*Research Article*

# Assessing the Potential Resistance of Floating Vegetation against Different Flow Rates

# Yüzer Halde Bulunan Bitkilerin Farklı Hız Akış Oranlarına Karşı Potansiyel Dirençlerinin Değerlendirilmesi

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## Abstract

Constructed Floating Wetlands have been rising an innovative and environmentally friendly water treatment technology for both stormwater and wastewater over the decades. For the sustainability of these systems, hydraulic components of wetlands should be carefully monitored and properly managed. With this study, the root resistance of *Baumea rubiginosa* and *Phragmites australis* grown in the drinking water and a synthetic water mix representing stormwater and domestic wastewater with low and high nutrient content against different flow rates was examined. With the nutrient uptakes from intermediate bulk container water tanks, two plant species had reached at harvest stage over the period of 35 weeks, and then they were subjected to flume test experiment. Two plant species from five different water types showed different growth levels in roots and shoots, and thanks to their stronger and denser root structures, plant species of *Baumea rubiginosa* and *Phragmites australis* in domestic wastewater with low nutrient were found more resistant to the flow by pushing water deeper and cause a higher hydraulic head loss between upstream and downstream in comparison to the rest of plant types. The relationships between three different components: Root volume, flow rate and head loss were also analysed through correlation test in SPSS Statistics and the relationship between root volume and head loss was found positive at the higher flow rate(s). The results demonstrate that these native plant species in constructed floating wetlands could be used to reduce extreme flow rates in upstream side and provide a safe environment during extreme flood events.

***Keywords***: *constructed floating wetlands, stormwater, domestic wastewater, root resistance, floating vegetation*

## Öz

İnşa edilen yapay sulak alanlar son yıllarda hem hasat edilen yağmur suyu hem de atık-su için yenilikçi ve çevre dostu bir su arıtma teknolojisi olarak ortaya çıkmıştır. Bu sistemlerin sürdürülebilirliği için, bu sistemlerin parçası olan hidrolik bileşenlerinin dikkatlice izlenilmesi ve düzenli olarak yönetilmesi gerekir. Bu çalışma ile birlikte içme suyu, yağmur suyu ve evsel atık-suyu temsil eden sularda yetişen *Baumea rubiginosa* ve *Phragmites australis* bitki türlerinin kök dirençlerinin farklı akış miktarlarına gösterdiği dirençler araştırılmıştır. Su tanklarında yetiştirilip 35 hafta da olgunluğa erişen bu iki bitki türü akışkanlar mekaniği testine maruz bırakılmıştır. Beş farklı su türünde yetişen iki bitki türü köklerinden ve gövdelerinden farklı oranlarda gelişim göstermişlerdir. Düşük besin maddesi ile simüle edilen evsel atık-suda yetişen bitkilerin daha güçlü ve yoğun kök yapısına sahip olduğu ve bu sayede bu bitkilerin su akışına gösterdikleri direncin daha fazla ve yapay su kanalın memba ve mansap kısmı arasında daha fazla bir yük kaybı meydana getirdikleri belirlenmiştir. Kök hacmi, akış oranı ve hidrolik yük kaybı arasındaki ilişki SPSS de korelasyon yaklaşımıyla incelenmiş ve yüksek akışkan oranlarında hacimce büyük köklerin meydana getirdiği hidrolik yük kayıplarının daha fazla olduğu bulunmuştur. Sonuç olarak, söz konusu iki lokal bitkinin kök dirençleri sayesinde havza bazında aşırı hız akışını azaltma ve aşırı sel taşkınlarının olduğu durumda güvenli bir ortam sağlayabilecekleri bulunmuştur.

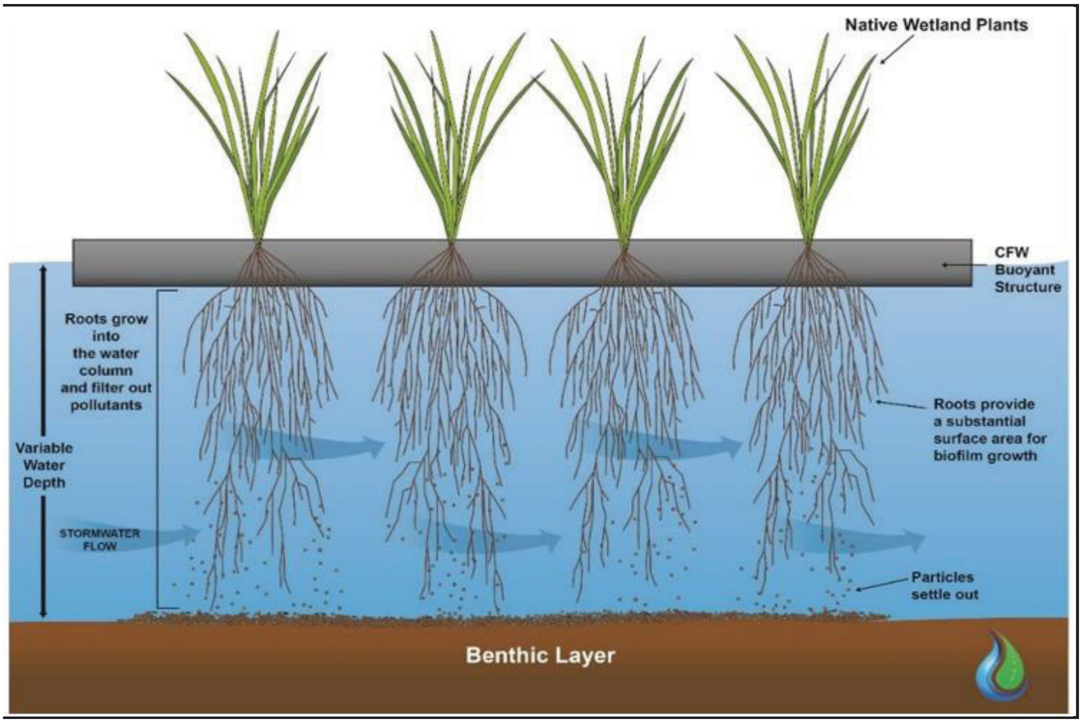
***Anahtar sözcükler***: *yapay sulak alanlar, yağmur suyu, evsel atık-su, kök direnci*

## Introduction

Urban waterways are under the threat of pollution mostly coming from wastewater and pollutants washed off from impervious urban landscapes during the stormwater events (Chance & White, 2018; Kumari & Tripathi, 2014; Nuruzzaman et al., 2021). Though, the concentration of pollutants such as Total Nitrogen (TN), Total Phosphorous (TP) and organic matter in stormwater is lower than in wastewater, a much larger area must be designed and much more attention should be paid to treating stormwater because of high volume of runoff, especially during rainy seasons (Liu et al., 2009). So far, several policies, standards, guidelines and treatment technologies have been set up by the governments, scientists and engineers to mitigate pollution problems in waters across the world (Daly et al., 2012). Water control and treatment strategies under the different names are developed in cities (Nuruzzaman et al., 2021), and these initiatives are generally termed as Best Management Practices (BMPs) that are stood out as stormwater control measures (SCMs) including treatment, green infrastructure (GI), low impact design (LID) in USA and New Zealand, sustainable urban drainage systems (SUDS) in England, water sensitive urban design (WSSUD) in Australia (Yang & Lusk, 2018). As one of the best management practices, Constructed Floating Wetlands (CFWs) that are defined innovative and environmentally friendly water treatment technology (Lucke et al., 2019; Stefanakis, 2020), are successfully implemented to treat and manage the polluted water types including stormwater runoff (Tanner & Headley, 2011), sewerage water (Van de Moortel et al., 2011), natural lake/river water (Kato et al., 2009), nutrition-rich agricultural/farm manure water (Sooknah & Wilkie, 2004), eutrophic water (Olguín et al., 2017), and paper mill wastewater (Ayres et al., 2019). CFWs in Figure 1, can be detailed through the presence of macrophytes over the floating beds taking a place of soil base that is supportive of terrestrial macrophytes for the sustainability, as well as economic, environmental and ecological water treatment methods in the water bodies (Ge et al., 2016).

**Figure 1**

*Design of Constructed Floating Wetlands (Lucke et al., 2019)*



Several factors including plant species, temperature, detention time, and pollutant loading rate play a significant role in evaluating the treatment efficiency of CFWs in addition to the hydraulics of CFWs that has also a substantial impact on the treatment by affecting the amount of inflow through root zone and residence time (Nuruzzaman et al., 2021). Moreover, vegetation acts as a principal source of hydraulic resistance against flow in wetlands (Kadlec, 1990), affects the flow in several ways (Piercy, 2010), and would bring about some difficulties in hydraulic design (Järvelä, 2005). As a result, the hydraulic components of these systems should be very well understood to manage these systems properly.

As reviewed from the recent studies, it is found that there are few experiments based on wetland hydrology since a majority of studies are mostly focused on water treatment performance, plant and root development and changes in water quality in wetland conditions. Schwammberger et al. (2017; 2019) are set up their experiments on CFWs with two different studies in Queensland, Australia. Through these studies, the investigation on monitoring changes in water quality parameters and plant development are done. Moreover, Ge et al. (2016) briefly point out Floating Treatment Wetlands referring that CFWs can improve the health of the aquatic environment and contribute to the life of other organisms by slowing down the velocity, which facilitates the settlement of suspended solids. However, there is no real implementation to find out the relation between flow and wetland vegetation.

A few studies have been found to determine the hydraulics of water bodies and the resistance of roots to different flows in CFWs. In addition to experiments carried out at the field-scale with different applications, a flume test experiment widely takes place in the laboratory to assess the impact of roots to flow in the laboratory.

As a matter of fact, the majority of flume test experiments are conducted via artificial vegetation that is made of either wood or synthetic material rather than real vegetation at varying flow velocity values (Chang et al., 2015). For instance, Liu et al. (2019) set up a flume test experiment through a staggered array of rigid dowels to examine the impacts of the floating treatment island FTI spacing on the flow. In this study, the approach of simulation of floating macrophyte roots is considered. Chang et al. (2015) test the effects of vegetation on the flow by placing artificial vegetation to identify the performance of the automatic pulse tracer velocimeter (APTV) in the lab, followed by the adaptation of obtained results into wetland conditions.

Despite a number of studies with a similar approach, it is believed that neither artificial dowels nor other artificial rigid materials of vegetation as mentioned create an environment below the water surface similar to the real root structures since the emerged roots cannot remain motionless below the water surface and are freely shaped in parallel to the flow when immersed them in water. A further step is taken by West (2016), the real plant roots belonging to Typha and Carex are grown in wetland conditions and artificial root structures are used to identify transverse mixing coefficients through a flume test experiment. However, the hydraulic performance of wetland plants through flow condition should be assessed considering several factors together.

Therefore, this research project is undertaken to identify the resistance of real root structures against a range of flow velocities through a flume test experiment and calculate the hydraulic performance of wetland conditions with the presence of real vegetation.

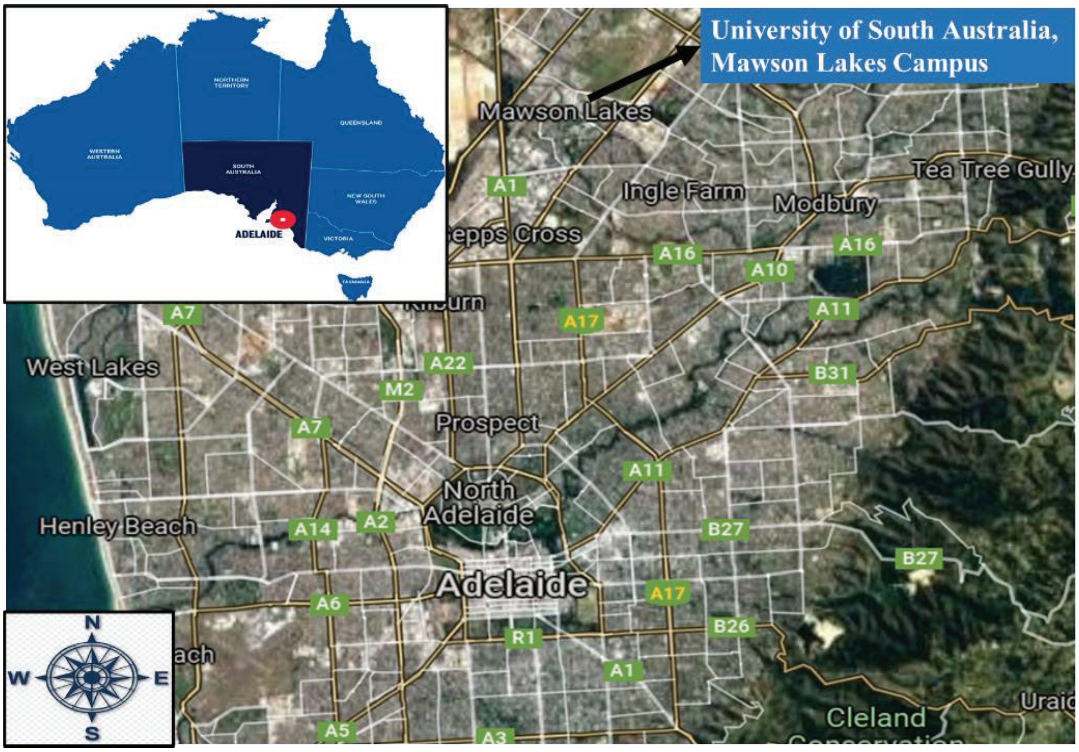
# Method

## System Information

The simulation of CFW was designed with 10 intermediate bulk container (IBC) water tanks at the University of South Australia on Mawson Lakes Campus in Adelaide, South Australia (34° 48´´ S 138° 37´´ E) and carried out between October 2019 and June 2020. The location of the conducted experiment can be seen in Figure 2.

**Figure 2**

*Location of Mawson Lakes Campus at the University of South Australia*

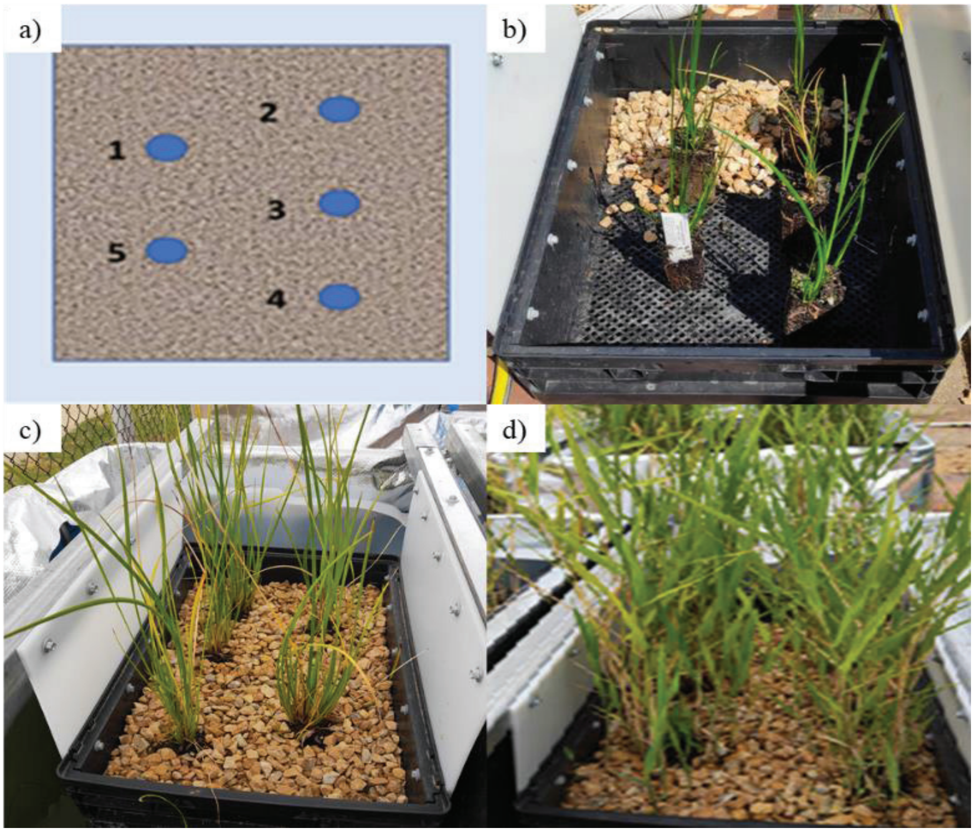


The system was split into two groups represented by *Baumea rubiginosa* (PA) and *Phragmites australis* (PB) plant species. Each tank was then filled with 950 L of potable water so that the plant baskets can be half soaked in order to simulate the CFW environment. The simulation components of each IBC tank consisted of two polypropylene baskets (57 cm * 38 cm * 17 cm) filled with almost 10 cm depth aggregate (Figure 3). Additionally, each tank was wrapped by aluminium insulation foil to limit light penetration from outside, which prevents the growth of cyanobacteria in the tank throughout the experiment.

For each group, four different synthetic waters environment named as W2: Low strength stormwater, W3: High strength stormwater, W4: Low strength domestic wastewater and W5: High strength domestic wastewater were prepared in addition to W1 which was filtered potable water without additional nutrients. Studies through comprehensive review were taken into account to add chemicals such as potassium nitrate ($KNO_3$) and potassium dihydrogen phosphate ($KH_2PO_4$) into mesocosm tanks to obtain required nutrient levels (Table 1).

**Figure 3**

*Seedling Setup in the IBC Tanks*



*Note.* The simulation of CFWs in IBC water tanks were made of two polypropylene baskets filled with ~10 cm depth with aggregate (a) and (b). The progress of plant development for *Baumea rubiginosa* (c) and *Phragmites australis* (d) as planted.

**Table 1**

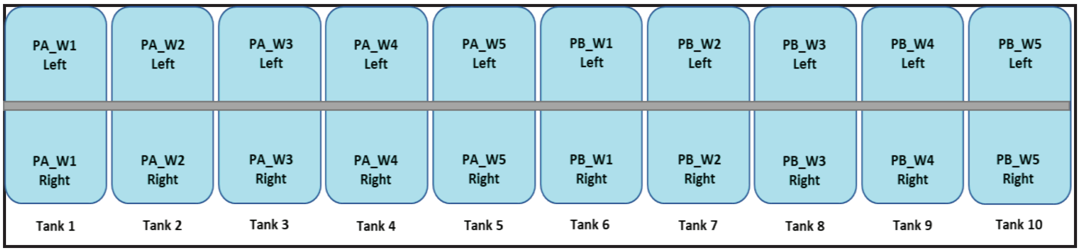
*Additional Nutrient Concentrations to IBC Tanks for The Simulation of Water Types (Awad et al., 2022; Carey & Migliaccio, 2009; Duncan, 2005)*

| Type | Description of Replica | Nitrogen (N) in mg/l | Phosphorus (P) in mg/l | Potassium (K) in mg/l |
|---|---|---|---|---|
| W1 | Potable water | No addition of nutrient | | |
| W2 | Low strength stormwater | 0.4 | 0.2 | 1.3 |
| W3 | High strength stormwater | 3.7 | 1.3 | 11.9 |
| W4 | Low strength domestic wastewater | 8.0 | 2.0 | 24.8 |
| W5 | High strength domestic wastewater | 25.0 | 7.0 | 78.5 |

To avoid any complexity over the samples, the following naming mechanism was taken into account: Each basket was named based on plant type, water type and location, and they were placed on the IBC tank. If PA_W1 Right or PB_W1 Right is taken as an example, PA stands for "Plant A", representing *Baumea rubiginosa*, and PB stands for "Plant B" representing *Phragmites australis.* W1 reflected the potable water, and the right specified the basket on the right side of the system when facing eastwards. The layout of the IBC tanks with the naming of each basket is as illustrated in Figure 4.

**Figure 4**

*The Drawing of the Entire System on the Site*



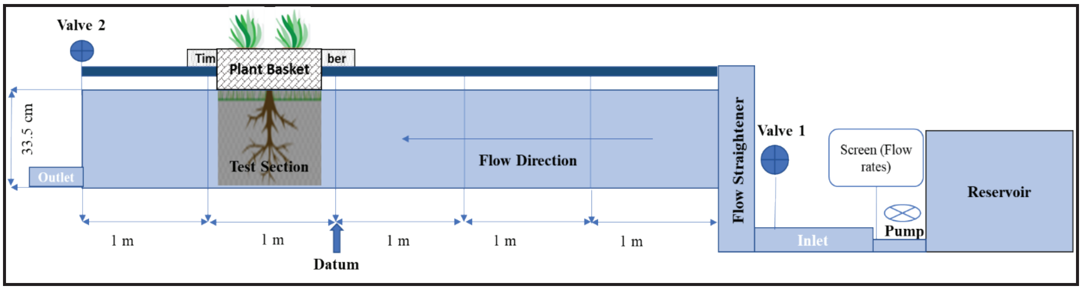
Note. PA: Plant A (*Baumea rubiginosa*), PB: Plant B (*Phragmites australis*), W1: Filtered water without additional nutrients, W2: Low strength stormwater, W3: High strength stormwater, W4: Low strength domestic wastewater, W5: High strength domestic wastewater.

## Flume Test

The flume test station on Mawson Lakes Campus was utilized to gain a better understanding of the resistance of root systems of grown plants against variable flow rates. The artificial water channel is 5 metres long, 0.66 metres wide, and 0.50 metres deep, with an effective depth of almost 0.4 metres (observable side-glass) (Figure 5).

**Figure 5**

*The Layout of the Flume Test Station Located on Mawson Lakes Campus*



The artificial water channel for flume test was installed with blue painted stainless-steel pillars one metre away from one another and equipped with observable side-glass placed in between. To create a stable one-directional flow, a pump with the adjustable flow was used. While Valve 1 was used to increase or decrease the flow rate provided by the pump, Valve 2 was used to adjust the water level to the desired level just below the basket in a water channel. For this experiment, the desirable flow speed going through an artificial channel was determined as low as 0.05, 0.10 and 0.15 m/s accordingly. As a result, the flow rate generated by the pump should be set as:

$$Q = h * d * V \quad \text{(Equation 1)}$$

Where, Q is flow rate generated by the pump ($m^3.s^{-1}$), V is desired flow speed ($m.s^{-1}$), h is water level in the channel (m), and d is the width of water channel (0.66 m).

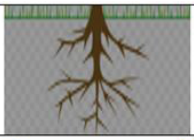
During the test, optimal water height was measured at 0.335 m when the majority of the roots were immersed in water and the bottom of the baskets was not contacted with water, resulting in a flow condition undisturbed by the baskets.

With the theoretical height and channel width, the flow rate from the pump was expected to be 11, 22, and 33 $L.s^{-1}$. However, the pumping rate was not measured as consistent as required owing to uncontrolled variables such as fluctuation of pump power output, and delay after adjusting water gate. In the actual test, the ultimately achieved channel flow rate was accordingly $Q1 = 10.00 \pm 0.19$ L.s$^{-1}$, $Q2 = 20.00 \pm 0.39$ L.s$^{-1}$, and $Q3 = 30.00 \pm 0.61$ L.s$^{-1}$; thus, the height of the water was adjusted accordingly to achieve the design flow speeds.

In order to monitor the placement of baskets on the flume, and the position of water level measured, the pillar on the upstream of the basket was set as the datum reflecting point zero, thus any measurement along the flume can be referenced in accordance with it. Hence, there were nine water levels marked; six on the upstream side 0.25 m, 0.5 m, 0.75 m, 1.25 m, 1.5 m and 1.75 m, and three on the downstream side at 1.25 m, 1.5 m and 1.75 m away from the datum. As shown in Figure 6, the negative sign indicates the orientation of the side in relation to point zero.

**Figure 6**

*Distance of Measured Water Levels from Datum at Different Locations*

| | Downstream Side | | |  | Upstream Side | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Water level (cm) | | | | | | | | | | |
| Locations away from datum (m) | -1.75 | -1.50 | -1.25 | ↔<br>1 m | 0.25 | 0.50 | 0.75 | 1.25 | 1.50 | 1.75 |

Water levels at both sides were measured before placing plants at once and after emerging each plant into the water at each flow rate. There were changes in water level at the beginning of the test area just after the flow straightener, which was inconstantly conveyed into both upstream and downstream sides of the channel; as a result, the alarm was set for approximately 15 minutes before commencing each flume experiment to ensure water level literally settled down and there was no up and down movement in water level at both sides.

There is no coincidence that denser roots  are able to reduce water flow; yet, owing to continuity, a portion of the flow would be driven to the channel's edges or bottom (Liu et al., 2019). In order to visualise the water flow through the streamline, the dye test was implemented. Once the basket from each IBC tank was placed on the top of the flume test channel one by one, regular food colouring kept in plastic pipettes was injected into the water from just right ahead of the basket at varying flow rates (Figure 7). Time taken to travel for food colouring droplet throughout 1 metre distance was recorded, and in the meantime, the trajectory of dye was recorded by GoPro HERO model camera from glass side in time series. To minimize any possibility of human error, dye injection for one basket was repeated three times even more at each single flow rate.

**Figure 7**

*The Footage for the Dye Test through the Channel in the Presence of the Plant Roots* (PA_W1, V= 0.05 m. $s^{-1}$)

In the end of the flume tests experiment for all plant groups, plant roots were cut off and yielded to examine the effects of magnitude of root volume on flow. Basically, a scissor was used to separate the roots from the plant; following that, the volume of roots was determined using 1000 ml cylinder. For this purpose, the cylinder with 1000 ml capacity was clogged with plant roots and compacted all the way by iron, then excess water was poured into the room of cylinder remained from the roots. The volume of root structures was calculated by subtracting 1000 ml from the quantity of water placed in the cylinder.

A correlation test in SPSS was used to evaluate the effect of the magnitude of root volume and flow rate on hydraulic head loss between upstream and downstream. This approach was determined after applying ANOVA not applicable due to limited data taken from the experiment. For the different cases, p-values $< 0.01$ and $< 0.05$ were taken into account as evidence of statistical significance.

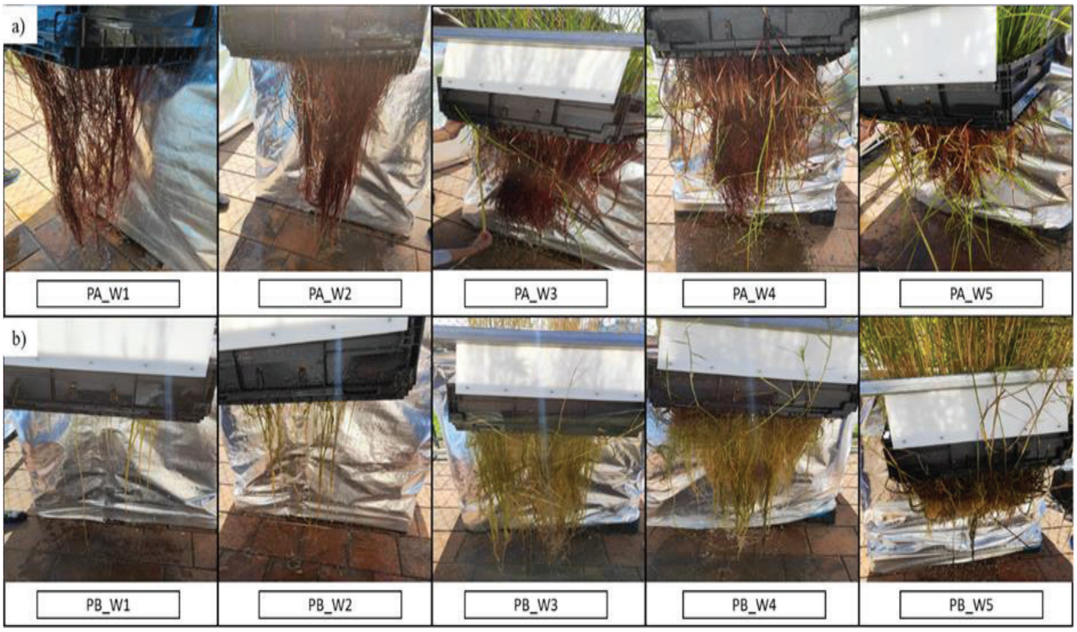
## Results and Discussion

Based on observation and experiment, it was concluded that two plant species: PA and PB through normal (control) water and synthetic stormwater and municipal wastewater reached out the harvest level over a 35-week period (Figure 8).

In the dye test, it was predicted that root structures would have no effect on the change in actual velocity if the density of the root was less, which means dye velocities equal to the designed velocity. However, regardless of having a low or high dense root, all root structures influenced the actual flow velocity in some way. With the measurement and video recording of the dye test, those plant species developed in synthetic stormwater and domestic wastewater both at low and high nutrient levels showed greater resistance against flow than the control group thanks to additional nutrients and possession of dense root structures (Figure 9).

**Figure 8**

*A Caption of Root Structure Looks for Baumea rubiginosa (*a) and *Phragmites australis* (b) *Just before Commencing the Flume Test Experiment*



From the synthetic domestic wastewater with low nutrient levels (W4), both PA and PB created such a greater block in the middle of water body at 30 L.s$^{-1}$ out and pushed dye and water mixture much deeper, resulting in an accelerated dye transmission throughout roots. Hence, the time taken by dye to travel along 1m was less than expected, which increased water velocity up to 16% for PA and 52% for PB respectively. In contrast, the plant types coming from the control group, even though PA has a denser root structure than PB due to characteristics of plant species, the flow after injection of dye in water easily passed throughout roots of both because of less intense root occurrence (Table 2).

Emerged macrophytes are defined as the dominant factor that affects flow conditions along the channel where they are placed (Green, 2005). These influences should be considered not only in terms of variations in flow direction and speed through the channel, but also in terms of hydraulic head loss between upstream and downstream. To develop a better understanding of how emerged roots depending on the magnitude of their volume would influence water level throughout the upstream-downstream line, initially head loss due to channel shape and the slope was measured at 0.75, 0.70 and 0.75 cm at Q = 10, 20 and 30 L.s$^{-1}$ respectively before placing plants in the artificial channel.

**Figure 9**

*Dye Test for Baumea rubiginosa (a; control group, and c; domestic waste-water with low nutrient) and Phragmites australis (b; control group, and d; domestic waste-water with low nutrient)*

*Note.* At Q= 10 L.s$^{-1}$; V= 0.05 m. s$^{-1}$, Q=20 L.s$^{-1}$; V=0.10 m.s$^{-1}$, Q=30 L.s$^{-1}$; V= 0.15 m. s$^{-1}$

From the synthetic domestic wastewater with low nutrient levels (W4), both PA and PB created such a greater block in the middle of water body at 30 L.s$^{-1}$, thus they pushed dye and water mixture much deeper, resulting in an accelerated dye transmission throughout root. Hence, the time taken by dye to travel along 1m was less than expected, which increased water velocity up to 16% for PA and 52% for PB respectively (Table 2).

**Table 2**

*The Response of Dye Transmission to Adjusted Flow Rates*

| | | Q = 10 L.s$^{-1}$ | | Q = 20 L.s$^{-1}$ | | Q = 30 L.s$^{-1}$ | |
|---|---|---|---|---|---|---|---|
| Plant Species | Water Types | Time (s) | V(m/s) | Time (s) | V(m/s) | Time (s) | V(m/s) |
| PA | W1 | 16.54 | 0.06 | 9.35 | 0.11 | 5.46 | 0.18 |
| | W2 | 17.64 | 0.06 | 9.22 | 0.11 | 6.46 | 0.15 |
| | W3 | 17.00 | 0.06 | 9.82 | 0.10 | 5.66 | 0.18 |
| | W4 | 16.31 | 0.06 | 8.79 | 0.11 | 5.51 | 0.18 |
| | W5 | 15.51 | 0.06 | 7.78 | 0.13 | 6.28 | 0.16 |
| PB | W1 | 17.73 | 0.06 | 9.35 | 0.11 | 6.11 | 0.16 |
| | W2 | 16.51 | 0.06 | 8.72 | 0.11 | 6.28 | 0.16 |
| | W3 | 18.15 | 0.06 | 9.06 | 0.11 | 5.97 | 0.17 |
| | W4 | 14.52 | 0.07 | 6.80 | 0.15 | 4.76 | 0.21 |
| | W5 | 14.20 | 0.07 | 6.80 | 0.15 | 5.22 | 0.19 |

**Table 3**

*Obtained Hydraulic Head Losses between Upstream and Downstream After Flume Test in Response to Root Volume of Two Plant Species in Five Different Water Types and Different Flow Rate*

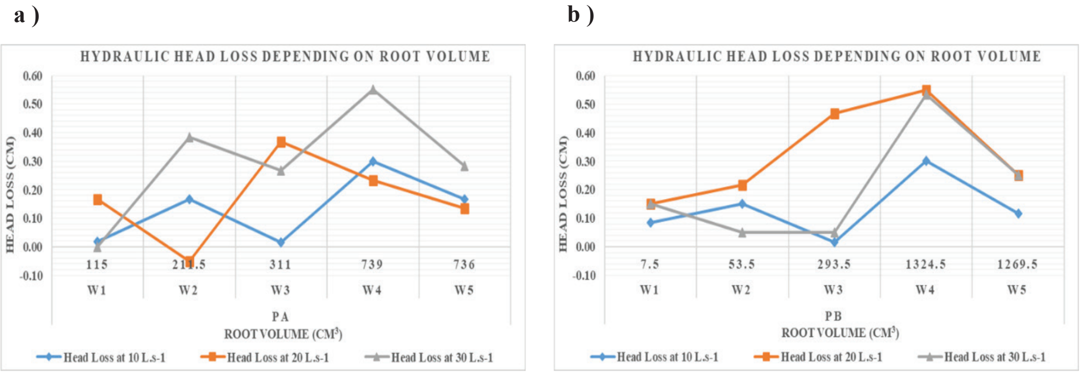
| | | | Q=10 $L.s^{-1}$ | | | Q=20 $L.s^{-1}$ | | | Q=30 $L.s^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Average Water Level(cm) | | | Average Water Level(cm) | | | Average Water Level(cm) | | |
| Plant Species | Water Types | Root Volume ($cm^3$) * | Upstream | Downstream | Hydraulic Head Loss (cm) | Upstream | Downstream | Hydraulic Head Loss (cm) | Upstream | Downstream | Hydraulic Head Loss (cm) |
| Without Plant | | - | 34.35 | 33.60 | 0.75 | 33.77 | 33.07 | 0.70 | 33.18 | 32.43 | 0.75 |
| PA | W1 | 115.00 | 33.37 | 32.60 | 0.77 | 33.37 | 32.50 | 0.87 | 32.65 | 31.90 | 0.75 |
| | W2 | 211.50 | 33.12 | 32.20 | 0.92 | 33.35 | 32.70 | 0.65 | 33.63 | 32.50 | 1.13 |
| | W3 | 311.00 | 33.73 | 32.97 | 0.77 | 33.27 | 32.20 | 1.07 | 33.32 | 32.30 | 1.02 |
| | W4 | 739.00 | 33.35 | 32.30 | 1.05 | 33.43 | 32.50 | 0.93 | 34.10 | 32.80 | 1.30 |
| | W5 | 736.00 | 33.45 | 32.53 | 0.92 | 33.27 | 32.43 | 0.83 | 33.67 | 32.63 | 1.03 |
| PB | W1 | 7.50 | 33.67 | 32.83 | 0.83 | 33.28 | 32.43 | 0.85 | 33.63 | 32.73 | 0.90 |
| | W2 | 53.50 | 32.90 | 32.00 | 0.90 | 32.48 | 31.57 | 0.92 | 33.40 | 32.60 | 0.80 |
| | W3 | 293.50 | 33.43 | 32.67 | 0.77 | 33.67 | 32.50 | 1.17 | 33.30 | 32.50 | 0.80 |
| | W4 | 1324.50 | 33.55 | 32.50 | 1.05 | 33.05 | 31.80 | 1.25 | 32.62 | 31.33 | 1.28 |
| | W5 | 1569.60 | 32.90 | 32.03 | 0.87 | 33.15 | 32.20 | 0.95 | 33.20 | 32.20 | 1.00 |

*Note.* Measurement of root volume was done just after the flume test experiment. The volume of roots for each plant species coming from different types of water was measured by the following method: In the lab environment, the mass of a 1000 ml cylinder filled up with 1000 ml water was measured and noted to determine the mass of 1000 ml water at the lab temperature. Then, the bunch of root biomass for one plant was pushed down to the empty 1000 ml cylinder and the cylinder with roots was filled up with water till the line over 1000 ml. After reaching to 1000 ml, the mass of the cylinder with a mix of both roots and water was measured again. Finally, the difference between the first and second measurements was taken down as the volume of roots belonging to which plant was measured.

The barriers, which consisted of the presence of a distinct volume of roots, produced intriguing results in terms of hydraulic head loss in addition to existence. In parallel to a simultaneous increase in root volume of PA and PB and flow rate, observation of lower water levels in downstream is possible. A close inspection of Table 3 demonstrates that both plant species grown up in synthetic domestic wastewater with low nutrient (W4) brought about a higher head loss at three flow rates in general, and this ratio was up to almost 70 % in addition to constant hydraulic head loss at the highest flow rate 30 L.s$^{-1}$. Comparing the rest of water level drops in downstream side, those plant types taken from control group illustrated almost the same scenario close to the condition of absence of roots through the flume test channel (Figure 10).

**Figure 10**

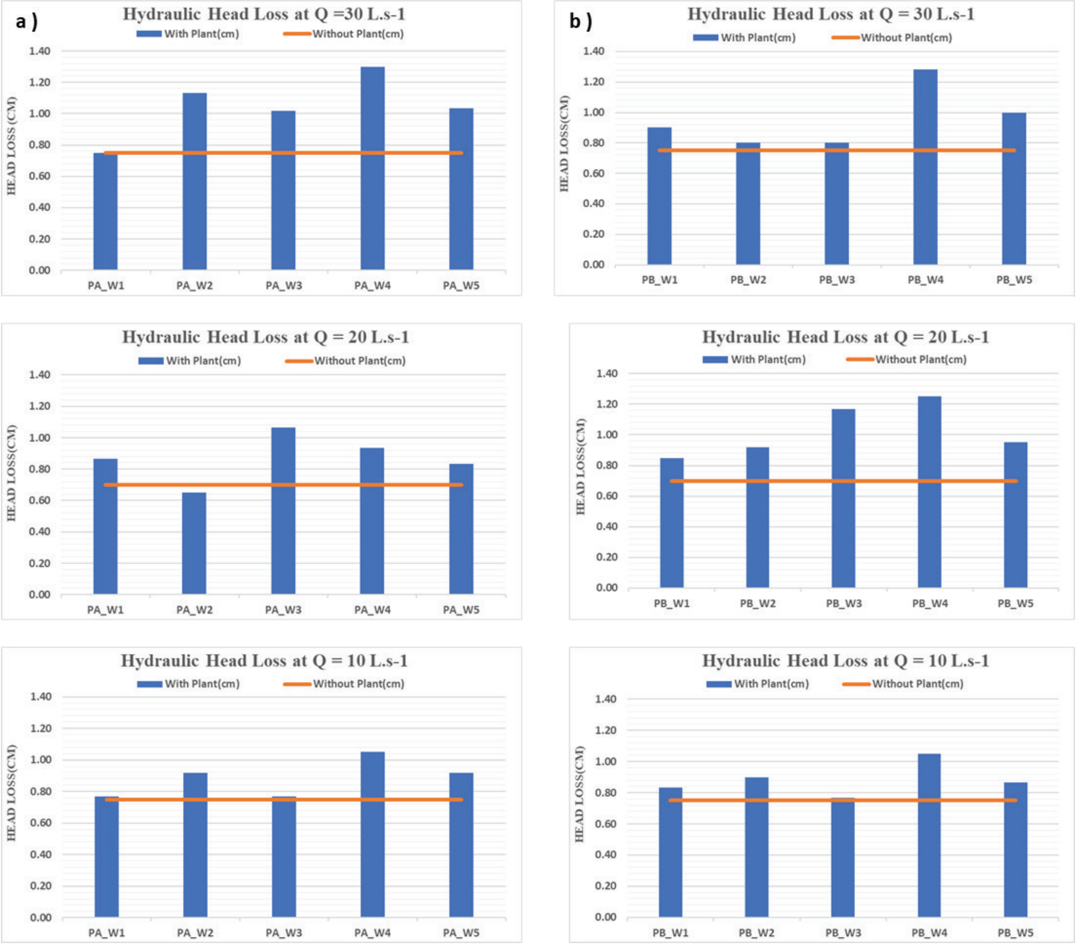
*Values Obtained for Additional Hydraulic Head Losses to Existing in Response to Root Structures with Different Magnitude and an Increased Flow Rate*



*Note.* Hydraulic head losses a = *Baumea rubiginosa* and b = *Phragmites australis*

**Figure 11**

*A Comparison between Two Different Hydraulic Head Losses; Existing Due to Channel Shape and Slope and Due to the Presence of Submerged Root Structures*



*Note.* Hydraulic head losses: a = *Baumea rubiginosa* and b = *Phragmites australis*

Figure 11 represents the hydraulic head losses caused by plants as well as the channel geometry at the same time. Regardless of shape, density, or magnitude of root structures, almost every single submerged plant generated head loss between upstream and downstream to some extent except PA grown in synthetic storm water with low nutrient content. Theoretically, the roots of PA were expected to produce head loss whatever flow rate was since it was grown in the environment put additional nutrients. This phenomenon was assumed to happen due to human involvement since every single stage of the flume test through dye was managed by the involvement of a group of people and measurements were done recorded by a group of researchers instead of devices such as flow meters and so on. Therefore, any error because of human involvement in the flume test cannot be prevented.

According to the results of the correlation test, a positive correlation was found between both root volume, discharge and head loss. In accordance with Table 4, the correlation was found higher between an increased root volume and head loss with $r = .513$, $p$ (.004) <0.01 in comparison with discharge values. In other words, an increase in the volume of roots triggers a more extensive head loss between upstream and downstream of the channel. As discussed by Tavşancıl (2006), the correlation found between two factors can be classified as average, i.e., .50 <.513<.69.

**Table 4**

*Outcomes of Correlation Test in SPSS Applied for Three Inputs; Hydraulic Head Losses Caused by Root Volume and Flow Rate*

| Variables | n | M | SD | Root Volume ($cm^3$) | Flow Rate ( $L.s^{-1}$) | Hydraulic head loss (cm) |
|---|---|---|---|---|---|---|
| Root Volume ($cm^3$) | 30 | 506.10 | 470.08 | - | .000 | **.513**$^{**}$ |
| | | | | - | 1.00 | **.004** |
| Flow Rate ( $L.s^{-1}$) | 30 | 0.94 | 0.16 | .000 | - | .298 |
| | | | | 1.00 | - | .109 |
| Hydraulic head loss (cm) | 30 | 20.00 | 8.31 | **.513**** | .298 | - |
| | | | | **.004** | .109 | - |

$^{**}$ $r = .513$ and $p < .01$

Additionally, the effect of increased discharge on the positive and significant correlation between root volume and hydraulic head loss was also interrogated. Hence the increased discharge sent into the flume test channel is evaluated potentially to create a higher head loss (Table 5). In 95% confidence level, when discharge goes up to 30 $L.s^{-1}$ and potentially above to 30 $L.s^{-1}$, and $r$ reaches from .513 to .657 almost a 28% increase ($p = .039 < .05$). It can be inferred that a large amount of change in hydraulic head loss between upstream and downstream can be generated while keeping root volume as given and flow rate up to 30 $L.s^{-1}$ and above.

**Table 5**

*Outcomes of Correlation Test in SPSS Applied for Three Different Parameters to Evaluate Influence of Magnitude of Flow Rate on Hydraulic Head Loss with the Same Size of Root Structures*

| | | | Root Volume ($cm^3$) | Hydraulic head loss (cm) |
|---|---|---|---|---|
| Discharge Q = 10 $L.s^{-1}$ | Root Volume ($cm^3$) | Correlation Coefficient | 1.000 | .462 |
| | | Sig (2-tailed) | . | .179 |
| Discharge Q = 20 $L.s^{-1}$ | Root Volume ($cm^3$) | Correlation Coefficient | 1.000 | .539 |
| | | Sig (2-tailed) | . | .108 |
| Discharge Q = 30 $L.s^{-1}$ | Root Volume ($cm^3$) | Correlation Coefficient | 1.000 | **.657***[*]** |
| | | Sig (2-tailed) | . | .039 |

[*] $r = .657$ and $p < .05$

## Conclusion

The object of this research was to evaluate how different root volumes of Australian native plants *Baumea rubiginosa* (PA) and *Phragmites australis* (PB*)* grown in normal regular water and synthetic water mixing representing stormwater, and domestic wastewater affected hydraulic resistance against flow current in open channel at different discharge values. Two plant species completing the period of their maturity over a 35-weeks were subjected to a flume test experiment using a dye test with flow rates of artificial water channels set at Q = 10, 20, and 30 $L.s^{-1}$. Before emerging the plants into the channel, the examination of hydraulic head loss due to channel shape was done and recorded at 0.75, 0.70, and 0.75 cm, respectively, at the specified flow rates. The dye test was then measured and observed to monitor changes in flow velocity and direction for ten distinct plant types. According to outcomes of dye injection, both plant species grown in low nutrient domestic wastewater simulation accelerated the flow by almost 16% for PA and 52% for PB at Q= 30 $L.s^{-1}$ among the flow rates adjusted. However, this was slightly less when the flow rates were reduced, especially for the plant types in the control group. Moreover, both plant species grown in synthetic domestic wastewater with low nutrients, i.e., W4 generated a larger hydraulic head loss between upstream and downstream in general. When the flow rate was kept at 30 L.s$^{-1}$, these plant species grown in W4 generated the future 0.55 and 0.54 cm hydraulic head loss to the existing one in comparison to the rest of plant types. When the flow rates are decreased, head losses dropped down simultaneously. To support these findings, results were also analysed via correlation approach in SPSS package, which revealed a strong and substantial correlation between larger and denser root structures and hydraulic head loss between upstream and downstream of the channel. This relation became strong when keeping the flow rate up to 30 L.s$^{-1}$ and potentially above.

Based on the experiment and findings, it is considered and suggested that *Baumea rubiginosa* and *Phragmites australis* might represent a feasible solution to remove the contaminants from stormwater and wastewater body. On the other hand, thanks to their strong and dense root structures, they can be useful in the future to mitigate extreme events like flood by slowing down the flow at the basin level.

Due to human involvement and the necessity of more reliable data collection for the flume test experiment, further studies should be done without any intervention of human involvement by adapting technological tools and machines for readings throughout the flume test experiment.

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## Extended Turkish Abstract
## (Genişletilmiş Türkçe Özet)

### Yüzer Halde Bulunan Bitkilerin Farklı Hız Akış Oranlarına Karşı Potansiyel Dirençlerinin Değerlendirilmesi

Bazen özel amaçlar için geçerli olsa da sürdürülebilirlik açısından dünya genelinde ve ülkemizde kirli suların arıtımı ve tekrar kullanımı oldukça yaygın bir şekilde yapılmaktadır. Su arıtımları geçmişten süre gelen geleneksel arıtma yaklaşım yöntemleriyle beraber son yıllarda yapay olarak inşa edilen sulak alan tipi sistemlerde de yapılmaktadır. Sulak alan tipi yapay olarak inşa edilen arıtma sistemleri, bitkilerin sisteme nasıl entegre edildiğine göre isim almaktadırlar ve bu adlandırmalardan bir tanesi de 2000'li yılların başından itibaren uygulamaya konulan bitkilerin yüzer halde sisteme entegre edildiği yapay sulak alanlardır. Bu tür sistemlerde kirli sularla beraber gelen kirleticiler doğrudan bitkinin biyokütlesine transfer edildiğinden diğer bir ifade ile sistemde besin maddelerini bünyesinde tutacak toprak varlığının olmayışından, bitkiler oldukça hızlı ve güçlü kök ve gövde yapısı göstererek gelişirler (Awad ve ark., 2022). Bu tür su arıtım sistemleri kirletici içeren evsel atık-suyuna ve sanayi atık-suyuna, ayrıca şehirlerde hasat edilen yağmur sularına bu sulardan kirleticilerin uzaklaştırılması amacıyla başarılı bir şekilde uygulanmıştır. Bu tür sistemlerde bitkilerin kirletici maddeleri bünyelerine alabilmeleri için arıtma sistemindeki suyun belli oranlarda hıza sahip olması ve sistemdeki kirletici maddelerini bir noktadan başka bir noktaya hareket ettirmesi sistemin devamlılığı açısından gereklidir. Diğer bir taraftan besin alınımına orantılı olarak sistemdeki bitkilerin kök ve gövdeleri bir gelişim göstermekte, bu proses bitki türüne göre ve kirli suyla beraber kirletici yoğunluğuna göre değişmektedir. Bu açıdan kirli suların arıtımından en iyi performans alınması ve sistemin sürdürebilirliği için sistemin hidrolik parametrelerinin ve bitkilerin ortamdaki su akış hızına gösterecekleri direncin geniş bir şekilde hesaplanıp bulguların sistem tasarımında hesaba katılması gerekir.

Bu araştırmada Avustralya'nın Adelaide şehrinde bulunan Güney Avustralya Üniversitesi'nin Mawson Lakes kampüsünde 10 tane 1000 litrelik su tankı kurulmuş, sisteme A grubu *Baumea rubiginosa* ve B grubu *Phragmites australis* bitkilerinin tank yüzeylerine yüzer bir şekilde adapte edilmesiyle bu bitkilerin su arıtma performansları ve buna bağlı olarak köklerde farklı oranlardaki gelişmenin su akış ortamında su akışına gösterebilecekleri dirençler hesaplanmıştır. 10 adet su tankı 5'erli olarak A ve B şeklinde iki gruba ayrılmış, A grubu *Baumea rubiginosa* ve B grubu *Phragmites australis* temsil edecek şekilde PA (Plant A) ve PB (Plant B) olarak adlandırılmıştır. Daha sonra her iki gruptaki tanklar 950 L su ile doldurularak ve tanklara normal su (W1), az besinli yağmur suyu (W2), zengin besinli yağmur suyu (W3), az besinli evsel atık-suyu (W4) ve zengin besinli evsel atık-su (W5) simülasyonu yapmak için yeterli ve gerekli miktarlarda azot(N), fosfor (P) ve potasyum (K) maddelerini sağlayacak kimyasallar konulup ve tankların alt kısımlarından hava kabarcıkları gönderilerek çalışma başlatılmıştır. Tanklarla kurulan sistemde bitkiler, su gövdesinden kökler yardımıyla alınan besin miktarına, yoğunluğuna ve su kullanım oranına bağlı olarak kök ve gövdelerinden farklı oranlarda gelişim göstermişlerdir. Yaklaşık 35 hafta süren bu çalışmada bitkilerin yeterli erginliğe ulaştığı kanısına varılıp bitkiler kampüs içerisinde bulunan akışkanlar mekaniği test istasyonuna alınmış ve kanala 10, 20 ve 30 $L.s^{-1}$ debilerine sahip akışlar gönderilerek bitkilerin su akışına gösterdikleri direnç ve kanalın memba ve mansap kısmında meydana getirdikleri hidrolik yük kayıpları hesaplanmıştır.

Elde edilen sonuçlara göre her iki bitki türü içinde zengin besinli yağmur suyu ve her iki az ve zengin besinli evsel atık-suyu simülasyonlarında yetişen bitkilerin kök gelişimlerinin ve yoğunluklarının diğer iki su simülasyonuna göre daha fazla olduğu ve su akışına gösterdikleri direncin daha fazla olduğu bulunmuştur. Özellikle *Phragmites australis* bitkisinin *Baumea rubiginosa* bitkisine göre az besinli evsel atık-su ortamında yetişen türlerinin su akışına gösterdikleri direncin ve yapay su kanalının memba ve mansap kısmında meydana getirdiği hidrolik yük kaybının daha fazla olduğu bulunmuştur. Diğer taraftan ölçümlerin araştırmacılar tarafından yapılması diğer bir ifade ile ölçümlerde insan faktörünün olması bazı durumlarda ölçümlerdeki hassasiyetin düşmesine sebep olmuştur. Örneğin, az besinli atık-su simülasyonu ortamında yetişen *Baumea rubiginosa* bitkisi sistemde kanal şeklinden kaynaklı hidrolik yük kaybı olmasına rağmen sistemde negatif yönlü bir hidrolik yük kaybı meydana getirmiştir. Bu açıdan ilerde yapılacak benzer çalışmalarda bütün ölçümlerin elektronik aletlerle hassas bir şekilde yapılması ve ölçümde düşünülen su kanalının daha büyük ve gerçeğe yakın olarak tasarlanması düşünülmelidir.

Sonuç olarak, her iki bitki türü de hasat edilmiş yağmur suyu ve evsel atık-sulardaki kirleticilerin arıtılmasında başarıyla uygulanmış ve her iki bitki türü de kök gelişmişlik yoğunluğuna bağlı olarak su akışına belirli miktarlarda direnç gösterip ve sistemin memba ve mansap kısımlarında su akışını etkileyerek hidrolik yük kayıpları meydana getirmişlerdir. Bu durum bu bitkilerin ve bunlara benzer bitkilerin havza bazlı su akışını yönetmede ve sel felaketleri gibi ekstrem doğa olaylarında kullanılabileceklerini göstermiştir. Ancak konunun daha geniş açıdan araştırılması ve bulguların geniş alanlarda uygulamaya aktarılması için çalışmaların yapılması önerilmektedir.