University of Southern Queensland

Faculty of Health, Engineering and Sciences

Applying Urban Stormwater Modelling to Aquaculture Prawn Farm Effluent in Queensland

A dissertation submitted by

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Abstract

Aquaculture in Australia represents 43% of Australian seafood and its current net worth is AU$2.81 billion, with an expectancy to climb to AU$3.40 billion by the 2020- 20221 harvest season. Current research by The Fisheries Research and Development Corporation (FRDC) has estimated that by the year 2030 an additional of 25 tonnes of seafood will be in demand globally.

All aquaculture operations in Australia are regulated and managed by a strict environmental act and monitored on an ongoing basis. These regulations have made Queensland the leading area in effluent treatment for their reticulation systems. Their current methods consist of 30% of the farmed land to be dedicated to treatment and the area increases if using bioremediation on top.

The aims of this dissertation were to simulate, analyse, and compare the efficiency of urban stormwater methodologies in dealing with prawn farm effluent pollutants in Queensland. Their performance was evaluated through the software MUSIC and categorised in 4 sections: total suspended solids (TSS), total nitrogen (TN), total phosphorous (TP), and gross pollutants (GP). A cost analysis was undertaken and based on manufacturer's unit prices or average square metre construction cost, found from publications.

It was found that urban stormwater devices manufactured by Ocean Protect were not a feasible option due to their design, flow rate for each filter cartridge, and unit cost to provide efficiency equivalent to other stormwater methodologies. SPEL's proprietary floating wetlands manage to reduce the surface area by 100% compared to best practice methods but were also the costliest form of treatment. Results of the models have ranked the treatment methods from best to worst as: bioretention with carbon filter, bioretention (no carbon), SPEL floating wetlands, constructed wetlands, Stormfilters, and Jellyfish. The models with combined treatment methods scored as the second best but due to their total combined cost they are not feasible options. The most inexpensive option is the vegetated bioretention (no carbon), as it produced removal rates higher than best practice in 3 of the 4 categories with TP falling just short. Those removals rates are 95%, 85%, 71%, and 100% for TSS, TN, TP, and GP. The total surface area required was 79% smaller than best practice, and with an average construction price of $280,000 which is only 1.5 times the cost of best practise methods.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyse, and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Manuel Flores

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Nomenclature

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
AHC	Australian Health Committee
BIARC	Bribie Island Aquaculture Research Centre
FRDC	Fisheries Research & Development Corporation
GP	Gross Pollutants
IFREMER	Institut Francais de Recherche pour l'Expoitation de la MER (French Research Institute for the Exploitation of the Sea)
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
NASAA	National Association for Sustainable Agriculture Australia Limited
SCAAH	Sub-Committee on Aquatic Animal Health
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
WSUD	Water Sensitive Urban Design Standards

1.0 Introduction

1.1 Background

Aquaculture is a fast-growing sector in Australia, and around the world, with an extra billion consumers estimated globally by 2030. The Fisheries Research and Development Corporation (FRDC) has estimated that by this year an additional 25 million tonnes of seafood will be in demand globally (FRDC, 2020) . Overseas farms are well established, especially in the tropical and subtropical regions, however it is also known as “Shrimp Farming” (Robertson et al. 2006).

According to the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) statistics report of 2017, the value of aquaculture production has increased significantly and will continue to grow. Over the last few decades, and in 2012-2013, it comprised of 43% of Australian seafood production (Department of Agriculture, water and the Environment, 2019). The current production net worth is estimated at AU$2.81 billion with expectancy to rise to AU$3.40 billion in 2020-21 season.

Figure 1 illustrates the current prawn farming areas in Queensland and New South Wales. These locations contain a combined area of approximately 900 hectares, and produce more than 3500 tonnes of prawns every year (Lobegeiger & Wingfield 2004; Robertson et al. 2006). In Queensland, Black Tiger Prawns and Banana Prawns make up the majority of the of produce, these species are also significant in Asia (Robertson et al. 2006). In temperate Australia, the growing season runs the length of the summer seasons, especially south of Mackay where the winter months are too cold for aquaculture. In the tropical norths of Queensland, where winter is commonly

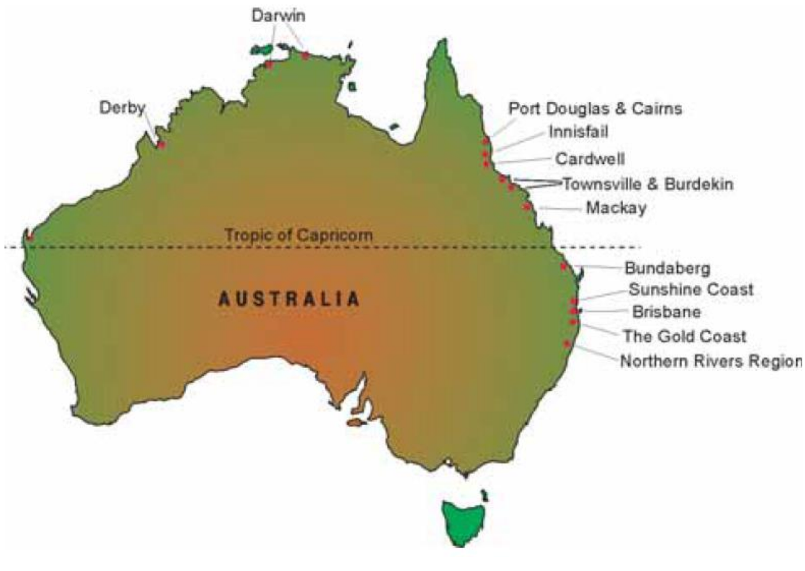


Figure 1 - Prawn Farming Areas in Queensland and New South Wales

known as dry season, there is an opportunity to produce two crops per year, however farmers choose not to (Robertson et al. 2006).

All aquaculture operations in Australia are managed by strict environmental guidelines, especially those that discharge into public waters. Operations are required to comply with strict environmental control, monitored by the state on an ongoing basis (Department of Agriculture, water and the Environment, 2019). This is particularly important in Queensland as agricultural effluent can damage estuarine, coastal, in-shore, and even offshore ecosystems. Obviously, this has an impact on the Great Barrier Reef. The Great Barrier Reef is a series of coral reef stretching over 2,300 km off the coast of Queensland. World Heritage Listed, the Great Barrier Reef is ecologically significant as well as culturally important to the Aboriginal people of Queensland. It is also important to the local economy bringing in around 4.5 billion dollars annually. These guidelines not only include the treatment and discharge of effluent, but the type of feeds and biosecurity that the farmers need.

The current conventional method for treatment is settling ponds, with several bioremediations as secondary treatment for reticulation systems. These settling ponds consist of up to 30% of the land and mainly remove Total Nitrate (TN), Total Phosphate (TP), and Total Suspended Solids (TSS). Studies have been conducted, both in Australia and overseas, to improve the amount of nutrient removal from pond effluent. Most bioremediation treatments studies involved bivalves, fish, or plants. There have been other smaller studies conducted at the Bribie Island Aquaculture Research Centre (BIARC) in southern Queensland, with the inclusion of worms and SKIM filters (Palmer 2005; Palmer et al. 2016).

Current stormwater methodologies allow urban areas to comply with treatment requirements as specified by each local council. Structures such as the Ocean Protect Stormfilters have proven to be able to comply with the required council demands. These filters not only remove TSS but also TP, TN, and small amounts of heavy metals. There are several types of filters to suit different systems which are all based on total area, percentage of impervious and pervious zones, outlet invert level, and discharge flow rates. There are other structures to manage urban stormwater water quality like bioretention, detention tanks, and wetlands that have also proven to work in subdivisions.

This dissertation will look at the use of the current urban stormwater methodologies and structures to ascertain if they can be used to treat aquaculture prawn farm effluent water. A single treatment or a combination of structures will be examined and compared with the BIARC prawn farm set up, to discern if a feasible option can be acquired to reduce current settling pond areas. Model for Urban Stormwater Improvement Conceptualisation (MUSIC) will be used to run the scenarios and present the results for comparison to traditional prawn farming treatments.

1.2 Aims and Objectives

This dissertation aims to analyse the methodologies used for urban stormwater discharge and management, as a standalone or combination of methods and structures, to see if there is a feasible solution in reducing pond settling areas for prawn and barramundi farmers.

The objectives of this study are to:

- Identify the key nutrients in the water discharge from prawn farms.
- Identify impacts of prawn farm pond effluent on the ecosystem.
- Review of current prawn farming systems used.
- Review of current treatments and bioremediation options in Australia and overseas.
- Review of current stormwater methodologies suitable for prawn farming.
- Design of multiple models based on stand-alone and combination structures to determine how to best treat the effluents. Run models through stormwater MUSIC software modelling.
- Provide a cost analysis of maintenance for the designed system.
- Evaluate and compare the designed system against the existing best practice.
- Provide suggestions and recommendations based on findings.

1.3 Outline of Chapters

This dissertation is broken down into individual chapters which attempt a rational progression in order to define and build the dissertation to accomplish the ideal outcomes and objectives

Chapter 1 presents the research project and outlines the foundation on why the topic was chosen, its importance to genuine applications in the relevant areas, and the inspiration or motivation for the topic. This chapter also incorporates the main aims and objectives of the dissertation.

Chapter 2 focuses on the literature review and contains most of the chapter. This includes research into aquaculture pond effluent and its impacts, the type of aquacultural systems, the current types and researches of bioremediation, current urban stormwater treatment devices, previous studies conducted in prawn farming, and the marine prawn farm wastewater licence requirements. All these topics were considered and emphasized in the justification section from chapter 2.

Chapter 3's framework the design methodology of this dissertation and includes the design constraints and inputs which were placed on the research project. The design process for model simulations are demonstrated in this chapter and some inputs rely on the manufacturer's treatment nodes and their limitations. This chapter also incorporates cost analysis based on average construction rates.

Chapter 4 presents the results and discussions for the project. These results and divided in four sections: total suspended solids, total nitrogen, total phosphorous, and gross pollutants. The results are presented on bar graphs and their findings are examined.

The last chapter concludes the research project with summary of the results and possible future work to expand this search project.

2.0 Literature Review

2.1 Pond Effluent

Pond effluent is the nutrients and sediments that are created in the water during the cycle of a prawn season. The word "effluent" means liquid waste (*The Oxford English dictionary* 2004), otherwise known as wastewater. This wastewater can prove to be environmentally challenging as they can be a source of pollution to receiving waters by overburdening the ecosystem and waterways with elevated nutrients and sediments. This process is called eutrophication (Dechorgnat et al. 2010). The estimates of nutrients and sediments entering the waterways from Prawn farmers indicate that most of the material originates from added feed (Macintosh 1992).

A cycle for prawn farming is called a season and as this progresses the amount of sediments that forms in the pond increases substantially. These sediments contain a mixture of inorganic matter, from the pond wall erosions, and organic matter such as: prawn moulds, uneaten food and phytoplankton (Australian Prawn Farmers Association, 2020). Along with the sediments, there are several nutrients present with the most significant being Nitrogen and Phosphorus. While these nutrients are significant in aquatic health, a higher concentration of these nutrients can cause issues (Solitude Lake Management, 2018) .

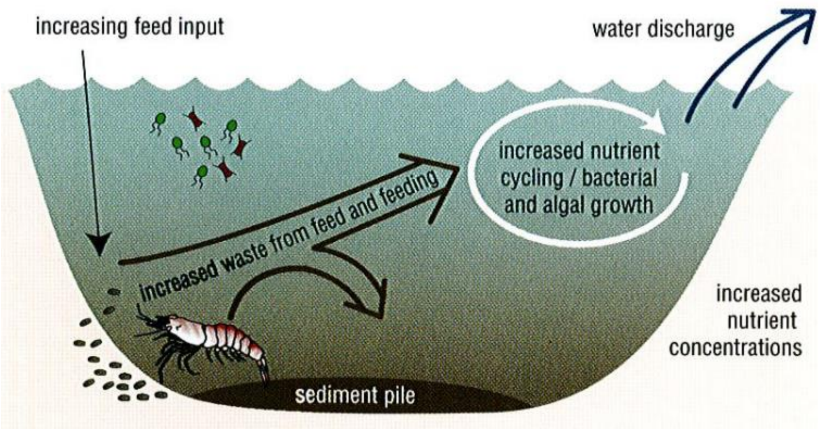


Figure 2 - Typical Grow Out Pond

Since nutrient concentrations increase during the season, it can be harder to maintain the optimal water quality required. Phytoplankton can grow rapidly and reduce the oxygen concentration of water to a dangerously low level.

To avoid this from happening, a small percentage of the pond water is replenished daily from local creeks or rivers. The pond water that is discharged is then transferred to a settling pond for a few days before being discharged back in the ecosystem. There is a possibility and potential of reticulating the water back into the pond and thus reducing the volume of discharge water (Australian Prawn Farmers Association, 2020).

In Australia, pond effluent has a significant effect on the Great Barrier Reef and other Marine Parks, if it is introduced untreated. There are a number of effluent treatment methods and strategies that have been researched, in order to better improve the environmental management of the industry (Preston et al. 2002).

2.1.1 Total Nitrogen (TN)

Nitrogen is an essential nutrient for plants and animals, along with Phosphorus, Nitrogen is a natural part of the aquatic ecosystem. Nitrogen can be commonly measured in water bodies in 4 forms: ammonia, nitrates, nitrites, and organic nitrogen. Each form is analysed as a separate component and it is the sum of all 4 that is measured as Total Nitrogen (TN) (Bremner 1965). Most of the nitrogen in a pond originates from feeds with only about a quarter, 22%, converted into prawns (Preston et al.).

Excess nitrogen in water bodies can overstimulate growth of phytoplankton as previously mentioned, in particular algae, and can have far-reaching environmental impacts and on public health. This significant growth in the algae and the decomposition of phytoplankton can cause fish deaths in the aquatic ecosystem, due to the depletion of oxygen required to survive. Large growths of algae are called algae blooms and can be harmful not only to aquatic life but also humans, as it contains elevated levels of toxins and bacterial growth (Carmichael & Boyer 2016).

2.1.1.1 Ammonia

Ammonia is one of the forms of nitrogen in aquatic environments and forms naturally from microbiological composition in organic matter. Ammonia exist in water bodies in two forms, ionised (NH_4^+) and un-ionised (NH_3) (Felipo & Butterworth 2002). It is toxic to all vertebrates causing convulsions, coma and death due to the un-ionized molecules (Randall & Tsui 2002). Concentrations of ionised and un-ionized molecules vary with the temperature and pH level of the water, and therefore toxicity increases as pH and temperature increase. At pH levels of 7.0 or below, more than 95% of the ammonia will be non-toxic in the form of NH_4^+. It has been reported that concentration levels of NH_3 ranging from 0.53 to 22.8 mg/L are toxic to freshwater organisms (Oram 2014a).

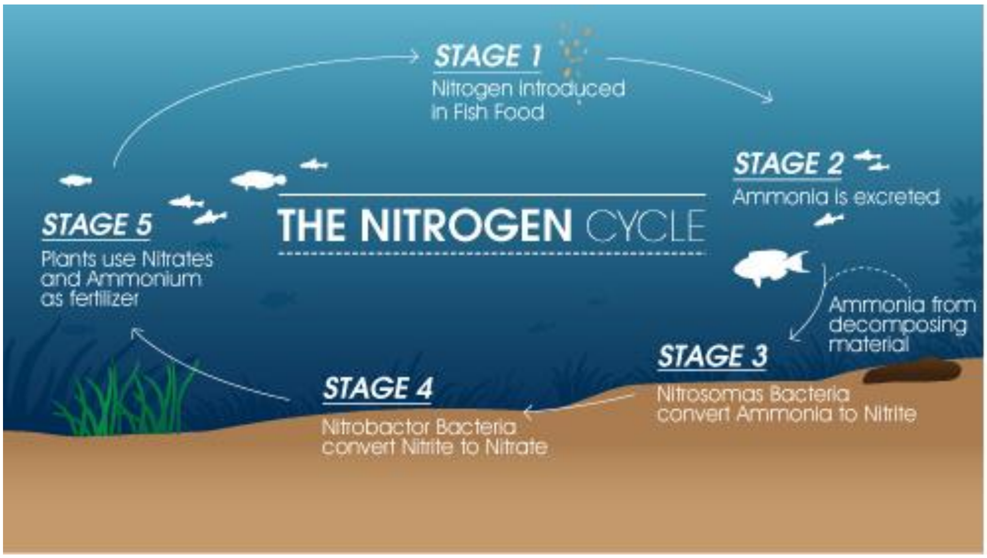


Figure 3 - Nitrogen Cycle

2.1.1.2 Nitrite

Nitrite (NO_2) is the second stage of the nitrogen cycle and it is the oxidation of ammonia compound to nitrite, which can be toxic at low levels (Sallenave 2016). This form of nitrogen can be a source of nutrients for plant and encourages plant multiplication, (Hovanec & DeLong 1996). Nitrite is then converted to Nitrate by oxidization from bacteria.

2.1.1.3 Nitrate

Nitrate (NO_3) in water is undetectable without a proper testing kit as it is colourless, odourless and tasteless (Oram 2014b). Like ammonia, nitrate is a form of Nitrogen and is the third stage in the nitrogen cycle. Nitrate is not highly toxic in low levels to both humans and the aquatic environment (Mullen 2009), however it can cause some discomfort . Elevated levels are not a health hazard to adults and children however in infants under 6 months it can cause methemoglobinemia, a blood disorder that reduces the effectiveness of oxygen release from the red blood cells, also known as blue baby sickness (Self & Waskom 1992).

Plants on the other hand use nitrate as a supply of nitrogen to make proteins and stimulate growth. Excessive amounts of nitrate are toxic to vertebrates and can also accelerate eutrophication (Dechorgnat et al. 2010).

2.1.2 Total Phosphorous

Total phosphorous (TP) is defined as the sum of all phosphorus compounds that occur in various forms. In water, it exists primarily as inorganic phosphate (PO_4) or in organic compounds (Palmer et al. 2016). The majority of the TN found in a pond is in the form of uneaten feed and faeces that have decomposed and release phosphate (Boyd 2007). Like nitrogen, plants require phosphorus for growth however, high levels of phosphorus can also fuel algae growth leading to algae blooms which can potentially lead to eutrophication (Environmental Protection Agency, 2017).

2.1.3 Total Suspended Solids

Total suspended solids or TSS is the measure of matter that is suspended within the water column that are not dissolved and can be trapped by a filter (Palmer et al. 2016). High concentrations of TSS increase turbidity and thus restricting light penetration in the pond (Oram 2011). It is a parameter used to assess the quality of a specimen of any type of water body.

2.2 Effluent Impacts

Figure 4 - Gulf of Mexico dead Zone

Effluent from aquaculture can contribute significantly to waterways and ecosystems, by the elevation of nutrient loading causing eutrophic zones that decrease the oxygen levels required, and reducing water clarity (Trott & Alongi 2000). One of the largest eutrophic zones by area in the world is in the Gulf of Mexico as per Figure 4. This phenomenon occurs every spring and lasts until late August or September when it slowly fades away due to tropical storms or hurricanes (Carlisle 2009). It appears in the northern part of the Gulf, from the mouth of the Mississippi River to beyond the Texas border. This is due to the major farming states in the Mississippi River Valley which include Minnesota, Iowa, Illinois, Wisconsin, Missouri, Tennessee, Arkansas, Mississippi, and Louisiana.

Introducing untreated, or poorly treated, effluent to an ecosystem can not only destroy an aquatic ecosystem, but affect humans with illness, due to marine life becoming poisoned. An example of this is shellfish such as oysters that filter the nutrients of water and as such can consume tiny microbes, which are associated with algae bloom and are toxic to people (Costa et al. 2011).

2.2.1 Eutrophic Zones

Eutrophic zones, also known as dead zones, are zones in water bodies where very low oxygen resides (Glibert et al. 2005). These zones are caused by large amount of nutrients, such as nitrogen and phosphorus, that are added into the ecosystem, which cause algae blooms and hypoxia. During normal nutrient levels, they feed the growth of cyanobacteria, otherwise known as blue-green algae (Costa et al. 2011)

2.2.2 Turbidity

Turbidity is a measure of the cloudiness or clarity in water bodies and therefore the higher the turbidity, the cloudier the water body is (Palmer et al. 2016). Turbidity is a directly caused by suspended solids in the water column that scatter the light, but it is not a direct measure of the TSS present. Turbidity can come from suspended soils from either soil, silt or clay, organic matter such as algae or inorganic materials (Kemker 2014). The clarity of water can also affect aquatic life and ecosystems, the clearer the water the greater the potential of photosynthesis.

2.2.3 Oxygen Levels

Low oxygen levels caused by eutrophic zones or algae blooms is called hypoxia, which is the lack of oxygen available that causes organisms to die (Costa et al. 2011). Not all hypoxia zones are caused by effluent, some are cause naturally due to stratification. This occurs when less dense freshwater mixes with heavier seawater (Levin et al. 2009).

2.3 Types of Systems

There are two types of pond systems that are used, and they are the flow-through settlement pond system and the reticulation and bioremediation systems, that recycles the pond water, also known as RAS (Robertson et al. 2006).

2.3.1 Flow-through

A flow-through design is the typical conventional prawn farm design. It involves water intake from estuary or coastal ocean frontage that is distributed to the ponds. At the same time effluent flow into the treatment pond, where water is detained for the required minimum time before it is discharged back into the water body, usually a different point from the water source, (Robertson 2001). Bioremediation options can also be used through this system to convert waste nutrients into other commercial crops, (Robertson 2001).

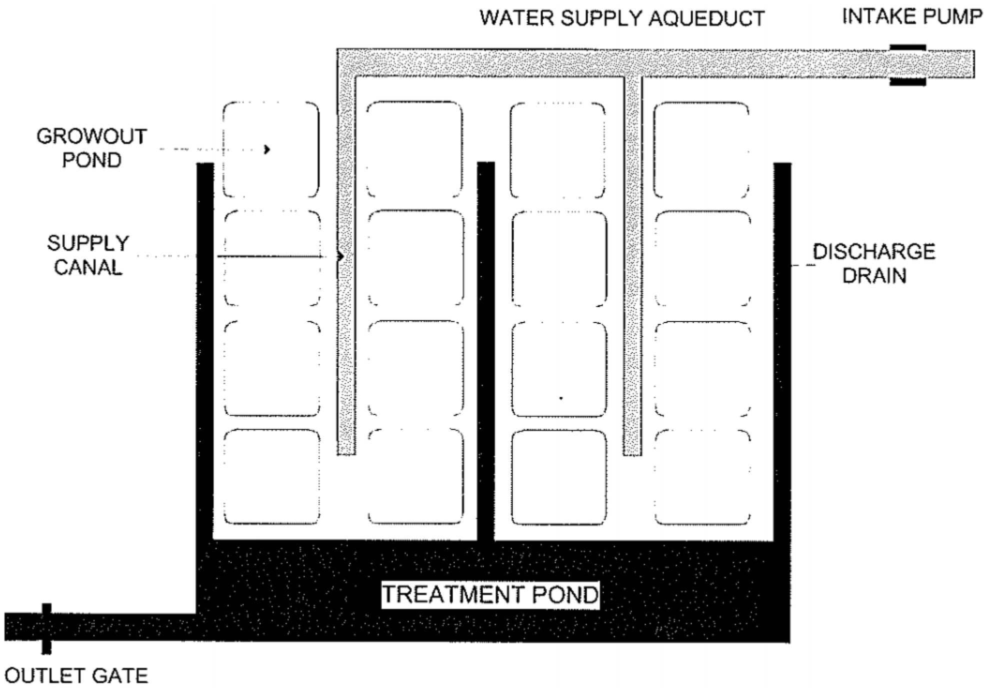


Figure 5 - Conventional Flow Through System

2.3.2 Reticulation and Bioremediation System

Reticulation and bioremediation systems are also known as closed systems, they involve treating effluent water through different treatment system or organisms and minimizing the amount of water intake from rivers (Robertson et al. 2006). Currently, in Australia, the prawn farming industry has adopted this style where they reticulate pond water within the farm as a mixture with new intake, or it is used for the earlier stages of the crop where "green water" is require for the larva growth. In other countries, reticulation systems have proven to produce lower effluent nutrients, as they are designed to achieve higher environmental standards than normal due several factors such as: shortage of land, biosecurity or the potential to produce a secondary crop (Robertson 2001).

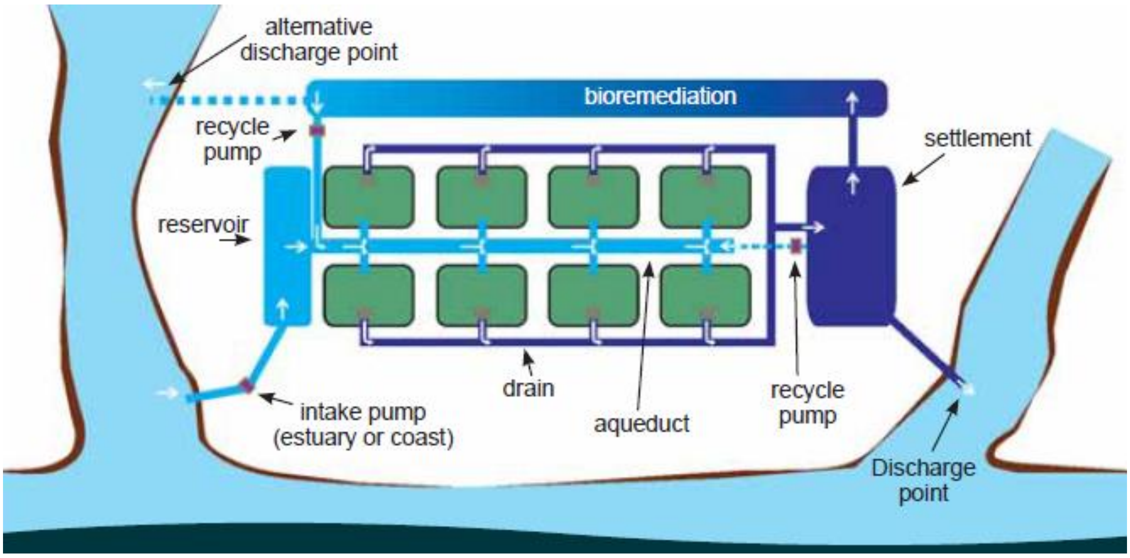


Figure 6 - Reticulation and Bioremediation System

2.4 Types of Effluent Treatments

In the current operation policy for marine prawn aquaculture there is a very strict set of guidelines and maximum concentration amounts that aquaculture farmers have to abide by, since the majority of prawn farmers are located in Queensland where the risk of damage to the Great Barrier Reef is significant. The policy enforces that this reef system should be protected as much as possible. The operation policy of wastewater for prawn farmers regulates activities under the Environmental Protection Act 1994 and the Environmental Protection (Water and Wetland Biodiversity) Policy 2019.

There are several types of effluent treatments for aquaculture systems both, physical and biological, that are used in current farms which are explained in the following sections.

2.4.1 Settling Ponds

The current practice for Australian prawn farmers is to allocate up to 30% of the land for settling systems. The system is designed to reduce TSS and dissolved nutrients in the effluent before discharge or reuse (Preston et al. 2000; Robertson et al. 2006). Current methods world-wide all include some form of settling tanks or ponds for not only prawn farms, but most aquaculture farming. Teichert-Coddington et al. (1999) proved that as little as 6 hours retention time decreased the amount of TSS by 88%, TN by 31% and TP by 63%. Although for the overall pond effluent, this only meant approximately 7% of TN removal as total ammonia nitrogen, which was significantly high in the last 20% of the effluent discharged. This demonstrates that sediment ponds paired with other forms of bioremediation are the best treatment system to minimize effluent impact in the ecosystem.

Between the years of 1995 -2002, 30 skilled researchers and scientists from Australia and the U.S. from several institutes including CSIRO, Australian Institute of Marine Science, Queensland Department of Environment Heritage, New South Wales Environmental Protection Authority, Marine and Freshwater Resources, and several universities including the University of Maryland, conducted successive studies through production cycles on the large prawn farms in Queensland and New South Wales (Preston & Miller 2009). The multidiscipline study developed a comprehensive analysis of the environmental management of prawn farming, and rigorous techniques for sampling eutrophic pond ecosystems (Preston & Miller 2009)

2.4.2 Banana Prawns

Banana prawns *(Penaeus Merguiensis)* mainly inhabit mud-mangrove environments or at the bottom of coastal waters (Staples et al. 1985) and are heavily farmed in Asian countries as they are believed to be a better species. Post larvae banana prawns have been demonstrated to be carnivorous, praying on copepods. Juveniles have shown to be carnivorous detritivores, while consuming mainly organic matter they also prey on small animals (Chong & Sasekumar 1981).

Figure 7 - Banana Prawn (Fenneropenaeus Merguiensis)

Experiments conducted at The Bribie Island Aquaculture Research Centre (BIARC) identified that banana prawns have little effect on the water column’s nutrient levels, unless implemented on a large scale (Palmer 2005).

2.4.3 Macroalgae

Macroalgae is one of the two major types of algae, more commonly referred to as "seaweeds", which are being consumed by a growing number of people (Feng et al. 2020). Aquatic plants have proven to be a low-cost option as a biosorbent in several studies (Ho et al. 2000; Halide et al. 2003). Macroalgae are not true aquatic plants as they lack roots and stems, but instead they have holdfast, which act in a similar way. There are 3 main types of macroalgae: green algae, red algae, and brown algae. Algae filtrations have been known to counteract the production of CO_2 by aquaculture and the consumption of oxygen.

Macroalgae was experimented as a biofilter for juvenile sea cucumber reticulation system. The results of the experiments over 90 days demonstrated that the macroalgae were efficient in removing toxic ammonia and maintaining water quality for sea cucumbers at acceptable levels (Wang et al. 2007). The total removal of ammonia-nitrogen was up to 68% at an average rate of 0.459g m^{-2} day^{-1}. Another study in the fishponds of Tanzania demonstrated that the biomass produced from macroalgae for *Ulva Reticulata* and *Gracularia Crassa* was of good quality and nitrogen was removed at rates of 0.4g m^{-2} day^{-1}. These macroalgae's were also able to raise the pH values of the pond effluent and they oxygenated the water. The study also showed that the species *Chaetomorpha Crassa* and *Eucheuma Denticulatum* of algae performed poorly in effluent ponds (Msuya & Neori 2002).

Figure 8 - Macroalgae Brown Type

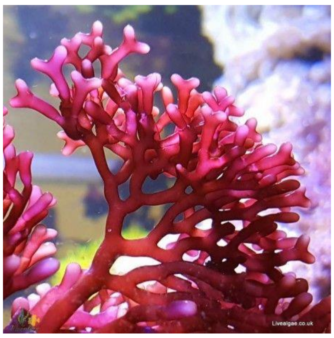


Figure 10 - Macroalgae Red Type

Figure 9 - Macroalgae Green Type

2.4.4 Microalgae

The second type of algae are the microalgae that lay at the bottom of the food chain in freshwater and saline environments. Compared to macroalgae which are large in size, microalgae are microscopic in size. They require light, carbon dioxide, nitrogen, and phosphorus to grow, which would make them an ideal remediation treatment after removing suspended solids (Shpigel & Neori 2007). The best way to describe microalgae is the unwanted slimy algae that is found in an aquarium (Chen & Wang 2020).

Microalgae have a quick biomass production and contain high oil levels, which have been recognised as good raw material for biodiesel production. Dense microalgae populations can maintain good water quality in ponds if given proper environmental conditions (Shpigel & Neori 2007). In a bivalve integrated system, they filter the microalgae which then it is converted to macroalgal biomass.

2.4.5 Sea Mullet

Sea mullets *(Mugil Cephalus)* which are part of the *Mugilidae* family, are usually medium to large and silvery-grey colour (Bray & Hoese). They have been shown to increase the organic matter decomposition rate and also decrease the thickness of sediment layer (Katz et al. 2002). One of their most noticeable feature is that mullets feed at the lowest trophic levels in the food chain (Brusle 1981).

Figure 11 - Typical Sea Mullet

Studies have been done around the world on the removal efficiency of organic matter removal from enriches sediments, to have a positive effect on the water column (Chareonpanich et al. 1994), and Lupatcsh, Katz & Angel (2003) conducted a study that showed reduced organic matter in the sediment underneath fish farming cages in the Gulf of Aqaba. Their experiment yielded results that sea mullet effectively removed 4.2g of organic carbon, 0.7g of nitrogen and 7.5mg of phosphorus kg^{-1} mullet m^{-2} day^{-1}. However another study shows that artificial substances may be needed where mullets are present or used in prawn farms, as they have a negative effect on water quality due to the inability to retain nitrogen (Erler et al. 2004).

2.4.6 Bivalves

Currently around the word, shellfish aquaculture is considered by many researchers as an ecological sustainable activity as pond effluent contains organic matter, including bacteria, phytoplankton, and detritus that could provide food (Vaughn & Hakenkamp 2001; Shumway et al. 2003). They are highly efficient water filters which reduce turbidity; however, oysters have always been known to have difficulties coping with high sediment load (Loosanoff & Tommers 1948), which is unfortunate as 72% of TSS in the pond effluent can be made up of inorganic matter (Jones & Preston 1999).

Bivalves do not add nutrient loading to water bodies but rather produce a transfer of nutrients, they actively pump water through their gills and release nutrients in two forms; bio-deposits or dissolved into the water (Dumbauld et al. 2009). Phosphorus has also been observed to be reduced by mussels in Lake St Clair, or to be more precise, it has been retained by sedimentation of the bio-deposits (Nalepa et al. 1991).

BIARC have conducted a case study on three bivalve species, the mud ark *(Anadara Trapezia)*, the rock oyster *(Dendostrea Folium)*, and the pearl shell *(Pintada Maculata)*, for their tolerance of silt loading and the remediation of pond effluent occurring with banana prawn. The results yielded that the mud ark demonstrated the highest tolerance with 99% survival followed by the pearl shells at 88% and the rock oysters at 63% (Palmer & Rutherford 2005).

2.4.7 SKIM Foam Fractionator

Foam Fractionation is a water treatment technology that can be easily applied to aquaculture reticulation systems. It is based on wastewater treatments industry to reduced organic loads before the water reached the activated sludge reactors. The cyclonic SKIM unit is produced by the French Research Institute for the Exploitation of the Sea (IFREMER) (Palmer 2005). Foam fractionator is mostly popular with indoor hatcheries aquaculture systems, and less common in outdoor systems (Hussenot 2003). They are designed to remove the excess feed before dissolving and becoming a problem by releasing nitrogen. Figure 12 demonstrates how a typical foam fractionator works.

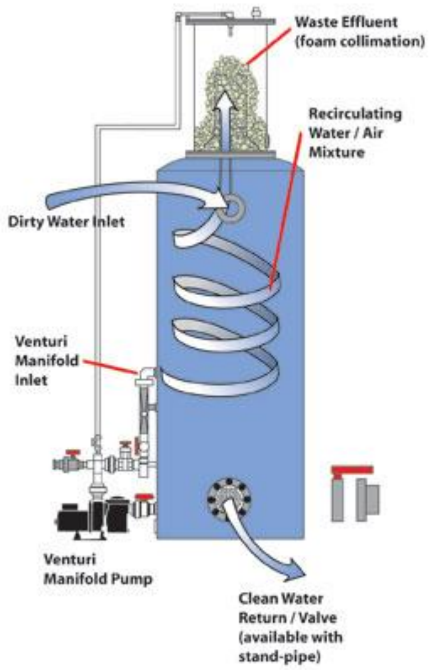


Figure 12 – Schematic Diagram of a Foam Fractionator

Foam fractionator systems are well suited were water intake is low and therefore a well reticulated system is required (Hussenot 2003). Some short term treatments were applied at BIARC, to investigate the effect of nutrient and suspended solids removal (Palmer 2005). The results of the experiment showed that the foam fractionator was very efficient in removing TSS by 30% within a timeframe as early as 2 hours and as high as 50% in 4 hours. TP levels for the effluent reached a high 69% from a 6 hour operation, however TN levels were only reduced 30 – 40% (Palmer 2005). Previous data for the SKIM model suggest that the unit functions more efficiently when larger volumes of clearer foam are used (Hussenot 2003).

2.4.8 Polychaete

Polychaete are commonly known as bristle worms and are mainly found in marine environments, (Fauchald 1977). They are a diverse and abundant group of segmented worms that have small legs or tentacles for feeding. The name ‘polychaete’ is derived from the Greek meaning of ‘having much hair’ which refers to the bristles on the worms (Fauchald 1977).

Polychaete worms have been observed in the Mediterranean for their fast growth rate (Giangrande et al. 2005) and therefore studies have been done to utilize them as biofilters in aquaculture. In a farming scenario in Italy, Stabili et al. (2010) experimented the survivability, growth, and capabilities to remove several bacterial groups: heterotrophic bacteria, culturable bacteria, halophilic vibrios bacteria, faecal bacteria, and coliform bacteria. The results were positive, with the polychaetes mortality less than 10%, filtering capacity higher than 12 m^3 d^{-1} m^{-2} and high bacterial removal properties.

Several other studies have been conducted at BIARC with the assistance of sand filters. studies from Palmer et al. (2016) demonstrated two successful seasons of over 5.4 tonnes of black tiger prawn production, and about 930 kg of polychaete biomass. Nutrient discharge from the experiment was about 1/3 of the current license conditions, it was still a concern with the high amount of TN at 58.4 kg ha^{-1}, for the more strict sections of Queensland (Palmer et al. 2016). The system was designed as a full reticulation with no water intake during the seasons and no settlement pond or other remediation systems.

Figure 13 - Different Types of Polychaete

2.4.9 Constructed Wetland

Wetlands are semi-aquatic eco-systems, with a mixture of shallow pools and vegetation that vary in composition with the season. They exclude growth of plant species from saturated soils and alter the soil properties due to flooding. These areas include swamps, marshes, mudflats, mangroves, fens, bogs, peatlands, and saltwater marshes (Kadlec & Wallace 2008). A well-established wetland is a cost-effective method for treating wastewater.

A constructed wetland differs from natural wetlands as they are constructed uniquely to the local landscape and treatment requirements as a secondary treatment. Constructed wetlands have demonstrated efficiency at removing pond effluent nutrients when planted with *Salicornia* (Turcios & Papenbrock 2014). A constructed wetland can be simply be put as a settling pond with aquatic plants for nutrient removal. Mangroves have also proven to be effective in tropical regions as they also promote biodiversity (Robertson 2000).

The Water Sensitive Urban Design Technical Manual (WSUD) have different chapters for water planning and design and the management of total water cycles in an urban development. Chapter 13 focuses on constructed wetlands and discusses things like landscape considerations, design process, construction process and approximate costing. Table 1 below is taken from WSUD chapter 13 and demonstrates the ranges of pollutant and nutrient removal from a constructed wetland. There are two major types of constructed wetlands: surface flow and subsurface flow (Lee et al. 2009).

Table 1 - Typical Annual Pollutant Removal from Wetlands

Pollutant	Expected Removal	Comments
Litter	> 95 %	Subject to appropriate hydrologic control
Total Suspended Solids	65 - 95 %	Depends on particle size distribution
Total Nitrogen	40 - 80 %	Depends on speciation and detention time
Total Phosphorus	60 - 85 %	Depends on speciation and particle size distribution
Coarse Sediment	> 95 %	Subject to appropriate hydrologic control
Heavy Metals	55 - 95 %	Quite Variable

2.4.9.1 Surface Flow

Free water surface flow has areas of open water and are similar in appearance to natural marshes. They contain floating vegetation and emergent plants either by design or as an unavoidable consequence (Kadlec & Wallace 2008). Since surface flow mimic natural wetlands, they attract a variety of wildlife. Since the is potential for human exposure to pathogens, free surface wetlands are rarely used for secondary treatments, but more so for advance treatments.

2.4.9.2 Subsurface Flow

Subsurface flow contains of two types, horizontal and vertical. Horizontal subsurface flow wetlands consist of gravel or soil beds planted with wetland vegetation. The wastewater is intended to stay underneath the surface of the media and streams in and around the roots (Kadlec & Wallace 2008).

Vertical subsurface flow delivers water across the surface of a sand or gravel bed planted with wetland vegetation. Water then percolates through a plant root zone, where it is treated. Vertical surface wetlands were designed to provide a better oxygen transfer, hence supplying more nutrified effluent (Kadlec & Wallace 2008).

Since the water is not exposed during treatment, there is minimal risk to humans or wildlife of exposure to pathogenic organisms. Subsurface flow wetlands are normally constructed as a primary treatment for effluent, prior to discharge (Kadlec & Wallace 2008).

2.5 Urban Stormwater Treatments

Stormwater is water generated by precipitation or melted snow. The surface runoff transports different pollutants, both organic and inorganic due to land modifications associated with urbanisation. These new pollutants are from anthropogenic activities (Barbosa et al. 2012). Numerous studies have identified the first flush of a stormwater runoff to contain the highest concentration of pollutants (Horsley & Platz 1995) due to being associated with sediment particles.

Urban areas produce higher discharge volumes and velocities which can affect downstream water bodies. To ensure public health, stormwater runoff is treated to regulatory requirements based on rainfall data, size of the site and allowable discharge. Many prefabricated devices to provide treatment have been approved for use in Australia, with the leading companies being Ocean Protect and SPEL stormwater. There are several techniques for treating stormwater, but most of the structures employ some form of sedimentation and filtration (Horsley & Platz 1995). The most common used devices can be found in the sections below.

2.5.1 Cartridge Filter System

The Cartridge filter system comprises of multiple media filters cartridges inside an enclosed concrete or fiberglass vault. The cartridges used are rechargeable and self-cleansing to absorb the pollutants from stormwater runoff (Minton 2004). This system is available in multiple cartridge heights to meet site requirements, and each cartridge treats a specific flow rate. To meet the design flow rate of the site, a suitable number of cartridges are placed inside the vault (Minton 2004).

The filter has an up-flow treatment where a siphon is established within each cartridge. Hydraulic pressure pushes stormwater runoff through the media, where it filtrates, then passes through the centre wall within the cartridge. The treated water moves downward to an underdrain system which can be seen in figure 14 (Ocean Protect, 2020). As solids accumulate in the filter media, the flow rate gradually decreases until clogged. These cartridges are then replaced to return the flow rate to normal.

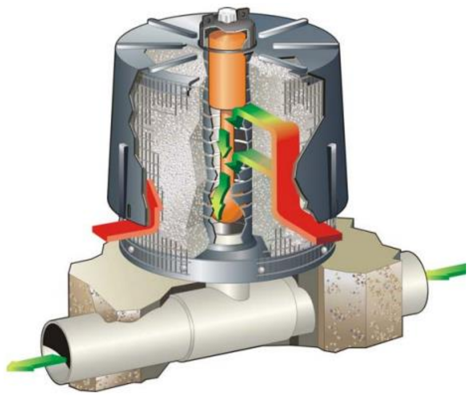


Figure 14 - Cartridge Filter

There are a variety of media options which are designed to regulatory specific requirements. The current range of media are PhosphoSorb, ZPG, and Perlite.

2.5.1.1 PhosphoSorb

A filter media that achieves optimum combination of pollutant removal and cost effectiveness. This media targets both the particulate and soluble phosphorus fractions and it is comprised of heat expanded volcanic granules impregnated by activated alumina (Lenhart et al.). There have been several studies that showed a rapid kinetic rate of effective absorption by activated alumina (Hano et al. 1997; Genz et al. 2004), which is stable and does not leach harmful substances.

2.5.1.2 Perlite

Natural occurring puffed volcanic ash that is effective for TSS, oils and grease removals (Ocean Protect, 2020). When heated to a range of 760 to 1100°C, perlite expands between 4 to 20 times its original volume making it light in weight and reaching a high surface area (Gironás et al. 2008).

2.5.1.3 ZPG

ZPG consist of zeolite, perlite, and granular activated carbon and it is an approved media for removing suspended solids and nutrients (Ocean Protect, 2020). The zeolite is an occurring mineral that is effective at removing soluble metals, ammonium, and some organics. While the granular activated carbon provides effective micro-porous with high surface area and is effective at removing oils, grease, and some organics (Ocean Protect, 2020).

2.5.2 Jellyfish

The Jellyfish filter is a compact treatment device from Ocean Protect, configured to capture stormwater runoff pollutants. Each cartridge has 11 tentacles like filters, as displayed in figure 15, that remove trash, oils, debris, TSS, silt size particles, TP, TN, metals, and hydrocarbons (Ocean Protect, 2020).The Jellyfish is designed to have a much smaller footprint than other filter devices, while still achieving the regulatory treatment requirements.

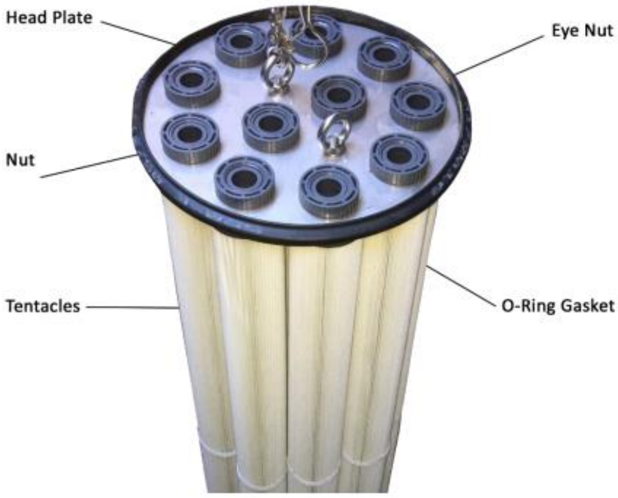


Figure 15 - Jellyfish Tentacle Filter

The tentacles are designed to be light weight with low maintenance cost, as maintenance is performed by removing, rinsed, reusing the cartridge tentacle. Full cartridge replacement varies with pollutant loading; however, replacement can be between 2 – 5 years (Ocean Protect, 2020).

2.5.3 Gross Pollutant Traps

Gross pollutants traps play an important role in stormwater management in preventing visible street waste from contaminating the environment (Madhani & Brown 2011). They are designed to be a primary treatment device with ease of access for maintenance. Gross pollutants are defined as debris larger than 5mm which include litter and vegetation, which are transported by stormwater runoff. Gross pollutants are a major environmental threat to aquatic habitats as they cause marine life death, they look unpleasant, can attract vermin if found on shorelines, and create a horrid smell (Allison et al. 1997).

2.5.4 Bioretention

A Bioretention is a collecting pool, that consist of organic matter and multiple layers which are: mulch or soil layer, filter media layer, transition layer, and drainage layer. They are used to slow and treat stormwater runoff before being directed into receiving waters or nearby stormwater drains (Trowsdale & Simcock 2011). Treatment occurs through soil filtering, absorption, biotransformation mechanisms. Bioretention emphasized increased depth to increase the likelihood of pollutant attenuation or transformation (Davis et al. 2003). High nutrient intake plants are used to densely vegetate the basin and achieve a high rate of pollution removal, after all, the main key of a bioretention basin is to remove pollutants.

Bioretention basins can be installed in various sizes and areas to suit urban designs such as landscape planter boxes, parks, parking lots, and streetscapes, and thus minimizing the area required for treatment. They can be combined with other treatment technologies such as gross pollutant traps or Stormfilters.

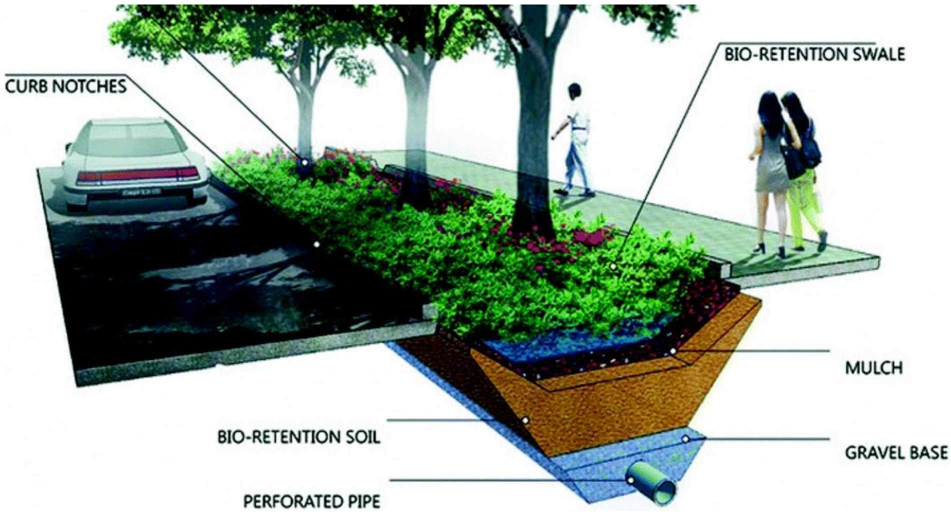


Figure 16 - Bioretention section in urban areas

2.5.5 Floating Wetlands

Floating Wetlands are similar to constructed wetland however, they do not need their own pond area to work. The idea is that high nutrient intake plants are placed into existing ponds to reduce nutrient concentration. They are made from 100% recycled polyethylene terephthalate, more commonly known as PET (SPEL, 2020). The recycled plastic is made into non-woven, non-toxic durable matrix of fibres which bond together and provide the buoyancy needed. Plants are then inserted into the material and grow down into the water hydroponically. The treatment is then anchored into a secure position depending on the water and climate conditions (SPEL, 2020). The floating media is patented product of SPEL stormwater and are designed to be incorporated on existing water environments. (SPEL, 2020) “The biological processes occurring within the biomass of the floating treatment media are the same as sludge but have added advantage of Symbiosis and increased microbial activity”, (SPEL, 2020).

The floating media produces minimal environmental impact and can work with fluctuation water levels for seasonal changes.

The following table demonstrates the result of nutrient loading for the floating media treatment on a wastewater pond between the years of 2010 and 2011 conducted by SPEL.

Table 2- SPEL Wastewater Pond Results 2010/11

Contaminant	Influent	Effluent	Removal Rate
BOD_5 (g/m3)	265	< 10	> 95%
Total Suspended Solids (TSS) (g/m3)	265	< 10	> 95%
Ammonia (NH_4N) (g/m3)	45	2 – 5	> 95%
Total Nitrogen (TN) (g/m3)	55	< 10	> 95%
Total Phosphorus (TP) (g/m3)	10	2 - 3	> 95%
F Coliforms(cfu/100ml)	7,000,000	≈ 100	> 95%

2.5.6 MUSIC

MUSIC was first developed in 2001 for the use of catchment hydrology. Today MUSIC can incorporate a wide range of treatment trains and simulations, for both stormwater runoff quantity and quality. The catchments used for modelling can range from single house blocks to agricultural farms of many square kilometres. These simulation models are all base on the treatment devices provided by the manufacturers or by using a generic template. All treatment and removal rates are based on manufacturer's lab and field testing over a period of time, that the desired local council dictates.

The software helps developers, planners, and engineers devise development proposals that meet Water Sensitive Urban Design Standards (WSUD) (ewater, 2020) for the stormwater management of their catchment. The software's algorithm helps predict the performance of stormwater treatment trains. MUSIC lets the user choose appropriate size for stormwater infrastructure options until the design meets the appropriate standards for stormwater volume and pollutants (ewater, 2020). The simulation models in MUSIC are based on rainfall events collected over a 10-year period and predicts the performance, which allows rigorous analysis and comparisons between short-term and long-term benefits of any stormwater treatment system (ewater, 2020). MUSIC can also provide life-cost estimates for different treatments systems (ewater, 2020) if the information is provided by the manufacturer.

2.6 Previous Studies

There are several studies conducted for biofilter and bioremediation treatments on aquaculture farms and pond effluent, there are also several studies conducted for stormwater treatment and management. However, there is a gap in studies conducted on aquaculture with stormwater treatments. This could be because the structures are not completely designed for continuous water flows and require a dry period for the filters to backwash.

The overhead cost in setting up and using a stormwater filter is higher there could be potential benefits to the ecosystem, which no price can match. Cost comparisons need to be made to for short term and long-term farming to ensure results are not skewed.

Potential goals that could be achieved:

- Total removal of settling ponds allowing farmers to make use of the extra land.
- Reduction in settling pond/retention time which could increase crop.
- Complete water reticulation system making farms less depended on rivers and oceans.
- Healthier crop and larger prawn sizes.
- Single pond treatment benefits vs complete farm treatment.

This dissertation will determine if investigation and experiments can be conducted in the future, or if urban stormwater structures do not work in aquaculture environments.

2.7 Operational Policy Manual for Wastewater

As previously mentioned, the operational policy for marine aquaculture activities fall under the Environmental Protection Act 1994 and the Environmental Protection (Water and Wetland Biodiversity) Policy 2019. The policy is used in the evaluation and setting appropriate wastewater discharge standards.

The aim is to enhance and protect the environmental values of the water environment while allowing ecologically sustainable development. The key objectives are to:

- Provide consistency across marine prawn aquaculture licenses in Queensland for the parameters that are to be measured and the way these parameters are reported.
- Define minimum standards for discharge and impact.
- Define monitoring programs to measure the performance of each facility.

There is an additional objective on the policy, and that is to encourage improvement for environmental performance with a preference towards enhancing on-site treatment.

The policy contains 3 license categories which are summarised below:

- Category A – For existing farms with no change in their operation.
- Category B – For existing farms with expansions in their operation.
- Category C – For existing farms that have more stringent standards.

This dissertation will focus on section 2.2 Biostimulants, of the operational policy in the category A section. The biostimulant section deals with the physico-chemical indicators and nutrients as per below:

- Dissolved Oxygen – Minimum concentration shall be not less than 90% of the background value or 4 mg/L, whichever is greater.
- pH Level – Minimum of 6.5 and maximum of 9.0
- TSS – 40 mg/L mean; 75 mg/L maximum; 12 kg/ha/day average over the season
- TN – 3.0 mg/L maximum; 1.0 kg/ha/day average over the season
- TP – 0.4 mg/L maximum; 0.15 kg/ha/day average over the season

The results from the dissertation models and simulations will be compared to the above to ensure they meet criteria requirements. They will also be compared to BIARC site allowance pollutant discharge rate.

2.8 Justification

As the global population continues to grow, aquaculture is well positioned to solve incipient food problems. However, at the same time, environmental issues are becoming an increasing concern, and so aquaculture also faces increasing environmental scrutiny. This literature review stands as a demonstration of several organic treatment options and their application as bioremediation, as well as their environmental benefits to aquaculture farming. These technologies address the environmental concerns on the impact of wastewater by safeguarding the surrounding environment and the people and industries that rely on it. Natural bioremediation also has the benefit of not using chemicals to remove effluent, which means that other processes used to fix nitrogen and phosphorous do not spill into the environment and potentially damage it. The majority of options still require a dedicated settling pond before water flows through the bioremediation treatment.

The dissertation stands on existing literature and technologies to eliminate or reduce settling pond area by using treatment designed for urban stormwater. The intent is to prove whether stormwater structures and their filter media can be useful to the Australian aquaculture industry.

3.0 Design Methodology

3.1 Overview

The development of a complete aquaculture effluent treatment system will incorporate several combinations or a single structure of an urban stormwater treatment device. Different scenarios will be created based on BIARC's pond size and previous datasets. This information will be used to maximize the effluent removal for both a flow through system and a reticulation system, while reducing the current footprint required in best practice methods. Each system has their own minimal hydraulic head requirement before water can be passed through their filters.

The model analysis and simulations will be done through the stormwater management software, MUSIC, developed by eWater. The software will estimate the concentrations of TSS, TN, TP, and other smaller nutrients in the effluent, based on the treatments and structures programmed. Several parameters will need to be assumed in the treatment nodes, as MUSIC is based on rainfall events and probability.

Once all the simulations are completed, the treated water will be compared to BIARC allowed discharge licence to determine which models have met the requirement. An average construction cost for each system will be prepared to ensure a feasible option is available.

3.2 Design Parameters

This dissertation will look at recreating the pond parameters from Bribie Island Aquaculture Research Centre. BIARC is located approximately 90km north of Brisbane in the Moreton Bay Region, and the centre conducts replicated research on live marine organisms. Currently BIARC specializes in extensive high-quality supply, filtration and aeration, freshwater and seawater reticulation systems, and reverse osmosis desalination units. It features from 16, 10ML tanks to 32, 1ML tanks with two temperature controlled experimental rooms.

The centre contains 4 large ponds of roughly 1600m^2 in surface area which are square shape of 40m by 40m, with the corners truncated for to allow for better movement of the pond water. An aeration system is supplied to maintain oxygen levels in the tanks. The system delivers the pond effluent through pipes to the settling tank with a detention time of 72 hours before it moves to the bioremediation stage before reticulation.

The model designs will look at how to best reduce the settling tank area and lowering the detention time to increase production for Queensland prawn farmers.

3.2.1 Pluviograph Rainfall Data

A Pluviograph data in a rain gauge that has measured the amount of water that has fallen. The total rainfall data is recorded daily and stored for future use in estimating the probability of certain rainfall events. The closest data station to BIARC, that can collect rainfall data, is the Caloundra station, which is in-built to MUSIC, and therefore this data was used to create the flow. The 10-year period used was based on the years with the least in inconsistency or missing data from 1995 -2005. Figure 17 shows the recorded rainfall data set in mm for Caloundra. The current annual rainfall for BIARC is around 1200mm with a max temperature of 26.9°C.

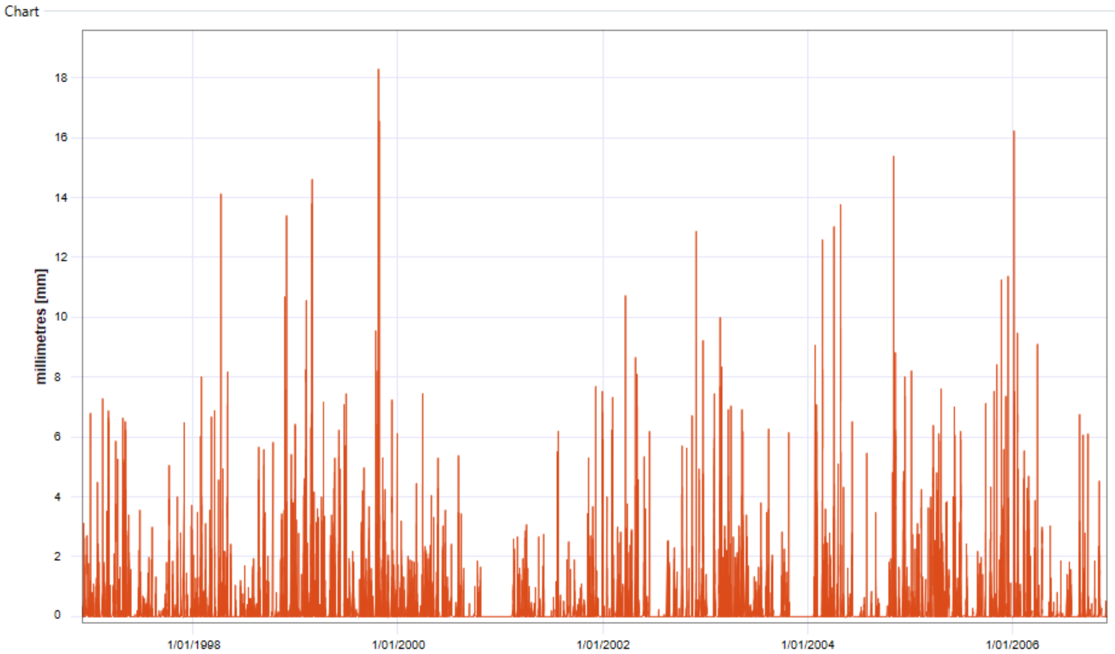


Figure 17 - Caloundra Rainfall Data set from MUSIC

3.2.2 Pond Recreation

MUSIC contains a large variety of source nodes where it contains pre-populated data based on the type of source data, from extended testing from e-water. Though the closest source type was agricultural, it was decided to create a custom source node for a combine 2 pond system.

In order to develop the different simulations for modelling through MUSIC software, the parameters for the pond nutrients needed to be recreated. The parameters of Total Nitrogen, Total Phosphorus, and Total Suspended Solids were based on a previous research conducted at BIARC from P.J Palmer's study "*Polybridge: Bridging a path for industrialisation of polychaete-assisted sand filters*". These results were tabulated in an excel spreadsheet from the 7-month prawn season on the 3 main categories, TN, TP, TSS and used to recreate the source node in MUSIC.

To import this information into MUSIC the create wizard was used that involved a multiple step process. Most of the information required was basic and straight forward like the amount of pervious and impervious area, source total area, zoning/surface type and import flow. The total area for two ponds was set at 3200m^2 and since the ponds are lined the amount of impervious was set to 100%, leaving the pervious area at 0%. The following step required the mean log and standard deviation for the 3 categories. The in-built function in excel was used to acquire the necessary information, which was then entered into MUSIC.

Error! Reference source not found. below shows the extract of the results from P.J. Palmer's r esearch. Though this data only shows weekly testing conducted, a mean and standard deviation were still able to be achieved for modelling computations.

Table 3 - Results from P.J Palmer's Research

Date	Flow data (m^3)	TSS (mg/L)	TP (mg/L)	TN (mg/L)
28/10/2014	0.0013889	48	0.39	2.5
4/11/2014	0.0013889	14	0.1	1.5
11/11/2014	0.0013889	16	0.1	1.7
18/11/2014	0.0013889	46	0.09	1.5
25/11/2014	0.0013889	13	0.6	5.1
2/12/2014	0.0013889	92	0.56	4.4
9/12/2014	0.0013889	78	0.49	4
16/12/2014	0.0013889	46	0.44	5
23/12/2014	0.0013889	59	0.38	4
30/12/2014	0.0013889	48	0.32	4.1
6/01/2015	0.0013889	42	0.32	4.2
13/01/2015	0.0013889	44	0.46	8.1
20/01/2015	0.0013889	52	0.62	9.3
27/01/2015	0.0013889	60	0.84	10.3
3/02/2015	0.0013889	61	0.82	11
10/02/2015	0.0013889	55	1.34	11.8
17/02/2015	0.0013889	55	1.56	16.6
24/02/2015	0.0013889	63	2.4	23.3
3/03/2015	0.0013889	68	1.46	15.5
10/03/2015	0.0013889	46	1.56	17.2
17/03/2015	0.0013889	94	1.52	19.5
24/03/2015	0.0013889	58	1.26	15.9
31/03/2015	0.0013889	94	1.22	15.1
7/04/2015	0.0013889	55	1.2	12.7
14/04/2015	0.0013889	50	1.18	11.9
21/04/2015	0.0013889	46	1.2	10.9
28/04/2015	0.0013889	47	1.1	10.5
5/05/2015	0.0013889	49	1.06	10.4

3.2.3 Data Validation

In order to validate the data for comparison, the cumulative volume of water from Palmer's research was adopted as a minimum annual flow for the prawn season. The total volume of water passing was based on $4700m^3$, as can be seen on Figure 18 below, as the minimum benchmark. This data was then used to create a simulation in MUSIC to achieve similar results for the current best practice scenario, in terms of nutrient removals. The MUSIC models were discharging about 8.1ML/year due to using rainfall data instead of a dedicated continuous flow. These results demonstrated that the simulations were treating roughly 1.7 more than the study conducted by P.J. Palmer and were still producing reliable results. Using a smaller cumulative amount of did not affect the removal percentages as reducing the amount of water going through the system meant that water treatment was as efficient or better with reduced maintenance cost for each system and longer lifespan. Therefore, for all the MUSIC simulations the annual water treated was kept at 8.1ML/year.

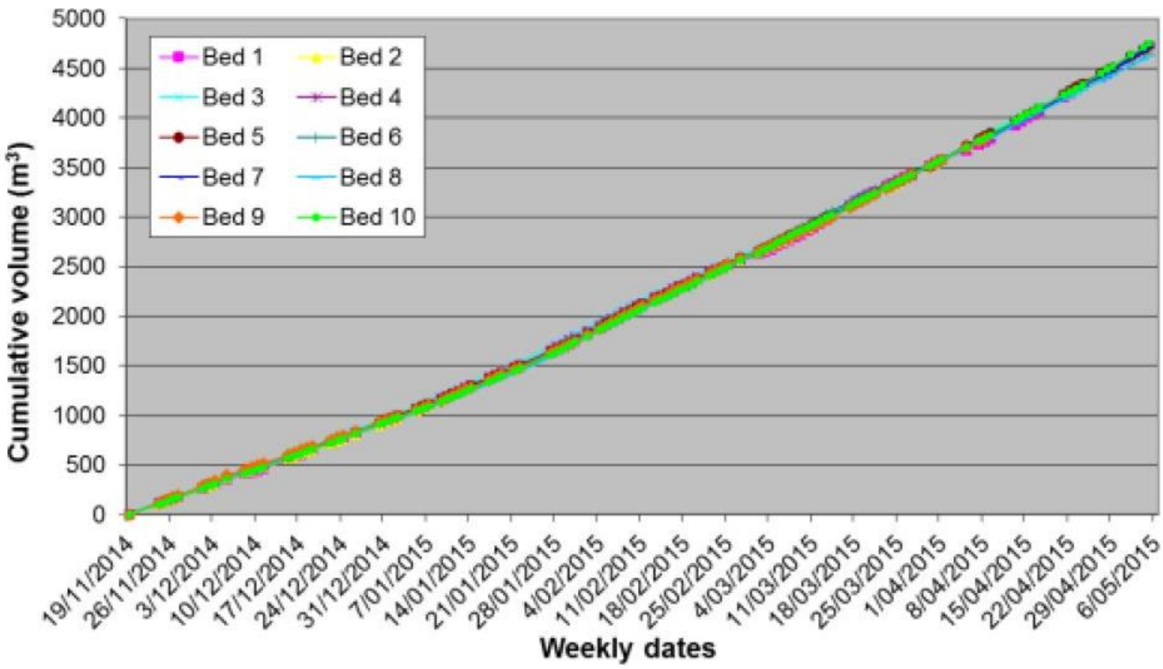


Figure 18 - Cumulative Volume from P.J. Palmers Polybridge Research

3.3 Model Simulation

As previously mentioned before, the initial model that was created was a replica of the research conducted by P.J Palmer, in order to compare the urban structures simulations. Each ponds pond is based on a rough area of 1600m^2 and the below calculations are set to determine the settling tank.

$$4\ pond\ area = 1600m^2 * 4 = 6400m^2$$

$$Settling\ tank = 30\%\ of\ required\ treated\ area$$

$$tank_s = 30\% * 6400m^2 = 1920m^2$$

Therefore, the settling basin was set with an area of 1920 m^2 for the treatment of the 4 ponds. The detention depth of the basin was set at 0.5m, this was only estimated by trial and error based on the results and comparing to P.J. Palmer's research. Since this is a simulation, the basin depth could be different as there may be variables that are un-accounted for at BIARC.

Pipe outlet from the sediment basin is set at 150mm diameter, which contains a detention time of 7.194 hours. Figure 19 below shows the information entered in MUSIC for the settling tank, while Figure 20 shows the treatment train for best practice.

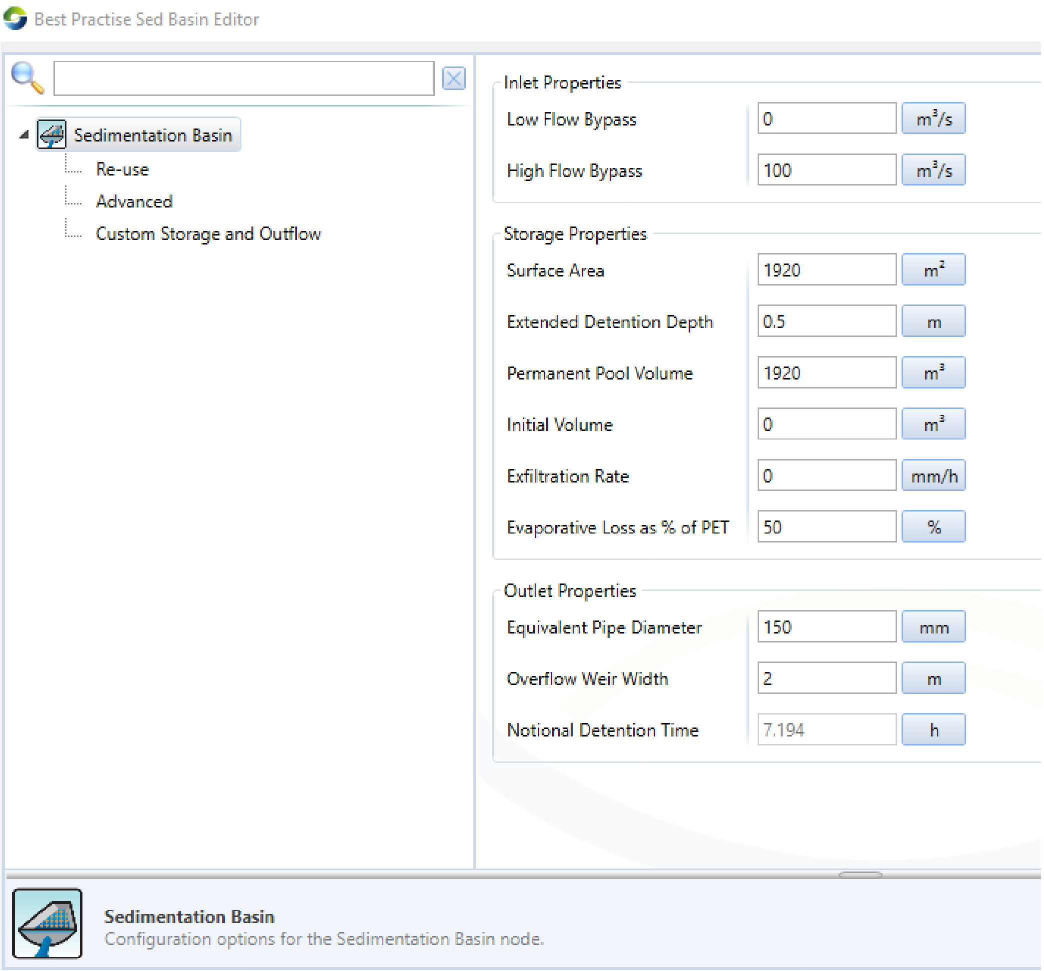


Figure 19 - Best Practice Settling Tank Parameters entered in MUSIC

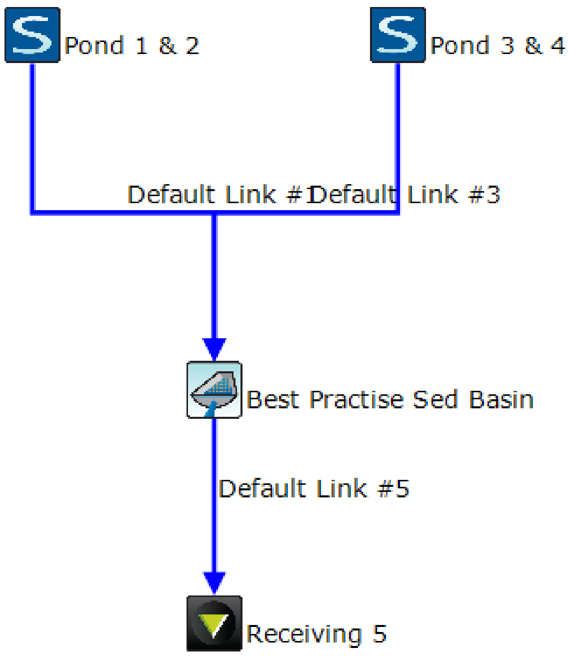


Figure 20 - MUSIC Treatment Train for Best Practice

3.3.1 Bioretention (No Carbon)

For the bioretention option initial trials were conducted on the required surface area. The areas started at $1920m^2$, same as settling tank, and were reduced until significant loading reductions were noted. Based on the trials, the smallest area required to treat the 4 ponds is $400m^2$ with vegetation efficient enough to remove the nutrient loading required. The size of this bioretention is 79% smaller than the required for best practice methods. The bioretention only requires 6.25% of the total combined pond treatment area.

The minimal filter depth use in this simulation was set at 500mm with a 200mm extended detention depth, where plants would be partly submerged. A 100mm transition layer was nominated, along with a 200mm typical granular drainage layer. Figure 21 shows a schematic section design of the bioretention.

Other parameters that were present in MUSIC can be found appendix B in Figure B-1. Since ponds are assumed to be lined along with the base and walls, the option in MUSIC was selected. TN content of the filter media was left as the default value due to no dedicated filter media mentioned.

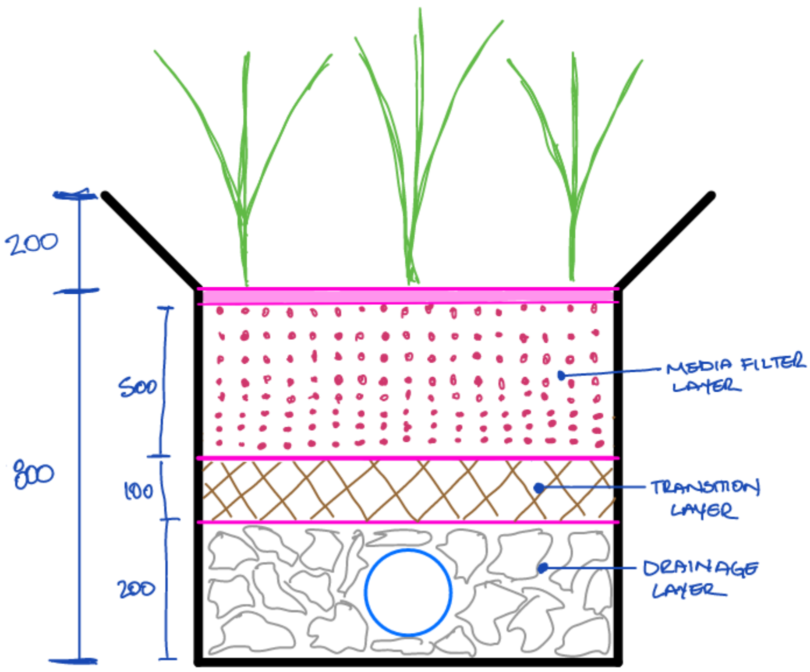


Figure 21 - Bioretention schematic Design

3.3.2 Bioretention (with Carbon)

The bioretention with carbon option is very similar to the bioretention without carbon media with the biggest difference, that the filter media contains a carbon layer or the filter media itself contains carbon. In this scenario a carbon media layer was chosen and placed above the filter media. The Filter surface area is still at 400m^2; however, the filter depth was reduced to 400mm. Extended detention depth is still set at 200mm for a total depth of 800mm. Figure 22 shows a schematic section of the bioretention.

This bioretention option still only requires 6.25% of the total combined pond treatment area with a slightly shallower depth. Even though this option mentions carbon, it can be noted that any media dedicated specifically to target nitrate, nitrite, and ammonia can be used. The idea here is that there is a small layer of especially design nitrogen combatant media that helps reduce Total Nitrogen from the system. These dedicated medias have a large range of options to choose from. The one thing they have in common is that this dedicated material will need to be replaced more often than the normal filter media in a typical bioretention. The remaining parameter can be found in appendix B in Figure B-2.

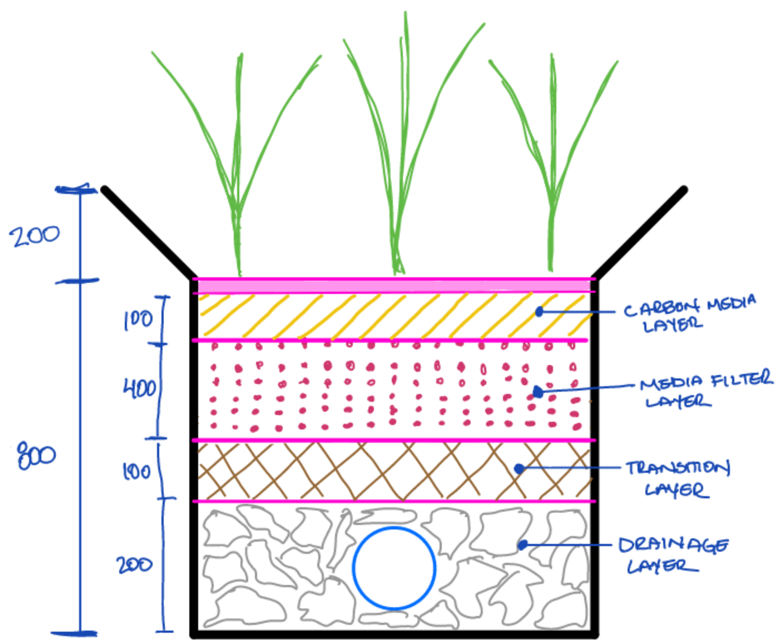


Figure 22 - Bioretention Schematic Design with Carbon

3.3.3 SPEL Floating Wetlands Only

SPEL's innovative floating wetlands produced a high result in nutrient removal, due to the high nutrient intake vegetation, that is specifically designed for each scenario. This was particularly difficult to recreate in MUSIC as there was no speciality design node for the treatment. For the purposes of the simulation procedure, a combination of two nodes were used.

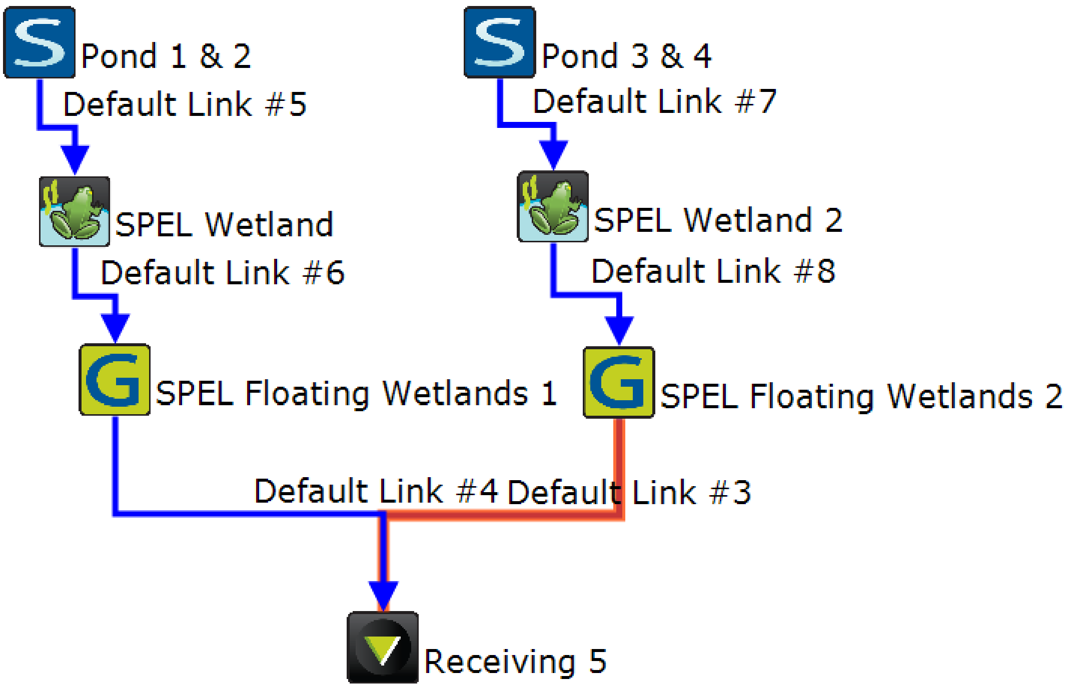


Figure 23 - SPEL Floating Wetland MUSIC Treatment Train

The first node used in MUSIC is a wetland node. Using the storage properties for the area that the floating wetlands occupy only, with no extended detention, and with an assumption of 1.0m pond depth. Each pond was configured to only used 200m^2 of surface area for treatment. Figure B-3Figure B-3 - SPEL Wetland 1st Node MUSIC Inputs in appendix B shows the values used for a 2-pond situation.

The second treatment node was a generic node where the parameters from SPEL's test during 2010/11 from Table 2 were used, as there was no other data available. These inputs can be seen in appendix B from Figure B-4 to Figure B-7. Using these parameters produces a reduction of 100% compared to the settling tank used in best practice methods, since the nutrient removal is happening within the pond itself. Though it would be wise to have a small settling tank, about 2.5% of the total required treatment area, to ensure that cumulative sediment does not affect the prawns and it is easier to clean if maintenance is required.

This model produced some very good results in terms of the removal percentages however, this model also contains several unknowns, with the biggest assumption set on the treatment nodes and their parameters.

3.3.4 *Floating Wetlands with Filter Swales*

The concept of using filter swales instead of drainage pipes to deliver the water to the next stage, or part of the way before reticulation, as well as the SPEL floating wetlands was to add extra treatment along the path to reduce the nutrient loading as much as possible. The idea was to create mini or small bioretention paths from each pond to allow for maximum treatment. One of the WSUD technical manuals contains guidelines for bioretention swales which were taken as a guide when adding the treatment node to MUSIC. Figure 27 shows a typical bioretention filter swale with the minimum required dimensions for the filter to have any effect.

These dimensions were taken into consideration when modelling the filter scenarios. 3 distinctive lengths, 25m, 50, and 100m were chosen for filter treatment. Filter base width was chosen at 0.8m to comply with WSUD guidelines. Depth of the swales were kept the same across all 3 lengths with a depth of 500mm for the filter media. Longitudinal slope of the swale was kept at 1% to allow for slower velocity and longer travel time to maximize the amount of contact time the effluent has on the filter media.

The vegetated swale slopes were set at 1V:2H to allow for any detention, giving the top width of the swale a total of 2.8m. The combination of the swale and media filtration nodes were used in MUSIC to try and simulate the scenario as close as possible. Figure B-8 and Figure B-9 in appendix B, demonstrate the values entered in MUSIC for simulation purposes.

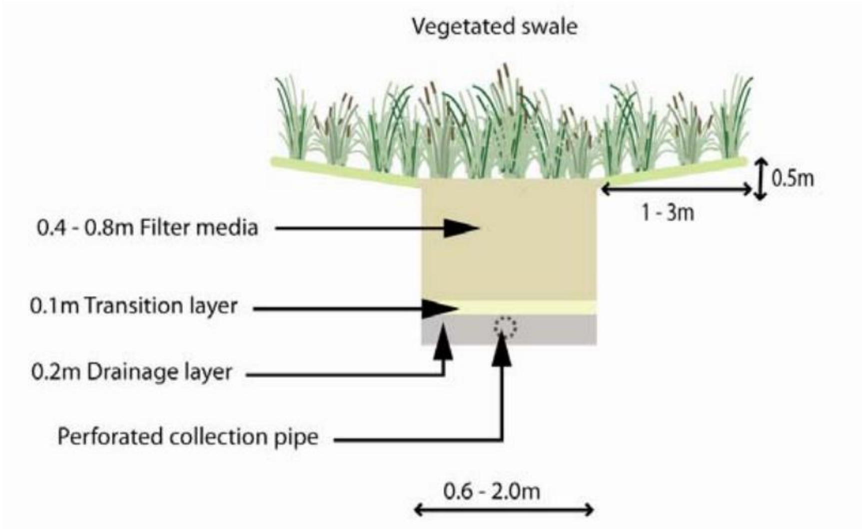


Figure 24 - Typical Filter Swale from WSUD Manual

3.3.5 Jellyfish Only

With the Jellyfish option, the parameters and MUSIC treatment node were acquired from the manufacturer, Ocean Protect. Different councils required slightly different variations and therefore the Moreton Bay treatment node was used since BIARC resides in Moreton Bay. The biggest advantage of using a Jellyfish treatment device is the low hydraulic head required for the filters to work. The tentacle filters are only manufactured in two sizes with the largest one only required a hydraulic head of 460mm and the smaller only requiring 230mm.

The Jellyfish treatment option is limited to the number of tentacles based on the vault size, and their treatment rate may not prove to be an effective method for continuous flow unless some alterations or addition structures are added. It is noted that the smallest tank was supplied by the manufacturer and as custom tank size was not able to be created within the limited time frame. This would skew results as this model will not be able to produce accurate results to compared to the other models. Further work is required to validate this model which will be mentioned in the results sections.

Figure 25 below demonstrate a typical design plan on the Jellyfish structure by Ocean Protect. Figure B-10 to Figure B-14 in appendix B contain the MUSIC treatment node parameters provided by the manufacturer.

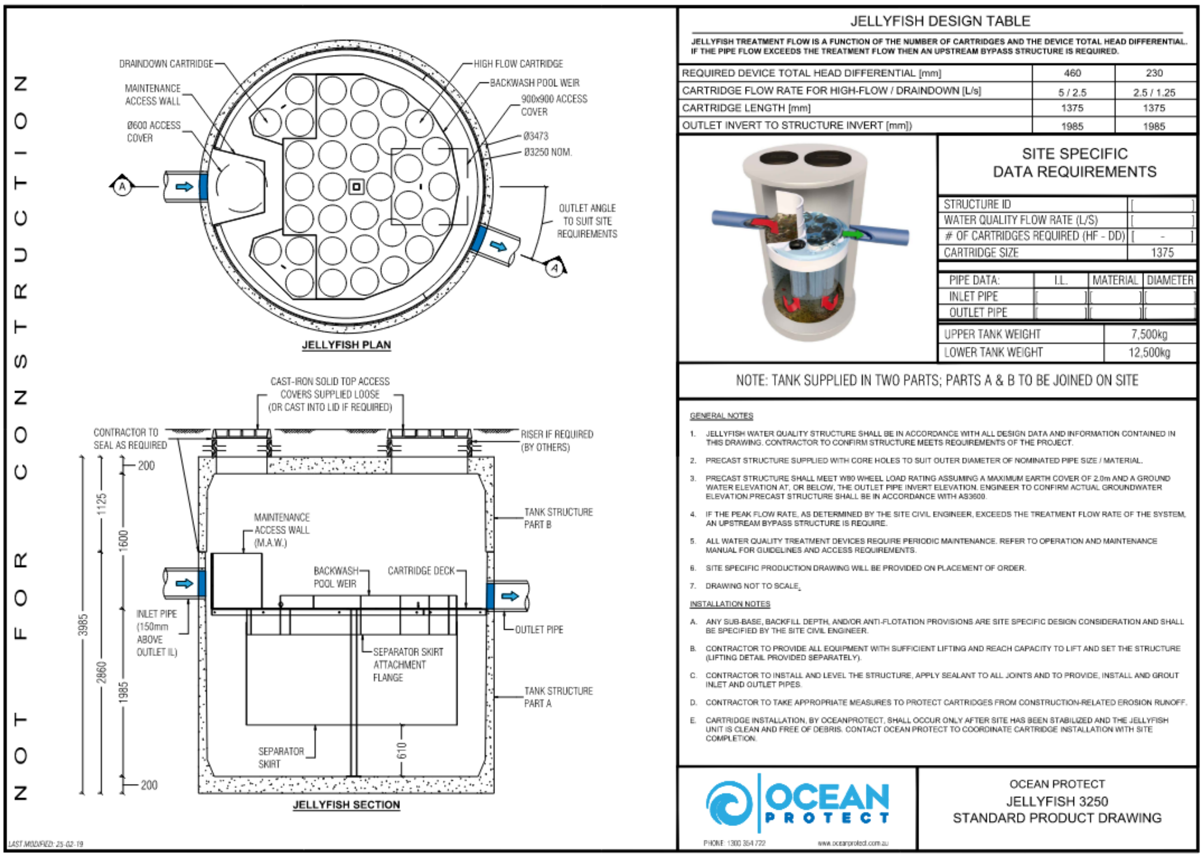


Figure 25 - Jellyfish Standard Drawing from Ocean Protect

3.3.6 Jellyfish with Sediment Tank

Due to the limited space and treatment area of the small Jellyfish provided, a miniature sediment tank was considered to provided additional initial treatment to the effluent. The concept of dealing with the heavier concentration loads in the sediment tank and allowing a slower discharge rate into the Jellyfish to try and achieve maximum treatment from the filter tentacles. This would also increase the lifespan of each filter tentacle while reducing maintenance cost and downtime for the filters. The diagram below demonstrates the schematic design used in this model.

Water from the pond would be controlled and discharged at set intervals to the sediment tank via a time valve and provide the effluent with enough time for settling, while also not disturbing the settled particles. Alternative designs were considered of a dual pipe system to the Jellyfish, a high pass, and a one low pass, where the high pass pipe would be used until the sediment tank required maintenance. The lower pipe would contain a valve or gate that would only open at the end of each prawn season for cleaning out sludge and sediment.

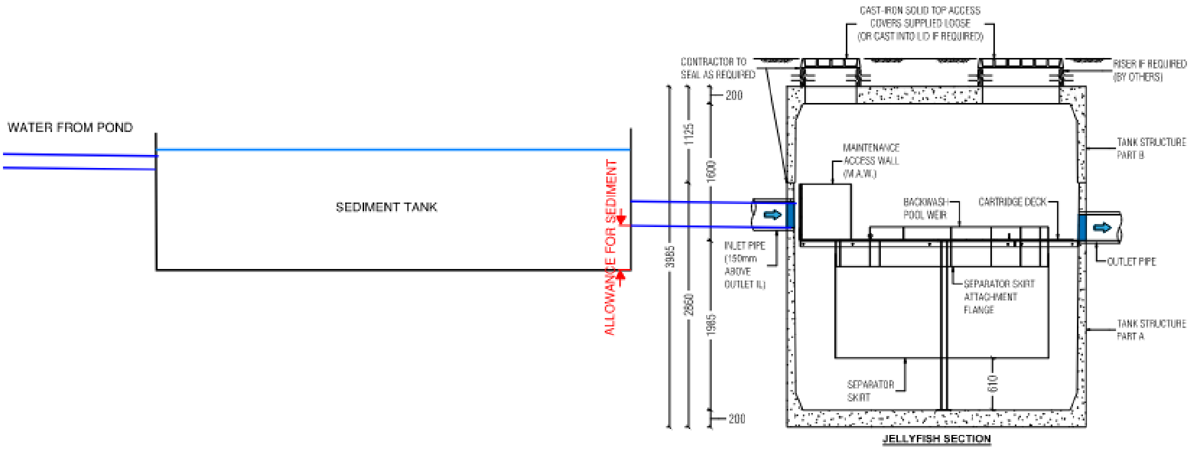


Figure 26 - Schematic Design of Sediment Tank with Jellyfish

Surface area of the sediment tank was set at 500m^2 with a minimum depth of 0.5m. No initial water was chosen as the concept is for the sediment tank to fill and get low enough to create a permanent pool of effluent to keep the sediments settled, while further effluent gets added. The inputs can be seen in appendix B Figure B-15.

3.3.7 Single Stormfilter Vault (with 50 filters)

The Stormfilter devices are all based on Ocean Protects data and their precast vault sizes. Pre-sizing is done through an excel spreadsheet to determine the parameters for the treatment nodes in MUSIC. The input parameters in the excel file consist of the system type (manhole or vault), the cartridge height, the number of cartridges and the type of media filter in the cartridges.

For the single structure option, the vault chamber SF2 was selected which contains a surface area of 13.2m^2 and a detention depth of 0.77m. The largest cartridge size was chosen to maximize the flow rate of the media. 50 filter cartridges were initially selected with the material Psorb, as this specific media filter is not only the cheapest of all 3 options but has a high phosphorus concentration absorption.

The following figures below, demonstrates the MUSIC model properties used from the excel spreadsheet for SF Vault 2 with 50 filters. The maximum number of filters in a single vault is

140 cartridges. 50 filter cartridges were chosen as 1/3 of maximum filter option and due to the size of the effluent requiring treatment.

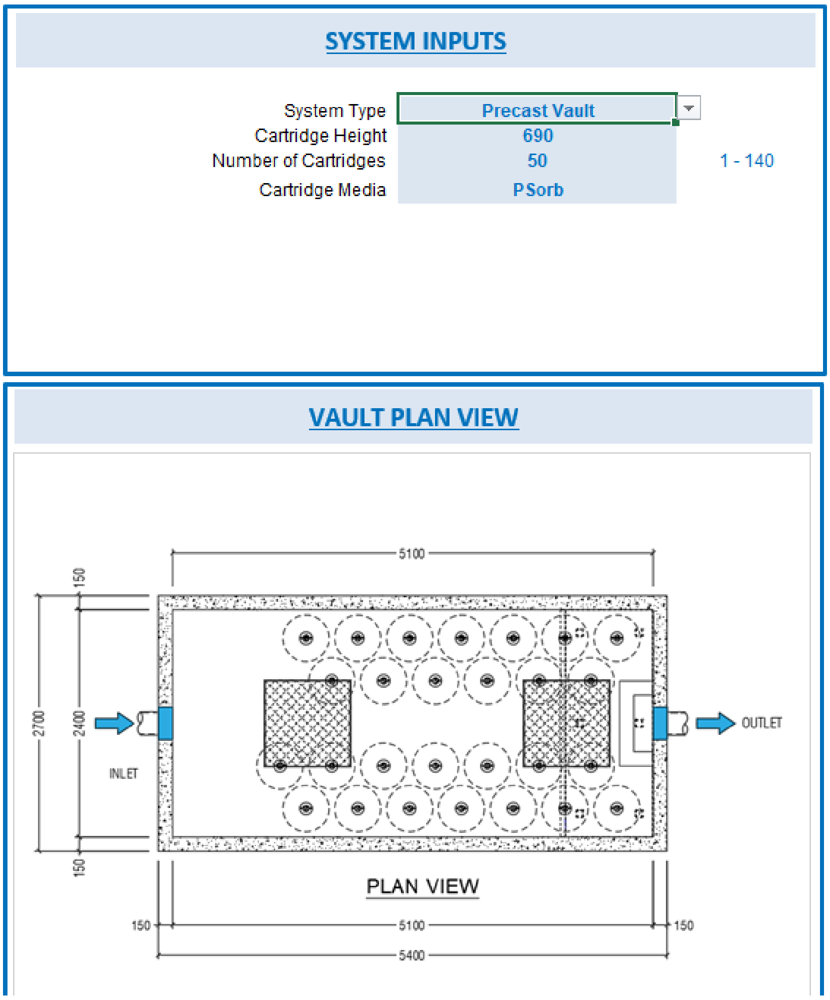


Figure 27 - Ocean Protect SF2 Vault Chamber Dimensions

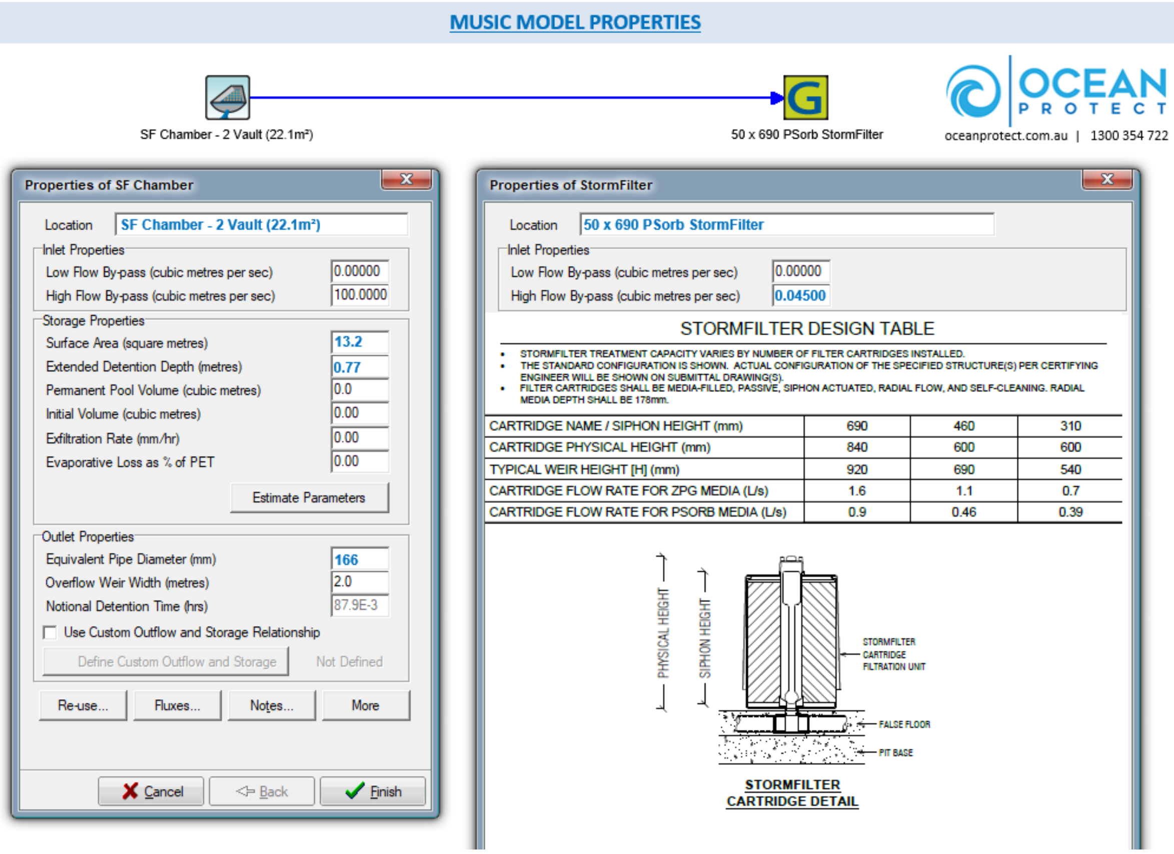


Figure 28 - Ocean Protect SF2 MUSIC Node Parameters

Other simulation models were conducted with the different types of filter material; however, the treatment results were not as efficient as the Psorb filter material and were therefore taken out of the simulation and results. As can be seen in Figure 28, each cartridge can only handle between 0.39L/s to 0.9L/s, pending on the filter size, for Psorb while the flow rate drops to 1.6L/s – 0.7L/s in ZPG media.

3.3.8 Stormfilter (Dual Option)

The second Stormfilter model option was to use two SF2 Vault tanks with 50 cartridge filters each, as mentioned above. Ideally each tank would treat the effluent of two ponds before proceeding downstream into the reticulation system. It is expected that the efficiency results produced from this model are much higher than a single treatment tank.

The same node inputs in MUSIC were used as stated above to simulate results.

3.3.9 Single Stormfilter Vault (with 140 filters)

A third option is provided for Ocean Protect Stormfilter, with the intention of maximum the number of filters to compare how this affect the efficiency rates. The excel spreadsheet was used to attain the MUSIC input parameters, which concluded with the model using the vault chamber 4 that can house a maximum number of 140 filter cartridges. The cartridge media was left as Psorb with the cartridge height at 690mm.

The vaults dimensions are as per and system inputs can be seen below in Figure 29.

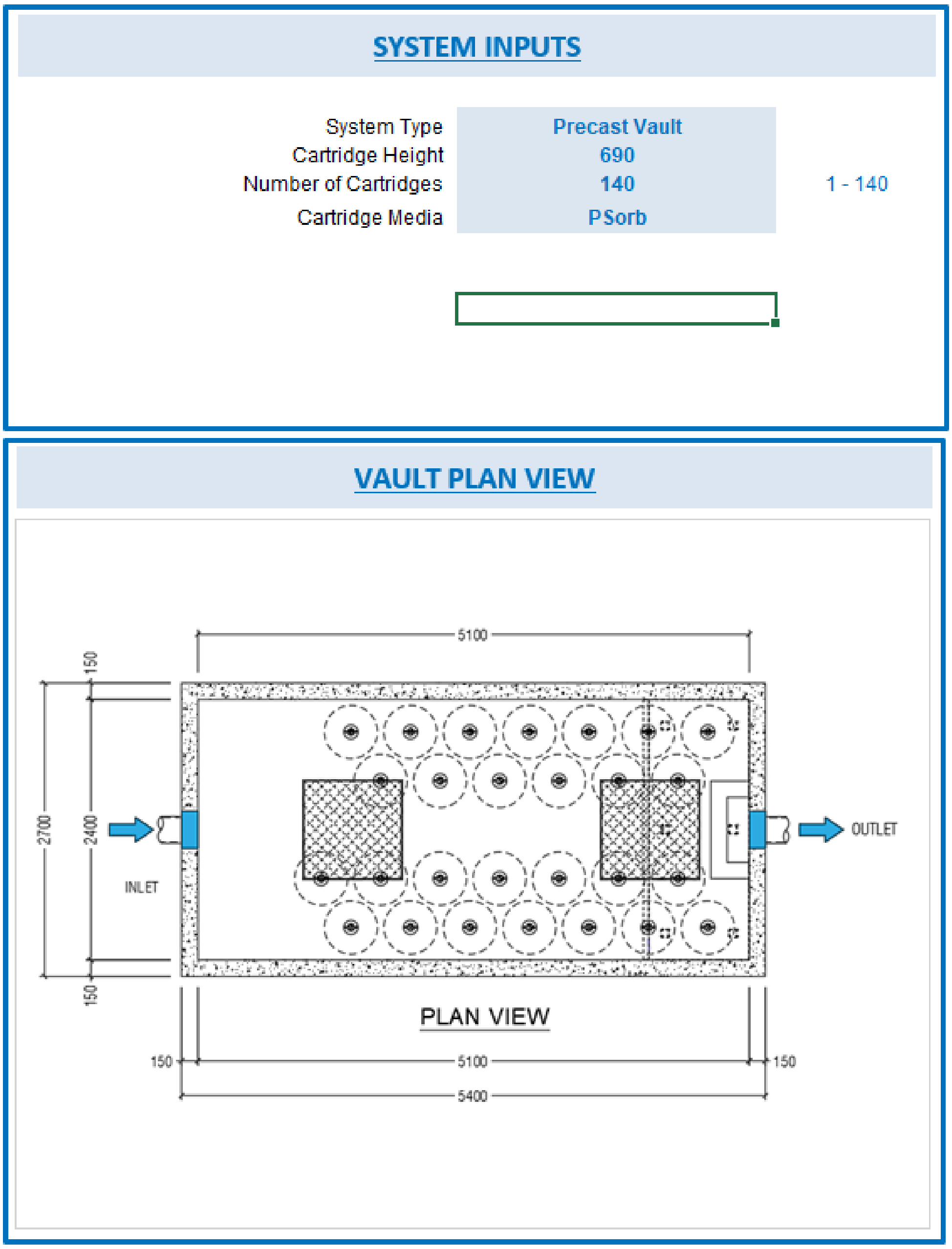


Figure 29 - Ocean Protect SF4 Vault Chamber Dimensions

A surface area of 19.4m^2 and a detention depth of 0.77m are demonstrated in Figure 30. Due to the number of filters increasing the flow rate it is expected that total nitrogen and total phosphorous efficiency should increase by 25% - 50% from SF2 chamber model, however total suspended solids are expected to stay the same as the chamber's physical dimensions are the same.

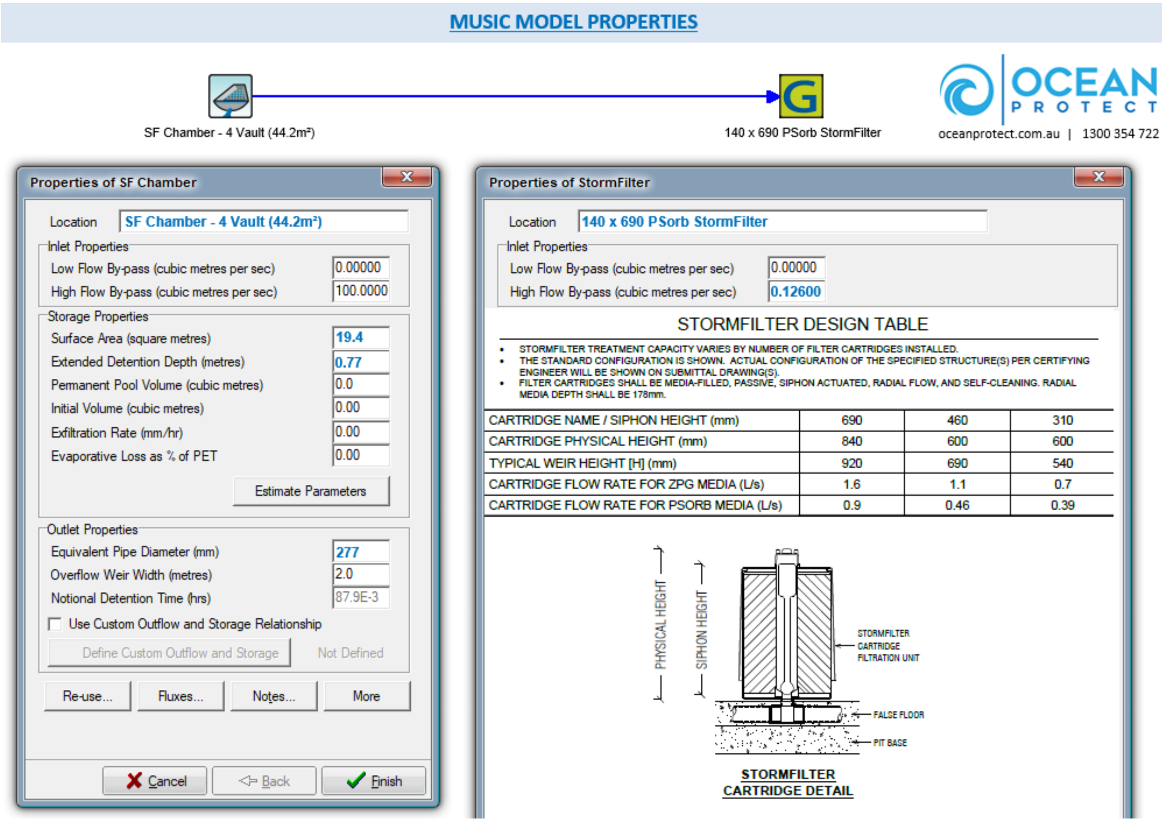


Figure 30 - Ocean Protect SF4 MUSIC Node Parameters

3.3.10 Stormfilter with Sediment Tank

Due to the results of the Stormfilters, their limited space and low efficiency rates a small sedimentation tank was also considered to provide pre-treatment to the pond effluent, with the concept of slowing flow rate down minimizing the amount of bypass from the effluent. Ocean Protect vault chamber SF 2 with 50 filter cartridges was the only model considered for this simulation. The sediment tank contained the same parameters use in the Jellyfish model with a surface area of 500m^2 and a minimum depth of 0.5m. No initial water was chosen as the concept is for the sediment tank to fill and get low enough to create a permanent pool of effluent to keep the sediments settled, while further effluent gets added. The inputs can be seen in appendix B Figure B-15. There was a second model created with a larger sediment tank with surface area of 750m^2. It is expected that this model will provide better performance than other Stormfilter models with and without a sediment tank.

Since the filters are dealing with less pollutants, the cartridge media's lifespan would increase while also reducing maintenance cost. Basic concept of the sediment tank and the discharge is as per Figure 26, for the Jellyfish model. Although initial tank depth is set as a minimum of 0.5m, actual tank depth will diverse based on pond depth and Stormfilter vault depth.

3.3.11 Wetlands

The wetlands treatment node in MUSIC is very similar to the sediment tank in terms of the inputs that it requires. Surface area calculated was set to 40% of current best practice methods, which was rounded up to 800m^2. Depth was set to 0.5m as a minimum with the intent of keeping a permanent pool volume of effluent. The extended height above the pool water level was set to 0.25m to allow for any excess flow. This returned a detention time of 2.119 hours through the software. Other parameters were left as default which can be seen in Figure B-16 in appendix B.

No other treatment models were created in combination with the wetland treatment node, as the performance is anticipated to be lesser than a bioretention or a sediment tank. Although wetlands contain vegetation which are partly submerged, MUSIC does not take this into account as there are no parameters for vegetation and their inputs. Further research into this is recommended as there may be a difference in the software's algorithm.

3.3.12 Multi-treatment Options

Several combinations of multiple treatment devices were modelled to compare their efficiency against single structures, and to attempt to achieve a zero-nutrient discharge. The 3 main models created were very similar with only the last treatment device being replaced with alternative options. The 3 model configurations consisted of the following treatment trains: pond > SPEL floating wetlands > filter swale > final treatment option. These final treatment options consisted of the following:

- A vegetated bioretention with a surface area of 50m^2, filter depth of 0.5m, detention above water level of 0.25m, no carbon. The treatment train used in MUSIC can be seen below. Bioretention MUSIC inputs can be seen in Figure B-17 in appendix B.

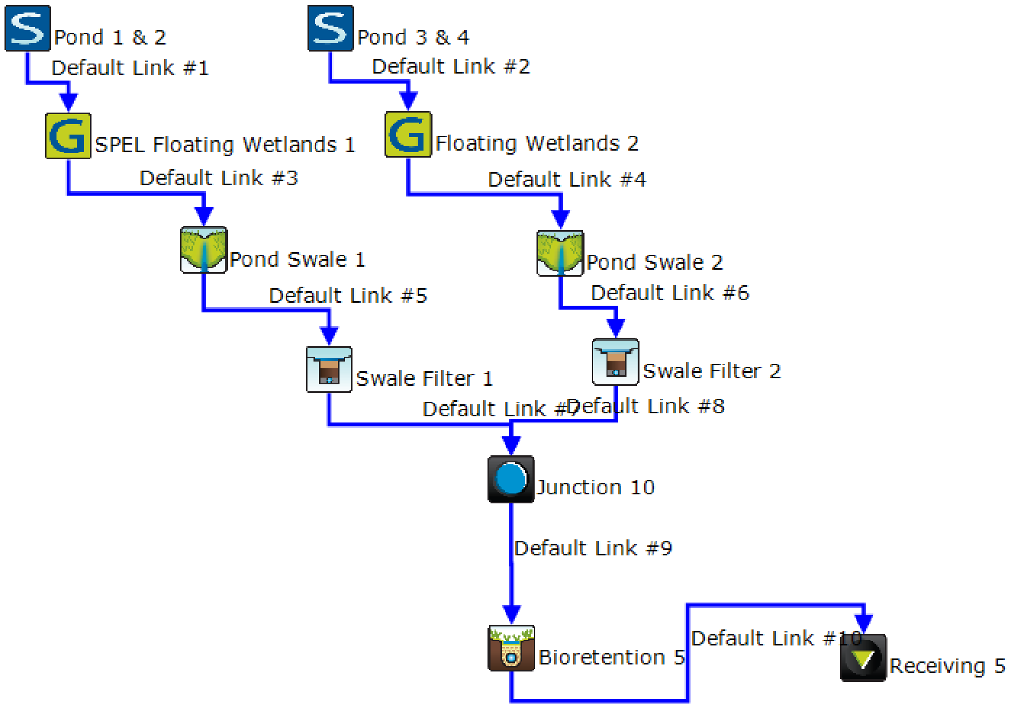


Figure 31 - Multi-Treatment Train Option with Bioretention

- Ocean Protect Jellyfish treatment. The parameters provided from Ocean Protect were used on this treatment. These parameters can be seen in Figure B-10 to Figure B-14 in appendix B. The treatment train used in MUSIC can be seen below.

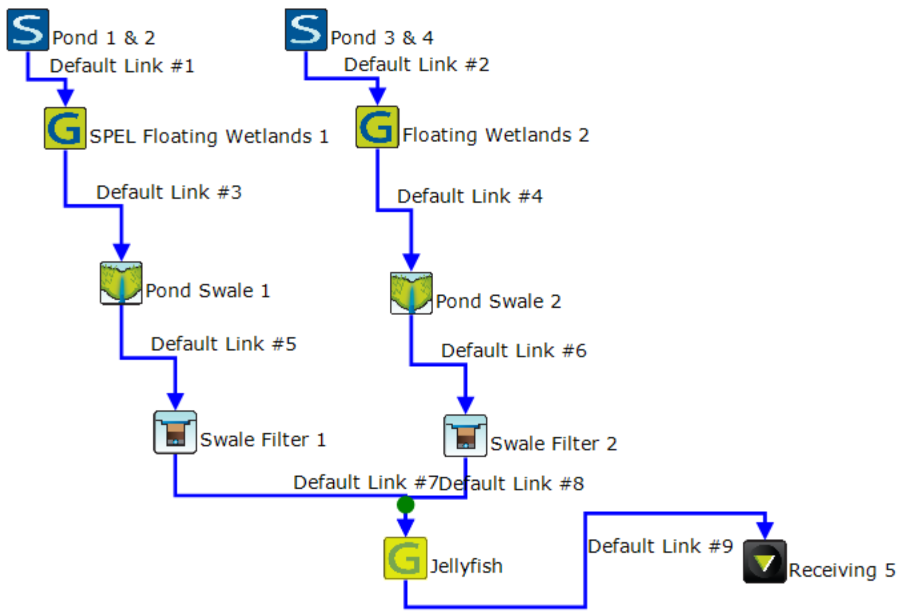


Figure 32 - Multi-Treatment Train Option with Jellyfish

- Ocean Protect Stormfilter treatment. The 50-filter cartridge option with SF 2 vault were used in this model. These parameters can be seen in Figure 27 and Figure 28 in section 3.3.7 Single Stormfilter design. The treatment train used in MUSIC can be seen below.

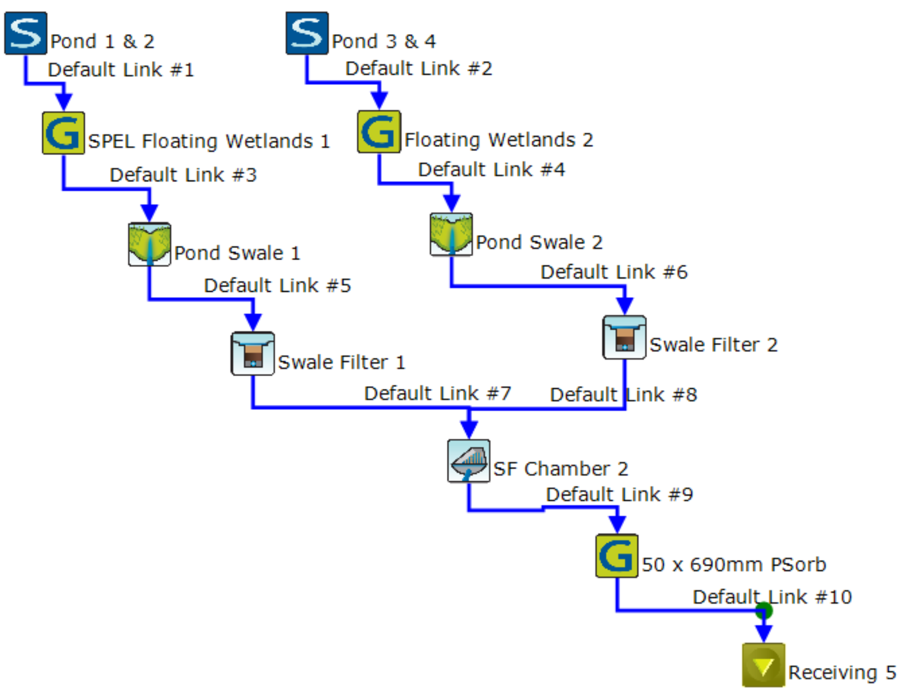


Figure 33 - Multi-Treatment Train Option with Stormfilter SF2 (50 filters)

3.4 Construction Cost Analysis

Initial average capital cost for stormwater structures can be found in Table 4 below. The prices are based on either a squared metre rate from publications or unit prices provided by the manufacturer. There are several costs and models not included in the table below and they are:

- Different types of media material including carbon.
- Vegetation types
- Delivery and receiving pipes
- Filter swales
- Multiple treatment options
- Pump
- Maintenance

Table 4 - Average Treatment Device Construction Cost

Device	area/size	average price	approximate cost
Best Practice	1920m^2	\$100 - \$700/m^2	\$192,000
Bio Retention	400m^2	\$500 - \$700/m2	\$280,000
Jellyfish only	unit	-	\$120,000
Stormfilter Chamber with 50 filters	22.1m^2	-	\$198,000
2x Stormfilter Chamber with 50 filters	44.2m^2	-	\$396,000
Stormfilter Chamber with 140 filters	44.2m^2	-	\$429,000
Floating Wetlands	800m^2	\$650/m^2	\$480,000
Constructed Wetlands	800m^2	\$500k - \$750k/ha	\$60,000

Other exclusions include:

- GST
- Rectification works
- Construction contingencies
- Installation cost or labour
- Site establishment or storage of materials
- Transport of materials

As may be visible from Table 4, the average value for best practice sediment tank is around $192,000 and it is the cheapest construction method, except for wetlands and the Jellyfish filter. Constructed wetlands are relative reasonably priced to build and because of the surface area dimensions used in the model, to keep a small footprint, the average cost is less expensive than that of best practice.

The jellyfish structure returned as the 2nd most inexpensive model and the cost of the unit also includes 12 months of maintenance. The device used in the MUSIC modelling and pricing is in fact undersized and the price for a new unit was expected to be double in cost. This was merely stated by the representative of Ocean Protect and to give any accuracy in pricing, a custom tank had to be designed with model parameters. Due to time restraints this option was omitted, and the initial treatment node provided was used.

The Stormfilter device with 50 filters returned with similar pricing for best practice methods and similarly to the Jellyfish structure all Ocean Protect structures include 12 months on maintenance. Stormfilter devices are inexpensive when it comes to construction cost as their footprint are kept to a minimum. This could balance out other construction cost that are not accounted for in this dissertation, compared to the other models. They do require a minimum hydraulic head for the filters to work efficiently, which pending on the delivery system of the water could mean deeper trenches and more backfill.

A bioretention option, could prove to be a feasible replacement for the best practice methods, as the average cost to build one is only 1.5 times the sediment tank in best practice methods. The bioretention demonstrated promising results which will be discussed in further detail in section 4.0. Utilizing carbon filter media inside the bioretention could increase the initial cost of construction and will certainly increase the maintenance cost, as the interval between maintenance periods will decrease.

As can be seen the floating wetlands are the most luxurious shape of treatment with an average price of $650 per square metre, they do not however require a separate or individual tank for treatment which means less cost in the overall design of a RAS system. Providing multiple treatment train in combination with the SPEL floating wetlands could appear to no longer prove a feasible choice due to the higher rate of the floating wetlands.

4.0 Results and Discussions

The methodology produced considerable amounts of data sets for the model simulations, and quantitative outcomes with simplified result graphs and tables have been supplied due to only being interested in categories. The arrangement of the outcomes will be supplied in four sections: total suspended solids, total nitrogen, total phosphorous and gross pollutants. These findings are presented within the following sections together with unique evaluation and interpretation of results.

4.1 Gross Pollutants

Gross pollutants mean debris or rubbish, and basically anything larger than sediment size. As all stormwater treatment devices contain a membrane or chamber to hold any debris from passing and damaging the filters. This means that all the simulations models, except for the Jellyfish, produced 100% gross pollutant removal from the site. The larger the chamber the greater the efficiency rate as it allows more room for holding these rubbishes before maintenance is required.

As previously mentioned for the other pollutants, the size of the Jellyfish model was too small and therefore was only able to reduce the gross pollutants by 60%. Increasing the filter tank area would produce a 100% removal rate and would also have higher efficiencies with the other pollutants. Further work needs to be conducted on Jellyfish treatment devices to see if they are an acceptable and reasonable option for aquaculture.

Gross pollutants can have a significant impact on the efficiency of the water treatment as it can damage filter cartridges or block the flow path of the water in the chamber. Regular maintenance is required not only to remove sediment but gross pollutants as well. Thought in this control environment of aquaculture there should not be any large gross pollutants that go through the system. The largest debris should be the uneaten feed stock or prawn moulds, which could break down into smaller pieces. This section is more so for urban stormwater design.

4.2 Total Suspended Solids

It was found that current removal rates of suspended solids for best practice methods are in the mid to high nineties, in terms of percentage, based on the recreated model. Though this value may be closer to 100% as the actual remediation tank and parameters like detention time and discharge, at BIARC are unknown. In order to meet minimum requirements, the removal rate of simulation models had to reach a minimum of 94% removal of total suspended solids, comparable to best practice. In this criterion all but four of the simulation models achieved this requirement and that could be due to possible factors. The following scenarios did not achieve the required removal rate: Jellyfish only, Stormfilter tank with 50 filters, dual Stormfilters with 50 filters each, Stormfilter with 140 filters, and the Wetlands simulation.

4.2.1 Manufactured Stormwater Devices

One of the main, and possibly biggest reasons the single stormwater devices, like the Jellyfish and Stormfilter, did not perform well in this category is that the size of the device or tank which is housing the filters was inadequate for the area that required treatment. Custom sizes were not considered in the designed models as this fell outside the range of catalogue products that were provided. Though it is possible to design custom tank sizes and the number of filters required to achieve minimum requirements, with a combination of filter material even, these models need to be designed by the manufacturer, Ocean Protect, to acquire accurate result.

The second reason that the requirement was not met could be a possibility that these devices are designed to clean the "first flush" of stormwater runoff, in urban or industrial areas. While continuous runoff after a set time frame, is assumed to be "clean" water as it does not make direct contact with the pavement or vegetation. This runoff is then designed to bypass the treatment area and continuous downstream until discharged, see Figure 34 for diagram. While in this simulation all the effluent is required to be treated, as all the water has been "contaminated" by the nutrients, and there should be no through passing allowed.

The filters are also designed to treat a set amount of discharge in litres per second and cannot treat more effluent than their limitation. Providing more filters would increase the total amount of discharge rate but at the price of more capital cost and higher maintenance fees.

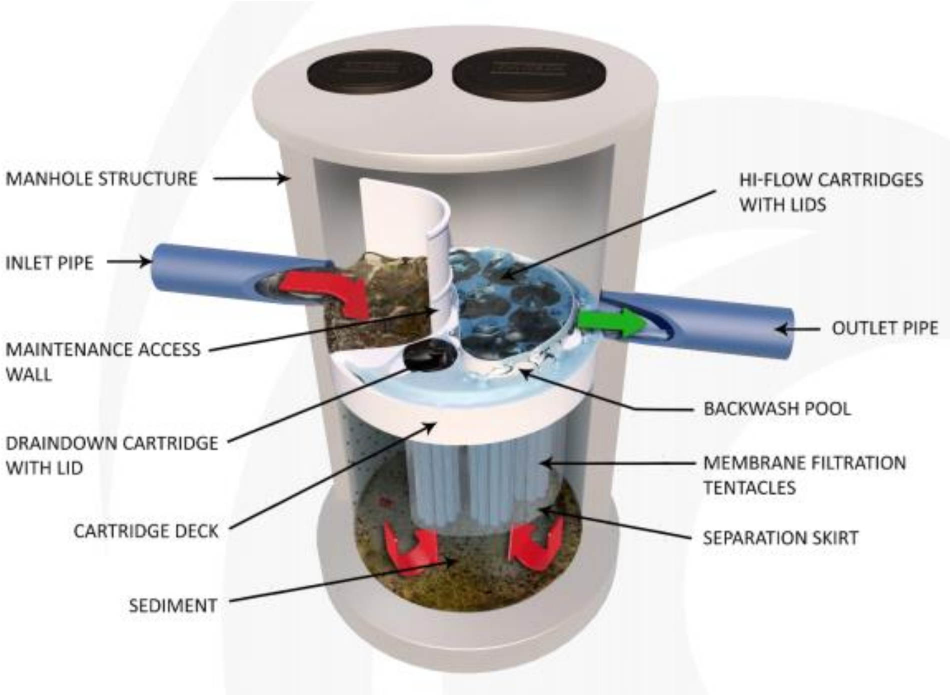


Figure 34 - Ocean Protects Jellyfish Design

4.2.2 Wetlands

The wetlands model required a longer detention time to deal with the total suspended solids and meet the minimum treatment requirements. The current model returned a 91% removal efficiency, for the annual 8.1ML water discharge, but fell 3% short. Increasing the surface area of the design from 600m^2 to 1100m^2 increased the detention time from 1.59 hours to 2.91 hours which would meet the removal requirement by achieving 95% as shown in Figure 35. This would also increase the phosphorous removal efficiency to 83% and the nitrogen removal efficiency close to 6%.

Increasing the wetland's surface area does also increase the initial construction cost by 27%, this however is still lower than the cost of sediment tank for best practice. The nitrogen removal and the phosphorous removal efficiency still do not meet the minimum requirement which will be discussed in their dedicated sections.

One other factor affecting the nutrient removal rates is that the software MUSIC did not considered any vegetation in the wetland design node. A combination of nodes had to be used in MUSIC for any vegetation to be considered, but this could also be a double edge sword were the second node is considered as a secondary treatment device. For this reason, only the wetlands node was considered and used in the design. Figure 35 also shows a reduction in water flow, this is due to evaporation rates once water has reached the wetlands treatment device.

Treatment Train Effec

(2) Wetlands : Treatment Train Effectiveness : Receiving 5

	Sources	Residual Load	% Reduction
Flow (ML/yr)	8.126	7.701	5.236
Total Suspended Solids (kg/yr)	1703	84.85	95.02
Total Phosphorus (kg/yr)	3.464	0.5764	83.36
Total Nitrogen (kg/yr)	23.4	9.787	58.18
Gross Pollutants (kg/yr)	171.3	0	100

Figure 35 - Wetlands MUSIC Results

4.2.3 Remaining Simulations

The remaining twelve simulations all met the minimum requirement of ninety-four percent removal efficiency with six of them achieving 96% or better. By providing a dedicated sediment area or tank area can make large contributions in settling solids. These tanks allow for extra detention time and have a low velocity discharge rate, so that the settling solids do not get disturbed from reaching settlement.

Alternatively, providing multiple treatment options also allows for better sediment removal as the effluent goes through different medias or filters that allow a secondary cleaning effect. This can be seen in Figure 36 from the multiple treatment options results, as the efficiency increased with longer treatment swales. The two treatments that reached 99% removal efficiency are the bioretention model with carbon in the filter media, and the multiple treatment option with a bioretention, no carbon in the media. The bioretention with carbon produces such a high removal efficiency due to the aid of the carbon in the media. The biggest concern with carbon is that it requires more monitoring of the effluent to know when the carbon is saturated, compared to other types of media.

The multiple treatment option uses multiple media filters, and as the name dictates, it reduces most of the pollution loading by providing a combination of shallow swales, with one percent fall, and detention time in the bioretention area. These devices all contain different removal rates for different pollutants and work together to achieve the best possible outcome. For a complete graph of all the model and their removal efficiencies, refer to Figure 36 below.

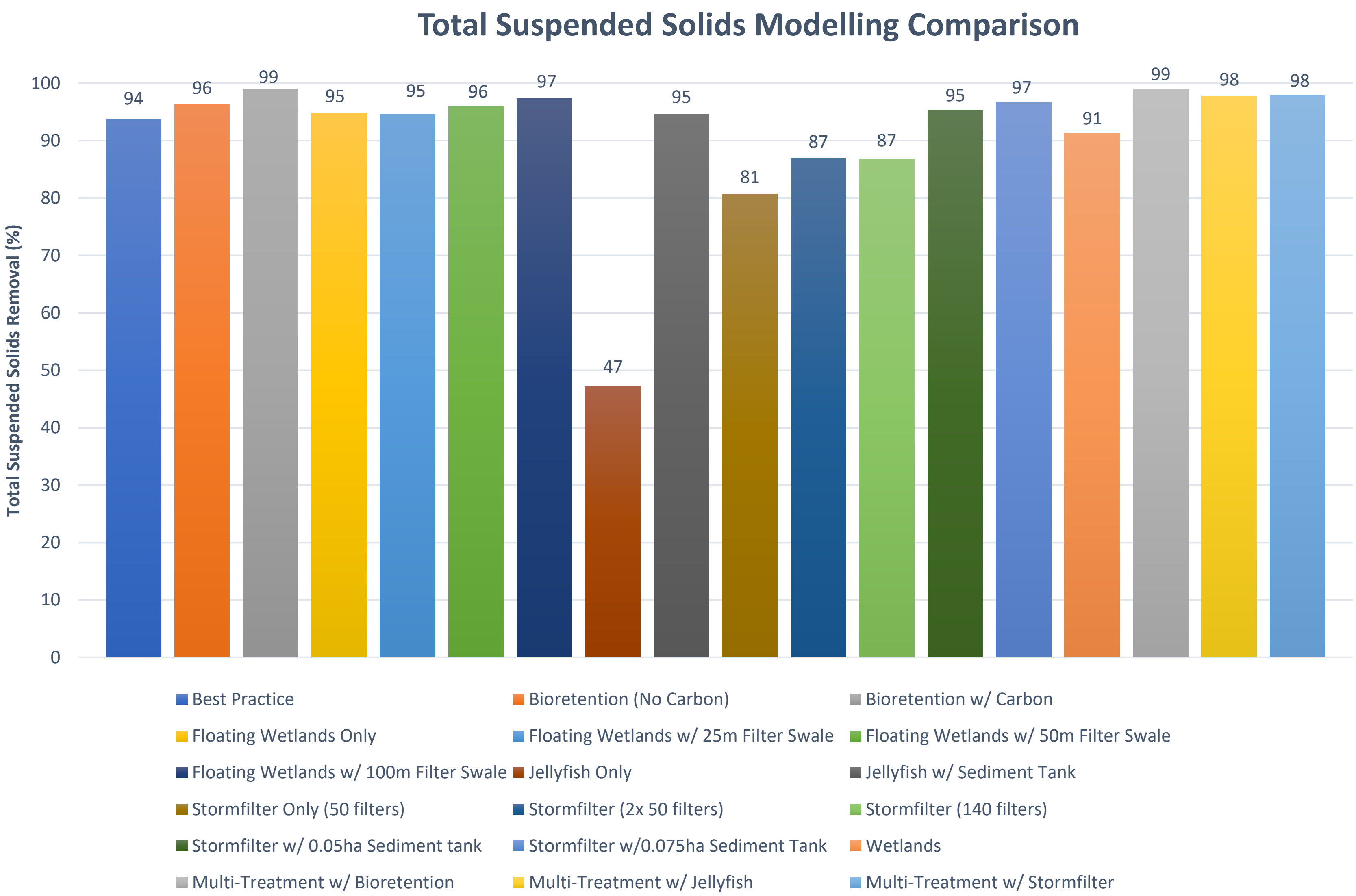


Figure 36 - TSS MUSIC Results

4.3 Total Nitrogen

One of the most abundant elements on earth is nitrogen. It comprises 78% of the earth's atmosphere. The are several complex processes involved in the nitrogen life cycle, including its conversion to gas. As previously mentioned, total nitrogen is the traces of all the sources of nitrogen that can be found within the effluent, such as ammonia, nitrate, nitrite and nitrogen that is organically bound.

It was found that the removal of total nitrogen from the best practice MUSIC model was questionably high, when compared to J.P. Palmer's report of 20% removal rate. This suggest that the MUSIC model's detention time is too high or that due to MUSIC only considering rainfall events, the program's algorithm is allowing for the effluent to be completely dried up in the tank before the next rainfall event. Further studies and more data are required on this model to make any further assumptions.

The current licenced discharge allowance for BIARC can found to be in the level of 1mg/L of effluent. This means that for a total assumed flow of 8.1ML per harvest season, a maximum allowance of 8.1kg would be discharged if the system were a flow through system, where water was to be discharged right after treatment. Based on the modelling results, the annual total nitrogen production was 24kg. This would mean that a minimum efficiency rate of 34% is required for the model to comply with BIARC licence requirements but compared to the best practice model simulation, the other models required a minimum of 69%. The modelling results are very different in range and in such have been broken down into three categories: low efficiency - models that did not comply with BIARC licence requirements, mid efficiency - models that do comply but produce lesser results than the best practice simulations, and high efficiency - models that achieve both.

4.3.1 Low Efficiency – Models that do not meet BIARC licence requirement

The only simulation model that falls in this category is the Jellyfish tank simulation. This could be due to the tank size and filter number as previously mentioned in section 4.2.1. A proprietary MUSIC treatment node file was provided by the manufacturer, Ocean Protect, and models were based on this treatment node. Due to the limitations of time and information, a generic node with a small tank and filter size was chosen, and as previously mentioned custom sizes were not taken into consideration for this dissertation. Had there been less limitations, a more suitable treatment node could be chosen and therefore produce different results. Jellyfish devices are dedicated to treat the first flush from stormwater runoff and therefore do not focus on removing large amounts of nutrient pollutions, but to remove the necessary amount required by councils. Jellyfish filters, like Stormfilter cartridges, can only handle a designed flow rate based on the filter size and therefore any flow extra flow goes over the weir and does not get treated. Table 5 shoes the flow capacities of the filters.

Table 5 - Jellyfish "Tentacle" Filter Performance

Hydraulic Loss (mm)	High Flow cartridge flow rate (L/s)	Drain Down cartridge flow rate (L/s)	Minimum hydraulic drop (mm)
460	5.0	2.5	150
230	2.5	1.25	150

Ocean Protect specification and laboratory testing demonstrate that a mean nitrogen removal efficiency for the Jellyfish filters is 50%. Since our model simulation produced results of 31%, it can be assumed that the treatment model has been under designed and therefore requires recalculations with the appropriate tank size to suit the required treatment area.

4.3.2 Mid Efficiency – Models that meet BIARC licence requirement but not best practice simulation

Six model simulations fall in this category where they under performed in comparison with the best practice model but have achieved BIARC license requirements. Those models are the Stormfilter simulations with different filter sizes, the Stormfilter with sediment tank, the Jellyfish with sediment tank, and the wetlands.

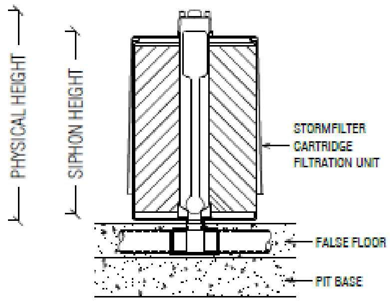
Proving the Jellyfish treatment device with a sediment tank prove to double the efficiency rate, and just fall under best practice efficiency by one percent. Again, this demonstrates that the Jellyfish treatment device chosen was undersize and providing a custom tank with set filters is required for large projects that produce high pollutants.

Mean nitrogen removal rates from Ocean Protects fielding testing are around 55%. Using a minimum of fifty filters, the removal efficiency was 49%, which demonstrates that the treatment is under performing according to the manufacturer' specifications. This could be due to most of the flow using the high bypass by not having the correct tank size. This assumption can be proved by comparing the Stormfilter (50 filters) model with Stormfilter with sediment tank (0.05ha) model. By adding the extra settling tank area, the nitrogen removal efficiency rises to 68% removal efficiency. Looking at the next model with an increased sediment tank, the removal rate increased again by 5%. The results revealed that the filter cartridges are not enough on their own due to their low flow rate capacity on the media PSorb, as can be seen in Figure 37. The possibility of using different media material can increase the flow rate and possibly produce higher nitrogen removal however, this was not investigated.

STORMFILTER DESIGN TABLE

- STORMFILTER TREATMENT CAPACITY VARIES BY NUMBER OF FILTER CARTRIDGES INSTALLED.
- THE STANDARD CONFIGURATION IS SHOWN. ACTUAL CONFIGURATION OF THE SPECIFIED STRUCTURE(S) PER CERTIFYING ENGINEER WILL BE SHOWN ON SUBMITTAL DRAWING(S).
- FILTER CARTRIDGES SHALL BE MEDIA-FILLED, PASSIVE, SIPHON ACTUATED, RADIAL FLOW, AND SELF-CLEANING. RADIAL MEDIA DEPTH SHALL BE 178mm.

CARTRIDGE NAME / SIPHON HEIGHT (mm)	690	460	310
CARTRIDGE PHYSICAL HEIGHT (mm)	840	600	600
TYPICAL WEIR HEIGHT [H] (mm)	920	690	540
CARTRIDGE FLOW RATE FOR ZPG MEDIA (L/s)	1.6	1.1	0.7
CARTRIDGE FLOW RATE FOR PSORB MEDIA (L/s)	0.9	0.46	0.39



STORMFILTER CARTRIDGE DETAIL

Figure 37 - Ocean Protect Stormfilter Design Table

Since there is no inclusion of vegetation in the wetland MUSIC treatment node, the removal of nutrients lies solely on the detention tank. The wetlands simulation performed 22% under the best practice scenario however, when these two are examined closely they contain the same parameters and thus the only different is the size of the surface area. As previously mentioned in section 4.2.2, increasing the surface area to $1100m^2$ would increase the removal efficiency and therefore would change the category to high efficiency.

The biggest downfall of this model is not providing an option to take vegetation into account as dedicated plants contain a high nutrient intake compared to allowing settlement. Whether it is a simple option in the form of a tick box like the bioretention, the efficiency rates would be predicted much higher for a smaller surface area, which is the aim of this dissertation.

4.3.3 High Efficiency – Models that meet both requirements

Referencing to Figure 38, the remaining ten models all performed above both requirements, which proved to be effective and acceptable treatment options as replacements for best practice methods. Amongst these ten models both the bioretention with carbon, and the multiple treatment train option with bioretention (no carbon), proved to be the highest efficient nitrogen removal with an efficiency rate of 95%. These two models are consistent with sediment removal as the best choice.

An interesting result presented in three simulations during the modelling. The scenarios involved are the SPEL wetlands only, and the remainder of the multiple treatment options. The SPEL wetlands produced an efficiency similar to multiple treatment options with both Jellyfish treatment and Stormfilter treatments at the end of the treatment train. The removal rate of the SPEL wetlands presented results of 85% nitrogen removal compared to 87% for both multiple treatments. The efficiency of the proprietary product demonstrates why the initial capital cost is the highest compared to other stormwater treatments.

Another interesting result in the nitrogen removal can be seen in Figure 38 between the SPEL wetlands model and the SPEL wetlands with swale filter. It was expected that the efficiency rate would increase with a longer filter swale however, the simulation models resulted in a decrease in removal rate. It is unknow how this result came about as the same parameters in the swale filters were used in all simulations that have them. This reduction only appears in the nitrogen removal as both the total suspended solids and total phosphorus demonstrate results as per the predictions. Further work and research are required to fully comprehend how the MUSIC treatment nodes interact with each other, and if there is a preferred sequence or order that they must be used in.

The bioretention (no carbon) model proved to be quite efficient too with a removal rate of 73%. The aid of vegetation with high nutrient intake proves to be a great factor in the modelling process when compared to the wetlands model, with an efficiency of 54%. Though desirable efficiency in the eighties is preferred, this factor can easily be improved by increasing the surface area, to allow for more media and vegetation.

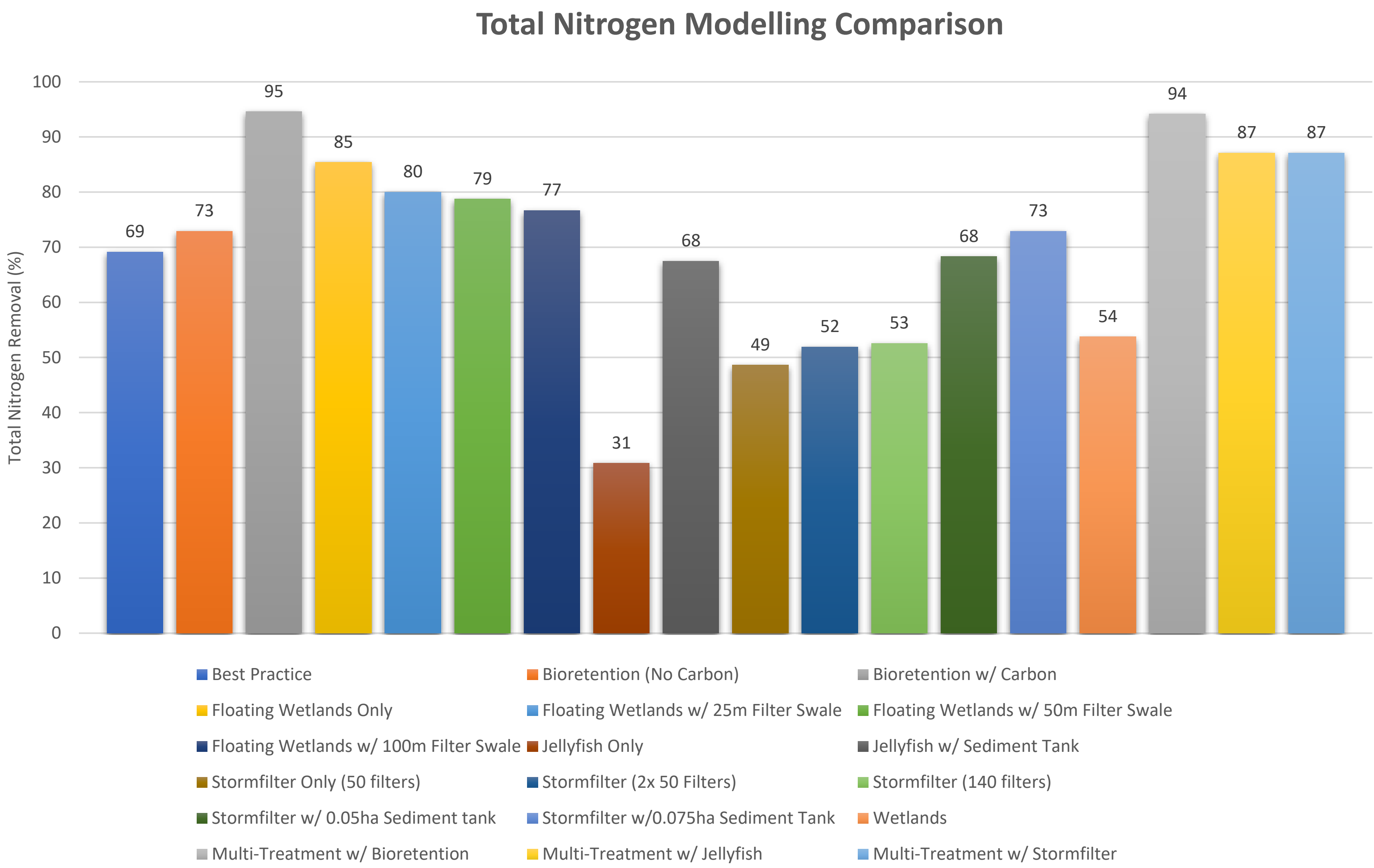


Figure 38 - TN MUSIC Results

4.4 Total Phosphorus

Phosphorous is a vital nutrient for growth in vegetation and animals because of its simple cellular structure. In contrast to nitrogen, phosphorus does not contain an atmospheric shape and it is susceptible to absorb to sediments. As previously mentioned, total phosphorous is the sum of all forms of phosphorous forms found in the water body. Scarcely found in fresh water, an abundance added to the ecosystem can lead to eutrophication.

Studies conducted by P.J. Palmers study concluded that total phosphorous removal was averaging around 66%. The modelling simulation for best practice presented removal efficiency results of 82%, for the total annual water flow of 8.1ML. BIARC allowable discharge for total phosphorous is the same as nitrogen at 1mg/L. Based on the water flow for the simulations, the annual or harvest season production of total phosphorous was found to be 3.4 kg. Comparing to a flow through system where the effluent would be discharged after the treatment, the minimum efficiency rate required is for treatment is 45%. As with the previous results of nitrogen, the Jellyfish simulation model did not reach the required removal rate in either scenario however, the Stormfilters produced a higher removal rate than anticipated.

The models have been broken down in 3 categories like the nitrogen results in section 4.3. These 3 categories are: low efficiency - models that did not comply with BIARC licence requirements, mid efficiency - models that do comply but produce lesser results than the best practice simulations, and high efficiency - models that achieve both.

4.4.1 Low Efficiency – Models that do not meet BIARC licence requirement

The single simulation model that is in this category is the Jellyfish tank simulation. This model does not meet BIARC discharge licence requirements or best practice. This could be due to the tank size and filter number as previously mentioned in section 4.2.1. Due to time restraints generic node with a small tank and filter size was chosen, and as previously mentioned custom sizes were not taken into consideration for this dissertation.

Field testing performance demonstrate that a mean total phosphorous removal efficiency for the Jellyfish filters is 55% and since the model simulation produced results of 35%, it can be assumed that the treatment model has been under designed and therefore requires recalculations with the appropriate tank size to suit the required treatment area.

4.4.2 Mid Efficiency – Models that meet BIARC licence requirement but not best practice simulation

There were eight models that fell into this category which were the bioretention (no carbon), the floating wetlands only, the floating wetlands with 25m and 50m swale strips, all the Stormfilter treatment models, and the wetlands. All the models in this category meet BIARC minimum discharge licence requirements.

The bioretention model without carbon produced a high efficiency of 71% removal for total phosphorous. Comparing to best practice model, the bioretention falls short in terms of efficiency. Some trial and error models were conducted to estimate the required size to achieve 81% efficiency, and after some calculations the required surface area is 1000m^2. For an 11% increase of treatment efficiency the surface area has increased by 80% which is not feasible, but it is still an option.

SPEL proprietary floating wetlands state that their model can remove up 95% of nutrient loading and so far, it was proving correct, except for this category. The removal efficiency of total phosphorous for the floating wetlands model returned at 71%, the same efficiency as the bioretention model, which is eleven percent shorter than best practice. Even with the aid of filter swales the treatment removal rate falls short at 79%. It was expected that the filter swales would not increase the efficiency by high amounts however, doubling the filter length from 25m to 50m only produce an increase of 3%, which was unexpected.

The Stormfilter structures produced better results at removal total phosphorus compared to total nitrogen. This is due to the media chosen, Psorb, a dedicated lightweight material suitably designed to remove phosphorus. Because of this the removal of total phosphorus of a single stormwater filter with fifty cartridges produced an efficiency of 72%. Doubling the number of Stormfilters, each tank with 50 filters each, had very minimal impact in the removal efficiency which only increased by 5%. Theoretically speaking, doubling the cartridge number should produce at least a 25% increase in efficiency but this was not the case. This leads to believe that the vault size is undersized and that the flow rate set in the model was too high. Alternatively, the third model with 140 cartridges in a single tank proved to produce the same efficiency result as the dual tanks. Field test results based on Ocean Protects data demonstrate an efficiency of 86% for Psorb media. This result is based on 11 rainfall events over a 20-month period in 2010.

The wetlands model falls just short with a 79% removal efficiency compared to the best practice model. Surprisingly, total suspended solids removal and total phosphorus are the only two areas that this model fell short. Though as previously stated increasing the surface area will produce better results while still maintaining the total treatment area required, smaller than the best practice sediment tank. It was previously mentioned that a surface of $1100m^2$ would provide the required removal efficiency, and this will also work for total phosphorus removal.

4.4.3 High Efficiency – Models that meet both requirements

The top result is the bioretention (with carbon) model with an efficiency of 94%. The aid of the carbon material really does help in removing pollution and should be considered against maintenance and material cost. There is a 24% difference in the bioretention models when adding carbon to the media versus not using it.

All the multi treatment options have achieved higher than 88% efficiency for total phosphorus, which is the same result for total nitrogen, and this is expected as the aim was to increase removal rates by combining different treatment devices.

The manufactured stormwater treatment models all performed high rates too when a dedicated sediment tank was added, especially Ocean Protect Jellyfish. This model doubled the efficiency from low to high at 82% removal rate, which again proves that the tank or space used in the MUSIC model is well undersized for the pond sizes. The Stormfilters on the other hand, did not received such a large boost by providing a dedicated sediment tank. There was an 11% increased for a sediment tank of $500m^2$ and 20% increase for the sediment tank of $750m^2$ in surface area. This reveals that the tank size does have a big effect on the removal of total phosphorus as most of the work is being conducted by the filter media.

Compared to P.J. Palmers research the highest removal of total phosphorous in that research was 68% which is below all the models in this dissertation except for the Jellyfish model.

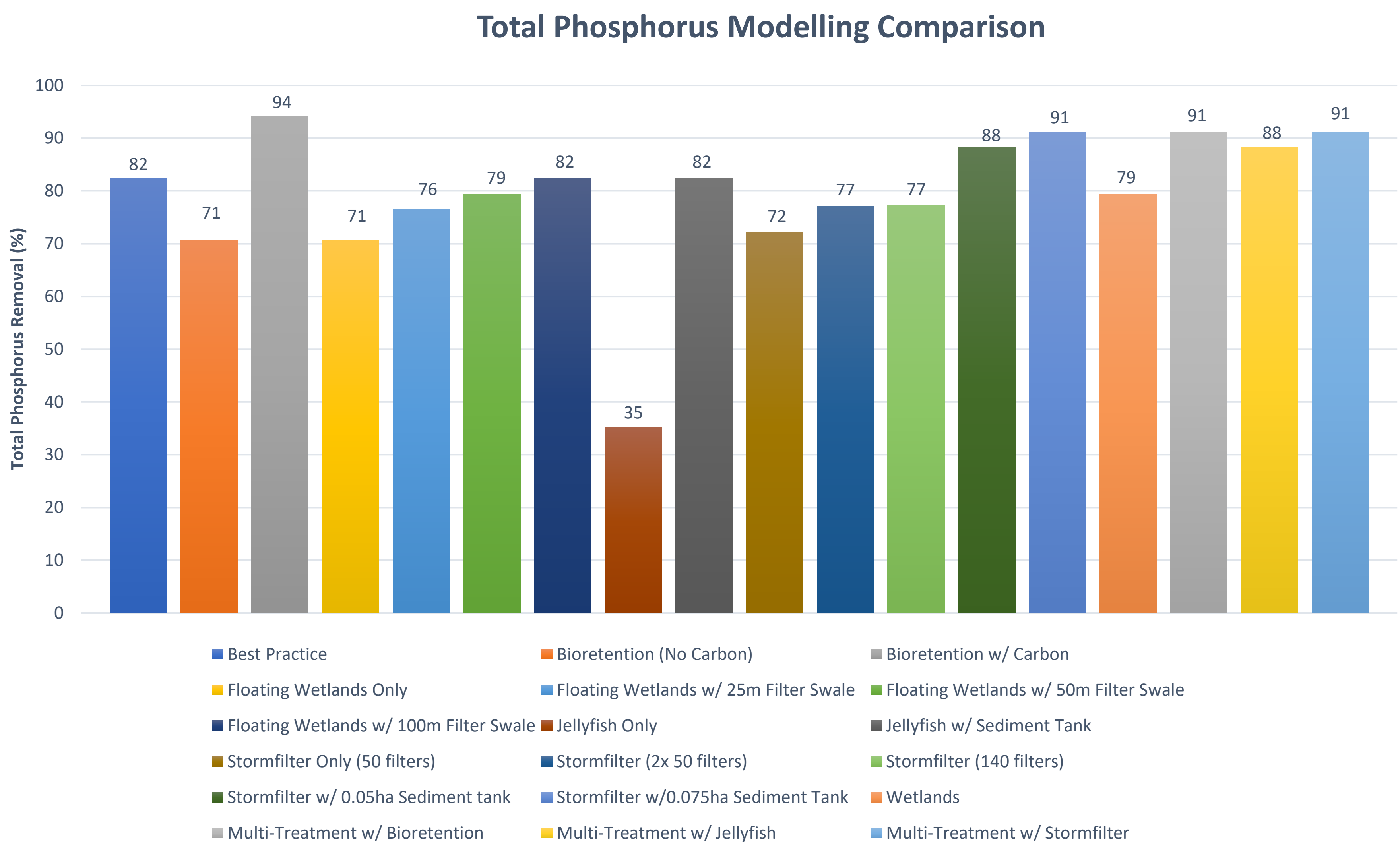


Figure 39 - TP MUSIC Results

5.0 Conclusions

This dissertation successfully presents the objectives and aims set out at the start of the research project, through research and model simulations. In order to determine the efficiency of urban stormwater devices in aquaculture effluent, several simulation models were created through the software MUSIC. These models were designed with the aim to increase the efficiency and reduce the footprint of current best practice treatment methods. Several stormwater devices were researched to be trial in these simulations along from the 2 biggest manufacturers' in stormwater management, Ocean Protect and SPEL Stormwater.

The summarizing outcome of the results yield that urban stormwater methodologies produce a high pollutant removal efficiency and are feasible in treatment prawn farm effluent in Queensland. Manufacture stormwater devices by Ocean Protect were not a feasible option due to their cost for providing similar efficiency results as other stormwater methodologies. SPEL's proprietary floating wetlands proved to be an efficient method of treating effluent nutrients but were the most expensive form of treatment available. SPEL's floating wetland should only be used when land constraints are a big factor.

The most acceptable option for a replacement of best practice methods is a bioretention with or without carbon filter media. The surface area of the bioretention will be bigger if no carbon media is used, but the maintenance cost will be lower and with fewer occurrences. The building footprint is 79% smaller than best practice methods, using a total surface area of 400 m^2. The construction cost of the bioretention were only 1.5 times the assumed cost of best practise methods, with an average price of $280, 000.

Comparisons of total suspended solids, total nitrogen, total phosphorus, and gross pollutants were completed in the results section. While most of the devices performed somewhat as anticipated there were some minor results that were inexplicable. These areas need to be further research to understand why the presented results did not performed as expected, and how MUSIC treatments node's parameters and placement affect the results.

Based on all 4 categories the results presented the best single treatment device as the bioretention with no carbon media, which proved to be the most reasonable choice while achieving results for TSS, TN, TP, GP of 99%, 95%, 94%, and 100%. While the best multiple treatment option demonstrated to be the treatment train with a bioretention. The removal efficiencies for the multiple treatment train achieved 99%, 94%, 91%, and 100% for TSS, TN, TP, and GP, which are very similar to the single bioretention with carbon filter. If no carbon is to be utilized, then the model of the bioretention still proved to achieved high results in 3 of the 4 categories. The TN efficiency was one of the better efficiencies from a single treatment device.

A cost analysis for average construction cost of the systems was completed. It was found that the wetlands surface area presented as the most inexpensive solution followed by the Jellyfish treatment device. Though the Jellyfish structure was undersized, and the appropriate size structure is expected to be double in expense and therefore cost more than best practice methods. The Stormfilter vault with 50 cartridges resulted in very similar pricing to the best practice sediment tank while dual tanks or using a single tank with 140 filter cartridges was not a feasible option. One of the best methods proved to be the most expensive as well, and therefore the SPEL floating wetlands may not be justified with their construction cost of 2.5 times of that of best practice. Multiple train options were not feasible as these models used the floating wetlands as their main pollutant removal.

5.2 Further Work

Throughout this dissertation, many opportunities for further research and analysis has been recognized. Some of the limitations of this research project are:

- MUSIC algorithm bases flow and pollution on rainfall events rather than a flow rate.
- Stormwater structures and filter media untested for continuous flow.
- BIARC RAS system parameters and nutrient removals rates.

Other minor limitations include accurate construction and maintenance costing, field or laboratory testing of stormwater structures with aquaculture effluent, and more pollutant concentration data over several harvest seasons. Though best practise was stablished in Queensland in 2002 for prawn farm effluent, these regulations have not been reviewed in the last 18 years. Stormwater management is still an emerging technology in Australia and around the world, as this area was not specialised until later in the 20th century.

Further studies are recommended to be undertaken into the removal effectiveness of stormwater treatment devices with aquaculture effluent, to see if modelling results produced in MUSIC yield similar efficiencies to laboratory testing. Alternative field testing is also recommended to be conducted to view how climate affects the results and how much impact the evaporation would have in the system. It is anticipated that a vegetated bioretention will perform well in terms of nutrient removal in an aquaculture system due to the usage of plants and media, for removal.

Further areas of study could involve other types of aquaculture marine life like barramundi or grey mullet fish. It is expected that effluent concentrations are very similar to prawn farm effluent, and therefore the removal efficiencies should yield very similar results. As this dissertation is based on a theoretical model of the effluent removal efficiencies, several case studies and further research into MUSIC treatments nodes and their parameters should be undertaken.

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A Appendix A

ENG4111/4112 Research Project

Project Specification

For: Manuel Flores

Title: Applying Urban Stormwater Methodologies to Aquaculture Discharge Water

Major: Civil Engineering

Supervisor: Dr. Antoine Trzcinski

Enrolment: ENG4111 – EXT S1,2020

ENG4112 – EXT S2, 2020

Project Aim: To verify if stormwater methodologies can be beneficial and feasible to aquaculture by reducing the size of nutrient settling area.

Programme: Version 1, 25.03.2020

1. Identify and evaluate the key nutrients in aquaculture farm, specifically in prawn and barramundi farms.
2. Identify current aquaculture best practises and standards for nutrient removal.
3. Identify any key system variables and the influence they have within the system and settling areas.
4. Analyse the data obtained, research and identify which urban methodologies would be best suited.
5. Identify capital and operating costs of chosen methods as one of the key indicators in the evaluation of the system.
6. Design multiple models based on single and combination methods of urban stormwater methodologies using MUSIC modelling.
7. Analyse and compare the designed system against existing applied best practice of aquaculture design principles.

B Appendix B

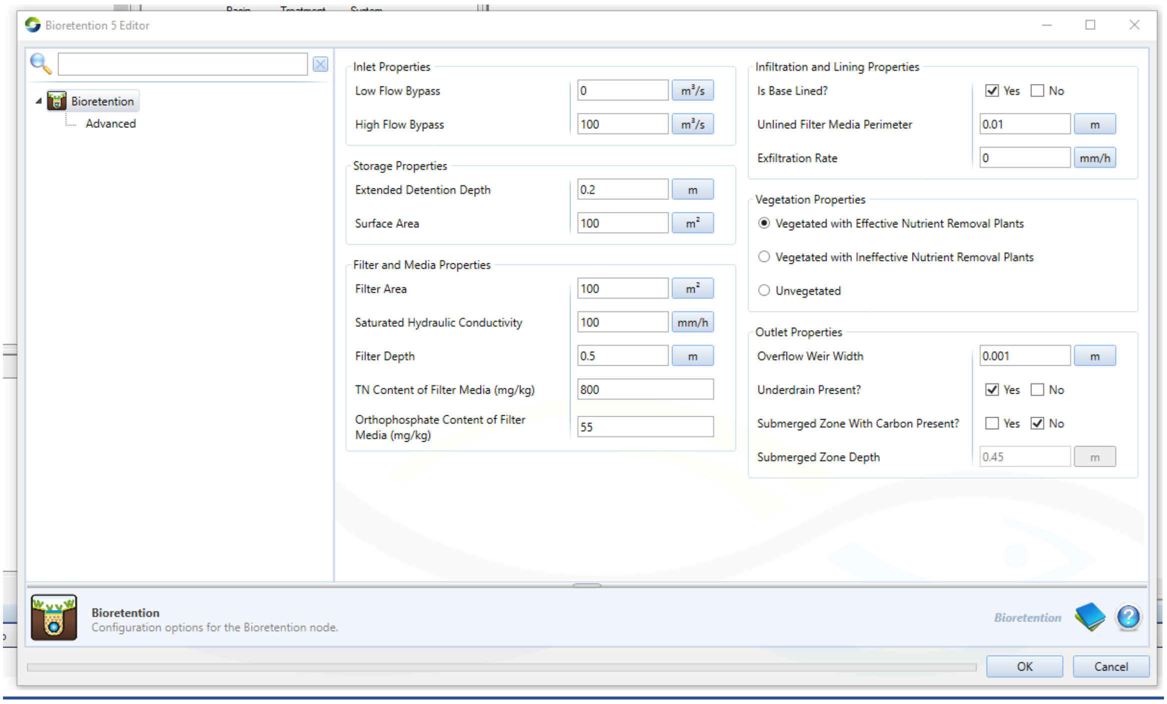

Figure B-1 - MUSIC Inputs for Bioretention (No Carbon)

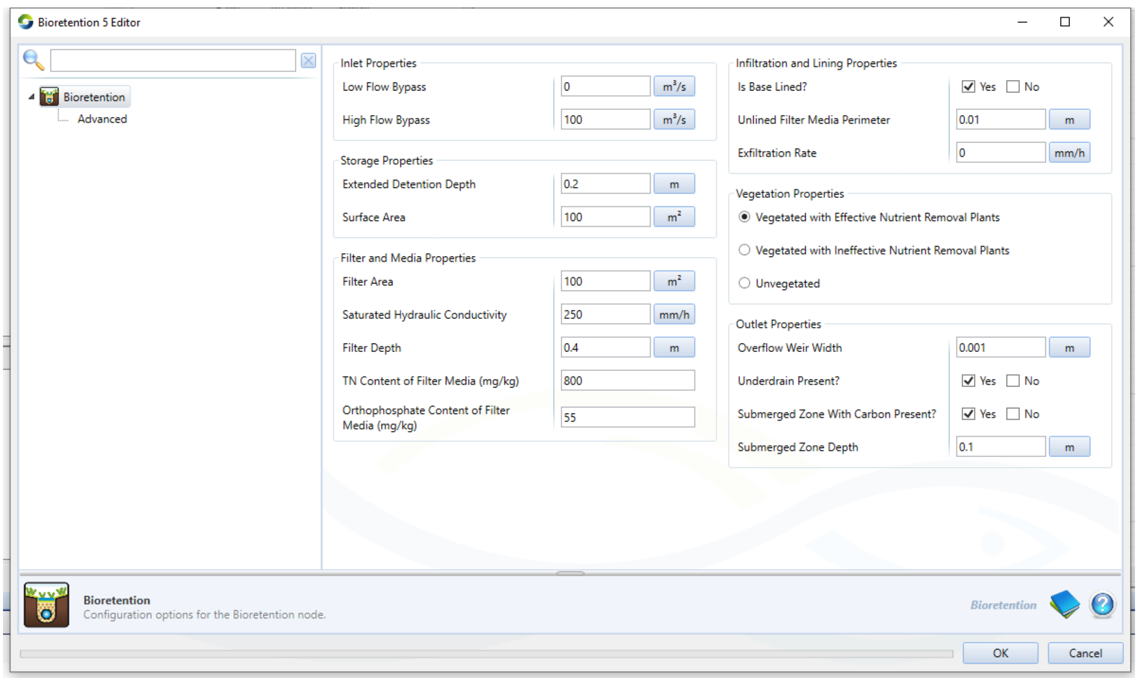

Figure B-2 - MUSIC Inputs for Bioretention with Carbon Option

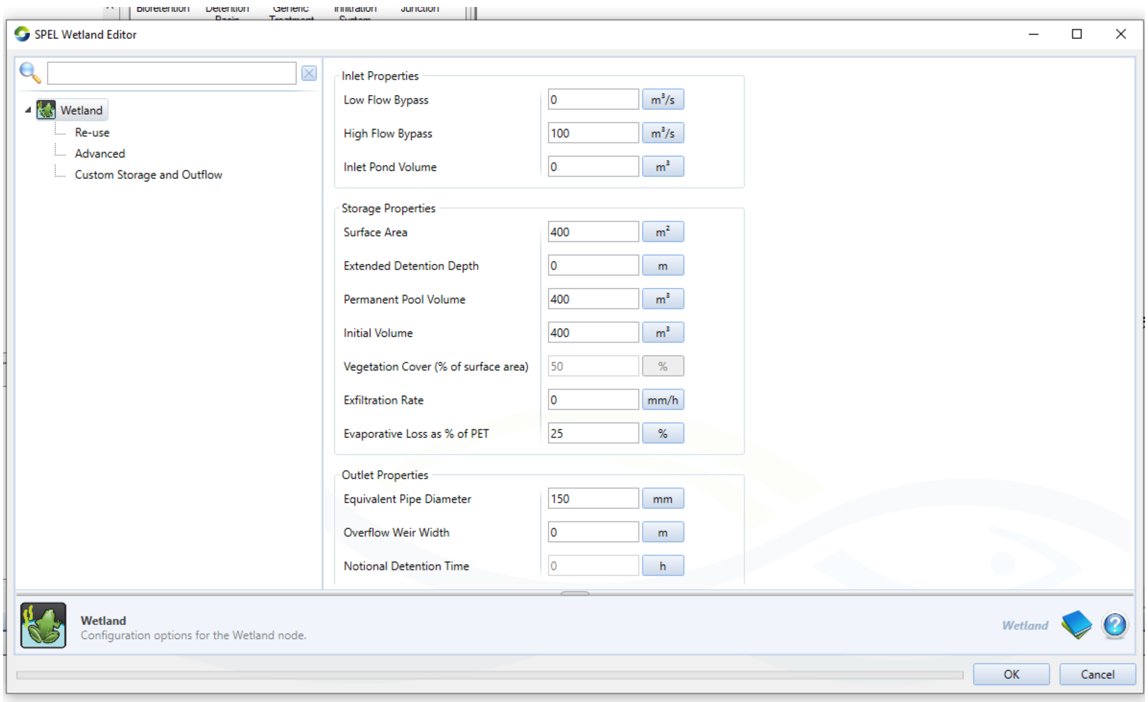

Figure B-3 - SPEL Wetland 1st Node MUSIC Inputs

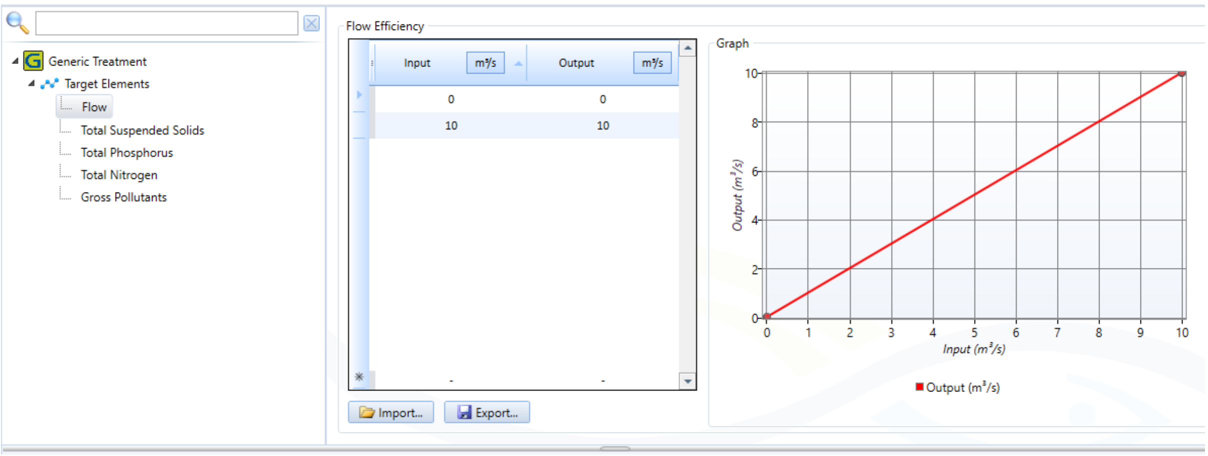

Figure B-4 - Generic 2nd Node Flow Input

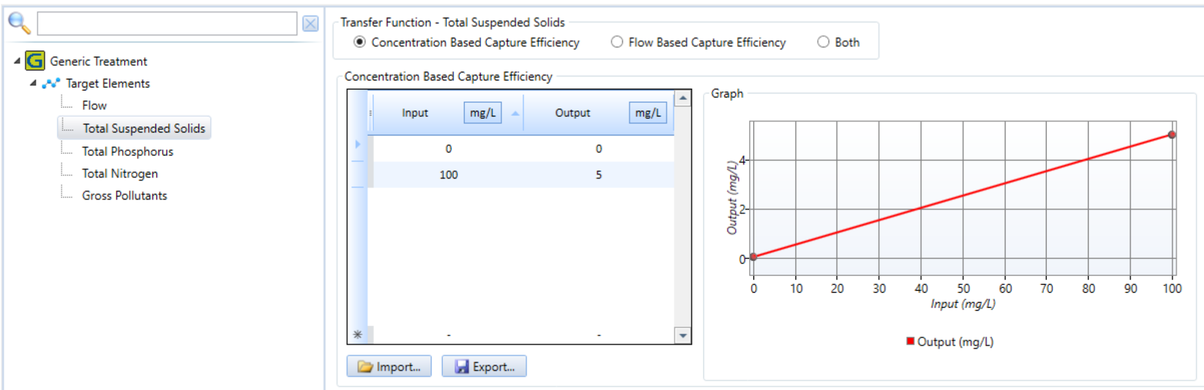

Figure B-5 - Generic 2nd Node TSS Input

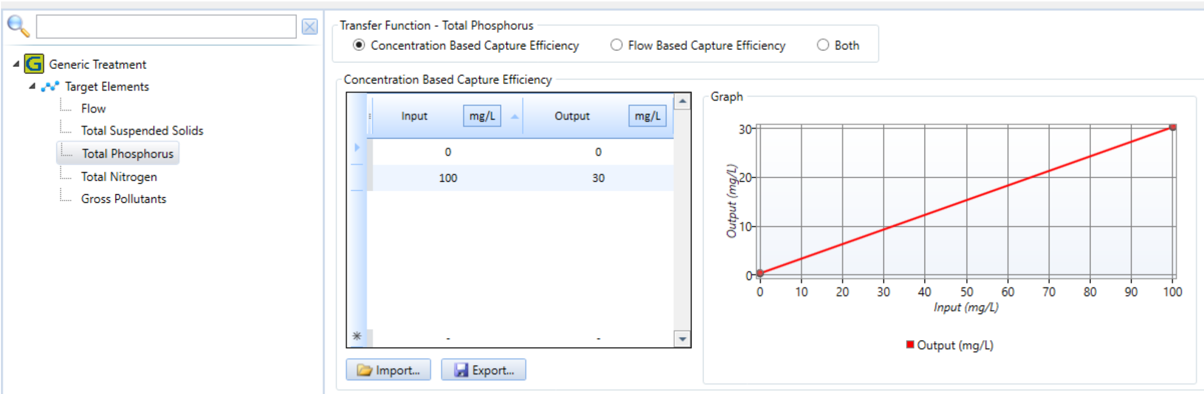

Figure B-6 - Generic 2nd Node TP Input

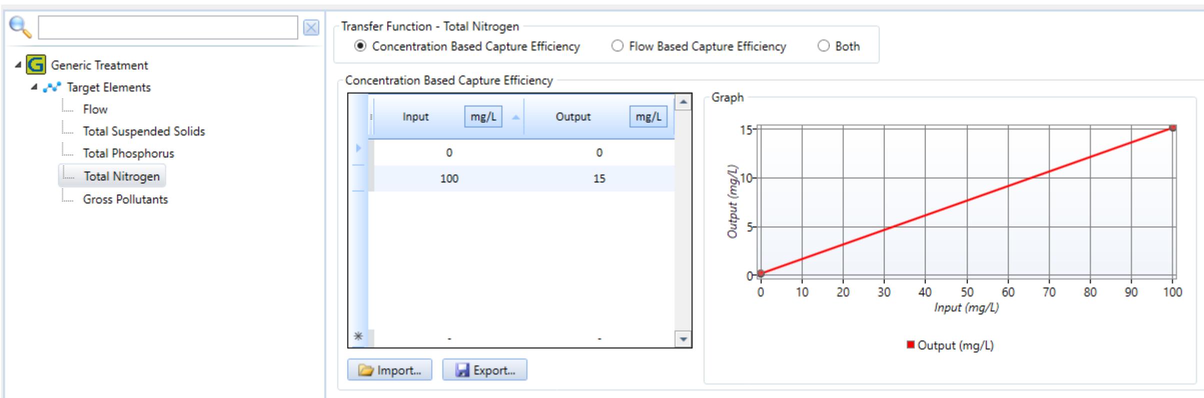

Figure B-7 - Generic 2nd Node TN Input

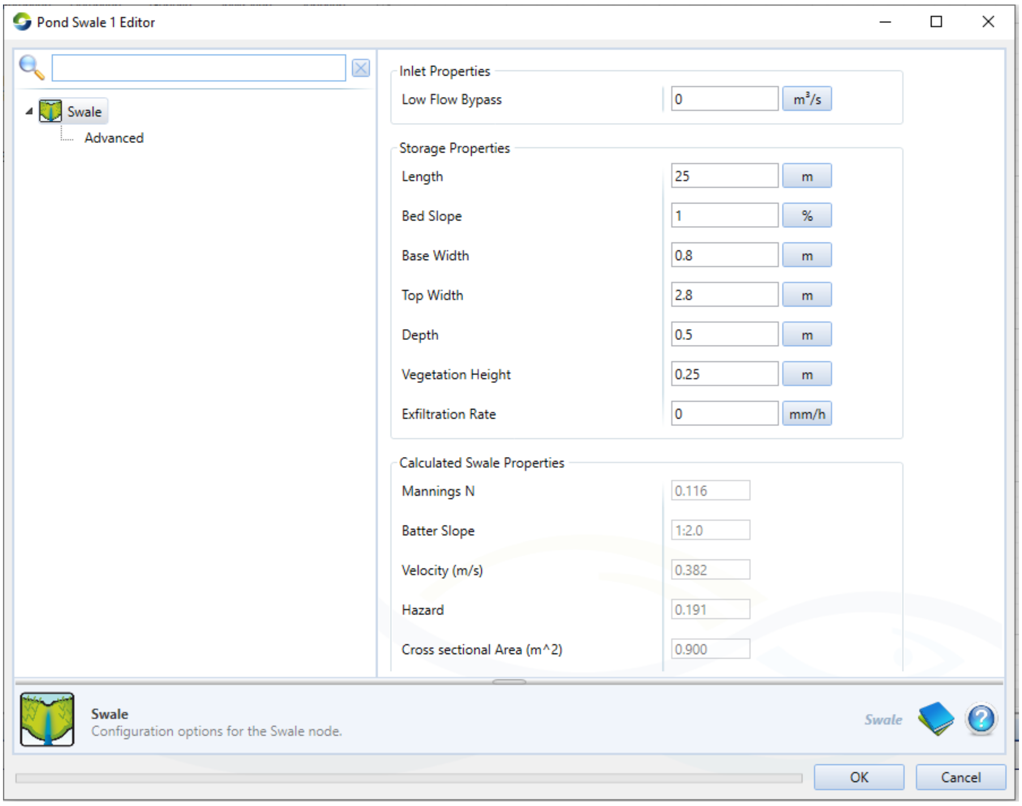

Figure B-8 - Filter Swale Inputs 1 of 2

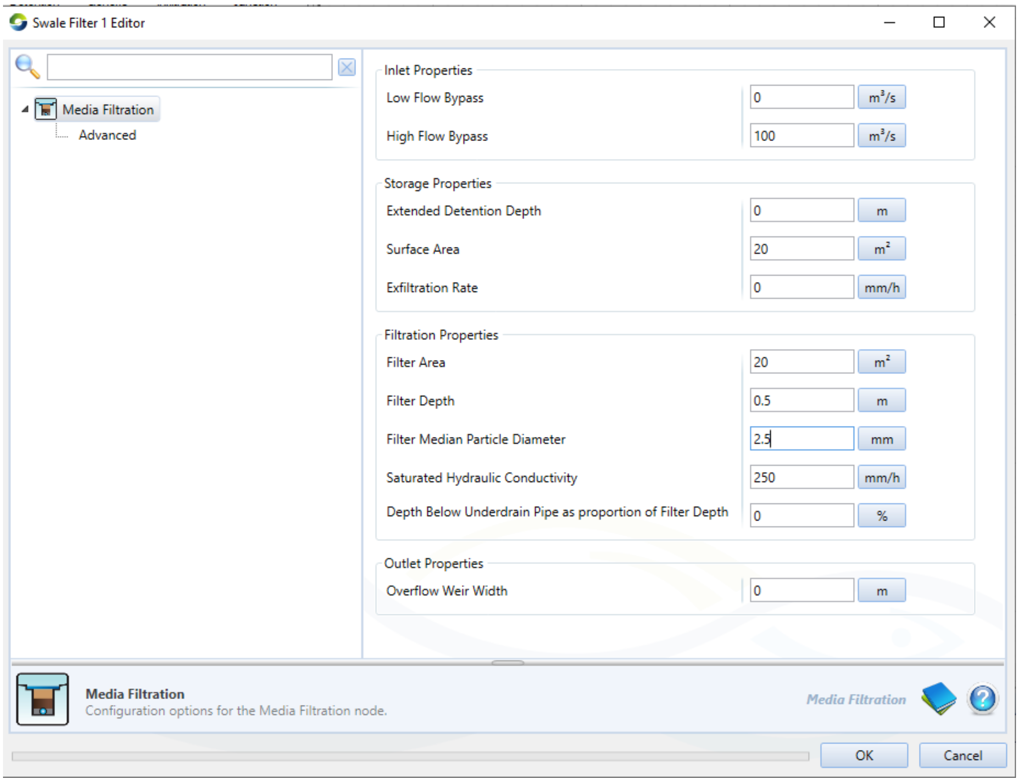

Figure B-9 - Filter Swale Inputs 2 of 2

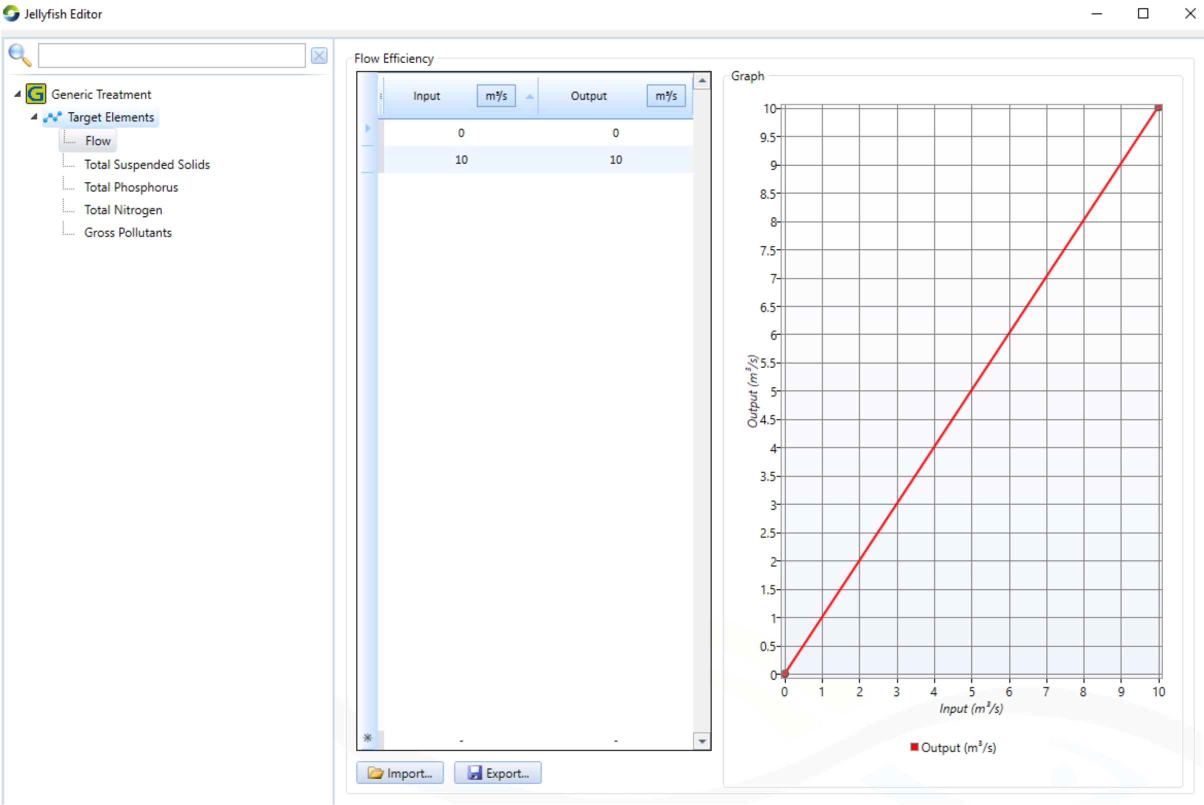

Figure B-10 - Jellyfish Flow Input

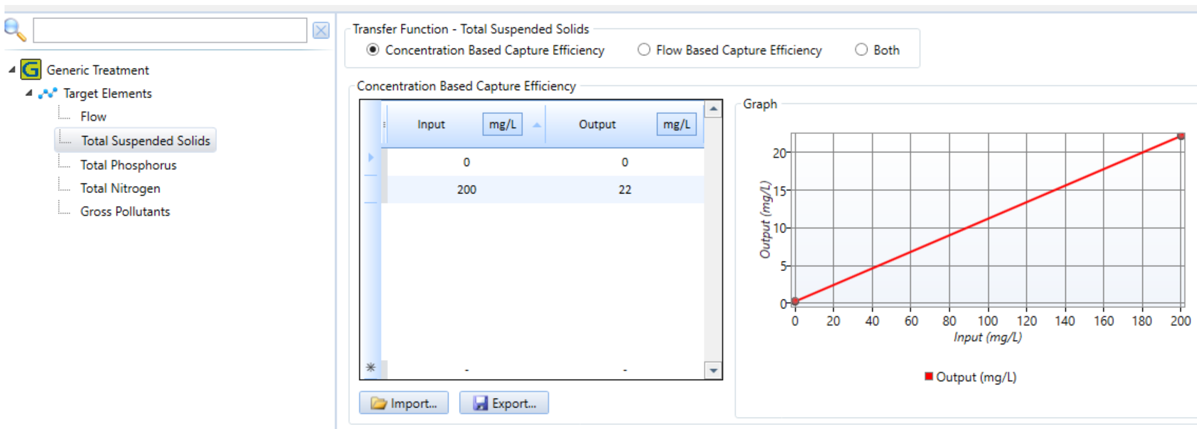

Figure B-11 - Jellyfish TSS Input

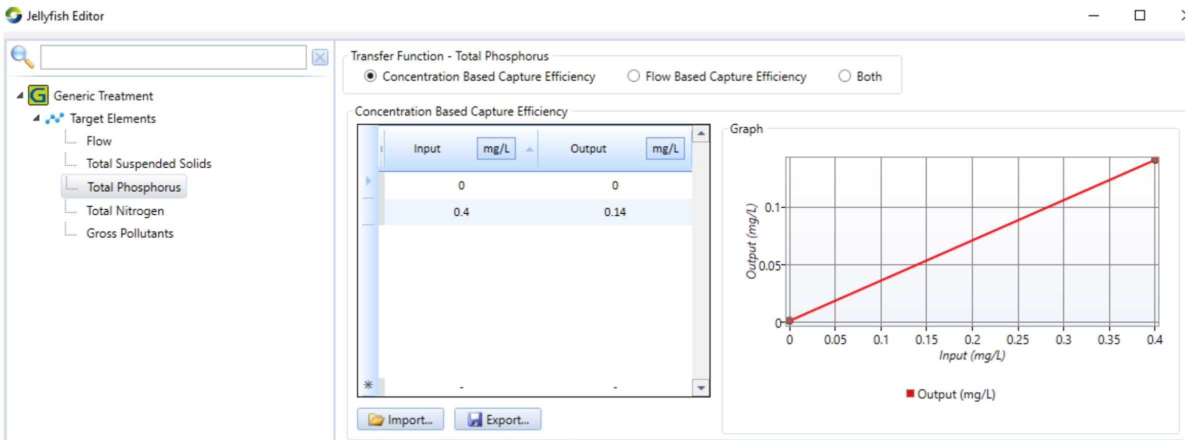

Figure B-12 - Jellyfish TP Input

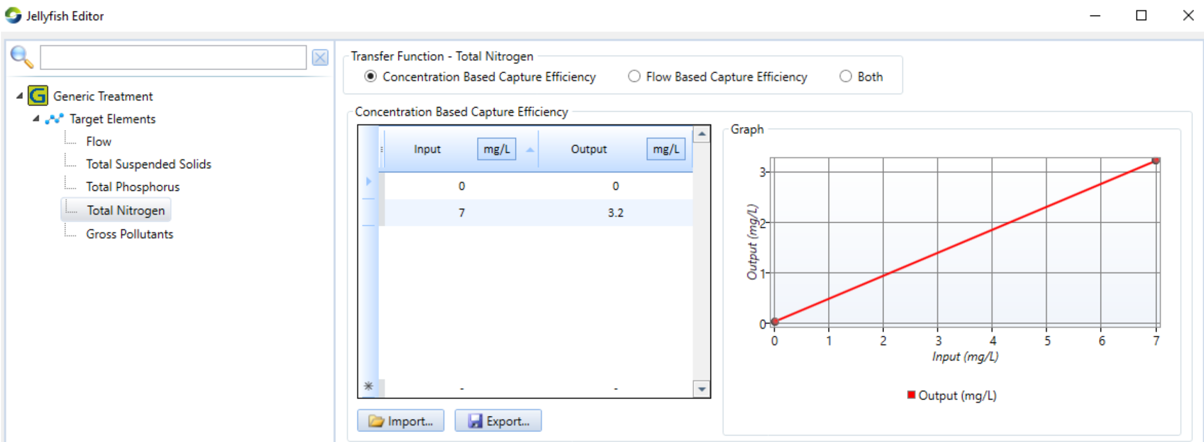

Figure B-13 - Jellyfish TN Input

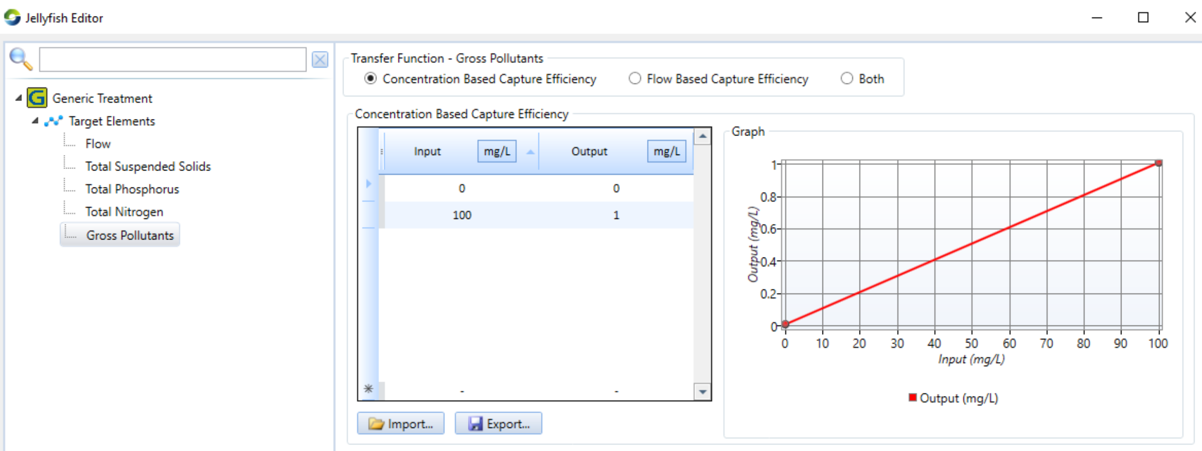

Figure B-14 - Jellyfish Gross Pollutant Input

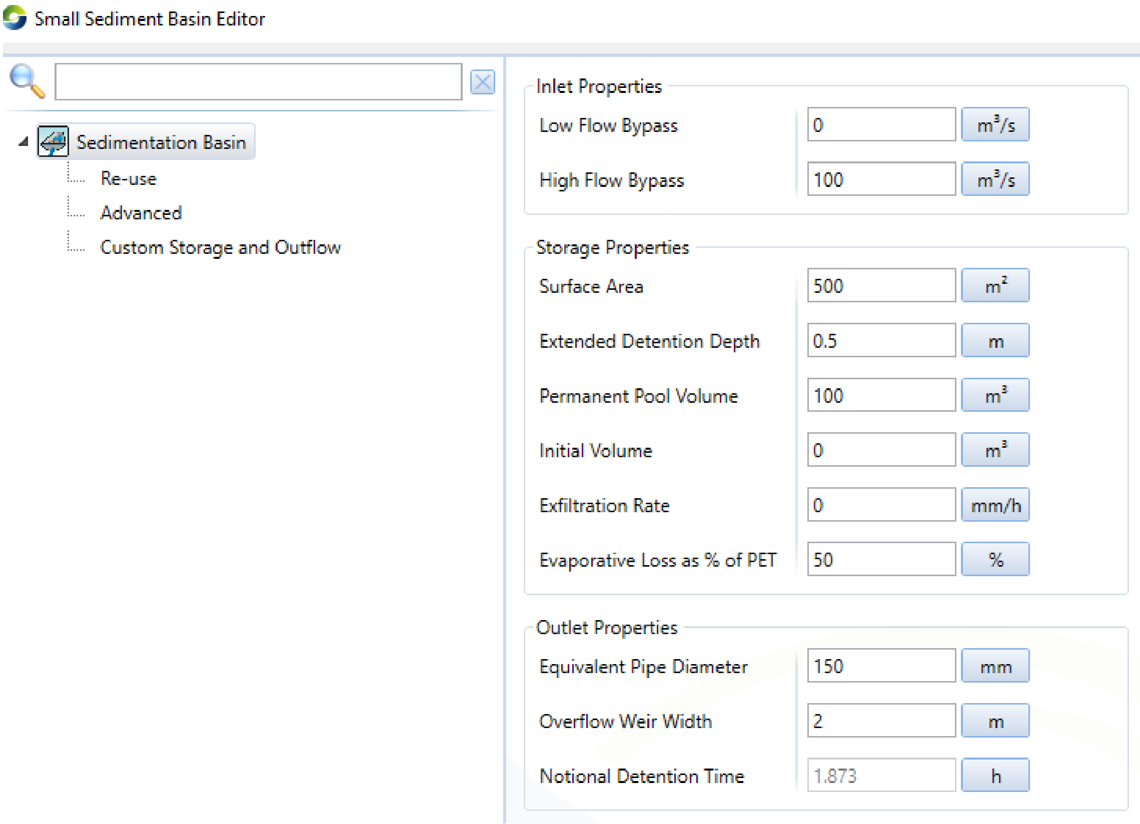

Figure B-15 - Sediment Tank for Jellyfish Inputs

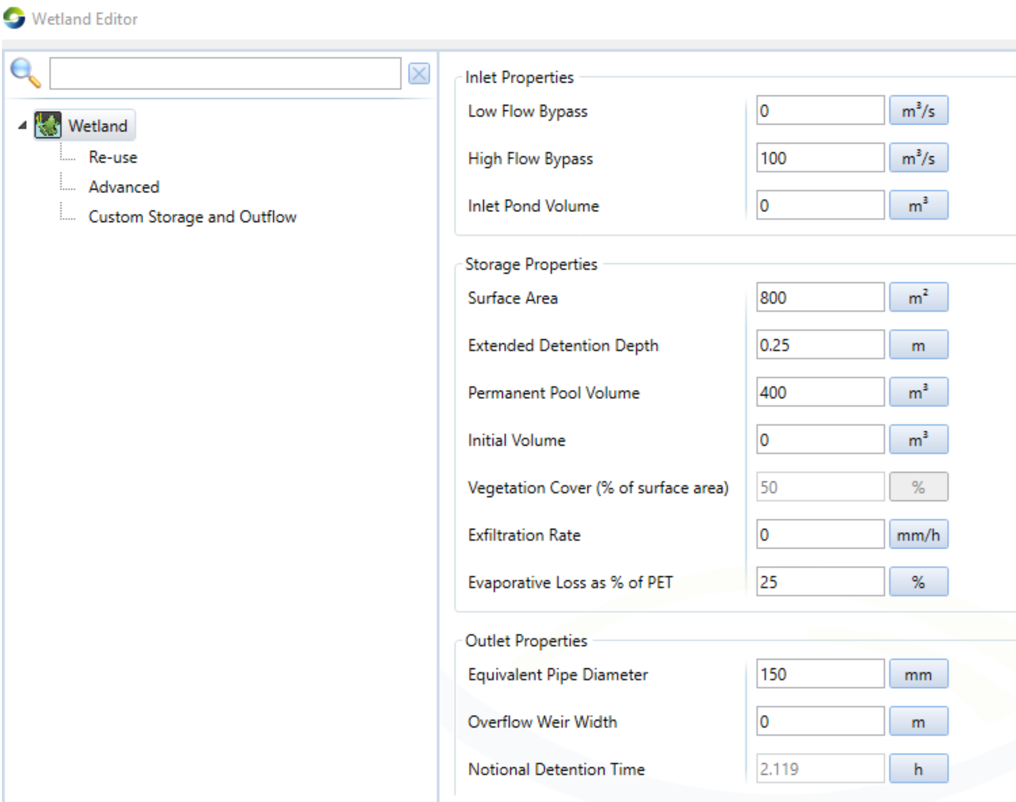

Figure B-16 - Wetland Inputs in MUSIC

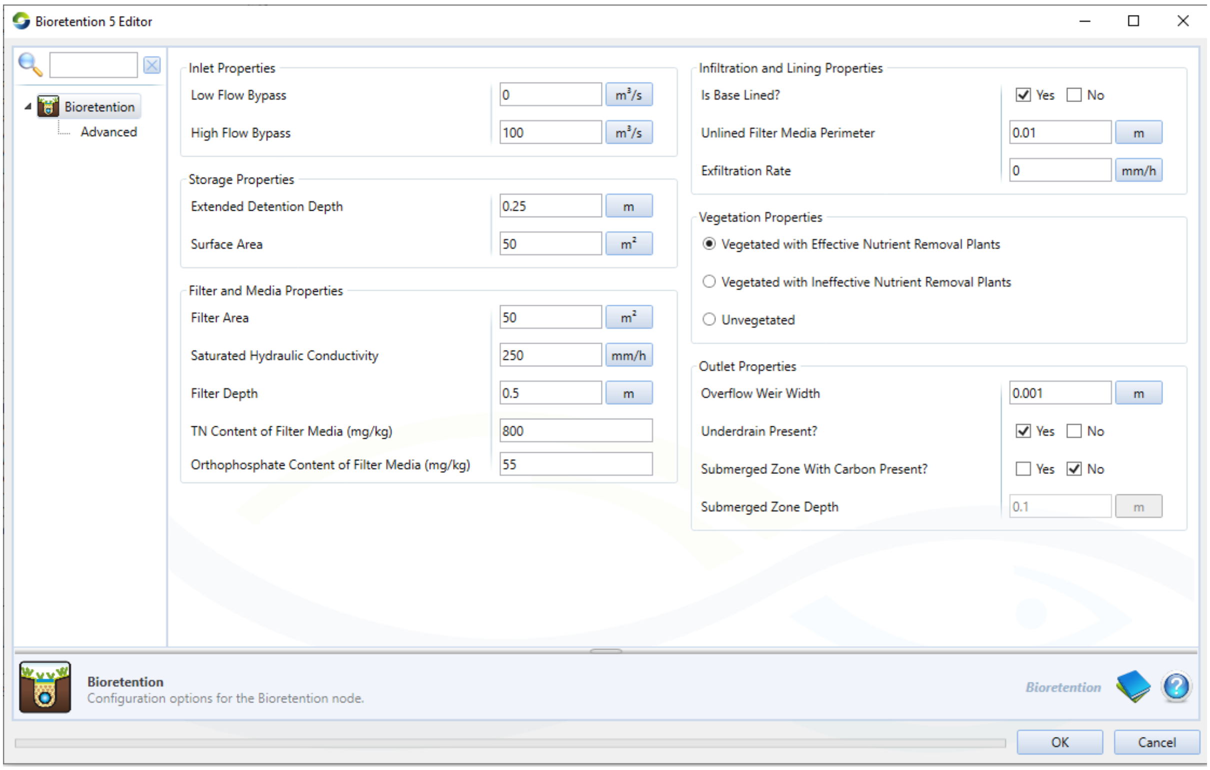

Figure B-17 - Multi-Treatment Bioretention MUSIC Inputs