University of Southern Queensland
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USE OF BIOCHAR GEOSTRUCTURES FOR URBAN STORMWATER WATER CLEANUP

A dissertation submitted by

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Abstract

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Introduction
Stormwater runoff from urban catchment areas is a leading contributor to water quality pollution which can result in limitations on urban development. Engineering systems used for the treatment of stormwater runoff, use in most cases, non-renewable resources. Biochar or charcoal is a renewable resource and is being investigated as a filtration media for stormwater cleanup.

Background
Currently engineering systems are available to control the volume of runoff after a storm event from urban catchments and influence the runoff water quality. In these engineered systems the water is not only slowed down, but also, physical, chemical and microbial processes are utilized for the removal of unwanted contaminants. An organic medium being researched for the use of stormwater cleanup is Biochar. Biochar is a form of charcoal produced through the thermochemical conversion of organic materials or biomass. The biomass remaining after pyrolysis is a fine-grained, highly porous material which gives the material large amounts of surface area resulting in a highly adsorbent material.

Methodology
The use of Biochar for improving stormwater water quality has been growing worldwide with product developers and researchers working to prove, advance science and markets of this emerging material. This thesis has been compiled using research material collated from various sources which provides insight into the use of Biochar geostructures for urban stormwater cleanup. Collectively, the material contained within this thesis represents research already undertaken by other parties; however it will provide information on emerging technologies using biochar.

Key Outcomes
Initial trials using biochar as a medium for improving stormwater quality for urban runoff has provided positive results. Additional research is required to determine cost effective, easy maintainable and to monitor performance versus economic considerations for the use of biochar geostructures. Research using enzyme additives to improve biochar performance is emerging.

Further Work
The next stage is the use of biochar as a medium for different geostructures for urban stormwater water cleanup and record the results of the reduction of heavy metals, herbicides and organics in stormwater.

Conclusions
The use of Biochar for improving stormwater water quality in urban catchments is in its infancy for practical testing. The different biomass used to create Biohar has an effect on its performance for improving stormwater runoff quality. Research is continuing to evolve to determine whether enzymes can be used to improve the performance of Biochar.

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Limitations of Use

Prof. Frank Bullen
Dean
Faculty of Engineering and Surveying

Certification

I certify that the ideas, designs and experimental work, results, analyses 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.

Giuseppe Rizzo
0050078473

Signature

29 October 2015
Date

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1. Introduction

Urban development increases the diversity and amount of pollutants discharged into Australia's natural water bodies. In urban and suburban areas, most of the land surface is covered impervious areas such as buildings, pavement and compacted landscapes with impaired drainage systems. These surfaces do not allow rainfall runoff to penetrate into the ground which results in an increase in volume and velocity of stormwater runoff. In addition, pollutants from urban runoff include heavy metals, herbicides and organics which can have a devastating effect on natural water bodies and ecosystems located downstream. These pollutants can harm fish and wildlife populations, kill native vegetation, result in foul drinking water, and make recreational areas unsafe and unpleasant.

Development leads to an increase in the amount of pollutants which emulate from an urban area. Sediment from construction sites can end up in streams and rivers, choking plant and animal life. Oil, grease and toxic chemicals from vehicles can leak onto roads and parking lots which wash into stormwater infrastructure during rain events. Viruses, bacteria and nutrients from pet waste and failing septic systems, can enter storm drains that discharge into wetlands, streams, or rivers. Fertilizers and pesticides, if not applied properly, can wash off lawns. Pesticides are often found in higher concentrations in urban areas than in agricultural areas (USGS, 1995). Household cleaning products and heavy metals from roofs can wash into stormwater systems if not disposed of properly. Many pollutants also bind to the sediment, so when sediment washes away it takes the pollutants with it. All of these pollutants can wash away when it rains and end up in streams, rivers, lakes, estuaries, or ground water.

Best management practices and engineering systems have been developed over the years to mitigate the negative impacts of stormwater runoff from urban catchments. However many are based on volume control such as detention systems (Kumar et al. 2012; Lloyd et al. 2002) where the main function is to separate suspended solids. Also, as runoff does not infiltrate into the ground and may leave the watershed, reduction in recharge of groundwater can occur (Birch et al. 2005; Datry et al. 2003; Dierkes et al. 2006). In most cases, detention systems occupy large areas which are not practical in all circumstances and do not address the wide range of contaminants which are present in stormwater runoff. As such engineering systems have resulted in filtration systems being implemented in detention systems to improve stormwater runoff quality which can separate total suspended solids (TSS) as well as removing contaminants from surface runoff. Filtration materials should be readily available, easily replaceable and inexpensive (McArdle et al. 2011; Reddy 2013).

Several studies have focused on the various potential of using biochar as a filtration material for urban stormwater cleanup. Biochar is a charcoal like product resulting from the thermochemical conversion of organic materials or biomass in an oxygen limited environment in a process called pyrolysis. Biochar's pores give the material extraordinary amounts of surface area, often exceeding 400 m2/g. This surface area makes biochar a highly adsorbent material. Biochar's incredible porosity and surface area provides biochar with a high capacity to adsorb a wide variety of contaminants from water. Worldwide research into the use of biochar as a filtration medium shows that biochar can effectively reduce contaminants including heavy metals, organics, chemical and oxygen demand (COD and

BOD), nutrients and totals suspended solids (TSS) from stormwater discharge from urban environments.

In stormwater, pollutant capture research into biochar geostructures are constantly evolving and being tested for their effectiveness and viability. Used on its own, mixed with other components, and/or amending biochar using enzyme additives, applications using biochar for the filtration of stormwater include; biochar filtration media in roof downpipe units used in above ground vaults; replacement media in existing treatment systems such as sand filters; direct application in bioretention or swale systems; filtration socks and slings; and filters in basins.

1.1 Study Aims

The main aim of this study is to investigate the use of biochar geostructures as a filtration media for urban stormwater runoff; including the latest research into emerging techniques and practices using biochar to improve stormwater runoff quality.

1.2 Study Objectives

The need for renewable resources to be implemented in engineering solutions in conjunction with the positive effect on both soil structure and microbial habitat, conducting research into the use of biochar geostructures to improve urban stormwater runoff was the objective of this study.

It has also been determined that different biochar produced, depending on originating biomasses, pyrolysis temperatures and processing time (Bracmort, 2010); will have significant influence in the results for removing different pollutants within urban stormwater runoff. Emerging research in the use of enzyme based products is evolving which demonstrates that the technology is technically capable of remediating water bodies (Scott, 2010) contaminated with the most common pollutants. Enzyme research has been funded by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) however has not progressed to enzyme trials with solid structures such as biochar; it does provide emerging research to be investigated as part of this dissertation.

Numerous engineering treatment systems have been devised to remove pollutants from stormwater runoff from urban development. In most cases, these systems remove different pollutants more successfully than others; additionally different treatment systems utilise non-renewable, expensive resources that are not easily maintainable. The objectives of this dissertation research are as follows:

- ➢ *To determine the pollutants found in stormwater directed from urban development;*
- ➢ *To determine the effectiveness of the use of biochar for urban stormwater water cleanup; and*
- ➢ *To develop geostructures utilising biochar for stormwater water cleanup which are feasible for the urban environment.*

2. Background

The initial discovery of biochar was in the Amazon regions of Central Amazonia, Brazil, Peru, Columbia, Southern Venezuela, and Guianas, through the discovery of Terra preta soils (Glaser and Birk, 2012). Patches of dark-coloured soils were found by researchers which are known as Anthropogenic Dark Earths (ADE) or *terra preta* (de Indio) and they exhibit different soil properties in comparison to most soils discovered in the region. The ADE was found to contain large stocks of stable soil organic matter (SOM) with high nutrient levels (Glaser, 2007 and Glaser et al., 2001). Archaeological evidence showed that terra preta formation at the Upper Xingu region and in Central Amazonia ranged between 60 and 1640 AD (Heckenberger et al., 2003). The image shown in Figure 1 below shows a poor oxisol on the left and in the middle the oxisol transformed into terra preta.

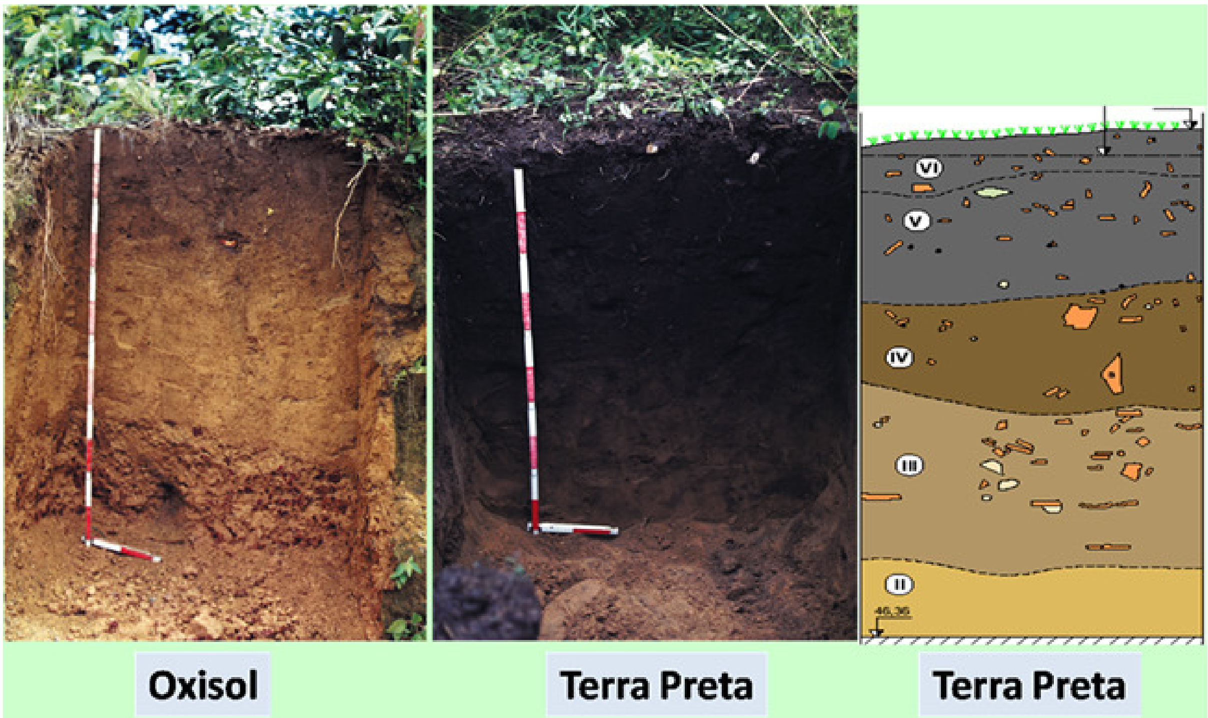

Figure 1 – Left a poor Oxisol, and middle an oxisol transformed into Terra Preta, (Image: Ecostewardblog)

It was found that ADE provided a model for sustainable agriculture in humid regions and for soils which exhibit a low capacity to retain nutrients. The existence of ADE has been known for more than 100 years and has resulted in emerging agricultural techniques for the formation of *terra preta* soil used to reclaim degraded areas used for intensive agriculture (Glaser, 2007). In addition, the high stability of SOM in ADE has proven that carbon can be sequestered for long periods in soils which have the potential to combine sustainable agriculture with long-term carbon dioxide sequestration. The stability of the ADE and properties resulting in increased fertility in soils is attributed to the biochar content within the SOM (Glaser and Birk, 2012).

It is difficult to define *terra preta* due to the variation between different locations as well as differences due to differences in time and land use structure. In general, typical *terra preta* is defined as soil characterized by a several decimetre-thick topsoil horizon with high levels of SOM, biochar, and nutrients which contains archaeological artefacts of pre-Columbian origin (Glaser and Birk, 2012). This lends itself to the difference in properties resulting in biochar which is highly dependent on the type of biomass used to produce the biochar. The result of the biomass used to produce the biochar lends itself to its physical and chemical properties thought to be responsible for many of its beneficial qualities.

2.1 Biochar Production

The manufacturing process used for producing biochar is similar to the production of charcoal which uses a pyrolysis process. Even where different biomasses are used, the pyrolysis process is used for the most common production of biomass. See Figure 2 below which details the method for the production of biochar.

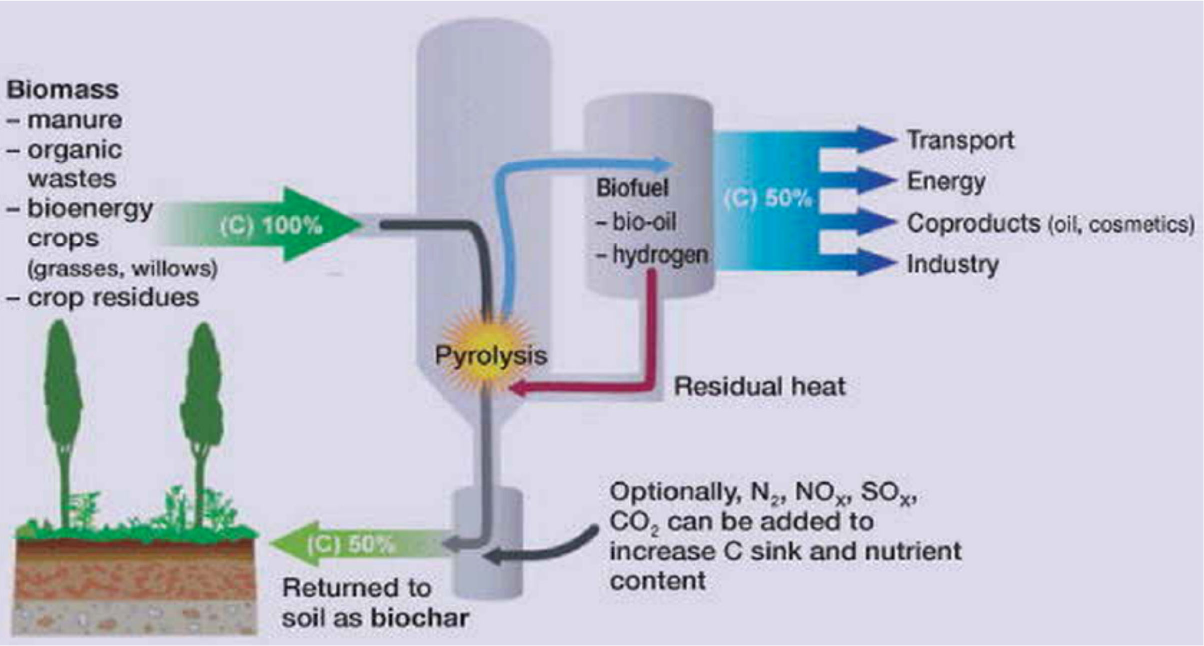

Figure 2 – Biochar Production Diagram (Image: Lehmann, J. *Frontiers in Ecology and the Environment*. 2007;5(7):381-387)

Pyrolysis production uses the thermal decomposition of biomass in an oxygen-free environment (Dominquez et al., 2007) where slow pyrolysis of the biomass occurs under moderate temperatures (500 °C), with vapour residence times of around 10 to 20 seconds (Brown, 2009). Figure 3 below outlines the method of pyrolysis for the production of biochar.

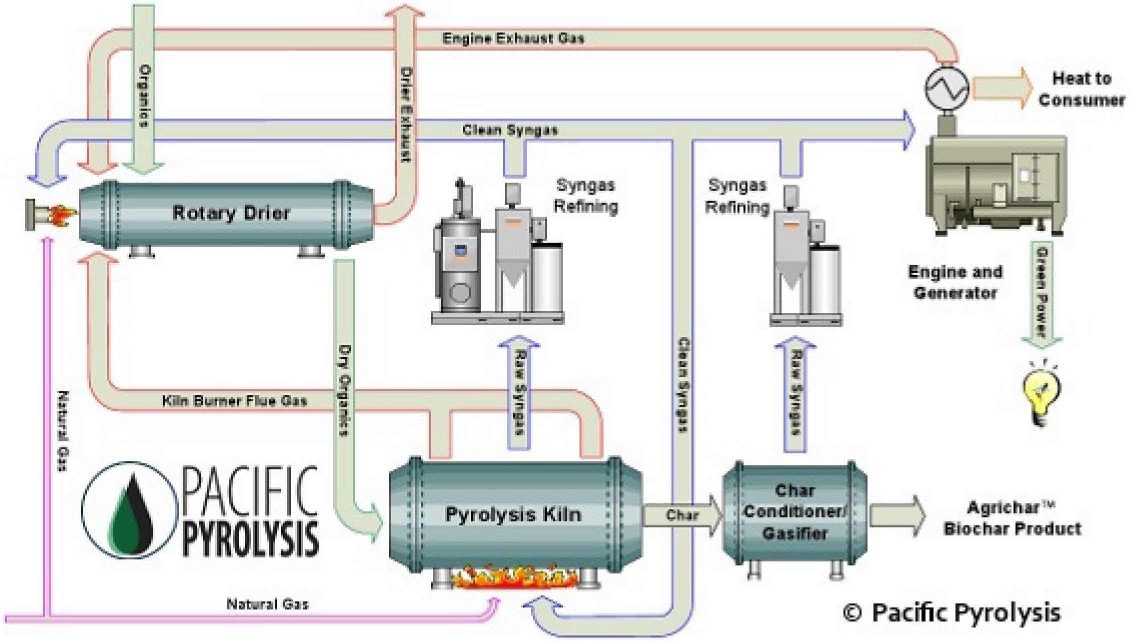

Figure 3 – Pyrolysis Process for Biochar Production (Image: Pacific Pyrolysis)

The biomass used for biochar production is any material which is from a biological source. Biomasses used include non-commercial wood and wood waste, manure, solid waste, non-food energy crops, construction scraps, yard trimmings, methane digester residues or grasses. Biomass is typically worthless as it is a renewable resource generated typically from waste, but is costly to dispose of; but it is regarded as a valuable resource for biochar production. Tip fees, overloading landfills, open burning and pollution are avoided as biomass is processed into an efficient, indigenous, sustainable and value-added product for urban, rural agriculture and forest communities. Depending on the size and capacity of the pyrolysis furnace, heat and power are generated and available as an alternative clean energy resource for residential, commercial, industrial and community applications.

2.2 Biochar Characteristics

Lehmann et al. defined biochar as a carbon-rich fine-grained, porous substance, which is produced by thermal decomposition of biomass under oxygen-limited conditions and at relatively low temperatures (<700 °C). The pyrolysis process results in a progressive decrease in the oxygen content of the biomass and an increased in its carbon content. The characteristics of biochar will be affected by the biomass used to produce the biochar and the preparation temperature during pyrolysis. Different source materials (biomass) used show different properties of surface area, porosity and the overall function of the biochar. A higher pyrolysis temperature results in an increased surface area and carbonized fraction of biochar leading to a high sorption capability for pollutants.

Biochar's physical characteristics can be both directly and indirectly related to the way in which it affects soil systems. Different soils each have their own distinct physical properties depending on the nature of the mineral and organic matter from which they are derived (Brady and Weil, 2008). When biochar is added to soil, the physical nature of the soil is altered including the depth, texture, structure, porosity and consistency, pore-size distribution, particle-size distribution, density and packing.

Biochar is increasingly receiving attention for its ability to be used as a filtration medium for urban stormwater water clean-up due to its characteristics. However the type of pollutants removed is dependent on the sorption capabilities of biochar which is directly related to the temperature and material used its production. The increase of pyrolysis temperature results in an increase of surface area of biochar which assists in higher sorption of chemicals. For example, charcoal made from wheat residue at 500-700°C was well carbonized and its surface area was relatively high (>300 m2/g), whereas chars formed at 300-400°C were partially carbonized and had a lower surface area (<200 m2/g); the former exhibiting higher sorption capabilities (Chun, 2004).

Studies have shown that biochar has the ability to absorb metals (Kolodynska et al., 2012; Park, et al., 2011; and Inyang et al., 2012), herbicides (Sun et al., 2012) and pesticides (Yu et al., 2011). The benefits associated with biochar's characteristics allow it to be neutral to alkaline pH which raises the pH of acidic soils and can eliminate or reduce the requirement for the addition of lime (Lehmann, 2009). In addition biochar has a low bulk density which reduces soil compaction, as a high surface area and pore space, provides substrate for soil microbes, has a high cation exchange capability, increases water retention and decreases nutrient leaching which reduces fertilizer additives and can treat stormwater run-off.

2.3 Biochar for Stormwater Management

Excess runoff from precipitation that appears as streams and lakes is the result of surface water from rainfall events. Mean annual precipitation in Australia is approximately 465mm per year; where 87% is lost through evapotranspiration). The water quality from rainfall runoff is a major concern for government agencies due to a range of characteristics concerned with the physical and chemical properties of materials dissolved or suspended in water. These can include dissolved gases, organic materials, heavy metals, pesticides, acid levels, temperature, colour and turbidity. Urban development leads to a higher rate and quantity of runoff due to an increase in impervious areas and loss of groundwater recharge. The additional runoff results in an increase in contaminants entering the drainage systems and natural waterways; in some cases exceeding that of raw sewage. Sediment particles in water serve as a media to transport other pollutants such as plant nutrients, pesticides, toxic metals, bacteria and viruses.

In order to reduce the environmental impacts of urban development, low impact development (LID) structures such as bio-infiltration ponds and vegetated filter strips are implemented within developments to capture and remove harmful pollutants present in urban stormwater run-off. Although a variety of suspended and dissolved pollutants are readily removed by LID structures, certain nutrient pollutants, heavy metals and pesticides are not consistently removed. Therefore, designers are continually evaluating economically viable substrates that can be added to existing LID structures that are cost effective, sustainable and enhance the removal of pollutants.

Potential benefits of incorporating biochar, a soil amendment, into wetland reclamation have been investigated due to the positive research conducted to date. Problems exist where poor soil characteristics such as sandy, low organic matter with low pH levels are encountered or where sites hydrology is poor due to insufficient water due to location and/or due to drought. As biochar is a carbon based material the carbon stores in biochar are stable for hundreds of years which create a carbon sink in the soil. This occurs as the pyrolysis process used to create biochar stabilizes the carbon and captures gases that would otherwise be released into the environment through natural decomposition. Early studies using biochar suggest that an amended soil mix can improve the water quality discharged from urban development (Kolodynska et al., 2012; Park, et al., 2011; and Inyang et al., 2012). Biochar increases the water holding capacity of the soil, which has important implications for the stormwater runoff reduction potential from urban catchments. Results so far indicate that biochar has excellent potential as a low-cost amendment to soil to improve downstream water quality.

3. Literature Review

In order to determine the results of using biochar geostructures for urban stormwater water cleanup, research regarding the studies and experimentation using biochar has been conducted. Biochar is a renewable resource which is a cheap alternate as a filtration medium utilised in stormwater geostructures due to its structure consisting of pores which makes biochar a highly adsorbent material. Biochar's incredible porosity and surface area provides biochar with a high capacity to adsorb a wide variety of contaminants from water.

Research has been conducted on biochar by many academics, students, and other professionals. A great deal of research on biochar has been on an experimental or environmental basis which is still in its infancy. This does not preclude the relevance of these papers; some findings and uses are helpful in using biochar geostructures for urban stormwater water cleanup. For example, Scott. et al. (2010) thesis on an initial field trial with an enzyme-based product, demonstrating that the technology is technically capable of remediating water body contaminants. Kolodynska et al. (2012) found that a biochar amended soil mix had a positive effect on improving stormwater runoff from urban development as it had the ability to absorb heavy metals. Furthermore, research conducted by Chun (2004) testing different biomasses used to create biochar had a significant effect on the sorption capabilities; in particular work by Brady and Weil (2008) has verified biochar's physical characteristics can be both directly and indirectly related to the way in which it affects soil systems.

However, to maximize the relevance of this literature review to the rest of the thesis conducted on biochar, it was necessary to apply a sorting process to the publications and resources identified as primary research. Because the biochar literature is so diverse and the term "biochar" is relatively new, it was necessary to filter the search in order to determine the documents which documented using biochar for stormwater cleanup. Throughout the screening process, it was noted that a majority of publications identified during the search were taken from organizational groups interested in biochar, such as the Australia and New Zealand Biochar Researchers Network and the International Biochar Initiative; which provided many publications used as resources, but also relevant links and contacts for the information provided within this thesis.

Significant work has been conducted by Lehmann (2012) which characterized the absorption on a variety of biochar. This has led to the literature review being conducted on the toxic and organics remediated with biochar. Reviewed research shows that a substantial amount of toxic organics are sorbed by biochar. These include such heavy metals as copper, zinc, lead, cadmium, chromium, and mercury; herbicides such as Atrazine, Acetochlor, Clopyralid, Fipronil, Glyphosate, Simazine, Trifluralin, Diuron; nutrient leaching such as Phosphorous and Nitrogen; removal of hydrocarbons; and Pesticides and Fungicides such as Pyrimethanil, Lindance, Isoproturon, Endosulfan, Clhorpyrifos and Carbofuran. Park et al (2011) evaluated the effectiveness of biochar at immobilizing metals in soil. It resulted in the conclusion that biochar is effective in the uptake and immobilization of heavy metals. This has provided the interest in using biochar as a filtration medium for stormwater cleanup for urban development runoff.

It is well documented by that biochar helps with re-vegetation and environmental remediation. Low impact designs using biochar in rain gardens, biofilters, storm drains and roof drains has been tested and is now growing as a filtration media marketed for its longevity, cost effectiveness and the fact it is a renewable resource. Using biochar geostructures for urban stormwater water cleanup is still in its infancy, however testing experiments continue with promising results.

The CSIRO in Australia is conducting research into the use of enzymes for the treatment of biochar. Scott et al (2010) examined the use of bioremediation in a field trial with an enzyme-based product to demonstrate the remediation of water bodies contaminated with a common herbicide. The study concluded that the enzyme was successful in removing the herbicide and that further studies were required to analyze the further potential of improving production of farming crops. Providing the catalyst for further research being conducted as part of this thesis for using enzymes for the treatment of biochar and implementing field trials to gauge what is required to make enzyme treated biochar successful and commercially viable.

3.1 Urban Stormwater Pollutants

Urban stormwater runoff has been the subject of intensive research since the inception of the River Murray Waters Agreement which was signed in 1914 by New South Wales, Victoria, and South Australia. The arrangements set out in the River Murray Waters Agreement remain largely unchanged until the commencement of the Water Act. The Environment Protection Agency (EPA) works to protect Australian waters, which includes creeks, streams, rivers, coastal waters, groundwater and aquifers, from the adverse impacts of pollution. The EPA samples monitoring sites across the country and measures water quality in relation to the environmental values that are to be protected which are set out in the EPA's *Environment Protection (Water Quality) Policy 2003*.

Urban stormwater is the leading source of water pollution due to human activities resulting in water quality impairment to ocean shoreline waters and one of the leading causes of pollution in estuaries across Australia. Urban stormwater is also a significant source of impairment in rivers and lakes and contributes to wetland degradation. The increase in volume of stormwater runoff from urban catchments along with the concentration of pollutants within the runoff has impaired urban watersheds physically, chemically, and biologically (Walsh et al, 2005). The degree and impacts to water bodies is significant; it affects water quality, water quantity, habitat and biological resources, public health, and the aesthetic appearance of waterways. There are four main types of stormwater pollutants.

- *Litter, such as:*
  - Cigarette butts
  - Cans
  - Paper or plastic bags
- *Chemical Pollution, such as:*
  - Household detergents
  - Petroleum products
  - Oils
  - Fertilisers
- *Natural Pollution, such as:*
  - Leaves
  - Garden clippings
  - Animal waste
  - Human waste
- *Sediment Pollution, such as:*
  - Soil erosion from building and farming sites
  - Road and paved surfaces.

The Department of Environment and Heritage's, *Introduction to Urban Stormwater Management in Australia* document outlines the major issues for urban stormwater systems for managing stormwater quality are as follows:

- *Visual Water Quality*
- *Contaminants and Nutrient Control*
  - Suspended Solids
  - Nutrients
  - Oxygen Demanding Materials
  - Micro-organisms
  - Toxic Organics
  - Toxic Trace Metals
  - Oils and Surfactants
  - Litter
  - Algal Blooms
- *Management Interventions*
- *Community Benefits*
- *Source Control*
- *Interception during the passage of contamination*
- *Management of receiving waters*

The Council of Australian Governments representing Commonwealth, State, Territory and Local Government in Australia has adopted a National Water Quality Management Strategy (NWQMS). This Strategy includes a major focus on water quality linked to Ecological Sustainable Development, which aims "To achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development".

Skinner et al (2009) detailed that estimated diffuse pollutant loads from urban development were higher than that from rural and undeveloped catchment areas. Nitrogen and phosphorus export coefficients (mass/area/wet season) were up to 12 times higher from urban catchments in comparison to undeveloped and rural land. Sediment coefficients were 8 times higher, whereas metal loads (lead, zinc, and copper) were more than 10 times higher from urban catchments when compared to undeveloped land. With ever growing populations future developments will result in increasing pollution which will result in an intensifying burden on receiving waterways. The table below details the export coefficients for urban and non urban catchments.

Pollutant	Contaminant Sources	
	Non-urban	Urban
TN (kg/ha)	3.2	9.9
TP (kg/ha)	0.12	1.0
Al (g/ha)	3800	50000
As (g/ha)	2.2	11
Cd (g/ha)	0.93	1.9
Cr (g/ha)	8.5	44
Cu (g/ha)	13	200
Ni (g/ha)	4.3	13
Pb (g/ha)	4.1	270
Zn (g/ha)	71	890
TSS (kg/ha)	110	730
VSS (kg/ha)	32	200

Table 1 – Average wet season export coefficients for urban and non-urban land uses (Source: Skinner et al 2009).

Pollutants which are associated with urban stormwater runoff which are harmful to receiving waters fall into common categories outlined by Horner et al, (1994) which are outlined below.

3.1.1 Suspended Solids

Solids are one of the one common pollutants found in urban stormwater. Solids originate from many sources including the erosion of pervious surfaces and dust, litter and other particles deposited on impervious surfaces from human activities and the atmosphere. Waterway bank erosion and erosion at construction sites are also major sources of suspended solids transported in stormwater. Suspended solids have two main constituents which are organics derived primarily from sewage and inorganics which are primarily derived from surface runoff. Frequent rain events where the volume and velocities of runoff are intensified by urban development result in mobilisation of sediments within urban water systems, triggering bank erosion, channel incision and disruption of biota (Walsh et al, 2005). The turbidity in water resulting from suspended solids reduces light penetration in water which affects the growth of aquatic plants. Silts and clay suspended particles smooth the bottom of waterways causes disruption to the habitats for fish and bottom dwelling organisms. Additionally metals, phosphorous and other organics are absorbed and transported via suspended solids in water which leads to slow leaching of toxins and nutrients into waterways. Typical concentration of suspended solids in urban runoff is substantially higher than that in treated wastewater (Bastian, 1997).

3.1.2 Pesticides and Herbicides

The EPA describes agricultural pollution problems as one of the most pervasive causes of urban stormwater water quality problems. The primary pollutants from non-irrigated croplands are sediment, nutrients, pesticides and herbicides. Losses of pesticides and herbicides applied to urban lands to control insects and weeds amount to an average of 5% of the applied pesticides (Novotny, 1995). Most of the pollution as a result of this loss ends up as pollution of groundwater due to leaching and surface waters such as rivers, streams and oceanic systems. This is compounded if rainfall occurs shortly after the application of pesticides and herbicides where the losses can be substantial, resulting in death to aquatic life. Herbicides for weed control are the most used pesticides where a study in the USA in 1980 found that approximately 200,000 tons of herbicides and 140,000 tons of insecticides were used; since 1980 these uses have doubled. Pesticides and herbicides elevate the chemical pollution in groundwater beyond acceptable levels. Startling levels of nitrate contamination of groundwater and surface water sources have been documented in eastern and central Europe. Zakova et al, 1993 documented damaging impacts in the use of fertilizers in the Czech Republic in two important water supply reservoirs. Nitrate levels detected in streams feeding the reservoirs have increased by 600% in the last 25 years, from approximately 5mg of NO_3 per litre in 1965 to 30mg of NO_3 per litre in 1995. A clear relationship was established between the fertilizer applications and nitrate concentration in the streams. Pesticides are also responsible for the contamination in groundwater and surface waters where atrazine was found in central Wisconsin, and the Po River Valley in Italy (Novotny, 1995).

3.1.3 Nitrogen and Phosphorus

Nitrogen and phosphorus are the primary nutrients of concern in urban stormwater. The major sources of nutrients in urban stormwater are urban landscape runoff (such as fertilisers, detergents, and plant debris), atmospheric deposition, and failing septic systems (Terrene Institute, 1996). Animal waste is also a major source of nutrient contamination in urban stormwater (EPA, 2010). Nitrogen and phosphorus can determine the tropic status and amount of algal biomass produced in a water system. A high proportion of nutrients in water increase primary biological proactivity which results in excessive growth of algae that leads to nuisance algal blooms and eutrophic conditions. The negative effect of decomposing algae is the form of sediment oxygen demand which depletes dissolved oxygen concentrations, which can cause fish and marine organisms to perish (Dowsett, 1994). Walker (1987) stated that "cause-effect relationships linking urban development to lake and reservoir eutrophication are well established," and that "urban watersheds typically export 5 to 20 times as much phosphorus per unit per year, as compared to undeveloped watersheds in a given region."

3.1.4 Micro-organisms

Micro-organisms are a potential public health threat when they are present in contact waters. Bacteria and viruses found in soil and decaying vegetation, and faecal bacteria from sewer overflows, failing septic tanks and animal waste, are common contaminants found in stormwater after heavy rainfall (Terrene Institute, 1996). Pathogens and micro-organisms, including bacteria, viruses and faecal coliforms, cause water borne diseases that can cause serious health risks such as cholera, typhoid, infectious hepatitis and gastrointestinal diseases (Dowsett, 1994). The Environmental Protection Authority's, *Nationwide Urban Runoff Program (NURP)* evaluated 17 sites for 156 storm events which concluded that coliform bacteria was present at high levels in urban stormwater runoff which exceeded EPA water quality criteria during and immediately after large rainfall events.

3.1.5 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) describe chemicals that are often found together in groups of two or more. PAHs are found naturally in the environment but they can also be man-made. In their purest form, PAHs are solid and are created when products like coal, oil, gas, and garbage are burned but the burning process is not complete. PAHs form when complex organic compounds are exposed to high temperatures or pressures.

Petroleum hydrocarbons found in urban stormwater are usually sources from parking lots, roadways, leaking storage tanks, vehicular emissions, and incorrect disposal of waste oil. Petroleum hydrocarbons found in stormwater runoff include oil and grease and compounds such as benzene, toluene, ethyl benzene and a variety of polynuclear aromatic hydrocarbons (PAHs); which are known for their severe toxicity even at low levels (Schueler, 1987). Research conducted (Shepp, 1996) measured the petroleum hydrocarbon levels in urban runoff from a number of impervious areas which found that the number of traffic generation was directly associated with the concentration of hydrocarbons present in stormwater, ranging 0.7 to 6.6 mg/l. Considering the maximum concentration of petroleum hydrocarbons for protection of fisheries is 0.01 to 0.1 mg/l (Shepp, 1996), these levels exceed the maximum concentrations recommended for the protection of drinking water supplies and protection of aquatic life. Population growth as a result of increased urban sprawl has been proven to correlate with increased traffic activity which is directly related for the high levels of PAHs found in urban runoff and the consequent dilapidation of water quality in downstream water systems.

3.1.6 Heavy Metals

Heavy metals, industrial and agricultural chemicals can have a severe impact on humans and aquatic life. Atmospheric deposition where gases and particulates are released to the atmosphere from combustion sources such as motor vehicle emissions, slash burning, and industrial sources, which contain nitrogen, sulphur, and metal compounds; eventually settle to the earth's surface as dust or fall in rain, snow and fog. A major finding of the NURP study found:

> *"Heavy metals (especially copper, lead and zinc) are by far the most prevalent priority pollutant constituents found in urban runoff. End-of-pipe concentrations exceed EPA ambient water quality criteria and drinking water standards in many instances. Some of the metals are present often enough and in high concentrations to be potential threats to beneficial users."*

A major study of the quality of urban stormwater (Bannerman et al, 1996) found that mean concentrations of metals, particularly copper and zinc, exceeded the water quality criteria for cold water fish communities; another study thesised lead and zinc levels from urban runoff of 100 to 500 times the concentration in ambient water (Pitt, 1995).

3.2 Sources of Pollutants

Stormwater runoff from urbanised areas is generated from a number of sources such as residential areas, commercial and industrial areas, roads, and bridges. This urbanised land use consists of rooftops, streets and parking areas and when land is developed from its natural groundcover ecosystem to an urbanized land, the developed surfaces do not have the ability to pond and infiltrate water which produces runoff during storm events. Water which under normal conditions previously infiltrated into the soil and was converted to groundwater, ponded in natural depressions in the land such as creeks and rivers, utilised by plants and evaporated or transpired into the atmosphere is now converted directly into surface runoff.

The climate of a region can have a significant impact on not only the quantity of stormwater runoff but also the quality. Factors such as the frequency, intensity and storm duration can all be contributing to the quality of stormwater runoff in urban areas. In areas where there are significant amounts of atmospheric deposition of particulates, urban stormwater runoff can contain high concentrations of total suspended solids, metals, and nutrients. Areas which have infrequent rainfall can have a high concentration of pollutants, mainly from "hot spots" such as large carparking areas, roadways and industrial developments. The infrequent rainfall tends to generate high intensity rainfall events over a short period of time which results in large amounts of suspended solids being located in stormwater runoff. Specific geographical factors can influence the nature and components which are found in stormwater runoff. This includes the soil types, slope of land, land use and amount of imperviousness of the stormwater runoff which can contribute to the quality of runoff that is discharged from a specific area.

The Department of Environment and Heritage's, *Introduction to Urban Stormwater Management in Australia* details the concerns associated with the wet weather peak overflow problems from sewage pipes into stormwater drains which discharges into natural waterways is a significant problem in most Australian cities. Water penetrates the sewerage system from illegal stormwater connections from structures, surface runoff into sewer manholes, and from damaged infrastructure. The volume of water exceeds the capacity of the sewage system causing overflow discharges into waterways. Studies in the Sydney area indicate that there are up to 6,000 overflow points that are capable of discharging raw sewage into stormwater systems.

Sidhu (2013) assessed the concurrence of human sewage contamination in urban stormwater runoff using microbial source tracking (MST) and chemical source tracking (CST). Out of 23 stormwater samples, 21 samples (91%) were positive for six to eight sewage related MST and CST markers, respectively. Additionally high prevalence of other enteric viruses were also found to be present in the stormwater samples which can pose significant health risks for humans.

The Environmental Protection Authority's, *Nationwide Urban Runoff Program (NURP)* outlines the following sources of contaminants in urban stormwater runoff which have been tabulated below:

Contaminant	**Contaminant Sources**
Sediment and Floatables	Streets, lawns, driveways, roads, construction activities, atmospheric deposition, drainage channel erosion
Pesticides and Herbicides	Residential lawns and gardens, roadsides, utility right of ways, commercial and industrial landscaped areas, soil wash off.
Organic Materials	Residential lawns and gardens, commercial landscaping, animal wastes.
Metals	Vehicles, bridges, atmospheric deposition, industrial areas, soil erosion, corroding metal surfaces, combustion processes.
Oil and Grease/Hydrocarbons	Roads, driveways, parking areas, vehicle maintenance areas, petrol stations, illicit dumping to stormwater drains.
Bacteria and Viruses	Lawns, roads, leaking sewer pipelines, sanitary sewer cross-connections, animal wastes, septic systems.
Nitrogen and Phosphorus	Lawn fertilizers, atmospheric deposition, vehicle exhaust, soil erosion, animal waste, detergents.

Table 2 – Sources of Contaminants in Urban Stormwater Runoff

Motor vehicle emissions, crankcase oil leaks, vehicle tyre wearing and asphalt road surfaces are all sources of chemical containments found in urban stormwater runoff.

Heavy metals such as copper, lead, and zinc and polycyclic aromatic hydrocarbons (PAHs) are widespread in urban stormwater which raises concerns due to their toxicity to aquatic organisms and the environment (Hoffman et al 1984; Walker et al 1999). Other sources of heavy metals and PAHs include fire emissions, spillage and dumping of contaminants, and corrosion of roofing and rainwater tank materials (Brown, 2005).

Among many non-point pollution sources, road runoff is one of the major sources of pollutants contributing to urban stormwater (Aryal et al, 2005). Studies conducted in Europe indicate that the components of road surface degradation are common constituents of urban runoff where up to 0.05-0.10 inch of pavement surface is worn away from a roadway each year. Surface deposits on roads contain toxic micropollutants such as heavy metals and PAHs (Barbos and Hvitved, 1999; Berbee et al, 1999). During rain events the surface micropollutants are washed off the road surface and discharged into pipe networks associated with urban development which ends up in aquatic environments. Gupta and Saul, 1996 identified that the initial runoff, or “first flush”, is where the pollutant concentration is at its most high. Many researchers (Sartor and Boyd, 1972; Hoffman et al, 1984; Lau, 2005) have documented runoff pollutants associated with road runoff. Barret et al, 1998 outlines that in road runoff, suspended solids are considered as one of the major pollutants due to their susceptibility for micropollutants to attach to them. High PAH concentration has been documented by Shinya et al, 2000 in the early stages of stormwater runoff from road surfaces, where according to Pitt et al, 1995 the pollutant accumulating behaviour is dependent on suspended solids particle size. Krein and Schorer, 200 thesised that higher molecular weight PAHs attached to coarse particle fraction.

Educational programs must be implemented to make the public aware of the pollution issues associated with irresponsible disposal of waste products. For example, the Environment Protection Authority (EPA) of New South Wales estimates the amount of dog faeces washing into Sydney’s rivers from stormwater drains each year would fill more than 10 Olympic-sized swimming pools. The Department of Environment and Heritage’s, *Introduction to Urban Stormwater Management in Australia* suggests the use of labelling stormwater pits to indicate the waterway that is impacted by this stormwater drain entry may provide a simple solution to a major problem.

3.3 Existing Geostructures for Urban Stormwater Cleanup

A number of documents are available in Australia which relate to existing geostructures that are available for urban stormwater cleanup. As part of the Austroads publications, guidelines were released for the treatment of stormwater runoff for roads (Wong et al, 2003), which provided an update of earlier guidelines (Wong et al, 2000). Although the document is primarily focussed on stormwater sensitive urban design for roads, it provides guidance on the design of swales, bioretention systems, infiltration systems and wetlands; including case studies for different regions throughout Australia.

In 1999 the Queensland Water Recycling Strategy released a Stormwater Recycling Background Study which was prepared by WMB Oceanics Australia (WBM, 1999). This study investigated the status of stormwater recycling in Queensland, interstate and overseas. This document identified advantages, disadvantages and potential benefits of stormwater recycling practices however it did not provide definitive guidance into the adoption of stormwater re-use measures.

The Cooperative Research Centre (CRC) for Catchment Hydrology published a thesis by Lloyd et al. (2002) which outlines key considerations in the planning, design and assessment of stormwater sensitive urban design. The thesis outlines both non-structural and structural measures, emphasising the significance of modelling practices to assess the performance of the proposed structures to be used. The guidelines identified best management practices (BMP) of structural measures to be applied for stormwater sensitive urban design which is outlined in Table 3 below.

Structural BMP	**Allotment**	**Streetscape or precinct**	**Open Space networks or regional scale**
Diversion of runoff to garden beds	✓		
Rainwater tank/ reuse scheme (ie garden watering, toilet flushing)	✓		
Sediment trap	✓		
Infiltration and collection system (biofiltration system)	✓	✓	✓
Infiltration system	✓	✓	✓
Native vegetation, mulching, drip irrigation schemes	✓	✓	✓
Porous pavement	✓	✓	✓
Buffer strip		✓	✓
Constructed wetland		✓	✓
Dry detention basin		✓	✓
Litter trap (side entry pit trap)		✓	
Pond and sediment trap		✓	✓
Swale		✓	✓
Lake			✓
Litter trap (gross pollutant trap)			✓
Rehabilitation waterway			✓
Reuse scheme (ie open space irrigation and toilet flushing)			✓
Urban forest			✓

Table 3 – Application of structural best management practices for stormwater sensitive urban design (Source: Lloyd et al, 2002)

The Institute for Sustainable Resources at Monash University compiled an inventory of integrated stormwater treatment and re-use practices in Australia in order to develop a record of systems used for collection, treatment, storage and distribution of general stormwater runoff (Hatt et al., 2004). The document detailed the regulation, performance, construction, operation, maintenance, implementation, and cost benefits of these systems. However as mentioned above, this document provided a review of current practices without providing any guidance for future practices to be used for urban stormwater cleanup.

The basic approach to urban stormwater cleanup is to use nature as a model and filter rainfall at the source. This is achieved by sequenced implementation of runoff prevention strategies, runoff mitigation strategies, and treatment controls to remove pollutants. The filtration process is where stormwater is passed through a filter media to remove solids and other pollutants. The gradation of the media, irregularity of the shape, porosity, and surface roughness characteristics all influence solids removal. Other pollutants such as nutrients and metals are removed through chemical and/or biological processes. Filtration systems can be designed as large scale geostructures to remove pollutants at the end of a system, or configures in decentralized small-scale stormwater inlets to allow stormwater runoff to be treated close to its source without additional collection or conveyance infrastructure.

There are a limited number of journals, conference and technical papers which address integrated stormwater treatment for urban environments however existing literature is generally specific to particular systems. Most of these systems can be found on various Australian research institutions, Local Government websites and relevant Water Association documents.

The basic processes to manage stormwater include pretreatment, filtration, infiltration, and storage for reuse. The approach to site development and stormwater management is to create a sustainable site that mimics the undeveloped hydrologic and pollutant properties emulating from a site. In order to develop geostructures utilising new and emerging products it is important to research the performance of some of the existing geostructures installed for urban stormwater cleanup. It is important to note that as part of this dissertation it is not possible to review the performance of every different type of geostructures available for urban stormwater cleanup, but rather provide an overview of the typical systems used and their performance.

3.3.1 Filtration – Engineered Landscaping

Engineered landscape practises are an example of geostructures which can be utilised to effectively remove pollutants from urban stormwater runoff. This type of filter is used where site conditions are difficult such as where clay soils are encountered, the water table is high, steep grade levels, soils that are contaminated, and site which discharge high pollutant loads. As engineered landscape filters can be integrated into the landscape this type of filter is considered both functional and aesthetically pleasing.

Pollutants are removed by filtration through the grass, sedimentation, adsorption to soil particles, and infiltration through the soil (Field and Sullivan, 2003).

Tree box filters and enhanced biofiltration systems that utilise biological and engineered media are typically designed to treat small catchment areas that can be combined with underground infiltration. A biofiltration system operates where the grasses and vegetation within the geostructure “filter” the stormwater as it flows over them (EPA, 1999). High flow rates from a catchment will bypass the biofilter so that the tree box filter treats the initial runoff with high pollutant concentrations. The types of trees used should be suitable for the climate conditions of the area to be installed and should have a non-aggressive root structure. Leinster (2004) studied the construction costs associated with bioretention systems in greenfield developments as follows:

- Bioretention systems greater than 100m^2 in area: \$125-\$150/m^2 (including vegetation);
- Bioretention systems less than 100m^2 in area: \$225-\$275/m^2 (including vegetation);
- Swale Bioretention systems: \$100-\$120/ linear metre (including vegetation).

Raingardens are utilised to filter pollutants from stormwater whilst also acting as a system to detain peak flows of stormwater from entering the drainage system and as an infiltration system. The main function of a raingarden is to capture stormwater runoff from hardstand areas such as roads, and roofs via downpipes during rainfall events. A raingarden not only slows the peak runoff of a rain event from a hardstand area but it also acts as a filter. This filtration is achieved via layers of gravel, and sandy soil which filtrates pollutants such nitrogen, phosphorus and fertilizers (Davis et al, 2009). Microorganisms in the soil degrade pollutants to reduce toxic leaching into groundwater. Plants are installed within the raingarden which further aid in the uptake of pollutants from the stormwater which provide a visually appealing, non-impact stormwater control; adding to the streetscape of a developed urban area.

Vegetated Swales are open vegetated open drains which provide stormwater filtration prior to discharge to downstream drainage systems and/or receiving water bodies (Wong et al., 2000). Treatment of pollutants relies heavily on dispersed flows which have low hydraulic loading which is severely reduced in high flow channelized systems. The table below provides a broad estimate of overall performance for a range of pollutants which are indicative only and not to be regarded as prescriptive. Filtration which is also promoted within vegetated swales has not been taken into consideration in the values provided in the table below.

Pollutant	Expected removal (mean annual load)	Comments
Litter and organic matter	Very High (>90%)	Should be almost 100% removal, provided there is adequate vegetation cover, and flow velocities are controlled (below 0.5m/s).
TSS	60% - 80%	Assumes low level of infiltration. Will vary with varying particle size distribution.
TN	25% - 40%	Dependant on speciation and detention time.
TP	30% - 50%	Dependant on speciation and particle size distribution.
Coarse sediment	Very high (>90%)	Assumes re-suspension and scouring is prevented, by controlling inflow velocities to <0.8m/s, and maintaining dense vegetation.
Oil and grease	n/a	No reliable data available.
Faecal coliforms	n/a	No reliable data available.
Heavy metals	20% - 60%	Highly variable: dependent on particle size distribution, ionic charge, detention time, etc.

Table 4 – Pollutant Removal Estimates for Vegetated Swales and Filter Strips (Source: Fletcher et al, 2003)

Ponds, wetlands and sediment basins are obviously constructed differently; they operate using similar mechanisms such as flow attenuation, sedimentation and filtration to remove contaminants from urban stormwater. The change in wetland performance is due to the relationships of key factors of the systems such as hydraulic loading and input concentration which vary in the flow processes which influence stormwater flow and quality. The table below provides a summary of the typical range performance for stormwater wetlands, ponds and sedimentation basins.

Pollutant	Expected removal (mean annual load)	Comments
Litter and organic matter	Very High (>95%) (s,p,w)	Subject to appropriate hydrologic control. Litter and coarse organic matter should ideally be removed in an aerobic environment PRIOR to a pond or wetland, to reduce potential impacts on BOD.
TSS	60% - 85% (p) 65% - 95% w) 50% - 80% (s)	Depends on particle size distribution
TN	30% - 70% (p) 40% - 80% w) 20% - 60% (s)	Dependant on speciation and detention time.
TP	50% - 80% (p) 60% - 85% w) 50% - 75% (s)	Dependant on speciation and particle size distribution. Will be greater where a high proportion of P is particulate.
Coarse sediment	Very high (>95%)	Subject to appropriate hydrologic control.
Oil and grease	n/a	Inadequate data to provide reliable estimate, but expected to be >75%.
Faecal coliforms	n/a	Inconsistent data.
Heavy metals	50% - 85% (p) 55% - 95% w) 40% - 70% (s)	Quite variable: dependant on particle size distribution, ionic charge, attachment to sediment (vs % soluble), detention time, etc.

Ponds (p), Wetlands (w), Sedimentation Basins (s)

Table 5 – Summary of Expected Pollutant Removal by Ponds, Wetlands and Sedimentation Basins (Source: Fletcher et al, 2003)

The annual maintenance costs associated with wetlands in greenfield developments were estimated at 2% of the total construction cost. The total cost for wetland construction in Penrith NSW based on 10 years experience were estimated at $500,000 per ha of surface areas for design and construction, and approximately $10,000 per ha per annum for routine maintenance in the first two (2) years (2% of design and construction cost) followed by $5,000 per ha per annum for routine maintenance thereafter (1% of design and construction cost); then major corrective maintenance every ten (10) years (5% of construction cost), Hunter, 2003. It is also recommended that the macrophyte zone of a wetland should be replaced every 20-50 years at a cost of 50% of the initial construction cost (Fletcher et al., 2002).

3.3.2 Media Filters

Sand filters are one of the most common types of geostructures used for urban stormwater cleanup due to their relatively small size and their ability to remove challenging pollutants such as solids, soluble heavy metals, oils and grease, and total nutrients. Sand filter geostructures are also favoured due to the ability of using sustainable media as filtration. Sand filters are designed to capture and treat a water quality volume from urban catchments which must be maintained periodically to restore the system to its full efficiency and effectiveness. The maintenance requirements and frequency of sand based filters are dependant of the pollutant load characteristics associated with the site being treated.

A sand filter and storage basin with a catchment area of 60,000m^2, a sand filter size of 32m^2, and a 'storage plus filter area' of 150m^2 constructed in Sydney (Gibbs, 2003) estimated cost $167,815 to construct; which was calculated to cost $1,500 per m^2 of sand filter including storage capacity. Newcastle City Council (2002) estimated that the construction cost for a sand filter treating approximately 5,000m^2 was $36,153 including site establishment, survey, design, and supervision costs.

3.3.3 Infiltration

Infiltration systems are a type of belowground geostructures such as chambers, perforated pipes and vaults. Belowground geostructures are favoured as they allow infiltration to occur without occupying large land area that could be used as developed land or land that is required to be preserved. This type of geostructures minimises the impact on the land while providing an efficient groundwater recharge system which is incorporated to meet detention requirements for an urban development. However it is important to note where stormwater runoff is from a commercial or residential area with a higher potential for metal or organic contamination, infiltration may not be appropriate in areas where groundwater is used as a source of drinking water due to contaminant migration (Schueler, 1987).

Pollutant	Expected removal (mean, range)	Comments
Litter and organic matter	100%	Expected to trap all gross pollutants, except during high-flow bypass.
TSS	65% - 99%	Pre-treatment required to reduce clogging risk.
TN	50% - 70%	Dependant on speciation and state (soluble or particulate).
TP	40% - 80%	Dependant on speciation and state (soluble or particulate).
Coarse sediment	95% - 100%	May pose a clogging risk. These systems should have pre-treatment to remove coarse sediment prior to entry into the filter media.
Oil and grease	n/a	Inadequate data to provide reliable estimate, but expected to be >75%.
Faecal coliforms	n/a	Inadequate data.
Heavy metals	50% - 95%	Dependent on form (soluble or particulate).

Table 6 – Pollutant Removal Estimates of Infiltration and Bioretention Systems (Source: Fletcher et al, 2003)

The construction cost of an infiltration trench is estimated at $60-$80/m^3 of trench (assuming a 1m wide by 1m deep trench), (Fletcher et al, 2003). Whereas Earthtech

Engineering Pty Ltd in Melbourne estimated in 2003 that an estimate for construction costs of $46-$48 per linear metre is used.

3.3.4 Gross Pollutant Traps (GPT)

Research in the effectiveness of GPTs does not provide substantial data in relation to the removal efficiency of pollutants but rather focus on the load captured during a certain rainfall event. This deficiency in available data has be noted by Allison et al., (1998) where Australian Runoff Quality guidelines detail gross pollutant and sediment traps, however do not provide typical performance data (Allison and Pezzaniti, 2003). The table below provides data derived from a review by Fletcher et al, (2004), which includes rationale and estimates for pollutant removal estimates for GPTs.

Pollutant	Expected removal (mean annual load)	Comments
Litter and organic matter	10% - 30%	Depends on effective maintenance, specific design (hydraulic characteristics etc). 10% where trap width is equal to channel width, 30% where width is 3 or more times channel width.
TSS	0 – 10%	Depends on hydraulic characteristics, will be higher during low flow.
TN	0% (negligible)	Transformation processes make prediction difficult.
TP	0% (negligible)	TP trapped during stormflows may be re-released during inter-event periods, due to anoxic conditions.
Coarse sediment	10% - 25%	Depends on hydraulic characteristics; will be higher during low flow.
Oil and grease	0 – 10%	Majority of trapped material will be that attached to organic matter and coarse sediment.
Faecal coliforms	unknown	
Heavy metals	0% (negligible)	

Table 7 – Pollutant Removal Estimates for Gross Pollutant Traps (Source: Fletcher et al, 2003)

The NSW EPA (2002) developed a spreadsheet to provide an approximate of unit prices for a wide range of proprietary GPTs. The costs are outlined in Table 8 below.

Manufacturer	Capital Cost	Maintenance Costs
Rocla Downstream Defender	$12,000 - $36,000	$20 per ha per month (suction cleaning)
Stream Guard (catch basin insert)	$290	$200 per annum
Stream Guard (passive skimmer)	$60	$200 per annum
Enviropod (100-500 micron screen)	$40-$620	$200 per annum
Ecosol RSF100	$430-$903	$200 per annum
CSR Humes Humceptor	$10,000-$50,000	$20 per ha per month (suction cleaning)
Rocla Cleansall	$20,000-$150,000	$14,400 per annum
Ecosol RSF 1000	$4,000-$12,000	$12 per ha per month
Baramy	$15,000-$40,000	$12 per ha per month
CSR Humegard	$18,000-$51,000	$14,400 per annum
Trash Racks (Hornsby Shire Council)	$2,117/ha	$708 per annum, $42 per ha

Table 8 – Approximate Capital Cost and Typical Maintenance Cost for a range of Proprietary Gross Pollutant Traps (Source: NSW EPA, 2002)

3.3.5 Porous Pavements

Porous pavements are a type of pavement geostructures which promote infiltration to the underlying soil or to a dedicated storage reservoir below the pavers. Porous pavers are monolithic or modular; where monolithic pavers include porous concrete and porous pavement; and modular pavers include porous pavers made of a porous material or constructed which a gap between each paver, or as modular lattice type structures. Porous pavements are laid ontop of medium which aids in the filtration of pollutants such as sand or fine gravel, usually underlain by a layer of geotextile fabric with coarse aggregate below. Porous pavements have advantages of stormwater management by improving water quality through filtering, interception and biological treatment; however they are prone to clogging and are expensive (EPA, 1993). The table below provides a summary of pollutant removal by porous pavements.

Pollutant	Expected concentration reduction (+ range)	Comments
Total Suspended Solids	80 (70-100)	
Total Nitrogen	65 (60-80)	Will decrease with proportion dissolved.
Total Phosphorus	60 (40-80)	Will decrease with proportion dissolved.
Hydrocarbons/Oils/Grease	85 (80-99)	Depends on level of microbial activity.
BOD	-	Inadequate data
Pb, Cu, Cd, Zn, Ni	75 (40-90)	Will decrease with proportion dissolved.
Litter	-	Litter will simply 'wash off"
Pathogens	-	Inadequate data

Table 9 – Summary of expected porous pavement performance (Source: Fletcher et al, 2003)

Boral in NSW in 2003 outlined the following costing for permeable paving based on five types of design:

- Permeable paving allowing infiltration - $111/m^2$
- Permeable paving over sealed subgrade, allowing water collection: $119/m^2$
- Augmentation with permeable paving (i.e. mixing permeable with normal pavers): $98/m^2$
- Permeable paving with asphalt: $67/m^2$
- Permeable paving with concrete slab: $90/m^2$.

3.3.6 Technology Systems

A number of engineered technology systems are available for use of urban stormwater cleanup. These systems include water quality inlets, hydrodynamic devices, filtration devices etc. which incorporate combinations of filter media, hydrodynamic sediment removal, oil and grease removal, or screening to remove pollutants from stormwater. This literature review does not detail vendor-supplied systems and other proprietary devices due to lack of peer reviewed performance data for these systems. Technology systems such as oil/grit separators or oil/water separators consist of one or more chambers that promote sedimentation of course materials and separation of oil from stormwater (Field and Sullivan, 2003). Many modern separators include screens to retain debris, sand filters to provide additional removal of finer suspended solids, and/or coalescing units to promote oil and water separation (Pitt et al, 1999). These types of systems are used in areas where stormwater runoff has a high probability of containing high concentrations of oils and other toxic organic pollutants that are difficult to treat (Pitt et al, 1999).

3.4 Biochar for Urban Stormwater Cleanup

In order to determine the results of using biochar geostructures for urban stormwater water the research was conducted to identify the performance of biochar for urban stormwater cleanup from current practice. Biochar is a low cost, renewable resource and highly efficient sorbent material, which is being used for removal of various kinds of pollutants (Lehmann et al. 2009; Chen et al. 2011). The recalcitrant and alkaline nature of biochar has been well documented to remove pollutants in water (Lehmann et al. 2006).

3.4.1 Effects of Different Biomass

Biomass is defined as a once living organic matter such as crops, plants, marine organic waste, solid waste, and sewage (Demirbas, 2000). Under different heat conditions the cellular structure of the organic matter is broken down macromolecules fuse together creating stable aromatic structures, micro to nano-sized pores and producer gas (Bridgewater et al, 1999). The physiochemical properties of biochar produced, such as composition, particle size, and pore size depends on the biomass used (Sparkes and Stoutjesdijk, 2011). These properties have a profound effect on the performance of the biochar used for urban stormwater cleanup.

Biochar has a high surface area and porosity where the latter is sourced from the restructuring of the carbon molecules and the release of organic matter. The pore sizes of biochar differ depending on the biomass used to create the biochar where the large surface area provided by micropores within the biochar structure allow for large absorptive capacities, as well as retention (Downie et al, 2009). The biochar surfaces are located within nanometer-sized pores that contain reactive sorption sites, where contaminants become trapped indefinitely. The cation retention of fresh biochar is relatively low compared to biochar which has aged in soil, and limited results exist which clearly identify under what conditions and over what period of time biochar develops it adsorbing properties.

Biochar derived from various biomass show different properties as outlined in Table 10 below.

Parent material	Temp (°C)	SA^a (m2 g−1)	TPV (mg/g)^b or MPA (m2/g)^c	Adsorbate	Effect	Ref.
Pine needle	100	0.65	ND^d	NAPH, NB, m-DNB	The concentration of adsorption in the order of P100 < P200 < P300 < P400 < P500 < P600 < P700	Chen, 2008
	400	112.4	0.0442^b			
	500	236.4	0.0952^b			
	600	206.7	0.0764^b			
	700	490.8	0.186^b			
Cotton seed hulls	350	4.7 ± 0.8	ND	Ni^{2+}, Cu^{2+}, Pb^{2+}, Cd^{2+}	Total concentration of soluble metal ions in soil interstitial waters in the order of: CH350 < CH500 ≈ CH650 < CH800	Uchimiya, 2011
	500	0	ND			
	650	434 ± 3	0.007 ± 0^c			
	800	322 ± 1	274 ± 1^c			
Oak wood	350	450		ND	ND	Nguyen, 2011
	600	642				
Corn stover	350	293		ND	ND	Nguyen, 2009
	600	527				
Broiler litter manure	350	59.5 ± 19.7	0c	Ni^{2+}, Cd^{2+}	350BL < 700BL	Uchimiya, 2010
	700	94.2 ± 5.1	41.8 ± 2.0^c			
Soybean stalk	300	144.14	ND	Methylene blue	The amount of methylene blue sorption in the order of BC300 < BC400 < BC500 < BC600 < BC700	Kong, 2011
	400	138.76				
	500	152.98				
	600	179.03				
	700	250.23				

a SA means BET specific surface area
b TPV means total pore volume
c MPA means micropore area
d ND means not determined

Table 10 – Influence of parent materials and pyrolysis temperatures on surface area and porosity of biochar

Throughout recent decades the development of biochar from low cost adsorbent biomass has gained momentum for their superior ability to remove a broad type of agrochemical pollutants dissolved in aqueous solutions. Experiments by De Wilde et al. (2009) to determine the effectiveness of different biomasses for biochar production such as cow manure, straw, willow chopping, soil, coconut chips, garden waste compost, and peat mix for leaching of herbicides such as metalaxyl, isoproturon, linuron, lenacil, bentazone and isoxaben; it was concluded that the adsorption capacity of the biochar was directly correlated with the organic carbon content, CaO content and the cation exchange capacity of the biomass.

Most recently Rojas et al. (2014) investigated the use of biochar derived from sunflower seed shell, rice husk, composted sewage sludge and soil for the potential of their adsorbent qualities for removal of herbicides such as atrazine, alachlor, endosulfan sulphate and trifluralin molecules from water solutions. The maximum removal efficiency of 73.9% resulted when 1 gram of rice husk was used with 50 ml of pesticide solution. Njoku et al. (2014) investigated the use of sky fruit husk biomass for biochar production as a sorbent for the removal of the herbicide bentazone; which resulted in positive results due to the large surface area derived from the sky fruit husk.

It has been well documented that urban stormwater runoff can carry chemical and nutrients into aquifers. Many factors affect the adsorption properties of biochar which besides the type and chemical structure of the biomass a number of physico-chemical factors affect the adsorption efficiency of biochar. Gupta et al, (2001) studied the behaviour of pesticides for different pH conditions. It was determined that pH had a substantial effect of the adsorption capacity of the biochar due to the change in pesticide solubility and uptake capacity over its surface. Increasing pH levels had a positive effect which was observed by El Bakouri et al. (2009) where raising pH levels decreased biosorption efficiency of endosulfan sulphate using biomass of bamboo canes, date stones, peanut shells, and avocado stones.

3.4.2 Biochar Hydrology

Research has been conducted to determine the water uptake and water movement through biochar (Gray, 2014). Some of this research has been focussed on the ability of the inner ports of the biochar to store water, and the water movement through the tiny pore spaces within the biochar structure. The physical parameters experimented include pore size, total porosity along with the biochar repelling water and having an affinity for water. The experimentation focussed on the main factors of the type of biomass used to create the biochar and the temperature at which the biochar is produced. Results indicated that the highest temperature used to create the biochar had the highest water holding capacity. Additionally the difference in biochars used affected the ability of the biochar to hold water which may have been due to water being repelled.

Few researchers have investigated the effects of biochar to erosion. Researchers such as Cheng et al, (2008), Nguyen et al. (2008, 2010), Cheng and Lehmann (2009) note that large amounts of biochar are lost during stormwater runoff. Rumpel et al, (2006) documented significant black carbon content in eroded sediments sampled at the outlet of a watershed which was twice of that found in the original soil. This provides evidence that biochar is more susceptible to erosion that natural occurring soils in some instances. Wang et al, (2013) conducted small scale column experiments to determine the effects of erosion to biochar which resulted in “diffusion-like” movement of the biochar. It was not apparent as to the specific mechanisms which resulted in the diffusion-like movement, however it was suspected that either the relatively dense sand used in the experiments displaced the light biochar or that buoyancy forces may have been acting on the biochar (Wang et al, 2013).

3.4.3 Does the Science Support the Claims

Biochar has been widely evaluated for its high ability to adsorb pollutants in order to determine its effectiveness in the application of biochar geostructures for urban stormwater cleanup. In recent decades researchers have observed increases in aquatic primary production which is attributed to increased nitrogen and phorphorus supplementation, resulting in eutrophication (Nixon, 1995; Boesch, 2002) which can have negative effects on animals, humans, and aquatic species (Bates et al, 1991). It has been determined that nitrogen and phosphorus over supplementation is a leading cause of impaired waters. Biochar has been extensively documented as an environmental sorbent which can reduce nitrogen and phosphorus leaching from soils (Lehmann et al, 2003), Ammonium (NH_4^+) (Ding et al, 2010), Nitrate (NO_3^-) (Ohe et al, 2003) and Phosphate (PO_4 –P) from aqueous solution (Yao et al, 2011).

Research has proven biochar's ability to sorb molecules in soil, including pesticides (Yu et al, 2006), hydrophobic organic molecules (Smernik, 2005), plant leaf extracts (Peietikainen et al, 2000), and to inhibit growth of microorganisms (Warnok et al, 2007) which has an ability to assist in the breakdown of faecal traces in stormwater runoff. This follows research conducted by Ozeszczuk et al, (2012) to determine the influence of biochar on freely dissolved polycyclic aromatic hydrocarbons (PAHs) in sewage sludge; which concluded that biochar was effective at reducing PAH pore-water concentrations.

Biochar's ability to retain more nutrients coincides with the fact that nutrient loss through leaching can be reduced. This has been proven in the laboratory (Dunish et al, 2007; Noval et al, 2009; Laird et al, 2010; Singh et al, 2010) and green house studies with plants found that biochar addition to a tropical soil led to a reduction in leaching of ammonium (NH_4^+), calcium (Ca), and magnesium (Mg) (Lehmann et al, 2003). Beck et al, 2010 studied the effect of changes in stormwater runoff quality and quantity for greenroof water and its ability to retain nutrients in soil. Experimentation was carried out using prototype trays as greenroof models with planted sedum and ryegrass with barren soil trays used as controls. Using a rain simulator it was determined that the addition of biochar to greenroof soil resulted in increased water retention and a significant decrease in discharge of total nitrogen, total phosphorus, nitrate, phosphate, and organic carbon from tray samples.

Biochar based contaminant filters is one of the most promising geostructures for the removal of contaminants from urban stormwater runoff. The *Biochar Demonstration Project* for pollution remediation for Sweet Home, Oregon conducted experiments on a Water Treatment Plant was submitted by the Family Forests of Oregon in 2014. The project evaluated the potential of locally available biochar products to remove water-borne pollutants contained in treated outflow wastewater from a wastewater treatment plant in Sweet Home, Oregon. Although this project did not relate to experimentation of biochar for removal of pollutants from urban stormwater it does provide interesting data for the removal of similar pollutants found in stormwater. Wastewater samples were collected and tested to establish the baseline pollutant levels from the wastewater treatment plant. The water samples were then passed through filters containing biochar, made from forest biomass, and biochar blended with a range of materials including compost, oyster shells, perlite, iron filings, and steel wool. The samples were then tested post-treatment to determine the performance of contaminate removal. The following tables outline the results obtained.

Media Mixture	Biochar Source	% Biochar	Components
1	#1	100%	100% biochar
2	#1	75%	25% compost
3	#1	75%	25% oyster
4	#1	75%	12.5% compost, 12.5% oyster
5	#2	100%	100% biochar
6	#2	75%	25% perlite
7	#2	75%	12.5% perlite, 12.4% oyster
8	#1	87.5%	12.5% iron rust
9	#2	87.5%	12.5% iron rust
10	#1	75%	12.5% iron rust, 12.5% oyster
11	#1	75%	12.5% iron rust
12	#1	87.5%	12.5% steel particles
13	#2	87.5%	12.5% steel particles
14	#1	75%	12.5% steel particles, 12.5% oyster
15	#2	75%	12.5% steel particles, 12.5% oyster

Biochar sources #1 and #2 had similar levels of organic carbon and mineral ash, however a substantially higher pH in biochar #2.

Table 11 – Media mixtures used in nutrient and heavy metal removal experiments (Source: Family Forests of Oregon, 2014)

Media Mixture	Ammonia % removed	Nitrate % removed	Phosphate % removed	Copper % removed	Zinc % removed
1	9.1%	-1.2%	3.5%	96.8%	7.5%
2	-63.6%	3.3%	-0.5%	100%	99.7%
3	45.5%	-6.1%	14.5%	98.2%	44.3%
4	27.3%	-2.5%	7.6%	99.5%	67.1%
5	27.3%	-3.5%	4.4%	97.4%	6.5%
6	9.1%	-4.5%	6.1%	97.2%	7.6%
7	9.1%	-2.6%	7.6%	96%	17%
8	-9.1%	15.3%	6.1%	-	-
9	27.3%	12.4%	2.1%	-	-
10	-9.1%	13.5%	8.7%	-	-
11	27.3%	12.7%	22.8%	-	-
12	40%	-0.8%	97%	99%	98.4%
13	96%	3.1%	97%	96.3%	93.1%
14	44%	0.8%	97%	96.3%	93.6%
15	35%	3.8%	97%	96.8%	94.1%

Table 12 – Removal rates by biochar media (Source: Family Forests of Oregon, 2014)

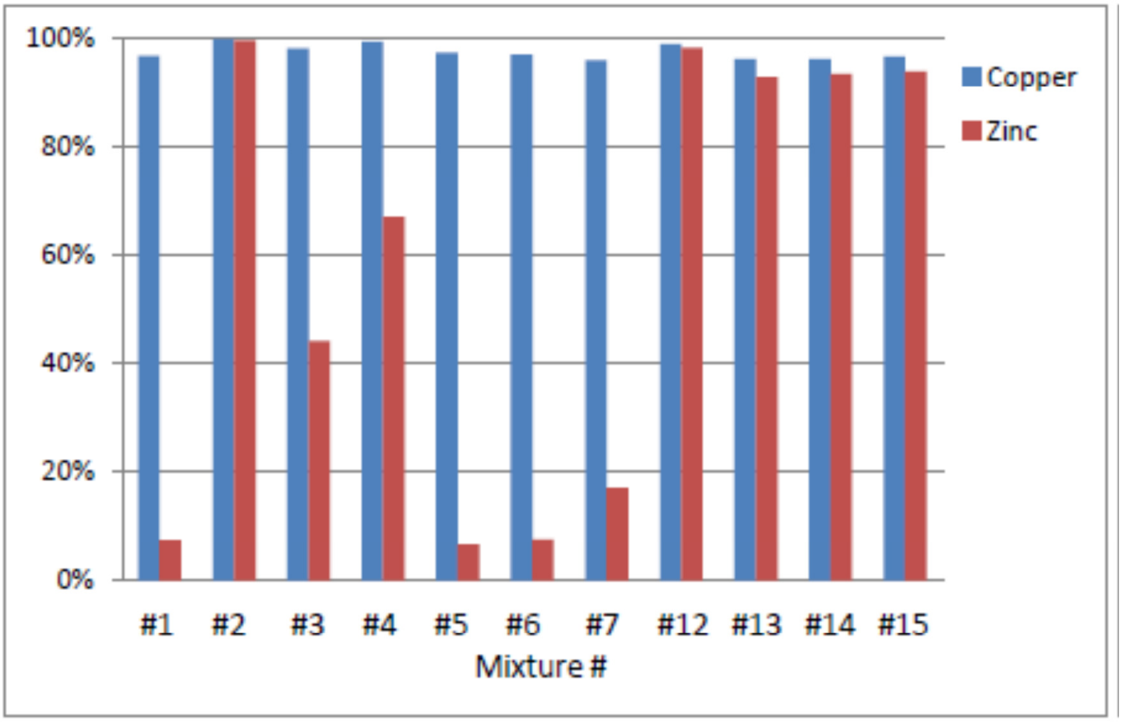

Figure 4 – Copper and zinc removal rates for biochar based filtration media mixtures (Image: Pacific Pyrolysis)

The laboratory results outlined above show that biochar based filters are effective as filtration media to remove contaminates from polluted water, however it is important to note that the media mix is required to be designed for specific pollutants.

Figure 5 below outlines the results of experimentation conducted by Al-Anbara et al., (2008) for different filtration media used for the removal of pollutants from urban stormwater samples. The results clearly show that the use of biochar (GAC denoted for biochar) as a filtration media in test samples provided positive results. Overall biochar and zeolite provided the most positive results for pollutant removal over the entire filter media used. It is important to note that no one filter media provided 100% removal of all pollutants, and a combination of biochar and zeolite used as filter media for pollutant removal provided further removal rates of pollutants from urban stormwater. This is positive research for the use of biochar to be used in combination with other filter media for improved pollutant removal from urban stormwater.

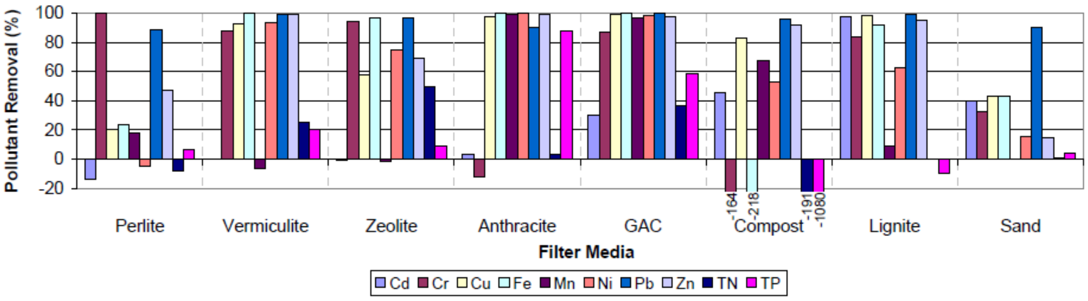

Figure 5 – Biochar vs Other Filtration Media (Source: Al-Anbara et al, 2008)

The herbicide atrazine is used widely throughout the world and is also documented as a widespread groundwater and surface water contaminant. Biochar has proven ability to sorb organic compounds and research by Delwiche (2013) experimented to determine biochar impacts on atrazine leaching in different soil conditions. The research determined that biochar additions in undisturbed soil columns did not significantly reduce atrazine leaching however peak groundwater atrazine concentrations were 53% lower in field experimentation. This concluded that biochar application to soils has the ability to decrease peak atrazine leaching; however varied soil conditions, mainly in favoured flow paths, reduced its ability.

Liqiang Cui et al. (2013) experimented with pymetrozine, an insecticide widely used in China, which concluded that biochar derived from different biomass had great potential to adsorb pymetrozine. However a number of parameters during the experimentation had an impact on adsorption, namely the pH of solution, contact time, initial concentration of the ions and temperature. The results showed that the biochar had adsorbed the pymetrozine by both physical adsorption and partial chemical ion exchange; which shows the effects different forms of biochar (derived from different biomass) can have on insecticides.

3.5 Biochar Existing Geostructure Research

To date, extensive experimentation using biochar in the laboratory has been conducted. Limited field trial experimentation has been conducted to determine the effect of using biochar for the removal of urban stormwater pollutants. Field trials are necessary as it provides site specific results which can be documented to evaluate the short and long term effects of pollutant removal using biochar.

The Hope Mine project in Colorado saw a research team install the world's first fully scaled biochar reclamation trial at the historic silver mine in Aspen, Colorado. Biochar was added as a soil amendment derived from dead pine tree biomass which was applied to the mine waste rock piles. This was conducted to increase the moisture content to revegetate the steep slope stock piles which had zero irrigation, 35 degree slopes and only 80 continuous frost free days. The result was overwhelming in that in less than 1 year (11 months) the stock piles were visually covered in substantial vegetation. This provides positive results outlining the potential of biochar used as a soil medium for revegetation to assist with reduced soil erosion and the ability of biochar to aid plant life in poor soil types with low water exposure. This field trial provides results which show biochar will assist with improved stormwater quality due to the filtration of stormwater via bioretention methods.

Several field studies have been conducted using biochar as a soil amendment; an interesting study conducted Ground level, Inc. investigated the potential benefits of incorporating biochar as a soil amendment for wetland reclamation. The location selected for the study had poor soil characteristics which were sandy, containing low organic matter and low pH levels. Additionally the site does not receive sufficient water due to large drought periods. Water quality degradation is also an issue due to pollutants found in the stormwater runoff from the agricultural areas. The purpose of the study was to find a cost-effective and sustainable tool to improve current restorations practices and increase plant survival and growth to decrease restoration management time and cost. The goal of the research was to find the biochar application method and rate that will significantly increase tree survival and growth while still being cost effective.

The application methods used were disking the biochar into the soil and hand filling the planting hole with biochar. The disking application of the biochar into the soil provides long term tree growth and contributes to the establishment of ground cover vegetation where large areas are covered for stormwater runoff treatment; however this method requires a large amount of biochar to be used and requires the use of heavy equipment. Whereas hand filling application of biochar into the soil around the plant provides for initial tree establishment assistance as the biochar is concentrated around the tree base which requires no heavy equipment and less biochar being required. However this method does not assist in ground cover establishment therefore providing less stormwater runoff filtration and less long term tree growth assistance due to the small amount of biochar used.

Biochar was used in sand biofilters for industrial stormwater filtration in the Port of Tacoma, West Hylebos Pier Log Yard. Due to debarking treatments to ensure pests are not transported across oceanic waters, the stormwater runoff from the facility carried high pollutants loads which were difficult to control. Faced with the possibility of the operations being closed, the Port designed and constructed a $2.7 million treatment facility. A number of runoff treatment approaches for the site including transferring flow to the local municipal wastewater treatment plant, wetlands, and other advanced treatment methods. The port chose to mimic nature's own filtering processes as it provided the most cost-effective solution and achieved the desired result. A pilot study was implemented to evaluate the adequacy of biofiltrations for treating polluted runoff, which resulted in the construction and implementation of the full biofiltration system onsite. The entire system constructed was 183 metres long and 14 metres wide. The system consists of four filtration stages which consist of two pretreatment stages of pea gravel and sand amended with biochar; and two biofiltration stages which consist of sand amended with compost planted with vegetation, and sand amended with compost planted with vegetation. Each filtration stage is layered on pea gravel ontop of a layer of drain rock which consists of underdrain pipes to collect the filtered stormwater flows. Monitored parameters have been reduced by 92% for zinc, 81.3% for copper, 94% for turbidity, and 85% for total suspended solids. Figure 6 below shows the monitoring results for pre and post treatment of the filtration system.

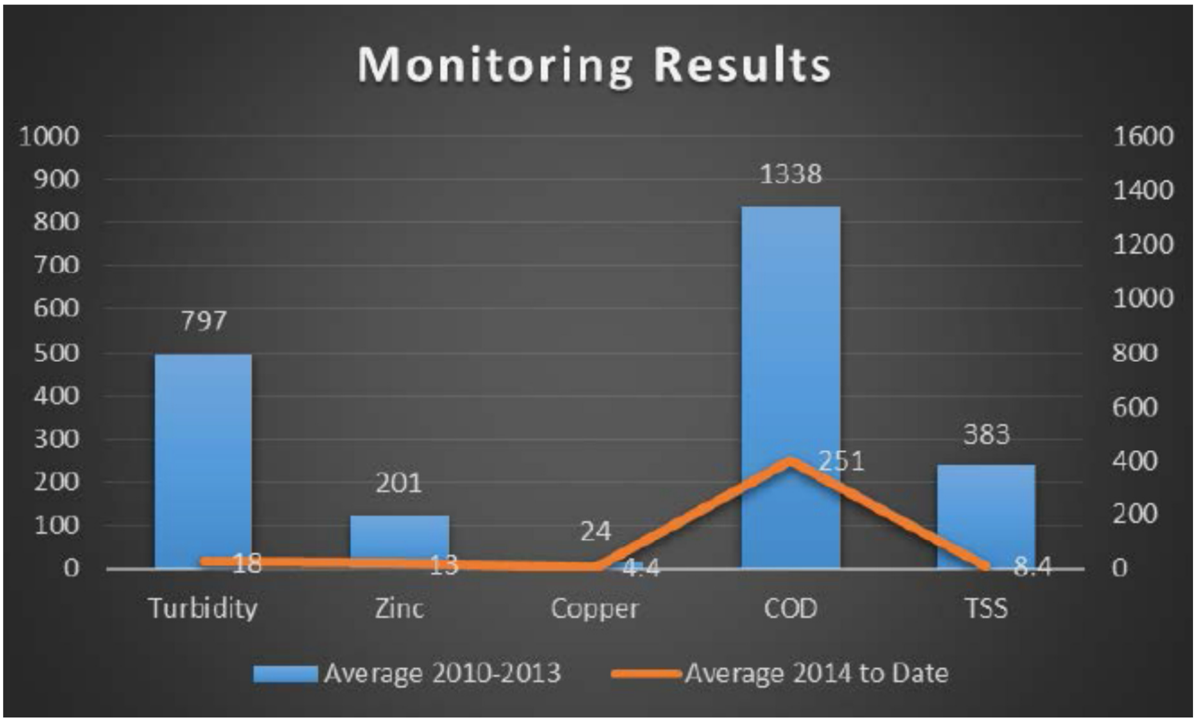

Figure 6 – Monitoring results for pre and post treatment for filtration system at West Hylebos Log Yard (Source: Port of Tacoma)

The use of biochar in green roof media has been successfully trialled by Cao et al, 2014. Using 30% of biochar in scoria roof media was proven to increase plant water availability by 16%. Beck et al, 2011, conducted field trials for green roofs by adding 7% biochar to scoria based media which improved the effluent runoff with 70% reduction in Nitrates, 40% reduction in Phosphates and 70% reduction of organics; compared to an un-amended control green roof.

An interesting field trial conducted at the Port of Port Townsend boatyard, named Boat Haven supported an initial laboratory testing procedure to determine the most effective biochar based treatment media to remove the most common pollutants found in the stormwater being generated from the site; namely copper and zinc. Some of the highest zinc sources for pollutants from the site and from galvanized roofs and chain link fences where the levels in the stormwater exceed site discharge permit requirements. Laboratory experiments were designed to test different biochar mixtures for metals removal from the site stormwater runoff which investigated both flow rate and metals removal characteristics. The experiments were compared to that of the untreated stormwater runoff being captured from the site. Both flow rate and metals removal data was used to select the most effective mixture using biochar to be implemented in the field trial. Following the laboratory testing a pilot project was installed at the site in April 2014, which consisted of the installation of the downpipe from one of the structures from the site to an in-ground sand filter with a biochar based media. Results from the field trial were positive as the zinc levels were reduced by over 99%. A similar field trial for an industrial roof downpipe system discharging into a biochar media mixture in a large plastic container has been conducted in Vancouver, WA. The system has been in use for 3 years and has resulted in 49-63% copper removal, 31-67% lead removal, and 49-98% zinc removal for stormwater runoff from the industrial roof system.

3.6 Enzymatic Bioremediation

World dependence in the use of herbicides to improve primary production has resulted in groundwater and surface water bodies being polluted by the most commonly used group of herbicides known as triazines. Within the group of triazine herbicides one of the most widely used in Australia is called atrazine. Even when atrazine is used at the recommended levels the herbicide migrates into waterways having detrimental impacts on aquatic life and humans; symptoms such as headaches and nausea to more chronic illnesses such as cancer and endocrine disruption have appeared from animal studies. Studies of cities in the farm belts of the United States of America has revealed spikes in the levels of atrazine in the drinking water supplies which exceed the health limit set up by the Environmental Protection Agency.

Research into the use of biological agents (bioremediation) to remove triazine from the environment using genetically modified organisms (bacterium called *Escherichia coli*) was trialled, however was not successful due to the high level of regulation and ecological uncertainties surrounding using genetically modified organisms. However researchers at NewWater with a vision of cleaning atrazine from drinking water have had successful trials with a group of bacterium called *arthrobacter* which feeds on atrazine. The organisms are effective in that they can consume their weight in atrazine every two seconds, which results in 50 grams of organisms consuming 50 grams of atrazine every two minutes. Using these organisms' researchers are developing a water filter that exploits the appetite of the organism. The filters would operate differently to current water filters in that they do not capture the atrazine, but rather break down the atrazine into harmless substances. The concept has also been tested in the field where a truck spill resulted in atrazine contaminating a field in South Dakota. A researcher from the laboratory using the enzyme *arthrobacter* offered the enzyme at the site which had eaten the atrazine to a level that the EPA certified the soil as clean. It was a good demonstration that the bacteria would work outside of the laboratory as up to 1,000 pounds of the atrazine that had polluted the soil was removed (Wackett, 2005). To date, resistance from regulators to approve the use of genetically modified organisms has stalled their use as larger scaled tests are to be conducted to obtain government approvals. The drawback in using living organisms for urban stormwater cleanup is that they require ideal conditions to thrive, where in some regions where long periods of drought occur, the organisms cannot survive; therefore making them ineffective.

As a result, CSIRO Entomology scientists have been working on an enzyme based remediation alternative which involves the use of non-living organisms. The CSIRO group conducted a large scale trial of an enzyme based product in the sugar growing region of northern Queensland. The trial has shown that water bodies contaminated with the most common triazine herbicide, atrazine can be successfully remediated using enzymes. In order to develop the enzyme, the CSIRO group found specific bacteria that fed on atrazine and then identified the enzymes within the bacteria which converted the atrazine to non-toxic by products (Scott, 2009). The enzyme was then modified in a laboratory so that it was suitable for large scale applications and mass production. The trial captured water runoff from an irrigated sugar field into a holding dam with irrigation tailwater treated with a concentration of atrazine. Water samples were taken prior to the addition of the enzyme, and then the enzyme was evenly spread across the surface of the holding dam by hand. Initially there was a short delay prior to any atrazine reduction, which was most likely due to the mixing of the enzyme with the water in the dam; however within the first four hours the concentration of the atrazine in the water was reduced by 90 per cent. It is also worth mention that the trial identified that enzyme degraded in the environment as it stopped working after 24 hours of being applied to the water in the dam. Therefore further long term field studies are required to determine the longterm efficiency removal of pesticide removal using enzymatic bioremediation techniques.

As documented earlier within this thesis, the different use and production techniques for biochar development produces varied results for specific pollutants removed in aqueous solutions. That is, not one type of biochar will successfully remove all pollutants in stormwater samples. This is the same for enzymatic bioremediation. Specific enzymes have varied efficiency removal results for different pesticides. This is due to the chemical diversity used in pesticide development; where the biochemistry of pesticide bioremediation requires a large range of catalytic mechanisms to neutralise the toxicity of the pesticide which therefore requires a wide range of enzyme classes. Table 13 below provides a summary of enzymes that have the potential or proven application in the bioremediation of pesticides.

Enzyme	Enzyme Commission (E.C.)	Source Organism(s)	Cofactor Requirements	Documented Target Pesticide(s)	Current Bioremediation Strategies Employed
Gox	1.5.8	*Pseudomonas* sp LBr; *Agrobacterium* strain T10	Flavin (FAD)	Glyphosate	*In planta*
Esd	1.13.14	*Mycobacterium* sp.	Flavin and NADH	Endosulfan and Endosulfate	Not yet in use
Ese	1.13.14	*Arthrobacter* sp	Flavin (FMN)	Atrazine, Norfluazon and Chlortoluron	Not yet in use
Cyp1A1/1A2	1.14	Mammalian (Rat)	Heme and NADN	Linuron, Chlortoluron and Isoproturon	*In planta*
Cyp76B1	1.14	*Helianthus tuberosus*	Heme and NADN	Linuron, Chlortoluron and Isoproturon	*In planta*
$P450_{cam}$	1.14	*Pseudomonas putida*	Heme and NADN	Hexachlorobenzene and Pentachlorobenzene	Transgenic *Sphingobium chlorophenolicum*
TOD	1.14.12	*Pseudomonas putida*	Fe^{2+} and NADH	Trifluralin herbicides	Not yet in use against pesticides
E3	3.1.1	*Lucilia cuprina*	None	Synthetic pyrethroids and phosphotriester insecticides	Not yet in use
OPH/OpdA	3.1.8	*Agrobacterium radiobacter;* *Pseudomonas diminuta;* *Flavobacterium*	Fe^{2+} and Zn^{2+}	Phosphotriester insecticides	Free-enzyme bioremediation
LinB	3.8.1	*Sphingobium* sp.; *Sphingomonas* sp.	None	Hexacholorcyclohexane (β- and δ-isomers)	Bioaugementatation with *Sphingobium indicum*
AtzA	3.8.1	*Pseudomonas* sp. ADP	Fe^{2+}	Chloro-s-triazine herbicides	*In planta* and GM bacteria
TrzN	3.8.1	*Nocardioides* sp.	Zn^{2+}	Chloro-s- triazine herbicides	Not yet in use
LinA	4.5.1	*Sphingobium* sp.; *Sphingomonas* sp.	None	Hexachlorocyclohexane (γ- isomer)	Bioaugementatation with *Sphingobium indicum*
TfdA	3.8.1	*Ralstonia eutropha*	α-ketoglutarate and Fe^{2+}	2,4-Dicholorophenoxyacetic acid and pyridyloxyacetate herbicides	*In planta*
DMO	1.13	*Pseudomonas maltophilia*	NADH and a Rieske Fe-S centre	Dicamba	*In planta*

Table 13 – Different enzyme removal of specific pesticides (Scott et al. 2008)

4. Methodology

Protecting natural water bodies and ecosystems has been identified by governments as a main priority due to the increasing urban development having a significant impact on water quality pollution. Strict conditions are being applied to urban developments in an attempt to reduce stormwater pollutants such as heavy metals and organics from entering into waterways. As a result research has been conducted on biochar and its effect on being implemented in geostructures to improve urban stormwater pollution to achieve an acceptable stormwater quality being discharged from developments. This thesis focuses on the efficiency of biochar as a filtration media for stormwater and the on-going research being conducted on different biochar media sourced from different biomass and the effect of emerging methods such as the use of enzymes for the treatment of biochar.

Using biochar geostructures for urban stormwater water cleanup will change the water quality thus proving biochar's effectiveness for stormwater remediation. Due to its sorption properties as well as its positive effect as a soil additive, experimental results show that biochar can be utilised as a renewable filtration medium (Lehmann, 2009). Options derived from the review of literature and current practices using biochar within this thesis will be collated to determine full scale field studies which can be implemented to test biochar's pollution removal efficiency. With this information options for developing engineering geostructures which can be implemented in order to document the practicality in using biochar for the removal of pollutants in urban stormwater and to determine the long term efficiencies of the pollutant removal using biochar.

Interest in biochar has been growing internationally with engineers, scientists, and researches working to validate the use of biochar for stormwater water cleanup. The potential uses of biochar include water treatment, carbon sequestration, soil amendment, re-vegetation, and being utilised in bio-retention systems. Due to the strict regulations being imposed on urban development, increasing interest is evolving for alternative filtration media that can successfully remove certain pollutants from stormwater.

In order to determine the results of using biochar geostructures for urban stormwater water a review of the research conducted to date was compiled. This was a critical component of this thesis as it provides a basis to collate the work carried out using biochar and allows a way forward for the type of geostructures that will be effective in practise due to the current results obtained by researchers. As an example, a study into biochar to determine the saturated hydraulic conductivity and methoylene blue sorption characteristics as applied to storm water treatment; Morrow (2013) concluded that high velocity passing through the biochar did not affect the hydraulic flow of the stormwater which shows promise for large amounts of stormwater being able to flow through a geostructures system containing biochar. However, it was also concluded in the study by Morrow (2013) that the contaminants would most likely not adsorb onto the biochar unless the retention time was increased to allow the contaminants time to adsorb into the biochar. This shows that biochar would work more effectively as part of a larger stormwater system such as part of a rain garden or a biofiltration system to help reduce the stormwater flow through the system allowing for longer retention time. Additionally it was determined that by reducing the size of the biochar would also decrease the macro-porosity while at the same time reduce the velocity of water flow through a system utilising biochar.

4.1 Biochar Development for Specific Characteristics

With many potential raw materials (biomass) used for biochar production and the multiple positive attributes of each, biochar remains a mystery. The specific desirable properties of the different biochar produced is a basis for aspiring research programs on what specific pollutants can be removed from urban stormwater runoff. Biochar has properties and molecular structures that possess unique adsorption properties for vapour and liquid phase organic molecules.

The biomass material used for producing biochar will affect the physical structure, texture, porosity, particle size distribution and density of the final product. The manufacturing process used to create biochar is the pyrolysis process where the conditions of the production can be altered to change the product characteristics. Pyrolysis temperature processes at temperatures above 500˚C produce biochar that have a higher resistance to weathering, due to the higher surface areas and aromatic structure (Kim, 2003). The higher surface areas lead to greater pore formation which allows more areas for the binding of nutrients and provides more areas for microorganisms to thrive. Larger pore sizes also allows for increased binding of cations and anions which provide nutrients for plants and soil organisms. Additionally pore formation influences the binding of macronutrients such as nitrogen and phosphorus which provides great benefits in reducing the eutrophication process in creek and river systems.

Biochar produced at lower temperatures (<500˚C) are able to better retain nutrients, and the ability for higher reactivity in soil providing added benefits for soil fertility purposes. This not only assists with soil fertility due to the nutrients being less mobile in biochar so that they last longer in the soil, but also as biochar provides the added benefit of reducing leaching and volatilization over longer periods of time instead of polluting groundwater and waterways. As there are advantages and disadvantages for biochar production at both high and low temperatures, the optimum temperature for biochar production is mostly set at 500˚C.

This leads to the conclusion that biochar created at high temperatures are well suited for bioretention geostructures for urban stormwater cleanup due to their ability to adsorb pollutants due to the large pore size and structure. These large pores sizes within the biochar structure also provides greater nutrient and water sorption capabilities which provide an ideal environment for wetland plant life to be sustained longer during drought periods and for increased nutrient uptake. This is especially important in sandy soils which have poor nutrient retainment and water holding capacity.

The selection of the type of biomass used to manufacture biochar is dependent on the type of contaminants being targeted within urban stormwater runoff. Section 3.4.1 within this thesis provides examples of the different types of biomass used for biochar manufacture and its effect of specific pollutant removal based on literature currently available. For the purposes of batch experimentation which is conducted as part of this thesis, biochar derived from hardwood biomass was sourced online from Dolph Cooke, founder of the organisation named Biochar Industries Australia. Biochar derived from hardwood was chosen due to the large surface area and large pore structure that is a result of the biochar manufactured from hardwood. Additionally the hardwood biomass used to manufacture the biochar is readily available and produces less soluble minerals, reducing the potential to contribute to the pollution of the batch experiments conducted in the field.

4.2 Biochar as a Soil Amendment

Biochar is often referred to as an amendment to improve soil quality. Improvements include improved biological nitrogen fixation and nutrient retention (Chan et al, 2007), to reduce pesticides in plants (Yu et al, 2009; Kookana, 2010), control of phytotoxic heavy metals (Uchimiya et al, 2010), a decrease in nitrogen and phosphorous pollution (Lehmann et al, 2006). The carbon in biochar can be resistant to decomposition when placed in soil and can persist for hundreds or even thousands of year, hence interest in the utilisation of biochar as a soil amendment (Roberts, 2010). The specific impacts on the soil vary from the biomass used to create the biochar or using different pyrolysis conditions to create the biochar (Singh et al, 2010; Uchimiya et al, 2010). The main purpose of using biochar as a soil amendment is its ability to sequester carbon as it is more stable than that of biomass (Lehmann, 2007), where its application to soil enhances soil fertility and crop productivity. However it is important to review literature on how the above mentioned properties are advantageous in using biochar as a soil amendment for use in geostructures for the potential of urban stormwater cleanup.

Biochar has been investigated as a soil amendment to date, due its ability to reduce greenhouse gas emissions as the carbon stores in biochar are stable for hundreds of years which creates a carbon sink in the soil. Due to the pyrolysis process for making biochar, carbon in stabilised and captures gases that would normally be released into the environment through natural decomposition such as CO2, Methane, and Nitrous Oxide (Lehmann and Joseph, 2009). Advantages of using the biochar as a soil amendment in field studies are due to its characteristics of being neutral to alkaline pH where biochar raises the pH level of acidic soils and eliminates and/or reduces the lime requirements for soil (Lehmann and Joseph, 2009). The low bulk density of biochar also reduces soil compaction which aides in improving the sorption of water into the soil and provides ideal conditions for plant species to grow due to improved root penetration, which also reduces fertilizer need. This provides the ability for nutrients to be retained in soil and remain available for plant species by adsorption of minerals and organic matter. Biochar does not have the ability to change the mineralogy of soil; however it does have the ability to change the amount of soil organic matter to aid in adsorbing cations per unit carbon, retaining exchangeable and therefore plant available nutrients in the soil (Lehmann, 2007). This makes biochar a unique substance for use as a soil amendment for wetlands, biofiltration systems and other natural open space infiltration methods used for urban stormwater cleanup due to its ability to promote vegetation growth while decreasing pollution volumes due to nutrient uptake by the vegetation within these systems.

The use of biochar geostructures for urban stormwater cleanup by incorporating the biochar as a soil amendment would be useful for data extraction to determine the longevity of biochar after many years of its application in the ground. Little is known of the effects of weathering and the reactions that occur after the application of biochar to soils (Singh and Cowie, 2009; Kuzyakov et al, 2009). The ageing of biochar takes place from the moment it has been manufactured, and continues once it is applied to the ground which is governed by conditions of moisture (Nguyen and Lehmann, 2009) and temperature (Cheng and Lehmann2009; Nguyen and Lehmann 2009). Some biochars may decompose rapidly in soils, while others are maintained for thousands of years; therefore more information is required to study the behaviour of biochar in soil and the effects the changes will have on the pollution removal in urban stormwater runoff.

4.3 Batch Experimentation

The biochar geostructures outlined within this thesis are derived based on the information provided from experimental work conducted by researchers to date and have been extensively collated to obtain a methodology of field experimentation to remove pollutants from urban catchments. Biochar selection for specific sites and the type of geostructures used will primarily be most successful when based on batch tests. As such the methodology used for this thesis will consider the use of batch experimentation for the type of biochar geostructures to be implemented on a specific site for urban stormwater cleanup.

In order to conduct experimentation as part of this thesis a batch experiment was conducted using a biochar geostructure for urban stormwater cleanup. The batch experimentation was conducted as research has shown that different biomass used to create biochar, the process used to manufacture the biochar (i.e. pyrolysis temperature), the type of pollutants to be targeted for removal, soil types, and the environmental conditions of a site; all have an effect on the performance of biochar for the removal of pollutants from urban stormwater runoff.

For the purposes of this study the site chosen was a 100 lot residential development located in Griffith NSW (Figure 7). The catchment of the development area is 115 km^2 and comprises of a mixture of low and high density residential allotments which are predominately developed. The different surface types within the development (such as roof, roads, driveways, lawn areas etc.) influence the timing and volume of runoff that reaches the drainage channel system at the end of the developed area. The residential area is part of a new residential zone area which has the potential to be an example of the way in which the use of biochar geostructures can be implemented to improve the pollutant loads discharging from the developed area.

Figure 7 – Locality Map of Experimentation Conducted

It is well documented that urbanisation has one of the greatest impacts of any land-use on catchment runoff. Urban developments have large areas of hard impervious surfaces such as roads and roofs that limit infiltration into the ground. This results in a greater volume of runoff and greater pollutant loads entering the drainage systems. The residential development used for the research areas incorporates an underground trunk stormwater drainage system along with overland surface flow from the development drains to a designed detention basin system which is planted with kikuyu grass. The design of the detention system has been sized to cater for pre and post development flows from the site. This reduces the time for stormwater flows to leave the catchment and enter into the downstream drainage channel system of the development which results in lower flows and longer during peaks in the channel flows.

Discharge from the residential development drains to the detention basin which enters the downstream drainage system. The downstream drainage channel system, is part of a network of drainage channel systems which discharge into the end drainage wetland system located south of the city of Griffith. The pollutant runoff volumes play an important part in determining the health of the drainage systems in Griffith and it is this premise that the methodology for this dissertation takes into consideration for experimentation work. As such it is the immediate drainage channel system which the subject development discharges into which will be the focus of designing a system utilising biochar as a soil amendment for a biofiltration system to remove pollutant loadings from the runoff generated from the development. Samples of stormwater runoff into the drainage system will be taken and a series of tests will be conducted to determine the effect biochar added as a soil amendment will have on the reduction of pollutants from the water.

Figure 8 – Study Area Drainage Channel retention system, where a 100 residential lot development discharges stormwater runoff.

The area chosen for the design system to be implemented within the drainage channel system is shown in Figure 8 above, and the discussion section of the dissertation examines how the pollutant runoff concepts discussed within the previous sections of the thesis can be put into practise to improve the immediate environment.

The value of this work is the use of actual stormwater taken from the end system of the 100 residential lot development in Griffith NSW, whereas similar studies consider only a synthetic matrix to emulate stormwater qualities of pollutants (Liu *et al.*, 2005, Trowsdale *et al.*, 2007). Additionally, soil from the subject site will also be used for the batch experimentation in order to determine the suitability of using biochar geostructures for this system; and the testing of different media parameters which has the greatest result in pollutant removal.

As such it was the intention of this thesis for experimentation to be conducted in order to substantiate the system proposed to be used at the site. The addition of biochar to stormwater treatment systems will change the physical properties and activity present within the soil, resulting in increased retention of pollutants allowing microbial activities to change the toxins within the soil to less invasive chemical structures on the environment. Through the research conducted on the effective results of biochar in removing pollutants in laboratory settings, along with the need for improved sustainable resources for use in geostructures for urban stormwater cleanup in field trials, combining the two research areas is a logical direction for the research conducted as part of this thesis.

It is known that different biomasses used to produce biochar, along with the different pyrolysis temperatures used in the manufacture of biochar; have different results in different pollutant removal. As such the research aim for this thesis is to conduct batch experiments using stormwater and soil samples from an urban study area to record the results of the potential benefits to the area when employing biochar as a use for geostructures for urban stormwater cleanup. Additionally this thesis will provide a basis for future work using biochar when literature has shown the potential for its use in stormwater geostructures for pollutant removal in stormwater runoff.

5. Materials and Methods

As documented within the literature review of this thesis, laboratory experimentation has been conducted by researchers using biochar to determine is effect on pollutant removal from stormwater and wastewater. This is invaluable information as it provides results from a controlled environment which reduces the effect of irregularities which may occur in the environment. Laboratory experimentation provides an opportunity to establish common grounds for testing biochar so that comparisons can be made in regards to its performance under specific conditions.

The materials and methods used for the experimentation conducted as the basis for this thesis were chosen in an attempt to replicate a real life model. It would enable to establish the performance of the biochar under conditions obtained from the study site such as stormwater runoff from the urban environment, and utilise the soil from the site to study the performance of the biochar. This would provide a basis to design the appropriate biochar geostructures to be implemented for urban stormwater cleanup in the locality. Once this was achieved, an attempt was made by the author to document the use of biochar in existing stormwater geostructures, which were modified to establish the most effective means of removing pollutants in urban stormwater runoff. This would also form the basis of further work which could be conducted using biochar geostructures for urban stormwater cleanup.

5.1 Biochar for Testing

Initially it was attempted by the author to produce biochar from biomass readily available in Griffith NSW. As Griffith is located in an agricultural area, known for its mass production of poultry, wine and grain produce. This provides substantial opportunity for a number of sustainable products to be used as biomass for the production of biochar. Ultimately the premise of using the biomass which is readily available in Griffith holds true for the production of biochar and its benefits in the agricultural sector have been widely documented (Lehmann, 2009); however for the purpose of this thesis which is for the removal of pollutants in stormwater, it cannot be confidently stated within this thesis that the production of biochar using this biomass holds true. However for the purposes of this thesis the method attempted for the production of biochar by this author for experimentation purposes will be briefly discussed.

Substantial documentation is available as to the process of biochar production. This has been discussed in previous chapters of this thesis; biochar is created by the process known as pyrolysis. This process is where biomass (usually in its most pure form for biochar production is made via renewable resources) is heated in a process where the biomass is deprived of oxygen which produces a charcoal like product, widely known as biochar.

In one of the crudest ways to make a form of biochar, a 44 gallon drum was used which contained a lid which could be sealed tight so prevent oxygen escaping the drum. A number of 20mm holds where drilled into the bottom of the drum on one side in a circle so that this part of the drum would be face down over the fire (again ensuring oxygen could not escape from the drum). Rice stubble and chicken manure were used in different batches which involved placing the chicken manure in the 44 gallon drum and sealing the top of the drum with the lid; then rolling the drum onto a fire with the holes of the drum facing down into the fire. The drum was elevated off the ground by the use of bricks so that the fire could penetrate the bottom of the drum as even as possible. The drum was left on the fire for 5 hours, after which time the drum was rolled onto a bed of fine sand, with the holes in the drum again facing down onto the sand to promote oxygen depletion in the drum. The contents of the drum were allowed to cool and the contents were removed. What should have been produced was biochar, however this was not successful and all that was produced was foul smelling soot. Other attempts were made however were also unsuccessful.

As such biochar was gratefully donated from charmaster Mr Dolph Cooke of Biochar Industries Australia (Figure 9). The biochar was produced from hardwood plantation thinning (trees that fell over naturally known as hardwood category 1) and is marketed as Barefoot Biochar; which is available for purchase online through Biochar Industries Australia.

Figure 9 – Photo of Actual Biochar Media Used for Experimentation

5.2 Biochar Sample Analysis

Moisture content of the biochar (scientifically tested based on single determinations of subsamples from the manufacturer) are between 14-22% moisture with the following average analysis results obtained by the manufacturer during testing:

Fixed Carbon	85.2% (Highest Carbon)
Volatile Matter	9.4% (Lowest Volatile Matter)
Ash Content	5.4% (Lowest Ash)
pH	9.18
Loose Dry Density	0.29%

Table 14 – Sample Biochar Used Testing Analysis Results (Source: Biochar Industries Australia, 2014)

It is important to note that the biochar at the end of the production process is smothered with water to avoid the material becoming hydrophobic. The pyrolysis temperature of the biochar sourced is measured as being between 480˚C and 650˚C. It is important to note that the biochar used is created only for soils and has every drop of volatiles removed via soaking in heat; where the char is subjected to 5 hours of radiant heat to break down all of the chains of the biomass (Biochar Industries Australia, 2014).

5.3 Container Experiments

Container experiments were used to evaluate the effect of biochar on Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, and E-Coli concentration in stormwater runoff samples taken from the stormwater retention system from a 100 lot residential development located on Citrus Road, Griffith. The sorption rate of stormwater through different soil and biochar ratios in the containers was also experimented. The containers used for the experiments had a volume of 18 Litres with approximate dimensions of 300mm long, 220mm wide, and 260mm high. The containers were filled with soil taken from the subject site and flushed with stormwater samples for 15 minutes until the soil media was saturated. Each container experiment was conducted using the same method with the different soil and biochar ratio mix and samples were collected via a porous 20mm diameter pipe at the bottom of the container as the stormwater passed through the soil media. Stormwater was collected from the retention pond via 5 Litre containers which contained distilled water only which ensured contaminants from the containers would not be transferred to the experiment.

Figure 10 – 18L Container with porous PVC pipe at bottom used for Experimentation

In order to ensure a controlled flowrate of stormwater was added at the top of the soil media within the container, a plastic bucket with a ball valve installed in PVC pipework at the bottom was used (Figure 11). 4mm diameter holes were drilled at the bottom of the PVC pipework for the stormwater to exist to resemble rainfall and to ensure a uniform flow of water was used for all experiments.

Figure 11 – 9L bucket, PVC pipework and ball valve used to apply stormwater over soil media within container.

5.3.1 Initial Experiments

Initially samples of stormwater were taken from the retention pond so that the concentration of Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, and E-Coli within the stormwater could be tested. Additionally, soil from the site of the retention pond was collected and placed into the test container so that stormwater from the ponds could be filtered through the soil and samples collected at the bottom of the container through the porous pipe. Initially stormwater was flushed through the soil within the container for 15 minutes to remove as many anomalies as possible so that a uniform sample for each of the experiments conducted could be obtained; this would also ensure the soil within the container was fully saturated and to reduce the stirring of the soil within the container due to the addition of the stormwater. Samples were taken so that the concentration of Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, and E-Coli within the stormwater could be tested.

This initial test was also conducted so that the concentrations of Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, and E-Coli which may be present within the soil could be tested. This would be used as a benchmark for when the biochar was added to the soil in different ratios as to the pollutants removed as a result of the biochar being added.

5.3.2 Changed Parameter Experiments

The remaining experiments were conducted using the same materials and testing for the same pollutants; however in each of the cases the containers were filled with 50/50 soil and biochar medium, 60/40 soil and biochar medium, and 70/30 biochar medium. This would enable a comparison to be drawn from the different additions of biochar to the soil to gauge the ability of biochar to remove concentrations of pollutants. The soil obtained for the experiments were collected from the same location to ensure consistency of the soil used from the retention pond site.

Experimentation was also conducted using a 70/30 soil and biochar mix at different depths within the container to compare the results of the effect on the depth of the media on removing pollutants from the soil. The different depths of media within the container were at 18cm, 12cm and 6cm depths within the container. Again the same materials and experimental procedures detailed above were used.

The final experimentation conducted was the timing of the water depth penetration of the stormwater through the media within the container. The container was filled with 50/50 soil and biochar medium, 60/40 soil and biochar medium, and 70/30 biochar medium and a measure of depth versus time was documented. This was to record the results of the effect the different ratios of adding biochar to soil would have on water penetration within the container. This was considered to be an important experiment, via a simple method, due to the known clay soil material witnessed in the area during construction of the development (known to the author due to inspections conducted during construction of the development) and also during the collection of the soil samples from the site. This would be also important information as part of the discussion section of this thesis, where the author will provide design solutions for the development to improve the removal of pollutants from the stormwater runoff from the area. The different experiments are listed in Table 15 below.

MEDIA	SAMPLE	TEST
Stormwater Sample	1	Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, E-Coli
100% Soil	2	Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, E-Coli
70% Soil / 30% Biochar	3	Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, E-Coli
60% Soil / 40% Biochar	4	Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, E-Coli
50% Soil / 50% Biochar	5	Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, E-Coli
70% Soil / 30% Biochar Depth 18cm	6	Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, E-Coli
70% Soil / 30% Biochar Depth 12cm	7	Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, E-Coli
70% Soil / 30% Biochar Depth 6cm	8	Total Suspended Solids, Total Nitrogen, Phosphorus, Thermotolerant Coliforms, E-Coli
100% Soil	9	Stormwater Sorption Depth vs Time
70% Soil / 30% Biochar	10	Stormwater Sorption Depth vs Time
60% Soil / 40% Biochar	11	Stormwater Sorption Depth vs Time
50% Soil / 50% Biochar	12	Stormwater Sorption Depth vs Time

Table 15 – Experimentation Conducted using Biochar for Stormwater Pollutant Removal

5.4 Testing Procedure

As per the experimentation procedure detailed above, samples of the stormwater were collected via 200ml sterilized bottles obtained from the Griffith Water Reclamation Plant which are used as part of the testing procedures for the said facility. The containers were sterilized and sealed and were only opened at the time of collection via a person using plastic sterile gloves, and sealed immediately to avoid any outside contamination. The sample bottles once, collected were taken directly to the Griffith Water Reclamation Plant and placed in the refrigerator so that the samples would not deteriorate and so that testing could occur within 24 hours of sample collection.

Testing of the samples collected during the experimentation were conducted at the laboratory of the Griffith Water Reclamation Plant under sterile and controlled conditions. Testing for the concentrations of the Total Suspended Solids, Total Nitrogen, Phosphorus, and Ammonia within the stormwater samples was conducted using one of the industries most advanced laboratory spectrophotometer called the HACH DR 6000 UV VIS Spectrophotometer with RFID Technology (Figure 12).

Figure 12 – HACH DR 6000 UV VIS Spectrophotometer (Source: HACH website)

The procedure for testing the stormwater samples using the spectrophotometer was the same method that is used to test potable water at the laboratory of the Griffith Water Reclamation Plant. The testing procedures vary slightly using the spectrophotometer, depending on the pollutant being tested but are similar; however for the purposes of this thesis the testing procedure for testing of Nitrogen using the spectrophotometer will be provided.

The settings on the spectrophotometer were changed to the required pre- programmed methods into the machine for the testing of Nitrogen. A 2.0ml sample of the stormwater collected was added to one AmVer Diluent Reagent Test N Tube vial for Nitrogen. Another 2.0l of Nitrogen free water is added to one AmVer Diluent Reagent Test N Tube vial for Nitrogen as a blank sample. The contents of another two Reagent Powder Pillows are added to each vial; the vials are capped tightly and shaken to dissolve the powder. A instrument timer is set for 20 minutes to allow the reaction time to take place. At the end of the 20minutes reaction time, the Nitrogen free blank sample is added into the cell holder of the spectrophotometer and the instrument is zeroed. The display on the spectrophotometer will show 0.00 mg/L. The sample vial to be tested containing the stormwater is now inserted into the spectrophotometer and the instrument reads the results of the concentration of Nitrogen within the sample in the units of mg/L. The types of reagents added to the sample are dependent on the pollutant being tested, and are available from the manufacturer of the HACH DR 6000 UV VIS Spectrophotometer. The spectrophotometer reads the concentration within the sample by taking in light, and breaking it into its spectral components which then digitizes the signal as a function of wavelength. This can be conducted for a range of signals based on the spectral components of the chemical being tested for.

6. Results

The following results were obtained from the experiments conducted onsite from the stormwater runoff collected from the 100 residential allotment development which discharged into the retention pond system located along Citrus Road in Griffith NSW.

The biochar used for the experimentation as part of this thesis was consistent throughout the process and was obtained from the same sample provided from Biochar Industries. Although it is not accurate to state that the biochar provided in the sample was 100% consistent in that it was manufactured using the exact same biomass and the exact same pyrolysis temperature; for the purposes of this thesis it is assumed that this is the case. As mentioned previously within this thesis the biochar obtained from Biochar Industries Australia was manufactured from category 1 hardwood biomass using the pyrolysis temperature between 480˚C and 650˚C. The biochar used was in a granulated form (similar consistency as commercial potting mix) and it was difficult to determine the surface area due to the small particle size which also made it difficult to ascertain whether the biomass and temperature used to process the biochar had an effect on the surface areas and pore size. The first experimentation analysed the effect of different ratios of soil and biochar and its effect on pollutant removal concentrations in the stormwater samples collected. The results are listed in Table 16 below.

MEDIA	**SAMPLE**	**TEST**				
		Total Suspended Solids (mg/L)	**Total Nitrogen (mg/L)**	**Phosphorus (mg/L)**	**Thermotolerant Coliforms (MPN)**	**E Coli (MPN)**
Stormwater Sample	1	1	0.6	0.15	> 200.5	8.7
100% Soil	2	1586	8.39	3.41	> 2419.6	524
70% Soil / 30% Biochar	3	2601	0.53	3.80	No Test	No Test
60% Soil / 40% Biochar	4	1465	3.30	3.31	> 2419.6	378
50% Soil / 50% Biochar	5	800	5.46	2.87	579.4	104

Table 16 – Results of Pollutant Concentration in Stormwater Experimenting with Biochar and Soil Mixtures

The results in Table 16 did not provide definitive results that correlate with the findings of experimentation conducted by researcher as listed in the literature review of this thesis. All of the results in the table show that the pollutant rates from the initial stormwater sample

(Sample 1) rose significantly. The initial stormwater sample shows that pollutants are indeed present in stormwater runoff; however the values are lower than the values obtained after conducting the experimentation. It can be safely stated that the results from Sample 1 of the initial stormwater sample taken from the retention dam system had low readings as the samples taken were from still water, and not from flowing stormwater entering the system during a rainfall event. If the samples were collected from flowing stormwater it would have provided significantly higher readings as the stormwater would have pollutants immediately discharged into the retention system in comparison to still water which has had time to settle and dissipate. Whereas in comparison Samples 2-5 had higher pollutant readings than Sample 1 due to the stormwater being agitated during the experimental process and also flushing any pollutants contained within the soil samples and biochar used.

Experimentation results for Samples 2-5 in Table 16 provide a more accurate comparison between experiments conducted based on the different soil to biochar mix used in the containers; although a uniform trend cannot be visually concluded from the results overall across the pollutants tested. What was concluded from the experiments is that the more biochar added to soil, had a positive effect in the reduction of concentration of bacteria in the stormwater. It is important to note that the results from the 100% soil media used (Sample 2) and the 50% Soil / 50% Biochar soil media (Sample 5) that the results did decrease across the whole range of pollutants tested. The findings are similar to other reports that explain that biochar does effectively reduce the concentration of pollutants in stormwater.

The next experiment conducted was to compare different depths of soil and biochar mixed media in order to determine whether the depth of mixed media had an effect on pollutant removal from stormwater. This would provide an accurate method for cost savings in the field when implementing the biochar as a soil additive as adding more volume may not always provide more benefit. The results of the depth of media test are tabulated in Table 17 below.

MEDIA	**DEPTH**	**SAMPLE**	**TEST**				
			Total Suspended Solids (mg/L)	**Total Nitrogen (mg/L)**	**Phosphorus (mg/L)**	**Thermotolerant Coliforms (MPN)**	**E Coli (MPN)**
70% Soil / 30% Biochar	18 cm	6	2601	0.53	3.80	No Test	No Test
70% Soil / 30% Biochar	12 cm	7	1090	1.65	3.49	517.2	244
70% Soil / 30% Biochar	6 cm	8	1168	1.46	2.47	228.2	40

Table 17 – Results of Pollutant Concentration in Stormwater Experimenting with Varying Biochar and Soil Depths

The results from Table 17 above are not consistent with findings that would have been expected and also as per the finding of the literature review of other experiments conducted by researchers. It could be interpreted from the results in Table 17 that the shallower the depth of the media provided better results which would indicate that savings could be made in the field as to the volume of biochar actually required to be added to the ground. However a more reasonable explanation would be that the less media depth resulted in less pollutant concentrations being flushed from the media itself.

The final experiment conducted was a sorption test, which was to compare the results of different mixtures of biochar and soil and the effect this has on the ability of water to absorb through the media. The results are tabulated in Table 18 below.

	100% Soil	70% Soil / 30% Biochar	60% Soil / 40% Biochar	50% Soil / 50% Biochar
Time	Depth of Sorption	Depth of Sorption	Depth of Sorption	Depth of Sorption
(Sec)	(mm)	(mm)	(mm)	(mm)
10	30	40	40	60
20	30	50	55	60
30	30	55	60	70
40	35	60	70	80
50	40	65	80	95
60	45	70	85	105
70	48	75	90	108
80	55	85	90	112
90	55	90	100	115
100	60	95	105	120
110	60	98	108	120
120	60	100	112	120
130	60	105	115	120
140	65	108	115	120
150	70	112	120	120
160	73	115	120	120
170	80	120	120	120
180	80	120	120	120
190	85	120	120	120
200	90	120	120	120

Table 18 – Results of Sorption Rates with Varying Biochar and Soil Ratio Mixtures

This test provided the most decisive results that were typical with similar findings by researchers that have been documented within this thesis. The findings from this experiment show that the more biochar added to the soil promotes better sorption of water through the media. This is consistent with biochar properties which has been definitively been shown to be a highly porous material with a large surface area allowing more voids to be created within the soil allowing water to flow through more readily. The results show that the addition of more biochar can improve the water sorption of clay soils, as the soil used for this experimentation had a high clay content which was verified in the geotechnical report from the area during construction of the residential development. The graph in Figure 13 below shows the visual trend from the results of Table 18 outlining that the higher biochar content to soil improves water sorption.

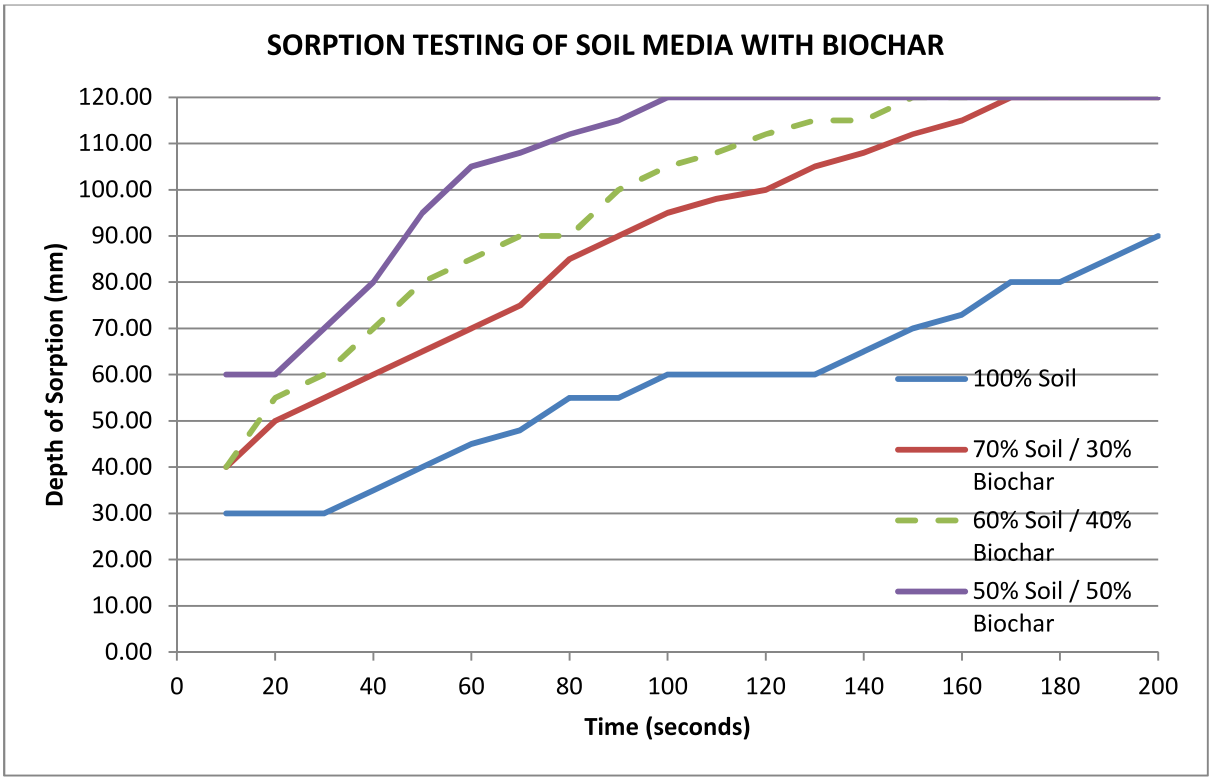

Figure 13 – Depth of Sorption vs Time for different Biochar and Soil Mix Ratios

Figure 13 shows the efficiency of the sorption of the stormwater with the more biochar present within the soil. 100% soil which was the soil sample taken from the retention pond site has a high content of clay which results in the soil being less pervious which results in more time taken for the stormwater to sorb through the soil. As biochar is added to the soil, it uniformly results in the stormwater being able to more readily penetrate through the soil at a quicker rate. The soil mixture with 50% biochar took half the time to penetrate through the soil in comparison to the soil mixture with 30% biochar; whereas the 100% soil sample in the container did not penetrate to the bottom as per the samples with biochar added.

6. Discussion

Due to the literature review conducted on the effectiveness of biochar to remove pollutants from urban stormwater runoff (Kolodynska et al., 2012) it was evaluated that a combination of a biofiltration and wetland system will have the greatest effect on the pollutants encountered in the study area chosen for this thesis. Combining pervious pipes within the detention system draining into a mixture of biochar and soil medium would then be discharged to the drainage wetland system which would be constructed with a biochar and soil mixture as the base. This combination system will allow a system which will act as a filtration system within the detention basin and the overflow will be directed to the wetland which will allow for the uptake and immobilization of pollutants from the stormwater as documented by Lehmann et al., (2006) and Park et al., (2011). Literature has shown that the longer contact time with the biochar provides for better pollution absorption (Liqiang Cui et al., 2013) and as such the wetland area will allow for retention of stormwater for a prolonged contact with the biochar. Once the wetland reaches the top water level, the treated stormwater will discharge to the adjacent drainage channel system via a spillway. Additional benefits of utilising biochar for this type of system is that it has been shown that biochar has a greater ability for water uptake and erosion control (Rumpel et al., 2006; Gray, 2014). Research has shown the ability for the inner ports of the biochar to store water which will assist with maintaining vegetation for longer periods in the detention basin and wetland during drought periods.

The biochar used was in a granulated form (similar consistency as commercial potting mix) and it was difficult to determine the surface area due to the small particle size which also made it difficult to ascertain whether the biomass and temperature used to process the biochar had an effect on the surface areas and pore size. This would account for the reduction in pore volume and radius for pollutant removal concentrations within the stormwater samples taken due to grinding of the biochar. The pore size can be used as an estimate of water holding capacity and available space for microbial habitats. Larger the pore volumes the better to retain stormwater in a bioretention facility. This would allow more detention time for pollutants to adsorb to the biochar surfaces; providing more sites for the pollutants to adsorb and be broken into non-toxic pollutants by microbes.

The fine consistency of the biochar used explains why the high levels of Total Suspended Solids were encountered from the batch experimentation conducted. Additionally a more accurate measure of the beneficial effects of using biochar as a soil additive as per the experimentation would be to run the experimentation over a long period of time. This would allow sufficient flushing of suspended solid material within the soil and biochar to obtain more accurate readings. For practicality purposes the media of biochar and soil mixtures were only flushed for a 15 minute period. Scott et al, (2009) conducted research into the evolution of biochar when exposed to soil over a period of time. The research concluded that over time the biochar structure did change in its binding to the soil structures. This occurred by root penetration within the soil allowed the minute roots within the soil to attach to the micropores of the biochar. It was also suggested by Scott that microbes living within the pore structure of the biochar, broke down the different components within the soil and biochar composting the two materials together (similar to composting) which still retained all of the positive properties of the biochar. This would prove that with prolonged time within the soil, biochar would be effective for pollutant removal and would not contribute to the total suspended solid matter in stormwater runoff which was evident from the experimentation conducted as part of this thesis.

It is also interesting to note from the experimentation conducted as part of this thesis that the buoyancy of the biochar used was evident at the top layer of container when the stormwater was added. As mentioned above, this would not have occurred once the biochar material had sufficient time to bond to the soil structure surrounding it; although it did tend to result in the visual findings of the biochar fine ash structures to be buoyant at the top of stormwater in the container experiments as it slowly sorbed into the soil media.

The value of this thesis is that actual stormwater was taken from the end system of a 100 residential lot development in Griffith NSW, and used sample soil taken from the subject site at the current drainage channel system. A significant outcome of this thesis was the verification of batch experimentation being conducted at site specific areas, in order to determine the most effective system utilizing biochar's for pollutant removal in stormwater in real life situations. Initial case study simulations used in this thesis have predicted that a biofiltration system combined with a wetland system utilizing biochar would be most suited for the study site selected. This outcome has led to the concept design shown in Figure 14 below. The design incorporates the use of biochar as an additive to the soil which aids in the filtration of stormwater being adsorbed by the surrounding soil so that natural biological processes can take place in pollutant removal within the soil. Not only does the biochar result in the removal of pollutants from the stormwater by direct contact, but also provides the environment for microbes to live within the pores of the structure of the biochar. This further enhances the pollutant breakdown within the soil and water. The result of biochar's proven ability to sequester water within its pores and its ability for the soil to sorb water through the media allows vegetation within a bioremediation system to thrive for longer periods of drought in conjunction with using drought tolerant plant species as shown in Figure 14 below.

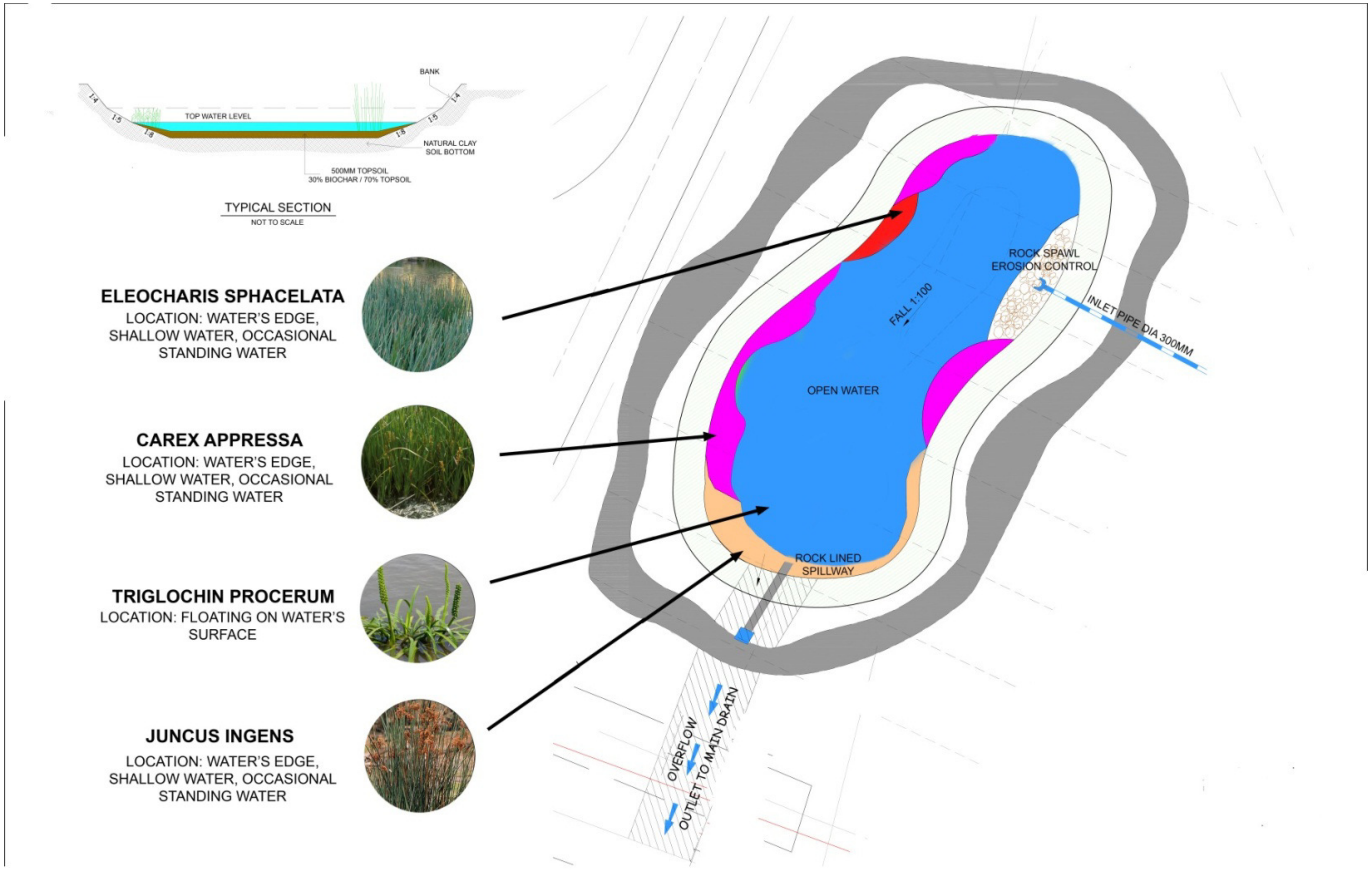

Figure 14 – Design of Biofiltration and Wetland System Using Biochar

7. Future Work for Biochar Geostructure Development

The literature review conducted on biochar within this paper provides diverse laboratory research which is critical prior to full scale implementation in the field. This however leads to the future work resulting from the research and experimentation conducted as part paper. That is, to collate all the information performed to date and design geostructures using biochar which can be constructed in real life applications for urban stormwater cleanup. It would be ideal to have obtained results as part of this paper of full scale experimentation implemented in the field; however this would be not only an expensive exercise but also an unrealistic goal as results would be required to be obtained over a long period of time to provide any real long term data to compare biochar pollutant removal efficiencies in stormwater and record its longevity of life in geostructures. This would provide ideal economic and maintenance cost comparisons in the field of biochar geostructures. Therefore this section of the paper will provide design of geostructures that can be used in urban stormwater cleanup using the positive characteristics obtained by research conducted to date using biochar.

7.1 Biochar Use For Small Scale Systems

Biochar use for small scale implementation can be designed for pollutant removal using existing best practises during and after construction of housing development. While these geostructures will not ultimately remove all pollutant loading from housing construction sites, the overall reduction in pollutants will have an immediate positive result. This includes not only directly above ground on the site itself but also downstream within the underground stormwater pipe systems and ultimately to the final discharge point(s) of natural water systems such as canals, rivers, creeks and oceans. This is evident in experimentation conducted using biochar (Lehmann et al, 2003; Ohe et al, 2003; Ding et al, 2010; Yao et al, 2011; Park et al., 2011; Kolodynska et al., 2012; Inyang et al., 2012).

The *Soils and Construction – Managing Urban Stormwater by Landcom (Blue Book)* provides best practices to be implemented onsite to reduce soil and erosion discharging from construction sites. This is where low-cost temporary geostructures utilising biochar can be installed on construction sites to reduce pollutant loadings to downstream systems.

7.2 Biochar Sedimentation/Silt Sock

Sedimentation socks are currently widely used at construction sites for the primary purpose of filtering sedimentation and erosion at specific discharge points of a site. Usually sedimentation socks are made from nonwoven geotextile fabric and generally filled with sand or gravel. This method is an extremely low cost and a versatile method to remove silt and sedimentation loads from entering into larger trunk stormwater systems. Current applications of sedimentation socks do not specifically target pollutants beyond sedimentation and silt of earthen soil. Utilising biochar within these sedimentation socks would not only continue to remove sedimentation and silt (Uchimiya et al. 2011) from construction sites as per conventional sedimentation socks, but also remove other pollutants such as heavy metals (Kolodynska et al. 2012) washed into stormwater systems due to building materials used onsite.

The type and amount of biochar used for this type of system would not be critical due to the amount of contact time of stormwater runoff with the biochar within the sedimentation sock. The primary purpose would be for the removal of suspended solids within the stormwater runoff with the added benefit of minor removal rates of other pollutants such as heavy metals which would be located in the stormwater runoff from building sites. If used as current practise at building sites the cumulative results of pollutant removal would be significantly noticeable at the discharge end water system. Laboratory tests using biochar for suspended solids removal was considered as effective as other most common filter media such as sand, perlite, and zeolite; where biochar performed as effectively (Fletcher et al. 2003). Assessment of experimental results noted within this paper would recommend the use of a mixture of 30% biochar and 70% gravelly sand within the sedimentation sock. This was the ultimate biochar/soil mixture implemented in small scale filtration experimentation using glass columns by Al-Anbari, 2008. The use of sedimentation socks are most commonly located around stormwater inlet grates as shown in Figure 10 below which would be effective in the removal of pollutants. However this practice can lead to overflow into the stormwater inlet grates and as such it is recommended that sedimentation socks are installed in a V shape at regular intervals within the kerb and gutter system. This will assist to dissipate flow and to capture pollutants prior to entering the stormwater inlet grate. Installation of the sedimentation socks at intervals will not only dissipate flow of stormwater along the kerb and gutter system but also provide more contact time of the stormwater with the biochar located within the sedimentation sock which will provide greater pollutant removal as experimented by Morrow, 2013.

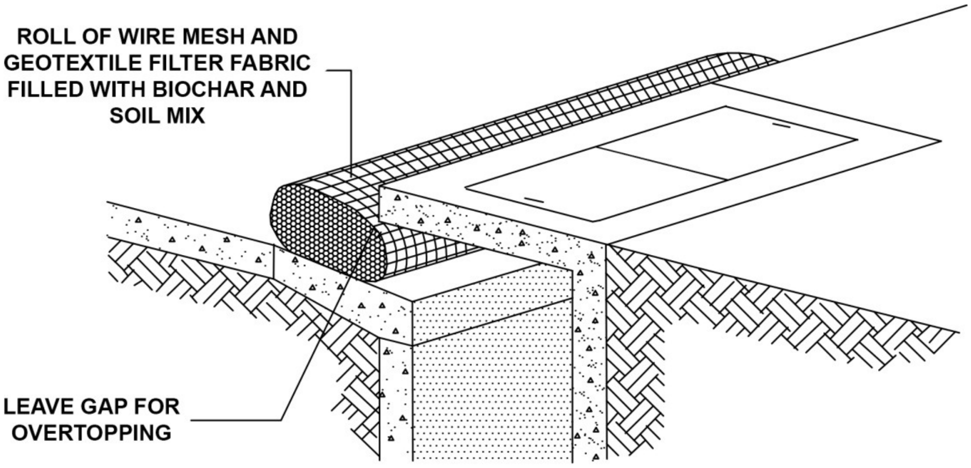

Figure 15 – Biochar/Soil Mix Sedimentation Sock at Stormwater Inlet Pit

Another purpose for the sedimentation sock filled with a biochar and soil mix is as an alternative to a rock check dam. A rock check dam is constructed usually within a drainage swale or waterway to counteract erosion by reducing water flow. As it primary purpose is to reduce erosion; this structure is not well suited to reduce pollutants from stormwater other than large soil particles. A rock check dam also makes maintenance of a swale around the rock check dam tedious. Whereas, the installation of a sedimentation sock within the swale has the potential to reduce pollutants flowing through a swale which is easy to maintain and cost effective, see Figure 16 below.

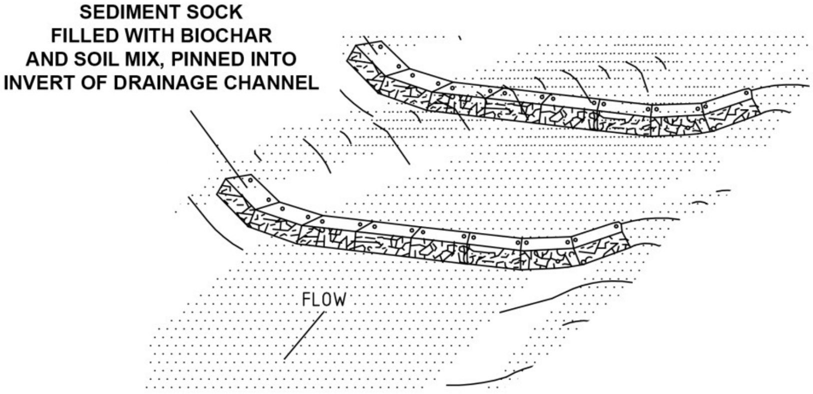

Figure 16 – Biochar/Soil Mix Sedimentation Socks located within earthen swale

A similar method using biochar within modular cells which could be utilised in similar instances as those mentioned above for sedimentation socks; or within plastic modular cells behind silt fences to reduce pollutant runoff from large construction sites.

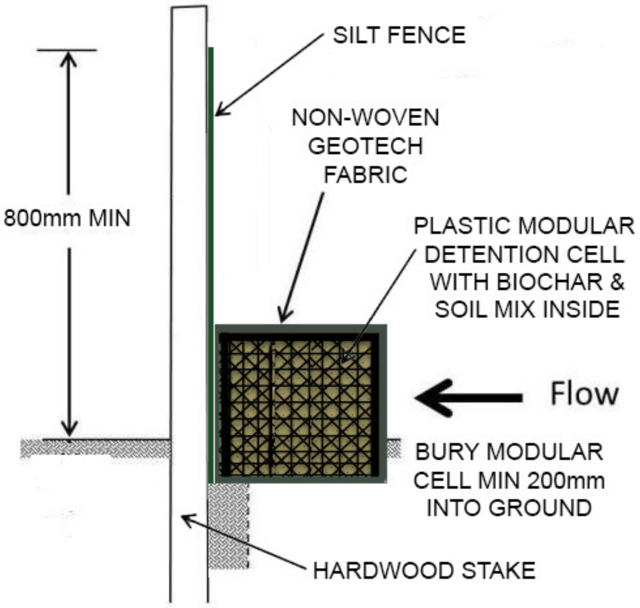

Figure 17 – Biochar Plastic Modular Cell behind Siltation Fence

7.3 Biochar Raingardens

The use of biochar raingardens are a simple cost effective measure for pollutant removal in stormwater runoff. Using shallow depressions planted with deep rooted native plants and grasses that are drought tolerant can provide an aesthetic system to treat stormwater runoff from urban catchments. The adoption of using biochar as a soil additive to increase the porosity of soil would result in removing toxins, providing mineral content to the vegetation, and better water adsorption.

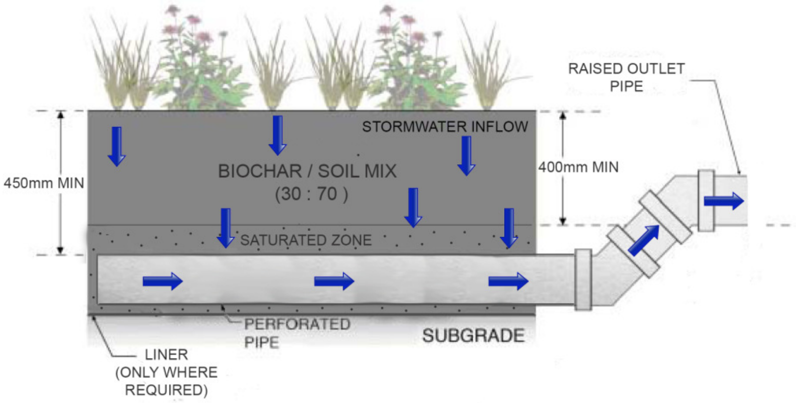

Figure 18 – Biochar Raingarden

7.4 Biochar Use as an Additive

Biochar use as an additive for porous pavers would purify the polluted stormwater runoff from urbanised areas. This would allow the water to be captured underground and utilised for irrigation, cleaning and also for water re-use such as flushing of toilets. Biochar could be used as an additive into the porous paver manufacturing process by mixing it into the sand or also in the bedding used to lay the pavers. This would allow the biochar to capture the pollutants within the pores; allowing biological process to then break down the toxins prior to entering the downstream water systems. This method has be tested where pavers have been injected with ferrous hydroxide to trap toxic heavy metals such as lead, zinc and cadmium which emulate from sources such as car tyres, brake and exhaust systems; and building sidings. Granulated activated carbon has been tested under pavers which traps dissolved organic matter from leaf litter which is responsible for algal blooms in rivers. The pavers with biochar additives would also promote vegetation growth as they would grow readily as the root system has access more access to water and air voids so that the vegetation would soak up pollutants within the water in which they make contact. The pavers have the added benefit of enabling stormwater to infiltrate soil to replenish ground water and to reduce peak runoff rates from hardstand urbanised areas.

Innovative stormwater infiltration and filtration systems are shown to have a positive ability to reduce and retain pollutants present within stormwater runoff. A system containing specifically designed porous concrete pipes with biochar used as an additive in the concrete mix would be an effective measure. As stormwater passes through the permeable concrete walls of the pipes the biochar within the concrete will filter the pollutants within the stormwater into the surrounding substrate soil. This system would be similar to experimentation conducted using iron oxides which are recognised for their ability to remove heavy metals from stormwater due to chemical precipitation Dunphy et al (2007). An underground filtration/infiltration system would utilise porous pipes with the biochar additive used in the concrete mix for the construction of the pipes. The pipes would be laid in a sand and/or gravel trench to allow the polluted stormwater to drain through the porous pipes so that the treated stormwater can infiltrate into the surrounding soil at the end of the pipeline. Figure 19 below provides a sketch of the porous pipe geostructures utilising biochar as a concrete additive.

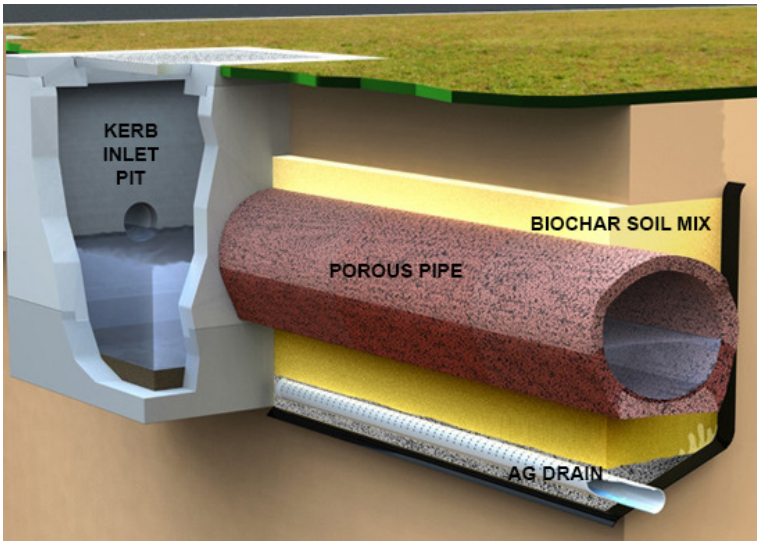

Figure 19 – Porous Biochar Pipe Geostructure for Stormwater Treatment

7.5 Biochar Use in Kerb Inlet Stormwater Pits

Biochar use in kerb inlet pits effectively would work in a similar fashion to raingardens for pollutant removal due to ease of installation at kerb inlets resulting in appealing geostructures for urban cities. It does remain unrealistic for large cities with hundreds of kerb inlets to install this type of system and expect uniform performances as this system may not meet the features and pollutant load removal quantities desired. Therefore an important study incorporating strategies for placement of kerb inlet pits with a biochar media installed to eliminate the necessity of a filter per catch basin to reduce pollutant loads and maintenance costs would be a worthwhile exercise. The Filterra™ system has incorporated the premise for this type of geostructures, however the media used within the system does not utilise biochar. The performance of using this system with biochar would be advantageous as the beneficial effects for pollutant removal in stormwater using biochar has been well documented.

8. Conclusion

As a result of research conducted to date it can be confidently stated that the use of specific types of biomass used to manufacture biochar significantly vary the performance to remove pollutants from stormwater depending on the type of contaminant. The more biochar added to soil resulted in a greater reduction in the concentration of pollutants tested as part of this thesis. This indicates that biochar ability to remove pollutants from stormwater will have environmental benefits. Additional work is necessary to address other potential opportunities for the use of biochar geostructures for urban stormwater water cleanup. Recent work has suggested that enzyme bioremediation techniques could be employed with biochar which enhances biodegradation of herbicides and pesticides. This is motivating for further studies to be conducted in order to explore the full potential of biochar to be used for pollutant removal.

The batch experimentation conducted as part of this thesis identified that the addition of biochar to soil was effective in the removal of pollutants present within the sample stormwater from an urban catchment. The biochar was highly effective in the reduction of Thermotolerant Coliforms and E-Coli throughout all of the tests conducted for biochar being used as a soil amendment. Uniform reduction in the experiments did not occur for the reduction in pollutants of Total Suspended Solids, Total Nitrogen, and Phosphorus, within the stormwater, however results did indicate that in comparison to 100% soil being use; the addition of biochar did reduce the concentration levels of pollutants within the soil.

Experimentation conducted along with research by others identified within the literature review for this thesis outlines the importance of increased retention time for effective removal of pollutants in urban stormwater runoff. The types of biomass and pyrolysis temperatures used for biochar manufacture need to be selected depending on the type of pollutant removal to be targeted. This in most cases has been effective by initial trials being conducted to identify what combination of biochar properties and geostructures to be used are effective. Therefore a balance is required to be determined between the properties of the biochar to be used and the treatment effectiveness for optimize overall performance of the geostructures to be implemented for urban stormwater cleanup. For this thesis it was identified by the batch experiments conducted that an infiltration and bioremediation system would be highly effective for the removal of the pollutants identified from the urban catchment studied. The conditions created by the biochar within the soil increased the overall hydraulic properties of the soil for improved infiltration to increase pollutant concentrations of runoff pollutants. The system design for the subject urban area for this thesis has the potential for being an effective best management practice for reducing pollutant loads for urban runoff conditions.

The potential for the wide range of initial biomass to be used for biochar production is a desired practice in this age of sourcing renewable resources for engineering systems. Using waste products to produce biochar can assist in repurpose an unwanted material taking up valuable area at landfills, in addition to creating a system for pollutant removal in stormwater.

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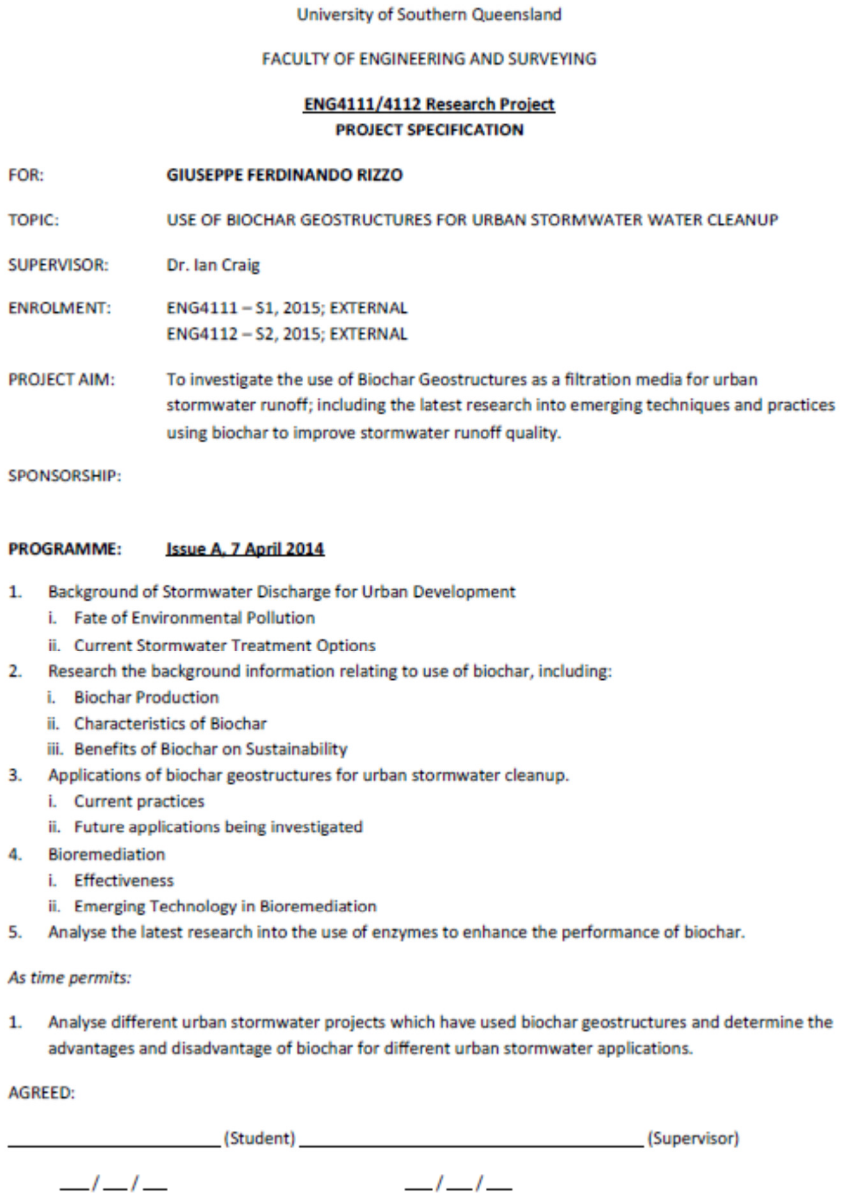
APPENDIX A



University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	**GIUSEPPE FERDINANDO RIZZO**
TOPIC:	USE OF BIOCHAR GEOSTRUCTURES FOR URBAN STORMWATER WATER CLEANUP
SUPERVISOR:	Dr. Ian Craig
ENROLMENT:	ENG4111 – S1, 2015; EXTERNAL ENG4112 – S2, 2015; EXTERNAL
PROJECT AIM:	To investigate the use of Biochar Geostructures as a filtration media for urban stormwater runoff; including the latest research into emerging techniques and practices using biochar to improve stormwater runoff quality.
SPONSORSHIP:	

PROGRAMME: **Issue A, 7 April 2014**

1. Background of Stormwater Discharge for Urban Development
   i. Fate of Environmental Pollution
   ii. Current Stormwater Treatment Options
2. Research the background information relating to use of biochar, including:
   i. Biochar Production
   ii. Characteristics of Biochar
   iii. Benefits of Biochar on Sustainability
3. Applications of biochar geostructures for urban stormwater cleanup.
   i. Current practices
   ii. Future applications being investigated
4. Bioremediation
   i. Effectiveness
   ii. Emerging Technology in Bioremediation
5. Analyse the latest research into the use of enzymes to enhance the performance of biochar.

As time permits:

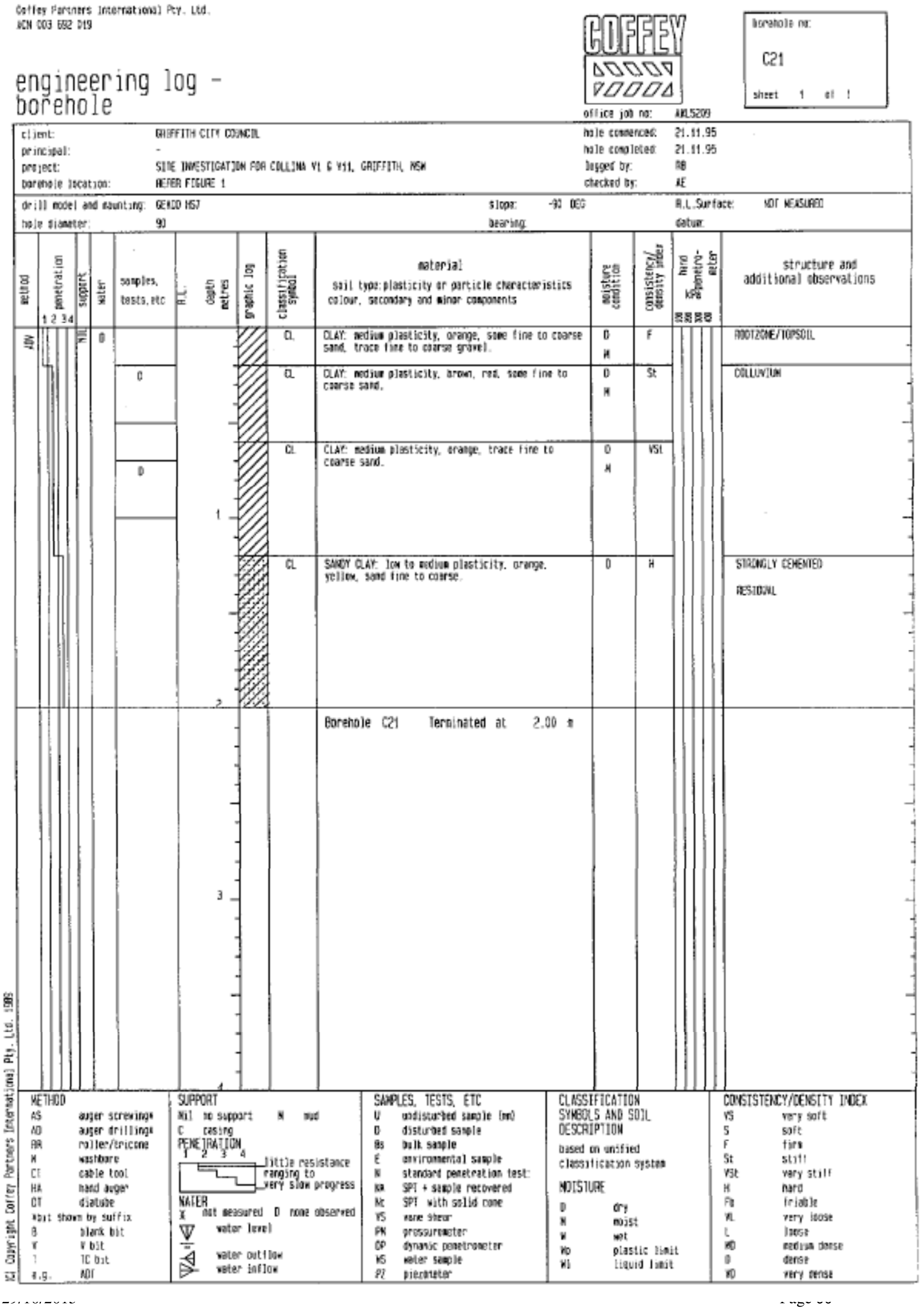
1. Analyse different urban stormwater projects which have used biochar geostructures and determine the advantages and disadvantage of biochar for different urban stormwater applications.

AGREED:

____________________ (Student) ______________________________ (Supervisor)

__/__/__ __/__/__

APPENDIX B



Coffey Partners International Pty. Ltd.
ACN 003 692 019

COFFEY

engineering log - borehole

borehole no: C21
sheet 1 of 1

office job no: AKL5209

client:	GRIFFITH CITY COUNCIL	hole commenced:	21.11.95
principal:	-	hole completed:	21.11.95
project:	SITE INVESTIGATION FOR COLLINA Y1 & Y11, GRIFFITH, NSW	logged by:	RB
borehole location:	REFER FIGURE 1	checked by:	AE

drill model and mounting:	GEMCO HS7	slope:	-90 DEG	R.L. Surface:	NOT MEASURED
hole diameter:	90	bearing:		datum:	

method	penetration 1 2 3 4	support	water	samples, tests, etc	R.L.	depth metres	graphic log	classification symbol	material soil type: plasticity or particle characteristics colour, secondary and minor components	moisture condition	consistency/density index	hand penetrometer kPa 100 200 300 400	structure and additional observations
ADV		Nil	D					CL	CLAY: medium plasticity, orange, some fine to coarse sand, trace fine to coarse gravel.	D M	F		ROOTZONE/TOPSOIL
				D				CL	CLAY: medium plasticity, brown, red, some fine to coarse sand.	D M	St		COLLUVIUM
				D		1		CL	CLAY: medium plasticity, orange, trace fine to coarse sand.	D M	VSt		
						2		CL	SANDY CLAY: low to medium plasticity, orange, yellow, sand fine to coarse.	D	H		STRONGLY CEMENTED RESIDUAL
						3 4			Borehole C21 Terminated at 2.00 m				

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METHOD

AS	auger screwing*
AD	auger drilling*
RR	roller/tricone
W	washbore
CT	cable tool
HA	hand auger
DT	diatube

*bit shown by suffix

B	blank bit
V	V bit
T	TC bit
e.g.	ADT

SUPPORT

Nil	no support	M	mud
C	casing		

PENETRATION
1 2 3 4
little resistance ranging to very slow progress

WATER

X	not measured
D	none observed
▽	water level
◁	water outflow
▷	water inflow

SAMPLES, TESTS, ETC

U	undisturbed sample (mm)
D	disturbed sample
Bs	bulk sample
E	environmental sample
N	standard penetration test:
Nr	SPT + sample recovered
Nc	SPT with solid cone
VS	vane shear
PM	pressuremeter
DP	dynamic penetrometer
WS	water sample
PZ	piezometer

CLASSIFICATION SYMBOLS AND SOIL DESCRIPTION

based on unified classification system

MOISTURE

D	dry
M	moist
W	wet
Wp	plastic limit
Wl	liquid limit

CONSISTENCY/DENSITY INDEX

VS	very soft
S	soft
F	firm
St	stiff
VSt	very stiff
H	hard
Fb	friable
VL	very loose
L	loose
MD	medium dense
D	dense
VD	very dense