A Life Cycle Costs (LCC) Assessment of Sustainable Urban Drainage System Facilities

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ABSTRACTS

Stormwater management practice has evolved from simple removal of runoff using traditional storm drainage and "end of pipe" approaches to comprehensive management approaches employing control measures which are more sustainable ecological solutions. In response to the needs for paradigm shift the way the stormwater is managed, the Malaysian Government has introduced a new approach of planning and design of urban areas through the New Stormwater Management Manual for Malaysia (MSMA) that offers a sustainable solution for integrating the land development and urban water cycle. Bio-Ecological Drainage System (BIOECODS) is an example of an innovative sustainable urban drainage system suggested in MSMA that designed to restore the natural environment. The BIOECODS combines three engineering techniques to manage stormwater based on *"Control-at-Source"* approach namely infiltration, storage, conveyance and treatment by integrating the drainage components (i.e. ecological swales, on-line sub-surface detentions, and dry ponds) with the ecological pond components (i.e. detention pond, constructed wetland, wading stream and recreational pond). In combination, this increase runoff lags time, increase opportunities for pollutant removal through settling and bio-filtration, and reduce the rate and volume of runoff through enhanced infiltration opportunities.

However, perception of increased cost is known as barrier to the wider acceptance of the new concept of sustainable drainage systems in Malaysia. Many developers and contractors were sceptical to the successful of the system especially when dealing with construction and maintenance costs. Therefore, the challenge is to develop a clear life - cycle costing of MSMA and traditional drainage systems which has been identified as one key of sustainability challenges for urban drainage. Life - cycle cost analysis (LCC) is an economic evaluation technique to evaluate the sustainability of the drainage systems. This technique is well suited to compare alternative designs, with differing cost expenditures over the project life. This must take into account the full range of benefits, downstream implications and

maintenance implications of each system to enable holistic and comparative cost-benefit-risk assessment.

This paper presents a simple method to conduct life cycle cost analysis of BIOECODS. The method was applied to a pilot project of USM Engineering Campus and it is found that the BIOECODS method has a lower capital cost but due to higher maintenance cost, its life cycle cost is little higher than the traditional method. However, BIOECODS method has proven to have greater overall benefit than the traditional method such as attenuation of the peak flow hence reduce the flooding problems, cleaner waterways with reduction in litter, aesthetic values to the surroundings and improvement to the quality of storm water. Thus, the little increase in life cycle cost associated with the BIOECODS method can be balanced with the long term benefits gained from these innovative urban drainage systems as part of sustainable approach in the new development area.

1 Introduction

Rapid urban growth in Malaysia over the last 30 years has resulted in increased stormwater flow into receiving waters, increases in flood peaks, and degraded water quality. Traditionally, stormwater management focuses on easing flooding through drainage of stormwater runoff from the urban areas to receiving water bodies. The conventional stormwater drainage has been designed to provide the fastest possible transport (rapid disposal approach) of stormwater runoff out of the catchments into receiving waters. The design philosophy of the conventional drainage system is based on solving localized floods either by transferring excessive flows in drainage systems downstream by upgrading the drainage systems or relieving localized problems by constructing storm overflows. The consequence of removing the stormwater from the land surface so quickly is to increase volumes and peak rates of flow discharge and finally overloading the conventional drainage systems. This results in a greater runoff volume that generally requires expensive enhancement of drainage network to reduce severity and frequency of flooding in urban areas. This also results in a higher pollutant washoff from the urban areas leading to deteriorate water quality in the receiving water bodies (Mohd. Sidek, 2001).

Several researchers have stated that the conventional urban drainage systems have reached a limit and that there is a demand for alternative technologies (Marsalek et al., 1993; Kaise, 1997; Argue, 2000). Therefore, there is a need to seek holistic and sustainable solutions not only to mitigate existing flooding problems and water quality degradation but also to prevent the occurrences of such problems in new areas to be developed. With the increasing understanding of non point source pollution, which has traditionally included stormwater sources, a holistic design of urban stormwater management systems needs to incorporate the multiple purposes of controlling major and minor floods, as well as stormwater pollution.

In response to the needs for paradigm shift the way the stormwater is managed, the Malaysian government has launched the new Stormwater Management Manual for Malaysia (DID, 2001) incorporating the latest development in stormwater management that is known as control-at-source approach. The source-control approach is a relatively new concept in stormwater management practices in Malaysia. This approach refers to Source Control Systems indicating any processes which modifies the runoff from an area of land where that modification is close to the source of the flow. Mohd Sidek et al. (2002) adopted the approach of WSUD (Whelan et al., 1994) into MSMA approach as the integration of various Best

Planning Practices (BPPs) and Best Management Practices (BMPs) in the new stormwater management concept.

More recently, there has been a major shift in stormwater management that has multiple objectives such as drainage, flood protection, ecosystem protection, recreational and landscape facilities. A new design philosophy in New Stormwater Management Manual for Malaysia (MSMA) is also known as sustainable urban drainage system has evolved, which can be considered as an integrated stormwater management practice to control peak flows, protect and/or enhance water quality and promote water conservation activities to meet environmental objectives and achieve sustainable urban development. In adopting MSMA, local authorities in Malaysia are confronted by a number of problems including a lack of clear and agreed standards for the environmental management of urban stormwater and a lack of environmental and performance data on MSMA measures to support planning and design (Mohd. Sidek, 2002).

Currently, drainage system could categorize as conventional open drainage systems or ecological drainage system. The open drainage systems should consist of grassed swales, ditches, or channels. The function of grassed swales have previously been studied by Kercher et al. (1983), Yousef et al. (1985, 1987), Wigington et al. (1986), Maestri and Lord (1987), Schueler (1987), Lorent (1992 a, b), Finley and Young (1993), Backstorm (1989) and Llyod (2001). The typical conventional drainage systems in Malaysia is open concrete drain with the precast u-shape drain to collect the stormwater and conveyed the stormwater runoff as soon as possible to the downstream. In the long term, this system have increase volumes and peak rates of flow discharge and finally overloading the conventional drainage systems causing flooding at downstream.

Realising the disadvantages of conventional drainage systems, Mohd Sidek et. al. (2001) invented new type of drainage systems called Bio-Ecological Drainage Systems (BIOECODS) capable in attenuating the peak flow and volume and improving the stormwater quality. The BIOECODS has been implemented in pilot project at USM Engineering Campus, which has adopted the design standard recommended in the MSMA. The BIOECODS combines three engineering techniques to manage stormwater based on *"Control-at-Source"* approach namely infiltration, storage, conveyance and treatment by integrating the drainage components (i.e. ecological swales, on-line sub-surface detentions, and dry ponds) with the ecological pond components (i.e. detention pond, constructed wetland, wading stream and recreational pond). A BIOECODS is a shallow, grassed-lined channel underlain with drainage module as a subsurface conveyance (Mohd. Sidek, 2001). As stormwater runoff flows through these channels, it is treated through filtering by the vegetation in the channel, filtering through matrix, and/or infiltration into the underlying soils. In combination, these increase runoff lag time, increase opportunities for pollutant removal through settling and bio-filtration, and reduce the rate and volume of runoff through enhanced infiltration opportunities.

The change towards a more sustainable urban drainage systems will be a complex and time-demanding process. This is due to the fact that it is difficult to clearly state what is sustainable. Furthermore, the diversity of the existing systems increases the complexity. Thus, there is a need for indicators on sustainability. Backstrom (2000) used physical resources called exergy and cost analysis as indicator on sustainability. He investigated the utilization of financial resources and natural resources and found that the pipe system demanded considerably more physical resources than a swale system during the construction phase (transport and excavation). He also concluded that the pipe system was 34% - 80% more expensive than the swale system in areas with poor topsoil and 5 - 6 times higher than the cost of swale with good topsoil. Finally, the maintenance cost for the pipe was found 10 times higher than the maintenance cost for a swale system but a pipe system demands less physical resources for maintenance than a swale system does.

This study is aim to produce a simple method to conduct life cycle cost analysis of BIOECODS methods under tropical climates. In Malaysia, there is still a lack in design data on MSMA approach and there is a perception that MSMA approach is more expensive to implement and maintain than the traditional method. It is expected that the research outcomes from the recent and on-going applications of the MSMA projects will play a key role in changing the present attitude of the Malaysian citizens on MSMA approach.

2 Methodology

The two drainage systems were classified as conventional (open concrete drain) and ecological drainage systems (grass swale and BIOECODS). The three alternative urban drainage systems were designed to have comparable function in terms of capacity to transport stormwater. A simple life cycle model for each alternative systems were established in Figure 1 to Figure 3. The conventional and ecological drainage systems will undergone the whole process throughout the lifetime starting from production until the end of life cycle of the systems as shown in Figure 1 to Figure 3. Therefore, the life cycle cost analysis will be based on the life cycle model of each drainage system. The three alternatives urban drainage system were designed to have comparable function in terms of capacity to transport stormwater divided into three categories namely open concrete drain system, swale drain system and Bio-Ecological Drainage Systems (BIOECODS).

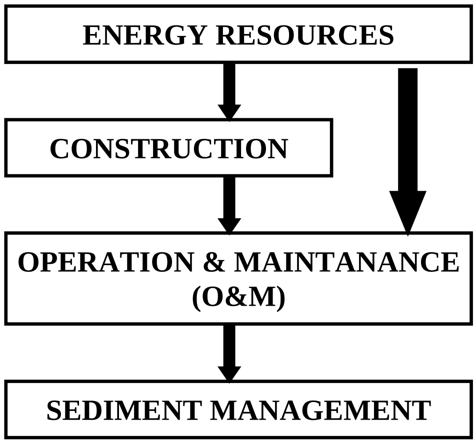

Figure 1 Life Cycle Model for Grassed Swale System (Backstrom, 2001).

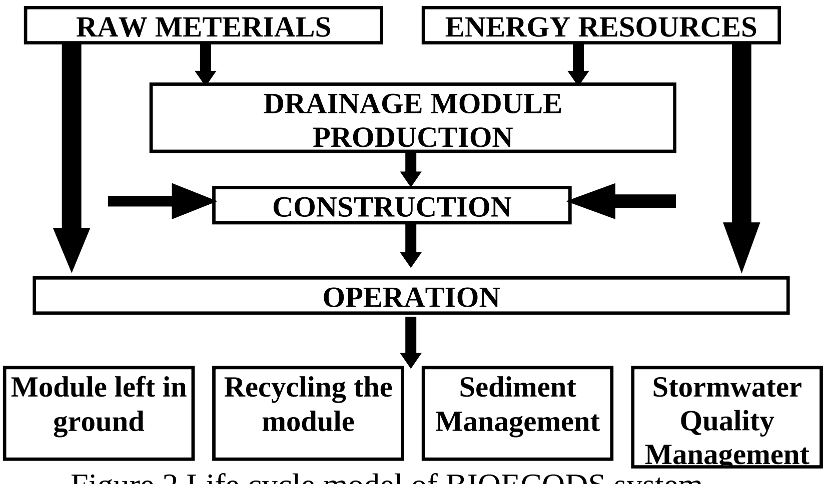

Figure 2 Life cycle model of BIOECODS system.

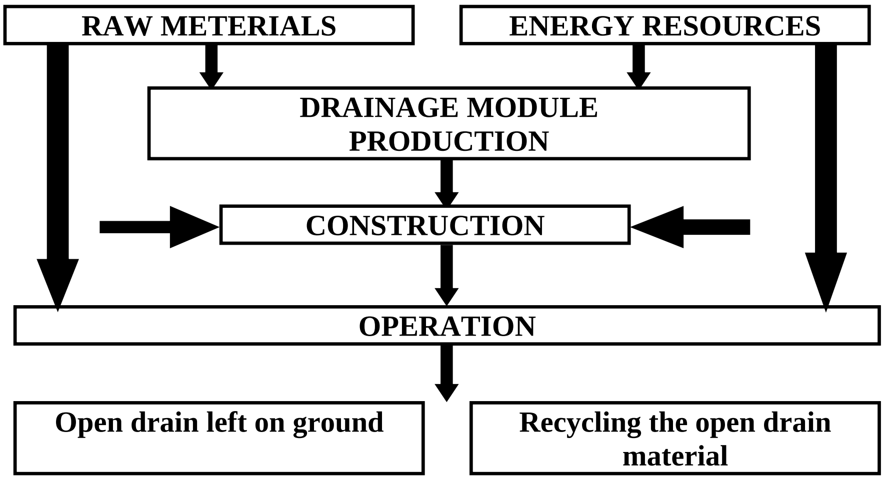

Figure 3 Life Cycle Model for Open Drain System.

The term production as shown in Figure 2 and 3 in BIOECODS and open drain systems were defined as the phase where all raw material production and all industrial production of system components took place. The raw materials may be produced for BIOECODS with either recycled polypropylene. Meanwhile, the open drain system normally used concrete and cement as raw materials.

The term construction shown in Figure 1 to 3 comprised all activities performed at the site where the conveyance system was built. This is usually the major first cost incurred to build the facility. All costs to construct the facility are included: design, construction, contract administration, inspection, supervision, and any other costs associated with the construction process. This also included the transport of open drain and building materials. Construction of BIOECODS is not too complicated as compared to concrete drainage system which needs particular processes such as mixing and placing concrete, all this work has to do properly otherwise concrete drainage will be collapsed or failed. However, BIOECODS did not require such processes in the construction work but the specification and design must be followed strictly.

The term construction comprised all activities performed at the site where the conveyance system was built. This also included the transport of open concrete drain and BIOECODS drainage materials. Construction of concrete open drainage involved work such as open concrete drain installation, mixing and placing concrete, open drain bedding and jointing. Meanwhile, the construction work of BIOECODS involved excavation, leveling, sand bedding, module laying, sand installation, back filling, slope trimming, top soil application and close turfing. The estimation of the construction costs must also consider a number of local issues. These include the design flow rate, size and configuration of the stormwater facilities (with regard to site constraints), hydraulic impedance and the requirements for operation, and safety and other construction issues. If any of this factors can not be adequately satisfied by a particular stormwater facilities it should be deemed as potentially inappropriate for that location.

Meanwhile, all the work with maintaining the function of the system was defined as operation and maintenance (O&M) shown in Figure 1 to 3. The term of operation and maintenance are also contained necessary inspections, measurements and management of sediments. Used open drains could either be left on the ground or the material in the open drain could be recycled. Where as, for the BIOECODS the materials in the module can be recycled or left in the ground with particular attention in the sediment and water quality management. It is therefore imperative to carefully consider the maintenance requirements and estimated costs when selecting the stormwater management facilities.

For the maintenance of the concrete open drainage, the owner of storm drainage facilities should conduct the inspection on an annual or semi-annuals basis as well as following major storm. For BIOECODS, periodical maintenance will be required to maintain the hydraulic capacity of a BIOECODS system. Grassed should be regularly mown and sediment, litter, and debris deposits removed, particularly at flow restrictions such as vehicular crossing points. Besides that removing dead grass, filling scour holes and reseeding with a recommended permanent grass seed mix must repair bare patches and scoured area. Used drainage module could either be left in the ground or the material in the pipes could be recycled. In sediment management of the BIOECODS, the processes are pollutant removal and water quality control. Maintenance costs can be more difficult (but are sometimes the most critical variable) to estimate than the construction costs. Variances of the techniques used, the amount of material removed and the unknown nature of the pollutants exported from the catchments. In many cases maintenance costs are the most significant cost of a treatment measure.

3 Principle of Life Cycle Cost (LCC) Analysis

The overall cost of providing, operating, repairing, cleaning, maintaining and owning an asset over its predicted useful life is defined as Life Cycle Costs (LCC). Life cycle costs are a combination of the production, construction and operation/maintenance costs. To determine the life cycle costs the estimated duration of the project needs to be determined (e.g. 25 or 50 years) or if the BIOECODS is to control pollutants during the development phase only it may be 3-10 years. This is used to extrapolate the annual operating costs to project life costs. To estimate the life cycle costs for a stormwater facilites that the construction costs, maintenance costs and the annual operating costs (for the project duration include overhead and management) are combined. This can be simply performed for all stormwater facilities and then, with consideration to the other influences (social, political etc.), the most appropriate stormwater facilites can be selected based on the flow chart shows in Figure 5.

The life cycle cost for the BIOECODS is estimated using the following procedures:

1. Determine the project life (n: years)
2. Estimate the construction cost (including design, construction, contract administration, inspection, supervision, supply and transportation of the material, ancillary works and any other costs associated with the construction process)
3. Estimate the annual maintenance and operation cost (including overhead, management, inspections, measurements and management of sediments)
4. Estimate the Equivalent Annual Cost (EAC) by estimating the Life Cycle Cost (LCC) of the project and dividing by the project duration

LCC (RM) = Construction (RM) + [n x annual maintenance & operation (RM)] + [n x annual overhead/management cost (RM)] (1)

EAC (RM/year) = LCC (RM)/ duration (years) (2)

The economic analysis helps to calculate the ultimate project cost in terms of a single sum that is the annual equivalent cost or the present value of all costs over the life of the development. The methodology used in life cycle analysis incorporates basic discounting and financial appraisal techniques. The value of life cycle costing looks at the balance between initial and future expenditures by using a series of economic analysis. The future value of RM1 annual payments for *n* years at the compound interest rate of *i* equals (1 + i) *n*. Similarly, the present economic value due to a series of regular annual future payments of RM 1 at discount rates of *i* equals 1/(1+i) n.

4 Methodology for Life Cycle Cost (LCC) Analysis of BIOECODS Method

A simple spreadsheet has been developed to conduct life cycle cost analysis of BIOECODS and traditional methods. The procedure for the life cycle cost analysis is based on the Flow Chart shown in Figure 4. There are two schedules for each method: estimation of capital/construction cost and estimation of life cycle cost as shown in Tables 1- 4. From designs, the quantity of various items e.g. ecological swales, concrete drainage are estimated and entered into the schedule of capital/construction cost estimates (Table 1 or Table 2). The rates for various items are obtained from local authorities and/or civil contractors and entered into the schedule. The total capital/construction cost is obtained as the sum of all the costs in the last row of the schedule.

To compute the life cycle cost, the capital/construction cost obtained in Table 1 or Table 2 is copied into the column of capital/construction cost in the schedule for life cycle cost analysis in Table 3 or Table 4. The operation and maintenance costs are estimated and entered into the schedule. The assumed interest rate is entered into the appropriate box. The annual operation, maintenance and overhead costs are increased by a percentage after a number of years to account for inflation (For example, 3% increase in every 10 years).

5 Discussions

The life cycle costs are estimated for various interest rates and results are summarized in Table 5 and plotted in Figure 5 to examine the variation in life cycle costs with interest rates. At smaller interest rate, the life cycle cost of MSMA method is higher than the conventional method. The most important finding is that the point where two curves intersect at 15% interest rates as shown in Figure 5 indicates the interest rate at which life cycle costs for the two methods are the same whether the systems are conventional or MSMA method. The results show that the life cycle cost will be the same for both methods before life cycle reached 25 years.

The costs of the stormwater management scheme at USM Engineering Campus for conventional and MSMA method is shown in Table 1 and 2. The tabulated costs include drainage works, as this is component that differed with the implementation of the BIOECODS. Comparison of costs between implementing a BIOECODS stormwater management scheme and a conventionally designed stormwater drainage system shows only a minor decrease of 5% to the cost of the drainage component of the development. Considering the drainage works component represents only 10% of the overall cost, the incorporation of BIOECODS into stormwater management system at the USM Engineering Campus decreased the total budget by 0.5%.

Table 1 Schedule for capital cost estimation for MSMA method

COST SUMMARY

Drainage type: **Perimeter swale (package 2-9)-alternative way**
Design life period: 50 years

ITEM DESCRIPTION	UNIT	QTY	RATE (RM)	AMMOUNT (RM)
Excavation	cu.m.	15,334	5.25	95,842.75
Hydronet	sq.m.	18,032	7.50	135,240.00
Sand bedding	sq.m.	7,409	4.00	29,636.00
Geo Strip	lin.m.	20,964	102.00	2,138,277.00
Sand filling	cu.m.	2,594	30.00	77,820.00
Turfing				
a)close turfing	sq.m.	37888	3.50	132,608.00
b)hydroseeding	sq.m.	83270	3.15	262,300.50
			TOTAL =	**2,871,724.25**

Drainage type: **Ecological swale(package 2-9)-alternative way**
Design life period : 50 years

ITEM DESCRIPTION	UNIT	QTY	RATE (RM)	AMMOUNT (RM)
Excavation				
for all type(A,B,and C)	cu.m.	4,084	5.25	21,441.00
Hydronet				
for all type(A,B,and C)	sq.m.	7,391	7.50	55,432.50
Sand bedding				
for all type(A,B,and C)	sq.m.	2,070	4.00	8,280.00
Drainage Module				
a) type A	lin.m.	1,161	264.00	306,504.00
b) type B	lin.m.	1,150	530.00	609,500.00
c) type C	lin.m.	350	800.00	280,000.00
Sand filling				
for all type(A,B,and C)	cu.m.	1,801	30.00	54,030.00
Turfing				
a) close turfing (type A, B and C)	sq. m.	8,623	3.50	30,180.50
b) hydroseeding (type A,B and C)	sq. m	4,945	3.15	15,576.75
Detention Storage				
a) type A	No.	103	2,957	304,571.00
b) type B	No.	149	1,739	259,111.00
Ecological Pond				
a) Wetpond				368,425.00
b) Detention Pond				201,431.00
c) Wetland				339,170.00
d) Wading River				162,010.00
e) Recreational Pond				129,670.00
Dry Pond (14 No.)				227,022.00
Earth drain + Variation Order (VO)				72,300
Miscellaneous VO				660,898
			TOTAL =	**4,105,553.35**

Table 2 Schedule for capital cost estimation for conventional method.

Drainage type: **Conventional drainage (contractor rate)**
Design life period: 50 years

ITEM DESCRIPTION	UNIT	QTY	RATE (RM)	AMMOUNT (RM)
Initial costs	L.S.			345,000.00
Drainage works				
Monsoon drain				
a) precast concrete u-shape	lin.m.	623	400.00	249,200.00
b) ditto size 1200mm x 1200mm	lin.m.	1,245	500.00	622,500.00
ditto size 1500mm x 1500mm	lin.m.	2,075	600.00	1,245,000.00
Roadside drain (precast concrete)				
a) P.C. 1	lin.m.	7,482	156.00	1,167,192.00
b) P.C. 2	lin.m.	3,000	165.00	495,000.00
c) P.C. 3	lin.m.	8,450	215.00	1,816,750.00
Box culvert	lin.m.	54	2,000.00	108,000.00
Pipe culvert	lin.m.	440	650.00	286,000.00
Sump				
a) bricks sump to P.C 1	No.	1,247	300.00	374,100.00
b) ditto-bricks sump to P.C 2&3	No.	70	800.00	56,000.00
Outfall structure	No.	4	10,000.00	40,000.00
Grease trap	No.	3	5,000.00	15,000.00
G.I railing	lin.m.		35.00	178,500.00
Detention pond	L.S			250,000.00
			TOTAL =	**7,248,242.00**

Table 3 Schedule to estimate life cycle cost for conventional method.

Year	COST Capital (RM)	Operation Annual (RM)	Maintenance (RM)	Total (RM)	Discount Rate	TOTAL	PV of RM 1 (2% interest)	Present Value
0	7,248,242	---	---	7,248,242	0	7,248,242	1	7,248,242
1		12,000	57,600	69,600	6,960	76,560	0.98	75,059
2		12,000	57,600	69,600	6,960	76,560	0.96	73,587
3		12,000	57,600	69,600	6,960	76,560	0.94	72,144
4		12,000	84,000	96,000	9,600	105,600	0.92	97,558
5		12,000	57,600	69,600	6,960	76,560	0.91	69,343
6		12,000	57,600	69,600	6,960	76,560	0.89	67,983
7		12,000	57,600	69,600	6,960	76,560	0.87	66,650
8		12,000	84,000	96,000	9,600	105,600	0.85	90,129
9		12,000	57,600	69,600	6,960	76,560	0.84	64,062
10		12,000	57,600	69,600	6,960	76,560	0.82	62,806
11		13,200	63,360	76,560	7,656	84,216	0.80	67,732
12		13,200	91,872	105,072	10,507	115,579	0.79	91,133
13		13,200	63,360	76,560	7,656	84,216	0.77	65,102
14		13,200	63,360	76,560	7,656	84,216	0.76	63,825
15		13,200	63,360	76,560	7,656	84,216	0.74	62,574
16		13,200	91,872	105,072	10,507	115,579	0.73	84,193
17		13,200	63,360	76,560	7,656	84,216	0.71	60,144
18		13,200	63,360	76,560	7,656	84,216	0.70	58,965
19		13,200	63,360	76,560	7,656	84,216	0.69	57,808
20		13,200	91,872	105,072	10,507	115,579	0.67	77,781
21		14,520	69,696	84,216	8,422	92,638	0.66	61,120
22		14,520	69,696	84,216	8,422	92,638	0.65	59,922
23		14,520	69,696	84,216	8,422	92,638	0.63	58,747
24		14,520	101,088	115,608	11,561	127,169	0.62	79,064
25		14,520	962,496	977,016	97,702	1,074,718	0.61	655,074
26		14,520	69,696	84,216	8,422	92,638	0.60	55,358
27		14,520	69,696	84,216	8,422	92,638	0.59	54,273
28		14,520	101,088	115,608	11,561	127,169	0.57	73,043
29		14,520	69,696	84,216	8,422	92,638	0.56	52,165
30		14,520	69,696	84,216	8,422	92,638	0.55	51,143
31		15,980	76,666	92,646	9,265	101,910	0.54	55,158
32		15,980	101,059	117,039	11,704	128,743	0.53	68,315
33		15,980	76,666	92,646	9,265	101,910	0.52	53,017
34		15,980	76,666	92,646	9,265	101,910	0.51	51,977
35		15,980	76,666	92,646	9,265	101,910	0.50	50,958
36		15,980	101,059	117,039	11,704	128,743	0.49	63,113
37		15,980	76,666	92,646	9,265	101,910	0.48	48,979
38		15,980	76,666	92,646	9,265	101,910	0.47	48,019
39		15,980	76,666	92,646	9,265	101,910	0.46	47,077
40		15,980	101,059	117,039	11,704	128,743	0.45	58,307
41		17,560	84,326	101,886	10,189	112,075	0.44	49,762
42		17,560	84,326	101,886	10,189	112,075	0.44	48,787
43		17,560	84,326	101,886	10,189	112,075	0.43	47,830
44		17,560	111,168	128,728	12,873	141,601	0.42	59,246
45		17,560	84,326	101,886	10,189	112,075	0.41	45,973
46		17,560	84,326	101,886	10,189	112,075	0.40	45,071
47		17,560	84,326	101,886	10,189	112,075	0.39	44,188
48		17,560	111,168	128,728	12,873	141,601	0.39	54,734
49		17,560	84,326	101,886	10,189	112,075	0.38	42,472
50		17,560	1,066,406	1,083,966	108,397	1,192,363	0.37	442,996
					Total Net Present Value			11,302,706

Table 4 Schedule to estimate life cycle cost for MSMA method.

Year	COST Capital (RM)	Operation Annual (RM)	Maintenance (RM)	Total (RM)	Discount Rate	TOTAL	PV of RM 1 (2%) interest	Present Value
0	6,977,278	---	---	6,977,278	0	6,977,278	1	6,977,278
1		13,000	92,000	105,000	10,500	115,500	0.98	113235
2		13,000	135,100	148,100	14,810	162,910	0.96	156584
3		13,000	190,000	203,000	20,300	223,300	0.94	210421
4		13,000	230,000	243,000	24,300	267,300	0.92	246944
5		13,000	260,000	273,000	27,300	300,300	0.91	271991
6		13,000	295,000	308,000	30,800	338,800	0.89	300845
7		13,000	100,000	113,000	11,300	124,300	0.87	108211
8		13,000	100,000	113,000	11,300	124,300	0.85	106089
9		13,000	100,000	113,000	11,300	124,300	0.84	104009
10		13,000	100,000	113,000	11,300	124,300	0.82	101969
11		14,233	150,000	164,233	16,423	180,656	0.80	145295
12		14,233	100,000	114,233	11,423	125,656	0.79	99079
13		14,233	100,000	114,233	11,423	125,656	0.77	97136
14		14,233	100,000	114,233	11,423	125,656	0.76	95232
15		14,233	100,000	114,233	11,423	125,656	0.74	93364
16		14,233	132,000	146,233	14,623	160,856	0.73	117175
17		14,233	100,000	114,233	11,423	125,656	0.71	89739
18		14,233	100,000	114,233	11,423	125,656	0.70	87979
19		14,233	100,000	114,233	11,423	125,656	0.69	86254
20		14,233	132,000	146,233	14,623	160,856	0.67	108252
21		15,655	100,000	115,655	11,566	127,221	0.66	83937
22		15,655	100,000	115,655	11,566	127,221	0.65	82291
23		15,655	100,000	115,655	11,566	127,221	0.63	80678
24		15,655	145,200	160,855	16,086	176,941	0.62	110008
25		15,655	690,000	705,655	70,566	776,221	0.61	473130
26		15,655	110,000	125,655	12,566	138,221	0.60	82598
27		15,655	110,000	125,655	12,566	138,221	0.59	80978
28		15,655	145,200	160,855	16,086	176,941	0.57	101630
29		15,655	115,000	130,655	13,066	143,721	0.56	80931
30		15,655	115,000	130,655	13,066	143,721	0.55	79344
31		17,220	115,000	132,220	13,222	145,442	0.54	78720
32		17,220	150,000	167,220	16,722	183,942	0.53	97606
33		17,220	120,000	137,220	13,722	150,942	0.52	78524
34		17,220	120,000	137,220	13,722	150,942	0.51	76985
35		17,220	120,000	137,220	13,722	150,942	0.50	75475
36		17,220	159,700	176,920	17,692	194,612	0.49	95403
37		17,220	120,000	137,220	13,722	150,942	0.48	72544
38		17,220	120,000	137,220	13,722	150,942	0.47	71122
39		17,220	120,000	137,220	13,722	150,942	0.46	69727
40		17,220	159,700	176,920	17,692	194,612	0.45	88138
41		18,943	125,500	144,443	14,444	158,887	0.44	70548
42		18,943	125,500	144,443	14,444	158,887	0.44	69164
43		18,943	125,500	144,443	14,444	158,887	0.43	67808
44		18,943	175,650	194,593	19,459	214,052	0.42	89560
45		18,943	125,000	143,943	14,394	158,337	0.41	64949
46		18,943	125,000	143,943	14,394	158,337	0.40	63676
47		18,943	125,000	143,943	14,394	158,337	0.39	62427
48		18,943	175,650	194,593	19,459	214,052	0.39	82739
49		18,943	130,000	148,943	14,894	163,837	0.38	62088
50		18,943	1,013,550	1,032,493	103,249	1,135,742	0.37	421960
					Total Net Present Value			12,831,770

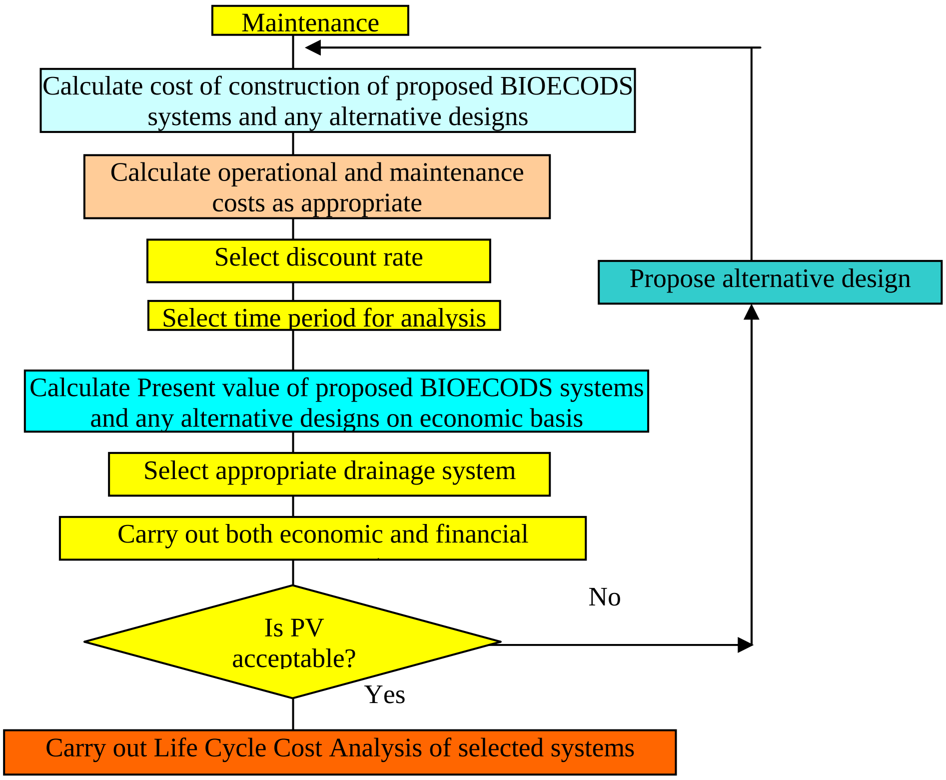

Figure 4 Flow chart Life Cycle Cost analysis of BOIECODS System.

Table 5 Summary of life cycle costs for various interest rates.

Method	**Life Cycle Cost at Various Interest Rates (%)**						
	1%	2%	3%	5%	7%	9%	15%
Traditional	**11,378,224**	**10,411,057**	**9,727,337**	**8,872,924**	**8,396,212**	**8,110,804**	**7719138.5**
MSMA	**14,303,387**	**12,636,358**	**11,450,462**	**9,956,133**	**9,113,191**	**8,603,155**	**7890017.5**
MSMA is % higher	20	18	15	11	8	6	2

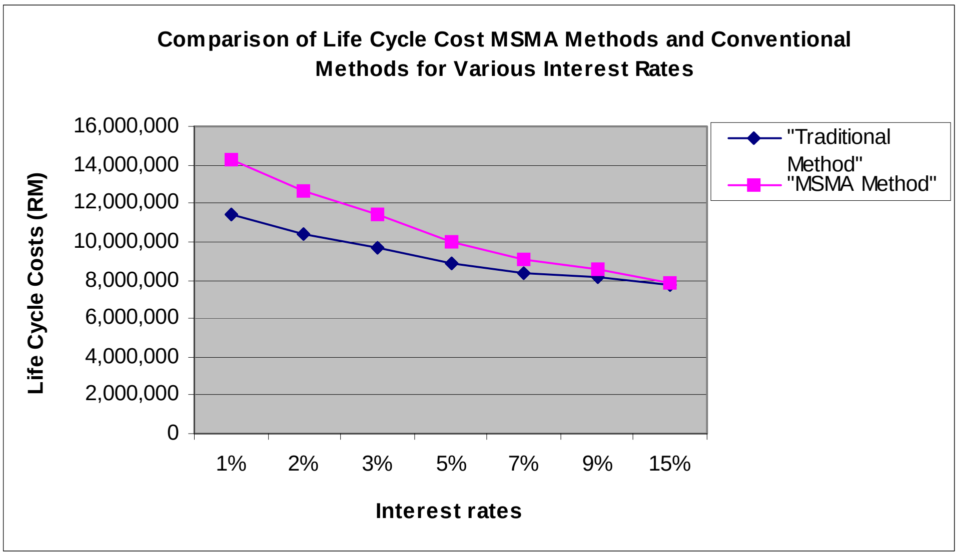

Figure 5 Comparison of Life Cycle Cost (LCC) of the traditional and MSMA methods at various interest rate.

6 Conclusion

Life - cycle cost analysis (LCC) is an economic evaluation technique to evaluate the sustainability of the drainage systems. It is well suited to compare alternative designs, with differing cost expenditures over the project life. The most critical elements of the evaluation are objective assumptions regarding project design life, material service life and the value of money or discount rate. The paper presents a simple method to compare life cycle costs of the new environmental-friendly drainage systems (MSMA) and traditional methods of urban drainage design. The method only considers the direct capital and operation and maintenance costs associated with the methods. This simple method can be used to compare the long-term financial feasibility of the MSMA method. The method was applied to an actual site in Pulau Pinang, Malaysia with typical drainage components and local rates were adopted to compare the life cycle costs of the two methods.

The finding of the study was the capital cost for the MSMA method is 5% lower than the traditional method. However, the MSMA method has a higher maintenance cost. It is expected that in the future construction cost neutral outcomes will predominantly occur as contractors become more familiar with the construction of MSMA infrastructure and remove the extra costs associated with a "safety margin" included into the project budget. The use of off-the-shelf construction components minimizes the costs associated with contractors adding exorbitant safety margins into their project budget. By using MSMA methods rather than traditional systems, development and stormwater infrastructure costs can be lowered. Other aspects of the life-cycle cost of stormwater management systems also can be reduced by using MSMA methods judiciously. In the long term, the capital costs can be reduced through MSMA methods, such as:

- Site designs incorporating clusters and reduced setbacks, resulting in less grading, reduced paving, less landscaping, and lower mitigation costs.
- Vegetated swales are less costly to install than curb and gutter, manholes, and open concrete drain
- Directing flow to vegetated filter strips or infiltration devices to reduce runoff rates and volumes can reduce the size (and cost) of downstream conveyance and storage devices (storm drains, culverts, and detention basins).
- Using upstream detention basins to reduce peak runoff rates can reduce the size (and cost) of major drainage ways and storm drains.

The observations are based on site-specific factors and selection of particular drainage components, which will vary from site to site. However, it gives an indication of the long term financial viability of the MSMA technique with respect to direct capital and maintenance costs. MSMA method contributes towards a number of additional benefits such as reduction in peak flow, delay or avoidance of major downstream channel upgradation or protection work to minimize flood hazard, and improvement the quality of stormwater. When these are considered, the MSMA method has much greater overall benefit than the traditional method. Thus, the little increase in life cycle cost associated with the MSMA method appears to be justified.

As a conclusion, the LCC analysis has shown that the construction cost for MSMA method is competitive to the conventional method and in the long term it can be cheaper if the materials is produce locally. However, the operation and maintenance cost for MSMA method is slightly higher as compare to the conventional method. The total life cycle cost at lower interest rate for MSMA method is higher than the traditional method but the differences in life cycle costs diminish with increased interest rate and become equal at about 15% interest rate. LCC analysis must take into account the full range of benefits, downstream implications and maintenance implications of each system to enable holistic and comparative cost-benefit-risk assessment.

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