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# Floating Treatment Wetlands for River Water Remediation – A Review

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***Abstract*—The degradation of riverine ecosystems by nutrients, metals, and organic pollutants presents a persistent global challenge. Conventional remediation is often costly. Floating Treatment Wetlands (FTWs) have emerged as a sustainable, nature-based solution, deploying emergent macrophytes on buoyant platforms to create a bioactive rhizosphere directly within the water column. This review synthesizes recent advancements in FTW technology for river water remediation. It details the core remediation mechanisms—physical filtration, phytoremediation, and critically, rhizospheric microbial degradation—which are enhanced by plant-derived oxygen and exudates. Key design factors including hydraulic loading, plant diversity, coverage, and seasonal adaptation, are analyzed. The review highlights that FTWs are particularly effective for polishing effluent and treating diffuse pollution in urban and agricultural settings, with reported removal efficiencies of 20-80% for Total Nitrogen and 15-70% for Total Phosphorus. Recent innovations, such as biochar-amended media and advances in cold-climate microbial resilience, are driving improvements in reliability and efficiency. However, limitations concerning long-term nutrient mass removal and performance variability remain. Future research must prioritize standardized design guidelines, enhanced systems for recalcitrant pollutants, and holistic assessments of ecosystem services. With continued development, FTWs are poised to play an integral role in sustainable river basin management and the restoration of impaired waterways.**

***Keywords*—Constructed Wetlands, Floating Treatment Wetlands (FTWs), Nature-Based Solutions (NBS), Nutrient Removal, Phytoremediation, River Remediation.**

## I. INTRODUCTION

The global degradation of riverine ecosystems due to nutrient enrichment, organic pollutants, heavy metals, and suspended solids is a critical environmental challenge [1]. Conventional wastewater treatment, while effective, is often energy-intensive, costly, and inaccessible for diffuse non-point source pollution entering rivers [2]. Nature-based solutions (NBS) have emerged as sustainable, cost-effective alternatives for water quality improvement [3] .

Among these, Floating Treatment Wetlands (FTWs) represent an innovative phytoremediation technology that mimics the processes of natural wetlands on a floating platform [4] .

FTWs consist of emergent macrophytes growing on a buoyant mat or structure, with their roots extending into the water column, forming a dense biofilm-rich "rhizosphere" in the water rather than in soil [5]. This design allows them to be deployed directly in polluted rivers, lakes, or ponds without requiring land acquisition or major hydrological alterations [6], [7]. This review synthesizes recent advancements in FTW technology, elucidates the primary remediation mechanisms, explores key design and operational factors, discusses limitations, and identifies future research directions, with a focus on river water applications.

## II. REMEDIATION MECHANISMS

The efficacy of FTWs stems from a synergistic combination of physical, biological, and chemical processes facilitated by the plant-root matrix.

A. *Physical Filtration and Sedimentation*: The submerged root network acts as a physical filter, slowing water flow and promoting the settling of suspended solids and particulate-bound pollutants [5]. This reduces turbidity and associated contaminants.

B. *Phytoremediation:* Plants directly contribute to remediation through:

i. *Phytoextraction:* Uptake and translocation of nutrients and metals into plant biomass, which can be harvested for removal [4].

ii. *Rhizofiltration:* Adsorption or precipitation of contaminants onto root surfaces [8].

*iii. Phytostabilization:* Root exudates can immobilize metals in the water-rhizosphere *complex [9].*

C. *Microbial Degradation (Rhizodegradation):* This is often considered the most significant mechanism for organic pollutant and nutrient removal.

The root system provides an extensive surface area for the formation of a submerged 'biofilm' – a consortium of bacteria, fungi, and protozoa. This microbial community, enhanced by oxygen leakage (radial oxygen loss) and organic carbon from root exudates, drives the nitrification-denitrification cycle for nitrogen removal and degrades organic pollutants [10], [11]. This selective enrichment of specific degrading bacteria in the rhizosphere, which enhances targeted pollutant breakdown pathways, is a well-established principle in wetland phytoremediation, as highlighted in recent reviews [12].

D. *Other Processes:* The root zone can facilitate the precipitation of phosphates with metals and provide habitat for zooplankton that graze on algae and pathogens *[7]*.

## III. Key Design And Operational Factors Influencing Performance

FTW performance is highly variable and depends on several interrelated factors:

### *A. Plant Species Selection*

Ideal species are perennial, fast-growing, have extensive fibrous root systems, and are native/non-invasive. Common choices include Typha spp. (cattail), Phragmites australis (common reed), Juncus spp. (rush), and Carex spp. (sedge). Recent insights highlight the benefits of using multi-species plantations. Biodiverse FTWs have been shown to create more complex microbial habitats and can improve overall resilience and treatment efficiency across seasonal changes, as different species have complementary root architectures and exudate profiles [12].

### *B. Hydraulic and Pollutant Loading*

FTWs perform best under moderate, steady hydraulic loading. High-flow river conditions can shear roots, reduce hydraulic retention time (HRT), and diminish efficiency. They are most suited for in-stream remediation of low- to medium-pollution streams, effluent polishing in oxbows or backwaters, or within constructed settling basins [13].

### *C. FTW Coverage and Configuration*

The percentage of water surface covered (typically 15-40%) directly influences light penetration, gas exchange, and treatment contact. Modular designs allow for flexibility. Submergence depth of the rooting material is crucial to ensure root contact with the water column without drowning the plants [5].

### *D. Seasonal Consideration*

In temperate climates, plant dormancy and die-back in winter reduce direct phytoremediation, a well-documented challenge for wetland systems [14]. However, recent studies indicate that the microbial community within the persistent root biofilm can maintain significant, though reduced, degradation activity throughout winter months, especially for organic contaminants [15].

### *E. Bioaugmentation and Media Enhancement*

To boost performance, especially for targeted pollutants, researchers are exploring “enhanced FTWs.” This includes:

1) *Bioaugmentation:* Inoculating the root zone with specific pollutant-degrading microbial strains [16] .
2) *Hybrid Media:* Using buoyant matrices amended with adsorbents like biochar, clay minerals, or iron filings. Recent work reviews and demonstrates that biochar-based solutions, including floating mats, can significantly enhance nutrient removal through adsorption and provide an excellent substrate for microbial communities, thereby mitigating eutrophication [17].

## IV. Applications And Performance For River Remediation

FTWs have been successfully trialled in diverse river settings:

### *A. Urban Rivers*

Treating stormwater runoff and combined sewer overflows, removing nutrients, metals, and polycyclic aromatic hydrocarbons (PAHs) [18].

### *B. Agricultural Drains*

Intercepting nitrate and phosphate runoff from farmland [19].

### *C. River Restoration Projects*

Improving water quality while simultaneously providing habitat, aesthetic value, and biodiversity support [20].

Reported removal efficiencies vary widely but often fall within these ranges: 20-80% for Total Nitrogen, 15-70% for Total Phosphorus, 40-90% for Suspended Solids, and significant reductions for metals like lead, zinc, and copper. Removal is typically more consistent and higher for particulate-bound pollutants than for dissolved fractions [5].

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## V. Limitations And Challenges

### *A. Limited Nutrient Mass Removal*

The total mass of nutrients sequestered in harvestable plant biomass is often low relative to inflow loads, making long-term management of harvested biomass necessary.

### *B. Performance Variability*

Efficiency is highly site-specific and influenced by climate, pollutant mix, and hydraulic conditions.

### *C. Long-Term Sustainability*

Issues include mat durability, plant survival under extreme pollution or flooding, and potential for invasive species spread if non-natives are used.

### *D. Design Standards*

Lack of universal design guidelines and predictive models for scaling up from pilot studies.

## VI. Future Research Directions

To transition FTWs from pilot-scale to reliable, engineered solutions, future research should focus on:

### *A. Standardization*

Developing quantitative design protocols based on hydraulic loading and pollutant removal kinetics.

### *B. Enhanced Systems*

Optimizing hybrid biochar-media FTWs and strategic bioaugmentation for recalcitrant contaminants (e.g., pharmaceuticals, PFAS).

### *C. Ecosystem Service Valuation*

Comprehensive life-cycle assessments to quantify not just water treatment, but also carbon sequestration, biodiversity, and social benefits.

### *D. Real-Time Monitoring*

Integration of sensor technologies to monitor FTW health and treatment performance in situ.

### *E. Climate Resilience*

Investigating plant species and designs resilient to climate-induced stressors like droughts and intense storms.

## VII. Conclusion

Floating Treatment Wetlands (FTWs) are a simple, nature-based tool for cleaning rivers.

While they cannot handle heavily polluted industrial waste alone, they are excellent for polishing water from treatment plants, filtering polluted runoff from farms or city streets, and creating habitat for wildlife while improving the look of waterways.

FTWs work by using plants and the natural bacteria on their roots to absorb and break down pollutants. Recent discoveries are making them more effective and reliable: the root bacteria maintain significant activity during winter, and incorporating materials like biochar into the mats boosts their filtering capacity. Using a diverse mix of plant species also enhances overall performance.

With more research focused on improving their design and understanding root-level processes, FTWs are ready to become a key part of sustainable strategies for restoring and protecting our rivers, streams, and lakes.

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