Stormwater Australia 2012 National Conference Paper

Research Paper Title: Floating reedbeds biofilter performance in urban stormwater treatment wetlands

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Abstract: Floating wetlands and reedbed biofilter research investigations undertaken by Tom Duncan during the period 2004 – 2013 have resulted in a significant body of research data being developed. Data in the paper demonstrates improved water quality resulting from the utilization of floating reedbeds. Projects have been completed in Australia, China and Malaysia involving the author. For the reference of the reader, the floating reedbeds that have been researched in this paper, mainly involve the Aqua Biofilter™ floating reedbed. Floating biofiltration technologies and design strategies have been refined over time, and this paper presents some of the most innovative field research completed to date on verifying the water quality improvement of floating reedbeds.

Sometimes termed floating wetlands or floating islands, the objective is to treat stormwater, wastewater and contaminated water of all kinds. The methodology is to utilise terrestrial and wetland species, grown on floating beds on the surface of stormwater sediment ponds and wetlands, or eutrophic lakes and ponds, waste water and contaminated water lagoons, to purify the water so as to treat the water quality to the desired level or fit for purpose level. In stormwater wetlands, the retrofit of floating biofiltration technologies restores ecological integrity of the aquatic ecosystem in which the system is embedded, mopping up nutrients, pollutants and metals, and also de-nitrifying difficult to treat nitrogen. The mechanism of treatment is through absorption and utilization of nitrogen, phosphorus and suspended solids by plants, and removal of colloidally suspended heavy metals, out of water body into the rhizosphere (root zone), in addition to de-nitrification and release to atmosphere of nitrogen gas. Results demonstrate that wetland plants grown on top of the water, can effectively purify water, with 15%, 30% and 45% plant coverage of the water surface, to a high standard. ANZECC Water Quality Guidelines for aquatic ecosystems and rivers require stringent standards. Floating biofilters have the potential to elevate water quality from 'poor' and 'degraded', up to the 'excellent' specification, as seen in the Chinese research of Dr Song, under the Chinese National Water Quality targets of Class I for Lakes, in particular, the Lake Taihu trial.

The mechanism for the treatment of nutrients, metals and minerals is via the rhizosphere exerting a strong algal and bacterial biofilm that acts as a fine mesh through which the stormwater column passes, shedding it's pollutant load onto the sticky biofilm. Further pollutant processing occurs under aerobic and anaerobic conditions inside the root zone and under the root zone respectively, to be further metabolized by the rootzone associate biofilms, transferring nutrients, minerals and metals into the roots and shoots of the plant, over sustained periods of time whilst also assisting denitrification to atmosphere. Lab tests presented in this paper, detail the levels of nutrients, minerals and metals inside plants and water prior to and at completion of trials. Research partnerships are sought with Australian Universities.

Keywords: Floating Treatment Wetlands, Stormwater Quality, Biofilter, Floating Reedbeds, Eutrophic Lake, Water Purification, Biofilm, Toxic Blue Green Algae, Microbial Treatment, Nitrogen, Phosphorous, Suspended Solids, Heavy Metals, Anaerobic Denitrification, Azolla Net Nitrogen Producing Water Assets,

Recent case studies

Wagga Wagga City Council, NSW, Australia
Council commissioned Tom Duncan and Aqua Biofilter™ to construct 120m2 of floating wetlands in Wollundry Lagoon that had been experiencing serious algal blooms, fish kills and stagnant odor problems. The problem was particularly urgent as Wollundry Lagoon occupies a significant portion of the Wagga Wagga Central Business District (CBD) and was an issue raised by community, local businesses as an urgent environmental problem that needed bioremediation.

The water quality is being monitored by Council and has been observed as increasing significantly in water transparency, decreased turbidity, no algal blooms and no fish kills throughout the hot summer of 2014 / 2015.

Photo above shows typical AquaBiofilter™ floating wetlands after installation at Wagga Wagga City Council Lagoon with young plants in establishment phase. Bird netting is important to prevent birds from trampling or consuming young plants.

Photo above shows typical AquaBiofilter™ floating wetlands after installation with maturing plants at 9 months growth at Wagga Wagga City Council Wollundry Lagoon.

Gold Coast City Council, Queensland, Australia

Gold Coast City Council commissioned Tom Duncan and a team associated with Aqua Biofilter™ floating reedbeds, to develop a experimental trial installation of 520m2 floating reedbeds, to improve water quality in sediment pond and lakes that experience toxic blue green algae (cyanobacteria) blooms. Particularly of concern for the Gold Coast Council, whom own a significant amount of water assets with excess nutrients from a highly urbanized environment and sub-tropical rainfall of over 2m per year, was the reduced amenity of surface water bodies including recreational lakes that had previously been used for swimming, triathalons, canoe and kayaking, in addition to impacts on catchments, waterway health and marine receiving environments and beaches.

Public health issues and contamination of freshwater and marine environments have been significant issues for Council and community. The only other options presented to Council were dredging and de-silting of water bodies, an expensive approach considering sediment can often exceed prescribed low level hazardous waste thresholds requiring expensive disposal costs, usage of phosphorous locking power, and aeration that has expensive operating costs, and restructuring the water bodies completely into conventional cell wetlands with sediment ponds and GPTs as per conventional approaches. Conventional wetlands would have been very expensive given the vast area that water bodies make up in the local Government area, and the requirement of considerable land area required and available land is becoming more expensive and in smaller supply as density of the city increases. Cost comparisons against conventional wetlands, to floating reedbeds, made the floating reedbeds on average 3.2 times cheaper than alternatives. Floating reedbeds were considered a cost effective solution to complex diffuse stormwater pollution issues and excessive sedimentary nutrients. Additionally, the floating reedbeds can eat into sedimentary nutrients as demonstrated in the China trial featured further on in this paper, remediating sedimentary nutrients.

Water quality indicators from samples taken by Gold Coast City Council demonstrated eutrophic conditions after storm events, whereby the sedimentary nutrients were re-suspended and mobilized into the water column, fuelling algal blooms, including toxic blue green algae. The concern with this particular algal bloom is that as the algae dies, it can release poisonous compounds into the water, which sometimes produce fish deaths, and the resulting ecological contamination throughout the food chain, and primary contact for humans is considered risky and is an ongoing issue for Council as owner of the water assets. The algae blooms and fish kills had also resulted in poor air quality from rotting fish corpses and stagnation affecting communities.

Above photo of coir model. Timelines precluded use of above model with GCCC.

A trial of floating reedbeds was chosen by Gold Coast City Council for several reasons, among which were cost competitiveness, effectiveness of the floating reedbed technology to remove nutrients that fuel algal blooms. Not all floating reedbeds have scientific data to demonstrate the effectiveness of the technology, hence the author was commissioned to carry out the construction. However, given severe time constraints put on the project by small window of opportunity, the product usually specified by the manufacturer of floating reedbeds (Aqua Biofilter™) used by the research author, could not be utilised with the lack of lead time. This meant that improvisation with less sustainable materials, was necessary and is advised not be repeated on future projects.

The floating reedbeds developed by the author is one of the few demonstrated and published technologies that has been installed both in Australia and involved internationally in countries such as China, with proven and quantifiable results. Plant species selection was based upon locally endemic species that have demonstrated effectiveness in trials in Australia and exotic species utilised in China. Additional sources of information include the Monash University Facility for Advanced Water Biofiltration (FAWB) results that demonstrated the excellent nutrient removal performance of Carex species including Carex appressa and Carex fascicularis. http://www.monash.edu.au/fawb/projects/project1.html

Plant density was 16 plants per square metre (16 / m2) to eliminate any need for further planting out if plant mortality was significant. Project results have demonstrated over 95% plant survival rate due to the design methodology and materials utilized in the floating reedbeds such as coir material which is a sustainable bio-resource materials left over as waste from de-husking coconuts, and this plant media supports excellent plant growth, wicking of water and significant biofilm production early on in the growth of the plants. The coir fibre acts as a vast matrix upon which biofilm can filter out pollutants, enhancing the treatment effectiveness. Natural fibres such as coir fibre are sustainable, non-toxic and do not release compounds into the water column that some plastic plant growth media release over time. Emphasis on sustainable materials is part of the overall ecological approach to ecosystem health and lifecycle embedded energy with low carbon footprint than plastic based plant media.

At time of installation June 30, 2011

A total of 8320 Carex plants were incorporated into the floating reedbeds of 520m2 and plants after 3 months plants have doubled in root and shoot growth. Water quality indicators are being monitored by Gold Coast City Council to measure improvements as the plants grow to maturity. As plant roots grow to maturity nutrient processing volume will increase and once maturity is reached the nutrient processing will be optimal. The process of nutrient absorption and de-nitrification occurs through a variety of mechanisms, including the anaerobic processing of nitrogen underneath the mat of floating reedbeds and in sediment, underneath the dense root zone transforming nitrogen and ammonia into nitrogen gas released to the atmosphere which delivers authentic de-nitrification.

At time of installation June 30, 2011

After 3 months growth, October 2011

After 3 months growth, October 2011

Smaller drain brings flows from the catchment into lake sediment basin at southern end

After 3 months growth, October 2011

After 5 months growth, December 2011 water quality significantly improved. No azolla growth, usually a thick blanket is growing by December

After 5 months growth, plants 1 metre high in centre of reedbed. After 1 year all plants will be at maturity 1 metre high, with root systems approximately 0.5m – 2m deep depending on water depth.

Dark green foliage is noticeable at month seven, indicating the plants are approaching maturity on the inner layers of floating reedbed where not subject to bird predation. Bird nets are sometimes necessary in first year of establishment, or significant predation can potentially reduce effectiveness of treatment through reduction of plant rootzone and plant shoots. Trampling and nesting can also influence growth negatively in first year of establishment, as per conventional wetlands. The same careful approach to establishment should be taken for floating reedbeds as sediment rooted wetlands.

After 5 months growth, December 2011. Aeration can be seen in main lake, receiving water from sediment basin in which reedbeds installed.

It is expected to publish water quality data when Gold Coast City Council has collected enough data with mature plants having been in the sediment basin for sufficient length of time to draw conclusive remarks based upon data. Verbal discussions with Council indicate that results are ‘Excellent’ with significant improvement in water quality indicators. The sediment basin in December, usually is completely covered in azolla in a thick blanket, drawing atmospheric nitrogen as well as soluble nitrogen into their biomass, which dies off after some time, putting all accumulated nitrogen and sediment into the lake, which is a net nitrogen production activity. In this aspect, whilst azolla is native, it has weedy tendencies due to its blanket effect, and building up of nitrogen and sediment into the sediment pond and lake. Nitrogen release from azolla die off exacerbates the nutrient volumes in the sediment basin and lake, leading to worsening water quality year on year. As a result, the intensity and frequency of algal blooms and aquatic weeds increases each year. This scenario is typical of many sediment basins where azolla or other aquatic weeds have taken hold. An appropriate design strategy would instead be to install floating reedbeds into sediment ponds, to ensure that the ecological niche on top of the water with abundant nutrients and sediment is occupied by a beneficial specie that is not adding further nutrient and sediment loads to the water system, and instead is stripping nutrients and pollutants out, whilst denying algae and azolla nutrients to bloom.

The floating reedbeds provide an alternative ecological function,and occupy this niche that is usually inhabited by aquatic weeds and algal blooms. This management intervention and has prevented azolla growth, and water quality has improved concurrently. Water transparency increase has been observed and no algal blooms occurred which was a significant factor in measuring the success of the trial.

February 2012, after 7 months growth. Plants reaching maturity with dark green foliage, compared to December 2011 foliage of light green on outer plants. Water quality greatly improved, no azolla due nutrient being processed by floating reedbeds. Water transparency increased greatly.

February 2012 after 7 months growth. Stormwater inflows can been seen entering the sediment basin where the floating reedbeds treat the water.

Water Quality Data before installation
Source:Draft Management Plan, Gold Coast City Council

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Chemical Analytical Results **Page 1 of 1**

	Sample Reference	J-0707-288-03 Surface Water#3	J-0707-288-04 Surface Water#1	J-0707-288-05 Surface Water#2
	Sample Point	Surface Water#3	Surface Water#1	Surface Water#2
	Date Collected	27/07/2007	27/07/2007	27/07/2007
	Date Received	27/07/2007	27/07/2007	27/07/2007
	Date Testing Completed	3/08/2007	3/08/2007	3/08/2007
WC250.232	Nitrite + Nitrate as N	0.04 mg/L	0.03 mg/L	0.03 mg/L
WC250.65_ WC270.312	Total Nitrogen as N	0.62 mg/L	0.57 mg/L	0.59 mg/L
	Total Phosphorus as P	0.40 mg/L	< 0.02 mg/L	< 0.02 mg/L
WC270.113	Orthophosphate as P	0.35 mg/L	0.013 mg/L	0.016 mg/L
WC400.X	Chlorophyll a	18 μg/L	15 μg/L	12 μg/L
WP100.X	Suspended Solids	3.0 mg/L	< 1.0 mg/L	< 1.0 mg/L

Notes:

Samples are disposed of 14 days after completion of testing.
Results reported on an 'as received' basis

Source: Draft Management Plan, Gold Coast City Council

Figure 29. Filamentous Green Algal mats observed in the Lake following flushing of lake water after 21 August 2007 rainfall event.

Source: Draft Management Plan, Gold Coast City Council

Table 7. Concentrations of water quality parameters during two storm events

analyte	parameter	units	Date 21/08/07	Date 29/10/07	accepted values*
physico-chemical	DO	% saturation	76.0	73.1	90.0 - 110.0
	DO	mg/L	7.0	6.0	-
	Conductivity	µS/cm	145.0	560.0	20.0 - 30.0a
	pH		7.5	8.0	6.5 - 8.0
	Turbidity	NTU	28.2	33.4	1.0 - 20.0
	Temperature	°C	18.9	27.1	-
	Chlorophyll-a	µg/L	25	9	< 5
	TSS	mg/L	13	23	-
nutrient	NOx	mg/L	0.30	0.10	< 0.01
	TN	mg/L	0.76	0.51	< 0.25
	TP	mg/L	0.14	0.13	< 0.03
	FRP	mg/L	0.150	0.072	< 0.015
microbial	Faecal Coliforms	CFU / 100ml	1160	3980	150b 1000c
phytoplankton	Cyanobacteria	cells/ml	3000	1500	< 20000
hydrocarbon	Total Oil and Grease	mg/L	-	<10	-

* values adopted from the QWQG (EPA 2006) for slightly to moderately disturbed systems, except where noted

[a] values for slightly disturbed ecosystems in South-east Australia

[b] value for primary recreational contact

[c] value for secondary recreational contact

non-compliance with accepted limits

Source: Draft Management Plan, Gold Coast City Council

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Microbiological Analytical Results **Page 1 of 1**

	Sample Reference	J-0707-288-03 Surface Water#3	J-0707-288-04 Surface Water#1	J-0707-288-05 Surface Water#2
	Sample Point	Surface Water#3	Surface Water#1	Surface Water#2
	Date Collected	27/07/2007	27/07/2007	27/07/2007
	Date Received	27/07/2007	27/07/2007	27/07/2007
	Date Testing Completed	3/08/2007	3/08/2007	3/08/2007
WB302.23	Faecal Coliforms - WW	10 CFU/100mL	17 CFU/100mL	17 CFU/100mL
WB361.	Algal Identification and Count	14,000 Cells/mL	2,700 Cells/mL	3,300 Cells/mL
	Diatoms	< 10 Cells/mL	< 10 Cells/mL	< 10 Cells/mL
	Flagellates	1,400 Cells/mL	230 Cells/mL	170 Cells/mL
	Green Algal Count	3,600 Cells/mL	1,100 Cells/mL	910 Cells/mL
	Red Algal Count	< 10 Cells/mL	< 10 Cells/mL	< 10 Cells/mL
	Yellow-Green Algal Count	< 10 Cells/mL	< 10 Cells/mL	< 10 Cells/mL
WB361.5	Blue-Green Algal Count/ID	8,800 Cells/mL	1,400 Cells/mL	2,200 Cells/mL

Estimate pollutant reduction levels

Pollutant concentrations in the sediment basin over one year after installation are believed to have been reduced significantly from the above sample levels prior to the trial. The author estimates a 40% reduction in total nitrogen (TN) and estimates a reduction of 60% total phosphorous (TP), and a reduction of algae (chlorophyll) by 70%, and increase in transparency by 130%.

As data is collected further by Gold Coast City Councils, these estimates will be further elaborated upon. Estimates are inferred by previous performance in past trials, and resultant water quality monitoring. Additionally, visual inspections were carried out a 2 and 3 month intervals regularly, with significant visual and odour improvement over the period, with no azolla blanket or algae bloom outbreaks observed during the 12 months of the installation.

The research author is waiting upon Gold Coast City Council water quality monitoring data that will be provided to the research author at the appropriate time, to further validate estimates of pollutant reductions.

Sydney Olympic Park Authority (SOPA)
Water bird refuge in marine estuary - habitat floating islands
Sydney Olympics in year 2000 set the world benchmark for a Green Olympics that still sets the standard for excellence. Extremely rare, threatened and endangered marine estuary ecosystems exist within the Sydney Olympic Park Authority area over hundreds of hectares within Sydney City, New South Wales (NSW), Australia. The Badu mangroves estuary has black swiflet water birds and also migratory birds that travel from Australia up to Korea and Siberia every year. The tidal water level variation is approximately 1 metre twice per day, and the floating islands were designed to rise and fall one metre per day, and provide an island habitat for the water birds. The tidal gate is powered by solar panels and regulates the tidal flows.

The existing earth mound island was being inundated in high tide which destroys the rare and endangered bird nests and consequently their eggs which is keeping the marine estuary water bird population low. Due to very rare saltmarsh ecosystems on site, the sensitive ecosystem could not be subject to the impacts of earthworks machinery. Aqua Biofilter™ and the Ecoplan Consulting Pty Ltd team of environmental scientists, planners and engineers surveyed the site with Sydney Olympic Park Authority (SOPA), identifying suitable sites for floating islands installation and appropriate materials for migratory and local water birds for nesting. Coconut fibre beds were combined with long lasting food grade plastic floatation frame covered to prevent UV degradation. Marine grade materials were utilised to ensure long term integrity of the floating islands. Sydney Olympic Park Authority rangers collected salt marsh bush seeds from on site, which the Aqua Biofilter™ and the Ecoplan team sowed into the floating islands before launching the islands into the marine estuary. This is a world first that marine species have been integrated into marine floating islands. The primary purpose is habitat, but over time other marine plants will add to biofiltration benefits for the water quality and roots will provide habitat for aquatic species. Installation of 120m2 in total was completed June 2012, made up of two islands, both 60m2 each. It is expected that bird watching enthusiasts will be able to utilise the bird hides located on site to view the rare water birds nesting, also alongside black swans which are a popular favourite with the locals.

Stormwater treatment with floating reedbed biofilter technology – research

During the research period from 2004 to 2009 author Tom Duncan action field tested various floating biofiltration design strategies, and developed a trialed and proven stormwater design treatment methodology. As a result of this research far more is now known about Australian conditions, species performance and water quality improvement of floating reedbeds, floating wetlands and floating islands, to effectively reduce nutrients and pollutants in water bodies. Sediment ponds and conventional ponds, wetland deep zones and lakes are all suitable for floating treatment wetlands. The water sensitive urban design approach to treat stormwater pollutants at source, is enhanced through the application of floating biofiltration in sediment ponds, as part of an enhanced treatment train, pre-filtering the stormwater column before entering the wetland. This can produce significant cost savings through reduced wetland management and excavation of sediment, due to a more advanced sediment control system at the initial treatment train entry. Denitrification occurs in the sediment pond at an advanced rate if the floating biofiltration system is designed thus, to create an anaerobic zone under the floating reedbeds, and in the rhizosphere (root zone), where particulate and pollutants accumulate an aerobic environment is created. The mixed aerobic and anaerobic zones inside and under the rootzone respectively, delivers genuine de-nitrification and enhanced nitrogen processing from biofilm sloughing into the sediment with a vastly increased surface area of biofilm on plants roots, as compared to conventional wetlands that rely somewhat on plant leaves biofilm to catch soluble nutrients, and then slough off down into sediment where de-nitrification under anaerobic conditions occurs. Uptake of phosophorous by plants occurs sporadically and settling of phosphorous attaching to fine sediment is also a function of convention construction wetlands, whilst phosphorous is taken up by plants quickly in floating wetland designs due to the almost hydroponic effect.

The mechanism for the treatment of nutrients, metals and minerals, is via the rhizosphere exerting a strong algal and bacterial biofilm that acts as a fine mesh through which the stormwater column passes, shedding it's pollutant load onto the sticky biofilm. Further pollutant processing occurs under mixed aerobic and anaerobic conditions inside the root zone, to be further metabolized by the rootzone associate biofilms, transferring nutrients, minerals and metals into the roots and shoots of the plant. Lab tests presented in this paper, detail the levels of nutrients, minerals and metals inside of the carex plants prior to the Bega wetland trial, planting out in July 2008, and 14 months later at field research project conclusion, October 2008.

Field research and lab testing reveals a higher distribution of nutrients and minerals to roots rather than shoots, and particularly metals distribution to be mainly in the root zone. As leaf shoots senesce, the mechanism for nitrogen loss from the system to atmosphere, occurs naturally, whereby the floating pontoon acts as a barrier, preventing nitrogen and carbon to re-enter the water column, keeping the stormwater column free of detritus and nutrients as the plant senesces. Conventional wetlands have sediment rooted plants that feature leaf senescent activities when plant growth ceases or flooding occurs. This die off process reduces wetland performance effectiveness, due to loss of biofilm, release of large volumes of nutrient rich biomass back into the stormwater column & subsequent receiving waters.

In the photo at right, the left container is sample taken during an algal bloom, and the right container, after floating reedbed installation. The mechanism for the control of algal blooms is through the reduction in available nutrient. The floating biofiltration technology acts as a very fast and effective mop up of nutrients, fuelling plant growth year round, through appropriate species selection. Denitrification occurs more rapidly, as does the changing of colloidal heavy metals under intense anaerobic microbial and algal biofilms, transferring metals from a colloidally suspended state in water, to an elemental form being taken into the roots of hyper-accumulator plants. The methylating of mercury and storage in roots is also of interest, for bio-remediation applications, in lakes and contaminated water sites, as are hydrocarbons.

Bega Urban Stormwater Wetlands, Field Research Project, 7/07 – 10/08
Site Description

The middle area of Bega Annabranch Wetland pictured below, receives most of Bega township (NSW) urban stormwater, with a catchment of over 60 hectares. The anabranch wetland becomes Bega River's flowpath in flood events, which is a 1 in 5 year ARI event. Floods regularly raise wetland water levels by up to 7 metres.
a flood event caused the floating reedbed technology, to rise 5 metres, and fall back by 5 metres after the flood.

Thick dense root mass, reduces TSS, TN, TP and intercept the 'difficult to treat' colloidally suspended metals in the stormwater column entering the wetland at velocity.

Stormwater low flows entering anabranch stormwater wetland, to be filtered by floating biofilter, from > 60 ha urban catchment

Bega River floods into anabranch wetland catchment > 1000ha

Annabranch Wetland receives all stormwater low flows from impervious catchment > 60ha

Pictured below, Bega Urban Wetland research project site, Carex fascicularis performing well

Bega Urban Floating Wetlands Project Description
In partnership with community and Government agencies, a trial was developed for the Bega township urban wetlands. Bega has some of the most significant natural wetlands on the south coast of New South Wales within an urban and rural catchment. The Bega urban wetlands drain to the Bega river, and subsequently to the fragile Tathra marine estuary with it's vast breeding grounds at the ocean inlet. The chosen wetland site, receives the majority of Bega's urban and semi-rural stormwater for the majority of the town, over 60 ha of catchment, with a large impervious catchment contributing flashy flows and heavy pollutant loads, and in flood events receiving Bega river waters from over >1000 ha catchment.

Species utilization was based upon the needs of the existing wetland ecosystem, and through consultation with local endemic flora and fauna experts, it was decided that a mix of the following plants would be suitable – Bolboshoenus, Baumea, Carex, Juncus. Sterile vetiver was also identified but was not utilised. Subsequent floating treatment wetland trials with vetiver have demonstrated that indeed that plant is sterile and does not rhizomatically creep beyond its small natural area. The most successful specie identified via the Bega urban wetlands trial, was Carex fascicularis, a very high performer in terms of nutrient, mineral and pollutant uptake, high rates

of plant growth, demonstrating good vigour and health over an extended period in a variety of conditions. This research concurs with findings from Monash University Facility for Advanced Water Biofiltration (FAWB) whom in partnership with EDAW, illustrated carex to be a high performer in lab simulated raingarden biofilters, with a high uptake of nitrogen. Source:
http://www.monash.edu.au/fawb/projects/project1.html

Carex fascicularis and appressa were tested at conclusion of Bega urban wetlands research project, for nutrient, minerals and metals concentrations in root and leaf tissue. Results show increased nutrient, mineral & metals levels, with the large biomass increase. There is good reason to believe that the uptake of nutrients and metals would continue, due to leaf senescing activity, rhizhomatic creeping nature of the plants selected, and autogenesis of new plants from the rhizome stock, with highly complex anaerobic/ aerobic rhizosphere zones, biofilms facilitating rapid plant root autogenesis. Plants however would not move out of the floating reedbed zone, as they are marginal wetland species and not dominant in wetlands.

Carex fascicularis being weighed prior to plant out in July 2007, small viro-cells, 20 grams/ plant

Carex fascicularis being measured prior to plant out in July 2007, small viro-cells, 30 cm in length

Carex fascicularis at field research trial conclusion, in October 2008, approx. 3.3 - 4 kilogram wet weight.

Carex fascicularis at field research trial conclusion, in October 2008, 2.2 metres length

Carex fascicularis lab tests below, conducted before planting out, July 2007, reported Feb 2008.

Sample No	**020247380**
Test Code	P2
Lab Report No.	
Lab Report Date	22/02/2008
Paddock Name	B.E.N.D.
Sample Name	Carex
Sample Type	Tissue
Sample Depth (cm)	-
Sampling Date	

Assay	**Unit**	**Value**
Nitrogen (Kjeldahl)	%	1.90
Nitrate Nitrogen	mg/kg	50.0
Phosphorus	%	0.29
Potassium	%	2.30
Sulfur	%	0.21
Calcium	%	0.58
Magnesium	%	0.25
Sodium	%	0.01
Chloride	%	0.86
Manganese	mg/kg	180.00
Iron	mg/kg	65.00
Copper	mg/kg	3.70
Zinc	mg/kg	47.00
Boron	mg/kg	7.50
N/P Ratio		6.6
N/K Ratio		0.8
N/S Ratio		9.0

Fertilser in seedling mix accounts for some of nitrogen present in seedlings.

Lab tests below conducted at end of field research, October 2008, reported Nov 2008

Sample No	**020247384**
Test Code	P2
Lab Report No.	
Lab Report Date	11/11/2008
Paddock Name	Bega Wetland Trial
Sample Name	Carex Vasicularis Roots
Sample Type	Tissue
Sample Depth (cm)	-
Sampling Date	

Assay	**Unit**	**Value**
Nitrogen (Kjeldahl)	%	1.70
Nitrate Nitrogen	mg/kg	200.0
Phosphorus	%	0.24
Potassium	%	1.10
Sulfur	%	0.31
Calcium	%	0.67
Magnesium	%	0.43
Sodium	%	0.10
Chloride	%	0.20
Manganese	mg/kg	4300.00
Iron	mg/kg	42000.00
Copper	mg/kg	20.00
Zinc	mg/kg	230.00
Boron	mg/kg	240.00
N/P Ratio		7.1
N/K Ratio		1.5
N/S Ratio		5.5
Moisture at 105 degrees celsius	%	77.0

The volume of nitrogen increases with biomass growth from 50mg/kg at planting, up to 200mg/kg inside of a 4 kilogram plant after 14 months growth. Over time, the plant will continue to accumulate nitrogen, senescing leaf nitrogen matter to atmosphere & denitrification under rootzone which contain anaerobic pockets.

Additional denitrification pathways include the conventional sedimentary based anaerobic denitrification to the atmosphere – the difference with floating reedbeds is that the process is sped up exponentially, due to the vastly bigger algal and bacterial biofilm on the rootzone, which in conventional wetlands relies instead on biofilm on plants leaves, which is far less in surface area for biofilm to catch nutrients and fine sediments laden with phosphorous. Roots of floating reedbeds provide far greater surface area and treatment efficacy than leaves, of conventional wetlands.

Research Conclusions
The volume of nitrogen removed in 14 months was equal to 20 kilograms at 9 plants / m2 and approximately 40 kilograms of nitrogen at 16 plants / m2 after lab tests confirmed the nitrogen values in the plants analysed. The planting density at 16 plants per square metre, made up a small floating reedbed of 200 square metres. The installation costs were minimal, at approximately $20,000.

Stormwater Quality Improvement - Performance
The average reduction in pollutants in the stormwater can be projected as:
Total Nitrogen Reduction 33-50%
Ammonia Reduction – 55%
Total Phosphorous Reduction 30-50%
Total Suspended Solids Reduction 30-80%
Chlorophyll Reduction – 80%
Increase in Stormwater Transparency 50- 252%

Technical & Site Considerations
The Aqua Biofilter™ floating reedbeds were anchored by a concrete anchor and chain. The concrete anchored chain reached the bottom of the wetland, and was of sufficient length so that in a flood event, the floating reedbeds simply rise with the water, and fall with the water, in the same way a boat stays nearly stationary, whilst anchored in the ocean waters under tidal ebb and flow motion. The anchoring of the floating reedbeds means that in a flood event, the concrete anchor holds the floating reebed line in place, avoiding any chance of loss during flood. This guarantees the safety of the reedbeds and manages risk effectively. The Bega stormwater wetlands trials experienced a flood event that occurred during the trial in 2007, producing a height differential of 5 metres, whereby the stormwater volume rose to such an extent that the anabranch water level, had a 5 metre rise during the flood, throughout which the floating reedbeds went up and down by 5 metres in level.

The floating reedbed system trialed, delivered effective treatment of pollutants in the test area, by creating anaerobic and aerobic pockets of water in close succession, providing a micro-treatment train within the floating reedbed zone. The reedbeds were spaced apart, in the deeper water area in the middle of the anabranch, so that strips of anaerobic and aerobic water was interspersed, keeping water viable for aquatic wildlife and biota, whilst maxmising processing power. The floating system provided bird safe havens amongst the reeds with nesting and grazing opportunities, and several nest sites and eggs observed. Water lizards and monitors were observed, as were turtles utilising the safe haven. By being in the middle of the water, this allowed access to birds and amphibians, free from terrestrial predators. A floating island performs the function of habitat, at less cost than conventional islands, and provides treatment, thus should be considered superior to conventional earth mound islands, that are often difficult to vegetate, and when water levels drop, the island is no longer an effective island, and often an eyesore or even land bridge.

Bird netting was not required in this instance, but in some wetland establishment phases, bird netting is necessary in the first 6 – 12 months of establishment, as per conventional wetland establishment. Observed wildlife on the floating reedbeds for refuge habitat included turtles, water monitors and lizards, rare and threatened birds, native frogs, fish eggs in rootzone. In addition to the benefits in aquatic biodiversity cleaning up pollutants in the stormwater, native fauna use the floating islands as refuge and habitat.

Summary

The benefit of floating reedbed technology, is better performance, lower costs, less requirements for excavation, and more water for re-use if applicable. Floating biofiltration should be a serious consideration when designing sediment ponds, wetlands and lakes. Maintenance is not an issue, as once installed past the 12 months establishment phase, there is little or no maintenance, above that of a conventional wetland or sediment pond. No special management is required once installed, and the cost is far less than an elaborate treatment train of serial wetlands or retro-fitting wetlands into existing lakes. Stormwater quality improvement with conventional wetlands and sediment ponds, in urban contexts will prove to be more costly as reduced land availability and the cost of land escalates. Floating wetland and reedbed biofilters offer a cheaper, reliable and flexible treatment train enhancement, particularly retro-fitting into poorly performing water assets.

Research Cooperation Partners

Research conducted by the Aqua Biofilter™ team on site in China, with researchers in 2004 at Lake Taihu, China's third largest lake, demonstrates that the floating treatment wetland approach can reduce chlorophyll (algae and phytoplankton) at a rate of nearly 80% or above. The floating reedbed approach demonstrates clearly how algal blooms affecting a stormwater lagoons, can rapidly clear after installation, reducing chlorophyll from 0.110 mg/L to a low 0.025mg/L. The Lake Taihu, China project, yielded the following research results. The author was involved in developing the floating wetland strategy at Lake Taihu and a holistic approach to stormwater management and monitoring evalution. The research presented in tabular form in partnership with the Aqua Biofilter™ team to demonstrate research outcomes in this emerging field of floating biofiltration.

Photos by Research Author Tom Duncan.

The above floating reedbeds utilise ornamental species that have good nutrient processing ability and fast root zones growth. Species included Egyptian sedge (Cyperus papyrus L.) and Canna lily (Canna *generalis* Bailey), both of which performed very well, with trial results provided below. Ipomea was also trialled, but due to poor growth was discontinued in the trial. The trial was 4 months long, and plants at 8 per square metre (8/m2).

Table 2 Comparative study on characteristics and dry matter of test plants *

Test plants	Testing date	Stem height (cm)	Root length (cm)	Stem number (stem/clump)	Dry matter (g/m^3)		
					Above water	Under water	Total amount
Cyperus	4/8/04 12/9/04 12/12/04	25.1 50.6 98.9	21.6 42.0 58.5	4.8 27.6 67.2	100.1 1928.4 6622.6	18.9 274.0 937.4	119.0 2202.4 7560.0
Canna	4/8/04 12/9/04 12/12/04	29.7 87.2 112.5	23.8 42.0 59.1	1.5 4.2 5.7	53.0 548.0 4857.8	6.8 92.5 365.6	59.8 640.5 5223.4
Ipomoea	8/8/04 5/9/04	8.0 65.0	0 40.5	1.5 10.0	10.0 350.0	0 61.5	10.0 411.5

*1. Harvesting date: Dec 12 for Cyperus and Canna and Sept 5 for Ipomoea
2. Dry matter above water includes stem, leave and flower; dry matter under water, root
3. All are mean value in three treatment areas

Table 3 Comparative study on dry matter and N and P removal rate among different plant coverage areas*

Cov (%)	Dry matter (kg/area)				Net removal of N			Net removal of P		
	Cyperus.	Canna	Ipo	Amount	g/m2	kg/ area	%	g/m2	kg/area	%
15	296.7	385.5	47.5	729.7	52.37	7.07	95.2#	20.67	2.79	422.7#
30	739.9	1047.5	121.1	1908.5	76.78	20.74	279.1#	33.33	9.00	1363.6#
45	1061.7	1503.0	175.9	2740.6	70.32	28.48	383.3#	29.48	11.94	1809.1#

*1) The total area of 15%, 30% and 45% floating reedbed is $135m^2$, $270m^2$ and $405m^2$, respectively.
2) The biomass of dry matter for each area includes plants above water and under water, being the shoots and roots.
3) The net amount of N and P removed by plants is the dry matter of the plant multiplied by the percentage of N and P with the initial amount of nutrients in seedlings deducted.
4) The removal rate (%) of N and P means the actual removal of N and P by harvesting plants to measure uptake, divided by the initial TN and TP in water body.
5) # values indicated by # are over 100% in most cases, because the plants entered the sediment and started absorbing the nutrients in the sub-strata

Table 4 Parameters on average in different test areas and their category of environmental standards of surface water*

Cov. (%)	TP mg/L	Class	NH_3-N mg/L	Class	COD_{Mn} mg/L	Class	BOD_5 mg/L	Class	DO mg/L	Class	pH	Class
0	0.21	V-	0.51	IV	23.9	V-	18.08	V-	7.4	I	8.6	IV-V
15	0.16	IV	0.34	I	8.4	IV	6.90	IV	6.4	I	7.7	I-III
30	0.10	II	0.34	I	6.0	III	3.99	III	5.5	III	7.4	I-III
45	0.09	II	0.22	I	5.1	III	2.8	I	5.0	III	6.9	I-III

- Data monitoring is in treatment zones under the study, with differing coverage ratios of surface area, shortened to cov. & Class of water as CLASS. Class V is very degraded & Class I China's National Lake Water Quality Targets, similar to ANZECC guidelines, however, the values differ between countries and ecosystems, according to aquatic environment behaviour and ecological signals.'

Table 5 Comparison between other parameters in different test areas. (Note these figures are only during the 4 months establishment phase of the trial and not from mature plants. Once plants mature and root zone is maximized, processing power is increased exponentially with biofilm contact)

Coverage (%)	TN (mg/L)	Chlorophyll a (mg/L)	SS (mg/L)	Turbidity (degree)	Transparency (cm)
0	2.99	0.110	33.8	48.6	46.9
15	2.83	0.092	31.8	38.9	66
30	2.32	0.035	16.8	27.6	118.3
45	1.95	0.025	11.8	20.4	165.1

Research Conclusions

The above data from tables 2 – 5 indicate the following reductions over 4 months establishment phase in pollutants when the surface area of 45% was covered by floating reedbeds:

- 55% reduction of ammonia
- 80% reduction in chlorophyll
- 53% reduction in total phosphate
- 80% reduction in Biological Oxygen Demand (BOD)

If installing less surface area coverage such as 30%, there are still significant reductions in pollutants, resulting in a reduction of chlorophyll for example of approximately 70%, resulting in less phytoplankton and algae that bloom under conditions of high nutrients and stagnant water. Plants were at 8 / m2 for all trial areas, and at 45% coverage with an area of 405m2, this resulted in 28.48kg total nitrogen removed. Floating reedbed installations generally have had 16 plants / m2 and over one year, as has been shown in the Bega trial, delivered at least 40kg nitrogen sequestration over one year when at 16 plants / m2, more than double the effectiveness of the China trial in 2004 over the period of one year.

Lake Taihu, after 5 months growth, Egyptian sedge (Cyperus papyrus L.) and Canna lily generalis Bailey, root zone has grown dramatically in the stormwater weir, part of Lake Taihu.

Photos by Tom Duncan.

Nanjing combined stormwater, sewage, biodigester and floating wetland treatment system

The floating wetland trials in Nanjing's urban stormwater system, demonstrating effective treatment performance in nutrient and pollutant removal. At the invitation of research scientists the Aqua Biofilter™ team became involved in the overall water quality improvement strategy, monitoring and evaluation of the project. The project was innovative in that the biomass is harvested for biomass energy applications, producing biogas and electricity for the local residential demand in the growing capital city, whilst mixing local blackwater and organics waste to boost biogas production and re-use for energy and heat.

The nutrient and energy cycling aspect to the approach is advanced and the ongoing will lead to future breakthroughs in technology applications and developments.

A highly urbanized stormwater catchment, with large impervious catchment feeding into waterways. Sewer cross connection issues, and large volumes of gross pollutants, resulted in a design with a plastic weir and trash screen to collect gross pollutants and litter, and floating biofiltration systems to mop up the suspended solids, nutrients and metal loads that remained in the stormwater and sewage flows. This approach to urban stormwater and waterways management is low cost but high impact water quality improvement. It is compatible with Australian conditions, where waterways still receive excessive pollutants from point and non-point sources that can difficult to treat with dwindling urban land resources.

The floating treatment wetlands are innovative in an artistic, educational and cultural sense, with the centerpieces being Chinese script, viewable from the high rise apartments and offices looking over the river, as seen below providing a positive message to community about water that states "Respect Water".

Photos by Tom Duncan

An on-site urban anaerobic biodigester, processes high nutrient biomass harvested from waterway lagoons, is mixed with precinct blackwater and produces biogas, heat and electricity for the local residential and office demand. The biodigester designed the pulse flow anaerobic biodigester, specifically to handle the diverse green organic waste streams delivered by floating wetland systems, which also included floating water hyacinth beds sectioned off by floating booms, harvested once per month and mixed with blackwater.

Photos below by Tom Duncan.

Biogas production at trial plant – aspiring to become a zero emissions urban development, worlds best practice ecologically sustainable design. A model for

China’s intense peri-urban environment, whereby impacts on waterways can be mitigated, and large demand for energy in some part satisfied – a natural synergy.

Floating Wetlands with vetiver phytoremediate heavy metals contaminating drinking water reservoir

Floating wetlands trials in drinking water reservoir contaminated by industrial, rural and mining leachate pollutants, are innovative and vast in their scale. Aqua Biofilter™ advised using sterile vetiver to effectively treat and phyto-stabilise the toxic metals and was involved in develop design strategies for treatment of heavy metals and removal from the water reservoir thought to be affected by mine leachate metals and hydrocarbons.

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Water supply catchments affected by polluted run-off, can be remediated through the application of floating biofiltration technologies. Large scale use of sterile vetiver achieved, to uptake and stabilise difficult to treat metals, in a cost effective manner.

Stormwater Australia 2012 National Conference Paper

Research paper: Floating reedbeds biofilter performance in urban stormwater treatment wetlands

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