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"FLOATING FARMS" – USING FARM DRAINS FOR GROWING PRODUCTIVE PLANTS

Bill Carlson[1], Katherine Tozer[1] and Michael Tyler[2]
[1]AgResearch Ruakura, Hamilton
[2]Bay of Plenty Regional Council, Tauranga

Abstract

Floating treatment wetlands (FTW) are a recent, but now accepted approach for improving polluted waters, making use of the water purifying effects of natural wetlands. They are used in New Zealand as a treatment in municipal sewerage and storm water systems, and to improve water quality of run-off water quality from construction and industrial areas. They are also used to improve water quality in lakes and environmental restoration projects. FTWs consist of wetland plants grown in a buoyant mat or structure on the surface of the water. The plant roots hang beneath the floating wetland, eventually forming a dense mass in the water. Because the plants are generally not rooted into the sediments below, they are encouraged to take their nutrients from the water and develop large root systems. Floating wetlands can also inhibit algal growth in the water through shading, and provide additional habitat for aquatic insects, fish and birdlife.

The use of FTWs on farms is still a novel idea, where efforts have focused more on improving riparian vegetation and on constructed wetlands in dairy effluent systems. In this project we examined this question - Using a "Floating Farms" concept, can FTWs on farm drains be used to grow plants to harvest for commercial or cultural purposes?

A small-scale study in a farm drain in the Kaituna Catchment Control Scheme trialled plant species with a range of uses including taro, and wasabi for human food, native plants flax, cabbage tree, sedge, rengarenga and manuka grown on for later transplanting at another site and the pasture species perennial ryegrass, tall fescue, phalaris, lotus.

In this paper we present the results of plant growth and nitrogen uptake in the trial. We also discuss the challenges faced by terrestrial agricultural scientists when conducting a field trial in a dynamic watery environment.

Background

AgResearch has a strong mandate to develop agricultural practices that contribute to 'restoring the health of our water'. Drains transecting intensive farmland are often rich in nutrients which degrade water quality of receiving waterways. In a small-scale pilot project Bay of Plenty Regional Council (BoPRC) had been evaluating the efficacy of installing floating wetlands planted with a range of native wetland plants for removing nutrients.

AgResearch and BoPRC, discussed and developed a novel idea of producing useful plant products while also removing nutrients from farm drains. Instead of planting native plants that remain on the floating wetlands without being harvested, it was hypothesised that intermittent harvesting of an alternative plant biomass would lead to greater uptake of nutrients. A range forage species (e.g. ryegrass, tall fescue, phalaris, lotus): native plants that could be grown on for later replanting at another site (e.g. cabbage tree, flax, rengarenga, manuka, sedge): and food plants (e.g. taro, wasabi) to harvest nutrients and clean up waterways while producing plants which have commercial and/or cultural value made up the treatments in the FTW pilot trial.

Study aims

The aims of the study were:

1) Quantify establishment success of a range of species using the floating farms concept and compare their ability to remove nitrogen (N) from farm drains in the Bay of Plenty area.

2) Identify science knowledge gaps and any development issues which may prevent the scaling up of the proof-of-concept.

3) Collect and publish data useful in developing FTW systems to improve water quality in farm drains and riparian areas.

Methods

The trial site was located in the Internal Drain of the (Kaituna Catchment Control Scheme, with access along farm races and paddocks from Kaituna Road (Figure 1). The drain is large, approximately six metres wide and over a metre deep at its normal water level (Figure 2). The site was approximately one kilometre west of a BoPRC demonstration site located in a smaller side drain (Figure 3). A sample of drain water was collected for evaluation of trial site suitability on 28 October 2020.

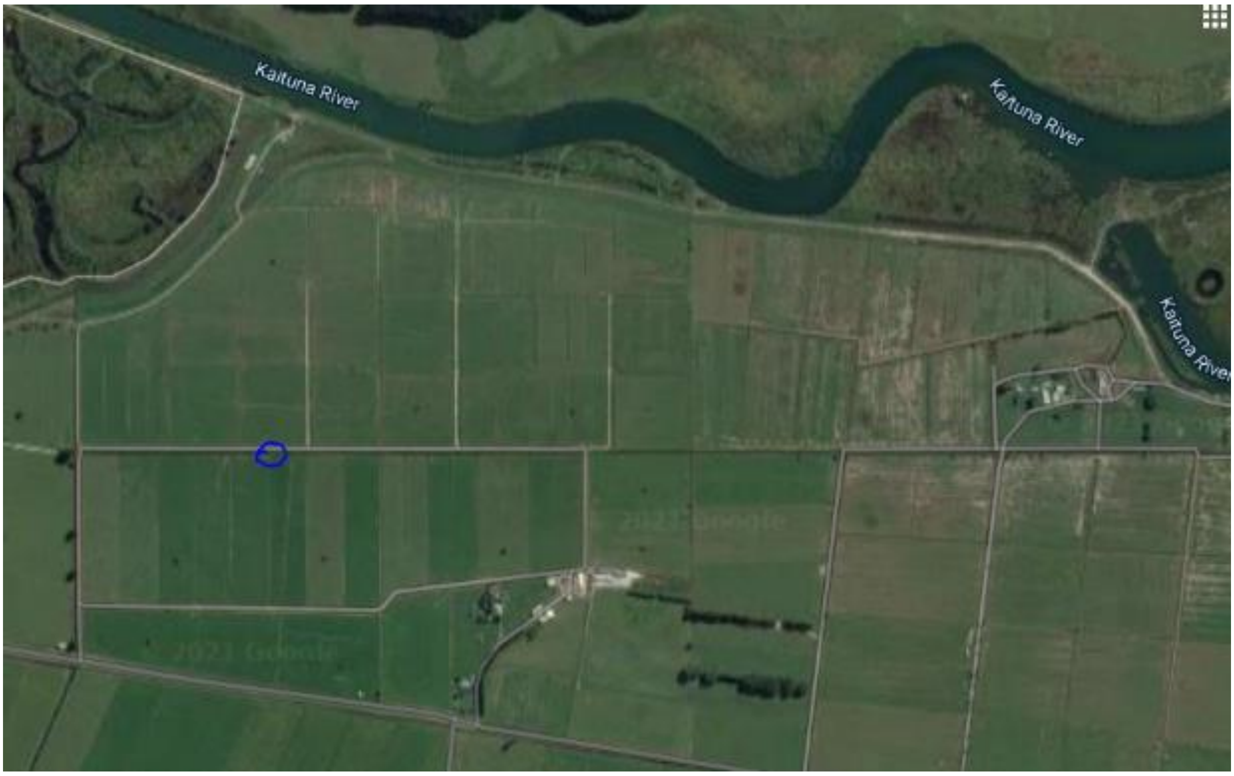

Figure 1: Floating Farms trial site location.

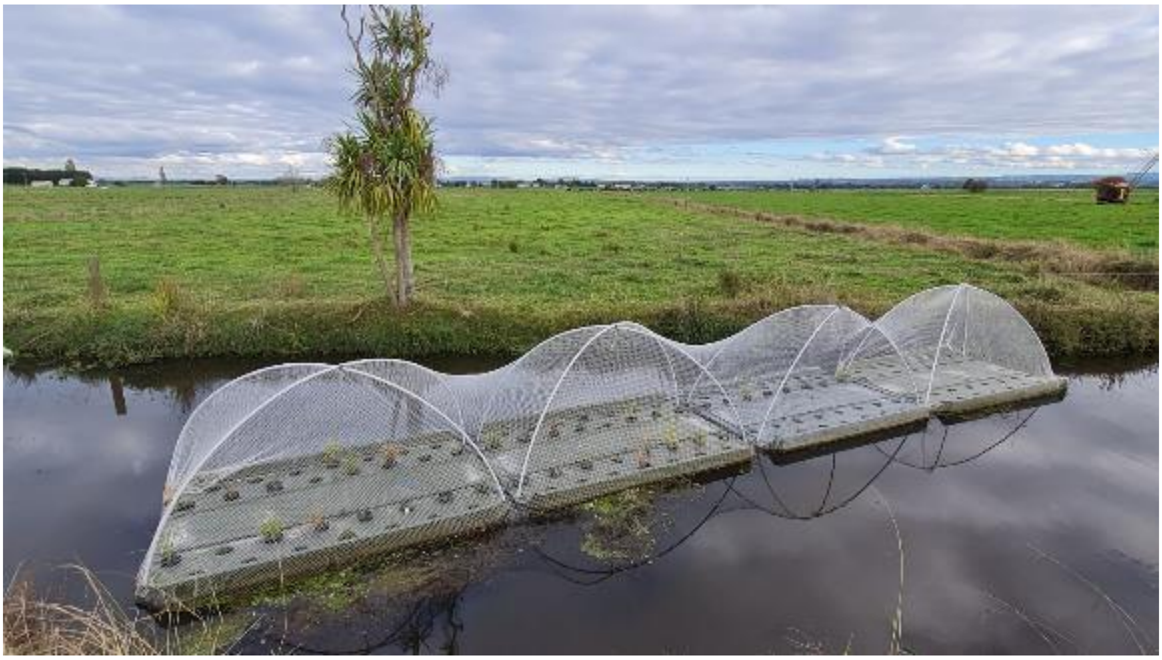

Figure 2: Trial site and floating wetland set-up.

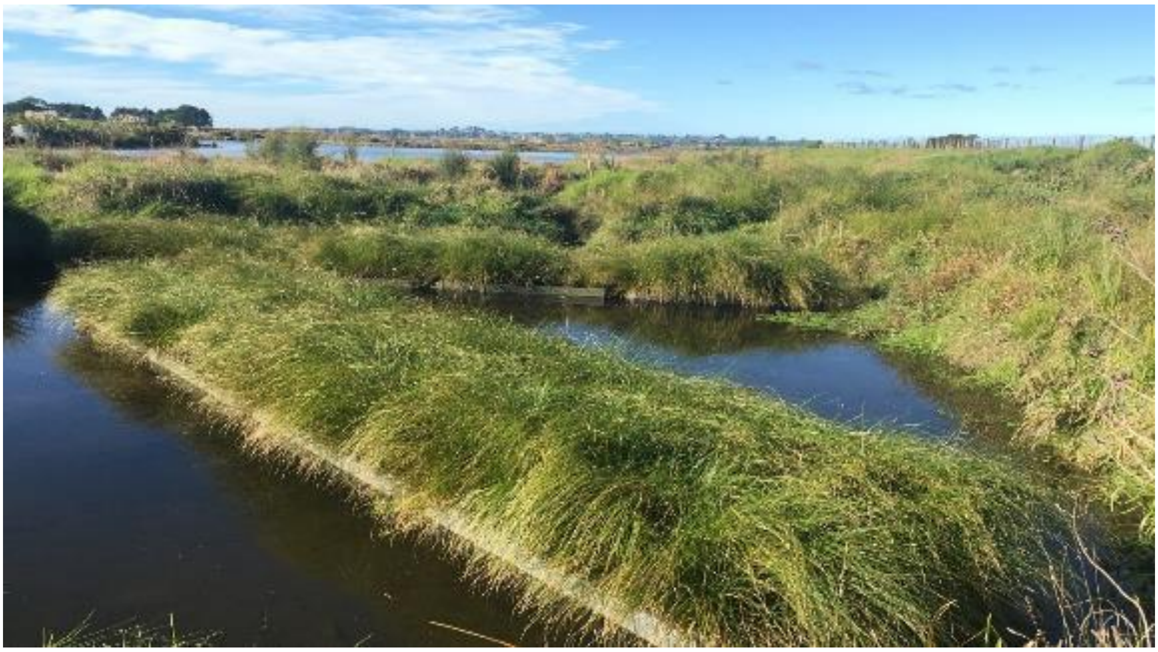

Figure 3: BoPRC demonstration site with floating wetlands of *Carex secta*.

Plant species were selected based on a number of criteria including: likelihood of surviving and growing in an aquatic and potentially saline environment with high sunlight and warm temperatures; availability and suitability of plants to fit in the one litre pots used on the FTWs; usefulness of the species to yield a product with commercial or cultural value; and species likely to take up and hold nutrients from the drain water.

An initial establishment of plants (Table 1) on FTWs was attempted in December 2020 (“Trial 1”) and a second plant establishment (“Trial 2”) was conducted in January 2021.

Table 1: Plant species selection details Trial 1.

Common name	Scientific name	Source	Potential Use
Cabbage Tree	*Cordyline australis*	Commercial nursery	Growing on for replanting
Flax	*Phormium tenax*	Commercial nursery	Growing on for replanting
Manuka	*Leptospermum scoparium*	Commercial nursery	Growing on for replanting
Sedge	*Carex dista*	Commercial nursery	Growing on for replanting
Ryegrass	*Lolium perenne*	AgR nursery plants	Livestock forage
Phalaris	*Phalaris aquatica*	Cores from paddock	Livestock forage
Taro	*Colocasia esculenta*	Commercial nursery	Human food, cultural values
Wasabi	*Wasabia japonica*	Commercial nursery	Human food

The plants for Trial 1 were obtained and potted into one litre pots in late November and established in a plant nursery at Ruakura prior to placement in the FTWs on 14 December 2020.

Trial 1 consisted of eight replicates of each species. Each replicate was randomly placed in the inside rows of the floating structure, with each section having two replicates. The FTWs were covered with netting to prevent damage from birds. Figure 2 shows is an image of the set-up FTW.

Measurements were taken of each individual plant's height and maximum diameter.

During an inspection visit to the site on 14 January 2021 poor plant survival of several of the species, and poor growth by all species was observed. No manuka, phalaris, taro and wasabi plants survived. Cabbage tree, flax, sedge and ryegrass had 100, 88, 50, and 25 percent survival of plants, respectively.

A decision was made to discontinue Trial 1 and redesign a Trial 2, after considering the factors which may have led to poor plant success. Factors identified as possible causes of failure were:

1. Plants sitting too low in the water due to the way the pots fit in the holes in the floating structure. The solution identified was to raise the plants 3 cm by placing the plant pots inside another pot.

2. A very high exposure to direct and reflected summer sunlight, which heated the surface of the floaters making them hot to touch. Proposed solution - place shade cloth over the bird netting that covered the floating wetlands.

3. Some species (taro and wasabi in particular) may not be suitable for growing in these conditions even with these improvements. Proposed solution - select alternative species, or varieties, which may be more successful.

4. Some species had a high leaf area to root ratio (flax, manuka and sedge in particular) which may have reduced the plant's ability to transport sufficient nutrients (and water?) through the small root system to the large leaf area to meet requirements. Proposed solution - trim30% from the leaf biomass.

5. Plants may not have been well enough established in their pots or of a suitable size to survive transplanting into the drain environment.

6. The drain water may not be suitable for growing the selected plants due to a combination of all or some of these; high salinity, inappropriate pH, low available oxygen. Proposed solution - change trial site location to one with less likelihood of saltwater intrusion.

In planning for Trial 2, the proposed solutions from points 1-5 above were implemented. Moving the trial site, point 6, was beyond the resources available for the project.

Plants for Trial 2 (Table 2) were obtained and potted in mid-January and placed in the FTWs on 28 January 2021.

Table 2: Trial 2 plant species selection detail.

Common name	Scientific name	Source	Use
Cabbage Tree	*Cordyline australis*	Commercial nursery	Growing on for replanting
Flax	*Phormium tenax*	Commercial nursery	Growing on for replanting
Manuka	*Leptospermum scoparium*	Commercial nursery	Growing on for replanting
Sedge	*Carex dista*	Commercial nursery	Growing on for replanting
Rengarenga	*Arthropodium cirratum*	Home nursery	Growing on for replanting
Ryegrass	*Lolium perenne*	Cores from paddock	Livestock forage
Tall fescue	*Festuca aurundinacea*	Cores from paddock	Livestock forage
Lotus	*Lotus pedunculatus*	Farm paddock	Livestock forage
Taro	*Colocasia esculenta*	Aotea Marae, Kawhia	Human food, cultural values

The rationale behind each of the plant selections for Trial 2 were:

- Cabbage Tree - High survival in Trial 1. On-growing young cabbage trees for riparian planting seen as a viable option. Cabbage trees grow successfully on the farm drain edges.

- Flax - Good survival rates in Trial 1. Flax for weaving grown in floating wetlands has potential cultural value and is a valuable riparian planting species.
- Manuka - A commonly used species in riparian planting, although this species was not successful in Trial 1 it is still considered a high value species worthy of further testing.
- Sedge - Only moderate success in Trial 1 but had been successful in BoPRC pilot studies in the same drain system thus deemed worthy of further investigation under the new conditions.
- Rengarenga - A hardy plant useful in native plantings.
- Ryegrass - Although not very successful in Trial 1, it is a standard NZ forage plant and so deemed worthy of testing under the new conditions. Trial 1 plants had been poorly established from plants with few tillers, more robust plants from paddock cores with a higher tiller count had potential to be more successful.
- Tall Fescue - A forage species known for salinity tolerance and suitability to wet conditions.
- Lotus - A forage plant adapted to growing in wet conditions.
- Taro - Although not successful in Trial 1, growing taro in floating wetlands has been successful in other cases. The Trial 1 plants were of a variety with oriental/ tropical origins however another hardier variety naturalized in New Zealand was selected for the follow up trial.

Twelve replicates of each of the nine species were established as a randomised complete block design. They were placed in the FTWs on 28 January 2021 in double pots to raise the plant height above the water level, and shade cover installed (Figure 4). Plant heights and diameters were recorded.

Figure 4: Trial 2 site and FTW set-up.

On 4 March 2021, 51 days after installation, plants were assessed for survival and growth. Height and diameter measurements were made on all plants. Three randomly selected plants of each species were removed, taken back to Ruakura, where they were harvested and oven-dried at 65 °C to determine foliar and root dry matter (DM), and subsamples were taken for analysis. On 25 May 2021, all remaining plants were removed from the FTWs and taken back to Ruakura. Plant height and diameter were measured, and all plants were harvested to determine DM, and subsamples were taken for N analysis.

Results and Discussion

Plant measurements

Table 3 shows the average plant heights and diameters prior to installation into the FTWs on 28 January2021. Flax, manuka and sedge plants had been topped to reduce leaf area by approximately 30%. The manuka also required heavy root pruning to fit into the one litre pots. Ryegrass and tall fescue plants were trimmed to 5 cm height. Lotus, taro and rengarenga were left untrimmed.

Table 3: Trial 2 average plant height at installation on 28 January, n=12.

Species	Average Height (cm)	Average Diameter (cm)
Cabbage tree	54	47
Flax	15	10
Manuka	71	32
Sedge	16	16
Rengarenga	20	21
Ryegrass	5	7
Tall fescue	5	8
Lotus	2	7
Taro	18	22

The March 2021 results from the measurements preformed on the three randomly selected plants from each species are shown in Table 4.

All flax, sedge and tall fescue plants survived the first 51 days in the FTW. Eighty-three percent of flax and sedge plants survived with negligible change in height or diameter. Tall fescue plants increased in both height and diameter. There was an 83% survival rate of cabbage trees and rengarenga, but they showed a reduction in the height and diameter due to senescence of the longest lower leaves. Eighty-three percent of ryegrass plants survived. Ryegrass plant height had increased, but shoots were sparse, and leaf blades thin. Only 58% of lotus plants survived, most lotus vegetation had died and there was only a small amount of green leaf remaining. Taro had near complete dieback of the tops present at installation but 50% survived with new top growth. No manuka plants survived.

Table 4: Trial 2 average plant height, diameter and dry matter on 20 March 2021, 51 days after installation.

Species	Number Living	Survival %	Height (cm)	Diameter (cm)	Tops DM (g)	Roots DM (g)
Cabbage tree	10	83	27	32	3.20	3.21
Flax	12	100	18	12	0.88	0.76
Manuka	0	0				
Sedge	12	100	16	15	7.36	7.10
Rengarenga	10	83	7	24	1.75	0.40
Ryegrass	10	83	10	11	1.66	5.45
Tall fescue	12	100	10	16	3.49	13.57
Lotus	7	58	1	1	0.01	0.18
Taro	6	50	5	9	2.57	9.75

n=12 for survival, n= number living for height and diameter; n=3 for dry matters.

Results of plant measurements made on 27 May during the destructive sampling of Trial 2 are presented in Table 5.

Tall fescue was the most successful species with 100% survival and increases in plant height and tops DM however, root mass was reduced by 40% compared to the 20 March 2021 measurements. Cabbage tree plant size and dry matter were similar to 20 March 2021 with 89% of plants surviving. Flax plants showed an increase in root dry matter, but plant size and tops dry matter remained similar, with a plant survival rate of 78%. Sedge survival decreased from 100% to 78% between the two periods, but although the dry matter remained a fairly constant weight it was mostly comprised of dead material and root dry matter decreased. Rengarenga survival was 89%, plant size and tops dry matter reduced, while root dry matter increased. Ryegrass survival was 89%, plants decreased in size and root dry matter decreased by 58%. No manuka, lotus or taro plants survived.

Table 5: Trial 2 average plant height, diameter and tops and roots DM on 27 May, 119 days after installation.

Species	Number Living	Survival %	Height (cm)	Diameter (cm)	Tops DM (g)	Roots DM (g)
Cabbage tree	8	89	26	23	2.91	3.42
Flax	7	78	17	9	0.76	1.14
Manuka	0	0				
Sedge	7	78	15	11	3.48	5.30
Rengarenga	8	89	8	9	1.01	0.70
Ryegrass	8	89	7	7	1.78	2.26
Tall fescue	9	100	12	13	5.17	8.10
Lotus	0	0				
Taro	0	0				

n= Number living

Plant N concentration

Samples of tall fescue, as the most successful of the species grown, were analysed for percent N, in herbage and roots by Dumas combustion (Table 6).

Table 6: Trial 2 N concentration of tall fescue tops and roots

	20 March 2021			27 May 2021		
	%N	StdDev	N, g/plant	%N	StdDev	N, g/plant
Tops	1.4	0.4	0.05	1.2	0.2	0.06
Roots	0.8	0.0	0.11	0.6	0.1	0.05

n=3, 20 March; n=9, 27 May

The N concentrations of the tall fescue tops at both measurements (1.40% and 1.2 %) were low compared to levels typically found in pasture grown plants. Dodd *et al.* 2019 reported N concentrations of 3.0 to 3.4% in tall fescue herbage when grown in pastures with plantain and lucerne.

The N concentrations of the tall fescue roots (0.8% and 0.6%) were also low compared to plants in a pasture situation. Malcolm *et al.* 2018 reported N concentrations of 0.8 to 1.1% in grass roots grown after a winter forage crop.

Drain water salinity characteristics

Results of analysis of drain water samples are shown below in Table 8.
Measurement of water salinity, with results in parts per thousand (ppt), and electrical conductivity (EC) in units of µS/cm are closely related and used for related purposes.

Table 7: Drain water characteristics

	Salinity	Electrical Conductivity	pH	Dissolved oxygen
Date	ppt	µS/cm		g/m^3
28 October 2020	0.200	561	7.5	4.42
24 June 2021	1.70	3480		

Drain water salinity on 28 October was 0.200 ppt and electrical conductivity (EC) was 561 µS/cm. According to standards published by the New South Wales Department of Primary Industries most crops, including salt sensitive crops, will accept irrigation water EC levels up to 700 µS/cm without yield loss.

FTWs are in effect a hydroponic growing system. Recommendations for water in hydroponics are crop specific but in general are EC<1500 µS/cm, pH 6.0-6.5, and dissolved oxygen > 5 g/m^3 *(*van Os *et al.* 2016*).* The drain water pH on 28 October 2020 was 7.5, which is within an acceptable range for most plants, but could be limiting for alkaline sensitive plants.

The water test on 24 June showed a salinity of 1.70 ppt and an EC of 3480 µS/cm. These levels are highly saline and would have serious effect on plant growth and survival.

The Internal Drain on which the trial was located empties into the Kaituna River approximately 2 kilometres east of the trial site. The drainage system is designed to prevent the tidal or flood flow of water from the river into the drains. However, it is known that there is incursion of river water into the drains in some areas of the system. A combination of high tides, easterly winds and a low flow of fresh water into the system is likely to have caused the trial site to periodically experience high salinity.

Conclusions and further work

While certain species, notably tall fescue and cabbage tree, survived, no species thrived, and most species died. Given that some of the unsuccessful plants have shown success in other FTW scenarios, it is important to narrow down the reason for failure in this case, whether it be water quality, especially the high salinity, pH, low dissolved oxygen, high temperature or an interaction between one or more. In hindsight, the selection of a site where salinity had the ability to fluctuate so much was regrettable when the focus was around plant species that were not, in general, salt tolerant.

Despite what disappointing results from this trial, there is nevertheless opportunity to make use of FTW technology on farm drains, waterways and ponds across New Zealand. Using the learning and infrastructure from this pilot study, further research could be conducted in waterways that offer more ideal conditions.

The environmental benefits have been demonstrated. However, uptake of the concept has been limited. Further work in this area should focus on removing barriers to the uptake of the concept by land managers. Infrastructure and labour costs are the usual deterrents. Another deterrent may be the use of plastic structures in the water which can be seen as less than desirable. Proposed further work includes development of FTWs using natural fibres, and systems which require less labour input, and which can capture nutrients and contaminants for removal from a wetland environment.

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