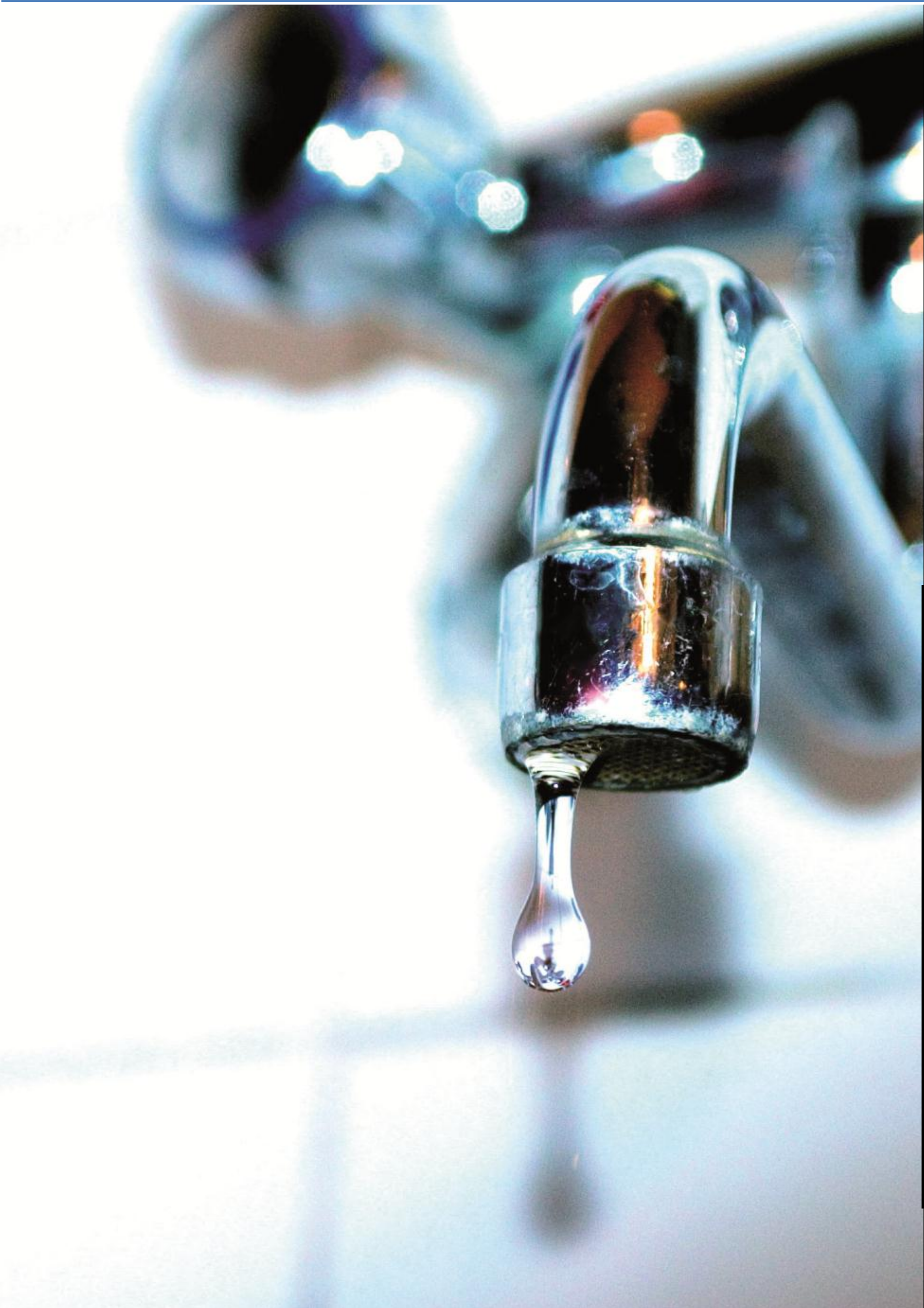
2012

Water Sensitive Urban Design cost balance model through life cycle costing methods



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Abstract:

Water Sensitive Urban Design (WSUD) is a sustainable urban stormwater management method that enhances drainage water quality through ecological techniques. Despite its benefits, uptake has been slow as a set of barriers still prevents its wide-spread adoption (Lee et al. 2010). These barriers include a lack of information about water conservation policy implementations and costs practices (Yigitcanlar 2010). The project aims to bridge the financial knowledge gap by developing a “cost model” that determines the Life-Cycle-Cost (LCC) and probable water quality of diverse WSUD implementations within a specified catchment area. The model will place emphasis on maintenance activities as maintenance is considered to be amongst the highest cost drivers and is of particular interest to WSUD adopting organizations (Yigitcanlar 2010). The Armadale town council was able to provide actual costing data on their implemented urban water management system (WSUD design), in one of their residential areas, situated at Lot 50, Wright Road, Armadale. This site was used as the project study site as it had a wide variety of implemented Best Management Practices (BMPs). This made it possible to incorporate the commonly practiced BMPs into the cost model. The Cost Model’s targeted BMPs are rain gardens, swales, wetlands, and infiltration basins which were all present at the site. With the acquired data, the LCC cost was determined by following the LCC costing procedure listed in the Australian Standard Life-Cycle-Costing Application Guide: AS IEC 60300.3.3 – 2005 (Australia Standard 2005). A selected discount rate of 5% used in the LCC calculation was assumed to be realistic in the Australian economic context (John 1997). The developed cost model has the benefit of being simple to use and it uses latest actual costing data obtained from a newly developed residential area to calculate LCC costing. The cost Model provides a stepping stone to making costing information available by determining costing from the maintenance plan perspective. This is likely to be useful during a decision making process.

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Letter of Transmittal

The Dean

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Dear Sir,

Please accept this submission to you of my thesis entitled “Water Sensitive Urban Design cost balance model through life cycle costing methods” as completion of part of my Bachelor of Environmental Engineering course requirements.

Yours faithfully,

Lin Zhiliang

Acknowledgements

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The Project

The project aims to develop a cost balance model that determines a balance between the Life Cycle Cost (LCC) and probable water quality of diverse WSUD implementations within a specified catchment area. The model's emphasis will be on maintenance activities and activity frequencies because maintenance was considered to be amongst the highest cost drivers and is of particular interest to WSUD adopting organisations. Maintenance activity's frequencies in the cost model will act as model inputs and the resulting LCC cost and water quality from the inputs will be the model outputs (e.g. would it be cheaper would it be to reduce maintenance frequencies by half and what would be the output water quality be? Is the designed maintenance schedule adequate for sustainability? Is the cost too high such that activity frequencies need to be adjusted?). The deliverable will be a developed customisable maintenance cost break down that displays their resultant water quality and life cycle costs in terms of a Net Present Value (NPV). The deliverable would cover financial knowledge gaps and help interested councils to have a better financial understanding of what to expect when adopting a WSUD design.

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Abbreviations used

Australian Bureau of Statics	ABS
Asset Life-Cycle	ALC
Bio-Ecological Drainage System	BIOECODS
Best Management Practise	BMP
Cost Breakdown Structure	CBS
Total Investment Cost	CI
Cost investment for Maintenance	CIM
Total Cost Maintenance	CM
Cumulative Net Present Value	CNPV
Total Cost Operation	CO
Total Cost of Maintenance for 50 years	COM
Engineered Cementitious composite	ECC
Event Mean Concentration	EMC
Environmental Protection Agency	EPA
Future Value	FV
Gross Pollutant Traps	GPT
Life Cycle Cost	LCC
Life-Cycle-Cost Analysis	LCCA
Model for urban stormwater improvement conceptualisation	MUSIC
Number of life cycle years	N
Net Present Value	NPV
Net Present Value	NPV
Obtained Importance Points	OIP
Public Open Spaces	POS
Priority Weighting System	PWS
Steel Reinforced Concrete	SRC
Total Acquisition Cost	TAC
Total Acquisition Cost	TAC
Total Annual Maintenance	TAM
Total Annual Maintenance	TAM
Total Annual Maintenance cost	TAM
Total Dissolved Solids	TDS
Total Dissolved Solids	TDS
Total Dissolved Solids	TDS
Total importance points	TIP
Total Operations cost	TOC
Water Quality Points	WQP
Water Quality Points	WQP
Water Sensitive Urban Design	WSUD

Introduction: Water Crisis

Not only is Australia amongst the driest countries in the world, but it also amongst the most water consuming (Dillon 2000). An average Australian uses 1,224,000 m^3 of water per annum and to put this into a global perspective, the average Briton's and New Zealander's annual water usage is 161,000 m^3 and 540,000 m^3 respectively (Conlon, 2006). Moreover, the growing Australian population that is expected to reach 25 million by 2032 places emphasis on finding water source alternatives to support this increasing demand. According to the Australian Bureau of Statics (ABS), household water usage only comprises 13% of Western Australia's total water consumption and is not expected to rise significantly over the next decade (ABS, 2012). The primary water consumption concerns are known to be agriculture and industry which consumes 68% of the total annual water supply. These are also increasing at a rapid rate in order to support the states agriculturally driven economy (Conlon, 2006). Additional pressure is placed on Australia's water sources as global warming is expected to decrease rainfall before 2030 (Preston & Jones 2006). Perth is predicted to be the most affected as local precipitation amounts are expected to drop by 20% as part of this decline (NOVA, 2008). The disproportional supply and consumption status has left the nation's water resources limited in both quality and quantity. Australia is thus held in desperation to find other alternatives to sustainably manage their precious water sources (Conlon, 2006).

A range of water management strategies have been set up to effectively address Australia's water crisis. This includes the launch of the National Water Initiative in 2004 (Agreement 2005). The initiative aimed to gain the co-operation of every state by signing an agreement that will commit them into encouraging water efficiency (Agreement 2005). Some of the strategies implemented included the installation of desalination plants, adoption of water recycling systems and stormwater reusable methods (Agreement 2005).This has provoked Australia to start treating stormwater as a viable source of water, initially; little attention has been paid to the reuse of stormwater and instead, has been flushed into oceans quickly to prevent flooding. It is estimated that 420 gigalitres of stormwater is flushed straight into the sea every year in Sydney (NOVA, 2008). This amount of water is equivalent to almost the entire contents of the Sydney Harbour (NOVA, 2008). Methods to reuse stormwater runoff are now highly sought after as continual efforts are being made to ensure water supply is sufficient to meet its demands.

Literature Review

Stormwater Management

During precipitation, water falls over the land and flows according to various paths before infiltrating into the ground. The groundwater would flow through subsurface lateral movement until it discharges into a large water body before evaporating into the air again. These processes come together to form the natural hydrological cycle. Initially, this natural hydrological processes dominate the hydrology in an ecological environment contributing to a self-sustaining ecosystem (h2g2 2002). The initial hydrological cycle is illustrated in Figure 1 below:

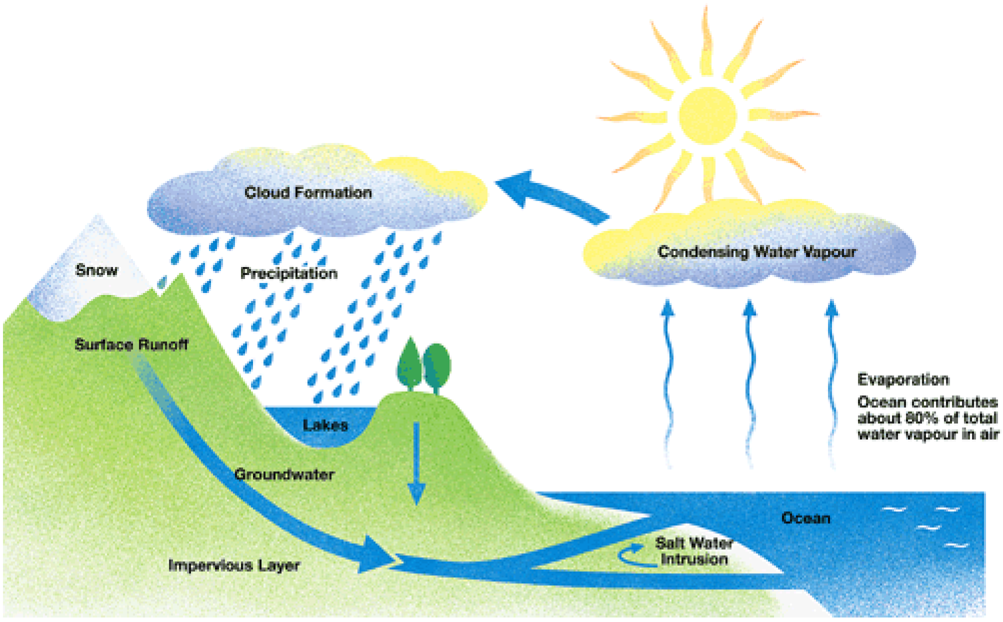

Figure 1: Initial self-sustainable hydrological cycle (SA Water, 2010)

In present days, urbanisation has brought about the increase of impervious surface areas that disrupt this natural process (Mudd et al. 2004). The result is an increase of surface runoff and decreased infiltration. Moreover, the runoff frequently contains pollutants such as oils, sediments, and nutrients that are accumulated from the polluted surface and eventually gets washed into the waterbody causing significant environmental impacts (Parkinson & Mark 2005).

Traditional methods for stormwater management seldom take the environment into consideration (Healthy Waterways, 2011). Instead, they aim to convey stormwater quickly away from potential affected areas so as to preserve loss of urban assets (Wong 2006). Examples of structural initiatives incorporated into traditional designs are curbs, gutters, street inlets, underground culverts, ditches and channels. These elements provide immediate relief from small rainfall events and are usually the first to collect the runoff before discharging them into the ocean (Parkinson & Mark 2005). The results of traditional methods being practised leads to more impacts on the environment thus affecting others that depend on it. The before and after effect of urban development on natural hydrology is illustrated in Figure 2 below:

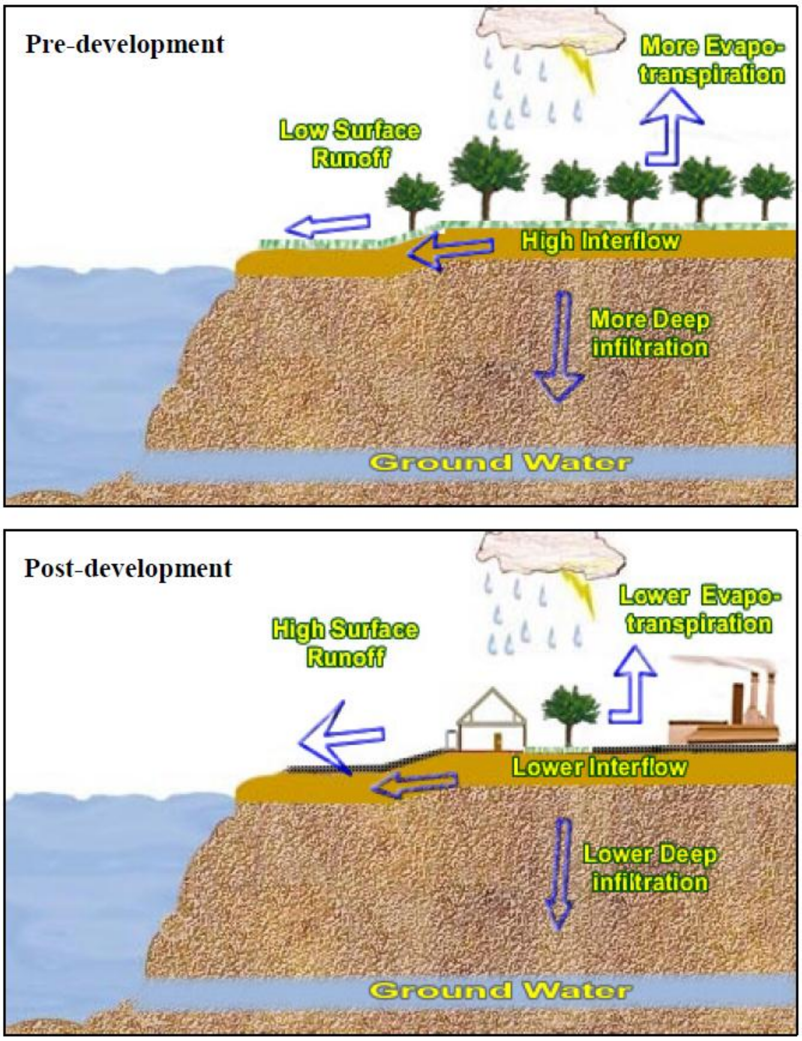

Figure 2: Effects of impervious surfaces on the hydrological cycle (Parker 2010)

The Santa Ana River that drains a large urban shed in south California is one of those that suffer the negative impacts of inappropriate stormwater management. Fecal indicator bacteria concentrations were found to exceed California ocean bathing water standards by nearly 500% (Ahn et al. 2005). The runoff ejected by the river is also able to extend to over 100km^2 from satellite observations causing significant damage to water quality along the south coast of California (Ahn et al. 2005). More places will suffer the same consequences if the method of managing stormwater does not change.

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Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is a sustainable urban stormwater management method designed to address the problems posed by traditional methods. The WSUD concept aims to manage stormwater with methods that are sensitive to the hydrological cycle. These methods include enhancing drainage water quality by pre-treating runoff with ecologically friendly techniques, stormwater harvesting and groundwater infiltration (Health waterways, 2011). In
conjunction, these methods have the potential in maintaining post-development hydrological status while minimising changes to the pre-development status (Lloyd, Wong & Chesterfield 2002).

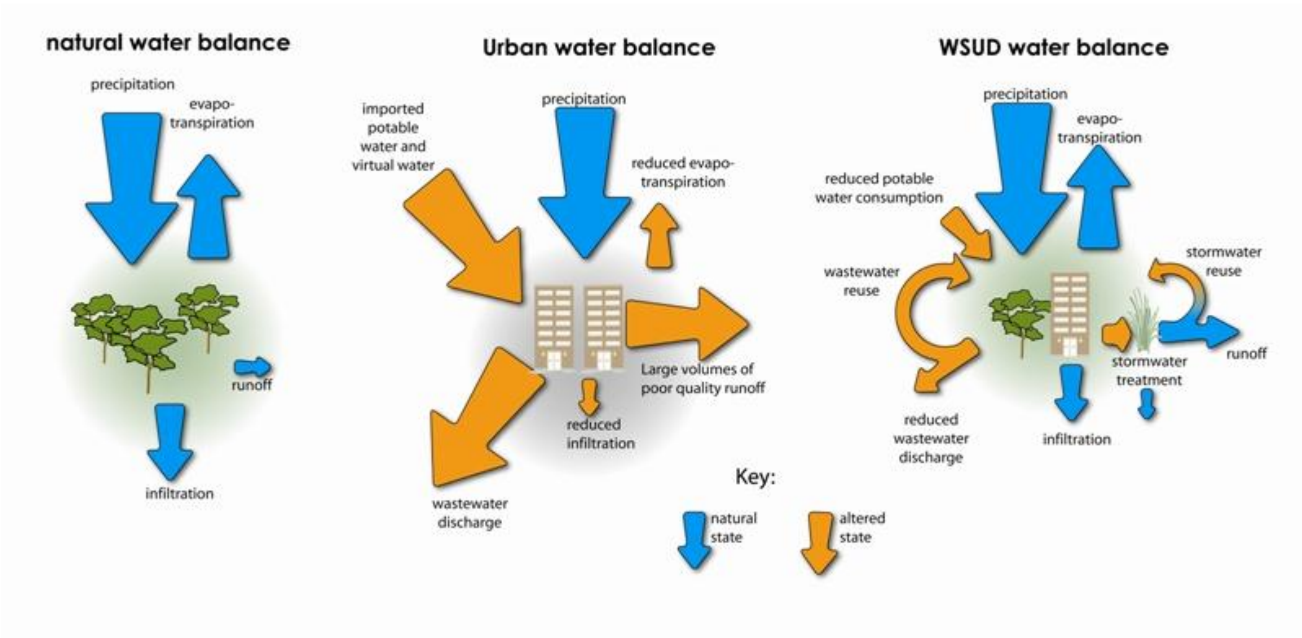


Figure 3: Water Sensitive Urban Design Concept (Healthy Waterways 2011)

WSUD involves integrating a series of Best Management Practices (BMPs) to manage stormwater. These BMPs include two types of practises, structural and non-structural practises (Coppock & Brown 2006). Non-structural practises are used to increase public awareness as well as to instil a water sensitive behaviour. This is usually achieved by conducting campaigns to educate the general public about water sensitivity (Wong 2006). Rebates, advertising and enforcement controls are also other forms of possible methods for non-structural application (Coppock & Brown 2006). On the other hand, WSUD structural BMPs refer to the construction of physical assets that usually contribute directly to the water management plan. Examples of structural BMPs are rainwater tanks, road side swales, bio-retention systems, constructed wetlands and infiltration systems (WBM 2009). Some of these structural BMPs are discussed as follows:

Infiltration System

An infiltration system is a shallow, excavated basin filled with porous material to which runoff can be collected (Melbourne Water, n.d). Infiltration systems are implemented to promote infiltration and they can be used for a wide range of different applications. These devices are highly permeable and suitable for various subsurface infiltration applications ranging from roads to public open spaces (POS) (Peel Harvey, 2006). In most cases, particles and dissolved pollutants get retained in the trenches during the infiltration process thus contributing to pollutant removal. The soil geochemistry and grading determines the infiltration's effectiveness at removing particles and dissolved pollutants (Melbourne Water, n.d). Infiltration systems have the ability to reduce stormwater flow, alter groundwater velocities and increase soil saturation at root zone (Melbourne Water, n.d). A diagram of a typical infiltration system is shown in Figure 4 below.

The inspections and maintenance procedures involved during the operation period of an infiltration system were obtained from the California stormwater BMP handbook (Donaldson 2009). These are described are as follows:

- Rectify clogging as a result of decreased soil permeability due to increased pollutants
- Requires frequent inspections and maintenance
- Regular maintenance of "pre-treatment" can minimize infiltration system's maintenance requirements
- Always remove deposited sediments before scarification
- Groundwater monitoring
- Ensure water infiltrates into subsurface completely

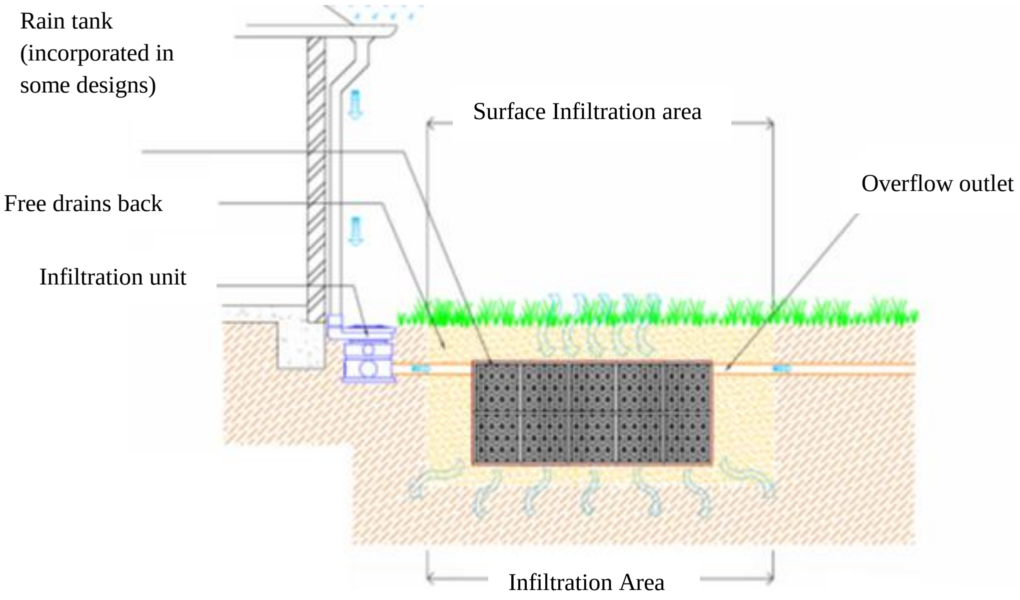


Figure 4: Typical Infiltration system design (Peel Harvey, 2006)

Vegetated Swale

Vegetated swales are open shallow natural channels used to convey stormwater runoff. They are usually implemented in place of traditional drains and pipes. Swales have the environmental advantage over drains due to their ability to promote infiltration and sediment interception by the vegetation (Peel Harvey, 2006). The system operation uses overland flow and mild slopes as its primary mechanism to convey runoff to different locations (Peel Harvey, 2006). The application of vegetated swales is highly versatile being suitable for residential, industrial or commercial areas, thus making them amongst the most commonly implemented features of WSUD designs (Donaldson 2009). A diagram of a typical vegetated swale is shown in Figure 5 below.

The inspection and maintenance procedures that may be involved during a swale operation were obtained from the California stormwater BMP handbook (Donaldson 2009). Some of these are described as follows:

- Maintain access to swales for maintenance activity
- Mow as appropriate for vegetative cover species
- Monitor health of vegetation and replace if necessary
- Remove litter and debris if required
- Mow and remove grass clippings, litter and debris
- Trim vegetation
- Replant eroded or barren spots to prevent erosion and sediment accumulation
- Remove sediment when accumulated sediment reduces original infiltration rate by 25-50%
- Seed or sod to restore ground cover

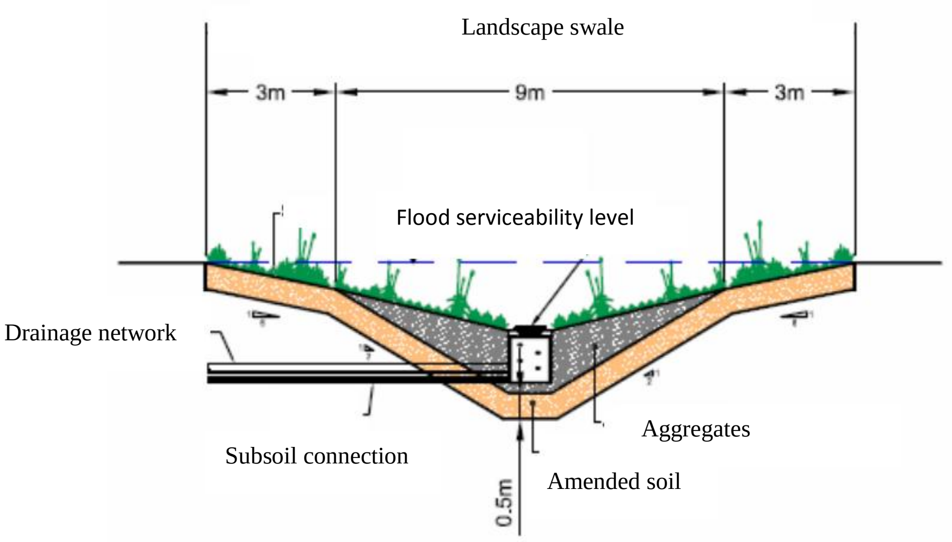


Figure 5: Typical Landscape swale design to allow subsoil drainage (Peel Harvey, 2006)

Rain Garden

A rain garden is a bio-retention system that consists of six primary components. They are the rain garden soil mix, the ponding area, plants, an over flow system, mulch layer, and a sand layer (Auckland Regional Council, n.d). A wide plant diversity, is usually incorporated into the system to promote social acceptance with is attractive appearance. A grass buffer strip can also be installed to enhance the removal efficiency of sediments and solid particles. A rain garden's primary purpose is to serve as a ponding area by holding runoff until the water sweeps through the planting mix (Auckland Regional Council, n.d). This process contributes to nutrients stripping by the vegetation and more sediment is removed through the natural filtration system within the infiltration media (Auckland Regional Council, n.d). The treated runoff that is eventually transferred to pipes and drains may be conveyed to other locations for discharge purpose or further treatment. A diagram of a typical rain garden is shown in Figure 6 below.

Inspections and maintenance procedures that may be involved during a rain garden operation were obtained from Auckland Regional Council operation and maintenance guide for rain gardens (Auckland Regional Council, n.d). These are described as follows:

- Clear inflow points of sediment, rubbish and leaves
- Check for erosion or gouging and repair
- Check that all water has drained 24 hours after heavy rain
- If crusts of fine sediments are present on surface of soil mix, remove with a spade and rework using rake. Top up soil and mulch as necessary. Dispose of contaminated crusted topsoil in a secure landfill

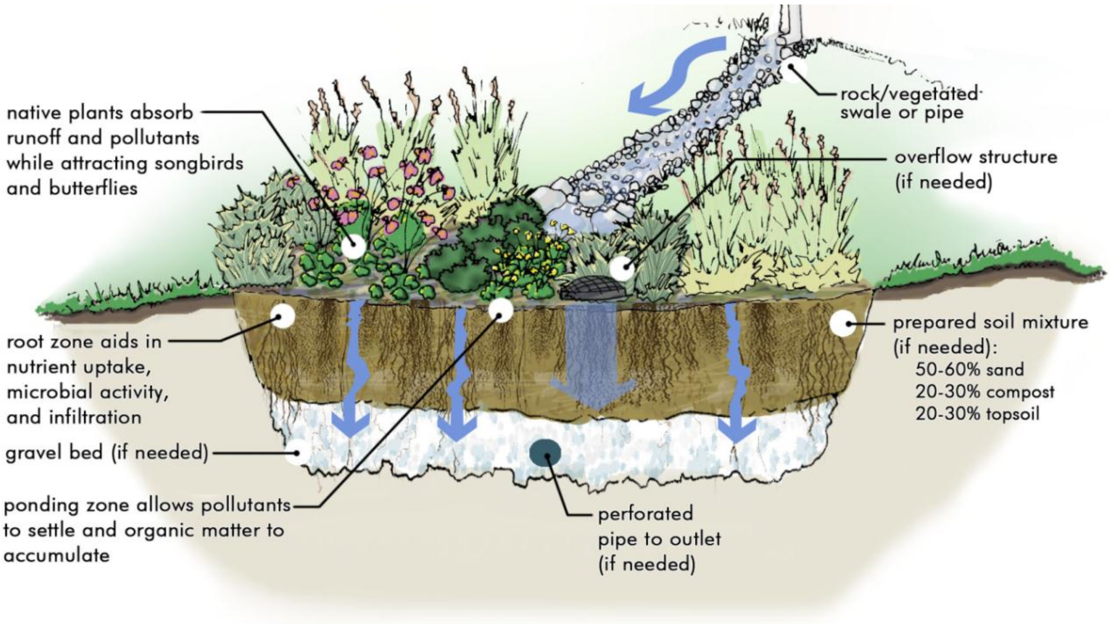


Figure 6: Typical residential rain garden design (Clear Choices, 2012)

Living Stream

A living stream is a constructed or retrofitted stormwater conveyance channel that mimics a natural stream or river (Department of Water, 2011). It usually consists of a complex ecosystem featuring stabilized vegetated banks and a natural morphology (Department of Water, 2011). Their primary role in stormwater management is to convey large amounts of runoff and improve water quality through the use of aquatic vegetation that acts as biological filters (Department of Water, 2011). They can also be designed to retain water at different times of the year when necessary and have the added benefit of being visually attractive if maintained properly. Living streams are applicable at a range of various sizes and are usually connected to a river system.

Inspection and maintenance procedures involved during a Living stream operation were obtained from the stormwater management manual for Western Australia (Stormwater Management Manual for Western Australia n.d) and are described as follows:

- Weeding and vermin
- Maintaining drainage function
  - Main channel of the drainage line may have to be cleared often
  - Vegetation cut
  - Fallen branches removed
  - Obstructions likely to cause debris accumulation removed
- Habitat monitoring and projection
  - Plant health should be inspect of health regularly
  - May be subjected to damage by human activity (vegetation damaged by vehicles, littering, vandalism,)
- Control of herbicide or pesticide use
  - To protect animals or are sensitive to chemicals living within the living stream

Constructed Wetland

Constructed wetlands are artificial areas of land designed to be intermittently or permanently inundated by shallow water (Melbourne water, n.d). They serve to reduce sediment loads from water by reducing flow velocities and removing nutrients through bio-contact. Wetlands have the reputation of being one of the most effective treatment processes for stormwater management thus offering high aesthetic value (Melbourne water, n.d). Wetlands generally consists of three main components, they are, the inlet zone, a macrophyte zone, and a high flow bypass channel (Landcom, 2009).

Wetland operations include stormwater flowing into the wetland through the inlet zone. At this point, leaf litter and coarse sediments would be removed by Gross Pollutant Traps (GPT) before entering the macrophyte zone (Landcom, 2009). The macrophyte zone is a vegetated area which frequently consists of native plants that have high nutrients stripping capabilities. Stormwater treatment begins in this area through Sedimentation and nutrients stripping by the vegetation (Landcom, 2009). The high flow bypass prevents flooding during excessive rainfall events by conveying the overflow away to possible direct discharge (Landcom, 2009). A typical diagram of a constructed wetland is shown in Figure 7 below.

Relevant maintenance and operation activities that may be involved in Wetland management were obtained from Landcom's Water Sensitive Urban Design Maintenance Book 4 (Landcom, 2009) and are described as follows:

- Optimal nutrients removal is being maintained through routine harvesting to prevent vegetation from reaching maximum density
- Inspection for burrows, sediment accumulation, structural integrity of the outlet, and litter accumulation
- Removal of accumulated trash and debris in the basin during the middle and end of the wet season
- Stock with mosquito fish to control mosquito breeding

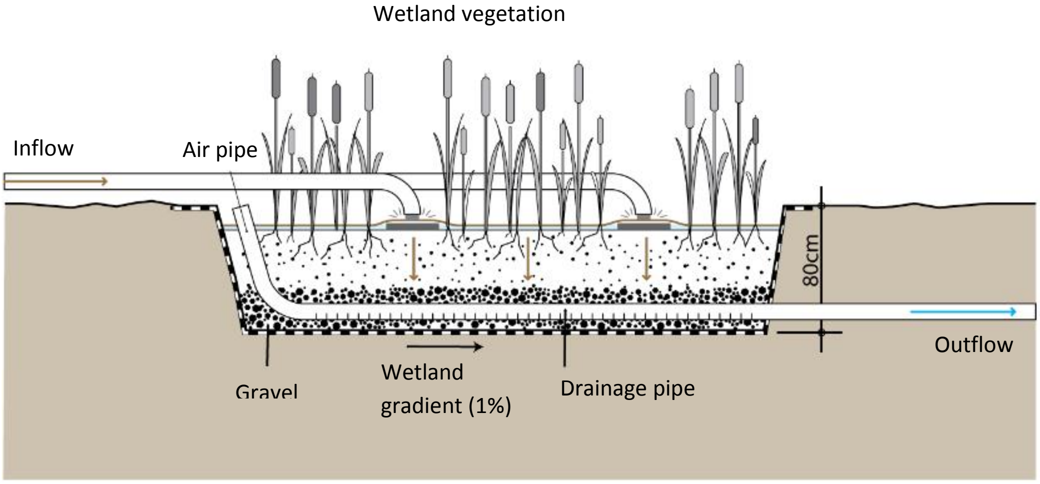


Figure 7: Typical vertical flow constructed wetland design (Domingos 2011)

Water sensitive Urban Design Adoption

Despite the awareness of Water Sensitive Urban Design's (WSUD) environmental significance (Brunton 2005), traditional stormwater management methods still dominate the majority of water institutions and agencies (Lee et al. 2010). Slow WSUD uptake is due to a set of adoption barriers that include a lack of information and guidelines about water conservation policy implementations, costs practices and methods to adapt them into local needs (Lee et al. 2010).

A survey study consisting of fourteen interviews and three discussion groups to uncover some of these barriers in more detail was conducted by "Water by Design" (Brunton 2005). These discussions involved a diverse range of participants such as engineers, environmental and town planners, landscape architect, and government representatives who were experienced with stormwater management (Brunton 2005). The discussion outcomes determined the top four barriers to adoption and are listed in Table 1 below.

Top four barriers identified
• Lack of broad policy direction, regulations and guidelines by State Government and local councils, and lack of detail in the approval and administrative process. • Costs for building, maintaining and replacing WSUD related infrastructure by government and private industry. • Lack of awareness by stakeholders and the community about the benefits and practicalities of WSUD, and lack of suitable training programs and access to relevant information. • Lack of consumer demand for WSUD developments, and lack of appropriate marketing about their costs, benefits and rewards.

Table 1: Main barriers hindering the widespread of WSUD adoption, identified during a survey study by Brunton in East Queensland, Australia (Brunton 2005)

The battle between WSUD and traditional methods is still under way as there is insufficient evidence to prove that WSUD is comparatively beneficial (Lee et al. 2010). Moreover, the convenience of sticking to traditional methods due to the readily available guidelines gives them the added disadvantage. Relative to older traditional methods; the WSUD concept is still very new and much research still needs to be done for it to prove its worth. Moreover, WSUD systems that require site specific applications often complicates the initial designing phase, thus making adoption a tricky and inconvenient process (Lee et al. 2010). Due to the lack of WSUD technical ability, majority of structural WSUD implementation mistakes are already being made during the design phase thus leading to potentially greater problems (Lee et al. 2010).

Unfortunately, these have given WSUD the reputation of being a complicated system with vague outcomes leading to a lack of social acceptance. Such a social acceptance problem is the public's perception that open drains and swales are mosquito breeding hazards (Lee et al. 2010), this however, may not always be true, the reason for such hazards to arise would only be because of poor management and maintenance practices, or the result of a poorly designed system. Survey studies suggest that the consumer demand for WSUD developments are still low in most places and appeal more to socio-economic groups who are environmentally motivated (Lee et al. 2010).

Global efforts are currently being made to develop models for estimating cost and measure performance efficiencies. With more cost estimating and performance efficiency tools, it would be possible to further prove the cost benefits of WSUD to encourage adoption. It is not feasible to use data or share research on an international level due to differences in climate conditions, geology, soil properties and plant species which are very important factors to consider during WSUD developments (Tian 2011). Therefore, advancement for WSUD thus becomes an individualistic process. United Kingdom, United States and Australia are seen to be amongst the leading nations for this field. Australia, an environmentally cautious nation that suffers a water crisis emphasizes the importance of WSUD adopting. Some states within Australia have gone to the extent of making it mandatory for WSUD to be adopted (Conlon, 2006). Overall, uptake improvement depends mostly on a local basis and in the Australian context, is a crucial step to addressing their water crisis problem (Conlon, 2006).

WSUD adoption in WA

WSUD implementations in Western Australia did not happen until recently and was seen as necessary due to its drying climate. The shortage of water, especially for irrigation to support agricultural activities, emphasizes the importance of switching from traditional methods to those that support sustainable management.

A meeting with the City of Aramdale town council was held to discuss the factors influencing WSUD adoption. It was clear through discussions that their implementation experiences closely relates to those found in published literature. Emphasis was placed on the lack of technical and costing information as they played a major role in hindering WSUD adoption. Councils would commonly implement BMPs only as stated within a guideline or according to a fixed budget instead of proper implementations through technical expertise. The lack of professional guidance usually leads to poorly designed BMPs, thus resulting in low cost benefits and may cause possible danger to the local community (Mr G Davies, 2012, pers. Comm., 5 Sept). It was further discussed that the most necessary information required during a decision making process are operational costs, cost efficiency, the type of maintenance required, and its water quality benefits. Without such information, it would be difficult to convince potential adopters that WSUD is beneficial. Suggestions that could aid the adoption decision process in WA were raised during the meeting. Several council representatives responded to this by suggesting that information on how maintenance costing could influence BMP performance would be helpful. Thus, this led to development of the cost model.

Case studies

During the research to find useful literature information, particular attention was paid to finding various methods available for addressing the cost information barrier. These included published and available models, where and how data was collected for cost estimating and the general WSUD research and development status.

Available Models

The Model for urban stormwater improvement conceptualisation (MUSIC) model was found to be one of the primary tools used for quantitative and qualitative evaluation of conceptual stormwater management designs (E water, 2011). The model includes a Life-Cycle-Cost (LCC) module which estimates costs of a design across a defined life span. The module uses algorithms derived from a statistical analysis to predict the unobservable cost elements within the LCC systems (E water, 2011). The data used to derive these algorithms were collected in 2004 from consultants and organisations around the different Australian states (E water, 2011). However, MUSIC is not a detailed design tool as there still are many limitations to its considered parameters. However, MUSIC forms a basis for stormwater management system design and has been widely applied around the world (E water, 2011).

The XP-SWMM model can be applied to overcome the limitations of the MUSIC model with a more detailed hydrological assessment. The XP-SWMM model is known to work well for estimating Australia's stormwater runoff quality and determining WSUD performance measures. XP-SWMM models measures the quality of surface flows based on either of the following approaches: the build-up/wash-off process rating curve, or an Event Mean Concentration (EMC). The wash-off process determines the built up of constituents in drainage systems by using a power-exponential relationship combined with a decay function, or with the flow rate's power function (Phillips et al. 2006). The EMC method defines pollutant distribution by specifying the mean and standard deviations of the EMC's log-normal distribution. Unlike the MUSIC model, XP-SWMM is not as widely applied due to the availability of other models that have the advantage of faster WSUD scheme assessment. It also does not estimate application costs which are a prime interest to potential WSUD adopters. However, there is still potential for its application when detailed analyses are required for hydrology, hydraulics and water quality (Phillips et al. 2006).

To address the costing issue, an LCC cost method was developed to estimate the costs for implementing stormwater control systems and BMP implementation at a parcel level within an area (Sample et al. 2003). Costs were obtained from published literature and standard cost estimating guides for each parcel of a land development. Some of the costs and performance summary data were selected from a capital cost functions data base produced by the Environmental Protection Agency (EPA) for stormwater capital cost estimation (Sample et al. 2003). The database's functions were derived by a single variable power function that relates two parameters obtained from a nonlinear regression plot. The simplicity of being able to estimate a cost with this regression analysis determined equation makes this a common method for cost estimation (Sample et al. 2003). The down side of this is that the regression fit may not always be accurate; accuracy would depend on the quality and amount of data. Virtually, all literature cost estimates are based on the conventional approach of regression equation fitting (Sample et al. 2003). The method developed in this study comprises mostly of such equations and has been effective for estimating costs for stormwater BMP applications (Sample et al. 2003).

New Zealand land developers also faced the problem of insufficient cost information for stormwater management. To address this issue, they started a cost modelling project that uses a unit cost approach to estimate costs (Ira, Vesely & Krausse 2008). This unit cost involved breaking down costing to a cost per square metre scale and projecting it out for other size applications. Unit cost data was collected from local authorities, maintenance contractors, and consultants throughout New Zealand (Ira, Vesely & Krausse 2008). The objective of this project was to develop a model that was easy to use for decision making based on the unit cost system (Ira, Vesely & Krausse 2008). The model was sent to various users after a prototype version was developed to gain feedback. The model was then refined before being launched at the end of 2008 (Ira, Vesely & Krausse 2008).

WUSD Adoption in Brisbane

Brisbane used a community involvement approach to address the WSUD adoption decision process. This method focuses on satisfying the community that will be affected by the decision being made It was thus important to include a diverse a group of stakeholders when addressing the problem (Taylor & Fletcher 2006). Including a diverse community encourages contribution from a variety of skills and perspectives leading to a better decision being made (Taylor & Fletcher 2006). The decision making process was perceived to be led by effective and decisive leaders which eased the decision making process (Edwards, Holt & Francey 2006). Brisbane used the Triple-Bottom-Line (TBL) assessment as a tool to help provide guidance to making the right decisions (Taylor & Fletcher 2006). The TBL provided information of what might be involved, factors to consider and expected budgets which could be useful for tackling complex problems (Taylor & Fletcher 2006).

LCC and LCA comparison studies

A LCC comparison in Malaysia between Bio-Ecological Drainage System (BIOECODS), Malaysia's water sensitive stormwater management system equivalent to WSUD, and traditional methods was conducted to weigh the cost differences between these two systems (SIDEK et al. 2004). A life cycle costing approach was used to compare cost benefits and the associated cost elements were estimated by field professionals (SIDEK et al. 2004). LCC costs for each system was calculated for a 50 year life-span, the cost comparison results showed that construction cost of BIOECODS were almost equal to traditional methods. Moreover, maintenance and operation costs were also found to be greater than traditional methods (SIDEK et al. 2004).

An integrated life cycle cost and assessment model was developed to evaluate infrastructure sustainability of two different bridge designs (Keoleian et al. 2005). One of which was a conventional Steel Reinforced Concrete (SRC) deck with mechanical steel expansion joints, and the other a SRC deck with Engineered Cementitious composite (ECC) link slabs (Keoleian et al. 2005). The life cycle cost was separated to calculate for two different types of costing. These were the agency and social costs. Agency costs include costs incurred through the life cycle phases of the system that could be represented by a dollar value. These cost elements were obtained from construction cost information provided by the construction company (Keoleian et al. 2005). Social costs included costs related to environmental effects from construction activities such as traffic congestions and emissions (Keoleian et al. 2005). This kind of life cycle cost determination cannot be represented by a dollar value and is measured according to the level of impact instead. Such a life cycle cost determination is referred to as a life cycle assessment (Finkbeiner et al. 2006). Therefore both a life cycle cost and life cycle assessment was conducted to holistically compare both the cost and environmental benefits of the two designs. Comparison results suggested that the ECC link slab system consumes 40% less total primary energy, produces 39% less carbon dioxide, and has a 37% cost advantage over the SRC system (Keoleian et al. 2005).

The feasibility of using WSUD techniques to manage water quality impacts during rural to residential landuse conversions was investigated by the Brisbane town council (McAlister 1998). A major part of the study involved comparing a conventional 3.3 ha residential subdivision with a proposed WSUD type management system. The study compared a wide range of BMPs which were included in the proposed design (McAlister 1998). Design and construction costs between the two methods were compared and an impact assessment was conducted. Study results showed that both methods had an equivalent lot yield, similar capital costs, and equivalent market values (McAlister 1998).

Cost Comparison

The traditional method of making a cost comparison is by comparing start-up costs. In this context Traditional Stormwater management systems would have the advantage due to the high acquisition costing reputation WSUD applications have (Yigitcanlar 2010). However, this does not conclude that traditional methods are more cost effective because there are other cost factors that needs to be considered over the lifespan of the initiative. One of which includes maintenance costing which was found to be lower for WUSD operations in most cases.

Asset Life-Cycle (ALC)

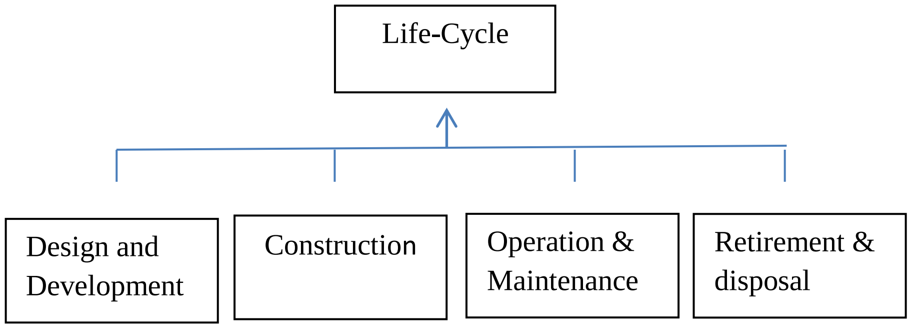


Figure 8: General life cycle diagram

An Asset Life cycle begins when the need for the system is being recognised, goes through its development and ends finally at disposal. The subject's life cycle span is defined by the following key stages (Commonwealth of Australia, 2001). A life cycle diagram is shown in Figure 8 above.

1. Initial concept definition
2. Development of asset requirements and documentation
3. Construction, manufacture or production
4. Purchase and operation
5. Usage
6. Upgrade and renewal processes
7. Ends when the asset is being disposed

Life-Cycle-Cost Analysis (LCCA)

The Australian Standard AS/NZA 4536:1999 defines life cycle cost to be the sum of all acquisition, operation, maintenance, conversion, and decommission costs that may be involved in the entire life span on an asset (Standard 2005). These costs which are referred to as LCC costs occur at different times during the life cycle stages and may be lost in the complexity of the life cycle system (Emblemsvåg 2003).

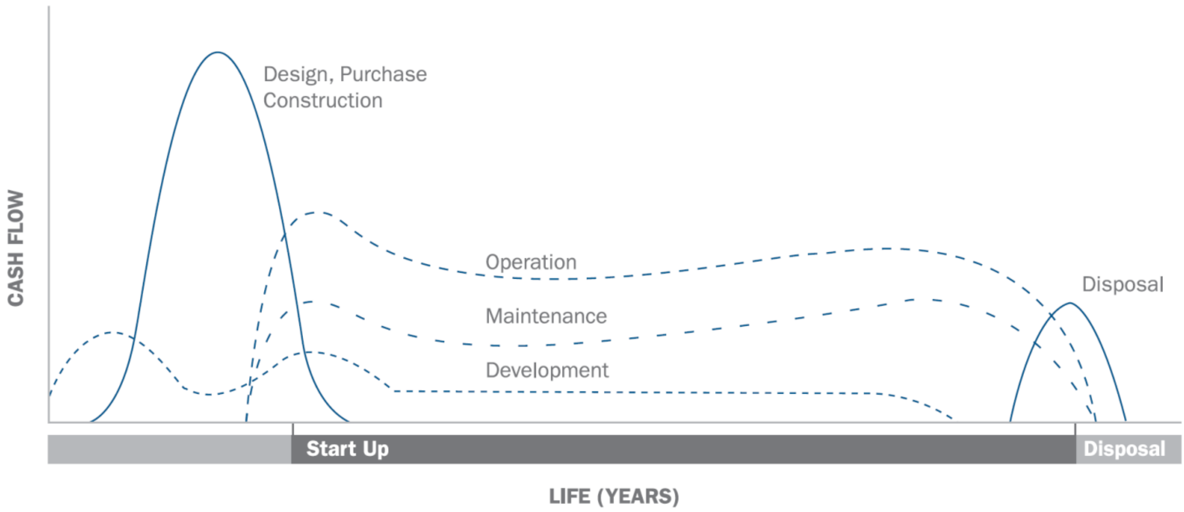


Figure 9: Typical Life cycle profile that presents the different life cycle phases within the subject being evaluated, (Commonwealth of Australia, 2001)

LCCA serves as one of the essential tools in assisting businesses make cost efficient choices. While businesses seek to increase revenue, minimising costs is even more important because if costs are greater than revenue, it will affect profit, which businesses aim to maximise. This is done by breaking down costing into elementary cost categories and identifying potential cost drivers to simplify the system (Blanchard & Fabrycky 2006). The LCCA method is also able to draw the user's attention to important information to be considered within the Life-Cycle system. A set of steps obtainable from the recommended LCC text book for engineering application: Blanchard's "Systems engineering and analysis" are included in the LCCA method. These are listed as follows:

Steps for conducting an LCCA
1. Define system requirements 2. Describe the system life-cycle and identify activities by phase 3. Develop a Cost Break Down structure (CBS) 4. Identify data input requirements 5. Establish the costs for each category in the Cost Breakdown Structure (CBS) 6. Select a cost model for analysis and evaluation 7. Develop a cost profile and summary 8. Identify high-cost contributors and establish cause-and-effect relationships 9. Conduct a sensitivity analysis

Table 2: Recommended steps for conducting an LCCA, steps were obtained from Blanchard's "Engineering systems and analysis" book (Blanchard & Fabrycky 2006)

Depending on the problem being evaluated, redefining the method may be necessary (Blanchard & Fabrycky 2006). The exact method used is often "objective specific" and the steps mentioned in Table 2 provide only a recommended framework. It is possible to incorporate different cost elements, group the elements in different ways or even leave certain elements that are deemed unnecessary for addressing the problem (Blanchard & Fabrycky 2006).

The resultant LCC calculated cost is usually represented in a Net Present Value (NPV) form determined with a discounting tool incorporated into the LCCA method (Paul & Barringer, 2003). The purpose of discounting is to convert future values to present value because monetary value never stays constant. This is done with a discount rate that is usually derived by accounting and financial organisations that weighs a range of economic factors to help engineers make economic decisions (Blanchard & Fabrycky 2006). The discount rate can range from 1 to 15% depending on the state's economic status and growth. The obtained Net Present Value (NPV) after the discounting process is able to quantify the impact of time on future costs. NPV is derived from a discount rate formula obtained from Blanchard's "Systems and engineering" stated below:

NPV = FV/(1+r)^n

NPV = Net Present Value

FV = Future Value

n = number of intervals between the present and future transaction (years)

r = estimated discount rate (applicable to the chosen intervals)

Due to the LCCA's ability to capture important details related to asset management and improved decision making (Fuller 2008) The LCCA has been applied in numerous businesses and government entities. LCCA can also be used for other applications. LCC costing serves as an effective engineering tool for designing and has remained one of the premier environmental management tools (Emblemsvåg 2003). The reasons are that cost is often a better indication of resource consumption than other physical analyses, and it provides a more direct measure than other scientific methods (Emblemsvåg 2003). LCC is important as it enhances economic competitiveness by allowing decision makers to tackle issues from a broader perspective by assessing the problem from a long term ownership perspective (Paul & Barringer, 2003).

Priority weighting System

The Priority Weighting system is a decision making tool that prioritises options based on a series of influencing items. It uses a system of weighting factors to quantify performance ratings for each considered option. Weighting factors are estimated values that indicate an influencing item's level of importance or impact on the option (Weighting Factors Handout, 2009). Assigning priority weightings help establish which items are more important than the other and serves as a useful tool to structure considerations in a systematic way (Weighting Factors Handout, 2009). Weighting factors should be assigned based on the following key factors:

1. Is this item considered to be a critical process?
2. How important is this item to the project or option to be considered?
3. The item's impact on the expected outcomes?
4. What is affected and how by this item?
5. What are the consequences if this item is not being considered at all?

For a priority weighting system to work efficiently, all influencing items will need to be assigned with a weighting factor (Tague, 2004). The Priority Weighting System can be executed by preparing a decision matrix consisting of a list of options arranged vertically, and with their associated influencing items arranged horizontally (Tague, 2004). Weighting factors will then be assigned to each influencing item based on the factors listed in Table 3. Points of influence achieved by the option for each specific item will be multiplied by the item's weighting factor (Tague, 2004). This will be repeated for all items and the sum of them will be the total importance score obtained for that option (Tague, 2004). The option which ultimately achieves the highest score is assumed to have the highest importance (Tague, 2004). An example of this is shown below:

	Item 1 Weighting factor = 5	Item 2 Weighting factor = 1	Item 3 Weighting factor = 3	Total score = Sum of items
Option 1	1 x 5	3 x 1	1 x 3	11
Option 2	2 x 5	2 x 1	2 x 3	18
Option 3	5 x 5	2 x 1	4 x 3	39
Option 4	4 x 5	1 x 1	3 x 3	30
Option 5	3 x 5	2 x 1	1 x 3	20

Table 3: Example priority weighting decision matrix, List of options (listed vertically) are being prioritised based on the items being considered (listed horizontally), each item being considered is assigned with a "weighting factor"

From the above example, it can be observed that option 3 has obtained the largest number of importance points (39) and is therefore the best option to make based on the influencing items being considered. The Priority Weighting System is widely used in business sectors and has been deemed as an effective option or problem prioritising tool (Tague, 2004).

Study Site

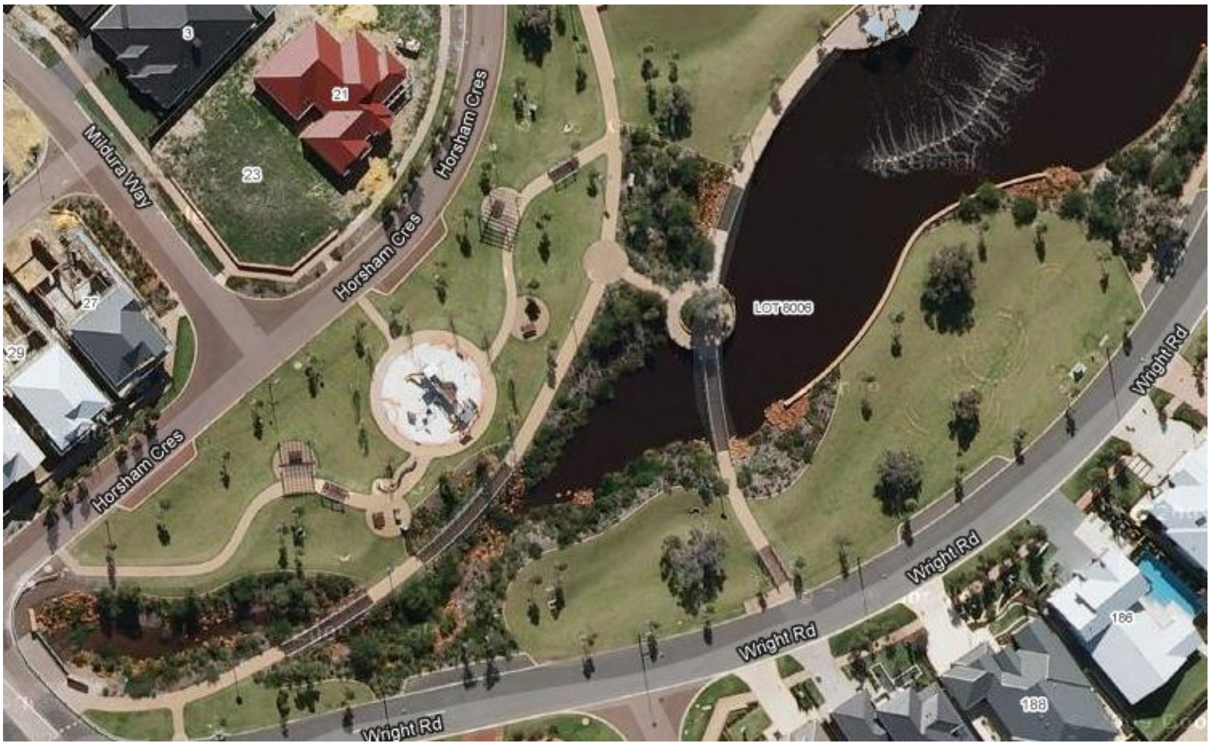


Figure 10: Aerial photograph of the study site, Lot 50 Wright Road, Armadale, photograph taken from google earth

A residential area situated at Lot 50, Wright Road, was provided by Armadale called "Vertu" as the project's study site.

Climatic conditions

The site consists of a Mediterranean climatic condition which is characterised by dry, hot summers, and cool wet winters (Stockland, 2006). Average annual rainfall since 2901 was found to be 869.6mm, obtained from the Bureau of Meteorology's Armadale weather station (station no. 009001) (Stockland, 2006). More than 85% of this rainfall occurs during the winter season of each year from May to October (Stockland, 2006).

Site surface conditions

The topographic characteristics of the site comprises of loose sandy soils on a relatively flat surface (Stockland, 2006). Two open water body locations were identified at the site, these water bodies were located along Wright road at the round after Elegant App, and along Wright road after the Lauraine Drive junction respectively (Stockland, 2006). A living stream connects these water bodies together and flows across Lot 50 towards Southern River.

Site soil conditions

The site's topsoil profile has an average depth of 0.3m and extends to 0.4m at some locations (Stockland, 2006). The topsoil predominately consists of fine to medium grained sands with fine organic content estimated to be greater than 2% by mass (Stockland, 2006).

Underlying the topsoil is a layer of Bassendean Sand which consists of fine to medium grey sand (Stockland, 2006). This layer extends to depths from 1.0 m to greater than 2.3 m below the surface (Stockland, 2006). Underlying the Bassendean Sand layer is iron rich dark brown cemented sand with variable strength properties known locally as "coffee rock". Excavation may be made difficult by the "coffee rock" causing backhoe refusal, but can be generally excavatable at some locations (Stockland, 2006).

Lot 50 Wright Road

This residential area situated at Lot 50, Wright Road, Armadale "Vertu" was used as the project's study site. The site was seen as ideal as it had a wide variety of BMPs implemented making it possible to include the commonly practised BMPs into the cost model. In addition, WSUD is also commonly implemented in residential areas as residential areas especially in Melbourne (EPA Victoria 2005). The data acquired from the study site would therefore be able to relate to other applications within the Perth metropolitan area.

Targeted BMPs to be incorporated into the model were identified at the site during preliminary site investigations and are listed below.

- Rain gardens
- Infiltration basins
- Vegetated swales
- Wetlands

Figure 11: Target BMP identified during preliminary site investigation on 23 May 2012 (Location: Lot 50, Wright Road, Armadale)

Methods and procedures

Feasible approaches to develop the model and current WSUD development status in Western Australia were determined from research and discussions with Town council representatives. From these, two crucial tools were identified to be incorporated into the model. These were the Life Cycle Costing method (LCC) and the priority weighting system.

Project Procedures

The Cost Model's targeted BMPs consist of those that have been implemented and identified at the site during a preliminary site investigation. The targeted BMPs include rain gardens, infiltration basins, vegetated swales and a constructed wetland. A list of maintenance activities was prepared by combining activities conducted at the site obtained from the Urban Water Management Plan (UWMP) (Stockland, 2006) and published literature findings. Stockland, the developers of Vertu provided maintenance costing data that included labour charges, activity costs per square metre and each activity's recommended frequencies. With the acquired data, the LCC cost was determined by following the LCC costing procedure listed in the Australian Standard Life-Cycle-Costing Application Guide: AS IEC 60300.3.3 – 2005 (Standard 2005) and Blanchard's 12 step method stated in "Systems engineering and analysis"(Blanchard & Fabrycky 2006).

Microsoft Excel was used for the development of the Cost Model. The spread sheet includes each BMP's maintenance activity breakdown. A Priority weighting system (PWS) was used to determine the influence level of each maintenance activity on water quality. Weighting factors in the PWS were assigned by stormwater management experienced representatives who intuitively input their opinions about each activity's influence on water quality on a 1 to 5 scale. Their individual weighting factor opinions were averaged to a single weighting factor that was used to quantify the probable resultant water quality in terms of water quality points (WQPs). Water quality is assumed to increase with increasing points (WQPs).

With the obtained LCC costing and WQPs, the balance between costs and water quality could be weighed. The objective is to repeat the process until the user is satisfied with the achieved water quality level based on the maintenance frequencies he/she has setup. If maintenance activities were set to be performed too frequent, costs may appear too high, whereas, too low frequencies will lead to water qualities being below the specified Australian Standards (ANZECC 2000).

The project flow chart is shown in Table 4 below:

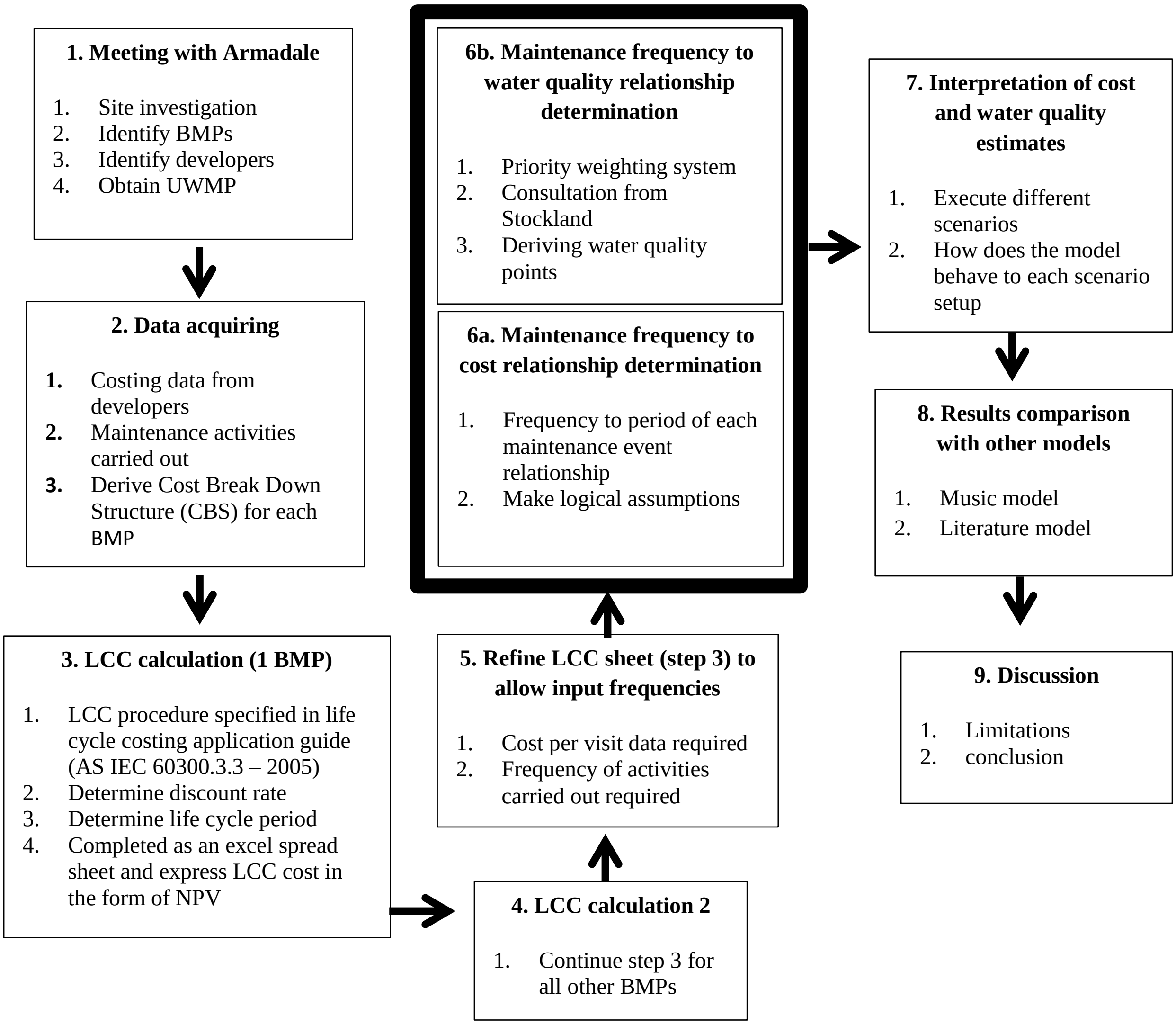
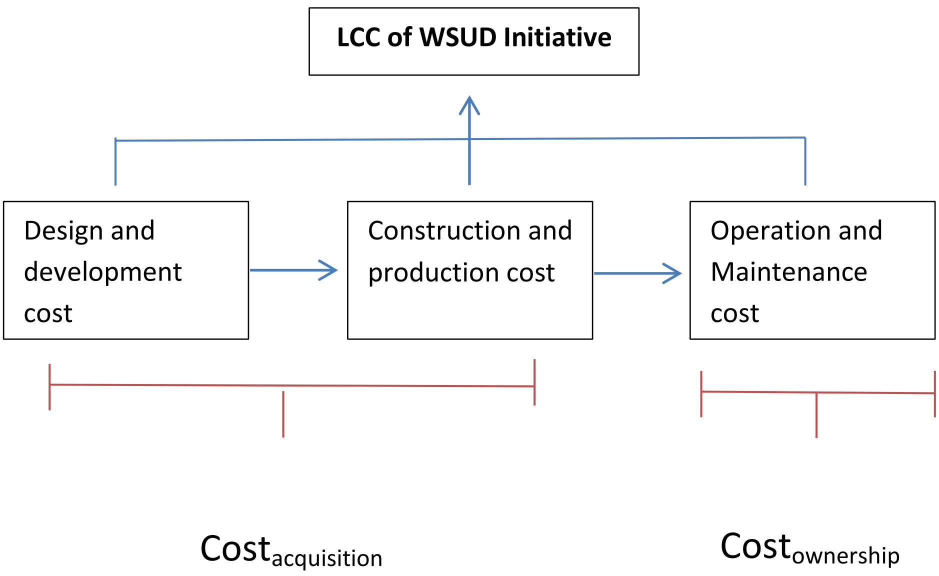


Table 4: Project execution framework

Life Cycle Costing Determination

The Australian Standard life cycle costing application guide: AS IEC 60300.3.3 – 2005 (Standard 2005) describes the steps required to achieve the LCC costing to a Net Present Value (NPV) form. The first step is to identify the life cycle cost phases involved in each BMPs life span. This was done through research and discussions with various town councils. It was learnt that a typical life cycle diagram consists of four phases: the development phase, construction phase, maintenance phase, and the retirement phase (Standard 2005). WUSD applications are usually designed to have an infinite life span with no decommissioning period (Lloyd, Wong & Chesterfield 2002); therefore, the retirement phase in the LCC diagram can be disregarded. The classified system life-cycle phases are thus illustrated in Figure 12 below:



$$LCC = Cost_{acquisition} + Cost_{ownership}$$

Figure 12: Life cycle phases considered for each BMP within "Vertu", the project study site

With the help of experienced stormwater management representatives from councils and developers, WSUD cost drivers and important activities that require special attention were identified. Maintenance costing was of particular interest to potential adopters, thus emphasis has been placed on the maintenance phase to ensure that all important maintenance cost elements have been considered in the LCC cost (Mitchell 2006). Moreover, the maintenance phase consists of values that are difficult to predict. The maintenance phase also forms a major component of the LCC costing that exceeds total acquisition costs for many cases (Mitchell 2006). The other phase’s costs (Design and construction phases) could be identified directly from consultant quotations.

LCC costing for all BMPs in the site were worked out with a selected discount rate of 5% that was assumed to be realistic in the Australian economic context (John 1997). Although WSUD applications were designed to have an infinite life span, the Australian standard for LCC costing requires a life cycle period to be defined. Therefore, the life-cycle period for each BMP was assumed to be 50 years as stated in the MUSIC model (E Water. 2011), which is a sophisticated Stormwater management model widely used in regional and local government agencies (E Water 2012). A 50 year life cycle period was also found to be commonly assumption for many cases when conducting an LCCA for stormwater management systems (SIDEK et al. 2004).

Cost Breakdown Structure (CBS)

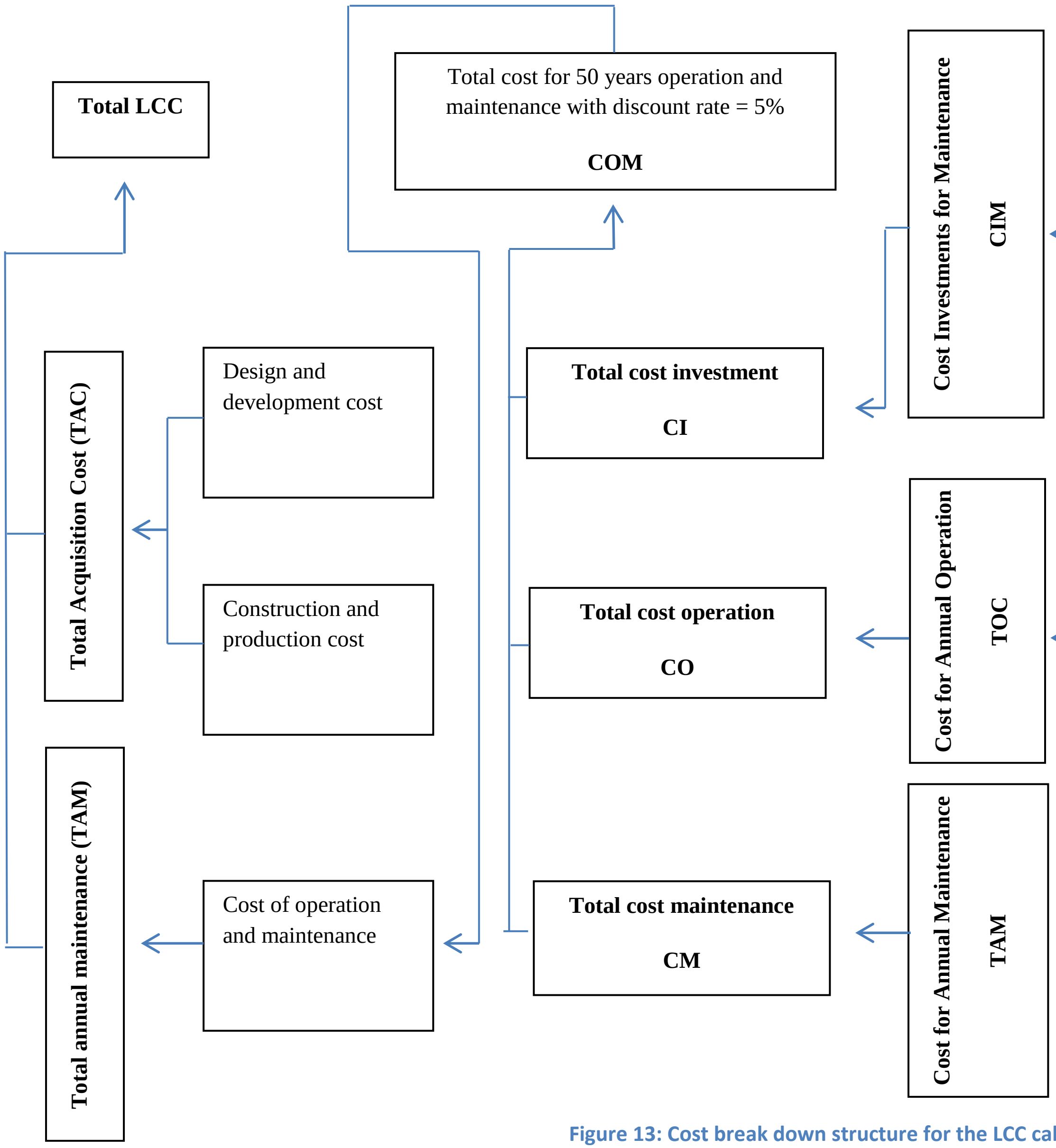
The CBS comprises of the maintenance activities currently being carried out obtained from the site's Urban Water Management Plan (Stockland 2006) and published literature findings (Ira, Vesely & Krausse 2008). Maintenance activities were separated into routine and corrective types. Routine activities included those which needed to be conducted on a regular annual basis (e.g. weeding, inspection and mowing) and corrective activities are those executed only when necessary (e.g. tree and plant replacement, sediment removal) (Ira, Vesely & Krausse 2008). Operations and maintenance facilities were identified during discussions and site visits with Stockland representatives. The following costs related to the operations and maintenance phase in Table 5 were considered relevant for the application. The LCC CBS is shown in Figure 13 below.

Cost elements	Abbreviations
Total cost for 50 years operation and maintenance	**COM**
Investments	CI
Operations	COM
Maintenance	CM
Costs for maintenance investment	**CIM**
Spare parts replacement (irrigation)	CIMSPP
Tree plant replacement	CIMTPR
Shrub planting replacement	CIMSPR
Facilities for maintenance at site	CIMFMS
Costs for annual operations	**CYO**
Irrigation	CYOI
Inspection routines	CYOIR
Monitoring	CYOM
Costs for annual maintenance	**CYM**
Weekly plant irrigation (inactive during May to September)	CYMWI
Garden maintenance (pruning/weeding/litter removal)	CYMGM

Re-mulch void areas.	CYMRM
Fertilizing of planting beds	CYMFPB
Replace tree stakes and wires	CYMRT
Treat diseased trees and shrubs.	CYMTDT
Mowing and edging	CYMME
Fertilising roll on turf	CYMFT
All grass area weed and pest sprayed	CYMGWS
Repair undercut or eroded areas	CYMRE
Seed or sod to restore dead or damaged ground cover	CYMSSDG
Scarification	CYMS
Monitor sediment accumulation and remove accumulated sediment and re-grade	CYMMAS
De-clog the pea gravel diaphragm	CYMDP
Pump used for aerating	CYMPA
Sluice Gate to control stream flow	CYMSG
Removal of sediment build up	CYMRS
Main channel of the drainage line may have to be cleared often	CYMDC
Fallen branches removed	CYMFBR
Obstructions likely to catch debris removed	CYMOR
Remove litter and debris from banks, basin bottom, trash racks, outlet structures, valves, inlets and outlets.	CYMRL
Supplement wetland plants if a significant portion have not established.	CYMSWP
Clean fore bay to avoid accumulation in main wetland area.	CYMCFB
Harvest plant species if vegetation becomes too thick causing flow backup and flooding.	CYMHP

Table 5: Cost elements in the maintenance phase to be included in the LCC calculation of each BMP

Cost Breakdown Structure (CBS)



CIMSPP	CIMJ13	CIMT45
CIMTN	CIMPP20	CIMT15
CIMS4	CIMPP40	CIMT5
CIMS6	CIMPP50	CIMSPR
CIMS12	CIMPP80	CIMS200
CIMSRN	CIMPP100	CIMS140
CIMHGS	CIMTP19	CIMSTS
CIMRP15	CIMWC	CIMSEC
CIMRP300	CIMBHT0.5	CIMFMS
CIMC15	CIMBHT1	CIMAP
CIMC20	CIMTPR	CIME40
CIMC25	CIMT500	CIME15
CIMC40	CIMT200	CIME20
CIMOE	CIMT100	CIMFEP20
CIMFTP20	CIMFT25	CIMS25
CIMFS	CIMFT20	CIMS40

CYMWI	CYMMAS	CYMOR
CYMGM	CYMDP	CYMRL
CYMRM	CYMPA	CYMSWP
CYMFPB	CYMSG	CYMCFB
CYMRT	CYMRS	CYMHP
CYMTDT	CYMDC	CYMSSDG
CYMME	CYMFBR	CYMS
CYMFT	CYMGWS	CYMRE

CYOI	CYOIR	CYOM
CYOW	CYOAP	CYOSA
CYOP	CYOIS	CYOWA
CYOAMB	CYOISC	CYOLTA
CYOISC	CYOIEC	CYOCBE
CYOOCR	CYOPMRI	CYOBEC
CYOBPC	CYORD	

Figure 13: Cost break down structure for the LCC calculation of each BMP

Defining cost categories and cost data

With the CBS and cost elements identified, the next step is to include each element cost and their relative frequencies or amounts (Standard 2005). Stockland was able to provide the required details through a cost tender that included labour charges, activity costs per square metre and each activities recommended frequencies.

LCC costing for each BMP

The LCC of each Implemented BMP was calculated individually before summing them all to obtain a single NPV for the entire catchment area. The BMPs included in the model's LCC costing were those implemented in the study site (Stockland 2006). These include the following:

- Vegetated swales
- Wetlands
- Infiltration basins
- Rain gardens

The LCC costs for each BMP were determined using the steps as shown below:

1. Determine purchase cost from quotations provided by Stockland or literature studies
2. Identify maintenance activities performed
3. List activities with their respective costing obtained from data provided by Stockland
4. Assign activity frequencies
5. Input data into an excel spread sheet
6. Calculate Total Operations cost (TOC)

$$TOC = \sum \text{Frequency} * \text{Cost per operations activity}$$

7. Calculate total maintenance cost (TAM)

$$TAM = \sum \text{Frequency} * \text{Cost per Maintenance event}$$

8. Calculate total Cash flow

   Cash flow = Purchase cost + TAM + TOC

9. Cumulative Net Present Cost

$$Cumulative\ Net\ Present\ Cost = \sum \frac{\text{Cash flow}}{(1 + Discount\ Rate)^n}$$

Discount rate = 5%

N (number of Life-Cycle years) = 50

10. Repeat steps for other BMPs

LCC Rain gardens

Initial costs for rain gardens were identified from a summary of cost relationships for structural BMPs made by Andre Taylor (Taylor 2005). The study was conducted by surveying 60 agencies across many states in Australia to obtain a cost database for LCC cost application (Ira, Vesely & Krausse 2008). $125 - $150/m^2 for an area greater than 100m^2 and $225 - $275 for an area less than 100m^2 were the costs for rain garden construction was stated in Andre Taylor (Taylor 2005). An average cost for each condition was used in the acquisition costing for the LCC costing. Acquisition cost for each rain garden is calculated as follows:

Rain Gardens	Size	Costing
Rain Garden 1	235 m^2	$29,487
Rain Garden 2	337 m^2	$42,225
Rain Garden 3	253 m^2	$31,671
Rain Garden 4	126 m^2	$15,835
Rain Garden 5	325 m^2	$40,725
Rain Garden 6	641 m^2	$80,125

Table 6: Respective size and acquisition cost of each rain garden in Vertu

The maintenance activities performed for each rain garden, frequencies and costing are listed as follows:

Annual Maintenance	Event/year	Cost/event	Event*Frequency
weekly plant irrigation	28	$296	$8,309
Garden maintenance	26	$329	$8,579
Re-mulch void areas	1	$480	$480
fertilizing of planting beds	2	$690	$1,380
Replace tree stakes and wires	1	$10	$10
Treat diseased trees and shrubs	1	$2	$2

Table 7: Rain garden maintenance cost of each maintenance activity according to its performed frequency in Vertu

CNPV (50 year life span) = $601,345

LCC Infiltration basins

Similar to rain gardens, initial costs for Infiltration basins were identified from Andre Taylor (2005). The costing stated in the document was \$60 - \$80m^3 assuming that the infiltration is approximately 1m deep. An average of \$70m^3 was used in the initial costing for each infiltration basin and calculated to be as follows:

Infiltration Basins	Size	Costing
Infiltration Basin 1	1235 m^2	\$86,512
Infiltration Basin 2	211 m^2	\$14,779
Infiltration Basin 3	316 m^2	\$22,161
Infiltration Basin 4	675 m^2	\$47,294

Table 8: Respective size and acquisition cost of each infiltration basin in Vertu

The maintenance activities performed for each Infiltration basin, frequencies and costing are listed as follows:

Annual Maintenance	Event/year	Cost/event	Event*Frequency
Mowing and edging	39	\$237	\$9,243
Irrigate swale during dry season (April through October) or when necessary to maintain the vegetation	12	\$376	\$4,522
Fertilising roll on turf	4	\$419	\$1,676
All grass area weed and pest sprayed	1	\$320	\$320
Scarification	1	\$110	\$110

Table 9: Infiltration basin maintenance cost of each maintenance activity according to its performed frequency at Vertu

CNPV (50 year life span) = \$474,268.00

LCC Wetlands

Initial costs for constructed wetlands were derived by averaging a series of published literature findings. Some of these included costing stated in the Stormwater Management Manual for Western Australia: Structural Controls (Water Corp n.d), Andre Taylor (Taylor 2005) and invoices of previously implemented structural BMPs in Brisbane from a “LCC of WSUD treatment system summary report” (D Thomson 2007). Constructed wetlands construction costs were calculated to be $150 per square metre from eastern state estimations. Little construction cost variability was found between Eastern states and Western Australia (Water Corp, n.d), therefore, the cost obtained was assumed to be realistic for normal Western Australian conditions. Initial costing for the implemented constructed wetland was calculated as follows:

Wetland	Size	Costing
Wetland 1	211 m^2	$31,650

Table 10: Respective size and acquisition cost of each wetland in Vertu

The maintenance activities performed for the constructed wetland, respective frequencies and costing are listed as follows:

Annual Maintenance	Frequency	Cost/Event	Event*Frequency
Garden maintenance (pruning/weeding/litter removal)	26	$36	$942
Fertilizer application to trees	3	$112	$336
Remove litter and debris from banks, basin bottom, trash racks, outlet structures, valves, inlets and outlets as required.	4	$52	$209
Supplement wetland plants if a significant portion have not established	1	$3,414	$3,414
Treat diseased trees and shrubs	1	$80	$80

Table 11: Wetland maintenance cost of each maintenance activity according to its performed frequency at Vertu

CNPV (50 year life span) = $127,597

LCC Vegetated swale

The initial costing for Vegetated swale two was mentioned to be approximately $2,200 (Mr M Walls, 2012, pers. Comm., 1 July). This price was broken down to a unit cost of $42 per square metre and found to differ significantly as compared with other swale construction costing from Andre Taylor (Taylor & Wong 2002) . However, the construction cost of $42/m^2 stated by the developers was used to ensure site specific results. This cost was used in the initial costing for the implemented Vegetated swales and calculated as follows:

Swales	Size	Costing
Swale 1	72 m^2	$3,028
Swale 2	53 m^2	$2,224
Swale 3	95 m^2	$3,981
Swale 4	92 m^2	$3,837
Swale 5	114 m^2	$4,742

Table 12: Respective size and acquisition cost of each vegetated swale in Vertu

The maintenance activities performed for the Vegetated swales, frequencies and costing are listed as follows:

Annual Maintenance	Frequency	Cost/event	Event*Frequency
Irrigate swale during dry season	12	$66	$795
Garden maintenance (pruning/weeding/litter removal)	26	$73	$1,917
Fertilizer application to trees	3	$225	$683
Treat diseased trees and shrubs	1	$80	$80
Replace tree stakes and wires	1	$2	$2

Table 13: Vegetated swale maintenance cost of each maintenance activity according to its performed frequency at Vertu

CNPV (50 year life span) = $103,496

LCC of Overall operations and maintenance

This section includes the activities that are performed on all BMPs such as inspection, monitoring and sampling routines. There is no start-up costing for this section and these maintenance activities and were obtained from the costing data provided by Stockland. Start-up costs have already been included in the previous calculations and this section only includes the maintenance activities that are similarly carried out for all BMPs. The activities performed, frequencies and costing are listed as follows:

Annual Maintenance	Frequency	Cost/event	Event*Frequency
Litter collection and disposal	52	$55	$2,860
Soil analysis	1	$233	$233
Water analysis	1	$243	$243
Lead tissue analysis	1	$181	$181
Preventative maintenance regime inspection	6	$140	$840
Sediment removal	1	$55	$330

Table 14: Cost of similar maintenance activities being performed for all BMPs according to respective frequency in Vertu

CNPV (50 year life span) = $83,898

CUMULATIVE NET PRESENT COST	
BMPs	**Costs**
Rain gardens	$601,345
Infiltration basin	$474,268
Vegetated swale	$103,496
Wetland	$127,597
Overall operations	$83,898
TOTAL NPV	$1,390,605

Table 15: LCC cost for all considered BMPs in the Study site and the cumulative NPV for a 50 year life span

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Maintenance to Water Quality relationship determination

Maintenance frequency to water quality relationship

The purpose of the relationship is to observe how water quality would respond to the various maintenance activities frequencies. The relationship will be able to measure the improvement or magnitude of change on water quality.

It is difficult to derive an exact water quality figure in terms of water quality parameters (e.g. Total Dissolved Solids (TDS), nutrients levels, pH) without BMP efficiency measures. Unfortunately, such data is still not available for Western Australia (Mr D Smith, 2012, pers. Comm., 9 Aug). However, monitoring records for groundwater quality is available but cannot be used as a substitute for BMP efficiency measures. This is because of the insufficient evidence that change in water quality is due to WSUD application, thus jeopardizing the credibility of the data, (Mr G Bremner, 2012, pers. Comm., 11 Aug). Water Corporation has placed storm water management efficiency as one of its priority research and development topics (Department of Water 2012). The city of Gosnells have also partnered in this project by investing $85,000 to install direct inlet and outlet data loggers in some of their BMP initiatives. With the new research being conducted, credible data will be made available approximately by the end of 2013 as it will take at least a year to collect results (Mr G Bremner, 2012, pers. Comm., 11 Aug).

Since BMP efficiency measure information was not available, a qualitative measure was assumed to be sufficient for monitoring water quality change. The PWS had the appropriate characteristics to achieve this (EZIPs 2010), and was thus deemed as appropriate to be incorporated into the model.

The PWS was conducted by sending a “maintenance activities list” to several stormwater management experienced representatives. These representatives intuitively assigned weighting factors to each maintenance activity’s influence on water quality on a 1 to 5 scale. Participants of this survey included technicians from Stockland experienced in direct WSUD maintenance, an environmental engineering professor from the University of Western Australia (UWA), and Gosnell Town council’s landscaping planners. The collected results were averaged to a single weighing factor for each maintenance activity. The obtained importance points (OIP) for each activity were calculated by multiplying their respective weighting factor with its conducted frequency and area. The total obtained WQPs which represents the probable resultant water quality is calculated by summing OIPs for all activities and multiplying it by the fraction of area allocated for BMPs. By taking the area portion allocated for storm water management practises into consideration, effects on water quality due to insufficient BMPs implementation will be reflected.

With this system, the probable resultant water quality is would increase with increasing points and decrease with decreasing water quality points. The WQPs obtained for the study site is shown in Table 16 below.

WATER QUALITY	
BMPS	**Importance points**
Rain gardens	189494.27
Infiltration basin	149364.02
Vegetated swale	9729.62
Wetland	3657.33
Overall operations	588206.67

Total importance points	949819
TOTAL WQP	9688

Table 16: Overall importance points and total WQP derived from the priority weighting system

This WQP system however, does not consider the BMP's direct contribution to water quality. For example, the total importance points obtained for constructed wetlands was only 3,657 as compared to vegetated swales with obtained points of 9,730, as seen from Table 16. This is highly unlikely since wetlands are considered to be high contributors to water quality with high nutrients stripping capabilities (Fisher & Acreman 2004). The weighting system only considers the performed maintenance activities contribution to water quality because the objective of the model is to measure the magnitude of effect on water quality based on the carried out maintenance. Therefore, the system has excluded BMPs direct contribution to show quality effects directly from maintenance itself.

Results: The Model

The developed model is represented by an excel spread sheet consisting of four major components. The components includes: the Model face, the Acquisition cost calculator, the Performance calculator, and the LCC cost calculator. The model sends the various input parameters to each of the four components where calculations will be made. The results will eventually be delivered back to the Model Face to be displayed as outputs. The model systems runs on a series of assumptions that were made based on published literature studies, discussion results and logic. The model's primary assumptions are listed below. A complete set of model assumptions made are described in Table 17 and the Model schematics is displayed in Figure 20. These figures are all available at the end of this section.

Model Assumptions:

1. 50 year life cycle (E water 2011)
2. Discount rate of 5% for Australian economy (John 1997)
3. The model assumes that site conditions are semi-arid, consists of fine to medium grained soils (Stockland 2006).
4. Model includes all necessary maintenance activities to be conducted and no additional activities can be included
    a. To include additional activities, there is a need to ensure that the activity has not been included in the model already as there are many similar activities with different descriptions
    b. Costing data associated with that activity will be required
    c. Site conditions associated with the costing will need to be similar with the other activities in the model
5. All BMPs assumed to remain in good work condition through its life span
6. Water quality will be affected linearly by BMP sizes
7. Water quality is only influenced by maintenance activities frequencies

The Model Face:

Users of the Cost model will first set the necessary parameters for the catchment size, amount and sizes of each stormwater treatment node in square meters, and annual maintenance frequencies. It was noted that 10% of the catchment area is to be reserved for stormwater management and does not include public open spaces (POS) (Mr G Bremner, 2012, pers. Comm., 11 Aug). After the catchment size has been set, the model will display the area to be reserved for Stormwater management. However, it is only a size value in square meters shown to keep the user informed; the "total area of implemented BMPs" box displays the area sum of all implemented BMPs and will need to be equivalent to the required area to meet development standards. The grey colored Boxes shown below are the models inputs. The Model face is illustrated in Figure 14 below.

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INPUTS					
	AREA input	UNITS			UNITS
Total catchment size	500000	m^2	Discount rate	5	%
Required (10% of catchment)	5000	m^2			
Total area of implemented BMPs	5000.0578	m^2			
Total number of BMPs	47				

INITIAL COSTING

RAIN GARDENS		TOTAL NUMBER OF RAIN GARDENS =	6		OPER	Amount	Frequency
					One-	0	1
		BMPs Breakdown	AREA input	UNITS	Reoccurring operating costs	0	1
	1	Rain Garden 1	235.9	m^2			
	2	Rain Garden 2	337.8	m^2			
	3	Rain Garden 3	253.37	m^2			
	4	Rain Garden 4	126.68	m^2			
	5	Rain Garden 5	325.8	m^2			
	6	Rain Garden 6	641	m^2			

VEGETATED SWALES		TOTAL NUMBER OF SWALES =	5		OPERATING COSTS	Amount	Frequency
					One-of-operation costs	0	1
			AREA input	UNITS	Reoccurring operating costs	0	1
	1	Swale 1	72.9686	m^2			
	2	Swale 2	53.592	m^2			
	3	Swale 3	95.9436	m^2			
	4	Swale 4	92.4636	m^2			
	5	Swale 5	114.28	m^2			

INFILTRATION BASINS		TOTAL NUMBER OF INFILTRATION BASINS =	4		OPERATING COSTS	Amount	Frequency
					One-of-operation costs	0	1
			AREA input	UNITS	Reoccurring operating costs	0	1
	1	Infiltration Basin 1	1235.89	m^2			
	2	Infiltration Basin 2	211.14	m^2			
	3	Infiltration Basin 3	316.59	m^2			
	4	Infiltration Basin 4	675.64	m^2			

WETLANDS		TOTAL NUMBER OF WETLANDS =	1		OPERATING COSTS	Amount	Frequency
					One-of-operation costs	0	1
			AREA input	UNITS	Reoccurring operating costs	0	1
	1	Wetland 1	211	m^2			

Inputs catchment size in m^2

Area required that takes 10% of the total catchment size

Total area sum of all implemented BMPs. Should be larger than required

Amount of start up operation cost if any

e.g. initiation ceremony, start up power consumption, etc.

Area input for each implemented BMP

Figure 14: The model face, inputs and maintenance frequencies are placed in this section of the model (inputs and values displayed are not site specific for Vertu)

Users will next have to put in their preferred annual maintenance frequencies for each activity; it is encouraged to calibrate the model first by inputting their recommended frequencies to get a baseline result to be compared with. Recommended frequencies can be obtained from developers, basic WSUD maintenance requirement guidelines or maintenance standards setup for Western Australia. Unfortunately, no additional maintenance activities can be included into the model. To include additional activities either then those specified, cost data will be required or a weighting factor survey will have to be conducted. Any unnecessary activities can be excluded by simply inputting a "0" into the frequency column. The maintenance frequency input table (part of the Model face) is shown in Figure 15 below:

MAINTENANCE FREQUENCY INPUT

RAIN GARDEN

Annual Maintenance	**Input Frequency**
weekly plant irrigation	28
Garden maintenance (pruning/weeding/litter removal)	26
Re-mulch void areas.	0
fertilizing of planting beds	2
Replace tree stakes and wires	0
Treat diseased trees and shrubs.	0
Tree replacement	
500 litre	0
200 litre	0
100 litre	0
45 litre	0
15 litre	0
5 litre	
Shrub replacement	
200mm	0
140mm	0
RENEWAL	**Frequency**
Replacement of Infiltration media	0

OVERALL

Annual Maintenance	**Input Frequency**
litter collection and disposal	52
soil analysis	1
water analysis	1
Lead tissue analysis	1
Preventative maintenance regime inspection	6
sediment removal	1
RENEWAL	**Frequency**
replace GPT	0

Frequency input for each implemented BMP

Figure 15: Model face section where maintenance activities are included or neglected by inputting maintenance activity frequencies (inputs and values displayed are not site specific for Vertu)

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The acquisition cost calculator

After the input parameters have been filled, Acquisition costs for each BMP will be calculated in the "Acquisition cost calculator". The resultant cost estimates are based on costing data acquired from Andre Taylor (Taylor 2005), which defines structural stormwater quality BMP cost to size relationship information similarly used in the MUSIC model. Literature information was used because actual initial costing for the site was unobtainable due to poor record keeping (Mr M Walls, 2012, pers. Comm., 8 Aug). The acquisition cost calculator is displayed in Figure 16 below:

WSUD initiatives	Acquisition Cost
Rain Garden 1	$29,488
Rain Garden 2	$42,225
Rain Garden 3	$31,671
Rain Garden 4	$15,835
Rain Garden 5	$40,725
Rain Garden 6	$80,125
Swale 1	[illegible]2.33
Swale 2	[illegible]5.32
Swale 3	[illegible]5.21
Swale 4	$7,859.41
Swale 5	$9,713.80
Infiltration Basin 1	$86,512.30
Infiltration Basin 2	$14,779.80
Infiltration Basin 3	$22,161.30
Infiltration Basin 4	$47,294.80
Wetland 1	$31,650.00

Acquisition cost = Used costing x Area of implemented BMP

COSTS FROM LITRATURE

BIORETENTION SYSTEM

Area	Capital cost	Units	Comments
>100m2	$125 - $150	/m2	includes initial design costs
<100m2	$225 - $275	/m2	
USED =	$125	/m2	
Frequency	**Maintenance**	**Units**	**Comments**
annual	4. 3	%	[illegible] cost
renewal and adaptation	2%		[illegible] cost

Used costing based on an average of literature findings

VEGETATED SWALES

Area	Capital cost	Units	Comments
NIL	$120	/m	
USED =	$85	/m2	provided by Stockland Martin Walls
Others	**Maintenance**	**Units**	**Comments**
	Cost		after 5 years
grassed	$2.50	/m2/year	
vegetated swales	$9	/m2/year	1.5 /m2/yr.

INFILTRATION SYSTEM

Area	Capital cost	Units	Comments
NIL	$60 - $80	/m3	
used	$70	/m3	
Frequency	**Maintenance**	**Units**	**Comments**
annual	5 - 20%		of total acquisition cost
renewal and adaptation	4.10%		of total acquisition cost

Figure 16: Acquisition cost calculator, in this section of the model, a unit cost method was used to calculate the acquisition cost of each BMP from costs information selected from literature findings (inputs and values displayed are not site specific for Vertu).

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The LCC cost calculator

The inputs and obtained data were used to calculate the Total Annual Maintenance costing (TAM). The resultant TAM will then be placed in the LCC calculator to calculate the cost of performing these activities over a life span of 50 years. The LCC calculator considers the discount rate effect and incorporates it into the BMP life span to produce a LCC cost in the form of a NPV. Nothing needs to be done by the user in this part of the model as everything is calculated automatically. However, the user may change the activity of interest's cost in this sheet if necessary. The LCC cost calculator is displayed in Figure 17 below:

Annual Maintenance	Annual Frequency	Work Area	Cost / Event	Event*Frequency
weekly plant irrigation	28	1920.55	$0.25	$7.00
Garden maintenance (pruning/weeding/litter removal)	26	1920.55	$329.99	$8,579.78
Re-mulch void areas.	0	1920.55	$480.14	$0.00
Treat diseased trees and shrubs.	2		$80.00	$160.00
fertilizing of planting beds	0	1920.55	$690.00	$0.00
Replace tree stakes and wires	0		$2.63	[illegible]
Tree replacement	0			
500 litre	0		1019	
200 litre	0		486.5	[illegible]
100 litre	0		298	$0.00
45 litre	0		130	$0.00
15 litre	0		47	$0.00
5 litre	0		15.225	$0.00
Shrub replacement	0		0	
200mm	0		15.225	$0.00
140mm			8.975	$0.00

Cost per event, derived from the basic cost x Area of application

Frequencies referenced from the "model face"

Cost for replanting, cost = per plant

TAM cost for each activity

Cost per event x frequency

Life- Cycle Years		0	1	2	3
CAPITAL COST					
Purchase Cost		$240,069			
Total Capital cost		$240,069		[illegible]	0

Life Cycle years:

Extends to 50

TAC referenced from the Acquisition cost calculator

OPERATING COSTS

One-of-operation costs		0			
Reoccurring operating costs		0	0	0	0
Total Operating Cost		0	0	0	0

Initial operations costing referenced from the "Model Face"

Annual maintenance cost (TAM)

weekly plant irrigation		$7.00	$7.00	$7.00	$7.00
Garden maintenance (pruning/weeding/litter removal)		$8,579.78	$8,579.78	$8,579.78	$8,579.78
Re-mulch void areas.		$0.00	$0.00	$0.00	$0.00
Treat diseased trees and shrubs.		$160.00	$160.00	$160.00	$160.00
fertilizing of planting beds		$0.00	$0.00	$0.00	$0.00
Replace tree stakes and wires		$0.00	$0.00	$0.00	$0.00
500 litre (Tree replacement)		$0.00	$0.00	$0.00	$0.00
200 litre (Tree replacement)		$0.00	$0.00	$0.00	$0.00
100 litre (Tree replacement)		$0.00			
45 litre (Tree replacement)		$0.00			
15 litre (Tree replacement)		$0.00			
5 litre (Tree replacement)		$0.00			
200mm (Shrub replacement)		$0.00			
140mm (Shrub replacement)		$0.00			

Annual maintenance cost for each respective maintenance activity

Discount Factor:

$$Discount\ Fator = \frac{1}{(1 + Discount\ Rate)^n}$$

n = life cycle year

Discount rate = 5%

Cash Flow:

Cash flow = Sum of all Costs

= Total operating costs + TAM

TAM =	$8,747	$8,747	$8,747	$8,747

CASH FLOW					
Cash Flow		$248,816	$8,747	$8,747	$8,747
DISCOUNTED CASH FLOW					
Discount Factor		1	0.95238095	0.90702948	0.8638376
Discounted Cash flow		$248,815.53	$8,330.27	$7,933.59	$7,555.80
CUMULATIVE NET PRESENT COST (per Rain Garden)	$408,496.17				

Discounted Cash Flow:

Discounted Cash Flow = Cash flow x Discount factor

Cumulative NPV =

$$\sum Discounted\ cash\ flow$$

Figure 17: LCC calculator, an LCC calculator is used to calculate the LCC of each BMP for a 50 year life span (inputs and values displayed are not site specific for Vertu)

The performance calculator

Simultaneously, the frequency inputs will be placed into the "performance calculator" for water quality to be determined. The water quality points obtained from calibration will be the ideal w to be achieved. Subsequent points obtained after adjusting frequency inputs will show how water quality has been influenced by comparing the point differences. The performance calculator is shown in Figure 18 below:

Average importance x Input frequency

Importance factors assigned by stormwater management experienced representatives

Sum of all importance points

RAIN GARDEN		Annual Maintenance	Input Frequency	IMPORTANCE 1	IMPORTANCE 2	IMPORTANCE 3	IMPORTANCE 4	IMPORTANCE Average	Total Importance points	Water quality points (improvement factor)
	1	Weekly plant irrigation (inactive during May to September)	28	3	0	2	1	1	28	189494
	2	Garden maintenance (pruning/weeding/litter removal)	26	5	3	5	4	3	69	
	3	Re-mulch void areas.	0	2	3	2	2	2	0	
	4	Treat diseased trees and shrubs.	2	2	0	2	2	1		
	6	Fertilizing of planting beds	0	3	0	0	2	1		
	7	Replace tree stakes and wires	0	2	0	0	1	1	0	
	8	Remove and replace dead and diseased vegetation	0	3	0	3	3	1	0	

Figure 18: Performance calculator, water quality points are calculated using the weighting factors assigned by stormwater management representatives, estimated water quality based on the maintenance frequency inputs by the user is represented by the obtained WQP (values displayed are not site specific for Vertu)

The model results output

The final results consists of both the total WQPs obtained and LCC costing and is displayed back on the "Model face" in the output section. The display results in Figure 19 include each BMP's Total Acquisition Cost, its TAM, the NPV for a 50 year life span and the probable water quality:

OUTPUTS

TOTAL ACQUISITION COST	
Rain Gardens	$240,068
Infiltration basin	$170,748
Vegetated swale	$17,812
Wetland	$31,650
TAC	$478,953

CUMULATIVE NET PRESENT COST	
Rain gardens	$601,345
Infiltration basin	$474,268
Vegetated swale	$103,496
Wetland	$127,597
Overall operations	$83,898
TOTAL NPV	$1,390,604

TOTAL ANNUAL MAINTEANCE COST	
Rain Gardens	$18,760
Infiltration basin	$15,871
Vegetated swale	$4,981
Wetland	$15,871
Overall	$4,687
TAM	$60,170

WATER QUALITY	
BMPS	Importance points
Rain gardens	189494
Infiltration basin	149364
Vegetated swale	9730
Wetland	3657
Overall operations	576673

Water Quality Points
9289

Figure 19: Result section of the cost model (values displayed are site specific for Vert)

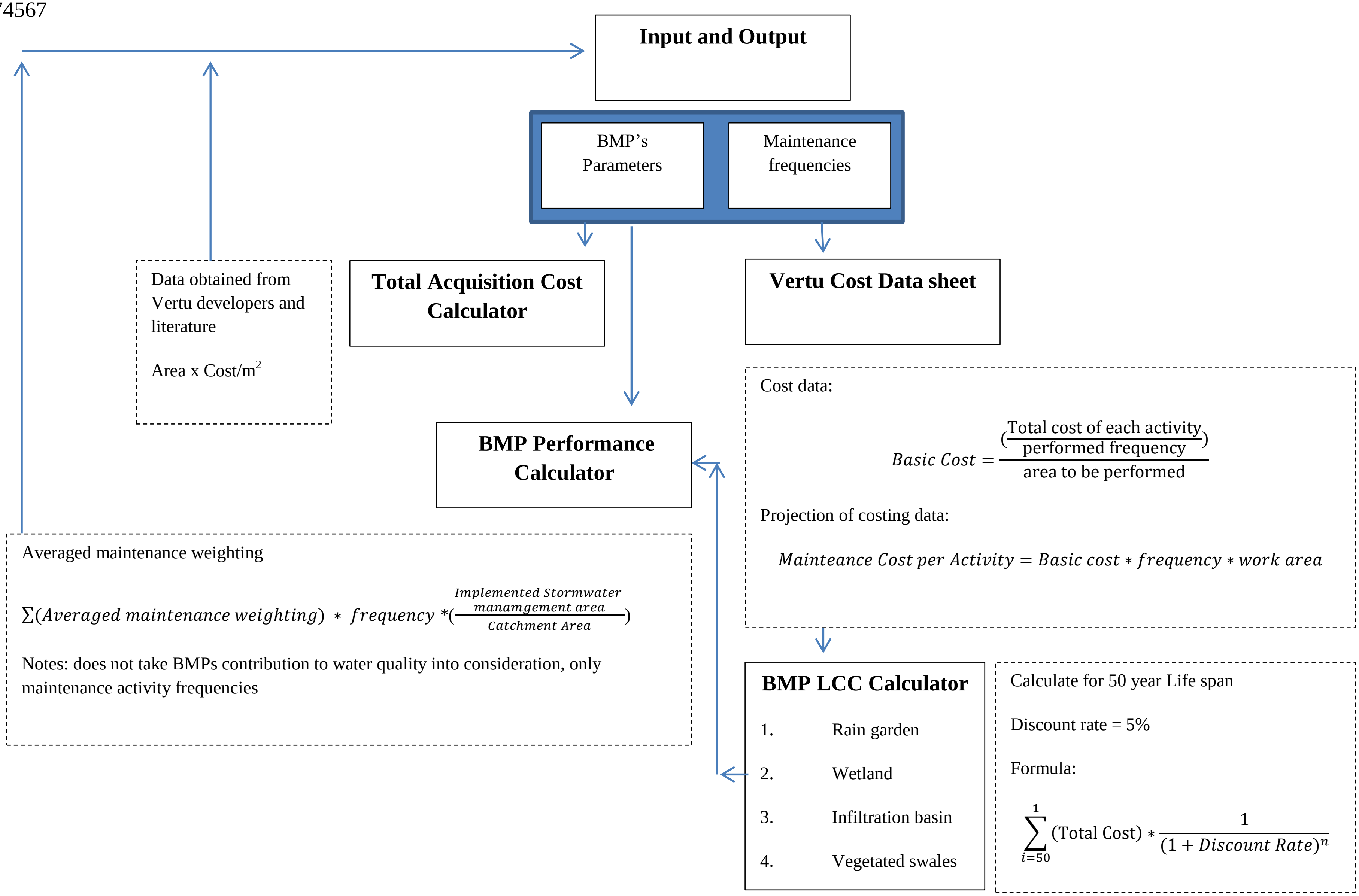

Figure 20: Cost model schematics, describes the functions and processes of each component in the model

Model Face		Acquisition cost calculator	BMP LCC Calculator	BMP Performance Calculator
Cost Assumptions: 1. Basic cost is the most elementary cost to be projected for other applications, it is broken down from cost per event provided by Stockland into Cost per event per m^2, and cost varies for each maintenance activity 2. Labour hours can be neglected because cost is charged per event 3. Cost for other applications in Perth will not differ significantly from those used 4. Special site conditions such as acid sulphate soil do not exist 5. Similar climatic conditions and soil properties throughout Perth Metropolitan area	Frequency Assumptions: 1. Basic costing is constant and not affected by frequency inputs 2. Maximum number of hours for 1 job = 12hrs, Minimum number of hours for 1 job = 0.5hrs, for model to be effective 3. Maximum frequency per year for each activity = 360, Minimum frequency per year for each activity = 1, for model to be effective 4. Number of hrs. for 1 job increases with decreasing frequency until it reaches the maximum limit, Number of hrs. for 1 job decreases exponentially with increasing frequency until it reaches minimum limit, for model to be effective	Assumptions: 1. Primary Cost/m^2 used in calculation is TAC per m^2 2. Total Acquisition cost include Design phase and construction phase	Assumptions: 1. Discount rate = 5% deemed realistic for Australia 2. Life-cycle period = 50 years, similar to most WSUD initiative long term LCCA assumptions 3. All initiative assumed to be in perfect working condition throughout its life span 4. Maintenance phase contributes as a major component in the LCC costing 5. Operation costs incorporated into maintenance costing 6. Structural BMPs included does not have a decommissioning phase	Assumptions: 1. Water quality is only affected by maintenance activities and their respective frequencies 2. BMP do not contribute to water quality 3. Ideal water quality points = 10000 4. Water quality is representative qualitatively by water quality points and increases with increasing water quality points or decreases with decreasing water quality points 5. There is no effect on water quality for over maintenance, and water quality can improve infinitely according to frequency

Table 17: Cost model assumptions, listed according each model compone

Model Performance

Model Result Comparison

In order to test the boundaries of the model, a series of scenarios were executed by changing maintenance frequencies, BMP sizes, and catchment area. These included extreme case scenarios with maintenance frequencies set to be conducted from as little as once a year, to as frequently as once a day. Other scenarios ran included more realistic cases where maintenance activity frequencies were slightly reduced and increased intentionally to improve cost efficiency.

The same set of scenarios was also run on other models such as the MUSIC model so that results can be compared. The reason for comparison was to find out how realistic the Cost model's results are, relative to others with similar outputs. The MUSIC model is adequate for comparison because it has been applied for many years as a stormwater management conceptual evaluation tool. Apart from the MUSIC model, another model included for result comparison is the Literature Model. The Literature Model consists of general TAM cost estimate information found in research. These information included TAM estimates taken from a percentage of the BMP's TAC or fixed maintenance and acquisition cost estimates per area. They are also the usual cost estimating tools used during the event when detailed costs information is unavailable (Ira, Vesely & Krausse 2008). In order to satisfy the TAC assumptions of the Literature Model because it requires a known TAC to determine TAM, two sets of TAC were used. One of which is from the TAC results of the Cost model and the other set, the MUSIC model. The models primary differences are described in the table below.

Cost Model	**MUSIC model**	**Literature Model**
• Estimates costing from maintenance frequencies • Costs per event increases with increasing area, but frequency remains the same • TAM Increases with increasing frequency, but area remains the same	• Derives TAM from TAC based on a relationship defined by a regression analysis. • Data used in the model to derive these relationships were obtained from eastern coast regions and Australia and refined to exclude outliers. $TAC = 387.4 \times A^{0.7673}$ $R^2 = 0.59; p = 0.04$ $TAM = 48.87 \times (TAC)^{0.4407}$ $R^2 = 0.94; p = 0.03$	• TAC cost affected by BMP size • Predicts values from all various perspectives. • Some estimates involve taking a percentage of TAC • Some use a fixed cost per area. E.g. Maintenance cost for Vegetated grass swale = $2.5 per meter

Table 18: Technical differences between each model to be used in the comparison

The first set of results shown in Table 19 was obtained by altering BMP implemented sizes. This in turn will force maintenance and acquisition costing to accommodate the size variations; the model schematic explains the size to cost effect in the “Vertu Cost Data sheet” execution box dialogue shown in Figure 20. Because the two other models do not have the ability to consider maintenance frequencies, the only parameter that can be varied to achieve comparable results was the BMP size. BMP sizes will affect TAC directly for all models thus producing comparable estimated TAM results. However, the cost model is unique in this context, it does not derive TAM directly from TAC, TAM is derived from the maintenance activities being carried out, and the cost and amount of maintenance activities being carried is dependent on the BMP size. Although the Cost model is able to estimate a LCC cost for a 50 year life span, TAC and TAM were compared instead of LCC because only TAC and TAM estimating algorithms could be found from published literature. The models different approaches to cost estimating are illustrated in Figure 21 below:

Cost model’s approach to estimating cost

Cost Model BMP size → Maintenance frequencies → Estimated cost

MUSIC and Literature model’s approach to estimating cost

Other Model BMP size → TAC → Estimated cost

Figure 21: Approach difference to cost estimating between the models used in the comparison

Model Behaviour

Apart from comparing estimate results with other models, it was also important to illustrate the characteristics of the Cost Model. This was done by varying frequencies of the different maintenance activities to see out how WQP would respond.

All test results and their respective graphical plots are shown below:

Model Performance Results and Discussion

Model Comparison

Size vs. Costing								
						Model	MUSIC	
		MODEL	MUSIC	MODEL	MUSIC	LIT	LIT	
Size	Frequency	TAC	TAC	TAM	TAM	TAM	TAM	WQ
7089.43	249	$687,435.51	$660,109.63	$47,893.18	$36,256.48	$45,204.72	43225.171	18540.14
6566.11	249	$637,770.51	$624,502.33	$44,103.63	$35,136.36	$41,641.88	41582.0722	16002.31
6061.07	249	$584,891.76	$592,854.66	$40,752.75	$34,119.98	$38,419.21	40186.8749	13643.17
5638.43	249	$541,980.39	$562,765.95	$37,957.70	$33,227.89	$35,870.24	38488.0745	11818.34
5000.06	249	$478,953.01	$519,791.88	$33,751.33	$31,979.77	$31,894.01	35833.8875	9289.29
2977.89	249	$297,951.91	$373,547.32	$20,047.01	$27,995.61	$18,675.88	24487.2897	3297.38
2427.88	249	$242,982.28	$327,716.21	$16,390.17	$26,286.20	$15,183.22	21742.2509	2193.99
1891.02	249	$194,430.66	$272,394.95	$12,644.05	$24,236.27	$11,683.86	17794.413	1346.86
1359.54	249	$141,105.21	$223,227.78	$9,121.63	$21,928.23	$8,230.34	14846.6061	698.26

Table 19: Comparison results between the models

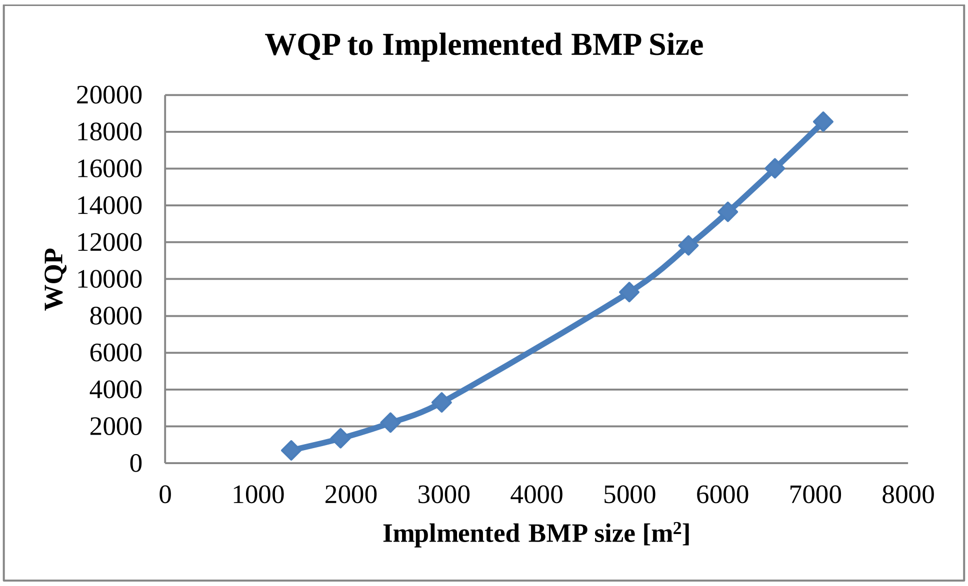

Figure 22: Relationship between WQP and implemented BMP sizes to investigate the models response to changing BMP sizes

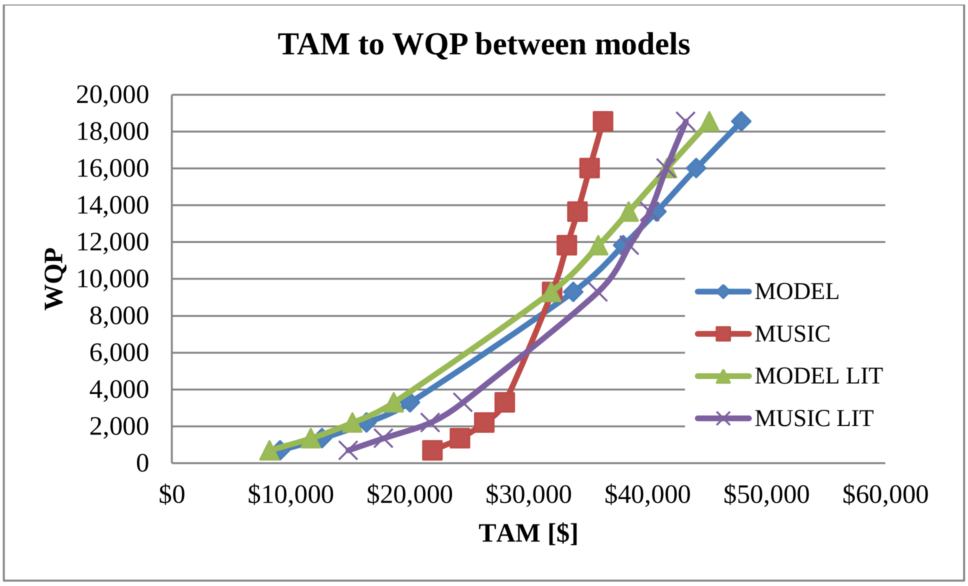

Figure 23: Relationship between TAM and WQP between the different models

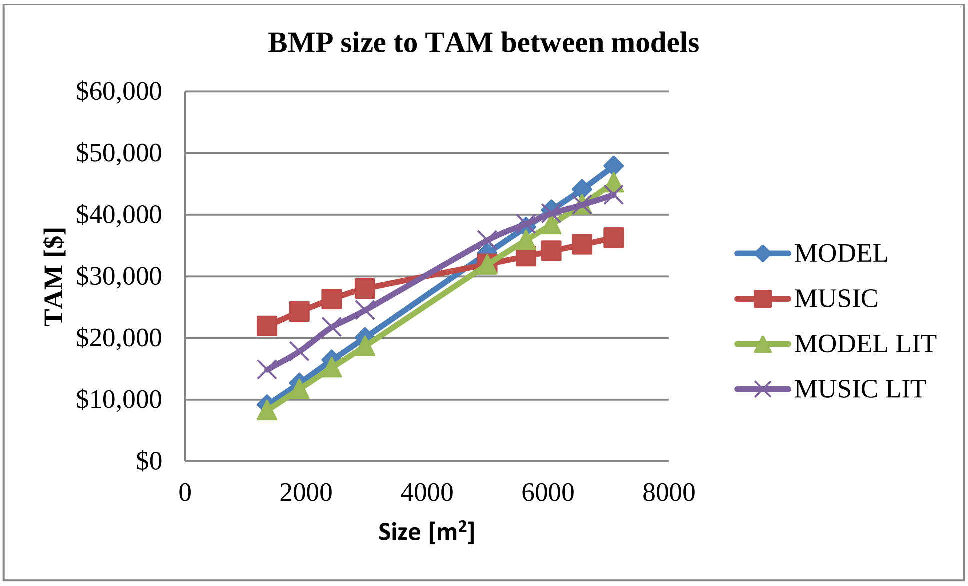

Figure 24: Relationship between BMP size and TAM to investigate how TAM would respond to BMP size variations

Model Behaviour

Frequency vs. Costing							
		MODEL	MUSIC	MODEL	MUSIC	LIT	
Size	Frequency	TAC	TAC	TAM	TAM	TAM	WQ
5000.06	402	$478,953.01	$519,791.88	$54,356.28	$31,979.77	$31,894.01	13806.72
5000.06	357	$478,953.01	$519,791.88	$52,094.52	$31,979.77	$31,894.01	13156.84
5000.06	304	$478,953.01	$519,791.88	$42,807.87	$31,979.77	$31,894.01	11113.50
5000.06	277	$478,953.01	$519,791.88	$38,891.37	$31,979.77	$31,894.01	10158.43
5000.06	249	$478,953.01	$519,791.88	$33,751.33	$31,979.77	$31,894.01	9289.29
5000.06	208	$478,953.01	$519,791.88	$26,560.79	$31,979.77	$31,894.01	8142.68
5000.06	154	$478,953.01	$519,791.88	$18,094.93	$31,979.77	$31,894.01	6866.70
5000.06	102	$478,953.01	$519,791.88	$11,986.68	$31,979.77	$31,894.01	4642.36
5000.06	71	$478,953.01	$519,791.88	$8,204.18	$31,979.77	$31,894.01	3714.22

Table 20 Results to investigate the cost model's response to the different maintenance frequency inputs

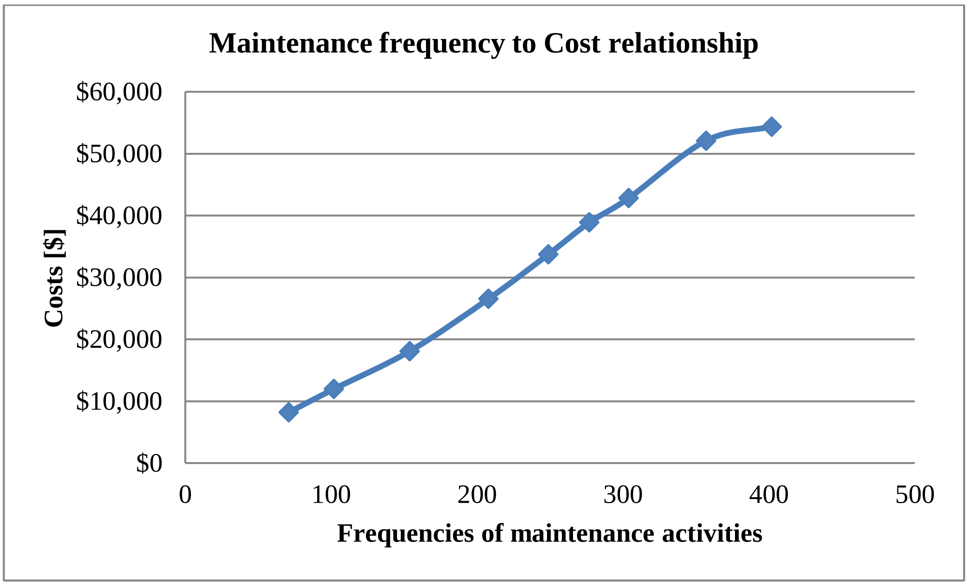

Figure 25: Relationship between cost and maintenance frequency inputs

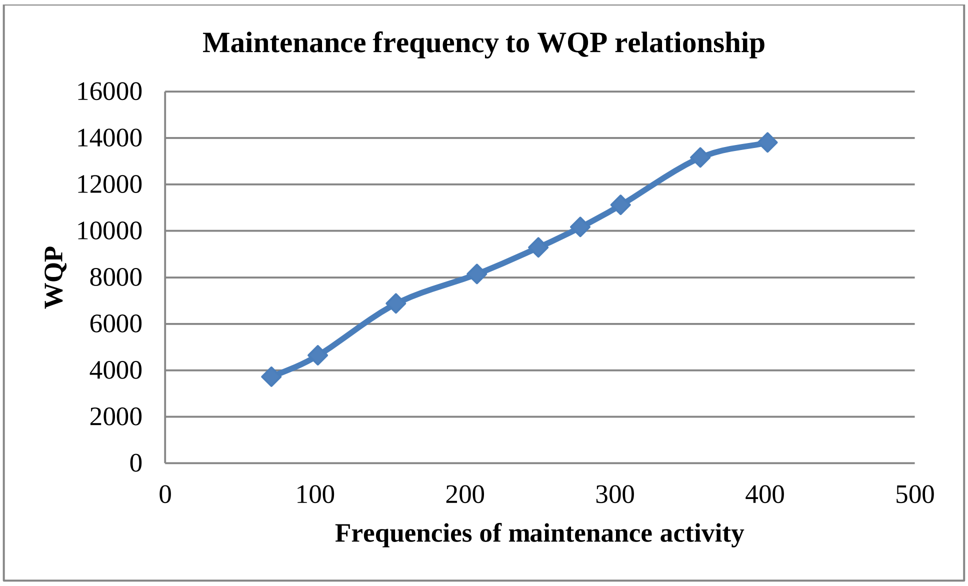

Figure 26: Relationship between maintenance frequencies and obtained WQP

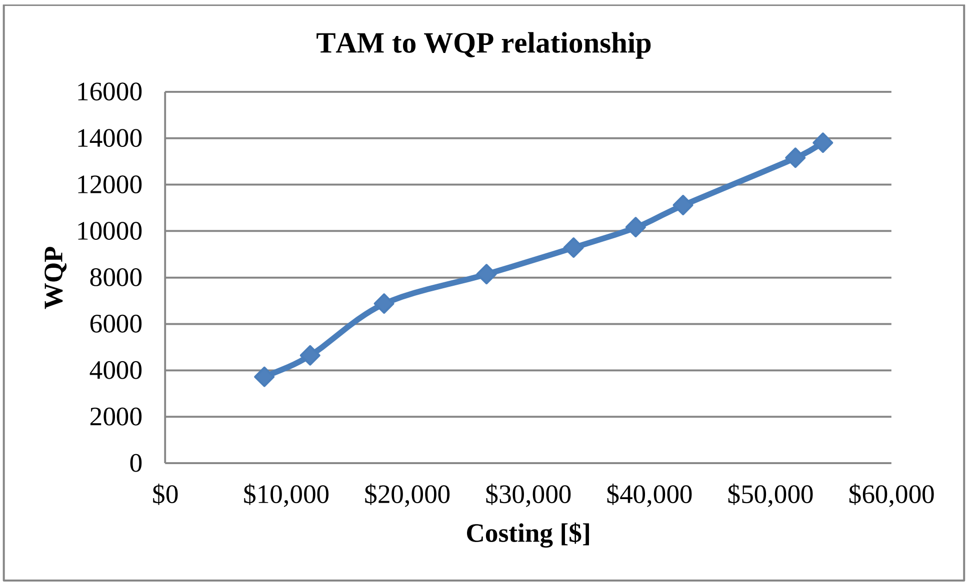

Figure 27: Relationship between TAM and obtained WQP

To analysis the obtained cost estimates, a single factor Anova test was conducted for TAC estimates. Anova could not be performed on TAM results because the Anova test assumptions were not satisfied for the obtained results. The Three Anova test assumptions which included normality, equal variance and independence were all tested for using the Shapiro-Wilks test, F-stat and Bartlett's test, and residual plots respectively. The hypothesis to be tested states whether there is a difference between each models estimated costing. Failure to reject the null hypothesis would lead to the conclusion that there is little difference between the results, suggesting that the model estimates are realistic.

Model Comparison Discussions

It is evident from visual observations on Table 19 that the size varying TAC and TAM does not differ significantly between the models. Moreover, the Anova test results showed similar means between the model TAC estimates (F-statistic of 0.144 against the F-critical 4.49). It is probable that the small sample size is the reason for the high P-value leading to a statistically insignificant result. However, the F-statistic values produced still suggest that there is little variation between the model's TAC results.

From Figure 22, it can be seen that WQP response to implemented BMP size with a slight polynomial fit. This is due to the different maintenance activity's weighing factors that contribute to the relationship. Moreover, increasing the size of the BMP will also affect WQP since area is being considered during the WQP determination (refer to Model Schematics BMP Performance Calculator Execution box for details). Since each activity has different importance, the rate of their contribution to WQP will depend on their weighting factors, the higher their weightings, the higher the rate of their contribution. For example, activity 1's weighting = 1, activity 2's weighting = 5, if area = 25, then the activities contribution to WQP will become 1 x 25 = 25 and 5 x 25 = 125 respectively.

Similar observations can be found in the relationship between WQP and TAM in Figure 23. This is because of the relative linear relationship between BMP size and TAM shown in Figure 24. All models in Figure 23 conform to the same pattern. This is because their WQPs are all derived from the Cost Model's WQP system as neither of the other models have the capability of producing a water quality estimate. So far, both Figure 22 and Figure 23 suggest that water quality would increase infinitely as their respective x-axis parameters increase. This is unrealistic because pollutants cannot be completely extracted from water, in most cases; a constituent removal efficiency measure is linked to each water quality parameter. For example, Western Australian wetlands was measured to have a nutrients stripping efficiency of 40% to 80% varying according to season and plant age (Khan, Zubair & Ali 2005). Moreover, additional stormwater treatments cannot exceed efficiencies of 100%, thus limiting the treatability of water. The graph is instead expected to increase at a decreasing rate which is evident in most treatment efficiency studies (Melbourne Water n.d).

Model Behaviours Discussions

The results in Table 20 show how costs would respond to the various frequency inputs without the effect of BMP size variations. It can be seen that cost increases linearly with frequency, this is expected due to the relationship derived between them in the model (refer to Model Schematics Vertu Cost Data Sheet Execution Box in Figure 20). The slight variation from a perfectly straight line is due to the cost differences between the maintenance activities. Results up to this point are realistic as linear cost estimating is still used during BMP applications (Ira, Vesely & Krausse 2008). Moreover the test statistics has justified the similarity between the TAC cost estimates of the different models. These two factors suggest that the costing estimates from the Cost Model are relatively realistic, making it suitable for application.

The relationship between “WQP and Maintenance frequency”, and “TAM and WQP” showed in Figure 26 and Figure 27 respectively is also relatively linear and deviates slightly from a perfectly straight line because of the variations in importance weighting. Similarly to what has been discussed in “Model Comparison Discussions” this is true as the relationship was not expected to be linear.

Graphs associated with WQP are not realistic as factors such as over maintenance effects were not taken into consideration and are assumed to have a negative impact on water quality. Some impacts may include nutrients leaching that may be the result of too frequent fertilizing (Barton & Colmer 2006). Excess nutrients may also be accumulated in runoff and be washed into water bodies thus affecting water quality (Easton & Petrovic 2004). Despite conducting too frequent fertilizing, the amount of fertilizer to apply depends on the leaf tissue and soil analysis and can be controlled accordingly if necessary (Department of Plant Science, 2012). For this case, the model assumes that appropriate amounts of fertilizer are applied at the given frequencies. Another factor to be considered regarding the WQP’s unrealistic result is that the Performance Calculator does not take into consideration the reduction in treatment efficiencies with increased frequencies.

This suggests that the Performance Calculator will need to include more factors when deriving water quality points to achieve more realistic results. Although the WQP system is not able to give the exact status of the resultant water quality, the user will still be aware of what the net improvement on water quality may be, after altering his/her maintenance sheet.

Conclusion and Recommendations

Although the Model is still in its initial phase, it provides a stepping stone to bridge the financial knowledge gaps that hinder WSUD adoption. Moreover, it is difficult to accurately quantify costing for WSUD applications as their prices are usually quoted for specific site conditions (Mitchell 2006). Generalizing costing in this context would lead to the overlooking of many site specific details, in turn affecting the accuracy of the estimated cost value. There can never be an exact costing as predicted costs are only estimates. For this reason, it is important to use other methods of estimation to get costing from a variety of perspectives.

The Cost model specifically estimates cost from a maintenance plan perspective thus making it possible for users to incorporate a desired maintenance plan into their designed urban water management system. The user is then able to observe the impacts of his/her maintenance plan on costing and water quality and make necessary adjustments. Although the MUSIC model has similar costing and water quality outputs, the model neglects the effects of the maintenance plan. But is has other benefits as it considers other factors for preliminary BMP designing (E Water 2011).
Either then the Cost or MUSIC models, there are other cost estimating models available for WSUD application. The approaches used by these models to estimate costs are usually different. With a wide variety of approaches to estimating costing, it is possible to broaden our understanding of the various factors that influence cost that could help us make a better financial decision.

Continual efforts are being made similarly to bridge this knowledge gap in WA. Such an example is a new type of maintenance cost estimate system that will be introduced in the near future (Mr M Walls, 2012, pers. Comm., 8 Aug). This system aims to simplify maintenance cost estimates for WA application by providing an approximate fixed price ranging from $2.80 to $2.90 per square meter that covers every maintenance aspect (Mr M Walls, 2012, pers. Comm., 8 Aug). However, in the event that these estimates do not meet client satisfaction; it is possible for them to find ways to cut down on costing with this developed Cost Model.

Model developing is an ongoing process, as data and information becomes available or updated, it is possible to further include these to update the model. It is recommended that more costing data be included in the model so that cost estimates can relate more accurately to other applications in WA. However, the larger data set will have to be refined to exclude costing applications for special site conditions and grouped into categories of similar conditions. By doing so, it is possible to introduce site conditions such as soil properties, water table heights and precipitation rates as model input parameters. With BMP efficiency measures made available in the future, the relationship between maintenance activity frequency and water quality can be more technically defined to provide users with adequate water quality estimates. The cooperation of stormwater management organizations to share and provide information will provoke further WSUD research and developments to create a water sensitive Australia.

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Appendix A

Life cycle cost of rain gardens

	Maintenance						Calculations			
	CYMWI	CYMGM	CYMRM	CYMTDT	CYMFPB	CYMRT	Total cost =	Cash Flow	Discount Factor	Discounted Cash flow
0	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.95	$17,868
1	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.91	$17,018
2	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.86	$16,207
3	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.82	$15,435
4	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.78	$14,700
5	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.75	$14,000
6	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.71	$13,334
7	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.68	$12,699
8	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.64	$12,094
9	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.61	$11,518
10	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.58	$10,970
11	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.56	$10,447
12	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.53	$9,950
13	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.51	$9,476
14	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.48	$9,025
15	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.46	$8,595
16	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.44	$8,186
17	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.42	$7,796
18	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.40	$7,425
19	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.38	$7,071
20	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.36	$6,734
21	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.34	$6,414

22	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.33	$6,108
23	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.31	$5,817
24	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.30	$5,540
25	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.28	$5,277
26	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.27	$5,025
27	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.26	$4,786
28	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.24	$4,558
29	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.23	$4,341
30	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.22	$4,134
31	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.21	$3,937
32	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.20	$3,750
33	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.19	$3,571
34	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.18	$3,401
35	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.17	$3,239
36	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.16	$3,085
37	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.16	$2,938
38	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.15	$2,798
39	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.14	$2,665
40	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.14	$2,538
41	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.13	$2,417
42	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.12	$2,302
43	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.12	$2,193
44	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.11	$2,088
45	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.11	$1,989
46	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.10	$1,894
47	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.10	$1,804
48	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.09	$1,718
49	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$18,762	0.09	$1,636
50	$8,309	$8,580	$480	$1,380	$10	$3	$18,762	$258,831	1.00	$258,831

Table 21: Rain garden LCC calculation for a 50 year life span

NVP = $601,345

Lin Zhiliang
20674567

Life cycle cost of infiltration basins

Year	Maintenance						Calculations			
	CYMWI	CYMGM	CYMRM	CYMTDT	CYMFPB	CYMRT	Total cost =	Cash Flow	Discount Factor	Discounted Cash flow
0	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$186,511	1.00	$186,511
1	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.95	$15,012
2	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.91	$14,297
3	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.86	$13,616
4	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.82	$12,968
5	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.78	$12,350
6	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.75	$11,762
7	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.71	$11,202
8	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.68	$10,669
9	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.64	$10,161
10	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.61	$9,677
11	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.58	$9,216
12	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.56	$8,777
13	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.53	$8,359
14	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.51	$7,961
15	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.48	$7,582
16	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.46	$7,221
17	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.44	$6,877
18	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.42	$6,550
19	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.40	$6,238
20	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.38	$5,941
21	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.36	$5,658
22	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.34	$5,388
23	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.33	$5,132
24	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.31	$4,887
25	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.30	$4,655

26	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.28	$4,433
27	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.27	$4,222
28	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.26	$4,021
29	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.24	$3,829
30	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.23	$3,647
31	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.22	$3,473
32	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.21	$3,308
33	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.20	$3,150
34	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.19	$3,000
35	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.18	$2,858
36	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.17	$2,721
37	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.16	$2,592
38	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.16	$2,468
39	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.15	$2,351
40	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.14	$2,239
41	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.14	$2,132
42	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.13	$2,031
43	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.12	$1,934
44	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.12	$1,842
45	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.11	$1,754
46	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.11	$1,671
47	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.10	$1,591
48	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.10	$1,515
49	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.09	$1,443
50	$9,243	$4,523	$1,676	$320	$110	$9,243	$15,762	$15,762	0.09	$1,375

Table 22: Infiltration basins LCC calculation for a 50 year life span

NVP = $474,268

Lin Zhiliang
20674567

Life cycle cost of Wetlands

Year	Maintenance					Calculations			
	CYMGM	CYMFPB	CYMRL.	CYMSWP	CYMTDT	Total cost =	Cash Flow	Discount Factor	Discounted Cash flow
0	$943	$336	$209	$3,415	$80	$4,983	$36,633	1.00	$36,633
1	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.95	$4,745
2	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.91	$4,519
3	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.86	$4,304
4	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.82	$4,099
5	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.78	$3,904
6	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.75	$3,718
7	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.71	$3,541
8	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.68	$3,373
9	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.64	$3,212
10	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.61	$3,059
11	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.58	$2,913
12	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.56	$2,775
13	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.53	$2,642
14	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.51	$2,517
15	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.48	$2,397
16	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.46	$2,283
17	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.44	$2,174
18	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.42	$2,070
19	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.40	$1,972
20	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.38	$1,878
21	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.36	$1,789
22	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.34	$1,703
23	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.33	$1,622
24	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.31	$1,545

25	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.30	$1,471
26	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.28	$1,401
27	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.27	$1,335
28	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.26	$1,271
29	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.24	$1,211
30	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.23	$1,153
31	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.22	$1,098
32	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.21	$1,046
33	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.20	$996
34	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.19	$948
35	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.18	$903
36	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.17	$860
37	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.16	$819
38	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.16	$780
39	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.15	$743
40	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.14	$708
41	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.14	$674
42	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.13	$642
43	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.12	$611
44	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.12	$582
45	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.11	$555
46	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.11	$528
47	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.10	$503
48	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.10	$479
49	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.09	$456
50	$943	$336	$209	$3,415	$80	$4,983	$4,983	0.09	$435

Table 23: Wetlands LCC calculation for a 50 year life span

NPV = $127,597

Life cycle cost of vegetated swales

Year	Maintenance						Calculations			
	CYMWI	CYMGM	CYMFPB	CYMRE	CYMTDT	CYMRT	Total cost =	Cash Flow	Discount Factor	Discounted Cash flow
0	$796	$1,918	$684	$0	$80	$3	$3,480	$39,966	1.00	$39,966
1	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.95	$3,314
2	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.91	$3,156
3	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.86	$3,006
4	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.82	$2,863
5	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.78	$2,727
6	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.75	$2,597
7	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.71	$2,473
8	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.68	$2,355
9	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.64	$2,243
10	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.61	$2,136
11	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.58	$2,035
12	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.56	$1,938
13	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.53	$1,846
14	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.51	$1,758
15	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.48	$1,674
16	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.46	$1,594
17	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.44	$1,518
18	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.42	$1,446
19	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.40	$1,377
20	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.38	$1,312
21	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.36	$1,249
22	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.34	$1,190
23	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.33	$1,133
24	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.31	$1,079
25	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.30	$1,028

26	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.28	$979
27	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.27	$932
28	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.26	$888
29	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.24	$845
30	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.23	$805
31	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.22	$767
32	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.21	$730
33	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.20	$696
34	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.19	$662
35	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.18	$631
36	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.17	$601
37	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.16	$572
38	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.16	$545
39	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.15	$519
40	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.14	$494
41	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.14	$471
42	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.13	$448
43	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.12	$427
44	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.12	$407
45	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.11	$387
46	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.11	$369
47	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.10	$351
48	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.10	$335
49	$796	$1,918	$684	$0	$80	$3	$3,480	$39,966	1.00	$39,966
50	$796	$1,918	$684	$0	$80	$3	$3,480	$3,480	0.95	$3,314

Table 24: Vegetated swales LCC calculation for a 50 year life span

NPV = $103,496

Lin Zhiliang
20674567

Life cycle cost of maintenance activities performed for all BMPs

Year	Maintenance						Calculations			
	CYMLCDI	CYOSA	CYOWA	CYOLTA	CYOPMRI	CYMRS	Total cost =	Cash Flow	Discount Factor	Discounted Cash flow
0	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	1.00	$4,357
1	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.95	$4,150
2	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.91	$3,952
3	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.86	$3,764
4	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.82	$3,585
5	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.78	$3,414
6	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.75	$3,251
7	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.71	$3,096
8	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.68	$2,949
9	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.64	$2,809
10	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.61	$2,675
11	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.58	$2,547
12	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.56	$2,426
13	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.53	$2,311
14	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.51	$2,201
15	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.48	$2,096
16	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.46	$1,996
17	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.44	$1,901
18	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.42	$1,810
19	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.40	$1,724
20	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.38	$1,642
21	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.36	$1,564
22	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.34	$1,489
23	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.33	$1,419
24	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.31	$1,351

25	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.30	$1,287
26	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.28	$1,225
27	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.27	$1,167
28	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.26	$1,111
29	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.24	$1,059
30	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.23	$1,008
31	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.22	$960
32	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.21	$914
33	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.20	$871
34	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.19	$829
35	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.18	$790
36	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.17	$752
37	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.16	$716
38	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.16	$682
39	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.15	$650
40	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.14	$619
41	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.14	$589
42	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.13	$561
43	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.12	$535
44	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.12	$509
45	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.11	$485
46	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.11	$462
47	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.10	$440
48	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.10	$419
49	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.09	$399
50	$2,860	$233	$243	$181	$840	$330	$4,357	$4,357	0.09	$380

Table 25: 50 year life span LCC calculation of similar maintenance activities performed for all BMPs

NVP = $83,898

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Appendix B

Water quality points derived from the priority weighting system

RAIN GARDEN									
	Annual Maintenance	Frequency	IMPORTANCE 1	IMPORTANCE 2	IMPORTANCE 3	IMPORTANCE 4	Averaged IMPORTANCE	Total Importance points	Obtained importance points (OIPs)
1	Weekly plant irrigation (inactive during May to September)	28	3	0	2	1	1	28	195896
2	Garden maintenance (pruning/weeding/litter removal)	26	5	3	5	4	3	69	
3	Re-mulch void areas.	1	2	3	2	2	2	2	
4	Treat diseased trees and shrubs.	2	2	0	2	2	1	1	
6	Fertilizing of planting beds	1	3	0	0	2	1	1	
7	Replace tree stakes and wires	1	2	0	0	1	1	1	
8	Remove and replace dead and diseased vegetation	0	3	0	3	3	1	0	

INFILTRATION BASINS									
	Annual Maintenance	Frequency	IMPORTANCE	IMPORTANCE	IMPORTANCE	IMPORTANCE	Averaged IMPORTANCE	Total Importance points	Obtained importance points (OIPs)
1	Mowing and edging	39	1	1	1	1	1	26	149364
2	Fertilising roll on turf and management	12	2	5	2	5	2	28	
3	Irrigate swale during dry season (April through October) or when necessary to maintain the vegetation.	4	3	0	3	0	1	4	
4	All grass area weed and pest sprayed	1	2	3	2	3	2	2	
5	Repair undercut or eroded areas (banks and bottoms).	0	4	4	4	4	3	0	
6	Seed or sod to restore dead or damaged ground cover	0	3	2	3	2	2	0	
7	scarification	1	2	2	2	2	1	1	

9	Monitor sediment accumulation and remove accumulated sediment and re-grade	0.1	5	2	5	2	2	0	

VEGETATED SWALES									
	Annual Maintenance	Frequency	IMPORTANCE	IMPORTANCE	IMPORTANCE	IMPORTANCE	Averaged IMPORTANCE	Total Importance points	Obtained importance points (OIPs)
1	Irrigate swale during dry season (April through October) or when necessary to maintain the vegetation.	12	2	0	2	0	1	8	11304
2	Garden maintenance (pruning/weeding/litter removal)	26	1	0	1	0	0	9	
3	Fertilizer application to trees	3	1	5	1	5	2	6	
4	Correct erosion problems in the sand/soil bed of dry swales.	1	4	3	4	3	2	2	
5	Treat diseased trees and shrubs.	1	2	0	2	0	1	1	
6	Replace tree stakes and wires	1	2	0	2	0	1	1	
7	Remove and replace dead and diseased vegetation (as required	0	2	2	2	2	1	0	
8	Tree replacement	0	2	3	2	3	2	0	
9	De-clog the pea gravel diaphragm, if necessary	0	5	3	5	3	3	0	

WETLANDS									
	Annual Maintenance	Frequency	IMPORTANCE	IMPORTANCE	IMPORTANCE	IMPORTANCE	Averaged IMPORTANCE	Total Importance points	Obtained importance points (OIPs)
1	Garden maintenance (pruning/weeding/litter removal)	26	1	0	1	0	0	9	4220
2	fertilizer application to trees	3	1	5	1	5	2	6	
3	Remove litter and debris from banks, basin bottom, trash racks, outlet structures, valves, inlets and outlets as required.	4	1	1	1	1	1	3	
4	Supplement wetland plants if a significant portion have not established (at least 50% of the surface area).	1	4	2	4	2	2	2	
5	Treat diseased trees and shrubs.	1	2	0	2	0	1	1	

6	Repair undercut areas, erosion to banks, and bottom as required.	0	3	3	3	3	2	0	
7	Remove and replace dead and diseased vegetation (as required	0	1	2	1	2	1	0	
8	Tree replacement	0	2	2	2	2	1.33	0.00	
9	Clean fore bay to avoid accumulation in main wetland area to minimize when the main wetland area needs to be cleaned.	0	2	3	2	3	1.67	0.00	
10	Harvest plant species if vegetation becomes too thick causing flow backup and flooding.	0	4	4	4	4	2.67	0.00	

OVER ALL MAINTENANCE N INSPECTION									
	Annual Maintenance	Frequency	IMPORTANCE	IMPORTANCE	IMPORTANCE	IMPORTANCE	Averaged IMPORTANCE	Total Importance points	Obtained importance points (OIPs)
1	litter collection and disposal	52	2	3	2	3	2	87	576673
2	Soil analysis	1	5	4	5	4	3	3	
3	Water analysis	1	5	4	5	4	3	3	
4	Leaf tissue analysis	1	5	0	5	0	2	2	
5	Preventative maintenance regime inspection	6	5	4	5	4	3	18	
6	Sediment removal	1	5	4	5	4	3	3	

Table 26: Cost model’s performance calculator table, WQP calculated from Vertu's BMP performed maintenance activities at their recommended frequencies

Appendix C

General test statistics

MODEL TAC		*MUSIC TAC*		*MODEL TAM*	
Mean	$423,056	Mean	$461,879	Mean	$29,185
Standard Error	$68,648	Standard Error	$54,657	Standard Error	$4,898
Median	$478,953	Median	$519,792	Median	$33,751
Standard Deviation	$205,943	Standard Deviation	$163,970	Standard Deviation	$14,695
Sample Variance	$42,412,564,704	Sample Variance	$26,886,147,740	Sample Variance	$215,942,297
Kurtosis	-$2	Kurtosis	-$2	Kurtosis	-$2
Skewness	$0	Skewness	$0	Skewness	$0
Range	$546,330	Range	$436,882	Range	$38,772
Minimum	$141,105	Minimum	$223,228	Minimum	$9,122
Maximum	$687,436	Maximum	$660,110	Maximum	$47,893
Sum	$3,807,501	Sum	$4,156,911	Sum	$262,661
Count	9.00	Count	9.00	Count	9.00
MUSIC TAM		*MODEL TAM LIT*		*MODEL MUSIC LIT*	
Mean	$30,130	Mean	$27,423	Mean	$30,910
Standard Error	$1,719	Standard Error	$4,674	Standard Error	$3,706
Median	$31,980	Median	$31,894	Median	$35,834
Standard Deviation	$5,158	Standard Deviation	$14,022	Standard Deviation	$11,117
Sample Variance	$26,608,926	Sample Variance	$196,628,949	Sample Variance	$123,579,836
Kurtosis	-$1	Kurtosis	-$2	Kurtosis	-$2
Skewness	$0	Skewness	$0	Skewness	$0
Range	$14,328	Range	$36,974	Range	$28,379
Minimum	$21,928	Minimum	$8,230	Minimum	$14,847
Maximum	$36,256	Maximum	$45,205	Maximum	$43,225
Sum	$271,167	Sum	$246,803	Sum	$278,187
Count	9.00	Count	9.00	Count	9.00

Table 27: General statistics calculated in excel to be used in the respective statistical tests

Shapiro-Wilk Test for Normality (N < 50)

Shapiro Wilk's test Hypothesis

H_0 = Population has a normal distribution
H_a = Population does not have a normal distribution

Test Statistic:

$$W_{calculated} = \left[\frac{\left[\sum_{i=1}^{k} a_{n-i+1} \left(x_{(n-i+1)} - x_{(i)} \right) \right]}{SD\sqrt{n-1}} \right]^2$$

n = total number of observations
SD = standard deviation
x(i) = ordered sample from smallest to largest
x(n-i+1) = ordered sample from largest to smallest
k = greatest integer less than or equal to n/2
an-i+1 = coefficient for observed n

	SHAPIRO-WILKS TEST											
	MODEL		**MUSIC**		**MODEL**		**MUSIC**		**MODEL LIT**		**MUSIC LIT**	
	TAC		**TAC**		**TAM**		**TAM**		**TAM**		**TAM**	
	687436		660110		47893		36256		45205		43225	
	637771		624502		44104		35136		41642		41582	
	584892		592855		40753		34120		38419		40187	
	541980		562766		37958		33228		35870		38488	
	478953		519792		33751		31980		31894		35834	
	297952		373547		20047		27996		18676		24487	
	242982		327716		16390		26286		15183		21742	
	194431		272395		12644		24236		11684		17794	
	141105		223228		9122		21928		8230		14847	
Shapiro-Wilk statistic (W) =	0.91		0.91		0.91		0.92		0.90		0.87	
Threshold (p=0.01)	*0.76*	H_0 accepted	*0.76*	H_0 accepted	*0.76*	H_0 accepted	*0.76*	H_0 accepted	0.76	H_0 accepted	0.76	H_0 accepted
Threshold (p=0.05)	0.83	H_0 accepted	0.83	H_0 accepted	0.83	H_0 accepted	0.83	H_0 accepted	0.83	H_0 accepted	0.83	H_0 accepted
Threshold (p=0.10)	0.86	H_0 accepted	0.86	H_0 accepted	0.86	H_0 accepted	0.86	H_0 accepted	0.86	H_0 accepted	0.86	H_0 accepted

Table 28: Shapiro Wilks test for normality

The Shapiro wilks test stats that the data is normal if the Shapiro wilk statistc (W) is smaller than W-critical

It is also possible to assume normality for small or low quality data sets (N<50). Thus, it can be assumed that the data set with 9 points satisfies the Anova's normality assumption (Statsoft, n.d).

Residual plots

Residual plots for TAC

Size	MODEL TAC	Predicted	Residuals
7089	$687,436	$683,357	$4,078
6566	$637,771	$633,909	$3,861
6061	$584,892	$586,188	-$1,297
5638	$541,980	$546,254	-$4,273
5000	$478,953	$485,935	-$6,982
2977	$297,952	$294,862	$3,090
2427	$242,982	$242,892	$90
1891	$194,431	$192,165	$2,266
1359	$141,105	$141,946	-$840

Table 29: residuals determination for Model TAC results

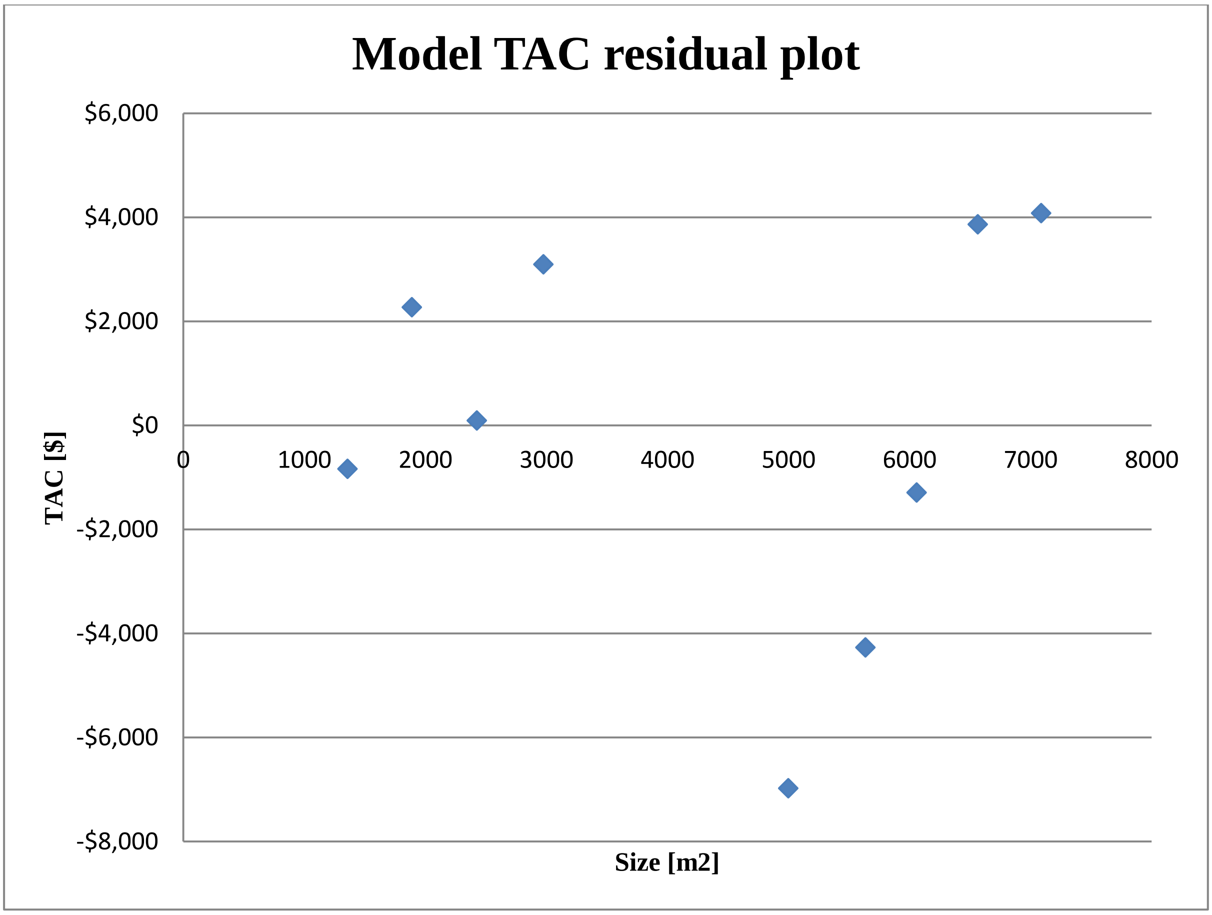

Table 30: Residual plot for Model TAC results

The residual plots suggests that the data is Independent

Size	MUSIC TAC	Predicted	Residuals
7089	$660,110	$655,527	$4,583
6566	$624,502	$624,804	-$302
6061	$592,855	$593,544	-$689
5638	$562,766	$566,169	-$3,403
5000	$519,792	$522,721	-$2,929
2977	$373,547	$368,413	$5,135
2427	$327,716	$322,057	$5,659
1891	$272,395	$275,000	-$2,605
1359	$223,228	$226,655	-$3,427

Table 31: Residuals determination for MUSIC TAC results

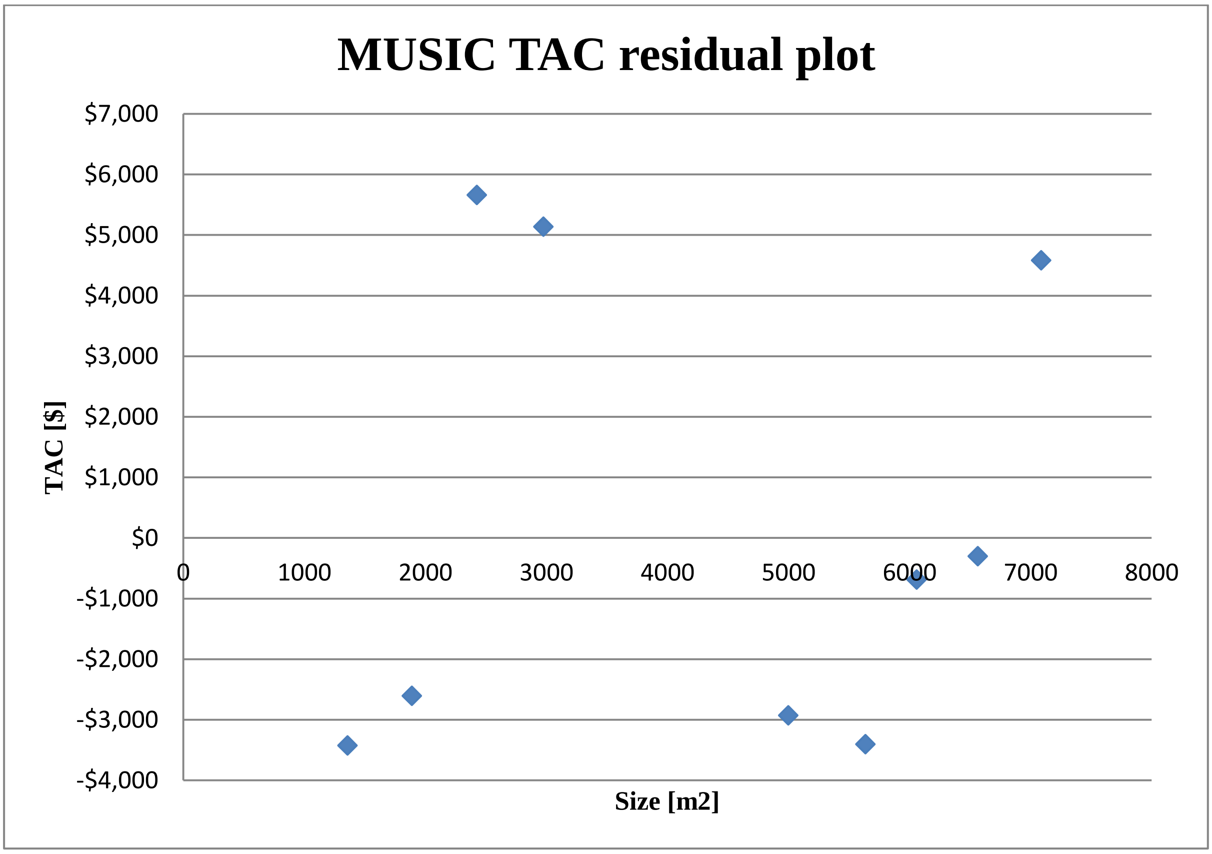

Table 32: Residual plot for MUSIC TAC results

The residual plots suggests that the data is Independent

Residual plots for TAM

Size	MODEL TAM	Predicted	Residuals
7089.43	$47,893.18	$47,761	$132
6566.11	$44,103.63	$44,233	-$129
6061.07	$40,752.75	$40,827	-$74
5638.43	$37,957.70	$37,977	-$19
5000.06	$33,751.33	$33,672	$79
2977.89	$20,047.01	$20,036	$11
2427.88	$16,390.17	$16,327	$63
1891.02	$12,644.05	$12,707	-$63
1359.54	$9,121.63	$9,123	-$1

Table 33: Residuals determination for Model TAM results

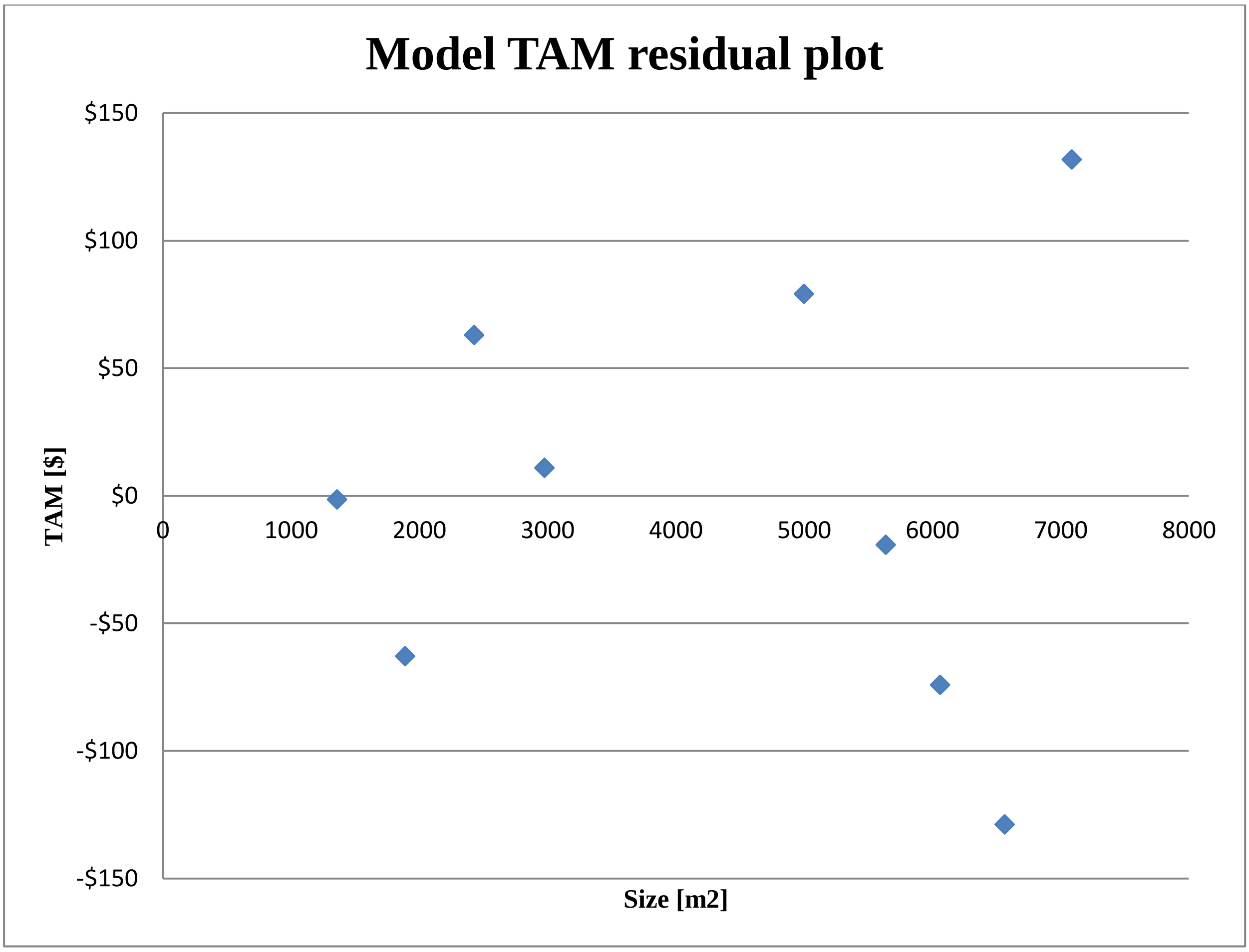

Table 34: Residual plot for Model TAM results

The residual plots suggests that the data is Independent

Size	MUSIC TAM	Predicted	Residuals
7089	36,256	36,600	-344
6566	35,136	35,371	-235
6061	34,120	34,185	-65
5638	33,228	33,192	36
5000	31,980	31,693	287
2978	27,996	26,943	1,053
2428	26,286	25,651	635
1891	24,236	24,390	-154
1360	21,928	23,141	-1,213

Table 35: Residuals determination for MUSIC TAM results

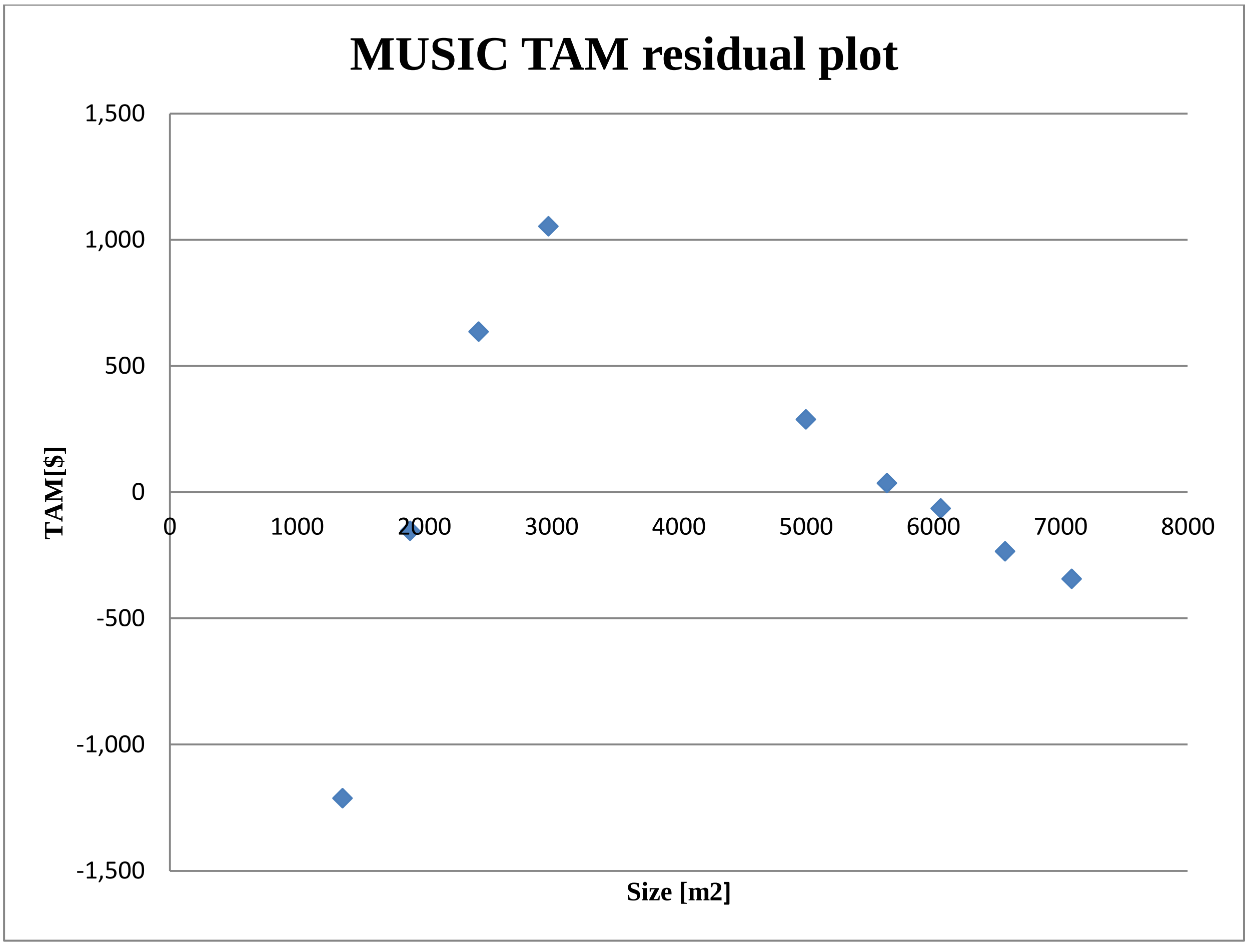

Table 36: Residual plot for MUSIC TAM results

The residual plots suggests that the data is Non-independent

Size	MODEL LIT	Predicted	Residuals
7089	45,205	45,149	56
6566	41,642	41,782	-140
6061	38,419	38,532	-113
5638	35,870	35,812	58
5000	31,894	31,705	189
2978	18,676	18,693	-17
2428	15,183	15,154	30
1891	11,684	11,699	-15
1360	8,230	8,279	-49

Table 37: Residuals determination for Model LIT TAM results

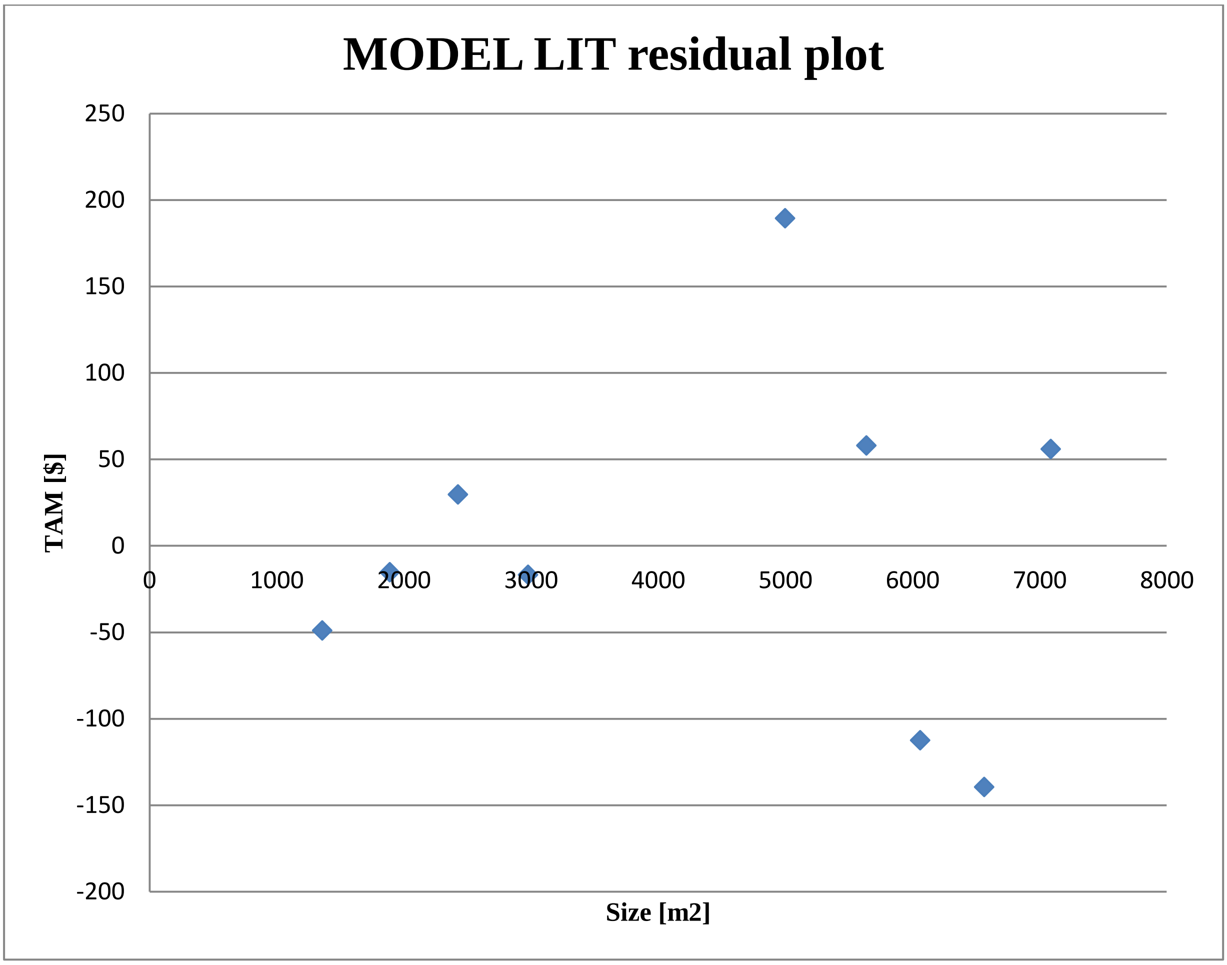

Table 38: Residual plot for Model LIT results

The residual plots suggests that the data is independent

Size	MUSIC LIT	Predicted	Residuals
7089	$43,225	$44,901	-$1,676
6566	$41,582	$42,243	-$661
6061	$40,187	$39,678	$509
5638	$38,488	$37,531	$957
5000	$35,834	$34,289	$1,545
2978	$24,487	$24,019	$468
2428	$21,742	$21,226	$517
1891	$17,794	$18,499	-$705
1360	$14,847	$15,800	-$953

Table 39: Residuals determination for MUSIC LIT TAM results

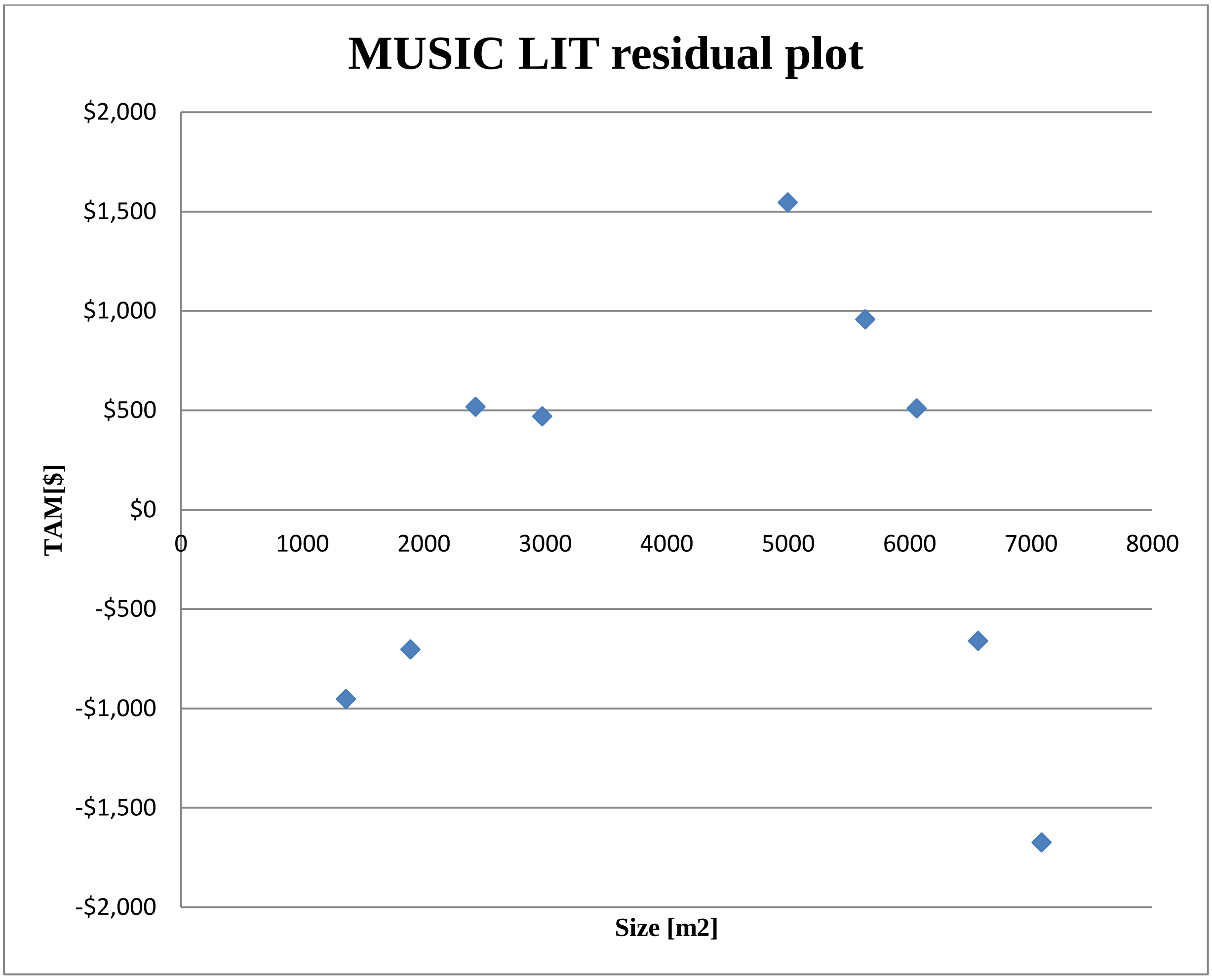

Table 40: Residual plot for MUSIC LIT TAM results

The residual plots suggests that the data is Non-independent

Equal Variance

F-test for equal variance (TAC results)

F-Test Two-Sample for Variances

	Variable 1	*Variable 2*
Mean	423055.6933	461878.9678
Variance	42412564704	26886147740
Observations	9	9
df	8	8
F	1.577487601	
P(F<=f) one-tail	0.266880043	
F Critical one-tail	3.438101233	

Table 41: F-test for two sample variances (TAC results to satisfy Anova assumptions)

$F(1.57)<3.438, P = 0.26$

Equal variance, fail to reject null hypothesis

Bartlett's test for equal variance (TAM estimates)

Bartlett's Test sample for Variances

	Mean	29184.606	30129.64	27422.6	30909.63
	Variance	215942297	26608926	196628949	123579836
	observations	9	9	9	9
step 1	S_p^2	140690002			
step 2	Sum $(n_i-1)\log S_i^2$	257.15968			
	q	3.5847424			
step 3	c	1.0520833			
step 4	Bartlett's stat	7.8456027			
step 5	df	3			
	P(F<=f)	0.0499			
	Chi Critical	7.82			

Table 42: Bartlett's test for sample variances (TAM results to satisfy Anova assumptions)

Bartlett's stat (7.84)>7.82,P = 0.0499

Unequal variance, null hypothesis rejected

Single factor Anova Test

Satisfying Anova assumptions

	Normal	independent	Equal variance
TAC results	Satisfied	Satisfied	satisfied
TAM results	Satisfied	Not satisfied (not all are independent)	Not satisfied

Table 43: Anova assumptions to be satisfied

Only TAC results satisfies all ANOVAs assumptions and therefore, Anova would only be used to evaluate TAC means, TAM means were evaluated via visual observations from the graphical plots in the model comparison discussion section.

Anova test conducted via excel data analysis single factor Anova test function:

TAC cost estimates

Groups	*Count*	*Sum*	*Average*	*Variance*
Cost Model	9	3807501	423055.7	4.24E+10
MUSIC Model	9	4156911	461879	2.69E+10

ANOVA for TAC cost estimates

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.78E+09	1	6.78E+09	0.19575	0.664096	4.493998
Within Groups	5.54E+11	16	3.46E+10			
Total	5.61E+11	17				

Table 44: Anova test for TAC results performed in excel spread sheet

H_0 cannot be rejected as 0.19 (F-stat) < 4.49 (F-Critical) with a P-value of 0.66, therefore, the cost model and MUSIC models TAC estimates are similar.