RECONSTITUTING THE CONCEPTS OF SUSTAINABLE STORMWATER MANAGEMENT

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ABSTRACT

Even though various sustainable stormwater managements are available, there is less clear discussion and classification of its concepts. Besides, little discussion on the relationship of the concepts with the hydrology cycle made the implementation of stormwater management less successful in managing the problem caused by stormwater such as flash flood and water pollution. Hence, this research aims to review the concepts of sustainable stormwater management. Two objectives formulated are (i) to identify the concepts of sustainable stormwater management, and (ii) to identify any relationship of the identified concepts with other factors in sustainable stormwater management. Online journal, forum discussion and e-mail interview were used as methods of data collection in this qualitative research. Six steps of descriptive comparative analysis were used to analyse the data. Consequently, the researcher had identified 11 concepts and listed the concepts in priority order. The 11 concepts are conservation of watershed, compact urban form, retain stormwater on site, treatment train, green network, harvest and reuse rainwater, redevelopment, streetscape ecosystem and restoration. The identified concepts were listed in priority order based on relationship with 7 hydrology cycles which are interception, infiltration, surface runoff, depression storage, evapotranspiration, groundwater flow and interflow. The concepts were analysed with hydrology cycles is because to ensure the sustainability factors in outlining the concepts to manage the stormwater.

Keywords: Stormwater management, concepts, hydrology cycle, sustainable

INTRODUCTION

Stormwater is an excessive amount of surface runoff. Stormwater occurs when rate of interception and infiltration of rainfall is decrease and rate of volume and speed of surface runoff is increased (Ahmad Sanusi Hussin, 2005; Marsh, 2005; Day & Dickinson, 2008). The changes in interception, infiltration and surface runoff are examples of changes in hydrology cycles in urban environment where pervious covers were changed to impervious cover. Clearance of vegetation covers and flattens of landform and developed into impervious cover such as buildings, roads, parking lots, solid pavements and storm sewers caused large discharge of stormwater with high frequencies especially during heavy precipitation. High discharge of stormwater reduces the capacity of river to contain the mass volume of stormwater in a short period of precipitation. Consequently, stormwater causes an overflow of river and flood the nearby area (Chia Chong Wing, 2004; Ahmad Sanusi Hussin, 2005; Marsh, 2005; Day & Dickinson, 2008).

In order to overcome the flooding issue caused by stormwater, structural conveyance approach are used for stormwater management (Chia Chong Wing, 2004). Conventional practice of structural conveyance for stormwater management involved increasing the number of concrete drainage and river modification such as broadening, deepening, straighten, structured and diversion. However, the structural conveyance approach have been identified as not sustainable in terms of ineffective in flood mitigation occurrence, high cost of construction and maintenance and unfriendly to the user and the environment (Department of Irrigation and Drainage, n.d.). In addition, environmental problems like erosion of riverbanks, decrease of water quality and degradation of river habitat also happen because of mass structured drainage and concreted river network (Marsh, 2005).

As an alternative to conveyance approach, there are other sustainable stormwater management approaches to reduce the stormwater volume and speed rate and simultaneously increase interception coverage of precipitation and infiltration rate of rainfall into the soil (Department of Irrigation and Drainage, n.d.). The approaches come with various terms such as Sustainable Urban Drainage Systems (SUDS), Low-Impact Development (LID) and Water Sensitive Urban Design (WSUD). All the sustainable stormwater management approaches have similar aim which is to replicate the natural hydrology cycle into site design. The approach is based on source control mitigation concept. The concept used is to reduce quantity of stormwater by increasing the interception of rainfall through vegetation cover and increase the infiltration rate of rain water into the soil. The source control concept focuses on how to use and integrate landscape elements with stormwater management strategies. The benefits of source control concept in sustainable stormwater management are less cost of construction and maintenance, aesthetic enhancement of urban image, rehabilitation of the urban ecosystem, robustness in use of space and user friendly (DID, n.d.).

The difference between structural conveyance approach and sustainable stormwater management approach is the concept applied. Based on the dissimilarity concept of stormwater management, this research sets out to reconstitute the concept in sustainable stormwater management to provide an alternative sustainable stormwater management.

The research questions raised in this research are “What are the concepts of sustainable stormwater management?” and “Are there any relationships of the identified concepts with other factors in sustainable stormwater management?” The aim of research is to review the concepts of sustainable stormwater management. To achieve the aim, two research objectives have been formulated which are (i) to identify the concepts of sustainable stormwater management, and (ii) to identify any relationship of the identified concepts with other factors in sustainable stormwater management.

LITERATURE REVIEW

Since the research focuses on stormwater, it is related to landscape design because stormwater management is about how the landscape is being design to manage the hydrology cycles. Therefore, it is vital to define landscape design. Few authors may use different terms such as landscape architecture, ecological planning and ecosystem design. Thus, other terms that relate and merely similar to landscape design will be reviewed for better definition.

The Penguin Dictionary of Architecture and Landscape Architecture defined landscape architecture as the art and science of creating open-air spaces as environments for human life. Whereas, Lyle (1999) who used the term ecosystem design suggests that to make the landscape design, landscape architect needs to have scientific knowledge of natural ecosystems. Steiner (2008) stated that ecological planning is the use of biophysical and socio-cultural information to suggest opportunities and constraints for decision making of landscape development. Meanwhile, McHarg (1995) argued that ecological planning is the understanding of biophysical and social process in an ecosystem through the operation of laws and time. The ecosystem is defined as an assemblage of interaction between living and non-living system in a landscape. Lyle (1999) also suggested that scientific knowledge of ecosystem design can be further divided into two. First is a fact or data about the landscape. It is important before designing a landscape to know the biological process, this is the import and export of energy and materials and biophysical elements involved in the process. Second is the concept of design. In landscape design, concept is crucial because it provides access to the mechanisms that join all of the facts. It offers a basis in constructing theories of ecosystem design to understand the scientific knowledge of landscape and its processes. Therefore, concept can be considered as general ideas and principles in stormwater management. Meanwhile, the landscape ecosystem needs to be studied first before designing the stormwater management is the hydrology cycle. It is also important to study the biophysical elements involved in the hydrology cycle.

Marsh (2005) argued, the vital to identify the hydrology cycle is to acknowledge that in landscape, hydrology features are an interrelated with other biophysical elements like topography, soils, and vegetation. In a natural landscape, hydrology cycle is the inflow and outflow continuous processes in its various forms in the air, on land and in the sea (Ferguson, 1998; Steiner, 2008). It represents the sequences movement of water in landscape by different phases and forms. The scientific knowledge gain from this literature will use as sustainability factors for the identified concepts.

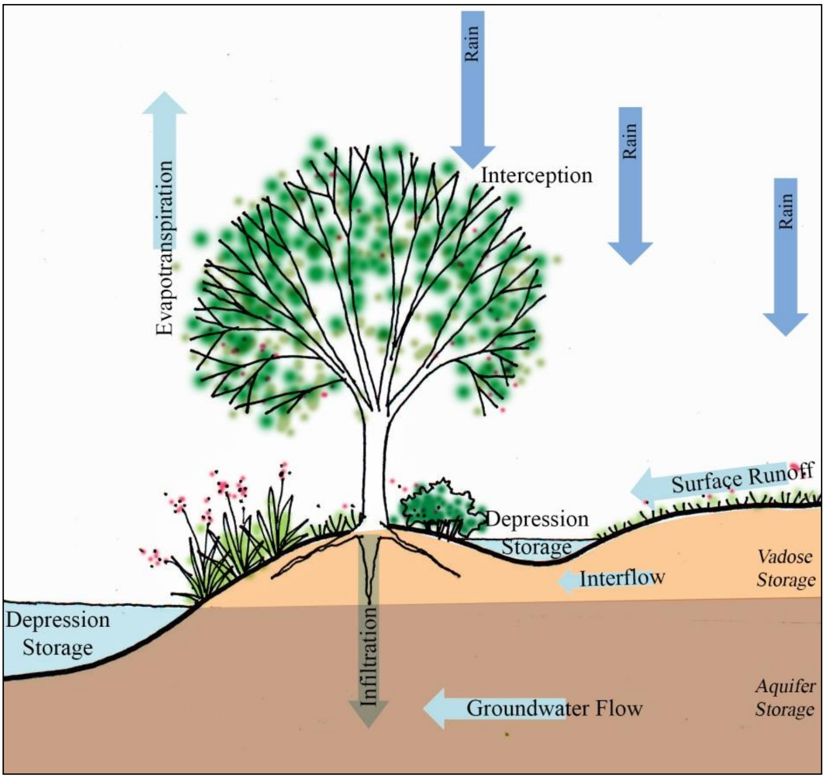

Figure 1 Revised Hydrology Cycle
*(**Source:** Modified from Ferguson, 1998; Marsh, 2005; Steiner, 2008)*

Meanwhile, Table 1 shows the summary of hydrology cycle and interrelated biophysical elements involved in the hydrology cycle.

Table 1 Hydrology Cycle and Its Interrelated Biophysical Elements

Hydrology Cycle	Biophysical Element Involved	Process
1. Interception	1. Vegetation (strata of trees, shrubs & groundcovers)	Interception & evapotranspiration.
2. Infiltration	1. Surface of landscape; 1.1. Soil (types, permeability & saturation)	Infiltration & absorption through permeability of soil & by root systems of

	1.2. Vegetation.	vegetation.
3. Surface runoff	1. Topography and slope. 2. Surface roughness; 2.1. Vegetation. 2.2. Soil type. 3. Water bodies (pond, lake, wetland & river)	Surface runoff flow into the lower area.
4. Depression storage	1. Topography (landscape depression) 2. Water bodies (pond, lake, wetland & river)	Collected within micro-topography & water bodies.
5. Evapotranspiration	1. Vegetation. 2. Water bodies (pond, lake, wetland & river)	Evapotranspiration; holding & retain the water & slowly evaporate to the air.
6. Groundwater flow	1. Soil (types, permeability & saturation)	Infiltration & absorption. Slowly discharge into streams through aquifer storage layer in the ground.
7. Interflow	1. Soil (types, permeability and saturation).	Infiltration and absorption. Slowly discharge into streams through vadose storage layer in the ground.

*(**Source:** Ferguson, 1998; Marsh, 2005; Steiner, 2008)*

The hydrology cycle and its biophysical elements will be used as the basis concept in landscape design of stormwater management in this research.

Four models of sustainable stormwater management which are (i) Stormwater Management Strategies, (ii) Low Impact Development, (iii) Water Sensitive Urban Design, and (iv) Sustainable Urban Drainage Systems were reviewed to identify the concepts used in the sustainable stormwater management. Table 2 shows the summary of identified concepts.

Table 2 Concepts of Sustainable Stormwater Management

Model of Sustainable Stormwater Management	**Characteristics of Concept**
1. Stormwater Management Strategies	1. Store and releasing stormwater slowly through evapotranspiration and infiltration over a long time. 2. Return the stormwater into the ground. 3. Direct to a holding basin and releasing it slowly. 4. Infiltrate stormwater into the ground. 5. Locate development on site with good hydrologic performance. 6. Avoid impervious surface wherever possible. 7. Balance density ratios between developed land and open space. 8. Increase travel time of stormwater through longer and slower route. 9. Increase surface roughness to slow the movement of stormwater. 10. Disconnect impervious surface from a drainage system to reduce flow continuity of stormwater. 11. Utilize grading and planting design to slow stormwater and enhance infiltration.
2. Low Impact Development	Manages rainfall on-site by attempting to integrate control into site and building design by creating condition for the rainwater to infiltrate into the soil. Apply distributed source-control approach designed to treat and manage runoff at the source by five concepts which are conservation and minimization, conveyance, storage, infiltration and landscaping.
3. Water Sensitive Urban Design	1. Minimizing impervious areas.

	2. Minimizing use of formal drainage systems. 3. Encouraging infiltration (where appropriate) 4. Encouraging stormwater reuse.
4. Sustainable Urban Drainage Systems	1. Dealing with runoff in the locality of the rainfall. 2. Managing potential flooding at its source in the present and in the future. 3. Protecting water resources from point pollution and diffuse pollution.

*(**Source:** Australian and New Zealand Environment and Conservation Council, 2000;
Construction Industry Research and Information Association (CIRIA), 2001;
Hager, 2003;
Marsh, 2005;Toronto and Region Conservation, 2010)*

In summary, as stated by Lyle (1999), the concept of sustainable stormwater management should be outlined based on hydrology cycle. This is because sustainable stormwater management is about how the hydrology cycle within a landscape is sustainably designed. Hence, the hydrology cycle and its biophysical elements will be used as the basis concept in landscape design of stormwater management in this research.

METHODOLOGY

Qualitative approach was used for this research based on three elements of inquiry identified based from Creswell (2003). Firstly, constructivism was used as alternative knowledge claims. Constructivism is defined as assumptions identified in the research where the researcher seek for the complexity of views into few categories or ideas in understanding a process. Constructivism is suitable to answer the research questions and objectives of research because researcher can identify the formation process of concepts in sustainable stormwater management. Secondly, grounded theory was used as strategy of inquiry. Grounded theory is suitable for the research questions and objectives because grounded theory is defined as an attempt to derive a general and abstract theory of a process or interaction grounded based upon the data collected from participants in the research (Charmaz, 1994; Glaser & Strauss, 1999; Merriam, 2002; Creswell, 2003; Hunter & Kelly; 2008). The collected data from the participants will be used to identify the concepts of sustainable stormwater management. Lastly, Google group forum discussion, e-mail interview and documents were used as methods of research.

Google group forum discussion from http://groups.google.com/group/rainwater-in-context was used as a semi-structured forum discussion platform. 112 professionals in stormwater and hydrology management have joined the Google group. 4 respondents had replied the topic posted and 8 attached links of documents were given by the respondents. To overcome the lack of respond, researcher had reviewed 20 topics related to concepts of sustainable stormwater management.

Moreover, 578 structured e-mail interviews were sent to professionals and academicians in stormwater and hydrology management industry in Malaysia, United States of America, United Kingdom, Australia and Japan asking about the concept in sustainable stormwater management. 8 responds were received with 13 documents were attached for references.

In addition, online journals from http://www.stormh2o.com were reviewed from issue January 2007 until May 2012 for documents method. 35 topics of online journals which related to concepts of stormwater management were reviewed.

Lastly, in analyzing the collected data, there are six sequential steps of data based from Creswell (2003) (Figure 2).

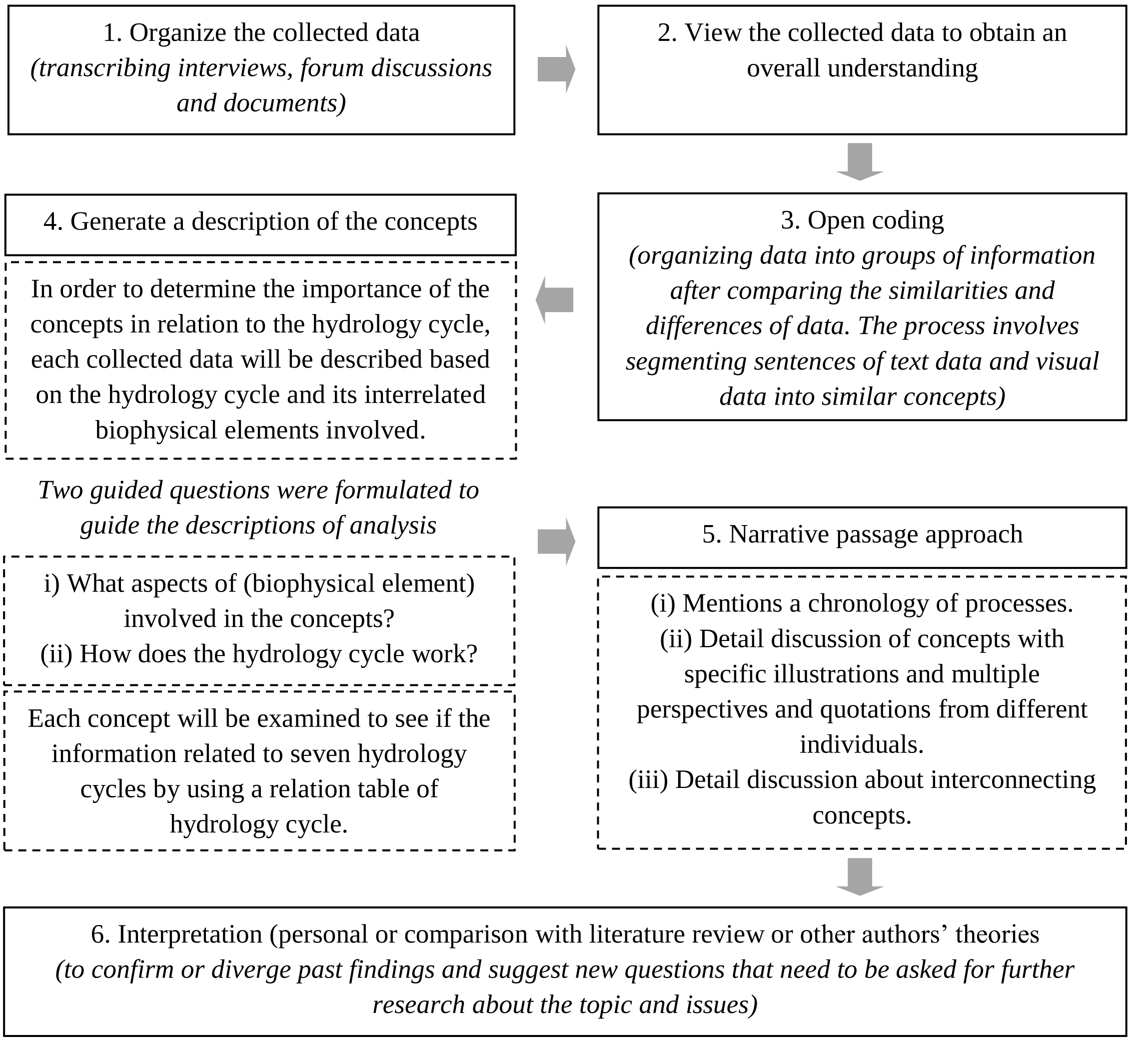

Figure 2 Six steps of analysis processes (based from Creswell, 2003)

RESULT

A total of 11 concepts had been identified after the analysis process. First is conservation of watershed. Based on the analysis of conservation of the watershed, it is clear that this concept is fully related to all the hydrology cycle and the biophysical elements involved in the cycle. This is because there are no changes or alteration made onto the biophysical elements within the conserved watershed which allow the hydrology cycle to function at its optimum level especially to filter stormwater from nearby development as highlighted by Richards (2011). Comparison between analysis and literature review reveals that conservation of the watershed should be the priority concept in stormwater management. In literature review, Toronto and Region Conservation (2010) has listed preservation of important hydrologic features and functions like stream buffers as its first site design concept. It also has listed to use existing natural systems as the integrating framework for planning as a first key principle in Low Impact Development. Existing natural systems can be referred as conserved water bodies' ecosystem. Table 3 summarizes the relation of hydrology cycle with conservation of the watershed. The table shows that conservation of watershed fulfils all the hydrology cycle which are interception, infiltration, surface runoff, depression storage, evapotranspiration, interflow and groundwater flow. All the biophysical elements of plants, soil, water bodies and topography which are conserved can optimally function in hydrology cycle.

Table 3 Relation of Hydrology Cycle with Conservation of Watershed

Concept	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspira tion**	**Interflow**	**Groundwater flow**
Conservation of watershed							

Second concept identified is harvest and reuse rainwater. Comparison between analysis data and literature review indicates that rainwater should be harvested and reuse as a resource as stated by Crabtree (2011) and by Hager (2003) as in the literature review. Even though Australian and New Zealand Environment and Conservation Council (2000) also suggested to capture and reuse of rainwater, but they are using the word stormwater, not rainwater. The researcher argued to use the word rainwater than using the word stormwater because it is more accurate to its condition. Rainwater shows that the rain is collected in a rain barrel. Meanwhile, stormwater refers to excessive surface runoff flowing towards the lowest point of landform such as drainage system and water bodies. Harvest and reuse of rainwater concept shows that it relates to six hydrology cycles which are interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow (Table 4). In harvest and reuse rainwater concept, the interception refers to directing rainwater into a rain barrel to be stored. The infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow refer to reuse of harvested rainwater for irrigation on planting or landscaping.

Table 4 Relation of Hydrology Cycle with Harvest and Reuse Rainwater

Concept	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspiration**	**Interflow**	**Groundwater flow**
Harvest and reuse rainwater	✓	✓	✓	✓	✓		✓

Third concept is compact urban form. Compact urban form is a concept of stormwater management at planning level. Compact urban form is a combination of (i) preservation of natural environment and (ii) designing a compact form or layout of a city, and (iii) high density of population and infrastructure. Relation of compact urban form and the hydrology cycle involve all seven cycles which are interception, infiltration, surface runoff, depression storage, evapotranspiration, interflow and groundwater flow (Table 5). The reason researcher stated that is because compact urban form starts with conservation or preservation of open or green spaces and critical ecological water bodies' ecosystem. Thus, these conserved green spaces can act as a cleaning or filtering the polluted stormwater or waste water from nearby compact development and high-density population. From the analysis of finding, Smart growth planning flowchart as suggested by Aurbach (2010) can be improved with statements from Dumont (2011) about the need to design multi-use green strategies or system and from Nisenson (2011) on the need to plan a mixed-use development of commercial, institutional and residential and to plan a mix-transit network (Figure 3). These concepts are important to ensure the sustainability of compact urban form with high-density population.

1. Preservation of critical ecological areas like riparian corridors, stream buffers, flood plains and wetlands and open spaces as niche areas to absorb and filter stormwater.

↓

2. Use smart growth strategies like high density and compact development to preserve land.

↓

3. Apply mixed-use land use development and mix-transit network through infill, retrofit and redevelopment of existing site.

↓

4. Design multi-use green systems of rainwater management strategies

Figure 3 Revised Smart Growth Planning Flowchart based from Aurbach (2010), Dumont (2011) and Nisenson (2011)

Table 5 Relation of Hydrology Cycle with Compact Urban Form

Concept	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspiration**	**Interflow**	**Groundwater flow**
Compact urban form							

The fourth concept is redevelopment. Redevelopment, infill or retrofit is a concept to achieve compact urban form and high density population. In the analysis, multifunctional of stormwater management concept is highlighted by EPA-NOAA Smart Growth Implementation Assistance for Coastal Communities for Sussex County, Deleware (2009) and Ferguson (2004). The relation of redevelopment and the hydrology cycle involve six cycles which are interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow (Table 6). Interflow cycle is not included because as discussed by Stephens and Dumont (2011) argued that interflow can easily loss due to removal of vadose storage layer of soil through construction works like insertion of pipe and digging of ditches. Since redevelopment focuses on an already developed area, the vadose storage for interflow had lost. As said by Stephens and Dumont (2011) that once the vadose storage layer had lost, there is no means to restore it. Thus, redevelopment projects can only restore interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow cycles.

Table 6 Relation of Hydrology Cycle with Redevelopment

Concept	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspira tion**	**Interflow**	**Groundwater flow**
Redevelopment							

The fifth concept is retain stormwater on site. Comparison between analysis data and literature review shows that retain stormwater on site has been stated by many authors. In literature review, Marsh (2005) highlighted to store stormwater on site and releasing it slowly over a long time, to return the stormwater into the ground and to use storage basin strategy. In addition, Hager (2003) urged the need for storage, infiltration and landscaping concepts of Low Impact Development to create subsurface storage and to create basin and rain garden. Moreover, Australian and New Zealand Environment and Conservation Council (2000) stated in Water Sensitive Urban Design's secondary level treatment through sedimentation and filtration by using filter strip, grass swale, extended detention (dry) basin, infiltration trench and infiltration basin. It also stated in tertiary level treatment through sedimentation, filtration and adsorption by using pond and wetland. Lastly, Construction Industry Research and Information Association (CIRIA) (2001) in Sustainable Urban Drainage System (SUDS) stated the usage of the basin and pond techniques to retain stormwater. Relation to retain stormwater on site and hydrology cycle involve four cycles which are infiltration, depression storage, evapotranspiration and groundwater flow. This is based on the arguments by Briglio (2011), Horner (2011) and Ferguson (2002) about the evapotranspiration, depression storage and infiltration cycles involved through retain stormwater on site concept. Meanwhile, Ferguson (2002), Rutherford (2007) and Low (2011) had highlighted the groundwater flow cycle involved through retain stormwater on site concept. Through this concept, the infiltration cycle happens through the roots of plants and soil. Depression storage is caused by the lower depression of landform. Evapotranspiration cycle is through plants and the groundwater flow cycle is through the roots of plants and soil. However, researcher argued to add interception and surface runoff cycles because retains stormwater on site concept usually using plants as part of its concept. Thus, the foliage of plants will intercept some of the stormwater flowing into a retention area. Meanwhile, surface runoff also involved as it is a process of directing the stormwater into the retention area. However, for interflow cycle, researcher categorized it into two situations. The first situation is where interflow cycle is not involved as the retention area for stormwater is a developed landscape. In developed landscape, Stephens and Dumont (2011) argued that interflow can easily loss due to removal of vadose storage layer of soil through construction works like insertion of pipe and digging of ditches. The second situation is where interflow cycle is involved as the retention area is a natural landscape. This is based on Briglio (2011), from the analysis data discussed above. Briglio (2011) stated that the retention area for stormwater can be both developed landscape and the natural landscape. In a natural landscape, the interflow cycle can happen because the vendor storage layer is still conserved. The above discussion about the relation of hydrology cycle with the concept of retain stormwater on site is summarized in Table 7.

Table 7 Relation of Hydrology Cycle with Retain Stormwater on Site

Concept	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspiration**	**Interflow**	**Groundwater flow**
(a) Retain stormwater on site (with conservation of natural water bodies ecosystem like wetland)							
(b) Retain stormwater on site (without conservation of natural water bodies ecosystem)							

Sixth concept is treatment train. Comparison between analysis data and literature review shows that the treatment train has been stated by many authors. The researcher found out that the terminology of "treatment train" and "retain stormwater on site" lead to similar definition. This is based on the definition of a treatment train by Low (2011), "treatment train is a method of integrating several of strategies or tools for various functions such as paving, channelling, storage and filtration that collectively manage the rainwater." The strategies in treatment train concept are similar to retain stormwater on site concept. Although, Broughton (2012) had argued to divide the site into two classifications which are (i) upper stream or highest point of the site and (ii) downstream or lowest point of site. Moreover, Broughton (2012) said that source control strategies are crucial within the upper stream area. In literature review, Marsh (2005) highlighted about the source control strategy to manage stormwater. In addition, Toronto and Region Conservation (2010) stated in one of the Low Impact Development's key principle is to treat stormwater as close to the source area as possible. Relation of treatment train and hydrology cycle involves seven hydrology cycles which are interception, infiltration, surface runoff, depression storage, evapotranspiration, interflow and groundwater flow. This is based on the arguments by Low (2011) that all seven hydrology cycles happen through collective strategies like paving, channelling, storage and filtration. Through this concept, the infiltration, interflow and groundwater flow cycles happen through the roots of plants and soil. Surface runoff cycle flowing into a lower point from the highest point of landform. Depression storage is caused by the lower depression of landform. Lastly, interception and evapotranspiration cycles are through plants. Besides, the researcher had classified the relation of a treatment train with hydrology cycle into two classifications (Table 8). The classification involved discrepancy of interflow cycle. First classification is where interflow cycle is not involved as the area within the treatment train concept is a developed landscape without any natural landscape. In developed landscape, Stephens and Dumont (2011) argued that interflow can easily loss due to removal of vadose storage layer of soil through construction works like insertion of pipe and digging of ditches. Second classification is where interflow cycle is involved as the area within the treatment train concept has a natural landscape. This is based from Broughton (2012) urged to conserve a natural environment of site for the downstream treatment train. As discussed before, in natural landscape, the interflow cycle can happen because the vadose storage layer is still conserved.

Table 8 Relation of Hydrology Cycle with Treatment Train

Concept	Interception	Infiltration	Surface runoff	Depression storage	Evapotranspiration	Interflow	Groundwater flow
(a) Treatment train (with conservation of natural water bodies ecosystem like wetland)							
(b) Treatment train (without conservation of natural water bodies ecosystem)							

The seventh concept is streetscape ecosystem. The Streetscape ecosystem concept is a combination of green infrastructure strategies integrated with the street and its component like median and traffic circles. Comparison between analysis data and literature review shows similarity in terms of the combination of discussing concept for streetscape ecosystem. Concepts like reducing the amount of impervious cover, retain stormwater on site and harvest and reuse of rainwater had been discussed in the analysis and literature review. The difference between analysis data and literature review is defining the street as a concept for ecological ecosystem through a combination of green infrastructure strategies. The relation of streetscape ecosystem with hydrology cycle involves six cycles of interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow (Table 9). Interception and evapotranspiration cycle happens through plant communities.

Surface runoff and depression storage cycles happen through topography and slope. Lastly, infiltration and groundwater flow cycles happen through soil and plant roots. Meanwhile, interflow cycle cannot occur because streetscape ecosystem covers the street which is within the developed area. Based on the argument by Stephens and Dumont (2011), in developed landscape, interflow is loss due to removal of vadose storage layer of soil through construction works like insertion of pipe and digging of ditches.

Table 9 Relation of Hydrology Cycle with Streetscape Ecosystem

Concept	Interception	Infiltration	Surface runoff	Depression storage	Evapotranspira tion	Interflow	Groundwater flow
Streetscape Ecosystem							

The next concept is restoration. Restoration concept is about restoring the normal state and condition of biophysical elements like topography and slope, vegetation, soil and water bodies for the hydrology cycle to function. There are similarities between analysis data and literature review in terms of the concept of treatment, infiltration, storage and conveyance. In literature review, Marsh (2005) underlined the storage concept through storage basin strategy and infiltration and treatment through source control concept. In addition, Hager (2003) highlighted the conveyance, storage and infiltration in Low Impact Development concepts. Meanwhile, the Australian and New Zealand Environment and Conservation Council (2010) emphasized three levels of treatment concepts of Water Sensitive Urban Design. Primary level treatment is targeting litter and other gross pollutants and coarse sediments. Second level is targeting sedimentary and primary removal of nutrients and bacteria. Third level of treatment is removing nutrients, bacteria, fine sediments and heavy metals. Lastly, Construction Industry Research and

Information Association (CIRIA) (2001) identified infiltration and treatment concepts through permeable and filter drain and infiltration devices. Meanwhile, storage can be done through basins and ponds. Lastly, conveyance can be done through filter strips and swales. Relation of restoration concept to hydrology cycle involves six cycles of interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow (Table 10). Interception and evapotranspiration cycle happens through plant communities. Surface runoff and depression storage cycles happen through topography and slope. Lastly, infiltration and groundwater flow cycles happen through soil and plant roots. Meanwhile, interflow cycle cannot occur because restoration is within the developed area. Based on the argument by Stephens and Dumont (2011), in developed landscape, interflow is loss due to removal of vadose storage layer of soil through construction works like insertion of pipe and digging of ditches.

Table 10 Relation of Hydrology Cycle with Restoration

Concept	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspiration**	**Interflow**	**Groundwater flow**
Restoration							

The subsequent concept is green network. The Green network concept is about the conservation and restoration of interconnected functioning hydrologic areas. The interconnected or network of green spaces which is to ensure the optimum level of stormwater and water quality treatment for a healthy hydrology cycle. Relation of the green network with hydrology cycle involve seven cycles which are interception, infiltration, surface runoff, depression storage, evapotranspiration, interflow and groundwater flow (Table 11). All hydrology cycles can function based on this concept is because the conservation of critical ecological areas likes wetlands, riparian corridors and flood plains where all the biophysical elements are intact for optimum biological functions especially the hydrology cycles. It is also contributed by the restoration of brownfield and greyfield into green spaces and parks which also function as natural environment in terms of the hydrology cycle except for the interflow cycle. This is based from Stephens and Dumont (2011), in developed landscape, interflow is loss due to removal of vadose storage layer of soil through construction works like insertion of pipe and digging of ditches.

Table 11 Relation of Hydrology Cycle with Green Network

Concept	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspiration**	**Interflow**	**Groundwater flow**
Green network							

Lastly, the identified concepts were listed according to priority order. The priority order was based on the highest number of each concept is related to the hydrology cycle. Table 12 shows the summary of concepts of sustainable stormwater management with the relationship to hydrology cycle.

Table 12 Relationship of Hydrology Cycles with the Concepts of Sustainable Stormwater Management

Concept	**Hydrology cycle**	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspiration**	**Interflow**	**Groundwater flow**
1. Conservation of watershed	**Relation**							
2. Compact urban form								
3. Retain stormwater on site (with								

conservation of natural water bodies ecosystem like wetland)								
4. Treatment train (with conservation of natural water bodies ecosystem like wetland)								
5. Green network								
6. Harvest and reuse rainwater								
7. Redevelopment								
8. Retain stormwater on site (without conservation of natural water bodies ecosystem)								
9. Treatment train (without conservation of natural water bodies ecosystem)								
10. Streetscape ecosystem								
11. Restoration								

Legend:	
	Similar concepts with yellow colour code but with the present of natural / undisturbed biophysical elements
	Similar concepts with green colour code but without the present of natural / undisturbed biophysical elements (retrofit, restored, man-made)
	The concepts have a relation with the hydrology cycle
White colour in the column of hydrology cycle	The concepts do not have a relation with the hydrology cycle

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, concepts in stormwater management according to Lyle (1999) can be considered as general ideas and principles. The concept is crucial because it provides access to the mechanisms that join all of the facts of the environmental scientific knowledge which are the hydrology cycle and its biophysical elements. Therefore, the scientific knowledge of landscape and its processes is a basis in outlining the concepts in sustainable stormwater management. There are 11 concepts identified where two similar concepts (refer to Table 11, number 3 is similar to number 8 and number 4 is similar to number 9) but has a different in terms the presence of natural or undisturbed natural water bodies ecosystem and without the presence of natural or undisturbed natural water body's ecosystem. The concepts with the present of natural or undisturbed natural water bodies' ecosystem were coded with green color and the concepts without the presence of natural or undisturbed natural water bodies' ecosystem were coded with yellow color. Those differences were found out by the researcher and listed in table form is crucial as it gives a new insight in classification of concepts in sustainable stormwater management. This is because the green color code which represents the presence of natural and undisturbed biophysical elements stressed the importance of conservation of natural biophysical elements to ensure the optimum level of hydrology cycle functions. Whereas, similar concepts and strategies which are without the presence of natural biophysical elements (man-made or restored) have a deficiency in certain hydrology cycles. The deficiency was examined and related to seven hydrology cycles and coded by white color. The identified 11 concepts were identified their relationship with the hydrology cycles and its biophysical elements to ensure the concepts comply with the aim of sustainable stormwater management and comply with the research questions and research objectives. In addition, the identified concepts were listed according to priority order based on the highest number of blue colour coded which relates the concepts and strategies with seven hydrology cycle (interception, infiltration, surface runoff, depression storage, evapotranspiration, groundwater flow and interflow). Researcher urges that the priority order listing is important to identify which concept and strategies should be focused and to give a clear classification and information in decision making in sustainable stormwater management.

There are 3 recommendations identified from the finding. Firstly, identification and classification of concepts in sustainable stormwater management at the local level need to be done. Local level means that the classification and identification of concepts are based on the scientific information of local's ecosystem and site condition. In the identification and classification process, involvement of professionals with hydrology and environment background is important. The most crucial part in the classification process is not the availability of scientific knowledge, but on how to relate and connect the available of various scientific knowledge from different professional backgrounds into a consensus classification of the concepts. Moreover, local manual and guideline of stormwater management that is based on local's ecosystem information is important to ensure the most suitable concepts can be conducted to optimize the success of concepts and to minimize the failure of the concepts used. Then, the local manual or guideline of stormwater management can be written and shared with practitioners. Secondly, it is important to raise the importance of sustainable stormwater management and to implement it. In raising the importance, it is essential to illustrate the importance of sustainable stormwater management as a cycle where it involves the (i) awareness of sustainable stormwater management among practitioners, (ii) need to implement the sustainable stormwater management in every development, (iii) getting feedback from practitioners for future improvement as the practitioners are aware about any failure of implemented stormwater management, and (iv) revision of sustainable stormwater management over time by local authority in improving any deficiency. Lastly, to improve the concepts of sustainable stormwater management, researcher found out that there are two scopes of research are crucial to be studied. First is the challenge to outline concept of sustainable stormwater management in a compact built up urban area. Hence, a study on how to integrate the concept with the impervious surface (buildings and roads) is important. Present green infrastructures like green roof, green wall and porous pavement are a good start to tackle the less availability space challenge.

Second scope of research is on how to outline concepts which are economical, ecological-oriented and user-friendly. This is because the majority of present concepts do not comply with all three sustainability components especially on economic and user-friendly aspects.

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