



HAL
open science

Turbidity reduction induced by Floating Treatment Wetlands (FTW): Aflume experiment to assess the impact of flow velocity

Karine E. Borne, Yves Andres, Félicie Theron

► To cite this version:

Karine E. Borne, Yves Andres, Félicie Theron. Turbidity reduction induced by Floating Treatment Wetlands (FTW): Aflume experiment to assess the impact of flow velocity. *Ecological Engineering*, 2021, 168, pp.106275. 10.1016/j.ecoleng.2021.106275 . hal-03254706

HAL Id: hal-03254706

<https://hal.science/hal-03254706>

Submitted on 24 May 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 **Turbidity reduction induced by Floating Treatment** 2 **Wetlands (FTW): a flume experiment to assess the** 3 **impact of flow velocity**

4 Karine E. Borne*¹, Félicie Theron¹, Yves Andrès¹

5
6 ¹IMT Atlantique, CNRS, GEPEA, UMR 6144, 4 rue Alfred Kastler, F-44307
7 Nantes, France.

8 * karine.borne@gmail.com [tel:+33 \(0\)2 51 85 82 53](tel:+33(0)251858253)

9 10 **ABSTRACT**

11 The aim of the present study was to investigate the impact of the mean flow velocity on the Floating
12 Treatment Wetland (FTW) roots' network behaviour and associated opportunity for suspended solids
13 entrapment. The objective was to identify the appropriateness of a FTW to reduce turbidity in a retention
14 pond subject to specific flow regimes. A flume experiment with and without FTW was run under three
15 mean flow velocities impacting roots' inclinations and roots' water column occupancy. For initial turbidity
16 of 60-70 FNU, the results indicate that inclusion of a FTW would increase turbidity reduction by up to
17 37%, 34% and 45% under flow velocity of 0.023 m/s (V1), 0.097 m/s (V2) and 0.181 m/s (V3),
18 respectively, compared to the Control (experiments without FTW). This suggests that even under high
19 flow velocity, inducing the roots to flatten under the mat, the FTW provided an efficient additional
20 particles removal process to settlement, i.e. entrapment of suspended solids into FTW roots' network.
21 For V1, turbidity thresholds for good and very good water quality status (EU guidelines) were reached
22 about 1:00 and 5:30 (h:mm) faster with the inclusion of a FTW. Providing that flow ratio through the FTW
23 roots' network could be promoted in a real retention pond, such as in the present flume experiment,
24 potential turbidity removal efficiency solely induced by a FTW covering 16% of a pond length and 70%
25 of pond width could be extrapolated for various pond sizes. As an example, the inclusion of a 8m long
26 FTW in a 50m long pond with inlet turbidity of 60-70 FNU, could improve turbidity removal efficiency by
27 ~32% at low flow velocity (V1) and by ~10% at medium and high flow velocities (V2 and V3).

28 29 **KEYWORDS**

30 Floating treatment wetland, flow velocity, hydraulic impact, turbidity, particle size distribution, Zeta
31 potential
32
33
34

35 **1 INTRODUCTION**

36 A significant fraction of pollutants commonly found in stormwater runoff tend to be associated to small
37 size particles (Kayhanian et al., 2012; Nielsen et al., 2015) which do not easily settle. There is thus an
38 interest in improving the treatment of fine particles that sedimentation ponds lack to remove. Floating
39 Treatment Wetlands (FTW) are hydroponic systems composed of a floating mat planted with emergent
40 aquatic plants that extend their roots into the water column. FTWs can be installed on any pond type
41 (e.g. stormwater ponds, wastewater lagoons) with the aim to introduce wetland like vegetation and allow
42 for additional pollutant removal processes to take place such as direct plant uptake, adsorption,
43 precipitation, nitrification, denitrification and particles' entrapment into the roots' network. Several
44 research studies have shown that FTWs can efficiently remove suspended solids, metals and nutrients
45 from contaminated waters (Abed et al., 2017; Barco and Borin, 2020; Benvenuti et al., 2018; Borne,
46 2014; Borne et al., 2013; De Stefani et al., 2011; Headley and Tanner, 2006; Van De Moortel et al.,
47 2010).

48 However the removal efficiency is significantly influenced by the pollutant types and inlet loads, the
49 design characteristics such as pond depth (Pavlineri et al., 2017), and the hydraulic conditions (Khan
50 et al., 2013). It is also thought that the fraction of flow which goes through the roots influences the
51 treatment performance (Borne et al., 2015; Headley and Tanner, 2012; Machado Xavier et al., 2018).
52 This is particularly true for the removal of fine suspended solids which do not settle easily and are
53 removed by entrapment into the FTW's roots network. The properties of the physical filter provided by
54 the roots' network is however impacted by the flow velocity which can flatten the roots under the floating
55 mat. This can generate preferential flow path below the roots, reducing opportunity for the incoming flow
56 and sediments to go through and be entrapped by the roots' network.

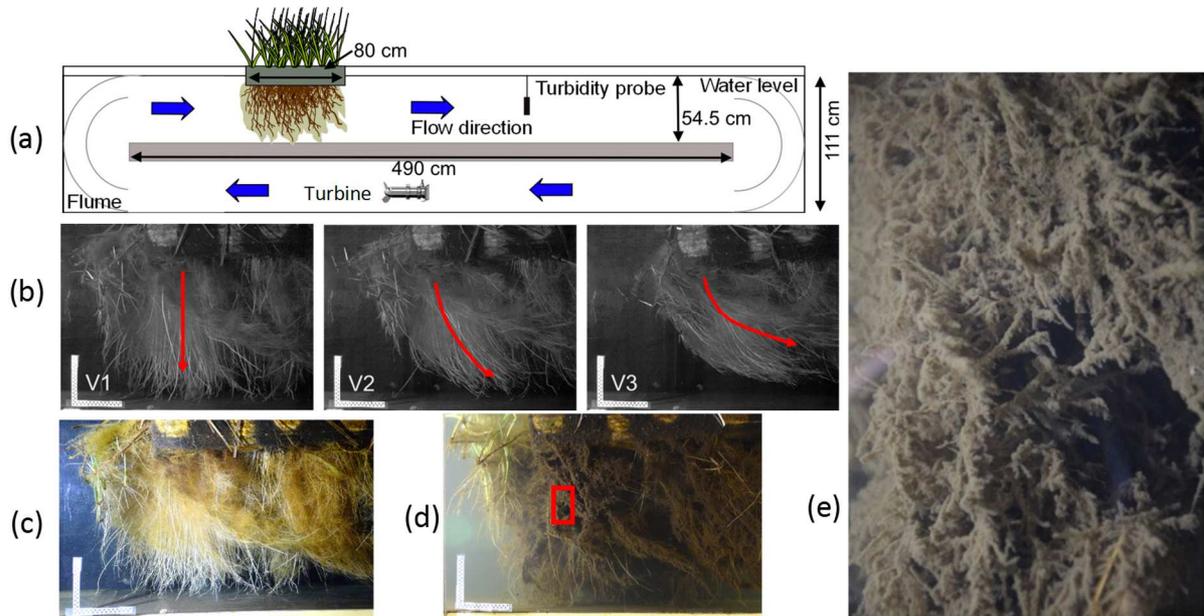
57 It is thus of interest to investigate the impact of flow velocity on the roots' network behaviour and
58 associated opportunity for suspended solids entrapment. This would help identifying the
59 appropriateness of a FTW to remove suspended solids in a retention pond subject to specific flow
60 velocities. The aim of the present study was to investigate in a flume experiment the impact of mean
61 flow velocity on turbidity reduction by a FTW.

62 **2 MATERIAL AND METHODS**

63 **2.1 Flume experiment**

64 Currently, no specific design criteria in terms of FTW surface coverage ratio are available. Real scale

65 applications have been implemented with various coverage ratios ranging from 8 to 50% of pond surface
66 area (Borne et al., 2013; Maxwell et al., 2020; Schwammberger et al., 2019; Tharp et al., 2019; Winston
67 et al., 2013). In the aim to minimize FTWs implementation and maintenance cost, the present study's
68 objective was to focus on a relatively low coverage ratio. A flume was thus equipped with a BioHaven
69 floating mat covering about 70% of flume width (0.67m) and 16% of the flume length (4.9m) accounting
70 for 11% of the flume open water surface area (Fig. 1a). The floating mat (0.47m*0.8m, width x length)
71 was planted with four *Carex riparia* 2.5 years before the experiment. The plants were therefore well
72 developed with roots' majority length (90th percentile) of 40cm in the present study (Fig. 1b). The FTW
73 thus occupied a significant ratio of the flume cross-sectional area perpendicular to the flow direction (62
74 %), promoting water to flow through the roots' network. The flume was designed as a closed loop to
75 generate a continuous flow using an axial turbine (Fig. 1a). Sediments collected from the bottom of a
76 highway stormwater retention pond were poured directly into the flume under full speed (~0.7m/s) to
77 reach a turbidity comprised between 60-70 Formazin Nephelometric Unit (FNU). Once water
78 homogeneity was reached, flume average velocity was reduced to V1, V2 or V3 and the FTW was
79 installed on the flume. The flume was entirely emptied and washed between each run, and similar mass
80 of sediments was added at the beginning of each run to reach 60-70 FNU. After each run the FTW was
81 removed from the flume and roots were gently washed with a water hose to remove attached sediments.
82 The roots needed only minimal washing as the sediments were not firmly attached as discussed in the
83 "results and discussion" section. The FTW module was then kept in a tank filled with tap water until the
84 next run. V1, V2 and V3 were selected depending on the roots' vertical inclination the flow would produce
85 and were 0.023m/s, 0.097m/s and 0.181m/s, respectively (Fig. 1b). Each run lasted about 22h. This
86 enabled to assess the impact of different roots' inclinations (inducing different roots' water column
87 occupancy) on turbidity reduction. Under static conditions the plant roots extended almost over the entire
88 depth of the flume (i.e 87% of the flume water depth).



89
 90 *Fig. 1 Side view of the flume experiment equipped with a FTW (a), roots' vertical inclination for*
 91 *different flume average flow velocities ($V1=0.023$ m/s, $V2=0.097$ m/s, $V3=0.181$ m/s) (b) and picture*
 92 *of the FTW before (c) and after a flume experiment (d,e) as well as zoom-in of the root network*
 93 *charged with particles (e). Arrows represent main roots' inclination. Rectangle in (d) indicates the*
 94 *location of roots zoom-in (e). The scale on b, c and d is 13 cm high and 13 cm wide.*

95 2.2 Suspended solids characterisation and monitoring

96 2.2.1 Turbidity measurement

97 Turbidity was measured continuously downstream of the FTW with a multiparameter meter Hanna HI
 98 9829 equipped with a turbidity sensor (HI 7609829-4). This meter operates to the ISO 7027 method
 99 using an infrared narrow band light source which is reportedly better suited to the measurement of small
 100 particle sizes and expresses results in Formazin Nephelometric Unit (FNU) (Bright et al., 2020). By
 101 comparison, the use of a wider band light source (400–600 nm) measuring turbidity in units of
 102 Nephelometric Turbidity Unit (NTU) is suited to detection of a greater range of particle sizes, but is less
 103 suitable for the detection of fine particles. Both methods use formazin calibration standards and while
 104 having different sensitivity depending of particles characteristics, they are often considered equivalent
 105 (World Health Organisation, 2017). Therefore for the purpose of this study and due to the lack of
 106 regulatory threshold expressed in FNU, recorded values in the present experiment were directly
 107 compared to thresholds for good (35 NTU) and very good (15 NTU) water quality defined in European
 108 Directive 2000/60/EC (European Parliament, 2000).

109 The sensor was calibrated with formazin standards before each run and calibration was checked after

110 each run with calibration check solutions. Calibration checks were within 90-110% of expected values.
111 Records emphasized turbidity reduction over time, reflecting entrapment of suspended solids after
112 successive flows through the FTW roots' network.

113 The experiment was run twice for each velocity: with FTW and without FTW (as a control to assess
114 turbidity removal solely due to settlement). Turbidity removal efficiency at time t (RE_t) was calculated
115 as:

$$116 \quad (1) \quad RE_t (\%) = \left(\frac{Turb_{t0} - Turb_t}{Turb_{t0}} \right) * 100$$

117 Where :

- 118 • $Turb_t$: turbidity at time t
- 119 • $Turb_{t0}$: turbidity at the beginning of the experiment

120
121 Turbidity removal efficiency at time t solely induced by FTW inclusion ($AddRE_t$) was calculated as:

$$122 \quad (2) \quad AddRE_t (\%) = RE_{t\ FTW} - RE_{t\ Control}$$

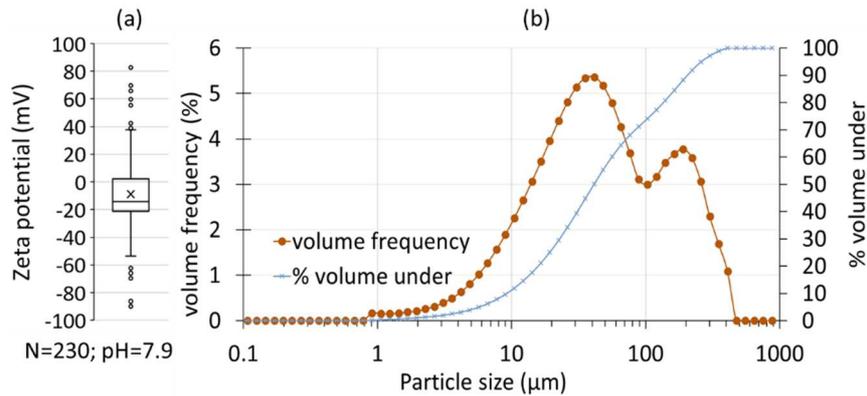
123 2.2.2 *Sediments characterisation*

126 Sediment samples collected from the stormwater retention pond were dried at 105°C until constant
127 weight. Weight Loss On Ignition (LOI), representative of the sample's organic carbon content (Wang et
128 al., 2010), was then determined by ashing 2 to 4 g of sample at 550°C for 12h. Particles electrostatic
129 charges (i.e. zeta potential (ζ)) informing on particle repulsion potential and stability, as well as particle
130 size distribution (PSD) are known to be important parameters governing removal mechanisms of fine
131 particles (Sansalone and Kim, 2008). PSD and ζ were thus analysed for water samples collected at the
132 beginning of the experiment in the flume. PSD was analysed with a laser particle size analyser
133 (Mastersizer 2000, Malvern Instrument). ζ was measured with a ZetaPhoremeter IV (CAD
134 instrumentations, France) after the sample was left to settle in a container. Only supernatant containing
135 the smallest particles left in suspension was analysed. All measurements were at least conducted in
136 duplicate.

137 3 RESULTS AND DISCUSSION

138 Sediments LOI was 24.5%, reflecting a relatively high organic content for highway runoff. This may result
139 from the presence of a large vegetated detention zone (15-35 m length) through which runoff has to flow
140 before reaching the permanent pool, contributing to organic input. Sediments' size used in this
141 experiment ranged from 0.8 to 409 μm with 2 main groups characterized by modal diameters of around
142 40 and 190 μm (Fig. 2b). D_{50} and D_{90} of the size distribution were 41 and 206 μm which are within

143 observed ranges for urban runoff (Charters et al., 2015). Fraction lower than 20 μm is not easily removed
 144 by quiescent settling (Sansalone and Kim, 2008) implying that ~26% of the sediments used in the
 145 present experiment (corresponding to particles <20 μm) would remain in suspension especially under
 146 dynamic conditions. Median ζ of non-settleable particles was -14mV with an interquartile range of 23
 147 mV (Fig. 2a), suggesting potential for particles repulsion and therefore relative stability.
 148

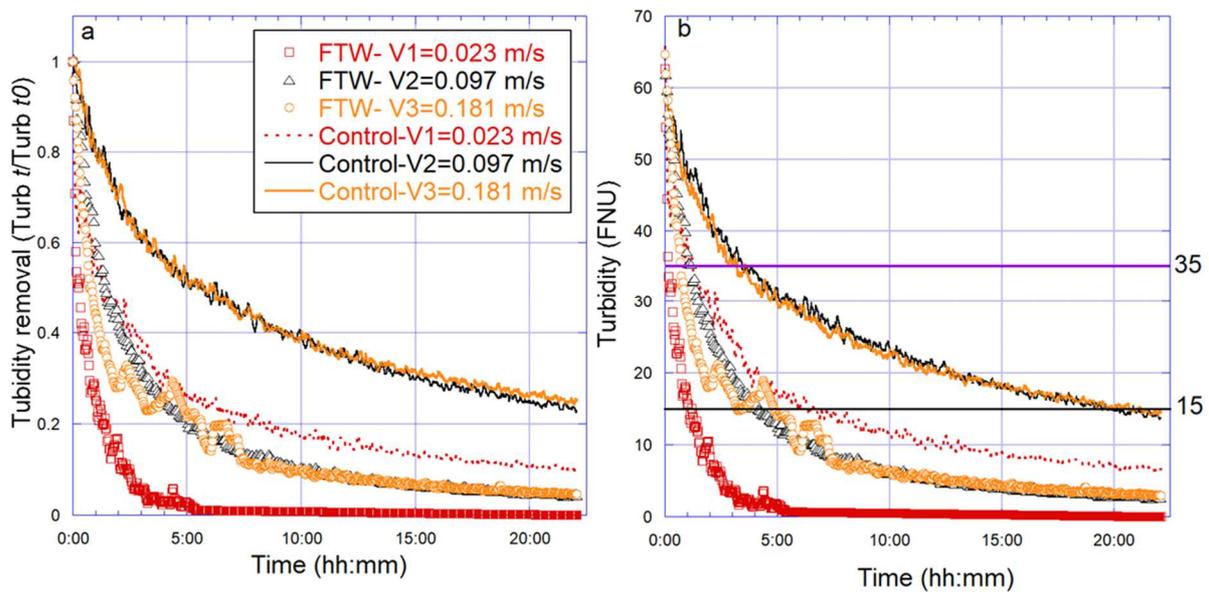


149
 150 *Fig. 2 Sediments zeta potential (a) and particle size distribution (b) sampled at the beginning of the*
 151 *flume experiment*

152 Flume tests performed with the inclusion of the FTW showed faster and greater turbidity reduction than
 153 the Control tests (Fig.3). Water column turbidity decreased more rapidly in presence of a FTW
 154 ($RE_{FTW}=97\%$ for V1, 79% for V2 and 78% for V3 after 5hours) than without ($RE_{Control}=74\%$ for V1, 47%
 155 for V2 and 48% for V3 after 5hours) (Fig. 3a). Even under high flow velocity (V3), inducing the roots to
 156 flatten under the mat, the FTW provided an efficient physical filter through particle entrapment into its
 157 roots' network as shown by the faster and greater turbidity reduction at V3 in presence of FTW compared
 158 to the Control. The presence of the FTW increased turbidity reduction by up to 37%, 34% and 45%
 159 (maximum of $AddRE_t$ over a 22h run) for V1, V2 and V3, respectively, compared to the Control. This is
 160 in accordance with Maxwell et al. (2020) who observed that FTW inclusion into a stormwater retention
 161 pond induced 10 to 45 % TSS reduction relative to a Control pond. Depending on the flow velocity, these
 162 greater reductions were observed 2:06 to 6:13 (h:mm) after the start of the runs.
 163 The turbidity reduction trends were relatively similar for V2 and V3 (Fig. 3). This suggests that V2 and
 164 V3 were above the critical flow velocity inducing hydraulic conditions under which turbidity could not
 165 decrease further, emphasizing the limit of both systems (flume with and without FTW) in terms of
 166 particles removal. Higher turbidity fluctuations were observed in presence of the FTW for V3 especially
 167 between 2:00 and 7:30 (Fig. 3). This is most probably due to the observed roots' movement which was

168 greater under this higher velocity (0.181 m/s) inducing either some partial particles release from the
 169 roots or lower temporary particle entrapment efficiency.

170 At flow velocity of 0.023 m/s (V1), threshold for good (35) and very good (15) water quality status
 171 (European Parliament, 2000) were reached at $t_0+00:09$ and $t_0+01:04$, respectively, with FTW and
 172 $t_0+1:11$ and $t_0+6:35$, respectively, without FTW (Fig. 3b). The presence of the FTW thus reduced by
 173 1:02 and 5:31 (h:mm) the time needed to reach good and very good water quality status. At V2,
 174 thresholds for good (35) and very good (15) water quality status were reached about 2:20 and 15:00
 175 (h:mm) earlier, respectively, with FTW. At V3, these thresholds were reached about 2:30 and 16h35
 176 (h:mm) earlier with inclusion of the FTW, for good (35) and very good (15) water quality status,
 177 respectively.

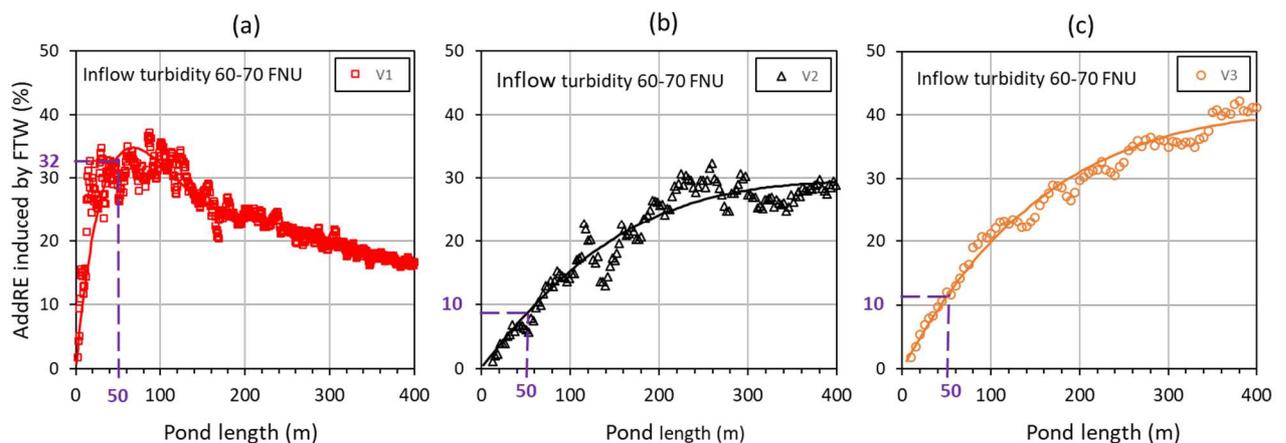


178
 179 Fig. 3 Relative turbidity removal (turbidity at t/turbidity at t_0) (a) and Turbidity (FNU) over time (b) in the
 180 flume equipped with a FTW and without (Control) under 3 different flow velocities (V1, V2 and V3)

181 Over the 22h flume experiments, water had the opportunity to complete a specific number of successive
 182 cycles, respective to each flow velocity (V1, V2 and V3) in the 4.9m long flume. These numbers of cycles
 183 are representative of various travelling distances into a pond equipped with a FTW covering 16% of the
 184 travelled distance. Turbidity removal efficiency solely induced by FTW inclusion ($AddRE=RE_{FTW}-$
 185 $RE_{Control}$) over the experiment running time can thus be extrapolated to $AddRE$ depending on the number
 186 of successive cycles or equivalent pond length (Fig. 4). Such extrapolation necessitates that the
 187 conditions prevailing in the pond be similar to those in the present flume experiment, especially
 188 favourable hydraulic conditions limiting short circuiting and promoting the water to flow through the FTW

189 roots' network. In such instance, for a 50m long pond, the inclusion of a 8m long FTW (=16% of pond
 190 length), covering 70% of pond width, could improve turbidity removal efficiency by ~32% at low flow
 191 velocity ($V1=0.023\text{m/s}$) and by ~10% at medium and high flow velocities ($V2$ and $V3$) (Fig. 4, purple
 192 lines).

193 Under $V1$, the additional effect of the FTW would be reduced for ponds greater than ~70m as shown by
 194 the decreasing AddRE (although still remaining above 15%, Fig. 4 a). This might be induced by
 195 increasing settling processes in larger ponds (>70m) providing longer residence time for settlement,
 196 therefore reducing additional particles treatment benefits provided by the FTW. For higher flow velocities
 197 ($V2$ and $V3$) more representative of high average recurrence interval storm events or flash flood events,
 198 such a decrease was not observed for pond length up to 400m. This suggests that, under high flow
 199 velocities (> $V2$), settling processes would be limited even in large sedimentation ponds, warranting
 200 inclusion of FTWs as supported by increasing additional turbidity removal efficiency (AddRE) solely
 201 induced by the inclusion of a FTW (Fig. 4 b and c). Indeed, while sedimentation processes would be
 202 limited, FTWs would provide additional particles' treatment through entrapment in roots' network.



203
 204 *Fig. 4 Estimated additional turbidity removal efficiency (AddRE) (%) solely induced by the inclusion of*
 205 *a FTW converging 16% and 70% of pond length and width respectively, under flow velocity $V1=0.023$*
 206 *m/s (a), $V2=0.097\text{m/s}$ (b) and $V3=0.181\text{ m/s}$ (c), for various pond lengths. Purple lines indicate*
 207 *estimated AddRE for a 50m long pond under $V1$, $V2$ and $V3$.*

208 At the end of a run, particle entrapment was visible in the FTW roots' network (Fig.1 d,e) demonstrating
 209 the capability of the roots to filter and trap suspended particles. However, while retrieving the FTW mat
 210 from the flume after a 22h run, the sediments easily sloughed off and dispersed into the flume water
 211 suggesting that they were not strongly attached to the roots. This is contradictory to field observations
 212 of a FTW having been installed for more than 6 months (Borne et al., 2013) whose roots presented

213 firmly attached particles into the sticky roots biofilm. This suggests that, although ζ was negative
214 suggesting electrical repulsion, particles could first impact the roots' network due to flow velocity and
215 formed clusters and/or layers of particles around the roots, which could, over time and in a real case
216 application, become strongly attached into the rhizosphere due to the formation of a denser sticky biofilm
217 favoured by root's exudates and bacterial development.

218 **4 CONCLUSION**

219 The results of the present study suggest that the inclusion of a FTW in an open channel loaded with
220 sediments would provide additional sediment removal mechanisms to settlement. Additional turbidity
221 reduction from 34 to 45% could be achieved in presence of a FTW under a flow velocity range of 0.023-
222 0.181 m/s.

223 Even under high flow velocity, inducing the roots to flatten under the mat, the FTW provided an efficient
224 additional particle removal process to settlement, i.e. entrapment of suspended solids into FTW roots'
225 network. Turbidity thresholds for good and very good water quality status (EU guidelines) were reached
226 1:02 and 5:31 (h:mm) faster with the inclusion of a FTW under a flow velocity of 0.023m/s. While direct
227 extrapolation of the present flume experiment results to real case application should be made carefully,
228 estimate of potential turbidity reduction induced by a FTW in ponds of various sizes is thought to provide
229 useful insight on FTW's benefits. In the present experiment a FTW with a dense fibrous roots' network
230 occupying 62% of the flume cross-sectional area was used, inducing a significant ratio of the water to
231 flow through the roots' network promoting particles' entrapment. Providing that similar conditions could
232 be matched in real retention ponds, turbidity removal efficiency solely induced by a FTW covering 16%
233 of a pond length and 70% of pond width could be extrapolated for various pond sizes. As an example,
234 the inclusion of a 8m long FTW in a 50m long pond, with inlet turbidity of 60-70 FNU, could improve
235 turbidity removal efficiency by ~32% at low flow velocity ($V_1=0.023\text{m/s}$) and by ~10% at medium and
236 high flow velocities (V_2 and V_3). At low flow velocity, FTW effect would be less visible as pond length
237 increases above 70m as it would increase potential for settling mechanisms to occur, therefore
238 compensating part of FTW's treatment benefits. This gives an insight of potential turbidity performance
239 improvement by the inclusion of a FTW (covering 16% of pond length and 70% of pond width) for various
240 pond sizes.

241 **ACKNOWLEDGEMENTS**

242 The authors thank Waterclean Technologies/Kauri Park Group, who provided the FTWs. Viewpoints

243 expressed in this paper are those of the authors and do not reflect policy or otherwise of supplier.

244

245 **LIST OF REFERENCES**

246 Abed, S.N., Almuktar, S.A., Scholz, M., 2017. Remediation of synthetic greywater in mesocosm—Scale floating
247 treatment wetlands. *Ecol. Eng.* 102, 303–319. <https://doi.org/10.1016/j.ecoleng.2017.01.043>

248 Barco, A., Borin, M., 2020. Treatment performances of floating wetlands: A decade of studies in North Italy. *Ecol.*
249 *Eng.* 158, 106016. <https://doi.org/10.1016/j.ecoleng.2020.106016>

250 Benvenuti, T., Hamerski, F., Giacobbo, A., Bernardes, A.M., Zoppas-Ferreira, J., Rodrigues, M.A.S., 2018.
251 Constructed floating wetland for the treatment of domestic sewage: A real-scale study. *J. Environ. Chem.*
252 *Eng.* 6, 5706–5711. <https://doi.org/10.1016/j.jece.2018.08.067>

253 Borne, K.E., 2014. Floating Treatment Wetland influences on the fate and removal performance of phosphorus in
254 stormwater retention ponds. *Ecol. Eng.* 69, 76–82.

255 Borne, K.E., Fassman, E.A., Tanner, C.C., 2013. Floating Treatment Wetland retrofit to improve stormwater pond
256 performance for suspended solids, copper and zinc. *Ecol. Eng.* 54, 173–182.
257 <https://doi.org/10.1016/j.ecoleng.2013.01.031>

258 Borne, K.E., Fassman-Beck, E.A., Winston, R.J., Hunt, W.F., Tanner, C.C., 2015. Implementation and maintenance
259 of Floating Treatment Wetlands for urban stormwater management. *J. Environ. Eng.* 141.

260 Bright, C., Mager, S., Horton, S., 2020. Response of nephelometric turbidity to hydrodynamic particle size of fine
261 suspended sediment. *Int. J. Sediment Res.* 35, 444–454. <https://doi.org/10.1016/j.ijsrc.2020.03.006>

262 Charters, F.J., Cochrane, T.A., O’Sullivan, A.D., 2015. Particle size distribution variance in untreated urban runoff
263 and its implication on treatment selection. *Water Res.* 85, 337–345.
264 <https://doi.org/10.1016/j.watres.2015.08.029>

265 De Stefani, G., Tocchetto, D., Salvato, M., Borin, M., 2011. Performance of a floating treatment wetland for in-
266 stream water amelioration in NE Italy. *Hydrobiologia* 674, 157–167. <https://doi.org/10.1007/s10750-011-0730-4>

268 European Parliament, 2000. Directive 2000/60/EC of the European Parliament and of the Council establishing a
269 framework for the Community action in the field of water policy.

270 Headley, T.R., Tanner, C.C., 2012. Constructed wetlands with floating emergent macrophytes: an innovative
271 stormwater treatment technology. *Crit. Rev. Environ. Sci. Technol.* 42, 2261–2310.

272 Headley, T.R., Tanner, C.C., 2006. Application of floating wetlands for enhanced stormwater treatment: a review
273 (Prepared by NIWA for ARC No. Technical Publication TP 324). Auckland Regional Council.

274 Kayhanian, M., McKenzie, E.R., Leatherbarrow, J.E., Young, T.M., 2012. Characteristics of road sediment
275 fractionated particles captured from paved surfaces, surface run-off and detention basins. *Sci. Total*
276 *Environ.* 439, 172–186. <https://doi.org/10.1016/j.scitotenv.2012.08.077>

277 Khan, S., Melville, B.W., Shamseldin, A., 2013. Design of storm-water retention pond with Floating Treatment
278 Wetlands. *Environ. Eng.* 139.

279 Machado Xavier, M.L., Janzen, J.G., Nepf, H., 2018. Numerical modeling study to compare the nutrient removal
280 potential of different floating treatment island configurations in a stormwater pond. *Ecol. Eng.* 111, 78–84.
281 <https://doi.org/10.1016/j.ecoleng.2017.11.022>

282 Maxwell, B., Winter, D., Birgand, F., 2020. Floating treatment wetland retrofit in a stormwater wet pond provides
283 limited water quality improvements. *Ecol. Eng.* 149, 105784.
284 <https://doi.org/10.1016/j.ecoleng.2020.105784>

285 Nielsen, K., Kalmykova, Y., Strömvall, A.-M., Baun, A., Eriksson, E., 2015. Particle phase distribution of polycyclic
286 aromatic hydrocarbons in stormwater — Using humic acid and iron nano-sized colloids as test particles.
287 *Sci. Total Environ.* 532, 103–111. <https://doi.org/10.1016/j.scitotenv.2015.05.093>

288 Pavlineri, N., Skoulikidis, N.Th., Tsihrintzis, V.A., 2017. Constructed Floating Wetlands: A review of research,
289 design, operation and management aspects, and data meta-analysis. *Chem. Eng. J.* 308, 1120–1132.
290 <https://doi.org/10.1016/j.cej.2016.09.140>

291 Sansalone, J.J., Kim, J.-Y., 2008. Suspended particle destabilization in retained urban stormwater as a function of
292 coagulant dosage and redox conditions. *Water Res.* 42, 909–922.
293 <https://doi.org/10.1016/j.watres.2007.08.037>

294 Schwammburger, P.F., Lucke, T., Walker, C., Trueman, S.J., 2019. Nutrient uptake by constructed floating wetland
295 plants during the construction phase of an urban residential development. *Sci. Total Environ.* 677, 390–
296 403. <https://doi.org/10.1016/j.scitotenv.2019.04.341>

297 Tharp, R., Westhelle, K., Hurley, S., 2019. Macrophyte performance in floating treatment wetlands on a suburban
298 stormwater pond: Implications for cold climate conditions. *Ecol. Eng.* 136, 152–159.
299 <https://doi.org/10.1016/j.ecoleng.2019.06.011>

300 Van De Moortel, A.M.K., Meers, E., De Pauw, N., Tack, F.M.G., 2010. Effects of vegetation, season and
301 temperature on the removal of pollutants in experimental floating treatment wetlands. *Water. Air. Soil*
302 *Pollut.* 212, 281–297. <https://doi.org/10.1007/s11270-010-0342-z>

303 Wang, Q., Li, Y., Wang, Y., 2010. Optimizing the weight loss-on-ignition methodology to quantify organic and
304 carbonate carbon of sediments from diverse sources. *Environ. Monit. Assess.* 174, 241–257.
305 <https://doi.org/10.1007/s10661-010-1454-z>

306 Winston, R.J., Hunt, W.F., Kennedy, S.G., Merriman, L.S., Chandler, J., Brown, D., 2013. Evaluation of Floating
307 Treatment Wetlands as Retrofits to Existing Stormwater Retention Ponds. *Ecol. Eng.* 54, 254–265.

308 World Health Organisation, 2017. Technical Breif: Water quality and health- Review of turbidity:Information for
309 regulators and water suppliers (No. WHO/FWC/WSH/17.01).

310