University of Southern Queensland

Faculty of Health, Engineering and Sciences

THE FEASIBILITY OF USING CONSTRUCTED WETLAND SYSTEMS FOR URBAN WASTEWATER

A dissertation submitted by

Yvette Lieschke-Mercer

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Abstract

Constructed treatment wetlands are used globally to treat stormwater and a variety of wastewater for the effective removal of nutrients and pollutants. This technology is a proven method for water treatment and is gaining greater momentum in its application in Australia. The technology allows for reductions in construction and ongoing capital costs such as energy consumption as is seen in traditional wastewater treatment works. In addition, this technology can reduce the need for chemical dosing treatment of waste water management systems.

Treatment wetlands are a passive system capable of treating primary, secondary and tertiary effluent, however, predominantly they have been employed to treat wastewater beyond the secondary level, often referred to as effluent polishing (Kadlec and Knight, 1996). Treatment wetlands are more commonly applied to the treatment of stormwater runoff however are also effective for treating human wastewater, industrial, mining and agricultural effluent. The reuse and reclamation of treated waste water is gaining momentum especially in countries where water is or is becoming more of a scarce and expensive resource but will also provide a benefit in terms of environmental sustainability with respect to the health of our waterways and our water resources in general.

Investigation into the feasibility of a passive treatment system was undertaken for a large urban population to determine if civil costs, operational costs and EPA load based license fees have the potential to be reduced. Specifically the comparison of the efficacy of two types of constructed wetland systems was undertaken. A traditional constructed wetland and a floating treatment wetland were compared, as part of the treatment process for municipal wastewater to meet discharge limits and to determine which type of wetland has greater viability with regard to its actual footprint, land availability and also treatment efficiency. The Constructed Wetlands Manual (DLWC, 1998) as well as sizing methodology put forward by Kadlec and Knight (1996) and Reed et al. (1995) were utilised to determine wetland surface area.

Floating treatment wetlands appear to be the most feasible option in terms of land footprint and enabling the retrofitting of existing structures, however in terms of treatment efficiency and installation costs have resulted, in this study, not to be a feasible option or alternative to the current wastewater treatment systems for Bathurst Regional Council without further trials and being undertaken both in terms of refining the treatment efficiency and also investigations in how to reduce the capital costs of installing a floating treatment wetland.

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Yvette Lieschke-Mercer

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Acronyms

AL – Assessable Load

BOD – Biochemical Oxygen Demand

BRC – Bathurst Regional Council

CF – Calculation Factor

COD – Chemical oxygen demand

DO – Dissolved Oxygen

DLWC – Department of Land and Water Conservation

EAT – Extended aeration tank

EP – Equivalent persons

EPA – Environmental Protection Authority

FTW – Floating treatment wetland

HLR – Hydraulic loading rate

HRT – Hydraulic retention time

IDEA - Intermittently decanted extended aeration tanks

LGA – Local Government Area

PL – Pollutant Fee

TN – Total Nitrogen

TOC – Total organic carbon

TP – Total Phosphorous

TSS – Total suspended solids

UV – Ultra violet

WWTW – Wastewater treatment works

1. Introduction

Constructed treatment wetlands have been implemented globally to improve the water quality from a wide range of industries; two most notably include stormwater runoff and the treatment of agricultural and municipal wastewater for the effective removal of nutrients and pollutants. This method of effluent treatment has wide ranging applications in North America and Europe although it has not been widely adopted in Australia; however, it is growing in popularity due to its effectiveness as a proven method for water treatment. Australian interest in the treatment method was seen to decrease in the 1990s which is thought to have been attributed to data reporting relatively low capacity for phosphorous removal in combination with more stringent discharge requirements put in place by the governments in terms of high quality tertiary treatment of effluent. There was also some concern as to the potentially for constructed wetlands to provide an ideal environment for mosquitos (Greenway, 2005). If constructed wetlands are correctly designed and managed then they will not serve as a breeding ground for mosquitoes (Greenway, 2005).

Treatment wetlands, when properly designed, have the ability to enhance environmental protection opportunities. They demonstrate optimized assimilation capabilities, as wetlands, both natural and constructed, exhibit a higher rate a biological activity than most natural systems and have the ability to transform pollutants into harmless by-products and even nutrients that can be utilised in further applications. In their different forms, constructed wetland technology can remove a high level of nutrients without leaving behind chemical sludge residue. Constructed wetlands also provide valuable habitat and additional public use functions (Kadlec and Knight, 1996).

Treatment wetland technology is capable of treating stormwater runoff from urban, agriculture and industry as well as wastewater from the same types of sources. Primary and secondary and tertiary components of municipal wastewater can be treated effectively using constructed treatment wetlands, however, predominantly they have been employed to treat wastewater beyond the secondary level, often referred to as effluent polishing. For small to medium communities, constructed treatment wetlands may provide a relatively low cost alternative for treatment and disposal of wastewater as opposed to conventional treatment technologies. For medium to larger cities a more viable alternative is to combine conventional treatment technologies with natural systems such a constructed treatment wetlands for further polishing of the effluent to meet discharge requirements (Kadlec and Knight, 1996).

The reuse and reclamation of treated wastewater is gaining momentum especially in countries where water is or is becoming more of a scarce and expensive resource. In addition to providing a basic resource, municipal wastewater that has been treated can also provide nutrients essential for plant growth and can be further utilised as a fertiliser for agricultural purposes as well as parklands and sporting fields which in return reduces the cost in terms of purchasing and the manual application of fertilisers.

The costs associated with the implementation of wetland treatment technology has the potential to be much less than construction costs associated with conventional treatment systems as they generally only consist of earthworks, pipes and associated inlet/outlet structures and vegetation planting. Conventional wastewater treatment technology utilises a combination of biological, chemical physical processes to achieve a standard of effluent that meets discharge limit requirements. Initial construction costs and ongoing capital costs for such technology can far exceed those of a constructed treatment wetland. Constructed wetland costs however, may or may not be cost effective if additional costs are incurred when available land space is limited and further land is needed to be acquired for construction purposes or if the geology and landform of a site is such that extensive earthworks are required.

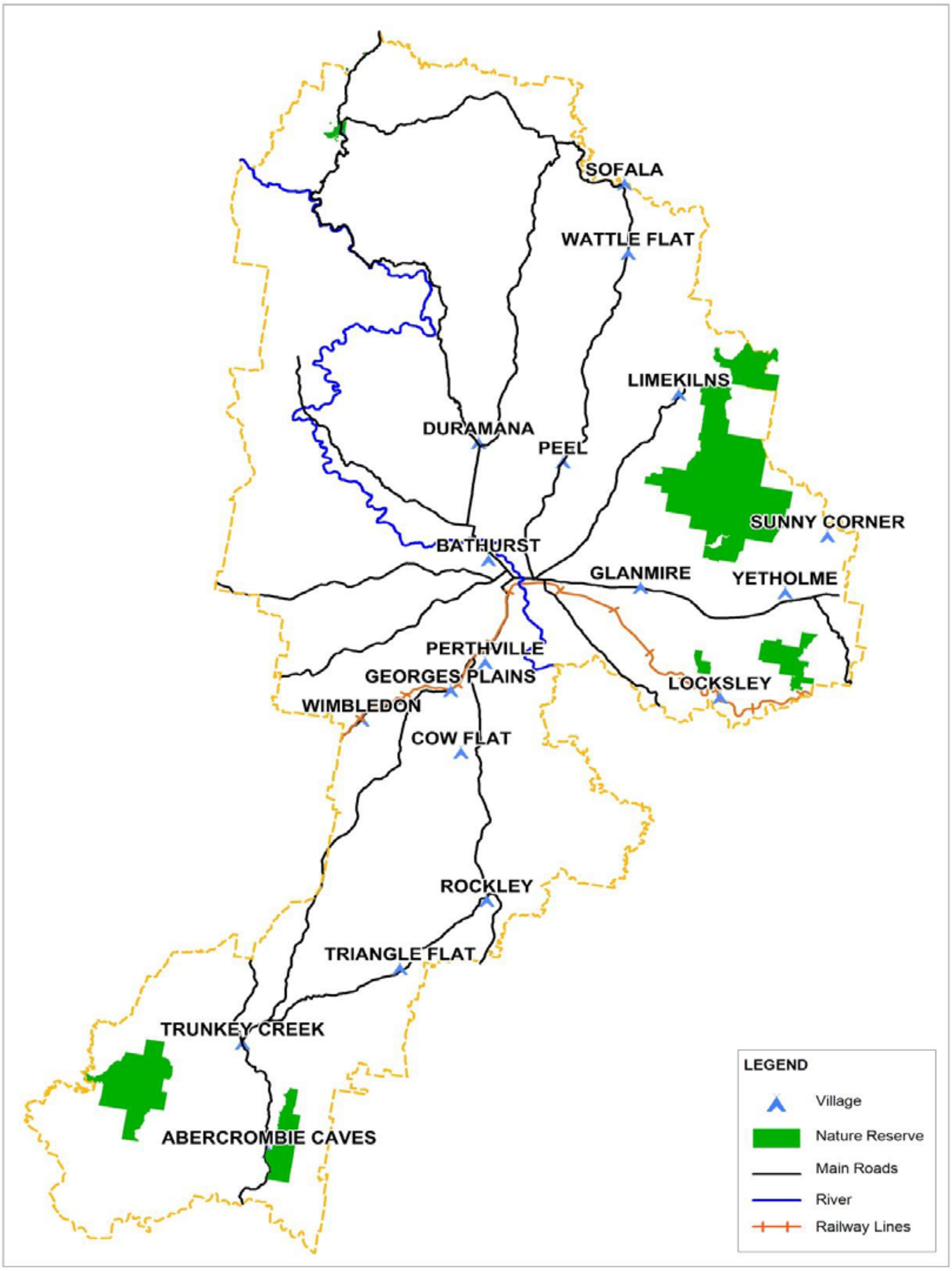
A solution to the limitations in terms of land area and land acquisition costs is the emerging technology of floating treatment wetlands providing an alternative option. This technology employs the concept of placing rooted emergent macrophytes on a floating pontoon that is placed on the water surface where the roots extend into the water column of a wetland or pond rather than into the sediments. The roots provide an extensive surface area for the attachment of biofilms and particulate matter and in turn the plants uptake nutrients from the water (Weragoda et al., 2012). There is flexibility in terms of water depth with this technology and fluctuations in water levels are tolerated to a higher degree than with plantings in typical constructed wetlands where water inundation can cause significant plant losses. Greater water depth capacity also enhances treatment efficiency in that more water can be stored and detention times can be extended (Tanner and Headley, 2011).

1.1. The Bathurst Region

Bathurst is located approximately 200 kilometres west of Sydney at the junction of the Great Western, Mid-Western and Mitchell Highways. The Local Government Area (LGA) of Bathurst covers an area of 3821 square kilometre and includes village and rural communities from Hill End to the north, Trunkey Creek to the south, Sunny Corner to the east and Fitzgerald’s Mount to the west. The City of Bathurst is the main urban centre within the LGA and is the oldest inland settlement in Australia, being declared a town site in 1815 and proclaimed a town in 1852. An overall map of the Bathurst LGA is provided in **Figure 1.1-1**.

Industries in Bathurst include education, being one of the largest, pet food, timber, food manufacturing and transport. These industries, along with retail, agriculture and health provide Bathurst with a diverse economy and employment opportunities and potential for economic growth.

Bathurst has a varied and unique natural environment with land based and aquatic ecosystems providing a diverse habitat for a wide variety of natural flora and fauna. Widespread clearing, land use changes and other habitat modification has placed increasing pressure on many of these ecosystems causing widespread degradation.



Source: BRC (2015)

Figure 1.1-1 Bathurst Regional Council Local Government Area

The Bathurst region is located in a cool temperate climate zone which experiences a variable climate with mild to warm summers and cool to cold winters and can experience light snow falls. The average minimum and maximum temperatures for the period of 1991 to 2015 are presented in **Table 1.1-1**.

Table 1.1-1 Average Temperatures for Bathurst for the period 1991-2015

Month	**Mean Minimum Temp (°C)**	**Mean Maximum Temp (°C)**
January	13.6	28.5
February	13.5	27.2
March	10.4	24.5
April	6.3	20.6
May	3.0	16.3
June	1.9	12.6
July	0.8	11.9
August	1.2	13.8
September	3.7	17.1
October	6.0	20.2
November	9.3	23.6
December	11.5	26.4
Average	**6.7**	**20.2**

Source: BOM (2015)

1.1.1. Bathurst Wastewater Treatment Plant

The first treatment system was completed in 1920. It was composed of large septic tanks with the effluent outflow passing over rubble filters before being directly discharged into the Macquarie River. By 1930 a more complex system was developed that still incorporated the septic tanks but in combination with trickling filters and an experimental system in the form of Imhoff tanks. Additional facilities for the drying of solid waste in the form of sludge and as well chlorination of the effluent were also developed. The septic tanks were completely abandoned in 1965 with the development of a conventional trickling filter system.

Inlet works consist of a number of step screens which incorporate the processes of screening, washing and dewatering as well as a grit removal system to remove and wash fine particles, sand and grit. These inlet works improve the efficiencies in the remainder of the treatment processes.

Intermittently decanted extended aeration tanks (IDEA) were introduced in 1976 with a further four added in 1982. This addition was in conjunction with the construction of a new inlet works, sludge lagoons and effluent ponds. The IDEAs were further investigated for the removal of phosphorous which resulted in two 17 500 litre IDEA Boo-P tanks being commissioned in the early 1990's This was technologically significant in that it enabled the effluent quality to achieve results that were well within the EPA licensing limits. The sewage undergoes periodic diffused aeration via pipes on the beds of the tanks. Sludge and microorganisms settle during the periods when aeration is halted and the treated effluent is decanted. During the periods of no aeration allows the promotion of bacteria for nitrification. This combination of process removes 90% or more of the solids and organic matter from the raw sewage while at the same time reducing nitrogen and phosphorous.

Sludge is pumped out on a regular basis to maintain the required proportions of raw sewage and active bacteria. With an increase in the production of sludge due to population increases the existing sludge lagoons were decommissioned due to being unable to cope with the increasing demands. They were replaced with a sludge handling plant that incorporates two sludge dewatering belt presses. The dewatering belt press enables wet sludge to be reduced to 'cake' which consists of approximately 14% solids and is currently disposed of off-site.

The advantage of a system incorporating IDEA tanks is that the biological stabilisation process and the settling of solids can be achieved with sewerage that has had grit and rags removed. Separate settling tanks, as a result, are no longer required.

An overview of the layout of the wastewater treatment works (WWTW) is shown in **Figure 1.1-2**.

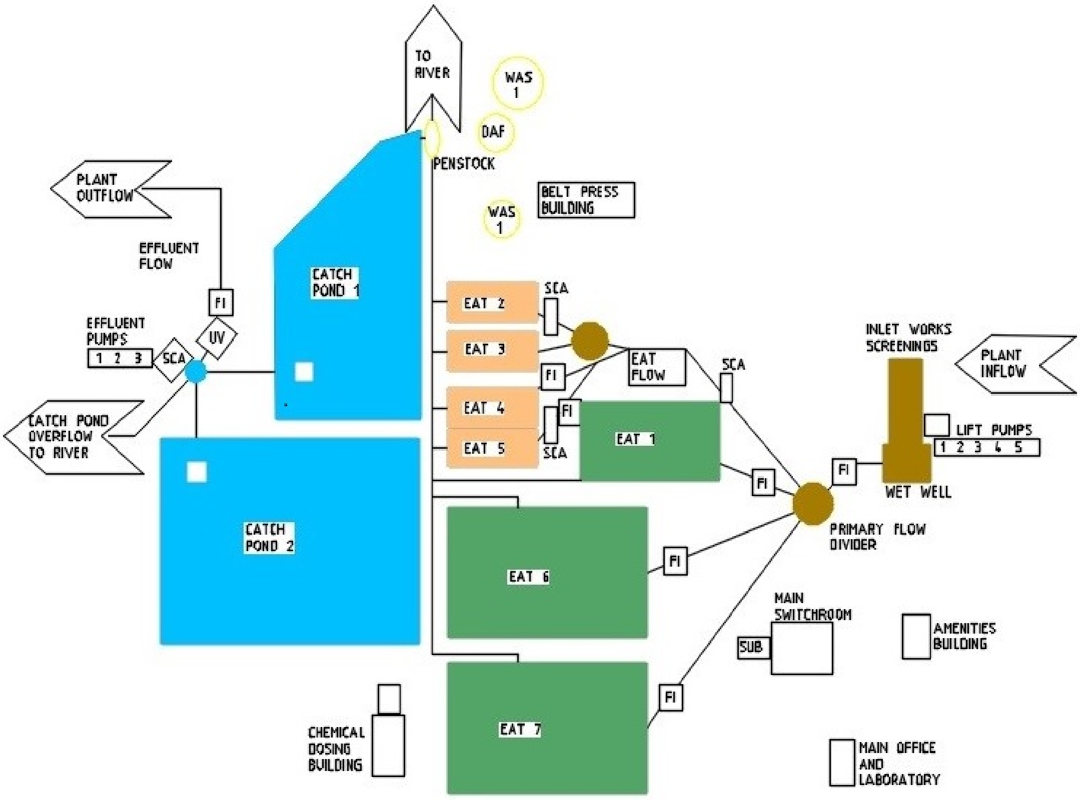


Figure 1.1-2 BRC WWTW Layout

The WWTW currently operates under a NSW Environmental Protection License that sets the discharge limits on BOD, faecal coliforms, nitrogen, oil and grease, pH, phosphorous and total suspended solids (TSS). The current system utilises three extended aeration tanks (EATs or IDEAs), two of which receive alum dosing when required and one of which receives no chemical treatment. For the 2014-2015 reporting period the concentration of pollutants, as regulated by the NSW Environmental Protection License is provided in **Table 1.1-2**.

Table 1.1-2 BRC WWTW EPA Pollutant Loads for 2014-2015.

Pollutant	Percentile %	Pollutant Load Limit mg/L	Pollutant Concentration mg/L
BOD	50	15	2.0
	90	20	3.7
	100	30	7.0
Total N	90	15	8.1
	100	20	16.8
Oil & Grease	100	10	5.0
Total P	90	1	0.6
	100	2	1.8
Total SS	50	20	6.0
	90	25	11.0
	100	30	17.0
pH	100	6.5	7.1
	100	8.5	8.5
Faecal coliforms	90	200	140
	100	600	1400

Source: BRC (2015)

Disinfection of sewerage effluent is undertaken through the injection of chlorine and in addition to this, prior to discharge into the Macquarie River, effluent is processed through a fully automated UV disinfection process.

The load based license fees for the BRC WWTW for the 2014-2015 reporting period are presented in **Table 1.1-3**.

Table 1.1-3 BRC WWTW EPA Load Based License Fees for 2014-2015.

Month	Load Limit (kg)	Actual Load (kg)	Load Based Fee
BOD	31600	6227	$26.54
Total N	44231	18197	$5 351.34
Oil & Grease	29511	0	$0.00
Total P	2937	1414	$16 571.08
Total SS	58987	20342	$6 762.41
			Total $28 711.37

Source: BRC (2015)

The challenges posed in the protection of human and environmental health within a developed world with significant population sizes has led to the development of advanced treatment technologies for waste storage and treatment as well as in relation to the prevention of pollution through methods of conservation, recycling and the re use of by-products (Kadlec and Knight, 1996).

The municipal wastewater of Bathurst is a combination of domestic wastewater from general households to businesses and education facilities as well as from commercial and local industrial sources. Municipal wastewater has been described as being composed of approximately 33 percent soaps and soil solids, 20 percent urine, 18 percent ground food wastes, 16 percent faeces and 7 percent paper with the remaining 5 percent being composed of solids that were already in the water supply (Metcalfe & Eddy, 1991).

The inflow received through the wastewater treatment works for the 2014-215 sampling period is presented in **Figure 1.1-3**. This is equivalent to an average daily flow of approximately 10 000 m^3/day.

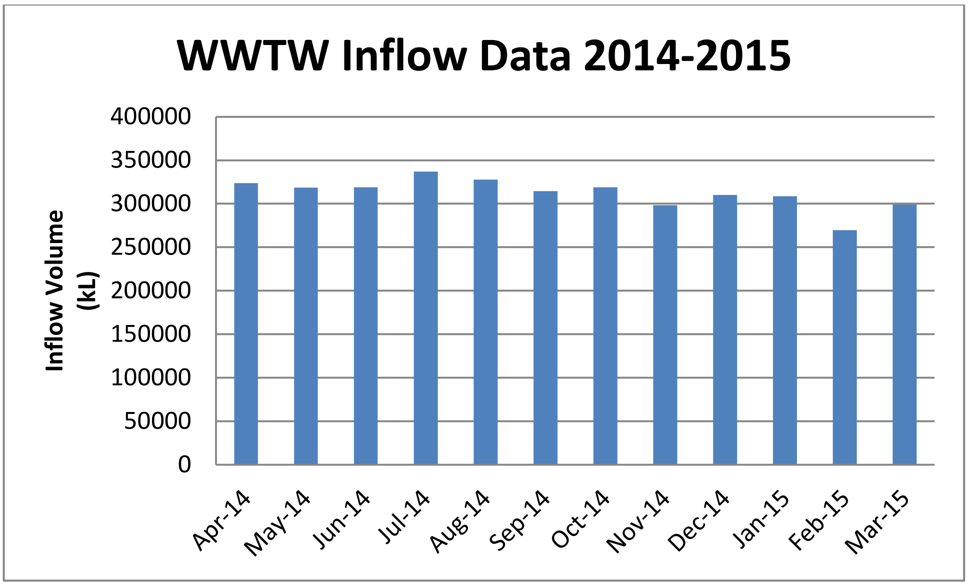
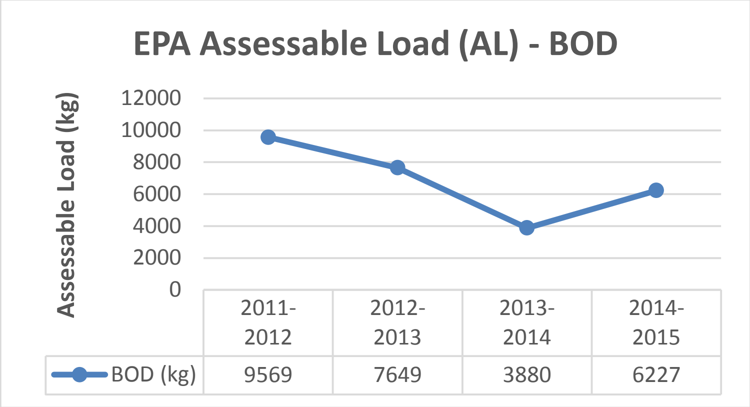


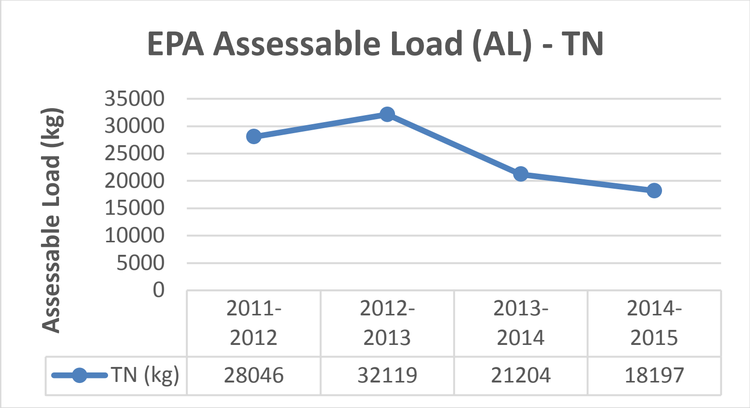
Figure 1.1-3 BRC WWTW 2014-2015 Inflow Volumes

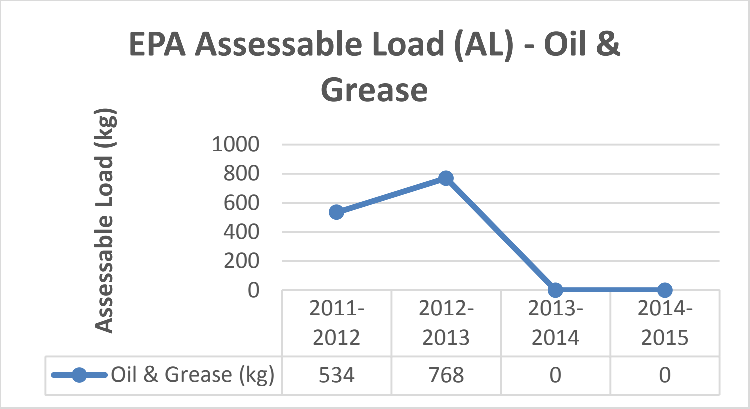
Bathurst Regional Council currently has an effluent reuse scheme in operation for water and cost saving benefits. The scheme treats effluent by pumping it through a 10 micron automatic backwash filter which then undergoes ultra violet disinfection. This treated effluent is then chlorinated and stored for the use as wash down and irrigation onsite. The quality of this reuse water is monitored daily. In addition to this the bio-solids generated through the sludge treatment facility are distributed on a local rural property for the improvement of soil structure, moisture holding capacity as well as improving crop quality translating to improved crop yields. An aerial view of the BRC WWTW is provided in **Figure 1.1-4**.

Figure 1.1-4 BRC WWTW Aerial View

While Bathurst Regional Council is successfully meeting the EPA load limit targets, Council is still required to pay a fee on what is actually discharged, even after meeting those limits. **Figure 1.1-5** presents the Assessable Loads (AL) of pollutants, in kilograms, for the discharge of effluent into the Macquarie River by BRC between the reporting periods of 2011 to 2015.


EPA Assessable Load (AL) - BOD
Assessable Load (kg)
12000
10000
8000
6000
4000
2000
0
2011-2012
2012-2013
2013-2014
2014-2015
BOD (kg)
9569
7649
3880
6227


EPA Assessable Load (AL) - TN
Assessable Load (kg)
35000
30000
25000
20000
15000
10000
5000
0
2011-2012
2012-2013
2013-2014
2014-2015
TN (kg)
28046
32119
21204
18197


EPA Assessable Load (AL) - Oil & Grease
Assessable Load (kg)
1000
800
600
400
200
0
2011-2012
2012-2013
2013-2014
2014-2015
Oil & Grease (kg)
534
768
0
0

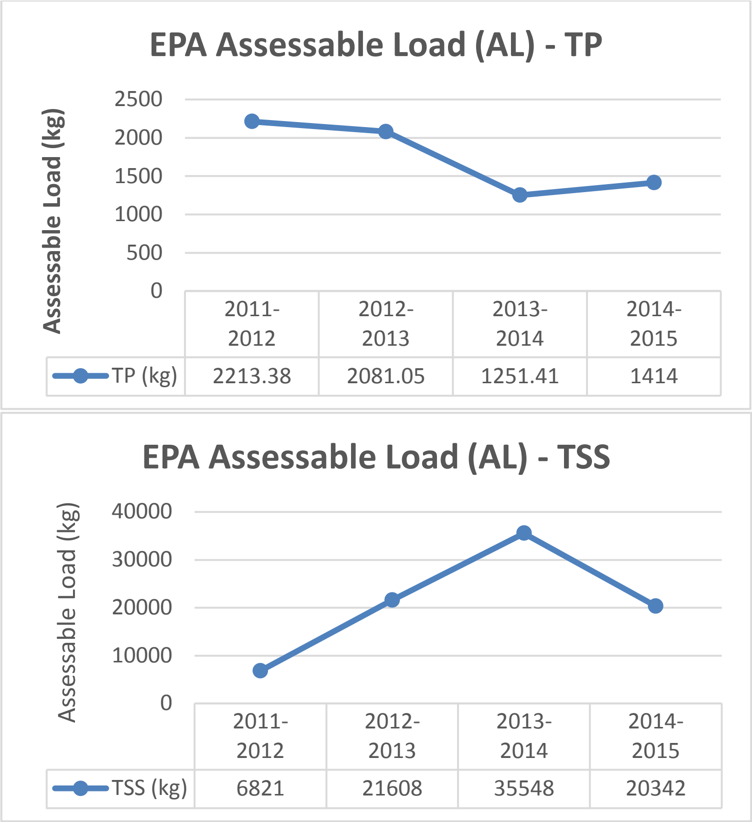


Figure 1.1-5 BRC Pollutant Assessable Loads (AL) 2011-2015

Figure 1.1-5 shows that the majority of the assessable loads recorded had a decreasing trend over the period of 2011 to 2015, with the exception of TSS which showed a consistent increase from 2011 to 2013 and then decreased from 2013 to 2015. The increasing trend of TSS was attributed to high levels of algae being produced during the retention time in the pond and the subsequent exposure to temperature and sunlight and the resulting decrease can be attributed to the introduction of aeration measures to the maturation pond to address the TSS issue in this case. Other treatments such as barely straw being placed in contained bales, in the maturation pond, had been trialled for the removal of TSS however the results show that aeration was most successful at reducing TSS overall.

The assessable loads in kilograms, of the target pollutants for the 2014-2015 reporting period are provided in **Table 1.1-4**.

Table 1.1-4 Bathurst Regional Council Assessable Pollutant Loads 2014-2015.

Pollutant	Pollutant Load (kg)
BOD	6 227
TN	1 8197
TP	1 414
TSS	20 342

Source: BRC (2015)

The EPA 2014-2015 reporting period discharge concentrations for discharge to the Macquarie River were addressed for the potential of further effluent polishing. It is interesting to note that the effluent being discharged from the maturation pond into the Macquarie River increases somewhat from the effluent that is discharged from the EATs to the maturation pond and these are provided in **Table 1.1-5**.

Table 1.1-5 Pollutant Discharge Concentrations to Macquarie River 2014-2015.

Pollutant	90 percentile Primary Treated Effluent (mg/L)	Effluent Discharged to Macquarie River 2014-2015 (mg/L)
TN	6.0	8.1
TP	0.3	0.6

Source: BRC (2015)

The 90 percentile for TN and TP of the effluent leaving the EATs was 6 mg/L and 0.3 mg/L respectively, while the final effluent discharged to the Macquarie River showed an increase of TN to 8.1 mg/L and TP to 0.6mg/L. This increase is assumed to be attributed to the additional nutrients being introduced to the maturation pond from birds, fish and turtles as well as algal growth content. In light of this, investigation into the floating treatment wetland option has used the data as reported in the calculations for the EPA load license determination of fees. **Figure 1.1-6** and

Figure 1.1-7 provide the EPA load based fee for nitrogen and phosphorous, respectively for reporting periods from 2011 to 2015.

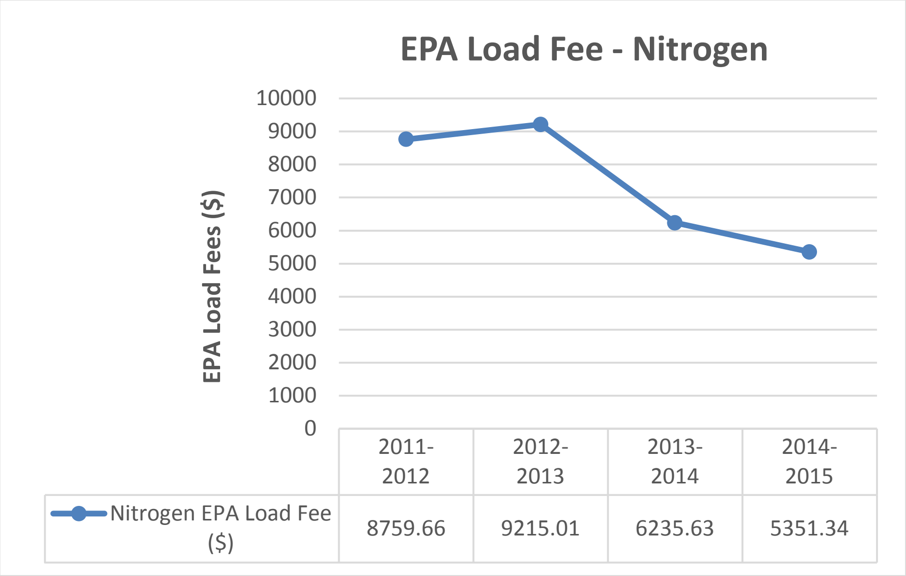


Figure 1.1-6 EPA Load Fee – Nitrogen

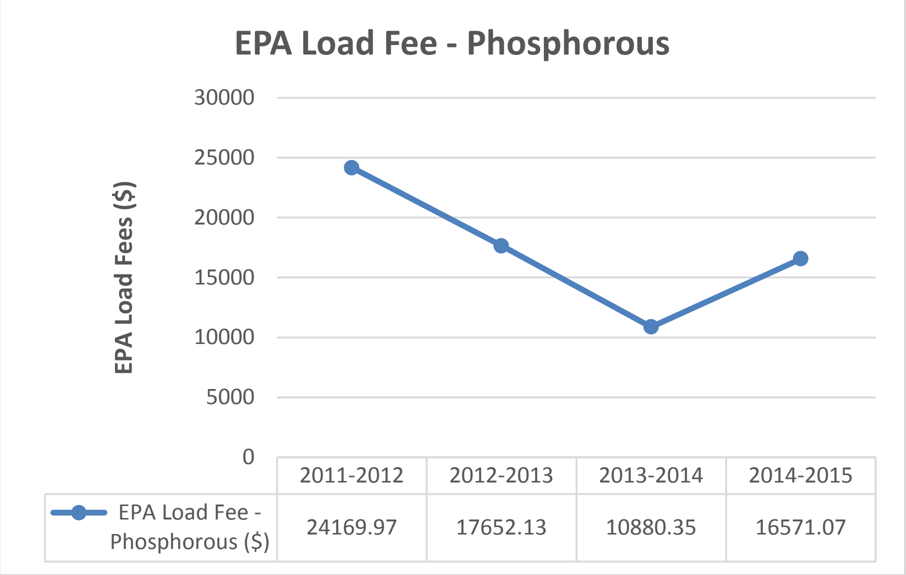


Figure 1.1-7 EPA Load Fee – Phosphorous

The EPA load fees for phosphorous increased during the period 2013 to 2015 due to a local industry, Devro Pty Ltd winding down and ultimately terminating production. Devro Pty Ltd was a leading international supplier of collagen casings for the food industry. During this shut down process Devro Pty Ltd acquired approval to increase the amount of effluent discharged to the BRC WWTW and this effluent contained higher levels of phosphorous than was had been previously discharged. While the discharge loads to the Macquarie River during this period did increase, and there by increasing the EPA load fees, the effluent discharged to the Macquarie River was still below the limits for discharge as set by the EPA.

1.2. Water Quality Treatment Requirements – Problem Statement

The population of Bathurst consists of approximately 35 000 people and related industry. The Bathurst Regional Council's WWTW has been designed to treat effluent generated by approximately 50 000 equivalent persons (EP).

This study investigates the feasibility of using constructed wetland technology options for additional effluent treatment or polishing for municipal wastewater to incorporate this with the current treatment system at BRC's WWTW. The first option to be investigated is the construction of a typical constructed wetland with the second option being the retrofitting of the existing maturation pond with floating treatment wetlands.

The feasibility of these options for a large urban population will be investigated to determine if civil costs, operational costs and the EPA loaded based license fees have the potential to be reduced when such a system is developed to complement the existing WWTW.

1.3 Objectives

The objectives of the study were to:

1. Determine the efficacy of using a constructed wetland system or a floating treatment wetland system as part of the treatment process for municipal wastewater to meet discharge limits.
2. Identify the key design requirements of the two main constructed wetland systems that could be used at the BRC WWTW.
3. Quantify the benefits and costs of using constructed wetland systems compared to the current treatment method.
4. Identify a preferred wetland system for the BRC WWTW.

The study will investigate two main options:

1. Design and construction of a new constructed wetland system for the treatment of wastewater with the following issues to be considered:
    a. Sizing and layout of a free water surface (FWS) wetland system.
    b. Treatment efficiency with regard to different climatic conditions and seasonal changes in terms of control to algal growth, temperature extremes and periods of wet and dry.
    c. Construction and operating costs and space limitations.

2. Retrofitting the existing maturation pond with a system of vegetated floating pontoons with the following issues to be considered (for secondary treated effluent):
    a. Plant selection and pontoon area requirement for current loadings.
    b. Treatment efficiency and capability of such a system to cope with current loadings.
    c. Construction and operating costs.

2. Literature Review

2.1. Introduction

There are multiple definitions of a wetland, as a wetland can vary widely depending on the natural environment, industry or context to which it is being referred or applied to. The Convention of Wetlands of International Importance (Ramsar Convention 1971) puts forward the following definition of a Wetland, ‘Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth at which at low tide does not exceed six metres (Article 1.1 of the Convention). This definition is very broad in nature and could be simplified by characterising a wetland as having the presence of water, a unique combination of soils for nutrient assimilation and the presence of vegetation that can survive in a water logged environment (Scholz and Lee, 2005).

Historically wetlands have been recognised and appreciated by humans as a useful resource, both in their natural state and in constructed forms, to aid in the treatment of water. Natural wetland systems were utilised by the Marsh Arabs on the Tigris and Euphrates Rivers in southern Iraq and constructed wetland systems are still being utilised in South East Asia in the form of rice paddies (Scholz and Lee, 2005). Natural wetlands are an integral part of the natural hydrological cycle and provide water to sustain biological diversity, agricultural production of food for human consumption, recreation and as an important habitat for a multitude of species.

Due to the destruction of our natural resources, and to add to that, climate change, water is being increasingly recognised as a delicate resource, both in terms of volume and in terms of quality due to increasing population and land use pressure. Constructed wetlands are presenting as not only an aesthetic and important feature of the natural environment but as a cost effective application for towns and industries requiring varying levels of stormwater, wastewater and effluent treatment and/or polishing. Constructed wetlands, in their various forms, have the ability of being able to function in conditions from the tropics to the artic and as standalone systems or as complementary components to traditional wastewater and stormwater management systems. It has also been suggested that looking even further into the future, past just the idea that constructed wetlands just perform as a water treatment option, that they may also be utilised for the installation of floating solar collection to run the systems energy needs or to be transferred to other applications energy requirements. In addition, the problematic issue of excessive algal growth that can be experienced could further be harnessed for the development of biofuels or as livestock feed supplementation with the potential to replace irrigated feed crops (USEPA, 2011)

2.2. Natural and Constructed Wetlands

Natural wetlands receive waters via the processes of stream flow, precipitation, runoff and Groundwater discharge. These waters define a wetland and also determine the constituent species, both plant and animal, that occur there as well as determining the nature of soils, and water chemistry that will be present. Constructed or treatment wetlands will exhibit similar characteristics, with the noticeable absence of water being received via streamflow and groundwater discharge which is an important factor in ensuring that contaminants do not enter groundwater or natural water bodies.

Water within natural and constructed wetlands will vary in volume due to natural wetlands being dry for extended periods of time whereas with constructed wetlands, inflow and outflow is regulated through various types of inlet and outlet control structures and therefore there is less, if no variability in the volume of water contained within a constructed wetland.

Kadlec and Knight (1996) emphasises that the treatment efficiency of a wetland, whether natural or constructed, is in terms of the hydraulic retention times (HRT – length of time that a soluble compound remains within the system), hydraulic loading rates (HLR– a ratio of flow divided by the surface area), and the proximity of the water borne substances to the sites within the wetland where biological and physical actions and processes take place.

In terms of water chemistry a pristine natural wetland could be expected to have a total phosphorous level of less than 0.1mg/L which is well below regulatory levels however it is also important to note that a pristine wetland is a rarity as most would be susceptible to agricultural, industrial and urban runoff in most cases so a more realistic value would be in the range of 0.1 to 0.7 mg/L (Kadlec and Knight, 1996). It is also noted by Kadlec and Knight (1996) that when the wetland water budget is dominated by rainfall then the total phosphorus present will be at relatively low levels and in an extremely pristine example in Florida, USA, the total phosphorus present was at a level of approximately 0.01 mg/L. Phosphorous within a wetland occurs as soluble and insoluble as well as organic and inorganic (Scholz and Lee, 2005). Phosphorous assimilation within a wetland is via sedimentation and adsorption into the soils, it is present in both floating and substrate plants. Due to the phosphorous occurring in varying processes within the wetland system, successful removal cannot be assured. Mackney (1991) comments that as long as the sediment zones remain oxidised the phosphorous should have a low biological activity and if sorbtion is the primary removal method then contact opportunities between the wastewater and the soil will be the limiting factor. Studies conducted by Mackney (1991) on wetlands in Byron Bay support the suggestion that removal of phosphorous occurs in the first section of the wetland and after that the levels remain essentially the same. Other studies also put forward the idea that phosphorous removal may also be limited by nitrogen (Post. et al., 1989).

The decomposition of organic matter produces organic nitrogen at low concentrations of approximately 1 to 2 mg/L. Organic nitrogen is further decomposed to form amines and ammonium nitrogen, under either aerobic or anaerobic conditions (Scholz and Lee, 2005). Ammonium nitrogen is essential for plant growth. During periods of high plant growth, ammonium nitrogen is taken up and will be present in very low levels in the water, in the order of approximately 0.05 to 0.10 mg/L. This soil bound ammonium nitrate is absorbed via plant roots. Increased temperatures also contribute to the reduction in ammonium nitrogen levels in the water via microbial processes (Kadlec and Knight, 1996). Ammonium nitrogen is further converted to other forms within the aerobic layers of the soil forming firstly nitrites (NO_2^-) and then nitrates (NO_3^-). This nitrification process will also take place within the plant root systems. This process is of particular interest in constructed wetlands to ensure that eutrophication in receiving waters are managed effectively. Nitrate and nitrates are commonly absent or at levels so low so as not able to be detected in natural wetland systems.

Natural and constructed wetlands are contrasted in terms of their carbon compounds with natural wetland carbon being represented by total organic carbon (TOC) and for constructed wetlands the carbon is presented in the form of biological oxygen demand (BOD) and chemical oxygen demand (COD). As many wetland plant species have root systems extending into anaerobic sediments the plants have developed the ability to transport dissolved oxygen into their root zone where it is metabolised, and if in excess it is utilised to sustain an aerobic layer around the root systems which in turn will support aerobic, heterotrophic and autotrophic bacteria. These forms of bacteria serve a function to oxidise organic material and also to nitrify ammonia in the wastewater (Mackney, 1991).

Constructed wetlands are known to be effective in the removal of total suspended solids (TSS), a component not commonly measured in natural wetland systems. Algal blooms can have a significant effect on the levels of TSS, dissolved oxygen (DO) and also affect the pH levels of the water.

Climatic and seasonal changes can impact the water chemistry of a wetland through changes in temperature, photoperiod (period of time each day during which an organism receives illumination), hydroperiod (seasonal pattern of water levels) and plant growth. Plant growth increases in warmer months which see an increase in the reduction of nutrients such as nitrogen, and this is slowed as plant growth slows in the cooler months. A dry season may reflect an increase in the decomposition of organic matter and a wet season will exhibit dilution processes.

2.3. Constructed Wetlands for Effluent Polishing

Constructed wetland applications are typically directed towards the removal of the following:

- Biochemical Oxygen Demand (BOD)
- Suspended solids (SS)
- Nitrogen (N)
- Phosphorous (P)
- Heavy metals
- Pathogenic bacteria and viruses
- Pharmaceutical chemicals and personal care products (PPCPs) removal is also gaining momentum.

Wetlands are known for their cycle of carbon compounds with the amounts processed within a wetland exceeding those actually contributed to by the addition to wastewaters even though wetlands exhibit non-zero background levels of both BOD and COD. Biological oxygen demand is a measurement of the oxygen consumption of microorganisms in the oxidation of organic matter and is typically measured in a test with duration of 5 days and there by termed BOD_5 (Kadlec and Knight, 1996). Biological oxygen demand is the most frequent supply of carbon in municipal wastewater with background levels reported to be within the range of 1 to 6 mg/L (Kadlec and Knight, 1996).

The efficiency of a constructed wetland to remove BOD_5 and SS is well documented as being consistently achieved. BOD_5 is effectively removed as long as the BOD_5 in the influent is greater than the background level of BOD_5 at which the wetland operates and consideration must be given to the processes that both consume and generate BOD_5 (Kadlec and Knight, 1996). Studies conducted in countries such as North America, Austria, Australia and Belgium show high removal performance in terms of BOD_5 with removal rates within the range of 70% to 96%, with the majority of results at the higher end of that range (Sundaravadivel and Vigneswaran, 2001). Kadlec and Knight (1996) support the view that the majority of constructed wetlands are overdesigned for the removal of BOD_5 with effluent concentrations within the range of background levels being achieved.

A constructed wetland environment is one in with total suspended solids are both produced and removed. Production is from the death of resident invertebrates and plant matter and the subsequent breaking up and distribution of these particles. In addition to this is the production of plankton and microbes that are found either in the water column or attached to the plant matter (USEPA, 2000). Removal of total suspended solids is via physical methods such as flocculation and sedimentation as well as filtration and interception. Idris (2010) suggests that constructed wetlands have limitations in the removal of SS when in the form of non-settling and colloidal solids. The size and nature of these solids are often such that wetland plants have an insignificant impact. SS removal should rely on measured settling rates for the wastewater in question as well as consideration as to the processes within the wetland that may produce variability in removal results (Kadlec and Knight, 1996).

Nitrogen forms associated with wetland environments consist of ammonia (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrous oxide (N_20) and dissolved elemental nitrogen (N_2). There are multiple factors that affect the total nitrogen removal rates in wetlands and they include the total nitrogen loading rate, climatic conditions, and the composition of the plant community as well as soil characteristics. Studies have reported that total nitrogen is reduced at a rate of about 46% to 72% in most wetland systems (Knight et al., 1985a). The removal rate of total nitrogen in a wetland system can be highly variable with dependencies on factors such as the makeup of the nitrogen in the influent, water depth, amount of dissolved oxygen present as well as the total nitrogen mass loading rate (Kadlec and Knight, 1996). Reduced efficiencies in the removal of total nitrogen have been observed at higher loading rates and are reported to be inversely related. Optimisation of nitrogen reduction can be achieved in specific design aspects of a wetland through the distribution of flow and residence times via deep water zones constructed perpendicular to the path of the inflow (Kadlec and Knight, 1996). This opinion is further supported by research in the US which has shown that the harvesting of wetland vegetation can remove less than 20% of influent nitrogen leaving nitrification and denitrification as the primary removal mechanisms and these mechanism are only effective if constructed wetlands are designed such that sufficient open water zones, providing aerobic conditions and vegetated zones, providing anaerobic conditions are provided (USEPA, 2000). Temperature and seasonal influences have been shown to affect the different processes involved in the removal of nitrogen forms. Lower temperatures are reported to introduce limiting conditions for effective removal (Kadlec and Knight, 1996).

The existing literature supports the theory that ammonia is a limiting factor when it comes to wetland design and is what predominantly drives the design process (Kadlec and Knight, 1996). Ammonia is an important in the wetland design process as it is known as the preferred nutrient form of nitrogen for most plant species and autotropic bacteria species, it can be readily oxidised in natural waters which can require significant oxygen consumption and in addition to this the un-ionised ammonia is toxic to many forms of aquatic life, even at low concentrations (Kadlec and Knight, 1996).

Nitrate is the most highly oxidized form of nitrogen present in wetland systems and due to this oxidation state it is chemically stable. Nitrate is an essential nutrient for plant growth however when in excess can cause eutrophication of surface waters (Kadlec and Knight, 1996). Nitrate exists and an intermediate oxidation state of nitrogen and as such is not chemically stable so is only found at low concentrations in wetland environments (Kadlec and Knight, 1996).

Microbial nitrification and denitrification are the primary removal processes of nitrogen in a constructed wetland. The reduction in nitrogen to the order of 70 to 90% is commonly reported across of wide range of loading rates and site conditions. Removal rates can also be tailored depending on the end product that is required. For instance, if the treated wastewater is for discharge into natural water ways then lower levels of nitrogen need to be achieved to meet licensing standards in contrast to treated wastewater that is to be used for irrigation purposes, as a higher nitrogen level will be required for plant/crop growth. A large majority of the research is in agreement to the successful removal of nitrogen in constructed wetlands as long as design configurations and other conditions are met. In opposition to this, a study by Verhoeven and Meuleman (1999) suggests that removal rates of nitrogen in constructed wetlands is limited in effectiveness much in the same way that the removal of phosphorous has been reported. For larger volumes of wastewater the view of Verhoeven and Meuleman (1999) may be more applicable in that constructed wetlands would be more suited to effluent polishing of secondary treated effluent from a conventional wastewater treatment system to further refine the effluent for a reuse/discharge capability.

Although consistency in the removal of total nitrogen in wastewaters can be achieved in wetland environments, not all factors that contribute to the removal efficiency are able to be effectively incorporated into design calculations and it is on this basis that caution needs to be taken and that limiting variables and conservative design in the sizing of wetlands should be acknowledged and applied.

The importance of phosphorous in a wetland environment is as an essential component for plant growth and as such, excessive levels discharged into natural aquatic environments can have a negative impact on those environments. Historically wetlands are not the most successful at removing phosphorous due to the complex nature of the biochemical processes in terms of inputs, cycling, storages and removal from the wetland environments and results can often be highly variable. As such it is this parameter that often requires the greatest area in terms of design (Kadlec and Knight, 1996).

Phosphorous removal in a wetland is via adsorption of soluble phosphorous onto soil particles, sedimentation of particulate phosphorous, precipitation and uptake by plants. Mackney (1991) reported that many studies reflect results similar to those found from a twenty one reed bed study in Denmark, where by an average removal success of phosphorous was approximately 20%. Verhoeven and Meuleman (1999) also comment that as phosphorous removal is dependent on the adsorption success as the process is reversible in nature as soon as the soil redox or base status changes. In addition to this, soils can become saturated which will limit further phosphorous adsorption. Constructed wetland systems can be effective in the removal of phosphorous if effluent polishing is the design aim, attributing reports of poor phosphorous removal results in the literature to a wetland system being optimised for the removal of a different priority pollutant rather than it being an unsatisfactory design concept (Bavor et al., 1995). Research results show that phosphorous removal efficiencies of 60% and in some instances >90% in constructed wetland systems receiving well treated effluent with phosphorous concentrations of 1.0mg/L over a period of four years (Bavor et al., 1995). This result is further supported by studies that show a mean phosphorous input level of 1-2mg/L being reduced to output levels of 0.005-0.3 mg/L (Knight, 1994). Further consensus for the limited capacity of constructed wetlands to remove phosphorous is that removal is limited to seasonal uptake by plants and that these levels would be much less than what the influent loading would be in municipal wastewater. In addition to this, phosphorus removal in the short term, within newly constructed wetlands would depict a greater uptake due to new vegetation, soils and media being able to uptake phosphorous at a greater efficiency rate than a more established wetland due to a greater saturation of sorption sites (USEPA, 2000).

Information on the heavy metal removal capability of constructed is not extensive however they are known to act as effective traps or sinks with relation to the wetland soils. Heavy metals are also taken up by wetland plants although this has its limitations in that if the concentrations of heavy metals in some plants become too high it will result in the plants dying.

Kadlec and Knight (1996) outline the following processes by which pathogens are effectively removed from wastewater in constructed wetlands:

- Natural die off
- Sedimentation
- Filtration through direct contact with plants and biofilms
- Ultra violet radiation through extensive exposure to natural sunlight
- Unfavourable water chemistry
- Temperature
- Predation via zooplanktons

Other literature supports the success of constructed wetlands in the removal of pathogens in which primary treated domestic wastewater was put through a constructed wetland system incorporating both horizontal and vertical flow beds with results showing that this method was superior to the conventional treatment system (Gesberg et al., 1990). It was also noted in the study that vegetated beds produced the most effective results. Constructed wetland configurations and environmental conditions create a favourable environment in which to remove pathogenic bacteria and viruses that are derived predominantly from human and animal faeces. In conventional wastewater treatment systems the removal of pathogens is not effective without the additional processes of chlorination, ozonation or UV treatment being employed. Wetlands provide an effective removal mechanism compared to traditional processes with longer residence times (greater than 10 days) shown to provide disinfection with vegetated wetlands providing higher efficiencies due to the physical contact between the pathogens and solid surfaces of the plant matter (Kadlec and Knight, 1996).

Constructed wetlands are an effective method for wastewater treatment however their application can have limitations in terms of the area required for effective removal to take place. Availability of land and land acquisition costs are often the limiting factors where larger volumes of wastewater are to be treated as the size of the wetlands required become too large to be feasible.

An aspect of municipal wastewater treatment that is gaining momentum is in the removal of a variety of PPCPs and their metabolites. The ecotoxicological effects of these substances are still relatively unknown in terms of discharge into waterways and conventional wastewater treatment plants are not designed for their removal. Although evident in low concentrations these substances have the potential to exhibit an unpredictability due to a large number of compounds currently discharged and also there is the problem that their interactions in natural systems, as loadings increase, are yet to be widely studied and understood. Recent small scale trials of various types of natural systems have shown evidence of success (Conkle et al., 2008, Hijosa-Valser et al., 2010, Matamoros et al., 2005) with greater removal efficiency from vegetated constructed wetlands as opposed to ponds. One of these trials consisted of seven mesocosms-scale constructed wetlands over a period of nine months and results in successful removal of PPCPs such as ketoprofen, naproxen, ibuprofen, caffeine and salicylic acid, just to name a few (Hijosa-Valser et al., 2010). The study assumed that constructed wetlands offer a multitude of microenvironments that provides various pathways for the degradation of the PPCPs (Hijosa-Valser et al., 2010). It was also concluded that the degradation was linked to physico-chemical parameters such as higher temperatures, high oxidant conditions, anaerobic conditions and that microbiological pathways are the most likely of pathways for the degradation of PPCPs (Hijosa-Valser et al., 2010).

2.4. Floating Treatment Wetlands for Effluent Polishing

Floating treatment wetlands (FTWs) are a relatively new and emerging technology to the constructed treatment wetland concept and they can overcome the constraints of required area and minimum depth experienced in the traditional constructed treatment wetlands approach to potentially achieve an improved treatment performance (Headley and Tanner, 2008). FTWs are currently applied to areas such as human wastewater treatment, stormwater runoff in retention ponds, agricultural, mining and industrial wastewater treatment. The FTW technology provides an opportunity to retrofit existing facilities with floating vegetated mats/pontoons supporting terrestrial macrophytes (Wang and Sample, 2014). **Figure 2.4-1** provides an example of a floating pontoon planted with vegetation for water treatment.

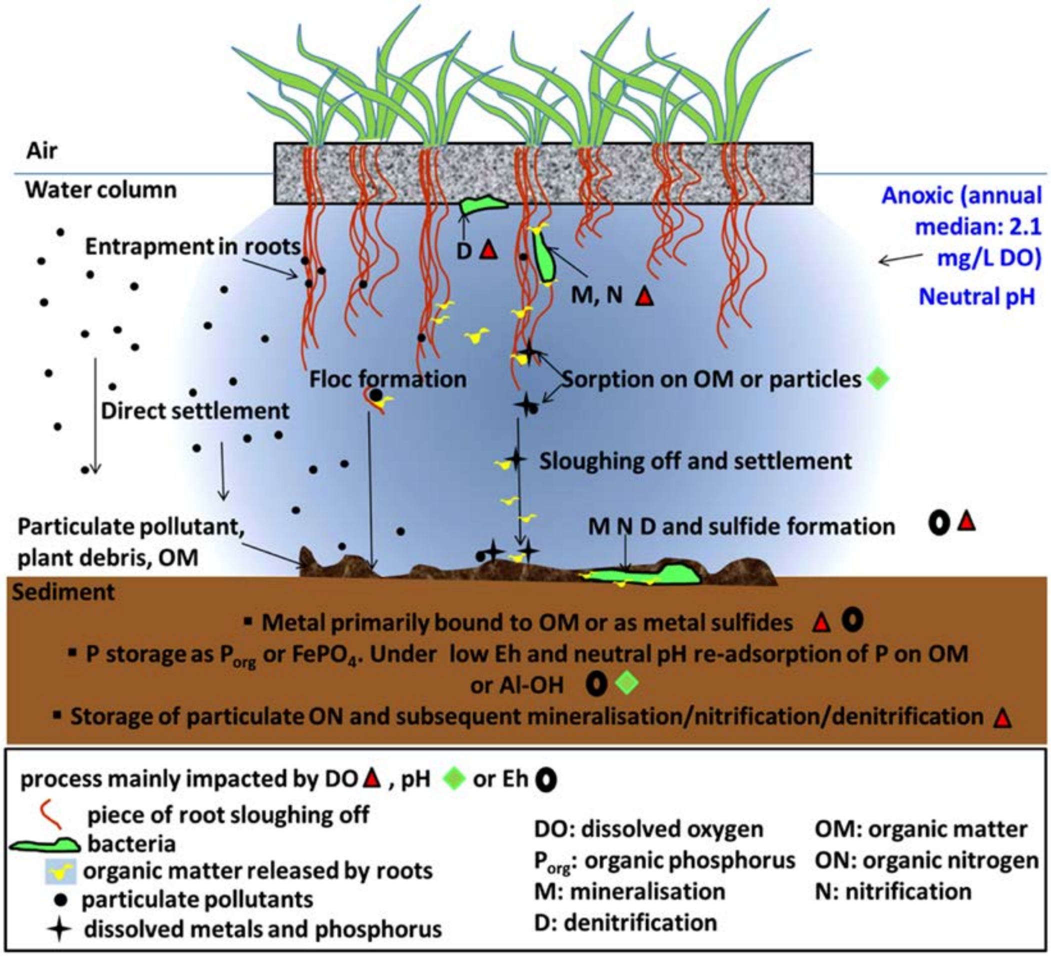
Source: *FIA (2015)*

Figure 2.4-1 Floating Treatment Wetland Pontoon

In addition to overcoming typical constraints in area and depth, floating treatment wetland systems also require less input in terms of construction and ongoing maintenance such as chemical or energy inputs and as such the costs are predominantly associated with the installation of the floating pontoons, plants and labour costs for planting and harvesting (Wang and Sample, 2014). Harvesting requirement is dependent on the type of plants selected and in terms of ongoing management, if no harvesting is required, then occasional spraying for introduced weeds from birds or overhanging vegetation would be required. Sediment removal and disposal may also need to be a consideration in with respect to long term costs, with stormwater ponds requiring a clean out every 15-25 years (USEPA, 1999).

A floating treatment wetland incorporates the traditional benefits of utilising emergent macrophyte species, such as rushes, reeds and sedges, grown on a floating mat or pontoon where the root zone of the macrophyte extends into the body of water requiring treatment while the rest of the macrophyte remains above the water level. The minimum water depth is recommended to be between 0.8m to 1.0m to ensure that no roots are able to anchor onto the bottom of the pond introducing the risk of the pontoon being inundated if the water levels rise causing death of the plants (Headley and Tanner, 2008). This increased depth capability also increases the hydraulic retention time of the wetland without increasing its footprint. Another advantage is that after a period of accumulation of sediment in the pond, the material can be excavated without any disturbance or damage to the plant systems on the floating pontoons.

Plant nutrition is derived directly from the water column beneath the pontoon on which they are grown. The submerged root network provides a large surface area on which biofilms can grow thus creating an active surface on which flocculation of suspended matter can take place and in turn enhancing the process of the settling of materials (Khan et al., 2013). The water column beneath the pontoon contributes to the removal of heavy metals and nutrients due to plant uptake as well as there being anaerobic conditions in this zone (Headley and Tanner, 2008) and (Hubbard et al., 2004). **Figure 2.4-2** provides a schematic diagram of the pollutant removal processes that can be expected with floating wetland treatment technology.



Source: Borne et al. (2015)

Figure 2.4-2 FTW Pollutant Removal Processes

Research into the effects of vegetation, season and temperature on the removal efficiency of various pollutants in floating treatment wetlands showed that the removal efficiency of total nitrogen, ammonia, nitrate, phosphorous, chemical oxygen demand, total organic carbon and heavy metals was measured for a floating treatment wetland against a control pond of the same configuration that contained no floating vegetation (Van de Moortel et al., 2010). Results showed that the floating treatment wetland had greater removal efficiency than the control, the averaged results are provided in **Table 2.4-1**.

Table 2.4-1 FTW Removal Efficiency

Parameter	**FTW** **% removal**	**Control** **% removal**
NH_4-N	35	3
TN	42	15
P	22	6
COD	53	33

Source: Van de Moortel et al. (2010)

Over the testing period pH was reported to be lower in the FTW than the control, and it was also noted that the removal of TN, NH_4-N and P was highest when the temperature was in the range of 5°C and15°C, with lower removal rates exhibited at lower and higher temperatures outside of this range. It was concluded that temperature, more so than season, had more effect over removal efficiencies.

Hydraulic retention time is an important factor in the design of a FTW in that the longer the residence time of the water in the wetland the more effective are the processes settling of sediments and other pollutants whether that be via biological and chemical reactions or physical settling processes (Khan et al., 2013). The plug flow model of uniform velocity for a wetland is not something that is seen in a natural wetland however can be designed into a FTW to achieve a particular flow path to ensure a determined residence time and also to eliminate dead zones where the flow short circuits a particular pathway and exits the wetland before effective polishing can take place (Khan et al., 2013). To avoid this short circuiting of flow, the design of the FTW could include baffles, walls and subsurface berms. Baffles have also been reported to cause short circuiting so correct design placement of the pontoons needs to be considered so that pollutant removal efficiency is not compromised (Khan et al., 2013). The study also described the optimal placement for a single large FTW as being $x/L_m=0.125$ for a side inlet pond and $x/L_m=0.25$ for a centred inlet pond, where x is the distance of the FTW from the inlet and L_m is the overall length of the pond. Pollutant removal was more effective with one large FTW as opposed to multiple smaller ones and also that the position of the FTW was more important in terms of hydraulic performance that the actual size of the FTW (Khan et al., 2013). Additional research into pond coverage reported that a 50%

surface area coverage induced greater dissolved oxygen depletion giving rise to a more favourable environment for denitrification as opposed to a water body with only 18% surface area coverage (Borne et al., 2015). Dissolved oxygen depletion creates a non-favourable environment for freshwater organisms and once the required effluent polishing is achieved, measures to re oxygenate the water for discharge would need to be considered. In terms of effluent polishing and the removal of nitrates and metals, large FTWs, with a surface area of $50m^2$ are suggested, whereas for stormwater quality and creating a favourable natural habitat smaller FTWs, in the range of $1\text{-}3m^2$ are advisable (Borne et al., 2015).

Water pH also plays an important role in the removal of nutrients, and should be in the range of between 6 to 8 to allow for sorption of positively charged metals on particles and for denitrification and nitrification processes the pH should be within a range of 7 to 8.5 (Borne et al., 2015). These pH ranges are well within the NSW EPA load limits set for the Bathurst WWTW which for the 100 percentile concentration state the pH range to be within 6.5 to 8.5. It has been reported that to maintain a pH between 7 and 8, for wastewater treatment systems, that a concentration above 35mg/L $CaCO_3$ is recommended (Borne et al., 2015).

2.5. Conventional Treatment for Municipal Wastewater

Traditional applications to the treatment of municipal wastewater typically employ the methods of biological, chemical and physical removal technologies. These treatment processes partially remove the solids and assist in the decomposition from highly complex putrescible organic solids to more stable organic compounds. Primary treatment consists of grit removal, screening, grinding, sedimentation and flotation. In this treatment stage Sonune and Ghate (2004) describes that approximately 25% to 50% of the BOD and 50% to 70% of the SS are removed which is further supported by similar result ranges in the data provided Kadlec and Knight (1996) presented in **Table 2.5-1**. Some organic nitrogen and phosphorus is removed during this primary treatment stage however it is not successful in removing the colloidal and dissolved constituents (Sonune and Ghate, 2004).

This primary effluent then undergoes secondary treatment processes with the aim of removing residual organics and additional suspended solids. Sonune and Ghate (2004) describes the distribution as being approximately 65% dissolved solids, 30% suspended solids with a remaining 6% made up of colloidal solids. Biological treatment during this stage aims to remove a variety of microorganisms through the supply of oxygen allowing for the organisms to metabolize the organic matter present (Sonune and Ghate, 2004).

As effluent standards became more rigorous, further treatment was required to meet discharge standards and as such more advanced systems of treatment needed to be applied. Primary and secondary treatment processes are effective at removing BOD and SS but exhibit a lower removal efficiency with phosphorous in the order of 10% to 20% removal and 15% to 25% removal for total nitrogen (Muga and Mihelcic, 2008). Tertiary treatment can consist of physiochemical treatment and a combination of biological and physical treatment technologies to remove additional organic and suspended solids, nutrient removal as well as the removal of any toxic substances that may be present (Sonune and Ghate, 2004).

Other applications of traditional wastewater treatment have included the use of lagoons. Lagoons either being aerobic or facultative in terms of their operation. Aerobic lagoons typically have a hydraulic retention time in the order of 3 to 10 days where as facultative lagoons have a hydraulic retention time in the range of 5 to 30 days (Reed et al., 1995). The longer the hydraulic retention time the higher the removal efficiency seems to be and if correctly constructed the removal efficiency of a lagoon system can be comparable to traditional mechanical systems (Muga and Mihelcic, 2008). Lagoons have shown a SS solids removal capacity in the range of 90% to 95% but a lower BOD removal capacity in the range of 75% to 95%. Phosphorous and nitrogen removal is also reported to be lower with removal efficiencies in the range of 10% to 50% for phosphorous and 10% to 60% for total nitrogen. Land treatment technology shows medium to high removal for BOD (67% to 100%), SS removal in the range of 58% to 99% and 40% to 99% for phosphorous removal and 38% to 95% for total nitrogen (Muga and Mihelcic, 2008).

A summary of approximate removal ranges of conventional treatment methods are provided in **Table 2.5-1**.

Table 2.5-1 Percentage Removal Efficiency for Conventional Wastewater Treatment Methods

Treatment Process	BOD	COD	TSS	TP	ORG-N	NH3-N	TN
Grit Removal	0-5	0-5	0-10	<1	<1	<1	<1
Primary Sedimentation without coagulation	30-40	30-40	50-65	10-20	10-20	0-20	10-20
Primary Sedimentation with coagulation	40-70	30-60	60-90	70-90	-	-	-
Activated Sludge	80-95	70-85	80-90	10-50	15-20	8-65	-
Trickling Filters	65-80	55-80	60-85	8-12	15-50	8-15	-
Rotating biological contactors	80-85	80-85	80-85	10-25	15-50	8-15	-
Oxidation Ditch	86-99	-	81-98	-	-	20-80	-
Tertiary Treatment	80	80	80	60-95	0-20	80-95	80-85

Source: Kadlec and Knight (1996)

Odour nuisance can be a negative impact relating to traditional treatment methods, both from mechanical treatment as well as from lagoon and land application systems. Less odour issues are reported from land treatment methods if the wastewater is adequately pre-treated with the removal or solids and algae land application. Odour issues often occur at the points of pumping stations, inlets and outlets or in lagoon system in periods of overloading or excessive sludge build up (Muga and Mihelcic, 2008).

Bathurst Regional Council's WWTW employs the activated sludge treatment method and it is a treatment method that has been widely used for both municipal and industrial wastewater treatment. Activated sludge treatment is popular due to being an efficient method, it has operational flexibility effective in terms of nutrient removal. However, disadvantages are also acknowledge and those consist of the need for a high level of mechanisation, high costs are reflected both in terms of construction and ongoing operation and ultimately the need to treat a large amount of sludge (Sperling et al., 2001).

In addition to the traditional systems already discussed are the land treatment systems incorporating methods such as slow rate (SR) systems, overland flow (OF) and rapid infiltration (RI) systems (Reed et al., 1995). These forms of land treatment consist of controlled application of wastewater to the soil to achieve the wastewater treatment targets required.

Slow rate systems have been utilised for municipal wastewater and also industrial wastewater and are similar to conventional agricultural irrigation with mass nutrient balances and loadings taken into consideration.

Overland flow systems incorporate a land treatment process by which wastewater is discharged to flow down ad graded and grass covered slope with the treatment runoff being collected at the bottom of the slope (Reed et al., 1995). Soils must have properties that enable slow permeability rates, or be compacted to limit the level of percolation or consist of an impermeable layer and the wastewater is applied via irrigation or directly to the surface. This treatment process is able to successfully remove BOD, SS and nitrogen and with the potential for phosphorous removal with some alum application (Reed et al., 1995). A local example of this treatment process was undertaken as a joint project with the Scenic Rim Regional Council in Queensland and Queensland Urban Utilities. This comprised of a system of vetiver grass plots for the overland flow treatment of the municipal wastewater for the township of Boonah, Queensland.

The third method of land application treatment options consists of rapid infiltration and this process treats wastewater by allowing it to percolate through a permeable soil via intermittent applications often in shallow spreading basins. Some systems recover the percolated treated wastewater for further use through collection and pumping methods if the indirect surface discharge to receiving waters is not allowable by regulators (Reed et al., 1995).

2.6. Wetland Technology for Wastewater Treatment – Case Studies

Constructed wetlands are a proven method for managing contaminated waters which in turn results in the benefit of being able to recycle water for a variety of human applications and for discharge back into the natural environment to assist in the rehabilitation of natural flows in rivers and streams. Constructed wetlands have been applied to the following areas:

- Primary and secondary sewage treatment
- Effluent polishing of secondary and tertiary treated effluent for discharge, recycling and reuse
- Disinfection
- Stormwater treatment
- Land fill and mining leachate treatment
- Industrial runoff
- Agricultural runoff

Floating treatment wetlands for water treatment has so far been applied in the following areas:

- Stormwater treatment
- Combined sewer-stormwater overflow
- Sewage
- Acid mine drainage
- Piggery effluent
- Poultry processing wastewater
- Water supply reservoirs

2.6.1. Case Study 1 – Columbia, Missouri USA

The Columbia wastewater treatment plant wetland system was designed in the late 1980's when the concept of using wetlands for wastewater treatment was still in its infancy. The City contracted with engineering firm Metcalf & Eddy Inc. for the design, and it was the first design of this type that they had undertaken (Cuvellier, 2015). The reason for the wetland concept was due to the wastewater treatment plant becoming hydraulically overloaded and the wetland concept was initiated to increase the capacity of the plant and to achieve the typical secondary wastewater quality standards of 30mg/L per monthly average of BOD and TSS. At this early time in the development nutrient removal was not a consideration and was therefore not designed specifically for nutrient reduction. To illustrate this, in the first twenty years only an average of 3% reduction in ammonia occurred (Cuvellier, 2015).

The Columbia wastewater treatment plant completed upgrades in 2001 which included the construction of a series of four wetland treatment ponds. The total design capacity of the plant is approximately 75 000 cubic metres per day (Columbia, 2015). These upgrades enabled the decommissioning of more than 75 small wastewater treatment facilities throughout Columbia. **Figure 2.6-1** provides an aerial view of the plant.

Source: Columbia (2015)

Figure 2.6-1 Aerial Photo of Columbia Regional Wastewater Treatment Plant

The wetland treatment facility was incorporated into the overall plant due to community demand for more environmentally sound systems of effluent disposal into the nearby Missouri Department of Conservation Area of restored riverine wetland, to which is provides a source of water (Columbia, 2015). This conservation area has an area of approximately 530 hectares of emergent marsh wetland that are seasonally flooded. The effluent discharged to the conservation area is monitored daily to conform to the pollution guidelines as set by the National Pollution Discharge System criteria (Columbia, 2015).

The total water surface area of the wetland is approximately 53 hectares and each cell has a clay liner that is 300mm thick for the prevention of potential leachates entering the surrounding environment, which is then topped with the same thickness of topsoil into which cattails have been planted. Cattails were the vegetation of choice to due to being suitable for the local environmental conditions, they exhibit fast growth rates and can be densely planted. In times of heavy rain to prevent over topping of effluent from the wetlands, flood control berms have been constructed around each treatment unit and a **Figure 2.6-2** provides an aerial view of their layout (Columbia, 2015).

Source:Columbia (2015)

Figure 2.6-2 Aerial Photo of Columbia Regional Wastewater Treatment Plant Wetlands

The basic limits set on wastewater treatment plants by the USEPA are on BOD, TSS and pH. Approximately ten years ago the USEPA also set limits on ammonia giving treatment plants a period of seven years to upgrade infrastructure to meet these new requirements. Nitrogen has recently had limits set by the USEPA however there are currently no limits set for the discharge of phosphorous. Each State is free, however to set their own limits on phosphorous on a case by case basis (Cuvellier, 2015). The effectiveness of this treatment systems and subsequent discharge into a natural ecosystem has gained the support of the community, environmentalists and regulatory agencies.

2.6.2. Case Study 2 – Pasco County, Florida USA

Floating treatment wetlands were used in this study conducted as part of the Pasco County Master Reuse System (PCMRS) for the provision of water treatment for effluent disposal for the county. PCMRS is a regional reclaimed water distribution system providing treated effluent from all wastewater treatment facilities in the Pasco Country through irrigation and rapid rate infiltration basin systems. The specific goals included the further reduction in nutrient levels in reclaimed municipal wastewater to meet total maximum daily load limits, with the parameters being studies including total nitrogen, total phosphorous, ammonia, nitrate, biological oxygen demand, total suspended solids, dissolved oxygen, pH and temperature. The sampling period was over the period of one year.

The total surface of the wetland area was 149m^2 with floating wetland pontoons of 2.4m x 3.0m in area covering a total area of 1122m^2 which represented 7% of the total ponds surface area. **Figure 2.6-3** shows the FTW configuration in relation to the pond inlet and outlet (Vazquez-Burney et al., 2015). The depth of the pond varied from 1m to 2m, with a volume of approximately 19ML. The pond received continuous inflow through a 100mm pipe containing a flow meter. A total of 18 different local plant species were chosen for planting into the pontoons (Vazquez-Burney et al., 2015).

Source: Vazquez-Burney et al. (2015)

Figure 2.6-3 Pasco County Floating Treatment Wetland

Sampling of the water was undertaken every two weeks at the pond inflow and outflow and analysed for ammonium nitrogen, nitrate, nitrite, organic nitrogen and total phosphorous. This sampling period consisted of three distinct project phases consisting of a growth phase (July 2012 to December 2012), performance phase (January 2013 to August 2013) and a control period which consisted of the removal of the planted pontoons (September 2013 to November 2013). Plant tissue sampling and analysis of harvested materials were also conducted to determine dry weight and percent total nitrogen (Vazquez-Burney et al., 2015). Results showed that the efficiency of the floating wetland to remove total nitrogen was 61% during the performance phase compared to 30% removal efficiency during the control period. A tracer was also utilised to monitor the hydraulic efficiency of the pond and from this dead zones and short circuiting of flow was observed, algal growth in these areas were also noted and as such showed that improvement in the flow characteristics of the pond would be warranted to ensure a higher removal efficiency than what was actually documented. It was also recommended that ponds with different sizes, depth and shape configurations must be assessed uniquely in order to achieve a consistent and effective TN removal (Vazquez-Burney et al., 2015).

2.7. Methods for Sizing Treatment Wetlands

2.7.1. Traditional Constructed Wetlands

The Department of Land and Water Conservation NSW (1998) provides a guide for the design of constructed wetlands – 'The Constructed Wetlands Manual', using models by Kadlec and Knight (1996), Reed et al. (1995) and a general 'rule of thumb' guide to sizing. The rule of thumb method of sizing will not be discussed in detail here other than to mention that the UK has employed this method in the design of constructed wetland systems. It is useful for preliminary sizing estimation suggesting that the area required is approximately 10-20m^2/m^3 of effluent per day. DLWC NSW 1998 suggests that this is a reasonable method for preliminary sizing where BOD and SS removal is being considered.

Kadlec and Knight (1996) and Reed et al. (1995) both employ the concept that the rate of removal of a particular component in a wetland is directly proportional to the remaining concentration of that component. This is referred to as a first-order plug flow kinetic model. Plug flow being an idealised mixing theory defined by the concentration of a reactant decreasing along the length of the flow path of a wetland. This is as opposed to a completely mixed reactor where by at any point in the wetland the concentration is the same as the effluent concentration. It is also suggested that ideal plug flow is not able to be achieved but is more a case of an infinite series of completely mixed flow wetlands (DLWC, 1998).

The methods of Kadlec and Knight (1996) and Reed et al. (1995) differ in the basis for the rate constant. Reed et al. (1995) have based their equations on the available volume and average temperature of the wetland whereas Kadlec and Knight (1996) equations are based on the surface area of the wetland with temperature only considered significant in the calculation for nitrogen removal. Another difference in the two approaches is that Kadlec and Knight (1996) include a minimum possible pollutant concentration in their calculations whereas Reed et al. (1995) use the minimum possible pollutant concentration as a checkpoint after the fact. The limitation in the equations including the minimum pollutant level is that when the required effluent concentration approached this minimum value the estimated size of the wetland increases exponentially which can result in an overly conservative wetland sizing.

It is important to note that these models were developed in the US with Kadlec and Knight (1996) using average water temperatures that would be generally lower than what is experienced in Australia. This could introduce the risk of overdosing (DLWC, 1998). Sizing of the wetland is determined by using the pollutant requiring the greatest area for removal.

The method proposed by Reed et al. (1995) is a first order plug flow model incorporating the assumption that the pollutants BOD, NH_4 and NO_3 are removed by biological processes. A different approach to the equations are assumed for the pollutants such as SS and TP, these equations being based on a regression analysis from early data on constructed wetlands from the North American Database (NADB). In terms of pathogen removal Reed et al. (1995) suggests that the approach is the same as if using waste stabilisation ponds and DLWC NSW 1998 suggest that this is supported through constructed wetlands investigations and tends to be on the conservative side however is useful as a guide. Calculations using the Reed model are based on the worst case scenario, using minimum temperatures for the reason that reaction rates will be slowest during the cooler months. The calculations are also based on the limiting factor which Reed et al. (1995) proposed to be ammonia removal, as the availability of oxygen through natural aeration is known to be a slow process.

In terms of TN it has been reported that ammonia can comprise up to greater than half the TN content in effluent from municipal and domestic sources with levels reported to be in the range of 20-60mg/L (Kadlec and Wallace, 2009). Effluent from food processing and landfill leachates have reported levels >100mg/L. As nitrogen plays a significant role in the degradation of environmental conditions in wetlands and natural water systems the reduction of ammonia in wetland processes often drives the design of a wetland and is a common limiting factor.

2.7.2. Floating Treatment Wetlands

Significant data for the design of floating treatment wetlands is minimal in the current literature with limited full scale experiments being published (Borne, 2014, Borne et al., 2013a, De Stefani et al., 2011). The majority of the literature is focused on the application of FTWs for stormwater treatment; however the basic processes for water treatment within the FTW remain the same. A trial conducted in New Zealand (Borne, 2014) illustrated factors that may contribute to the overall pond efficiency as being the provision of a dense root network for the attachment of biofilms through acting as a physical barrier to the flow for particulate particle removal. In addition, this was also thought improve the hydraulic efficiency of the pond encouraging particle settlement. The release of root detritus and organics acts as a bio solvent for dissolved metals and phosphorous while at the same time promoting floc formation which in turn promotes particulate pollutant as well as encouraging target bacteria for mineralisation, denitrification, nitrification and sulphate reduction. A neutral pH, reduced sediment and an anoxic water column contributes to increasing metal and phosphorous accumulation in the sediments (Borne et al., 2015).

As mentioned previously the size of the FTW and the pond surface coverage ratio determine the degree to which DO is depleted in the water column as the FTW provides shade to the water column inhibiting photosynthetic organism activity and the subsequent production of DO (Borne et al., 2015). Results from the New Zealand trial showed that with the FTW of 50m^2 the denitrification process was enhanced due to the lower DO concentrations over summer as opposed to the 23m^2 replicate set up in North Carolina, concluding that for promoting nitrate removal a greater coverage ratio of FTW is advised (Borne et al., 2015).

The removal processes dependent on pH levels are affected when there is a reduction in pH caused when bacteria that develop in the rhizosphere cause the release of H+ ions. The plants roots in themselves can release acidic substances into the water columns as can they alter the pH through anion and cation exchange. A good understanding of pH and DO is an importance factor when design the layout of the FTW (Borne et al., 2015).

There are Australian companies providing floating treatment wetland technology installation, and available information suggests that a surface area coverage of 3% to 7% is recommended and total nitrogen removal can be estimated as 3 to 5 kg/m^2 FTW/year and total phosphorous removal at a rate of 1 to 2 kg/m^2 FTW/year. Aeration is recommended for the removal of ammonia and thereby increasing the amount of nitrogen able to be removed via the FTW. It is assumed that approximately half of the total nitrogen in the effluent is ammonia.

Installation recommendations consist of a configuration of FTWs that are perpendicular to the inflow of effluent to both maximise the contact between the effluent and the plant roots (Headley and Tanner, 2006), while enhancing the hydraulic retention capacity of the wetland (Khan et al., 2013). This is also limits the possibility of short circuiting of the flow around the FTWs which would minimise plant root contact with effluent, reducing the possible treatment capacity (Headley and Tanner, 2006). This perpendicular configuration when applied to the New Zealand trial was shown to exhibited greater total zinc, total copper and total nitrogen sediment concentrations below the upstream edge of the FTW suggesting an effective removal due to accumulation on the plant roots in contact with the initial flows. Total phosphorous, however was not shown to exhibit similar removal in this section of the sediments of the FTW and this was attributed to the different removal mechanisms of different pollutants (Borne et al., 2015). It can be expected, that with this FTW configuration that the majority of sediment accumulation will occur under the FTW which is also a guide in terms of FTW placement for the ease of maintenance in terms of sediment removal (Borne et al., 2015).

Anchorage of plant pontoons is recommended to ensure the FTW is kept in the desired location within the pond and also the selection of tall plants is discouraged in order to avoid wind damage and excessive movement or the potential tipping of pontoons (Borne et al., 2015). Plants with significant fibrous roots are also recommended to enhance the entrapment of particulates and also enables to establishment of a dense root network (Cheng et al., 2009).

2.8. Macrophytes

2.8.1. The Role of Plants

An important component of wetland design is the role that plants play in the removal of nutrients and other pollutants from the water column, whether that be in a typical constructed wetland, or in the case here of the floating treatment wetlands. With biological processes of nitrification and denitrification as well as plant uptake presenting as the two predominant removal processes for the removal of nitrogen in constructed wetlands (Fisher, 1990). Plants assist the processes of nitrification, denitrification and BOD removal through a variety of complex processes and it has been reported by Dunbabin et al. (1988) that vegetated constructed wetlands showed a higher level of oxygen concentration, redox potential, pH and metal retention as opposed to constructed wetlands devoid of vegetation. Micro-organisms within the aerobic zone of the root masses assist in the stabilisation of organics as well as contributing to the nitrifying of ammonia to form nitrate. The removal of this nitrate is dependent on the process of denitrification which is promoted by the vegetation supplying organic carbon (Weisner et al., 1994) which is released from plant litter as well as from the living vegetation supplying attachment surfaces for epiphytes that in turn produce their own organic matter.

While the FTW concept is a relatively new application in water treatment, the application of aquaculture systems in general is not and has been used in treatment systems around the world, utilising both plant and animal monocultures or polycultures (Reed et al., 1995). The treatment response is via either the direct uptake by the plants or animals, or in the case of floating plants and FTW the attached biofilms on the plant roots. Traditionally with treatment systems incorporating floating aquatic plants have used species such as hyacinths, duckweeds, pennyworts and water ferns and are known to have the greatest potential for wastewater in such systems (Reed et al., 1995).

The floating treatment wetlands enable the roots of the planted vegetation to extend vertically down into the water column of the pond and the plants obtain their and nutrition directly from the water column (Headley and Tanner, 2008). This root extension into the water column provides both a physical filtration capability as well as providing a surface on which biofilms can accumulate. As such, under the pontoons of the floating wetlands, develops a hanging environment consisting of plant roots, rhizomes and the attached biofilms providing a complex surface area of biologically active regions for biological and physical removal processes to take place. The uptake of nutrients by the plants themselves is low in comparison to the contribution plants provide in terms sites for biofilm development which results in the efficient removal of nutrients (Masters, 2012).

2.8.2. Species Selection and Performance

Tanner (1996) provides an outline of the general attributes that are required of a particular plants species for them to be suitable for use in a constructed wetland environments for the encouragement of physical and biological processes for nutrient removal and uptake. These attributes consist of the plant being ecologically acceptable in terms of not presenting any threat to the local environment in terms of being a significant weed that may have the potential to affect local ecosystems and to avoid this issue the selection of indigenous species would mitigate this. The selected species must display a tolerance for local climatic conditions, pests and diseases as well as a tolerance for pollutants and hypertrophic conditions in a waterlogged environment. The plants must be able to be propagated and established with relative ease as well as have acceptable growth rates both for ease of establishment as well as economic viability. A high pollutant removal capability through direct assimilation and storage, or indirectly through the production of biofilms is also of importance. Rooting depth is also an important factor such that the plant roots are unable to attached to the substrate of the wetland as this has negative implications in terms of the floating treatment wetland being unable to respond to increases in water level such that the plants and substrate on the pontoon are inundated which can result in the death of the vegetation mat (Borne et al., 2015).

In the case of the floating treatment wetlands the plant species should be selected so as to maximise the surface area available for the attachment of biofilms and it has been suggested that plants that can develop dense and fine roots with numerous secondary lateral roots are optimal compared to species that only develop non-fibrous roots as they are not likely to have the ability to entrap incoming particles (Borne et al., 2015). As well as being resilient and slow growing with a low seasonal biomass turnover with persistent slowly decomposing litter (Tanner, 1996). Species selection based on their ability to form a dense perennial mat above the water with heights between 1 to 1.5m showed some success in a study conducted by Tanner and Headley (2011). A selection with these attributes also enabled the plant mat to successfully compete with weeds which assists in the reduction in costs of ongoing maintenance with weed removal and spraying. As well it enables the plant community to resist trampling by wildlife such as bird if bird covers are not provided and with plant selection within the range of height mentioned, also reduced the risk of the pontoons tipping in high winds. (Tanner and Headley, 2011) conducted field trials with a number of different species in New Zealand with temperate conditions that are similar to those experienced in Bathurst. It was reported that those species that exhibited a year round growth of shoots without significant senescence in winter were more favourable for floating treatment wetlands and also made them easier to maintain. Borne et al. (2015) also supports the avoidance of selecting plants species exhibiting a large degree of above ground biomass senescence to limit the release of additional accumulated pollutants in the plant matter to the water column. However it is also suggested that a thin litter layer on the surface of the pontoon may assist the denitrifying bacteria through the supply of organic carbon.

It is advantageous to select a range of plant species tolerant to local climatic conditions, possibly endemic to the local area and species that are capable of tolerating a range of incoming pollutant loads that may consist of sulphides, anoxic conditions and high rates of deoxygenation. A selection will also provide a greater robustness in the event of pest infestations as different species exhibit varying tolerances (Borne et al., 2015). Headley and Tanner (2012) provide a list of wetland plants which have shown successful performance for a number of floating treatment wetland applications and **Appendix F** provides some information of species relevant to Australia (FIA, 2015).

3. Methodology

3.1. The Reed Method

The Reed et al. (1995) method will be applied to size a wetland using the primary treated effluent data of ammonia, total nitrogen and phosphorous from the BRC WWTW. The wetland size achieved through the calculations of the limiting pollutant, ammonia, will be the size designated for the wetland. The following calculations are to be performed utilising the parameters that are defined in **Table 3.1-1** and the temperature rate coefficients are provided in **Table 3.1-2**.

Table 3.1-1 Parameters Required for Reed's Method.

Parameter	Definition	Units
$\mathbf{A_s}$	Treatment area of wetland	m^2
$\mathbf{K_T}$	Rate constant at temperature $\mathbf{T_W}$	d^{-1}
$\mathbf{K_R}$	Rate constant at reference temperature	
$\mathbf{c_i}$	Influent concentration	mg/L
$\mathbf{c_o}$	Outlet effluent pollutant concentration	mg/L
Q	Average flow rate through the wetland	m^3/day
y	Depth of wetland	m
n	Porosity (space available for water to flow through the wetland in terms of space also taken up by litter and vegetation. Typical Range 0.65 – 0.95)	
$\mathbf{\theta_R}$	Temperature coefficient for rate constant , refer **Table 3.1-2**	
$\mathbf{T_W}$	Water temperature in wetland	°C
$\mathbf{T_R}$	Reference temperature	°C

Source: Reed et al. (1995)

Determine the rate constant (K^T) for ammonia removal at specified temperature:

1) $$K_T = K_R \,.\, \theta_R R \,(T_W - T_R)$$

Determine wetland treatment area (A_S**)** for ammonia removal:

2) $$AS = (Q \,.\, ln\,(c_i/c_o))/\, K_T \,.\, y \,.\, n$$

Determine detention time (t) in wetland:

3) $$t = (A_S \,.\, y \,.\, n)/Q$$

To check is there is sufficient area available for denitrification:

4) $$K_T = K_R \,.\, \theta_R \,(T_W - T_R)$$

Determine the area required for denitrification:

5) $$A_S = (Q \,.\, ln\,(c_i/c_o))/\, K_T \,.\, y \,.\, n$$

From this series of calculations the area required for denitrification, the removal of ammonia (A_S) is achieved. This same calculation is performed using the influent data for nitrogen which results in an area for nitrification, or removal of TN.

To determine the extent to which phosphorous can be reduced in the wetland, the following calculation is performed:

Determine the hydraulic loading rate using the area (A_S) calculated for denitrification:

6) $$HLR = 100 * Q/A_S$$

The rate constant for phosphorous is $K_p = 2.73 cm/d$ (Reed et al., 1995).

To determine the outlet concentration of phosphorous (c_o):

7) $$c_o = c_i * exp^{(-\frac{Kp}{HLR})}$$

Table 3.1-2 Temperature Coefficient Rate Constants for Reed's Method

Parameter	BOD	NH_4[a]	NO_3[a]	Pathogen Removal
For Free Water Surface Wetlands				
T_R, °C	20	20	20	20
Residual mg/L	6	0.2	0.2	-
K_R, d^{-1}	0.678	0.2187	1.00	2.6
θ_R	1.06	1.048	1.15	1.19

a. Nitrification and denitrification not possible below 0°C

Source: DLWC (1998)

DLWC (1998) suggest that for the treatment of municipal wastewater, the area required for denitrification is smaller than for nitrification and for the purpose of cost reduction, as well as the potential requirement for mechanical aeration, it would be useful to consider achieving partial or even complete nitrification in a preliminary treatment step prior to entry into the wetland. A case study with a target ammonia effluent concentration to be achieved of 0.5mg/L received influent with an ammonia concentration of 8mg/L (DLWC, 1998). The required area for ammonia removal using the above calculations was 12.3 hectares with a detention time of 16 days. The area required for denitrification was 3.2 hectares. The Kadlec and Knight (1996) method was used, for the same effluent target, and resulted in a wetland area of 13.9 hectares with ammonia removal also being the limiting pollutant (DLWC, 1998). **Appendix B** provides the results for the application of the Reed method.

3.2. Kadlec & Knight Method

Kadlec and Knight’s method will also be applied to determine wetland areas based on primary treated effluent data of ammonia, nitrogen and phosphorous obtained from the BRC WWTW and the equations utilise the parameters defined in **Table 3.2-1**.

Table 3.2-1 Parameters required for Kadlec and Knight’s Method.

Parameter	Definition	Units
$\mathbf{A_s}$	Treatment area of wetland	m^2
$\mathbf{K_T}$	Rate constant at temperature $\mathbf{T_W}$	d^{-1}
$\mathbf{K_R}$	Rate constant at reference temperature	
$\mathbf{c_i}$	Influent concentration	mg/L
$\mathbf{c_o}$	Outlet effluent pollutant concentration	mg/L
$\mathbf{c_e}$	Target effluent pollutant concentration	mg/L
Q	Average flow rate through the wetland	m^3/day
q	Hydraulic loading rate	m/year
y	Depth of wetland	m
n	Porosity - space available for water to flow through the wetland in terms of space also taken up by litter and vegetation. Typical Range 0.65 – 0.95 (DLWC, 1998)	
$\mathbf{\theta_R}$	Temperature coefficient for rate constant , same as for Reed’s method refer **Table 3.1-2** (DLWC, 1998)	
$\mathbf{T_W}$	Water temperature in wetland	°C
$\mathbf{T_R}$	Reference temperature	°C

Source: DLWC (1998)

The general form of the model is:

8) $$ln(ce - c^*/ci - c^*) \ = \ -k/q$$

Where k is the first order areal rate constant in m/yr. The reference temperature being 20°C and c^* being the wetland background limit.

The hydraulic loading rate is determined by:

9) $$q \ = \ 365.Q/A_S$$

Where Q is the average flowrate through the wetland in m^3/day.

Determine the treatment area of the wetland A_S

10) $$A_S \ = \ (365.Q/k)ln(c_i - c^*/c_e - c^*)$$

Or alternatively

11) $$c_e \ = \ c^* \ + \ (c_i - c^*)exp^{(-As.\frac{K}{365}.Q)}$$

Table 3.2-2 Preliminary model parameter values for Kadlec & Knight's (1996) Method.

Parameter	**BOD**	**TSS**	**Org N**	**NH4-N**	**NOx-N**	**TN**	**TP**	**FC**
For Free Water Surface Wetlands								
k_{20} m/yr	34	1000[a]	17	18	35	22	12	75
θ[c]	1.00	1.00	1.05	1.04	1.09	1.05	1.00	1.00
c* mg/L	3.5+0.053 Ci	5.1+0.16Ci	1.50	0.00	0.00	1.50	0.02	300[b]
θ[c]	1.00	1.065						

Notes

a. rough unsubstantiated estimate, settling rater determination preferred (Kadlec and Knight, 1996)

b. central tendency of widely variable values

c. Temperature coefficient

Source: DLWC (1998)

The New South Wales Department of Land and Water Conservation, as it was then known, acknowledge that both the Reed method and the Kadlec and Knight method will result in an effective wetland for functional wastewater treatment with the

Kadlec and Knight method resulting in slightly larger surface areas being calculated (DLWC, 1998). It is the opinion of the DLWC, in the Constructed Wetlands Manual, that the Reed method is favoured and on this basis the Reed method was chosen for the purposes of sizing calculations for this study and no further reference to the Kadlec and Knight method will be made other than to compare the resulting surface area calculations in the results. **Appendix C** provides the detailed results the Kadlec and Knight method.

3.3. Floating Treatment Wetlands

The floating treatment wetland approach will be applied to determine how much further the effluent in the existing maturation pond could be further polished to reduce the annual fees charged by the EPA on the effluent discharged to the Macquarie River.

As there is no accurately defined methodology in the literature for the sizing of floating treatment wetlands it was determined that sizing would be in accordance with the assumption that a floating treatment wetland can achieve a removal rate of approximately 3kg/m^2/year of TN and approximately 1kg/m^2/year of TP as advised by FIA (2015).

To achieve these removal rates, a surface area coverage of 3% to 7% is required and for the purpose of this investigation the higher surface area coverage rate of 7% was selected due to the technology being applied to secondary treated effluent as opposed to stormwater that would exhibit lighter pollutant loads.

The existing 1.05 hectare maturation pond would be retrofitted with the pontoons.. The pontoons have a total area of 1.16m^2 and Australian distributors recommend 12 emergent macrophytes of varied species per pontoon. The pontoons would be configured perpendicular to the treated effluent flow within the maturation pond at the downstream end of the pond in the vicinity of the outlet (Headley and Tanner, 2006).

3.3.1. Cost Benefit Analysis

Cost benefit analysis provides a technique for the measurement of whether or not a the costs of a particular action outweigh the benefits of the action, with ‘action’ being defined as a deliberated decision to commit resources (Hanley and Barnier, 2009). The analysis adds up the benefits of a project and compares them to the associated costs of the project to determine a numerical ratio of cost versus benefit. The costs, once determined, are added and then expressed in present value (PV) terms. Time is factored into the calculation by way of expressing all costs and benefits being discounted by an assumed rate of interest ‘i’. The present value of a cost or benefit ‘X’ received in time ‘t’ can be calculated using the following expression:

1) $$PV\ (Xt)\ =\ Xt\,[\,(1-i)^{-t}]$$

The discount factor within this expression is shown within the square brackets. To determine if a project will be efficient in terms of its use of resources the net present value term requires calculation and it simply determines if the sum of discounted gains exceeds the sum of discounted losses, using the following expression:

2) $$NPV\ =\ \sum Bt(1+1)^{-t}\ -\ \sum Ct(1+i)^{-t}$$

With t running from $t = 0$ being the start of the project to $t = T$, the end of the project.

It is assumed that if $NPV > 0$ then the project should proceed and the project can be considered as an improvement to social welfare (Hanley and Barnier, 2009).

The benefit cost ratio simply becomes a ratio of the discounted benefits to the discounted costs and if this ratio exceeds one (>1) then this gives a basis on which to proceed with a project (Hanley and Barnier, 2009).

A cost benefit analysis will be undertaken for the floating treatment wetland option to determine the feasibility in terms of providing an additional method for municipal wastewater treatment for the BRC WWTW

4. Results and Discussion

4.1. Preliminary Feasibility

Geographic and economic constraints are two main factors that affect whether or not a constructed wetland is a viable option for effluent treatment or polishing. Geographic in terms of natural landform and whether or not the wetland can be sized fit within the proposed area and economic in terms of construction and land availability and whether or not the purchase of additional land for construction would be required. Technical constraints also need to be considered when applying this technology and typically include aspects pertaining to soils types, risks to ground water and climatic conditions that may affect biological processes and also plant growth and nutrient uptake.

The concept of a constructed wetland appears to be simple in nature both in terms of the application capability as well as the ease of design, however constructed wetlands are complex in nature such that much thought and investigation is required for all aspects of a wetlands functioning, processes and consistency of design in order to avoid a system that is inappropriate and under performs for its intended purpose.

The land area available at the BRC WWTW for the application of constructed wetland technology is approximately 2.2 hectares. Of this area, approximately 1.05 hectares consists of an existing maturation pond that could be utilised for retrofitting purposes and can be seen in the aerial view of the BRC WWTW provided in **Figure 1.1-4**.

With reference to the floating treatment wetland option, the existing 1.05 hectares maturation pond could be retrofitted with floating pontoons and the remaining land area is available for the construction of two new ponds to be fitted out with additional floating pontoons. As discussed previously, the costs associated with retrofitting an existing pond with vegetated pontoons to create a FTW are much less compared to the construction of a completely new structure for conventional wetland treatment. The footprint for a FTW would be much less than a typical constructed wetland with the capability of treating greater flows of effluent to achieve a similar polishing result.

4.2. Sizing of a Typical Constructed Wetland

Reed et al. (1995) proposed a method for the sizing of treatment wetlands in terms of the water quality goals that needed to be achieved. For the purpose of sizing the wetland for this study the parameters of total nitrogen, total phosphorous and ammonia were used for the sizing calculations, with ammonia removal efficiency being the limiting factor on which the size of the wetland was ultimately decided.

The water quality targets to be achieved for the Bathurst WWTW as set by the NSW EPA are listed in **Table 4.2-1**.

Table 4.2-1 NSW EPA Load Limits for the Bathurst WWTW.

Pollutant	90 percentile concentration limit	100 percentile concentration limit
BOD	20	30
TN	15	20
pH	-	6.5-8.5
TP	1	2
TSS	25	30

Source: BRC (2015)

The Reed et al. (1995) method for wetland sizing was applied to the 90 percentile primary and secondary treated effluent data. The primary treated effluent is post grit screening and the secondary effluent is post treatment through the EATs. The average daily flow of effluent being treated is 10 000m^3 per day.

The 90 percentile concentration of pollutants in the primary and secondary treated effluent is provided in **Table 4.2-2**.

Table 4.2-2 Pollutant Concentrations.

Origin Of Flow	Total Nitrogen (TN) (mg/L)	Total Phosphorous (TP) (mg/L)	Ammonia (NH_4) (mg/L)
Primary Treated Effluent (90 percentile)	77.0	11.8	43
Secondary Treated Effluent (Discharged to Macquarie River)	8.1	0.6	4

Source: BRC (2015)

The wetland area required for the treatment of the primary effluent to achieve discharge levels of 7.5mg/L for NH_4, 15mg/L for TN and 1mg/L for TP, by applying the Reed method are provided in **Table 4.2-3**. The discharge targets here are set to meet the EPA license discharge limits.

For the secondary treated effluent the Reed method was applied to achieve discharge levels of 1mg/L NH_4, 1mg/L TN and 0.1mg/L TP. The discharge targets here were determined in terms of providing further effluent polishing as the EPA license discharge targets have already been achieved. The goal here would be to reduce the EPA license fees for what is actually discharged which for the 2014-2015 reporting period were 8.1mg/L for TN and 0.6mg/L for TP and an assumed 4mg/L of NH_4. The results are provided in **Table 4.2-3**.

The assumption is being made that of the total nitrogen concentration; approximately 50% can be attributed to ammonia. The assumption was based on sampling results for ammonia and total nitrogen for the secondary treated effluent at the BRC WWTW. The results for the application of Kadlec and Knight’s method are also presented in **Table 4.2-3** only for the purpose of illustrating the greater areas that result compared to Reed's method.

Table 4.2-3 Wetland Areas Required for Pollutant Removal.

Pollutant	Reed's Method Area For Primary Treated Effluent (ha)	Reed's Method Area Secondary Treated Effluent (ha)	Kadlec & Knight's Method Area For Primary Treated Effluent (ha)	Kadlec & Knight's Method Area Secondary Treated Effluent (ha)
TN	12.7	13.9	71.7	31.1
TP	26.5	21.1	151.8	38.1
NH_4-N	26.5	21.1	57.7	9.5

Table 4.2-3 clearly demonstrates the differences in treatment areas resulting from the two methods in that the Kadlec & Knight method is overly conservative and does result in significantly larger areas for the same treatment capability. These results demonstrate why the Reed method was chosen for this investigation and that they align with the opinion put forward by DLWC (1998) in that the Kadlec & Knight method is overly conservative.

As previously outlined, the total area available for the construction of treatment wetlands is approximately 2.2 hectares. The calculated results presented in **Table 4.2-3** show that for primary treated effluent, an area of 26.5 hectares is required for the removal of ammonia to a level of 7.5mg/L, where the primary treated effluent concentration was 43mg/L.

For the removal of total nitrogen, with a primary treated effluent concentration of 77.0 mg/L an area of 12.7 hectares would be required to reduce the concentration to 15mg/L as required by the EPA. If 50% of the total nitrogen concentration was attributed to ammonia then a recalculation based on 38.4mg/L of nitrogen results in an area of 7.3 hectares required to reduce the concentration to 15mg/L. In making this assumption about nitrogen, further mechanical aeration would need to be incorporated into the wetland to address the removal of ammonia, in addition to what has been removed through the EAT process.

The Reed calculation for the removal of total phosphorous incorporates the calculated area for the limiting pollutant ammonia, and as such, the removal of total phosphorous that can be achieved with a surface area of 26.5 hectares is 5.9mg/L which is well above the load limit set by the EPA of 1mg/L, noting that the primary treated effluent concentration of total phosphorous was 11.8 mg/L.

Proposed treatment areas through the application of the Reed method to the secondary treated effluent resulted in areas in excess of land available. For TN removal to 1mg/L, 13.9 hectares would be required, for NH_4 to 1mg/L and TP to 0.1 mg/L removal, 21.1 hectares would be required. However it is noted that for the removal of TP the concentration able to be reduced to 0.17mg/L with 21.1 hectares and not 0.1mg/L.

The Reed method has also been manipulated further in order to determine what removal capacity of TN, TP and NH_4 could be achieved with the surface are already available with the existing maturation pond of 1.05 hectares. In order to do this **Equation 10** was rearranged to determine the final effluent concentration c_o.

12) $$c_o = c_i \,/(exp^{((K_T.y.n.A_S)/Q)}$$

The results of the final effluent concentration (c_o) using **Equation 12**, for TN, TP and NH_4 are provided in **Table 4.2-4**.

Table 4.2-4 Constructed Treatment Wetland results (c_o) using existing area of 1.05ha

Origin Of Flow	**c_i (TN) (mg/L)**	**c_o (TN) (mg/L)**	**c_i (TP) (mg/L)**	**c_o (TP) (mg/L)**	**c_i (NH_4) (mg/L)**	**c_o (NH_4) (mg/L)**
Primary Treated Effluent	77.0	67.2	11.8	11.5	38.5	35.9
Secondary Treated Effluent	6.0	5.2	0.6	0.58	4.0	3.7

The results provided in **Table 4.2-4** clearly show that when the Reed method is applied to the already available surface area of 1.05 hectares of the existing maturation pond that minimal pollutant removal (c_o) is achieved in comparison to the influent concentration (c_i) being received. For the primary treated effluent TN was only able to be reduced by 9.7mg/L, TP by 0.3mg/L and NH_4 was reduced by 0.4mg/L. For the secondary treated effluent TN was reduced by 0.6mg/L, NH4 was reduced by 0.3mg/L and there was a very minimal reduction in TP of 0.02mg/L. The results for both the primary and secondary treated effluent using this approach further emphasises that constructed wetland technology will not adequately service the needs of the BRC WWTW for effluent treatment.

The results for both the primary and secondary treated effluent illustrate that the area required to successfully remove pollutants, to meet the EPA Guidelines, as well as further polishing of the effluent for the reduction of EPA license fees, exceed the area available both in terms of utilising existing ponds as well as land area available for the construction of new wetlands. The area has been exceeded to an extent that for the current conditions it would not provide a viable option. On this basis, further calculations to determine the removal efficiencies in primary and secondary treated effluent for the removal of BOD, TSS and faecal coliforms has been excluded from this study. In addition, the investigation into the construction and operational costs of a traditional constructed wetland has not been incorporated due to the impracticality in terms of size and land limitations.

4.3. Floating Treatment Wetland

4.3.1. Removal Efficiency

The alternative to providing adequate area for effluent treatment with a constructed wetland would be to retrofit the existing concrete lined maturation pond that has a surface area of 1.05 hectares, an average depth of 1.5 m and a total volume of 13 ML.

While the literature reported successful removal rates of TN and TP (Borne et al., 2015) this also translated to pond coverage ratios in the order of 18%-50% which is later discussed as a cost prohibitive option for the current treatment proposition.

With the provision of a 7% surface area coverage to the existing 1.05 hectare maturation pond with floating pontoons that have an area 1.16m^2 results in a total area of approximately 736m^2 of the pond being taken up by floating treatment wetland. Applying the removal rate of 3kg/m^2/year to the actual load of TN of 17, 156 kilograms resulted in a removal efficiency of approximately 25%. Assuming again that 50% of the TN is composed of NH_4 then the provision of an aeration treatment in the upstream section of the maturation pond would allow for the nitrification process to remove the NH_4 content allowing for more effective denitrification process to take place through the floating treatment wetlands. This 50% reduction in TN is reflected in **Table 4.3-1** with the nutrient load of TN being 8578 kilograms of nitrogen per year as opposed to 17, 156 kg of nitrogen per year

For TP, applying the removal rate of 3kg/m^2/year to the actual load of 1,415 kilograms resulted in a removal efficiency of approximately 52%.

4.3.2. Financial Analysis

Table 4.3-1 provides a summary of the removal efficiency as applied to the 2014-2015 pollutant loads and the subsequent calculations that converts the load removed to a revised assessable load (AL_2) and the pollutant fee (PF) that this removal efficiency translates to in terms of a cost saving. Further details of these calculations are provided in **Appendix D**.

Table 4.3-1 Floating Treatment Wetland Removal Efficiency and Cost Savings

Parameter	TN Removal Results	TP Removal Results
Nutrient In (kg nutrient/year)	8578	1415.87
2014-2015 Pollutant Fee ($)	5351.34	16571.07
Pond Surface Area Coverage (%)	7	7
Total Pond Coverage with FTW	736.54	736.54
Total Nutrient removed (kg/m^2)	3.0	1.0
Nutrient removed (kg nutrient/year)	2209.62	736.54
AL_2 = AL – Nutrient In (kg nutrient/year)	6368.38	490.06
Revised PF = AL_2 x CF^a ($)	1872.30	4260.81
Cost Saving ($)	3479.04	12310.26
Achieved nutrient removal (%)	25.76	52.02

a. CF is calculation factor set by the EPA see details in **APPENDIX E**

The results present a 25% removal efficiency for TN and a 52% removal efficiency for TP with the 7% surface area coverage with the floating treatment wetlands. To express these removal efficiencies in terms of kilograms of nutrient removed per year translates to approximately 2, 209 kg of TN per year and approximately 736 kilograms of TP per year.

Converting the nutrient load removed per year to a pollutant fee shows that for TN the pollutant fee is \$1, 872.30 and for TP the pollutant fee is \$4, 260.81. This results in a cost saving of \$3, 479.04 for TN and \$12, 310.26 for TP, which in total equates to approximately \$16, 000 in EPA load based license fees. **Appendix E** provides the EPA load based license fees paid by BRC for the period 2011 to 2015.

Preliminary cost estimates, on advice from distributors of floating treatment wetlands was sought to determine the establishment costs of the floating pontoons. Initial estimates of the pontoons came in at approximately \$475 per pontoon. It was recommended to provide 12 plants per pontoon with an estimated cost of \$2.00 per plant. A single pontoon has an approximate area of 1.16m^2 which for a 7% pond surface area coverage amounts to 635 pontoons and a total cost of approximately \$301 000. This initial figure does not reflect additional costs that would be associated for installation, bird and turtle protectors, or factoring in salaries for staff as well as ongoing maintenance such as plant replacement and weed removal and spraying. These additional costs, however, have been factored in the cost benefit analysis to follow.

EPA license load fees for TN and TP (only) were reduced by approximately \$16 000, which highlights a significant difference in terms of financial outlay with respect to any financial gains and would therefore not warrant the installation of a floating treatment wetland based on these preliminary calculations. Based on the costs of the pontoons alone and the amount of savings achieved in EPA load based license fees, a pontoon costing approximately \$30 would bring the costs and savings into closer alignment. However this significant reduction in price of a pontoon is not able to be realistically reflected in the cost benefit analysis.

4.3.3. Cost Benefit Analysis

A cost benefit analysis was undertaken for the option of a floating treatment wetland which consists of retrofitting the existing maturation pond that has a surface area of 1.05 hectares with vegetated pontoons. The net present value of the option was annualised over 20 years at a discount rate of 7% with a rate of 15% applied to all capital costs. **Appendix G** provides the data for the cost benefit analysis undertaken.

Capital costs included items such as mobilisation/demobilisation which would consist of an area set aside at the WWTW for construction materials and equipment as well as plant stocks. This area may require some environmental controls for any soil disturbance and runoff.

The number of wetland pontoons required is 635 at a rate of $475 each and in addition to the pontoons there would be materials required for anchorage of the pontoons both for design configurations yet to be determined and also to prevent disturbance by winds such that the pontoons cannot float freely around the surface area of the pond with the likelihood of damage occurring. These materials would consist of items such as stainless steel cables, anchorage attachments and bollards for attachment. Pontoon installation, wetland plants, bird guard kits and the costs for planting have also been included. A pond aeration device would be required for the removal of ammonia through the nitrification process. This would also include some electrical and control equipment.

Operating costs have been determined by assuming that ongoing floating treatment wetland maintenance would require 25% of an employee’s time with the rest of the employee’s time spent working on other tasks at the WWTW. This ongoing maintenance would include weeding of pontoons and spraying of herbicides as required and also ensuring that any damage to the pontoons over time was rectified.

Clean out of the maturation pond would be required on a basis that has been estimated to be every three years, the cost here included the requirement for plant and equipment as well as relocation of wastes to landfill.

All these factors combined in terms of building the floating treatment wetland and operation over a 20 year period shows that in today’s dollars it would cost Council

$803,930. A savings in load based license discharge fees of only $16,000 can be recovered annually which results in the present value of the FTW savings being $169,504. The comparison of the present value and the present value of savings results in a cost benefit ratio of only 0.21 which clearly indicated that this option would not be feasible for Council.

Council may want to consider the procurement of grant funding for the capital costs of the works which in this option assessment was $613,731. This would leave operating costs to the amount of $190,199 which when compared to the present value of FTW savings of $169, 504 would result in the project being a more viable option.

5. Conclusions and Recommendations

Two options of constructed wetland technology were investigated for the purpose of this study to determine the efficacy of the technology for its potential application to the treatment of the municipal wastewater at the Bathurst Regional Council wastewater treatment works.

Option 1 investigated the site suitability and treatment capability of a traditional constructed wetland when applied to the treatment of primary and secondary treated effluent at the WWTW. Two methodologies were applied to the treatment data to determine a size suitable for the level of treatment required as specified by the EPA load limits for discharge focusing on total nitrogen, total phosphorous and ammonia. The methodologies consisted of first order plug flow models put forward by Kadlec and Knight (1996) and Reed et al. (1995).

The results showed that for the Kadlec and Knight method the resulting areas for the primary treated effluent were 71.7 hectares for the removal of total nitrogen, 151.8 hectares for the removal of total phosphorous and 57.7 hectares for the removal of ammonia. For the secondary treated effluent, from the extended aeration tank systems the resulting areas from the Kadlec and Knight method were 31.1 hectares for the removal of total nitrogen, 38.1 hectares for total phosphorous and 9.5 hectares for ammonia.

Results from the application of the Reed method to both primary and secondary treated effluent showed that for the primary treated effluent an area of 12.7 hectares would be required for the removal of total nitrogen and 26.6 hectares would be required for the removal or total phosphorous and ammonia respectively. For total phosphorous removal, the area of 26.6 hectares would only be able to reduce the effluent concentration from 11.8mg/L to 5.9mg/L which would not be sufficient to meet the EPA target for phosphorous of 1mg/L.

Application of the Reed method to the secondary treated effluent resulted in areas for the removal of total nitrogen being 13.9 hectares and for the removal of total phosphorous and ammonia, 21.2 hectares. The level of phosphorous was able to be reduced from 0.3mg/L to 0.17mg/L which was above the goal of reducing it to 0.1mg/L.

The Reed method was further manipulated to determine the treatment capability of the existing surface area available with the 1.05 hectare maturation pond. This was undertaken by rearranging the equation for the area determination such that the final effluent concentration became the unknown. The results from this showed that for primary treated effluent the reduction in the pollutants of total nitrogen, total phosphorus and ammonia were 9.7mg/L, 0.3mg/L and 0.4mg/L respectively. For the secondary treated effluent the reduction in total nitrogen was 0.6mg/L, ammonia reduction was 0.3mg/L and the reduction for total phosphorous was approximately 0.02mg/L. These reductions clearly show that with the existing surface area available constructed wetland technology is not able to be effectively applied to achieve any useful level of effluent treatment.

The resulting areas from applying both the Kadlec and Knight Method and the Reed Method to both the primary and secondary treated effluent were far in excess of the land area available, of only 2.2 hectares, at the BRC WWTW for the construction of wetland infrastructure to achieve the effluent treatment goals set out in this investigation. These areas would be in excess of land available for the majority of WWTWs looking to achieve similar treatment goals with effluent loadings representative of what is treated through the BRC system.

The Reed method results in less conservative areas of wetland sizing and is the method that is recommended by the Department of Land and Water Conservation. For the case of the BRC WWTW the Reed method would be the method of choice if the resulting areas were more suited to the available land areas of the current site.

Recommendations and consideration of alternatives with respect to a traditional constructed wetland would be that the application of the Reed method would be more suited to treatment plants that experience lower flows, such as those on peripheral villages to regional towns and cities as well as in developing countries for their water treatment requirements, this is also supported in the literature This would allow for less area being required for treatment capability and the ability of incorporating a system that does not have a significant economic cost compared to the installation of a traditional wastewater treatment plant. Area requirement is seen as one of the major limitations of a traditional constructed wetland for the treatment of municipal and other wastewater treatment and management.

Option 2 investigated the relatively new technology of floating treatment wetlands consisting of vegetated pontoons that float on the surface of the water allowing the roots of the plants to extend into the water column to aid in the removal of pollutants. Advantages of this technology are that less area is required to achieve the same treatment capability of traditional constructed wetlands and existing structures, such as maturation ponds, can be retrofitted with the pontoons. This ability to retrofit existing structures allows for additional capital costs such as those associated with the construction of new wetland ponds, are able to be avoided.

The investigation into option 2 looked at retrofitting the existing 1.05 hectare, concrete lined maturation pond at the BRC WWTW with floating pontoons to allow for the treatment of the secondary treated effluent that is discharged to the pond for settling and further UV sterilisation before being discharge into the Macquarie River.

The goal was to treat the secondary treated effluent to a level such that the EPA load based fees were able to be reduced with respect to the amount in kilograms of pollutants discharged to the Macquarie River each year. Investigation into the feasibility of this option was conducted with focus on pollutant removal capability of the pontoons with regard to surface area coverage and the subsequent costs involved in the installation of this treatment technology.

The amount of total nitrogen that was discharged to the Macquarie River for the 2014-2015 reporting period was 8.1mg/L which translates to a calculated assessable load of approximately 18,198kg and 0.6mg/L of total phosphorous, or a calculated assessable load of 1,414kg.

In the investigation into the removal efficiency of the FTW, as applied to the existing 1.05 hectare maturation pond, 3kg per metre squared of floating treatment wetland per year would be a likely outcome for the removal of total nitrogen and for total phosphorous the FTW would be expected to achieve approximately 1kg removal per metre squared of floating treatment wetland per year.

In applying these removal rates to the pollutants the study achieved a removal efficiency of approximately 25% for total nitrogen and approximately 52% for total phosphorous. This reduced the amount of total nitrogen to be discharged to the Macquarie River to 6.1mg/L and total phosphorous to only 0.3mg/L. This reduction was then expressed in terms of the reduction in EPA load based license fees and for total nitrogen and total phosphorous combined, the cost savings were only in the order of approximately $16,000 off the total of $28,711.37 for the 2014-2015 reporting period for BRC.

A cost benefit analysis was undertaken for the floating treatment wetland option to determine if this treatment technology had the potential to be a feasible option for Council for their wastewater treatment requirements in term of reducing the annual load based license fees.

Cost benefit ratios of >2 and >3 indicate the likelihood of a decent profit margin and would be feasible in terms of attracting investment opportunities providing a level of risk avoidance. A cost benefit ratio of >1 would not necessarily be regarded as viable option as risk would be high and significant profits potentially would not be achievable, however a project could still be based around this in terms of benefit to the community type projects such that a local Council might consider..

The net present value of the floating treatment wetland option was annualised over 20 years at a discount rate of 7% with a contingency rate of 15% applied to all capital costs. All capital costs associated with the technology were investigated as were ongoing running and maintenance costs over the 20 year period. The resulting present value of the floating treatment wetland was calculated to be $803,930 with a present value of floating treatment wetland savings of $169,504. These two figures resulted in a cost benefit of only 0.21 clearly suggesting that this option would not be a feasible alternative to wastewater treatment at the BRC WWTW.

In the consideration of alternatives, however, a recommendation would be that Council try to procure grant funding for such a proposal to cover the capital costs of the technology, and this would assist in aligning the cost benefit ratio closer to 1 which would potentially be a more acceptable and feasible option for Council which would also provide additional benefits to the community into the future.

6. Future Work

In undertaking a literature review, with regard to the floating treatment wetland technology it was determined that there was a lack of significant field trials undertaken in recent times incorporating full scale pilot trials and as such the results in the literature only reflected a high treatment efficacy with those trials that incorporated a large surface area coverage of the floating pontoons, from 18% to 50% surface area coverage, in small scale ponds and study tanks. This feasibility study demonstrated that with the recommended surface area coverage of 3% to 7% the pollutant removal efficiency is not high enough to warrant the installation costs, at least for the treatment of municipal wastewater. It appears at this stage that the technology would be more suited to smaller treatment works to assist in avoiding the financial outlay of constructing a traditional treatment system as well as to smaller wetland ponds for agricultural and industrial wastewaters. The efficacy of this treatment technology however has been acknowledged in terms of its suitability for stormwater treatment for lighter flows and for providing aesthetically pleasing and environmentally appealing solutions to stormwater treatment.

Looking to the future it would be recommended that a pilot study be incorporated at the BRC WWTW of a floating treatment wetland configuration to further investigate how greater pollutant removal effectiveness could be achieved and how to address the costs of building and installing the pontoons. The two maturation ponds at the BRC WWTW would provide an ideal study site for this to be incorporated to investigate and possibly determine how effective treatment of municipal wastewater, at this scale could be achieved.

The literature consistently emphasises the importance of the complex biological processes that take place within a treatment wetland in terms of the interactions within and between the pollutants, water column, macrophytes, biofilms and the wetland substrates, as well as the impacts of temperature and season. In addition to these the consistency and diligence of design all need to be incorporated for further streamline the process of developing a treatment technology that can address ecologically sustainable development principles both now and into the future.

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Appendix A – Project Specification

University of Southern Queensland
Faculty of Health, Engineering and Sciences

Eng4111 Research Project Part 1

Projection Specification

For: Yvette Lieschke-Mercer

Topic: The Feasibility of Using Constructed Wetland Systems for Urban Wastewater

Supervisors: Assoc. Prof .Thomas Banhazi and Dr Elad Dafny

Project Aim: To investigate the feasibility of using constructed wetland systems as a component of the treatment system at Bathurst Regional Council's (BRC) sewage treatment plant (STP). The passive treatment options to be presented would be incorporated to work in line with and complement the current traditional system of the STP.

Programme: Revision A, 18th March 2015

1. Collate operational data for the previous 2 years from the BRC STP. This would include daily flows and treated effluent quality.

2. Describe and review the existing treatment processes at the BRC STP and its treatment efficacy and ability to meet the EPL discharge limits.

3. Undertake a literature review of constructed wetland systems and their treatment performance focusing on the main objective identified in the study.

4. Prepare a concept design for the constructed wetland using published design methodologies and modelling.

5. Prepare an estimate of construction and operating costs for the system.

6. Undertake and options analysis comparing the benefits and costs of the system (both options if time permits) compared to the existing STP process.

7. Identify if a wetland system is feasible and identify a preferred wetland configuration.

Appendix B – Reed’s Method

REED METHOD FOR PRIMARY EFFLUENT

Pollutant	**Primary Influent Conc. mg/L**
90th percentile calc TP	11.8
90th percentile calc TN	77
90th percentile calc NH4	43

Area for NH4 Removal (Nitrification)		**Primary Effluent**
	K_T (d^{-1})	0.17
	KR	0.22
	θR	1.05
	y (m)	0.40
	n (%)	0.95
	Q (m^3/day)	10000.00
	Tw (°C)	15.00
	TR (°C)	20.00
	ci (mg/L)	43.00
	co (mg/L)	7.50
	t (days)	10.09
	Area (m^2)	265639.20
	Area (ha)	26.56

Area for TN Removal (Denitrification)		**Primary Effluent**
	K_T (d^{-1})	0.50
	KR	1.00
	θR	1.15
	y (m)	0.40
	n (%)	0.65
	Q (m^3/day)	10000.00
	Tw (°C)	15.00
	TR (°C)	20.00
	ci (mg/L)	77.00
	co (mg/L)	15.00
	t (days)	3.29
	Area (m^2)	126541.85
	Area (ha)	12.65

TP Removal Efficiency		**Units**
HLR=100*Q/As	4.02	(cm/day)
TP ci	11.80	mg/L
EPA Target TP	1.00	mg/L
co=ci*exp^(-Kp/HLR)	5.98	mg/L
Kp=2.73cm/d		

REED METHOD FOR SECONDARY EFFLUENT

Pollutant	Secondary Influent Conc. mg/L
90th percentile calc TP	0.3
90th percentile calc TN	6
90th percentile calc NH4	4

Area for NH4 Removal (Nitrification)		**Primary Effluent**
	K_T (d^{-1})	0.17
	KR	0.22
	θR	1.05
	y (m)	0.40
	n (%)	0.95
	Q (m^3/day)	10000.00
	Tw (°C)	15.00
	TR (°C)	20.00
	ci (mg/L)	4.00
	co (mg/L)	1.00
	t (days)	8.01
	Area (m^2)	210877.13
	Area (ha)	21.09

Area for TN Removal (Denitrification)		**Primary Effluent**
	K_T (d^{-1})	0.50
	KR	1.00
	θR	1.15
	y (m)	0.40
	n (%)	0.65
	Q (m^3/day)	10000.00
	Tw (°C)	15.00
	TR (°C)	20.00
	ci (mg/L)	6.00
	co (mg/L)	1.00
	t (days)	3.60
	Area (m^2)	138610.32
	Area (ha)	13.86

TP Removal Efficiency		**Units**
HLR=100*Q/As	4.74	(cm/day)
TP ci	0.30	mg/L
EPA Target TP	1.00	mg/L
co=ci*exp^(-Kp/HLR)	0.17	mg/L
Kp=2.73cm/d		

Appendix C – Kadlec & Knight’s Method

KADLEC & KNIGHT METHOD APPLIED TO PRIMARY TREATED EFFLUENT				
Design Flow (m3/day)	10000			
		TN	**TP**	**Ammonia**
Influent Conc (mg/L)	**Ci**	77	11.8	43
Target % Reduction				
Target Effluent Conc (mg/L) (90th %'ile)	**Ce**	2.5	0.1	2.5
Wetland Background Limit	**C***	1.5	0.02	0
Reduction fraction to target	**Fe**	0.97	0.99	0.94
Fe= 1-Ce/Ci				
Reduction fraction to background	**Fb**	0.98	1.00	1.00
Fb = 1-C*/Ci				
Areal Rate Constant (m/yr)	**k**	22	12	18
Required Wetland Area (A) (ha)	**A**	71.74	151.84	57.69
(A=[(0.0365*Q/k)(ln((Ci-C*)/(Ce-C*))]				
Hydraulic Loading Rate (m/yr)	**q**	1.05	1	1.04

KADLEC & KNIGHT METHOD APPLIED TO SECONDARY TREATED EFFLUENT				
Design Flow (m3/day)	10000			
		TN	**TP**	**Ammonia**
Influent Conc (mg/L)	**Ci**	8	0.3	4
Target % Reduction				
Target Effluent Conc (mg/L) (90th %'ile)	**Ce**	2.5	0.1	2.5
Wetland Background Limit	**C***	1.5	0.02	0
Reduction fraction to target	**Fe**	0.69	0.67	0.38
Fe= 1-Ce/Ci				
Reduction fraction to background	**Fb**	0.81	0.93	1.00
Fb = 1-C*/Ci				
Areal Rate Constant (m/yr)	**k**	22	12	18
Required Wetland Area (A) (ha)	**A**	31.05	38.10	9.53
(A=[(0.0365*Q/k)(ln((Ci-C*)/(Ce-C*))]				
Hydraulic Loading Rate (m/yr)	**q**	1.05	1	1.04

Appendix D – FTW Sizing Based on EPA Discharge

For the 2014-2015 Reporting Period

	Actual	**EPA Limit**
	Nutrient Load (90 percentile)	
Nutrient	**(mg/L)**	**(mg/L)**
TN	8.1	15
TP	0.6	1

Pond Area = 10522m^2 = 1.05ha

Nitrogen	
Total Weekly N load (kg)	2725.00
Total Weekly N Flow (kL)	460208.00
Flow Weighted Conc. (FWC) (kg/kL)	0.01
N Pollutant Load (PL)	18199.28
Phosphorous	
Total Weekly P load (kg)	212.00
Total Weekly P Flow (kL)	460208.00
Flow Weighted Conc. (FWC) (kg/kL)	0.00
P Pollutant Load (PL)	1415.87
Assumed Total N removal rate	3kg/m^2/yr
Assumed Total P removal rate	1kg/m^2/yr
Total P Load (kg)	1414.00
Total N Load (kg)	17156.00
Total Flow (kL)	3073562.00
N Assessable Load (kg)	18197.00
Calculation Factor N (CF)	0.29
Calculation Factor P (CF)	8.69
Nitrogen Pollutant Fee 2014-2015 ($)	5351.34
Phosporous Pollutant Fee 2014-2015 ($)	16571.07
P Assessable Load (kg)	1905.93
Phosphorous PF 2014-2015 ($)	16571.08

	Nitrogen Removal	**Phosphorous Removal**
Nin (kg Nutrient/year)	8578	1415.87
Pond Surface area ratio (7%)	0.07	0.07
Pond Coverage area (m^2)	736.54	736.54
Total Nut removed (kg/m^2)	3	1.00
Nutrient removed (kg Nut/year)	2209.62	736.54
Al2 = AL-Nin (kg Nut/year)	6368.38	490.06
Revised PF=Al2 x CF ($)	1872.30	4260.81
Cost Saving $	3479.04	12310.26
% removal	25.76	52.02

FTW Calculations	
No.of Pontoons (area of 1.16m^2)	634.95
Cost per pontoon ($)	475.00
Plants @ $1.00 ea 12 per pontoon	7619.38
0.5 person salary per yr ($)	25000.00
Total Cost ($)	334219.81

Appendix E – BRC EPA License Fees

Bathurst Regional Council Waste Water Treatment Works.
Data for, and Calculation of, Pollutant Loads

Week #	Date	Flow kL	BOD mg/L	PQL BOD	BOD kg	O & G mg/L	PQL O&G	O & G kg	Total N mg/L	PQL N	Total N kg	Total P mg/L	PQL P	Total P kg	Total SS mg/L	PQL SS	Total SS kg	pH
1	2-Apr-14	8,164	3		24.49	2	0	0	5.0		40.82	0.33		2.69	7		57.15	7.44
2	9-Apr-14	9,798	3		29.39	2	0	0	8.2		80.34	0.49		4.80	5		48.99	7.46
3	16-Apr-14	9,067	2	1	9.07	2	0	0	6.1		55.31	0.35		3.17	6		54.40	7.43
4	23-Apr-14	8,829	3		26.49	2	0	0	8.4		74.16	0.28		2.47	8		70.63	7.39
5	30-Apr-14	8,721	2		17.44	2	0	0	3.6		31.40	0.45		3.92	7		61.05	7.35
6	7-May-14	8,851	2		17.70	2	0	0	5.6		49.57	0.32		2.83	3		26.55	7.45
7	14-May-14	8,434	2	1	8.43	2	0	0	5.6		47.23	0.28		2.36	7		59.04	7.44
8	21-May-14	8,494	2	1	8.49	2	0	0	7.4		62.86	0.30		2.55	2	1.5	12.74	7.33
9	28-May-14	10,331	2	1	10.33	2	0	0	5.3		54.75	0.39		4.03	5		51.66	7.41
10	4-Jun-14	8,490	2	1	8.49	2	0	0	4.5		38.21	0.35		2.97	6		50.94	7.36
11	11-Jun-14	8,487	4		33.95	2	0	0	6.0		50.92	0.34		2.89	9		76.38	7.40
12	18-Jun-14	15,976	3		47.93	2	0	0	5.5		87.87	0.40		6.39	14		223.66	7.41
13	25-Jun-14	9,168	2		18.34	2	0	0	7.0		64.18	0.35		3.21	10		91.68	7.98
14	2-Jul-14	8,379	2	1	8.38	2	0	0	9.8		82.11	0.28		2.35	6		50.27	7.36
15	9-Jul-14	8,696	2	1	8.70	2	0	0	8.7		75.66	0.42		3.65	10		86.96	7.33
16	16-Jul-14	10,339	2		20.68	2	0	0	6.8		70.31	0.44		4.55	9		93.05	7.22
17	23-Jul-14	9,367	2	1	9.37	2	0	0	3.8		35.59	0.45		4.22	7		65.57	7.24
18	30-Jul-14	9,344	3		28.03	2	0	0	3.6		33.64	0.55		5.14	17		158.85	7.31
19	6-Aug-14	9,717	3		29.15	2	0	0	10.3		100.09	0.55		5.34	8		77.74	7.06
20	13-Aug-14	5,576	2	1	5.58	2	0	0	3.6		20.07	0.54		3.01	10		55.76	7.22
21	20-Aug-14	9,444	2		18.89	2	0	0	5.3		50.05	0.65		6.14	12		113.33	7.30
22	27-Aug-14	9,082	2		18.16	5	0	0	5.1		46.32	0.59		5.36	11		99.90	7.40
23	3-Sep-14	8,721	2		17.44	2	0	0	3.9		34.01	0.54		4.71	6		52.33	7.70
24	10-Sep-14	9,343	2	1	9.34	2	0	0	5.6		52.32	0.44		4.11	10		93.43	7.30
25	17-Sep-14	8,953	2		17.91	2	0	0	4.4		39.39	0.48		4.30	3	1.5	13.43	7.30
26	24-Sep-14	8,584	2		17.17	2	0	0	2.4		20.60	0.43		3.69	3	1.5	12.88	7.30
27	1-Oct-14	7,951	2	1	7.95	2	0	0	5.2		41.35	0.52		4.13	1	1.5	7.95	7.40
28	8-Oct-14	9,056	2	1	9.06	2	0	0	3.9		35.32	0.45		4.08	1	1.5	9.06	7.50
29	15-Oct-14	11,006	2		22.01	2	0	0	16.8		184.90	0.54		5.94	4		44.02	7.30
30	22-Oct-14	7,796	2	1	7.80	2	0	0	4.6		35.86	0.51		3.98	4		31.18	7.40
31	29-Oct-14	8,264	2	1	8.26	2	0	0	5.8		47.93	0.58		4.79	5		41.32	7.30
32	**3-Nov-14**	6,876	2	1	6.88	2	0	0	4.1		28.19	1.30		8.94	6		41.26	7.50
33	5-Nov-14	7,635	3		22.91	2	0	0	5.9		45.05	0.56		4.28	8		61.08	7.30
34	12-Nov-14	7,203	2		14.41	2	0	0	5.5		39.62	0.60		4.32	6		43.22	7.40
35	19-Nov-14	7,169	2		14.34	2	0	0	7.2		51.62	0.37		2.65	5		35.85	7.60
36	26-Nov-14	8,807	3		26.42	2	0	0	5.3		46.68	0.46		4.05	5		44.04	7.60
37	3-Dec-14	7,940	7		55.58	2	0	0	5.8		46.05	0.41		3.26	12		95.28	7.90
38	10-Dec-14	8,548	2	1	8.55	5	0	0	6.9		58.98	1.80		15.39	4		34.19	7.60
39	17-Dec-14	7,965	5		39.83	2	0	0	7.9		62.92	0.39		3.11	9		71.69	7.70
40	**22-Dec-14**	7,060	3		21.18	2	0	0	3.6		25.42	0.18		1.27	10		70.60	7.80
41	**29-Dec-14**	6,628	2	1	6.63	2	0	0	4.0		26.51	0.29		1.92	2	1.5	9.94	7.60
42	**5-Jan-15**	7,098	5		35.49	2	0	0	3.5		24.84	0.21		1.49	13		92.27	8.50
43	7-Jan-15	6,786	4		27.14	2	0	0	4.0		27.14	0.35		2.38	7		47.50	7.80
44	14-Jan-15	8,278	2	1	8.28	2	0	0	6.6		54.63	0.37		3.06	2	1.5	12.42	7.50
45	21-Jan-15	6,279	4		25.12	2	0	0	5.9		37.05	0.40		2.51	5		31.40	7.43
46	28-Jan-15	10,184	2	1	10.18	2	0	0	6.1		62.12	0.59		6.01	2	1.5	15.28	7.20
47	4-Feb-15	8,165	2	1	8.17	2	0	0	7.5		61.24	0.60		4.90	8		65.32	7.50
48	11-Feb-15	7,797	2	1	7.80	2	0	0	4.7		36.65	0.34		2.65	4		31.19	8.40
49	18-Feb-15	7,285	2		14.57	2	0	0	5.3		38.61	0.35		2.55	5		36.43	7.70
50	25-Feb-15	9,598	2	1	9.60	2	0	0	5.1		48.95	0.37		3.55	11		105.58	7.60
51	4-Mar-15	6,704	2		13.41	2	0	0	5.3		35.53	0.36		2.41	3	1.5	10.06	7.60
52	11-Mar-15	7,799	2	1	7.80	2	0	0	7.3		56.93	0.32		2.50	7		54.59	7.60
53	18-Mar-15	7,668	2		15.34	2	0	0	4.7		36.04	0.31		2.38	3	1.5	11.50	7.50
54	25-Mar-15	8,308	2	1	8.31	2	0	0	3.7		30.74	0.27		2.24	4		33.23	7.50
Total		**460,208**		**24**	**932.31**			**0**			**2,725**			**212**			**3,046**	
Minimum			**2**			**2**			**2.4**			**0.18**			**1**			
Practical Quantitation Limit (PQL)																		
			2			**5**			**0.3**			**0.02**			**3**			
If result < PQL, half the PQL can be used. If 50% or more samples <PQL, zero can be reported for those values.																		
Any changes required?			**Y**			**Y**			**N**			**N**			**Y**			
Flow weighted concentration (FWC) = kg/kL					**BOD**			**O & G**			**Total N**			**Total P**			**Total SS**	
FWC					**0.002026**			**0.0000**			**0.005920**			**0.000460**			**0.006618**	
Total volume of licence period (kL)				**3,073,562**														
Pollutant load (PL) (kg) = FWC * total licence volume																		
					BOD			**O & G**			**Total N**			**Total P**			**Total SS**	
PL (kg)					**6,227**			**-**			**18,197**			**1,414**			**20,342**	
Load Limit (kg)					**31,600**			**29,511**			**44,231**			**2,937**			**58,987**	
Compliant?					**OK**	**20%**		**OK**	**0%**		**OK**	**41%**		**OK**	**48%**		**OK**	**34%**
			BOD			**O & G**			**Total N**			**Total P**			**Total SS**			**pH**
		Minimum	2.0			2.0			2.4			0.18			1			7.1
		Mean	2.5			2.1			5.8			0.46			6.6			7.5
		Maximum	7.0			5.0			16.8			1.80			17			8.5
		BOD			**O & G**			**Total N**			**Total P**			**Total SS**			**pH**	
	Actual		**Limit**	Actual		**Limit**	Actual		**Limit**	Actual		**Limit**	Actual		**Limit**	Actual		**Limit**
50%	2.0	**OK**	**15**										0.4	**OK**	**20**			
90%	3.7	**OK**	**20**				8.1	**OK**	**15**	8.1	**OVER**	**1**	0.6	**OK**	**25**			
100%	7.0	**OK**	**30**	5	**OK**	**10**	16.8	**OK**	**20**	16.8	**OVER**	**2**	1.8	**OK**	**30**	8.5	**OK**	**8.5**
100%																7.1	**OK**	**6.5**
Notes:																		
Underlined values indicate less than.																		

Pollutant Fee for Total N

D1	Pollutant load		Result	
			18,197	See Data tab
	actual load	kg	18,197	
	weighted load	kg		Not applicable; no effluent reuse
	agreed load	kg		Not applicable; no load reduction agreements
D2	Assessable load (AL)	kg	18,197	Smallest of above loads; use actual load
D3	Calculate fee rate threshold (FRT)			
	volume	ML	3,073.562	See Data tab
	volume	ML	3,073.6	Actual quantity
	calculated FRT		30,736	actual quantity x FRT factor (=10 for Total N)
D4	Apply fee rate threshold			
	Is D2 > D3?	Y/N	N	
	If Y, 2 x AL(D2) - FRT(D3) = AL^1			
	2*AL			
	FRT			
	AL^1			
	If N, go to D5, use AL		18,197	
D5	Calculate Pollutant fee			
	PF = (AL or AL^1) x CF	AL	18,197	
		CF	0.294078	
	rounding to 7 decimal places	CF	0.2940780	
			2	
		PF	$5,351.34	Assessable load x calculation factor (CF)
	check number of decimal places			
	& beware rounding to7 places			CF= P fee unit amount x P weighting x critical zone)/10,000
			0.2940780	[CF = (42.62 x 23 x 3)/10,000]

Pollutant Fee for Total Phosphorous

D1	Pollutant load		Result	
			1,414	See Data tab
	actual load	kg	1,414	
	weighted load	kg		Not applicable; no effluent reuse
	agreed load	kg		Not applicable; no load reduction agreements
D2	Assessable load (AL)	kg	1,414	Smallest of above loads; use actual load
D3	Calculate fee rate threshold (FRT)			
	Volume	ML	3,073.562	See Data tab
		ML	3,073.6	Actual quantity
	calculated FRT		922.07	actual quantity(total volume) x FRT factor (=0.3 for Total P)
	actual FRT		922.07	
D4	Apply fee rate threshold			
	Is D2 > D3?	Y/N	Y	
	If Y, 2 x AL(D2) - FRT(D3) = AL^1			
	2*AL		2,828	
	FRT		922.07	
	AL^1		1,905.93	
	If N, go to D5, use AL			
D5	Calculate Pollutant fee			
	PF = (AL or AL^1) x CF	AL^1	1,905.93	
		CF	8.694480	
	rounding to 7 decimal places	CF	8.6944800	
		PF	$16,571.08	Assessable load x calculation factor (CF)
	check number of decimal places			
	& beware rounding to 7 places			CF= P fee unit amount x P weighting x critical zone)/10,000
			8.6944800	[CF = (42.62 x 680 x 3)/10,000]

Totals for LBL Fees
EPA Licence 1647 2014-2015

	2014-2015
Pfua	$42.62
Afua	$100.00
BOD	$26.54
Total N	$5,351.34
O & G	$0.00
Total P	$16,571.08
Total SS	$6,762.41
Total Pollutant fees	**$28,711.37**
Less admin fees paid	$7,345.00
Load Based fee	**$21,366.37**

Appendix F – Australian Wetland Plants for Floating Treatment Wetlands and Selection Considerations

AN EXAMPLE OF AUSTRALIAN WETLAND PLANTS FOR FLOATING TREATMENT WETLAND AND SELECTION CONSIDERATIONS.

Species should be selected with the following considerations:

- Local to the area where floating islands are to be installed
- Well suited to wet or moist root conditions
- Readily available for purchase from nurseries or obtainable from other sources
- Robust and able to withstand some damage from waterbirds
- In heavily polluted wetlands, able to survive in high nutrient waters,
- Perennial with no seasonal dieback of above-ground biomass and
- Capable of developing an extensive root system.

NOTES

1. Species marked * are recommended.
2. Species marked # are salt tolerant, although growth may be poor in high salinity water.
3. A number of samphire plants such as *Halosarcia* and *Tecticornia* species are well adapted to growing in highly saline water, but their use on floating islands has not been evaluated.
4. *Persicaria* species are likely to self-seed onto islands, so planting of this species from nursery stock should not be necessary.

Agrostis avenacea - blown grass
Amphibromus nervosus - common swamp wallaby grass
Amphipogon turbinatus - a grass
Anarthria prolifera - tangle rush
Apium prostratum var prostratum - sea celery
Aponogeton species
Astartea fascicularis
Austrostipa pycnostacha - salt speargrass
Austrostipa trichophylla
*Atriplex amm*icola - swamp/river saltbush
Atriplex bunburyana - silver saltbush
Atriplex hymenotheca
Atriplex hypoleuca - *a* saltbush
Atriplex lindleyi subsp inflata

Baumea acuta - pale twig rush
*# *Baumea arthrophylla* - fine twig rush
*# *Baumea articulata* - jointed twig rush
Baumea arthrophylla - sparse twig rush
Baumea vaginalis - sheath twig rush
Baumea juncea - bare twig rush
* *Baumea preissii* - broad twig rush
# *Baumea riparia* - river twig rush

Baumea rubiginosa - river twig sedge
Baumea vaginalis - sheath twig rush
* *Bolboschoenus medianus* - marsh club rush

Carex diversa is a declared weed and should not be used in any island or wetland plantings.
* *Carex appressa* - tall sedge
Carex bichenoviana - sedge
* *Carex fascicularis* - tassel sedge
Carex gaudichaudiana - fen sedge – may become invasive
\# *Carex inversa* - knob sedge
Carex preissii
*# <u>*Carex tereticaulis*</u> - common sedge
<u>*Centella asiatica*</u> - herb
<u>*Centella cordifolia*</u> - herb
<u>*Ceratopteris thalictroides*</u> - water sprite
<u>*Chaetanthus aristatus*</u> - bearded twine rush
<u>*Chordifex amblycoleus*</u> - bristle cord rush
<u>*Chordifex reseminans*</u> - lax cord rush
<u>*Chordifex sinuosus*</u> - twisted cord rush
<u>*Chorizandra australis*</u> - southern bristle rush
<u>*Chorizandra cymbaria*</u> - heron bristle rush
* <u>*Chorizandra enodis*</u> - black bristle rush
\# <u>*Cladium procerum*</u> - leafy twig rush
<u>*Cotula coronopifolia*</u> water buttons
*#<u>*Crassula helmsii*</u> - swamp stonecrop
Cyanthochaeta avenecea
Cyanthochaeta stipoides
Cyanthochaeta teretifolia

Damasonium minus
Desmocladus elongatus - spindle rush
*# *Distichilis disticophylla* - Australian sea-grass

Ecdeiocolea monostachya - mat rush
Elantine gratioloides
*# *Eleocharis acuta* - common spike rush
Eleocharis keigheryi
* *Eleocharis sphacelata* - tall spike rush
Enteropogon acicularis - curly windmill grass
\# *Eragrostis australasica* - canegrass
\# *Eragrostis dielsii* - mallee lovegrass
Eragrostis elongata - clustered lovegrass

* *Ficinia nodosa* (previously *Isolepis nodosa*) - club sedge
\# *Frankenia glomerata*

Frankenia pauciflora - sea heath

Gahnia trifida - coast sword sedge – best suited for use on larger islands
Gratiola peruviana - brooklime
Gymnoschoenus sphaerocephalus - button grass

Hemarthria uncinata - mat grass
Hemichroa pentandra - trailing joint weed
Hopkinsia anoectocolea - steel rush
Hydrocotyle sibthorpoides - shiny pennywort
Hypolaena humilis - kangaroo rush

Isachne globosa - swamp millet
* *Isolepis cernula* - nodding club rush
Isolepis cyperoides
* *Isolepis fluitans* - floating club rush
Isolepis inundata - swamp club rush
* *Isolepis nodosa* (now *Ficinia nodosa*) - club sedge
Isolepis oldfieldiana
Isolepis producta
Isolepis prolifera - budding club rush
Isolepis setiformis
Isolepis stellata - star club rush

Note: some *Juncus* species have the ability to invade wetlands and dominate, with several introduced species classified as weeds
* Juncus amabilis - hollow rush
* Juncus articulatis - jointed rush
* *Juncus australis* - austral rush
Juncus bufonius - toad rush
Juncus caespiticius - grassy rush
*# *Juncus flavidus* - yellow rush
Juncus fockei
* *Juncus gregiflorus* - green rush
Juncus holoschoenus – joint leaf rush
Juncus ingens
*# *Juncus kraussii* - shore or sea rush
Juncus meianthus
Juncus microcephalus
*# *Juncus pallidus* - pale rush
* *Juncus pauciflorus* - loose flower rush
* *Juncus planifolius* - broadleaf rush
Juncus radula
* *Juncus sarophorus* - broom rush
Juncus procerus - tall rush
Juncus semisolidus - rush

Juncus subsecundus - finger rush

Lepidobolus chaetocephalus - fringe rush
Lepidobolus - spiralis spiral rush
Lepidosperma gladiatum coastal sword sedge - best suited for use on larger islands
Lepidosperma longitudinale - pithy saw sedge
Lepidosperma scabrum - rough sedge
 # Leptinella reptans - creeping cotula
Leptocarpus aristatus - bearded twine rush
Leptocarpus tenax
Leptochloa fusca - brown beetle grass
Lilaeopsis polyantha - creeping crantzia
Lobelia irrigua - salt pratia
Ludwigia peruviana is classified as a weed.
Ludwigia peploides - claimed to respond well to high nutrient levels
Lyginia species
Lythrum salicaria

* *Marsilea drummondii* - common nardoo
Meeboldina roycei
Meeboldina coangustata - velvet rush
Meeboldina crassipes
Meeboldina crebriculmis
Meeboldina denmarkica
Meeboldina kraussii
Meeboldina roycei
Meeboldina scariosa
Meeboldina tephrina
Melanostachya ustulata
Mesomelaena pseudostygia - semaphore sedge
*M*icrolaena stipoides - weeping grass – found to be ineffective in nutrient removal in research trials
*M*imulus repens - creeping monkey-flower
*M*uehlenbeckia florulenta - tangled lignum
Myoporum caprarioides - slender *Myoporum* – many species are claimed to respond well to high nutrient levels
Myrio*phyllum crispatum* - upright milfoil
Myriophyllum salsugineum - lake milfoil
Myriophyllum simulans - amphibious milfoil
Myriophyllum verrucosum - red water-milfoil

Persicaria decipiens (synonym Polygonum decipiens) - slender knotweed
Persicaria hydropiper - water pepper
Persicaria praetermissa - spotted knotweed
Persicaria prostrata - creeping knotweed

Platychorda applanata
Poa ensiformis - sword tussock grass
*# *Poa labillardierei* - common tussock grass
Poa poiformis - blue tussock grass
#*Porphyroclados* - a perennial grass
Pratia concolor
Puccinellia stricta - marsh grass

Ranunculus diminutus - dwarf river buttercup
Ranunculus inundatus - buttercup
Ranunculus papulenthus
Reedia spathacea
Rumex bidens - water dock
Rumex brownii - swamp dock
Rumex dumosus - wiry dock
Ruppia species

Samolus junceus - a brookweed
Samolus repens - creeping brookweed
Schoenoplectus species are claimed to respond well to high nutrient levels, with all native species reported to be moderately salt tolerant
*# *Schoenoplectus pungens* - sharp leaf rush
*# *Schoenoplectus validus* - lake club rush
* *Schoenoplectus tabernaemontani* - river club rush
Schoenus acuminatus
Schoenus asperocarpus - poison sedge
Schoenus benthamii
Schoenus bifidus
Schoenus cruentus
Schoenus discifer
Schoenus efoliatus
Schoenus elegans
Schoenus fluitans
Schoenus grandiflorus - large flowered bog rush
Schoenus indutus
Schoenus laevigatus
Schoenus loliaceus
Schoenus maschalinus
Schoenus multiglumis
Schoenus natans - floating bog rush
Schoenus nitens - shiny bog rush
Schoenus obtusifolius
Schoenus pennisetis
Schoenus plumosus
Schoenus rigens
Schoenus subbarbatus - bearded bog rush

Schoenus subfascicularis - a bog rush
Schoenus subflavus - yellow bog rush
Schoenus sublateralis
Schoenus sublaxus
Schoenus submicrostachyus
Schoenus tenellus
Schoenus unispiculatis - grey sedge
Schoenus variicellae
Scirpus fluitans
Scirpus hookeranus
Scirpus inundatus
Scirpus litoralis
Scirpus nodosus
Scirpus validus
Selliera radicans - shiny swamp-mat
Sparganium subglobosum - native burr-reed
Sporadanthus strictus - erect scale rush
Sporobolus virginicus - marine couch
Stenotalis ramosissima
 # Suaeda australis seablite

Tetraria australiensis
Tremulina cracens
Tremulina tremula - quivery cord rush
Tricostularia neesii
* *Triglochin linearis* -water ribbons
Triglochin rheophilum
Triglochin striatum -streaked arrow grass

Yillarsia albiflora
Yillarsia exaltata - erect marsh flower
Yillarsia parnassifolia

* Villarsia reniformis running marsh-flower

Some *Typha* species are introduced weeds which should not be used in island or wetland plantings.
Bolboschoenus caldwellii sea or marsh club rush dies back over winter and should be avoided.

Appendix G – Cost Benefit Analysis

Wetland treatment systems: Option Assessment

Discount rate	7%	pa
Contingency applied to capital items	15%	
Survey, investigation and design (SID)	7.5%	

Option	Components	Qty	Units	Unit Cost	Cost	Present Value	0	1	2	3	4	5	6	7	8	9	10	11
2	***Captial Costs***																	
	Approvals	1	item	20000	20000	$ 20,000	20000											
	Mobilisation/demobilisation	1	item	15000	15000	$ 15,000	15000											
	Contractor Environmental Controls	1	item	5000	5000	$ 5,000	5000											
	Wetland Pontoons	635	item	475	301625	$ 301,625	301625											
	Pontoon Installation	635	item	100	63500	$ 63,500	63500											
	Pontoon Anchor System	1	item	10000	10000	$ 10,000	10000											
	Bird Guard Kits	635	item	40	25400	$ 25,400	25400											
	Wetland plants	7620	number	2	15240	$ 15,240	15240											
	Planting	7620	number	2	15240	$ 15,240	15240											
	Pond Aeration device	1	item	25000	25000	$ 25,000	25000											
	Electricals and Control	1	item	5000	5000	$ 5,000	5000											
	SID	7.5%	item		37575	$ 37,575	37575											
	Contingency	15%	item		75151	$ 75,151	75151											
	PV Capital Cost					***$ 613,731***												
	Operating Costs																	
	Wetland maintenance (Incl. 0.25 person salary)	15000	$/year			$ 158,910	0	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000
	Clean out	15000	per event			$ 31,289	0	0	0	10000	0	0	10000	0	0	10000	0	0
	PV Operating Cost					***$ 190,199***												
	Present value of wetland system	**$ 803,930**																
	Savings in LBL Discharge Fees	16000	$/year			$ 169,504	0	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000
	Present value of FTW savings	**$ 169,504**																
	Benefit/cost ratio	**0.21**																

Wetland treatment systems: Option Assessment

Discount rate	7%	pa
Contingency applied to capital items	15%	
Survey, investigation and design (SID)	7.5%	

Option	Components	Qty	Units	Unit Cost	Cost	Present Value	0		12	13	14	15	16	17	18	19	20
2	***Captial Costs***																
	Approvals	1	item	20000	20000	$ 20,000	20000										
	Mobilisation/demobilisation	1	item	15000	15000	$ 15,000	15000										
	Contractor Environmental Controls	1	item	5000	5000	$ 5,000	5000										
	Wetland Pontoons	635	item	475	301625	$ 301,625	301625										
	Pontoon Installation	635	item	100	63500	$ 63,500	63500										
	Pontoon Anchor System	1	item	10000	10000	$ 10,000	10000										
	Bird Guard Kits	635	item	40	25400	$ 25,400	25400										
	Wetland plants	7620	number	2	15240	$ 15,240	15240										
	Planting	7620	number	2	15240	$ 15,240	15240										
	Pond Aeration device	1	item	25000	25000	$ 25,000	25000										
	Electricals and Control	1	item	5000	5000	$ 5,000	5000										
	SID	7.5%	item		37575	$ 37,575	37575										
	Contingency	15%	item		75151	$ 75,151	75151										
	PV Capital Cost					***$ 613,731***											
	Operating Costs																
	Wetland maintenance (Incl. 0.25 person salary)	15000	$/year			$ 158,910	0		15000	15000	15000	15000	15000	15000	15000	15000	15000
	Clean out	15000	per event			$ 31,289	0		10000	0	0	10000	0	0	10000	0	0
	PV Operating Cost					***$ 190,199***											
	Present value of wetland system	**$ 803,930**															
	Savings in LBL Discharge Fees	16000	$/year			$ 169,504	0		16000	16000	16000	16000	16000	16000	16000	16000	16000
	Present value of FTW savings	**$ 169,504**															
	Benefit/cost ratio	**0.21**															