 PVC pipes	m	60,000	14	840,000
2	T-shaped core	Piece	47,000	2	94,000
3	I-shaped core	Piece	30,000	4	120,000
4	Plastic drawstring 40 cm	Bag	45,000	2	90,000
5	Plastic trellis net (2 m width)	m	155,000	4	620,000
6	Nylon string (3 mm)	kg	130,000	2	260,000
7	Nylon string (0.5 mm)	kg	110,000	0.5	55,000
8	Glue	0.5 kg	150,000	1	150,000
9	Saw	Piece	40,000	1	40,000
10	Hydroponic basket D57 (6.5 × 6.5 × 4 cm)	Piece	3,000	36	108,000
11	Hydroponic basket (7.0 × 6.0 × 4 cm)	Piece	3,500	36	126,000
12	Pincers	Pair	55,000	1	55,000
Sum					**2,558,000**

Note: 1 USD = 22,946 VND (currency exchange rate in April 2022)

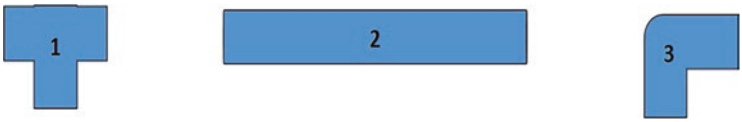


Fig. 10.8 Numbered PVC pipes and joints

10.2.3.4 Steps to Design the Rafts

10.2.3.4.1 Numbered PVC Pipes and Cores

Before installing the raft frame, use a marker to mark the joints (cores) and PVC pipes. In the design of this raft, two types of joints are used: T- and I-shaped joints (Table 10.2; Fig. 10.8). The T-shaped joints are numbered 1, the I-shaped joints are numbered 3, and the pipes are numbered 2 (Fig. 10.8). Each PVC pipe with number 2 has a length of 2 m.

10.2.3.4.2 Placing the Pipes on the Ground and Checking the Size

Choose a dry and flat area, before installation, it is necessary to remove sharp and hard objects on the ground, such as stones, gravels, and woods, to minimise the possible risks of damage to the pipes. Then proceed with the following steps in sequence:

– Place the PVC pipes on the flat ground.
– Double check the length of the pipes.
– Cut the ends of the pipes flat.

– If it is sunny, the pipes should be exposed to the sun to make it easier to glue the pipes because when the pipes absorb heat, the pipes become softer (note: it is necessary to wear gloves when the pipes are hot, to avoid burning your hands).

10.2.3.4.3 Glue the Joints and Pipes to Form the Frame

***Step 1*:** Fix the two T-shaped joints marked as number 1 to the centre pipe of the raft (pipes marked with number 2) to obtain product 1 (Fig. 10.9). Since the centre pipe is the pipe that affects the flatness of the raft, this step is very important. After gluing, you must place it on a flat surface to check if the two joints are even, if not, correct them immediately because the glue is not tight at this time, if it is, then proceed to the next steps.

***Step 2*:** Glue the two I-shaped joints marked with number 3 and the pipes marked with number 2, resulting in product 2 (Fig. 10.9). One raft needs these 2 products.

***Step 3*:** Next, stick the 2 pipes number 2 on the remaining 2 ends of the I-shaped joints cores of product 2, we get product 3 (Fig. 10.9).

***Step 4*:** Connect 2 products 3 to product 1, to get product 4, which is a complete 8 m^2 raft frame (Fig. 10.9).

After gluing the final positions, place the raft on a flat surface for final alignment before the glue dries. After checking, wait for about 2 hours for the glue to dry, at this time it is necessary to bring the raft to a shady place to quickly dry the glue and pay attention that the raft is placed on a flat surface.

10.2.3.4.4 Fix the Net to the Raft Frame

After the glue dries, fix the net to the raft frame with a drawstring or plastic tie. The length of the net needs to be about 20 cm longer than the edge of the raft frame so that when fixing the net, it is wrapped around a plastic pipe to increase the surface tension of the net, from which the plants when planted on the net will be stronger.

The net selected to be fixed to the raft is a plastic trellis net (Table 10.2; Fig. 10.10) made from PE (polyethylene) or HDPE (high-density polyethylene), the mesh is diamond shaped, with a mesh size of 1–2 cm. These two types of plastic have properties that make the mesh both flexible and resistant. The hardness is at the right level, and durable over time.

10.2.3.4.5 Fix the Baskets and Place the Plants into the Baskets

Plants are grown in specialised hydroponic baskets, so select the baskets made from PVC materials, synthetic plastics with high heat resistance, and without the need to worry about damage resulting from weather or water. The baskets are fixed to the raft with 0.5 mm small nylon string (Table 10.2), using the nylon string to tie the bottom of the basket in a cross-shaped and leaving the four extra string wires about

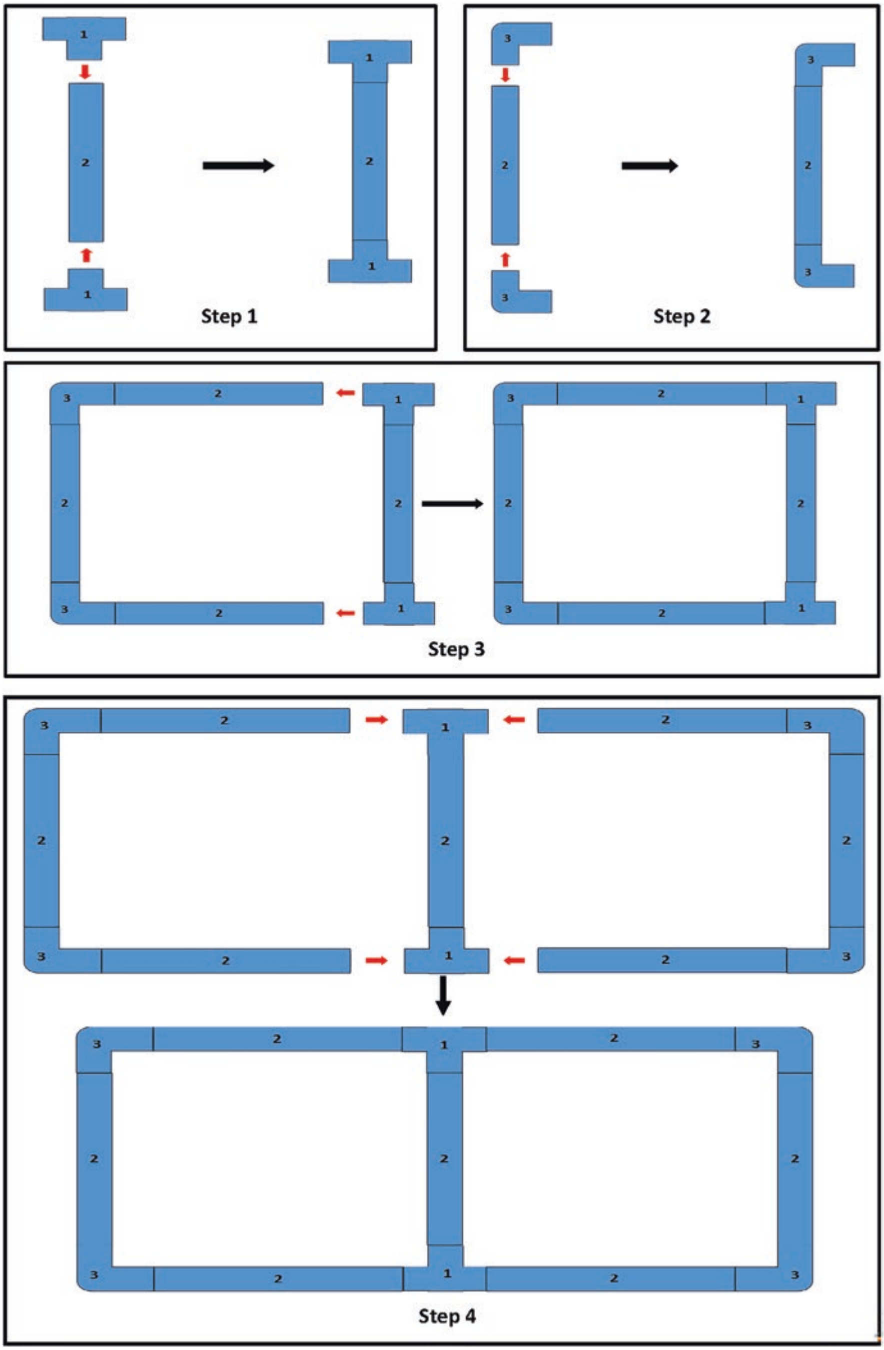


Fig. 10.9 Steps to build the floating raft

Fig. 10.10 The process of fixing the net to the raft frame

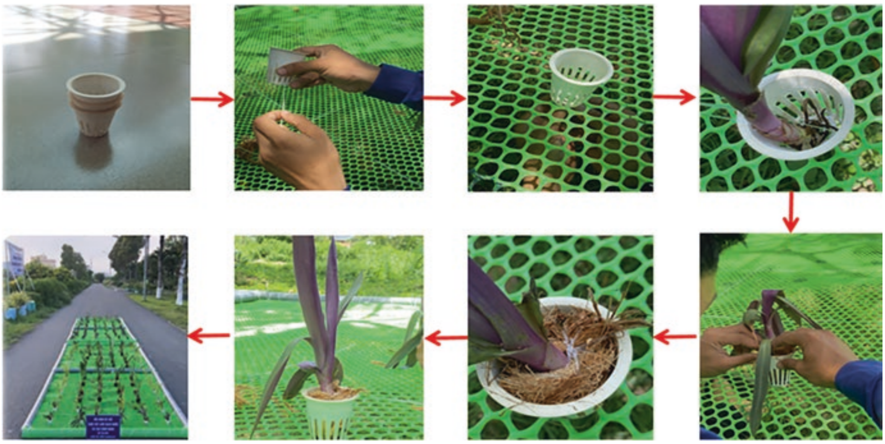


Fig. 10.11 The process of fixing the baskets and the plants within the baskets

20 cm, then, using these 4 ropes to fix plant into the basket. The distance between the baskets is 30 cm or the plants are 30 cm apart (Fig. 10.11). This results in a plant density of about 9 plants/m^2 (Huth et al. 2021; Schwammberger et al. 2019).

Plant species used to grow on the CFWs, should be selected from the species that are available and easy to collect from the surrounding fields. In addition, plants with fast growth rates and high biomass should be selected for high water treatment efficiency (mentioned in Sect. 10.2.2.1).

After tying the baskets to the plastic net, check the plastic baskets again and make sure that the plastic baskets are firmly tied to the net because when they are tied insecurely, the plants will fall and may die.

Next, take the coconut coir and wrap it around the roots of the seedling. The use of the coconut coir has the effect of keeping the seedlings firmly fixed within the basket. In addition, it also has the effect of keeping the plant roots moist. The coconut coir should not be tied too tightly that the roots cannot develop fully.

The last step is to use the remainder of the nylon string to fix the plants to the plastic baskets, be careful not to tie the plants too tightly to affect their growth. The raft is complete, as shown in Fig. 10.11.

10.2.4 Launching and Fixing the Rafts

After completing the fixation of the plastic baskets to the net and the raft is fully designed (Fig. 10.11), the raft is launched into the water body (Fig. 10.12), where the wastewater needs to be treated (noted that the rafts should be placed near the point at the inlet wastewater of the water body to increase pollutant uptake). Select a location in the water body where there is an open space, avoiding shaded trees and underwater stakes to launch the raft. It is advisable to wait for the highest tide of the day to facilitate the release of the raft, easy to manipulate and avoid affecting the seedlings (Fig. 10.12). If the place where the raft is launched has floating garbage on the water body, it is necessary to remove the garbage before launching to avoid the garbage getting caught in the raft, causing difficulties in future maintenance.

The way of placing and fixing the floating rafts on the water body to be treated also determines their efficiency. It is recommended that the rafts are placed so that the water flow is perpendicular to the rafts and there is no gap for the water to flow parallel to the raft (Lucke et al. 2019). In addition, as mentioned above, depending on the function and role of the water body, if the movement of waterways is not restricted, the rafts should be placed perpendicular to the width of the canal (Fig. 10.5), which increases the exposure of the water direction, lengthening the path and the passage of the water will increase the water treatment efficiency of the rafts.

The next step is to tie the drawstring to both ends of the raft and fix the raft on the shore with melaleuca poles to prevent the raft from drifting away with the tide. It is also possible to tie the end of the string to fix the raft on trees planted along the shore. For water bodies affected by tides, it should be noted that when fixing the

Fig. 10.12 Launching and fixing the rafts

Fig. 10.13 Maintaining the plants on the rafts

raft, it is necessary to leave a length of string with a length according to the water level of low tide and low water level, to avoid the case of low water level causing the raft hanging and the plants lacking water. In addition, for the inspection, maintenance of the raft, and plant biomass collection or cleaning on the raft, if you want to do it on the shore, just wait for the high tide and pull the raft ashore easily (Fig. 10.13). In the case that the pond or canal is quite large; it is possible to invest in a small boat or raft to harvest plant biomass.

10.3 Operation and Maintenance Manual

10.3.1 Operation

For the CFWs, the operation is very simple, just launch the raft into the water bodies to be treated. The raft works by itself according to the water filtration mechanism as described in Sect. 10.1. Seedlings use nutrients in the wastewater to grow and develop until the plants flower or show signs of ageing (depending on the species, the harvest time will be different). However, in order to increase the efficiency of nutrient uptake of the plants, after about 2 months, pull the raft to prune/trim and reduce the plant biomass (only collect old branches and flowering stems). Leave about 2–3 seedlings/cluster (Fig. 10.14) for the plants to regenerate without needing to replace plants (due to the nature of aquatic plants they have a very good self-regeneration ability), only replace new plants in the case of plant death or poor growth performance.

10.3.2 *Maintenance and Management*

10.3.2.1 Plant Well-Being and Pruning

In order for aquatic plants on the raft to grow well and create a beautiful landscape, the plants need to be cared for regularly and periodically pruned. Every month, cut weeds on the baskets for the optimal growth of plants. Additionally, replace dead plants with new ones. To prune/trim plants and clear grass on the raft, the raft can be pulled close to shore for trimming (Fig. 10.13). When pulling the raft ashore, be very careful not to damage the root system.

Depending upon each species, the plant growth time will be different, so it is advisable to select a combination of planting species on the same raft with the same growth period. The plants need to be pruned of old branches, flowering plants/stems in order to create space and stimulate the growth of young shoots. For *Cyperus alternifolius*, *Canna* sp., *Heliconia psittacorum* etc., it is advisable to prune the plant biomass once every 2 months (Fig. 10.14).

10.3.2.2 Using Plant Biomass

Some of the ultimate uses of plant biomass are as follows:

- The harvested plants' biomass can be used for biogas composting or composting.
- Ornamental flowers such as *Canna* sp., and *Heliconia psittacorum*, can be cut and sold.
- Branches of *Echinodorus cordifolius* can be separated into seedlings to sell as ornamental plants, with the remaining biomass composted for biogas.
- *Cyperus alternifolius* can be cut and dried for use as a lanyard or fresh branches can be sold at the florist.

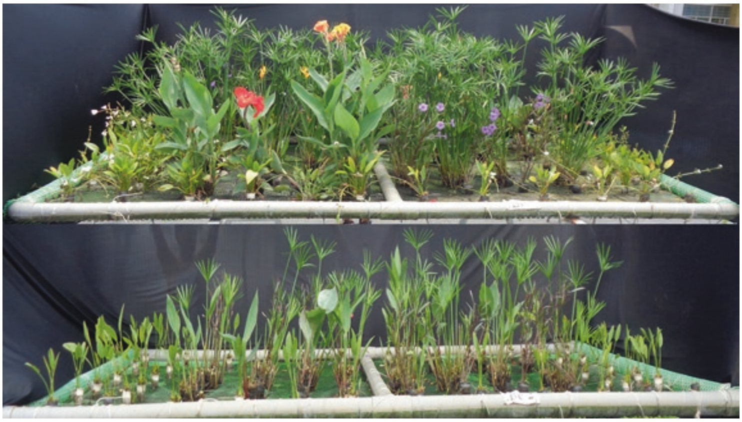


Fig. 10.14 Prune the plants on the raft once every 2 months

10.3.2.3 Common Problems

Some of the common problems or challenges in the management of CFWs are as follows:

- For water bodies with a lot of garbage, it is common for garbage to drift and entangle with the rafts, so it is necessary to monitor the raft regularly and clean up the trash on the rafts, otherwise, they will affect the plants and cause damage to the raft. More seriously, the plants may die, and the rafts may tilt or sink.
- The raft is placed in the water body, so depending on the tidal regime, it is necessary to check the fixed line regularly because the raft can become stuck on the shore at low tide, and the plants will die when there is no connection to water (Table 10.4; Fig. 10.15).

Table 10.4 Some frequent incidents, causes, and solutions

Problems	Causes	Solutions
Water leaking into the connecting pipes (raft tilting or sinking)	Insufficient gluing, or the operation of pulling the raft to the bank to collect the plant/grass because the plant's weight is too heavy, causing the joints to crack	Pull up the rafts, remove the pipes and joints and re-install/re-fix it, or add a float to raise the raft
The raft is hung on the shore when the water dries up	The string is too short in relation to the water level at low tide	Monitor the raft regularly and check the string

Fig. 10.15 Some common problems

10.4 Conclusions

The guidelines presented in this chapter for the installation, operation, and maintenance of constructed floating wetlands are intended to encourage investment in these urban ecological solutions. These guidelines offer a cost-effective approach to replicating constructed wetlands in various urban settings whilst minimising land requirements. Constructed floating wetlands can deliver significant ecosystem services, including provisioning, regulation, support, and cultural benefits. Their primary contribution lies in improving surface water bodies and subsequently enhancing biodiversity. However, challenges related to maintenance, plant harvesting strategies, and community involvement exist. Future endeavours could focus on improving data collection, enhancing design guidelines for nutrient and contaminant uptake rates, refining maintenance strategies, promoting plant diversity and adaptation to climate change, and understanding community perceptions and appreciation to ensure the sustainable replication of constructed floating wetlands.

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