World Sustainability Series

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Due to its scope and nature, sustainable development is a matter which is very interdisciplinary, and draws from knowledge and inputs from the social sciences and environmental sciences on the one hand, but also from physical sciences and arts on the other. As such, there is a perceived need to foster integrative approaches, whereby the combination of inputs from various fields may contribute to a better understanding of what sustainability is, and means to people. But despite the need for and the relevance of integrative approaches towards sustainable development, there is a paucity of literature which address matters related to sustainability in an integrated way.

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Handbook of Best Practices in Sustainable Development at University Level

Springer

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ISSN 2199-7373 ISSN 2199-7381 (electronic)
World Sustainability Series
ISBN 978-3-031-04763-3 ISBN 978-3-031-04764-0 (eBook)
https://doi.org/10.1007/978-3-031-04764-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

There is a perceived need for mobilizing the various stakeholders when attempting to promote sustainability in higher education and to promote best practices, which may inspire further initiatives. But despite this need, there are a few publications handling this matter in a coherent way. In order to meet the pressing need for publications which may document and disseminate examples of best practices on sustainable development at the university level, the *Handbook of Best Practices in Sustainable Development at University Level* has been brought to life.

This book has been produced by the European School of Sustainability Science and Research (ESSSR) https://esssr.eu/, and the Inter-University Sustainable Development Research Programme (IUSDRP) https://www.haw-hamburg.de/en/ftz-nk/programmes/iusdrp/ and contains inputs from authors from across all geographical regions.

It gives a special emphasis to the state-of-the-art descriptions of approaches, methods, initiatives and projects from universities, organizations and civil society across the world, regarding cross-cutting issues in sustainable development. This book contains a variety of initiatives that may be regarded as best practices (i.e. which are continuous, widely accepted, replicable, upscalable and may be applied in different contexts). It shows what can be achieved by both institutional and stakeholder engagement in higher education.

The book is structured into three parts:

- Part One—University Governance and Strategies towards Sustainable Development

This part introduces papers on matters related to governance and sustainability strategies.

- Part Two—Best Practices in Campus Operations

This part provides examples of best practices associated with campus operations.

- Part Three—Fostering Community Engagement

This part focuses on examples that showcase community engagement.

The book also discusses examples of initiatives coordinated by universities but involving civil society, the private sector and the public sector (including local, national and intergovernmental bodies). In particular, it also describes practical experiences, partnerships, networks and training schemes for building capacity aimed at fostering the cause of sustainable development at institutions of higher education.

We thank the authors for sharing their knowledge and their experience by means of their chapters and those colleagues who have contributed to it by assisting with the reviews.

Thanks to its design and the contributions by experts from various areas, it provides a welcome contribution to the literature on sustainable development, and it may inspire further works in this field.

Hamburg, Germany/Manchester, UK — Walter Leal Filho
Joao Pessoa, Brazil — Claudio Ruy Portela de Vasconcelos
Autumn 2022

Contents

Bio-ecological Drainage System (BIOECODS): A Sustainable Green University Drainage System

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Abstract Constructed in 2001, the Bio-Ecological Drainage System (BIOECODS) is a national pilot project located at the Engineering Campus, Universiti Sains Malaysia (USM), Penang, Malaysia. It is a drainage system that aims to restore the surrounding natural environment while maintaining river flow and controlling ground subsidence through an innovative and sustainable method. The concept of BIOECODS is based on sustainable urban drainage systems (SUDS) and best management practices (BMPs), namely the 'control-at-source' approach, which are integrated into urban planning and designed to achieve multiple objectives. By integrating green stormwater components (e.g. Ecological Swale, Dry Pond, Constructed Wetland and wet ponds) with the green area and landscape, BIOECODS can foster a 'healthy campus'. With the construction of BIOECODS in newly developed areas,

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W. Leal Filho and C. R. Portela de Vasconcelos (eds.), *Handbook of Best Practices in Sustainable Development at University Level*, World Sustainability Series,
https://doi.org/10.1007/978-3-031-04764-0_12

several water-related problems, including rapid flooding, river pollution and scarcity of water during the dry season, that have afflicted Malaysia will likely be overcome. BIOECODS at USM is a national pilot project and can be seen as a prototype for developing new urban areas. This project meets the Urban Stormwater Management Manual for Malaysia (MSMA) requirement, which was launched in 2000 by the Department of Irrigation and Drainage (DID) to manage and control the quantity and quality of stormwater runoff at its source. The implementation of BIOECODS will also help to maintain downstream waterways, such as Kerian River, in the natural environment.

Keywords Sustainable urban drainage system (SUDS) · Urban stormwater management manual (MSMA) · Bio-ecological drainage system (BIOECODS) · Stormwater management · Humid tropic

1 Introduction

Rapid development and urbanisation have caused numerous environmental problems, which are now of national concern in Malaysia. Specifically, urbanisation has resulted in significantly more impervious surface areas (Du et al. 2019; Hua et al. 2020; Salerno et al. 2018; Wu et al. 2020). This increase has negatively affected water balance, since it increases surface runoff (Hu et al. 2020; Wang et al. 2020), which subsequently reduces water purification, groundwater recharge and water quality (Camara et al. 2019), as well as increasing bed and bank erosion (Plumb et al. 2017), pollutant loadings and the risk of flooding in urban watersheds (Jia et al. 2013; O'Driscoll et al. 2010).

Techniques for sustainable urban drainage systems are widely recommended and applied in many parts of the world. While terminology differs across regions, there are similar design concepts for handling stormwater management, including low impact development (LID), water sensitive urban design (WSUD), best management practices (BMPs) and integrated urban water management (IUWM). The term 'sustainable urban drainage system' (SUDS) is used to refer to a type of urban drainage system that promotes ecological, environmental and social benefits (Chan et al. 2019). The SUDS approach consists of decelerating and decreasing the volume of stormwater runoff from developed areas to avoid possible stream floods and to reduce the pollution caused by surface runoff through harvesting, infiltrating, decelerating, storing, conveying and treating runoff on-site on the surface as opposed to underground. Furthermore, SUDS enhance the greenery in developed areas and also provide habitats for wildlife. SUDS highlight a holistic approach to stormwater management, addressing the multiple objectives of runoff quality, quantity, public amenity and biodiversity (Fig. 1); this is compared to the conventional approach, which solely focuses on quantity. The four pillars of SUDS design are shown in Fig. 1. The concept of the SUDS management train is illustrated in Fig. 2.

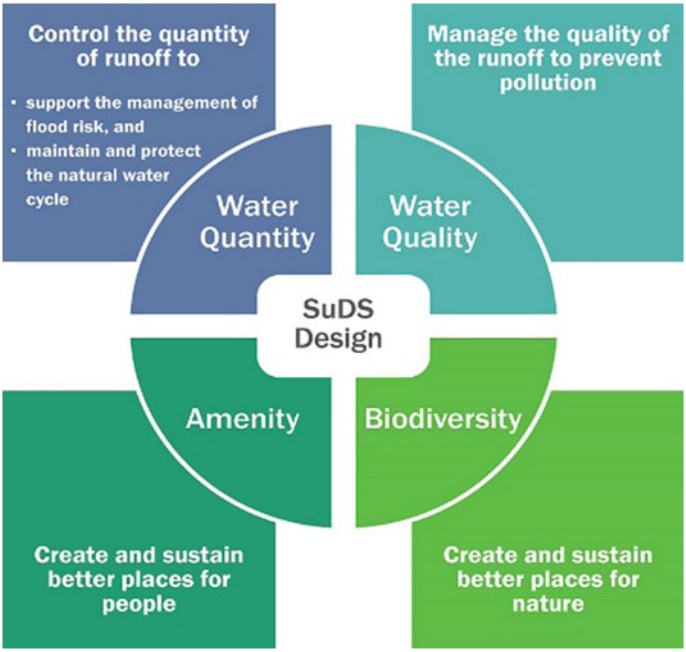


Fig. 1 The four pillars of SUDS design (CIRIA 2015)

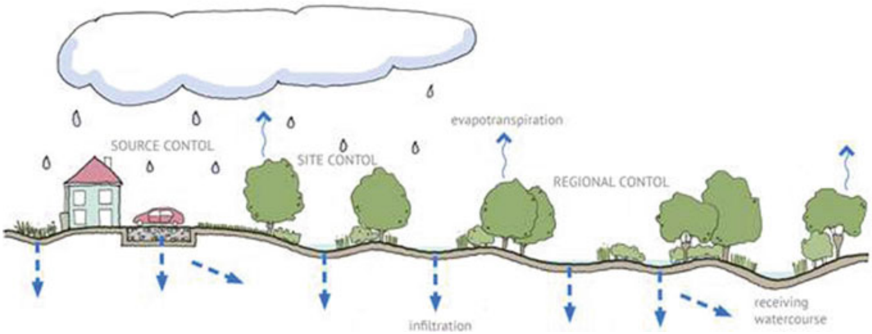


Fig. 2 The treatment train for stormwater management (https://www.susdrain.org/delivering-suds/using-suds/suds-principles/management-train.html)

In light of the successful application of SUDS worldwide, Malaysia through DID has replaced the country's previous Urban Drainage Design Standards and Procedure, which was published in 1975, with a rapid disposal to control-at-source concept, known as Urban Stormwater Management Manual for Malaysia (MSMA) (DID 2000).

2 Urban Stormwater Management Manual for Malaysia

Malaysia receives high annual rainfall depth (≈2500 mm/yr). In urban areas, most stormwater runoff is designed based on a conventional urban drainage system, which is called a rapid disposal approach; this approach seeks to convey runoff to downstream or receiving waterways. This conventional approach causes major issues, such as flash flooding, water scarcity and water pollution. Thus, the implementation of SUDS is highly recommended to overcome these issues in addition to excessive heat, which are particularly pertinent in Malaysia (Chan et al. 2019; Chang et al. 2018).

The Malaysian Government through DID took a proactive step forward on this issue by formulating MSMA (the first edition was published in 2000, and an updated edition published in 2012) (DID 2000, 2012). This manual promotes the control-at-source concept, as recommended in SUDS. MSMA features an integrated concept wherein the quantity and quality of runoffs are controlled equally. The manual has become the main reference for planning, designing and implementing stormwater urban drainage in Malaysia.

The main objectives of MSMA are:

1. ensure the safety of the public,
2. control nuisance flooding,
3. stabilise landform and control erosion,
4. minimise the environmental impact of runoff, and
5. enhance the urban landscape and ecology.

In order to promote the manual, a national pilot project called Bio-Ecological Drainage System (BIOECODS) was constructed at USM Engineering Campus through a smart partnership with DID. BIOECODS promotes a sustainable and environmentally friendly approach in stormwater management.

3 BIOECODS Concept

The BIOECODS concept focuses equally on quantity control, quality control and amenity in stormwater management (Zakaria et al. 2005). Based on MSMA, the objectives of the BIOECODS implementation are:

1. introduce an infiltration concept in which water is recycled naturally,
2. attenuate stormwater runoff,
3. introduce the concept of stormwater runoff treatment, and
4. create a greener and better landscape.

BIOECODS was developed in 2000 and continues to be innovated upon by the River Engineering and Urban Drainage Research Centre (REDAC), USM, in compliance with the MSMA requirement. By adopting the control-at-source approach, the BIOECODS project is capable of reducing runoff, runoff volumes and pollutant

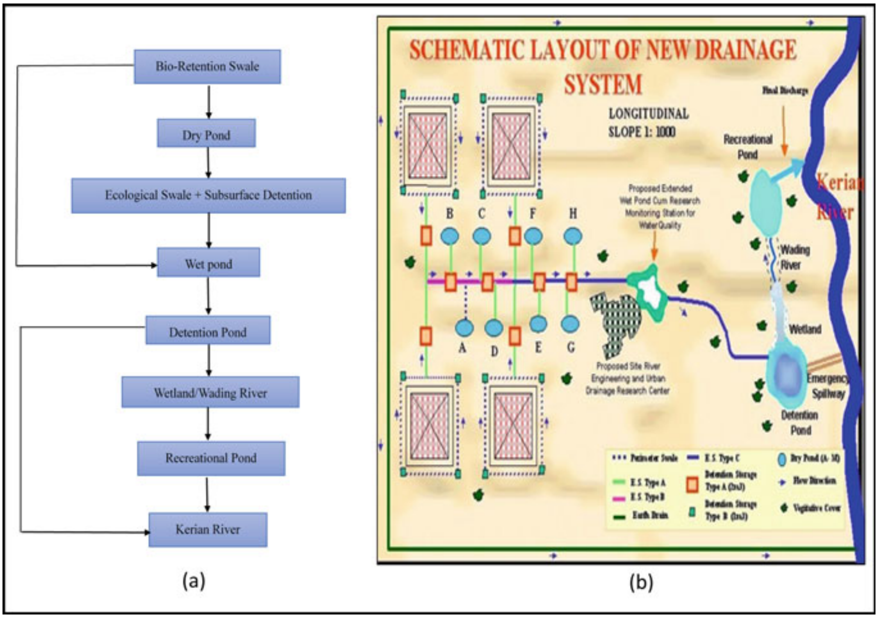


Fig. 3 **a** Flow concepts of BIOECODS; **b** schematic layout of BIOECODS at USM Engineering Campus

loads through the introduction of a variety of measures (Ab Ghani et al. 2004, 2008). BIOECODS includes a series of components from upstream to downstream, namely Ecological Swale, Dry Pond and Ecological Pond, which are comprised of Wetpond, Detention Pond, Constructed Wetland and Recreational Pond (Fig. 3a). The Detention Pond is the final component that controls the quantity of stormwater runoff. The Constructed Wetland is designed as an additional treatment facility for water quality before the water is discharged at Kerian River. At the same time, the end product of stormwater runoff that flows through the BIOECODS treatment is high-quality water and can be recycled for domestic use. Figure 3b shows the schematic layout of BIOECODS at USM Engineering Campus. The BIOECODS components adopted in the pilot project are summarised in Table 1.

4 Water Quantity and Quality Monitoring in BIOECODS

Data was collected to study the performance of water quantity and quality after going through all the BIOECODS components, which is located at USM Engineering Campus, Penang, Malaysia. Details of the data measurements are given in Mohd Sidek (2005), Sidek et al. (2004) and Beh (2014). Table 2 shows the equipment used for data collection at each BIOECODS component. Figures 4, 5, 6 and 7 show the

Table 1 BIOECODS Components (Zakaria et al. 2003, 2014)

No.	Component	Description
1. Ecological Swale		The ecological swale is a grass-earthen channel, combined with a subsurface module (410 mm width × 467 mm high × 615 mm length), enclosed within a permeable geotextile and surrounded by a clean river sand layer It is designed to convey, attenuate and reduce the peak flow of runoff It treats stormwater runoff by infiltrating the sub-surface module through the river sand underneath the swale for additional water quality treatment It is designed for a ten-year annual recurrence interval (ARI)
2. Dry Pond		The Dry Pond is an onsite detention (OSD), which is integrated with the Ecological Swale for temporary storage of storm runoff and to convey excess stormwater in the study area The Dry Pond area is usually designed as a green area for recreational purposes, not for roads, parking or construction It is designed and constructed with surface and subsurface storage functionality. Its subsurface storage consists of 64 modules, which are enclosed within a permeable geotextile and are surrounded by a clean river sand layer, which is located beneath the Dry Pond, where the stormwater is drained out by infiltration The storage module outflow path is connected to the Ecological Swale at the lowest point in order to drain the Dry Pond system

(continued)

Table 1 (continued)

No.	Component	Description
3. Wet Pond 		The Wetpond has a surface area of 4500 m^2 and a capacity of 5000 m^3. It receives stormwater discharges directly from the Ecological Swale All the excess water from the built-up areas, including schools and administration buildings, flows through a Wetpond to a Detention Pond The design rainfall is ten-year ARI for a minor event and up to 50-year ARI for a major event The bank of the pond is planted with *Axonopus compressus* grass with a side slope of 1:4
4. Detention Pond 		The Detention Pond is designed to reduce the peak flow, as advised in MSMA, where the post-development peak flow must not exceed the pre-development flow for both minor and major system design storm ARI It receives and stores stormwater runoffs from Wetpond discharges and student residences sub-catchment area. It has a surface area of 10,000 m^2 and a capacity of 18,000 m^3 Excess stormwater is drained from the Detention Pond into Kerian River through two stage outlets, which are designed to manage minor (50-year ARI) and major (100-year ARI) storm events For an event that is less than three-month ARI, the flow will convey to a Constructed Wetland for further biological treatment

(continued)

Table 1 (continued)

No.	Component	Description
5. Constructed Wetland 		The Constructed Wetland receives flows from events less than three-month ARI and the first flush from events exceeding three-month ARI. The design of the Constructed Wetland depends on the ratio of width and length to achieve optimum treatment capacity The Constructed Wetland system consists of only two zones: macrophyte zone and open water zone (micro pool). The macrophyte zone takes up 80% (9493 m^2) of the total wetland area It is planted with native wetland species, including *Eleocharis variegate*, *Eleocharis dulchis*, *Typha angustifolia*, *Hanguana malayana*, *Lepironia articulata* and *Phragmites karka*
6. Wading River 		The wading river is a channel connecting the wetland and the recreational pond It is an example of natural river morphology, which comprises a mainstream and flood plain on both sides of the river Water flow through coarse sand and gravel in the wading river creates the turbulence and increases the level of dissolved oxygen

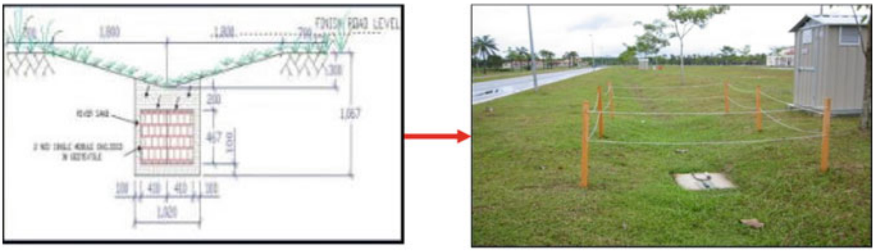
(continued)

Table 1 (continued)

No.	Component	Description
7. Recreational Pond 		The recreational pond is a pond that provides an area for recreational activity. Stormwater runoff flowing through the Bio-Ecological Drainage System is treated physically and biologically as well as collective in this recreational pond The water level is maintained in the recreational pond by a 600-mm pipe culvert that discharges to Kerian River

Table 2 Equipment used for data collection in BIOECODS study

No.	Component	Equipment	Parameter measured
1.	Ecological Swale	Rain gauge	Rainfall depth
		Velocity meter	Velocity (m/s)
		Flow meter	Flow (m^3/s)
		Automatic water sampler	Water sample for lab analysis
2.	Dry Pond	Automatic water sampler	Water level (m)
		Ultrasonic water level logger	Water level (m)
		Submerged water level probe	Subsurface flow (m^3/s)
3.	Wetpond	Flow meter	Flow (m^3/s)
		Automatic water sampler	Water level (m)
		Stage gauge	Water level (m)
4.	Detention Pond	Flow meter	Flow (m^3/s)
		Automatic water sampler	Water sample for lab analysis
		Stage gauge	Water level (m)
5.	Constructed Wetland	Automatic water sampler	Water sample for lab analysis
		Multiparameter SONDE (in-situ)	DO, pH, temperature



(a) (b)

Fig. 4 Ecological swale type B: **a** cross section and **b** monitoring station (Mohd Sidek 2005)

monitoring station for water quantity at the Ecological Swale, Dry Pond, Wetpond and Detention Pond.

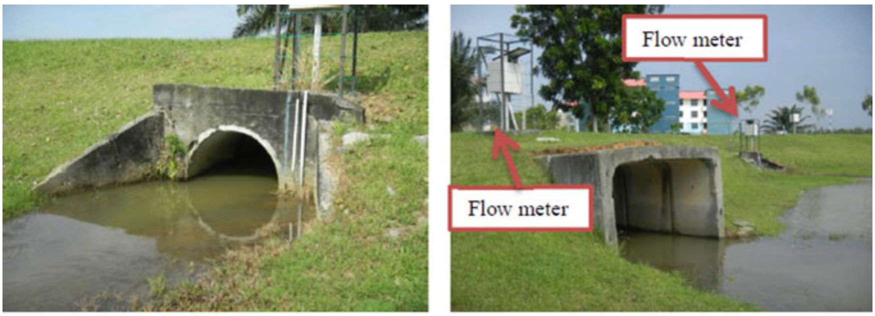
For water quality, grab sampling and in-situ monitoring were conducted from upstream to downstream, starting from (i) Ecological Swale (ii) inlet and outlet of the Wetpond, Detention Pond and Constructed Wetland. The laboratory analysis was carried out at REDAC Laboratory at USM Engineering Campus. Figures 8 and 9 show the water quality sampling locations at the Ecological Swale, Dry Pond, Wetpond, Detention Pond and wetland.

(a) (b)

Fig. 5 Typical cross section of a dry pond: **a** cross section and **b** monitoring station (Mohd Sidek 2005)

(a) **(b)**

Fig. 6 Inlet (**a**) and outlet (**b**) from Wetpond with the flow meter (Beh 2014)



(a) **(b)**

Fig. 7 Flow meter at outlet (**a**) from Wetpond and student residences sub-catchment (**b**) into detention pond (Beh 2014)

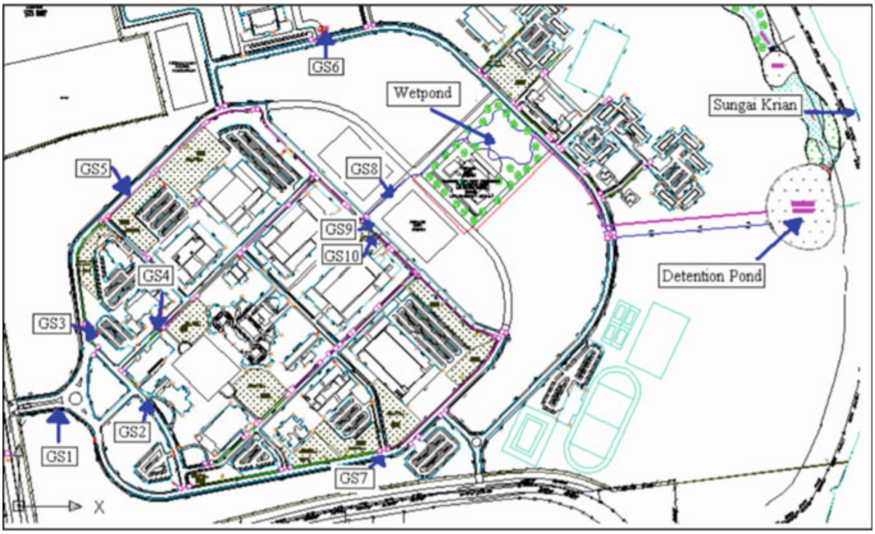


Fig. 8 Locations of water quality sampling at Ecological Swale (GS 1-GS 9) and Dry Pond (GS10) (Mohd Sidek et al. 2004)

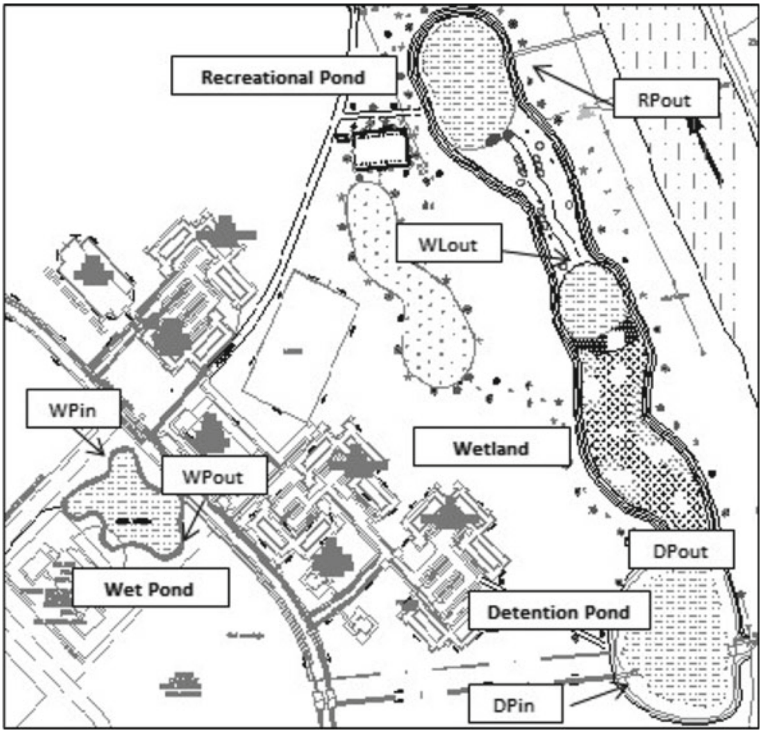


Fig. 9 Locations of water quality sampling at Wetpond, Detention Pond and wetland (Beh 2014)

5 Performance of BIOECODS

Since its establishment, BIOECODS has been closely monitored and evaluated for water quantity and quality. It has been shown that BIOECODS has the ability to reduce flow peak and flow volume by delaying the travelling times of flow discharges from the upstream to downstream components (Abd Manap 2009; Mohd Sidek 2005; Zakaria et al. 2003). In terms of quality, stormwater runoff are treated through filtration (Ayub et al. 2005; Mohd Sidek et al. 2004) and purification (Johari et al. 2016; Shaharuddin et al. 2014).

5.1 Quantity Aspect

5.1.1 Ecological Swale

The surface flow infiltrates the sub-surface swale until the soil is saturated. At the beginning of a storm event, most of the stormwater will flow and infiltrate the soil, and this will increase the attenuation percentage. Later, however, the attenuation percentage will decrease once the soil is saturated, with less stormwater infiltrating the soil. The efficiency of an Ecological Swale depends on quantity control in terms of peak flow attenuation. The data collection process to evaluate the effectiveness of the BIOECODS system started in June 2003 and ended in November 2003. Table 3 shows an example of an observation during the data collection period. Figure 10 shows flow attenuation at the Ecological Swale during an event. The hydrograph shows that the times-to-peak are different at the inlet and outlet of the study swale. The difference between these two times-to-peak indicates that the Ecological Swale has the capability to attenuate peak discharges between 24 and 90%.

5.1.2 Dry Pond

According to Abd Manap (2009), the purpose of a Dry Pond is to provide off-line on-site retention to decrease peak flow into the Wetpond, which is located downstream in the study. The Dry Pond is evaluated based on its ability to retain and drain stormwater. The water levels of the selected Dry Pond (labelled UWL 1 to UWL 5) were measured using ultrasonic water level sensors (Table 4 and Fig. 11).

Table 4 shows the water level at the Dry Pond outlet during data collection in September and November 2003. It would normally take seven days for the stormwater to infiltrate and empty the Dry Pond, though this varies depending on the capacity of the adjacent Ecological Swale. In addition, the Ecological Swale receives the flow from the Dry Pond as the water from the surface swale completely drains into the Ecological Pond. Thus, the water level in the sub-surface swale slowly recedes and provides room for the flow from the Dry Pond to the sub-surface Ecological Swale.

Table 3 Peak flow attenuation for Ecological Swale (June–November 2003) (Mohd Sidek 2005)

Rain Event (2003)	Rainfall Intensity (mm/h)	Average recurrence interval (ARI)	Location channel	Peak flow (l/s)		Volume (m^3)		Percentage reduction (%)	
				(Inlet)	(Outlet)	(Inlet)	(Outlet)	Peak Flow	Vol
24/6	11	3 months	Surface	128	91	418.5	246.6	28.9	41.1
			Subsurface	79	32	134.1	16.2	59.5	87.9
0/8	14.5	3 months	Surface	59	26	388.8	123.6	55.9	66.6
			Subsurface	41	50	119.1	90.9	0	23.7
3/11	44.2	1 year	Surface	172	120	1134.6	599.4	30.2	47.2
			Subsurface	41	23	108.9	11.7	43.9	89.2

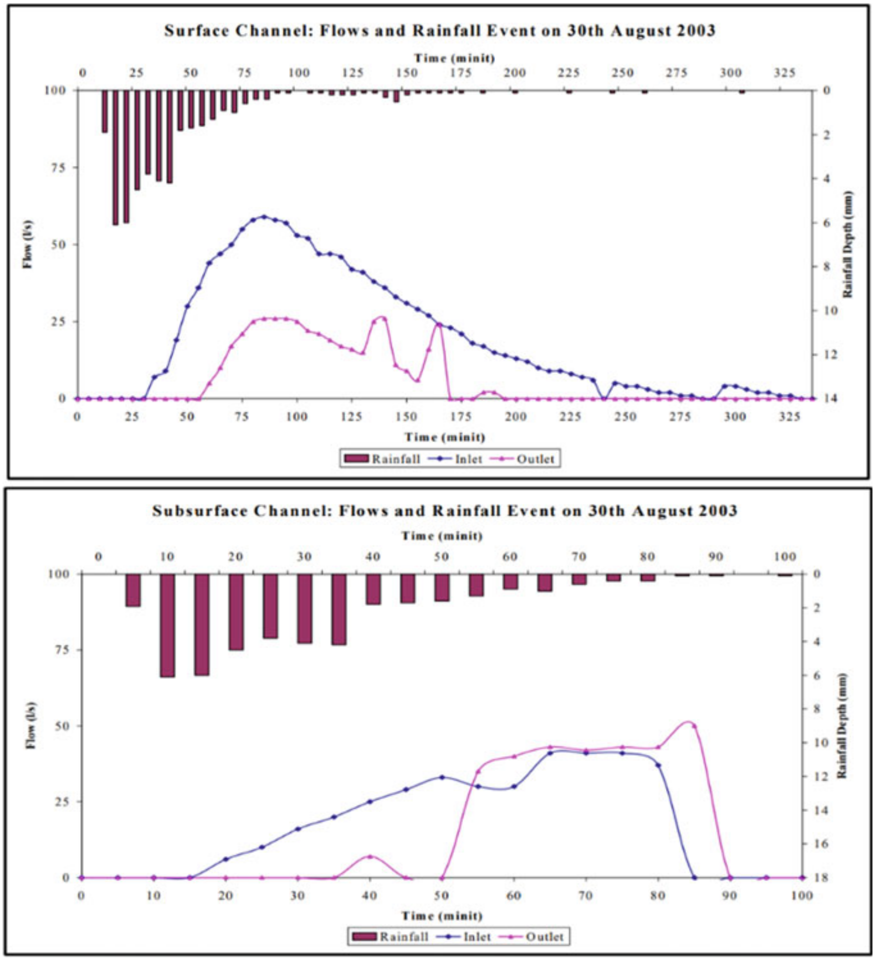


Fig. 10 Flow attenuation for rainfall events on 30 August 2003 (Mohd Sidek 2005)

Studies by Ainan et al. (2003) and Abd Manap (2009) indicate a similar pattern. The emptying time for the Dry Pond, as shown in Table 4, are up to 48 h as per design.

5.1.3 Wetpond

Measurements of the Wetpond flow were carried out on 19/2/2011 and 9/3/2011 by Beh (2014). The researcher also recorded ARI rainfall for 1 year and 5 years. The rainfall depth, water level and flow in the Wetpond are illustrated in Table 5 and Fig. 12.

Table 4 Performance of Dry Pond for typical rainfall event (September and November 2003) (Mohd Sidek 2005)

Rainfall event	Rainfall intensity (mm/h)	Average recurrence interval (ARI)	Location Dry Pond	Maximum water level at outlet (mm)	Emptying time (h)
8/9/2003	13.8	5 years	UWL 1	357	48
			UWL 2	669	36
			UWL 3	266	34
			UWL 4	511	44
			UWL 5	373	28
3/11/2003	44.2	1 year	UWL 1	247	27
			UWL 2	505	25
			UWL 3	164	25
			UWL 4	503	36
			UWL 5	322	21

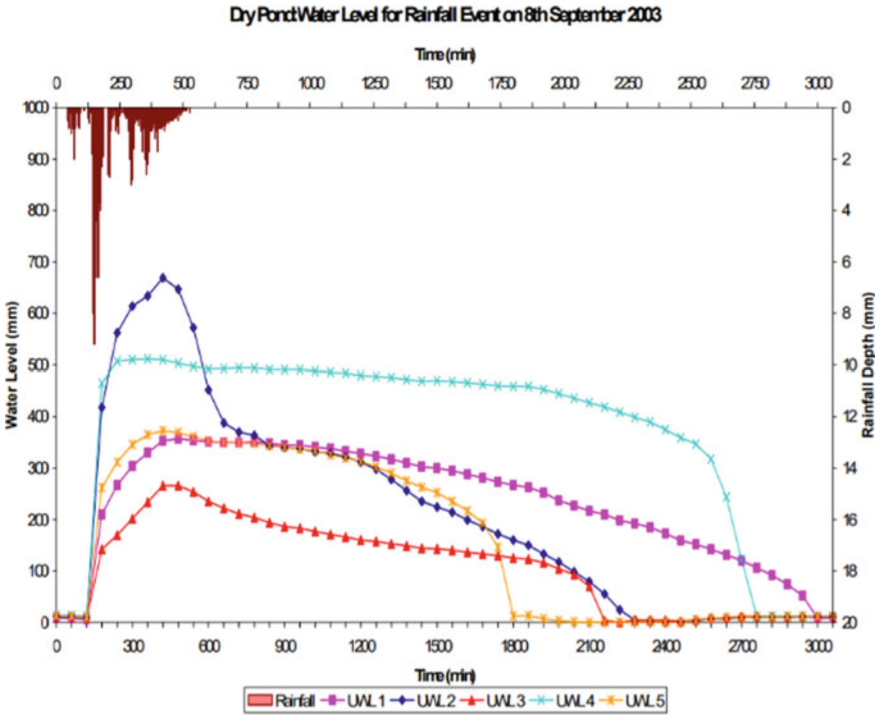


Fig. 11 Water level at outlets of UWL 1 to UWL 5 on 8th September 2003 (Mohd Sidek 2005)

Table 5 Rainfall and flow characteristics measured in Wetpond in 2011 (Beh 2014)

Date	Rainfall			Flow			
	Duration (mins)	Depth (mm)	Intensity (mm/hr)	Inlet (lps)	Outlet (lps)	Peak Reduction (%)	Delay time (hrs)
19/2/11	20	29.2	87.50	20.66	2.98	85.58%	2
9/2/11	160	91.9	34.36	307.57	32.53	98.85%	2

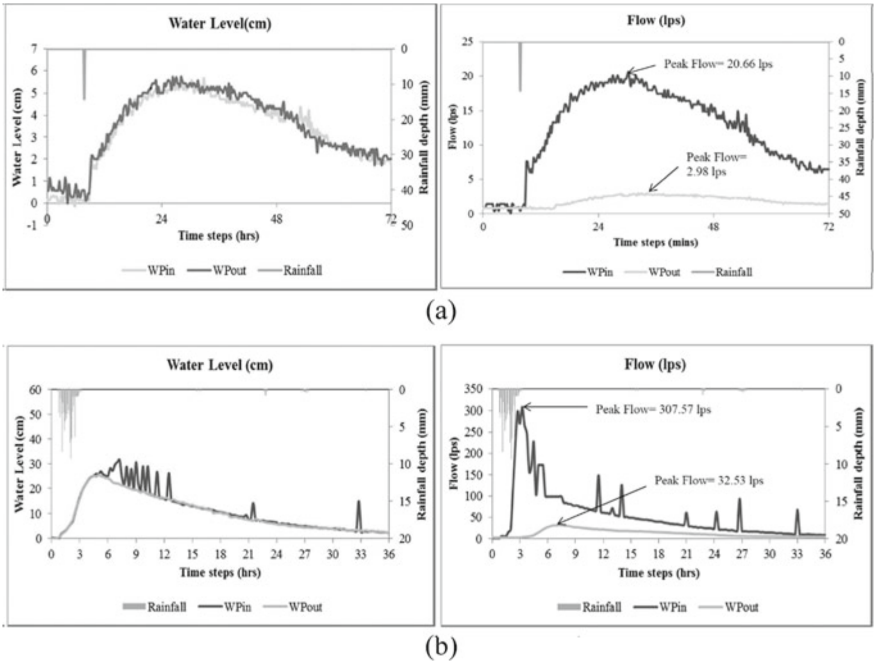


Fig. 12 Water level and flow event for Wetpond: **a** 19/2/2011 and **b** 9/3/2011 (Beh 2014)

It was observed that the peak flows were reduced by 85.58% and 98.85% in February and March, respectively. In the event of higher ARI, higher peak reductions were observed, but the delay time for both events was two hours. As per the requirement in MSMA, a Wetpond emptying time must not exceed 24 h. According to Beh (2014), this is because prolonged peak flow time can increase the overall peak flow in an event wherein a large watershed is evaluated. Nevertheless, as mentioned earlier, USM Engineering Campus normally experiences seasonal rainfall events occurring in less than one day during the rainfall season. The inability of SUDS to discharge stormwater runoff in time could result in upstream flood events.

5.1.4 Detention Pond

A study of flow measurements in the Detention Pond was carried out by Beh (2014). These measurements were conducted on 9/10/2011, 19/10/2011 and 21/10/2011, for which the recorded rainfall ARI was 50 years, 10 years and 3 months, respectively. The rainfall depth, water level and flow in the Detention Pond are illustrated in Table 6 and Fig. 13.

Figure 13 shows that the peak flows were reduced by 74%, 72.12% and 53.70% on 9/10/2011, 19/10/2011 and 21/10/2011, respectively. Similar to the Wetpond, in the case of higher ARI, higher peak reductions were observed. However, the peak reduction on 9/10/2011 was only slightly higher than on 19/10/2011. This could mean that the maximum peak reduction under submerged conditions in the Detention Pond was around 73%. The peak reduction also showed that the Detention Pond was able to meet its design criteria for the retention of runoff resulting from 50-year ARI rainfall. Figure 13 also shows that the Detention Pond could reduce peak flow on 21/10/2011 despite having received 10-year ARI rainfall two days earlier. The Detention Pond emptying time also did not exceed 24 h, as required by MSMA, which was similar to the Wetpond. Beh (2014) mentions that the location of Detention Pond upstream is also important in ensuring that the flows into Constructed Wetland are not overloaded during high flows.

Table 6 Rainfall and flow characteristics measured in Detention Pond in 2011 (Beh 2014)

	Rainfall			Flow			
Date	Duration (mins)	Depth (mm)	Intensity (mm/h)	Inlet (lps)	Outlet (lps)	Peak reduction (%)	Delay time (h)
9/10/11	210	173.5	49.57	175.17	45.51	74%	1
19/10/11	215	125.1	34.91	168.12	46.87	72.12%	3
21/10/11	330	43.1	7.84	105.35	48.57	53.7%	4

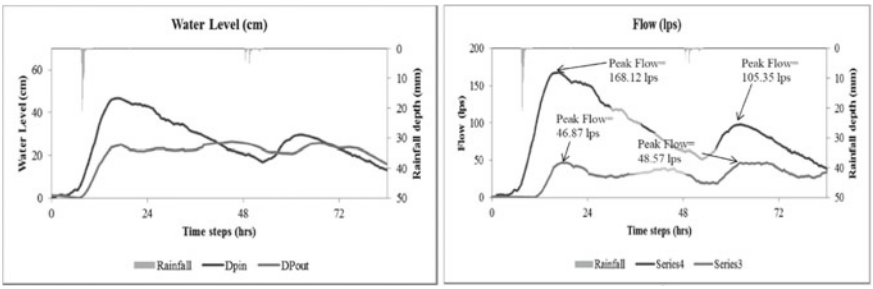


Fig. 13 Water level and flow for rainfall event for Detention Pond on 19th and 21st October 2011 (Beh 2014)

5.2 *Water Quality Aspect*

5.2.1 Water Quality Assessment

In the BIOECODS system, Constructed Wetland are the main component for water quality treatment in an additional purification process. Stormwater runoff will undergo a pre-treatment process through the Ecological Swale, Dry Pond, Wetpond and Detention Pond before flowing into the Constructed Wetland for further treatment (Ayub et al. 2005; Mohd Sidek et al. 2004; Zakaria et al. 2003). Water quality pre-treatment are the result of flow attenuation at the previous component. Table 7 shows the water quality results for the Ecological Swale (GS1-GS9) and Dry Pond (GS10). GS1-GS 4 is upstream of the Ecological Swale, while GS8 is furthest downstream of the Ecological Swale. Observation has shown water quality improvement from upstream to downstream, especially for parameters TSS, COD and BOD. The range of all the parameters falls under Class IIA National Water Quality Standards for Malaysia (NWQS).

At the Ecological Pond, there was continuous monitoring to measure water quality performance; the results are presented using the box plot method (Fig. 14). Most of the Ecological Pond measurements show water quality in the range of Class II to Class III Water Quality Index (Malaysia). Several pollutants were also reduced from upstream to downstream. Being at the downstream end of BIOECODS, the Ecological Pond was able to effectively treat the stormwater runoff from USM Engineering Campus.

The boxplot shows the removal of TSS, BOD, COD, NO_2^-, NH_3^-, NO_3^- and PO_4 from the Ecological Pond. Observation has shown that the Constructed Wetland achieves considerable reduction in all parameters. Beh (2014) observed that the wetland recorded significant removal of TSS with 74% efficacy. However, the study did not show significant removal of BOD and COD concentration. BOD concentration indicated low removal: 28% and 9% for the Detention Pond and wetland, respectively. Only the wetland component demonstrated significant removal of BOD and COD, with 9% and 24% efficacy.

Johari et al. (2016) on the performance of the Constructed Wetland during the wet and dry seasons shows that, during the wet season, there is removal of AN (66.7%), BOD (4.95%), COD (23.22%) and pH (10.55%). Meanwhile, during the dry season, there is removal of AN (62.29%), BOD (5.77%), COD (12.85%) and pH (2.6%). Observation has shown that the (NWQS) value for the wet and dry seasons achieved Class I and Class II, respectively.

Shaharuddin et al. (2011) observed improvement in water quality at the same site. The results show removal of COD (24.2%) and TSS (31.6%). Meanwhile, Alang Othman (2018) on the Constructed Wetland for stormwater treatment shows that TSS had the highest mean removal rate of 41.3%, followed by COD (16%), AN (27%) and BOD (8.5%). The discharge from the Constructed Wetland indicates that successful biological treatment does occur within the Ecological Ponds and Constructed Wetland. Ayub et al. (2005) on water quality in the Ecological Pond shows water quality improvement from upstream to downstream. According

Table 7 Storm water quality result on 28th June 2003 at Ecological Swale (upstream to downstream and Dry Pond (GS8) (Mohd Sidek et al. 2004)

Station	Parameter									
	pH	DO (mg/L)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	NH_3-N (mg/L)	NO_3-N (mg/L)	PO_4^{3-} (mg/L)	Zn (mg/L)	Pb (mg/L)
GS1	5.88	6.9	3	76.8	4	0.23	0.87	0.06	0.122	0.856
GS2	6.35	5.6	2	92.3	6	0.19	0.67	0.03	0.147	0.977
GS4	6.08	5.4	10	57.6	3	0.46	1.09	0.22	0.077	0.962
GS7	6.25	5.9	10	61.4	4	0.3	0.97	0.15	0.139	0.831
GS10	6.32	6.9	26	108.2	9	0.58	1.17	0.92	0.15	0.804
GS9	6.24	7.9	7	57.6	5	0.27	1.37	0.13	0.510	0.750
GS8	6.39	6.4	6	23.0	2	0.34	0.87	0.15	0.120	0.851

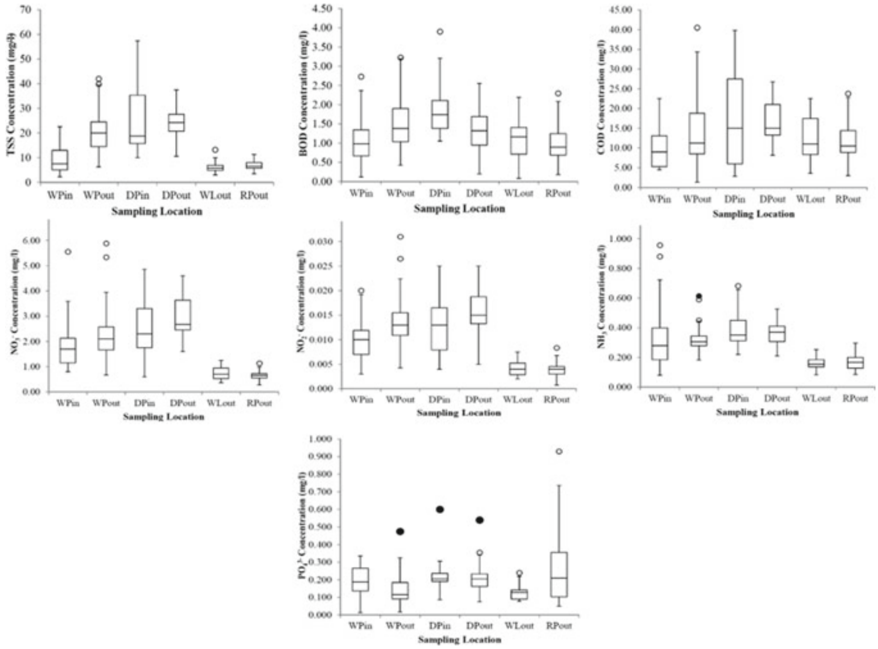


Fig. 14 Water quality trend of nutrients in BIOECODS (TSS, BOD, COD, NO_2^-, NH_3^-, NO_3^- and PO_4) (Beh 2014)

to Ayub et al. (2010), Constructed Wetland can treat stormwater runoff and control the quantity of stormwater downstream, in addition to storing water, according to design.

From all the quality assessment of BIOECODS, it is clear that water quality improves after passing through Constructed Wetland. Most of the results fall under Class I and II (NWQS).

6 Biodiversity at BIOECODS

A biodiversity study was also carried out at USM Engineering Campus, with the Constructed Wetland area selected as the case study. By maintaining water quality at the Constructed Wetland, water safety for humans can be guaranteed, in addition to securing the biodiversity of ecosystems and species. According to Shaharuddin et al. (2011), the number of phytoplankton, zooplankton and benthic macroinvertebrate species is high at the wetland inlet. The high amount indicates an abundance of plants, a sufficient amount of nutrient concentration (ammonium, nitrate, nitrite and phosphate), light and dissolved oxygen, which helps to trigger its distribution.

The benthic macroinvertebrate species in the wetland indicate how the species have responded to the condition of the water quality.

In terms of fish, 11 specimens comprising five species were caught and identified during the first sampling from December 2010 until May 2011. The Tilapia species (*Oreochromis niloticus*) was the most prevalent at 35%, followed by Tinfoil barb and Lampam sungai (*Barbodes schawanenfeldii*) at 30%, Marble goby, Ikan ketutu and ubi (*Oxyeleotris marmoratus*) at 15%, Rohu (*Labeo rohita*) at 10%, Pacu (*Colossoma macropomum*) at 8% and Silver barb, Lampam jawa (*Barbodes gonionotus*) at 2%. The number of fish shows that the wetland has emerged as a source of food for both local and migratory birds. Accordingly, a total of 15 species of birds were observed from December 2010 until May 2011, which comprised ten different families. The family Ardeidae had the most family members, consisting of five species (Shaharuddin et al. 2011). These results show that a variety of habitats are present due to the establishment of BIOECODS.

7 Recreational Pond for Recreational Activities

At the end of the water treatment system, there is a pond suitable for recreational activities, including kayaking and fishing. The aesthetic aspects of the surrounding areas, particularly at the downstream end of the drainage, will be enhanced by BIOECODS. The water level will be maintained at the recreational pond before being discharged into Kerian River.

8 Other SUDS Projects

After the establishment of BIOECODS at USM Engineering Campus, other implementations of this system were designed and constructed in other states in Peninsular Malaysia:

1. Cadangan Pembinaan Wad Forensik, Hospital Bahagia Ulu Kinta, Ipoh, Perak (2003)
2. Pembinaan Asrama di AtasTanah Wakaf Khas, Kota Bharu, Kelantan (2005)
3. Pembinaan Klinik Kesihatan Jenis 2, Taiping, Perak (2007)
4. Pembinaan Kampus Universiti Malaysia Kelantan, Bachok, Kelantan (2009)
5. Naiktaraf Sistem Saliran di Tasik Raban Resort, Lenggong, Perak (2010)
6. Naiktaraf Sistem Saliran Padang Utama Seri Mutiara, Georgetown, Penang (2011)
7. Pembinaan Kolej Universiti Automotif Antarabangsa, Pekan, Pahang (2013)
8. Naik taraf Saliran Padang Taman Astaka, Petaling Jaya, Selangor (2014)
9. Kwasa Damansara Township, Sungai Buloh, Selangor (2015)

10. Naiktaraf Sistem Saliran Padang Permainan Sekolah Kebangsaan Francis Light, Georgetown, Penang (2018)
11. Cadangan Pembinaan Ibu Pejabat Daerah Polis, Pasir Mas, Kelantan (2019)
12. Cadangan Pembinaan Klinik Kesihatan Jenis 2 Bandar Perda, Bukit Mertajam, Penang (2021).

9 Conclusion

The performance of BIOECODS since its completion in 2001 has evidenced the effectiveness of the components made up of Ecological Swale, Wetpond, Detention Pond and Constructed Wetland. The results obtained indicate that BIOECODS is able to meet its design requirements with flow attenuation by Ecological Swale (between 24 and 90%), wet ponds (between 85 and 96%) and Detention Pond (between 55 and 75%). Improvement of water quality is due to successful reductions in several pollutant parameters. Constructed Wetland achieved NWQS at Class I during the wet season. Thus, Recreational Pond achieve Class I for water supply purposes is very promising.

In addition to improved water quantity and quality, BIOECODS also provides biodiversity and amenity at USM Engineering Campus. BIOECODS is an evidence that MSMA can be implemented in new development in Malaysia. The national pilot project has been expended throughout the country with similar projects coming in the near future.

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