CONNECTING HYDROLOGY CYCLE WITH THE STRATEGIES OF STORMWATER MANAGEMENT FOR SUSTAINABLE ENVIRONMENTAL PLANNING AND DESIGN

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ABSTRACT

The central idea of strategies of stormwater management is about the environmental sustainability. The environmental sustainability can be achieved by synthesizing the strategies with the hydrology cycle. The reason is strategies of stormwater management are about the process to replicate the hydrology cycle. The connection between the strategies and hydrology cycle are crucial to be analysed and highlighted to help designer in understanding and making accurate planning and design of the strategies to reduce the quantity and to improve the quality of stormwater. Thus, the aim of this study is to analyse the strategies of sustainable stormwater management with the hydrology cycle. Two objectives were formulated: (i) to identify the strategies of sustainable stormwater management, and (ii) to analyse the connection of the identified strategies with hydrology cycle. In this qualitative approach study, three methods were applied for data collection - online journal, forum discussion and e-mail interview. The collected data was analysed based on five steps of descriptive comparative analysis. Subsequently, 17 strategies have been identified and listed according to the priority connection with 7 hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration, groundwater flow and interflow. The strategies were synthesized with hydrology cycle as an analysis factor of environmental sustainability to list the strategies in priority order. The list of the strategies are infiltration basin, barrier system, greenways, stream reclamation, vegetated surface channel, rainwater harvesting, narrow street, rain garden, stormwater wetland, tree canopy cover, green roof, disconnection of impervious area, porous pavement and soil modification.

Keywords: *Stormwater management, hydrology cycle, sustainable.*

1. Introduction

The decrease of interception and infiltration rate of rainfall during precipitation will lead to the increase in volume and flow rate of surface runoff known as stormwater. Subsequently, large discharge of stormwater flows into the low-lying area and into the river and causes flash flood within a short period of heavy precipitation (Day & Dickinson, 2008; Ahmad Sanusi Hassan, 2005; Marsh, 2005; Chia Chong Wing, 2004). Stormwater not only causes flood, but pollute the river and erode the soil which damage the habitat and property (Department of Environment Malaysia, 2007).

The stormwater issues happen because the hydrology cycles have been altered. The change and deterioration of pervious cover of nature to massive impervious cover in developing the urban has caused the alteration issues. The massive impervious cover comprises of roads, parking lots and buildings. The water bodies also have been changed particularly the river - straighten, widen and structured to be storm drainages where all types of contaminated water were disposed into (Day & Dickinson, 2008; Miguez, Mascarenhas & Magalhaes, 2007; Marsh, 2005). Marsh (2005) mentioned that the loss of vegetation cover, soil composition and texture, and landform slope has changed the runoff co-efficient in natural area from 90 to 100 per cent to 10 to 20 per cent in the urban area.

To overcome the stormwater issues, many stormwater management approaches have been proposed to manage the quantity and quality aspects of stormwater management. The stormwater management can be a conventional conveyance approach like storm drain or a sustainable approach that based on nature for example Sustainable Urban Drainage Systems (SUDS), Low-Impact Development (LID) and Water Sensitive Urban Design (WSUD). The manual of stormwater management provides guidelines based on two main aspects - the concept and the strategies. The concepts provide the basis of understanding of planning and design behind the strategies of stormwater management, whereas the strategies provide range of mechanisms or tools to manage the stormwater.

This study aims to deliberate the aspect of strategies in sustainable stormwater management. The aim of this research is to analyse the strategies of sustainable stormwater management with the hydrology cycle. Two objectives were established which are (i) to identify the strategies of sustainable stormwater management, and (ii) to analyse the connection of the identified strategies with hydrology cycle.

2. Strategies of Sustainable Stormwater Management

Planning and design of stormwater strategies involves connecting and synthesizing the knowledge of hydrology cycle with the strategies as mechanisms that manage the stormwater issues either the quantitative or qualitative issues. Naturally, in hydrology cycle process, the excess runoff (surface runoff) flows into the water bodies and infiltrate into the ground without causing flood. However, the change of hydrology cycle in the city leads to excess surface runoff (stormwater) that causes the flood. Hence, the strategies of sustainable stormwater management have to mimic the natural hydrology cycles to restore the process as before.

3. Hydrology Cycle as the Environmental Sustainability Factor

The processes of hydrology cycles are interrelated with biophysical elements - topography, soils, vegetation and water bodies as explained by Marsh (2005). Hydrology cycles take several forms and phases of inflow and outflow in continuous processes within the biophysical elements (Steiner, 2008; Ferguson, 1998) as summarized in Table 1. The understanding of the hydrology cycles, the biophysical elements involved and the processes was used as a sustainability factor for the identified strategies. This is crucial in ensuring the success of the strategies in managing the issues of stormwater as the best example in planning and designing the strategies of stormwater is by mimicking the hydrology cycles.

Table 1: Hydrology cycle, biophysical element and the process (Source: Steiner, 2008; Marsh, 2005; Ferguson, 1998)

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) 1.2. Vegetation	Infiltration & absorption through permeability of soil & by root systems of 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. Evapo-transpiration	1. Vegetation 2. Water bodies (pond, lake, wetland & river)	Evapotranspiration; 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 & absorption. Slowly discharge into streams through vadose storage layer in the ground.

4. Methodology

Three research methods of qualitative approach were used - online journal, forum discussion and e-mail interview. 35 topics of online journal (issue January 2007 until May 2012) about the strategies of stormwater management on http://www.stormh2o.com were studied. Besides, on Google group forum discussion - http://groups.google.com/group/rainwater-in-context, a topic on strategies of stormwater management was posted. Four respondents had responded and sent 8 attached links of documents. Also, twenty correlated topics on the forum discussion were reviewed. Moreover, eight respondents had replied the e-mail interview and thirteen documents were attached as references. In seeking the interaction within the collected data to identify the strategies of sustainable stormwater management, grounded theory was applied as the strategy of inquiry (Creswell, 2003; Glaser & Strauss, 1999; Charmaz, 1994). For data analysis, five progressive steps of descriptive comparative analysis were used (Creswell, 2003) (Figure 1).

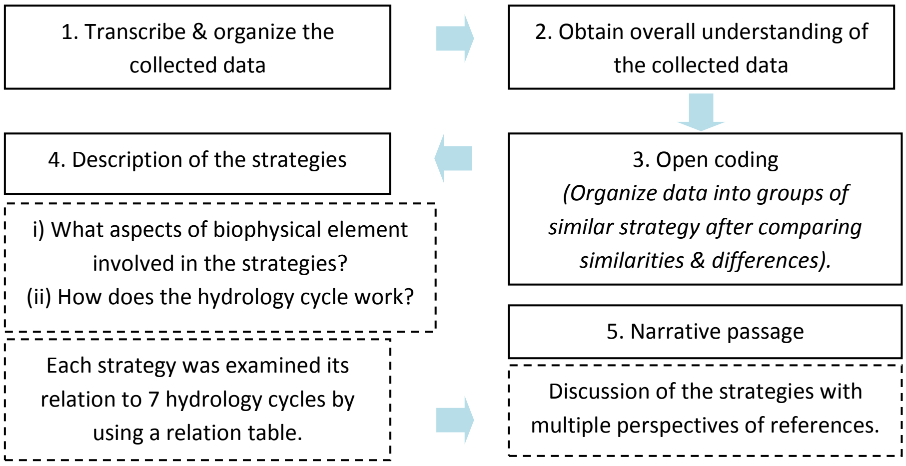

Figure 1: Five steps of descriptive comparative analysis
(Source: Creswell, 2003)

5. Result and Discussion

After the analysis, 17 strategies have been identified. The first strategy is stream reclamation. Reclamation is about restoration of natural ecosystem of the stream to manage the stormwater. Part of stream reclamation is stream daylighting. It is a strategy to remove the covered drain and to allow the sunlight to penetrate the stream ecosystem to function (Ferguson, 1991). Stream reclamation is related to six hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow. Interception and evapotranspiration function through inland and aquatic vegetation and stream surface. Surface runoff and depression storage function through topography, slope and stream water body, while infiltration and groundwater flow function through vegetation root system and soil permeability. However, interflow cannot function because the layer of vadose storage in the soil has lost. As stated by Stephens and Dumont (2011), in developed area, vadose storage layer has lost because it has been removed during construction work such as digging and insertion of pipe and drain.

The second strategy is tree canopy cover which is about planting big tree. Tree canopy cover is related to three hydrology cycles - interception, infiltration and evapotranspiration (University of Arkansas Community Design Center, 2010; Oberholtzer, Farr, Richart & Hughes, 2009; Ferguson, 2002). Interception and evapotranspiration happen through foliage and branches of tree, while infiltration happens through root system of the tree.

The third strategy is porous pavement. Porous pavement replaces the impervious cover of conventional pavement. This is to allow the stormwater to infiltrate into the ground (Beyerlein, 2012; Ferguson, 2004, 2002 & 1996). Porous pavement is related to infiltration and groundwater flow which happen through permeability and saturation of soil property, while interflow cannot happen in developed area (refer to Stephens and Dumont (2011)) as explained in the first strategy.

The fourth strategy is vegetated surface channel. This strategy is to replace the concrete drain where it uses vegetation for phytoremediation process in filtering the contamination of stormwater. Vegetated surface channel is about disconnecting the impervious cover to the pervious cover and directing stormwater into vegetated surface channel (Beyerlein, 2012; Beatt, 2011; Brzozowski, 2007; Ferguson, 2001). This strategy is related to six hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow. Interception and evapotranspiration function through the vegetation and channel surface. Surface runoff and depression storage function through the topography, slope and linear depression of the channel. Lastly, infiltration and groundwater flow function through the vegetation root system and soil.

The fifth strategy is rainwater harvesting. It is about collecting rainwater from the roof into rain barrel and to be used later especially for watering the plant (University of Arkansas Community Design Center, 2010; Brzozowski, 2007; Ferguson, 1996). This strategy is related to six hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow. Interception refers to collecting and directing rainwater through rooftop and gutter into a rain barrel. Infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow refer to the reuse of harvested rainwater.

The sixth strategy is infiltration basin. Toronto and Region Conservation (2010) and Marsh (2005) mentioned about the preservation or creation of micro-topography (depressed landform) to create detention or retention basin. This is to store the collected stormwater and discharge the stormwater into the ground and to evaporate slowly. Infiltration basin is related to seven hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration, interflow and groundwater flow. Interception and evapotranspiration happen through the vegetation and water surface of the basin. Surface runoff and depression storage happen through the topography, slope and landform depression. Infiltration, interflow and groundwater flow happen through the vegetation root system and soil. All hydrology cycles will function if it is a natural basin. However, if the basin is a constructed basin, the interflow cannot function (refer to Stephens and Dumont (2011)) as explained in the first strategy.

The seventh strategy is disconnection of impervious area. Marsh (2005) and Hager (2003) stated that this strategy refers to redirect stormwater to a vegetated area and to reduce the continuity of stormwater flow. Infiltration, surface runoff and groundwater flow are related to this strategy. Surface runoff functions through the topography and slope. Infiltration and groundwater flow function through the vegetation and soil within the pervious area.

The eighth strategy is green roof. Green roof strategy is to reduce the impervious surface of the rooftop and to beautify the city where limited space is available for the green area (Beyerlein, 2012; Ferguson, 1996). Green roof is related to interception, evapotranspiration and infiltration. Interception and evapotranspiration happen through the vegetation while infiltration happens through the growing medium (soil base) of the green roof modular. However, the infiltration is very limited and researchers have categorized it as absorption.

The ninth strategy is soil modification. This strategy is pertinent to repair the compacted and damaged soil in the urban area for a healthy growth of plants. It is also to improve the subsurface of hydrology cycles - infiltration and groundwater flow. Likewise, it improves the infiltration capacity through the soil pores, and recharges the groundwater table (Thomas, 2011; Westhelle, 2011; Beatty, 2008; Brzozowski, 2007; Ferguson, 2004). Soil modification is related to infiltration and groundwater flow which happen through the soil permeability. Unfortunately, interflow cannot happen because the vadose storage layer of the soil has lost (refer to Stephens and Dumont (2011)) as explained in the first strategy.

The tenth strategy is stormwater wetland. Roseen, Ballestero, Houle and Watts (2012), Buranen (2009) and Ferguson (2002) stated the function of wetland is to manage the stormwater in terms of removal of nutrients, bacteria, fine, sediment and heavy metals. Stormwater wetland is related to five hydrology cycles - interception, infiltration, depression storage, evapotranspiration and groundwater flow. Interception and evapotranspiration function through the inland and aquatic vegetation and the water surface of the wetland. Infiltration functions through the vegetation root system and soil base of the wetland. Depression storage functions through the concave depression of the wetland. Groundwater flow functions through the underground soil of the wetland.

The eleventh strategy is barrier system. Similar strategy was described by Marsh (2005) using the term filter berm and infiltration trench. Barrier system functions in containing and filtering the contaminants of stormwater (Boller, 2004). Relation of the barrier system to the hydrology cycle can be divided into two. First is a barrier system that directs the stormwater into natural depression which is related to seven hydrology cycles. Interception and evapotranspiration occur through the vegetation and surface of the barrier system. Infiltration, interflow and groundwater flow occur through the subsurface of soil and vegetation root system. Surface runoff occurs through the topography and slope where the stormwater flows into the depression area of the barrier while depression storage occurs within the depression landform of the barrier that retains and filters the stormwater. The second category of a barrier system is constructed within the existing developed area. The interflow cannot occur because the absent of the vadose storage layer of the soil.

The twelfth strategy is narrow street. Toronto and Region Conservation (2010) and Hager (2003) stated that the narrow street strategy encompasses the reduction of impervious cover of the street and its components – lane, length of the parking stall and drive aisle. The pervious cover then are to be integrated with the stormwater strategies - swale, planter, vegetated buffer strip, rain garden, infiltration trench, dry well, permeable paving, channel, runnel, screen, inlet insert and pipe filter (Australian and New Zealand Environment and Conservation Council, 2010; Marsh, 2005; Hager, 2003; CIRIA, 2001). The narrow street is related to six hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow. The interception and evapotranspiration happen by the plants within the stormwater strategies – swale, planter, buffer strip, rain garden and others. The infiltration and groundwater flow happen by the soil of swale, planter, vegetated buffer strip, rain garden, infiltration trench, dry well, permeable paving, channel and runnel. The surface runoff flows within the gradient slope of the swale, vegetated buffer strip, channel and runnel. Lastly, the depression storage happens by the depression landform of the swale, planter, vegetated buffer strip, rain garden, infiltration trench and dry well.

The thirteenth strategy is rain garden. Beyerlein (2012) and Hager (2003) mentioned that in rain garden strategy, soil and plants are used to slow, absorb and filter the stormwater. Rain garden functions as a collective area to retain the stormwater and filter the pollutant via phytoremediation process by the plant and soil. The rain garden strategy includes six hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow. The interception and evapotranspiration happen by the foliage of plants. The infiltration and groundwater flow happen by the soil of the rain garden. The surface runoff flows along the edge slope of the rain garden and collected within the depressed landform of the rain garden where the depression storage occurs.

The fourteenth strategy is greenway. The greenway strategy as mentioned by High (2010), University of Arkansas Community Design Center (2010) and Aird (2008) is a combination of several stormwater strategies in forming an interconnected stormwater strategies. Two categories of greenway have been classified by researchers. First is a conservation of the pristine hydrology ecosystem such as stream buffer and flood plain. Second is a restoration of the hydrology ecosystem and combination with other stormwater strategies. Thus, the relation of greenway to the hydrology cycles can be divided into two, based on its category. The first category, the conserved pristine hydrology ecosystem is related to seven hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration, interflow and groundwater flow. The interception and evapotranspiration occur by the plant communities. The infiltration, interflow and groundwater flow occur by the subsurface of soil and root system of plants. The surface runoff flows along the gradient slope of the fringe landscape of the greenway that directs the stormwater into the lowest depression of the greenway. Lastly, the depression storage occurs within the lowest landform of the greenway to retain and filter the collected stormwater. The second category, the restored hydrology ecosystem with other stormwater strategies is related to six hydrology cycles - interception, infiltration, surface runoff, depression storage, evapotranspiration and groundwater flow. The interflow is not occurring because of the absence of the vadose storage layer in the soil.

Lastly, priority orders of strategies were listed based on the highest relationship of the strategies with the hydrology cycles (Table 2).

Table 2: Relationship of hydrology cycles with the strategies of sustainable stormwater management.

Strategies	**Hydrology cycle**	**Interception**	**Infiltration**	**Surface runoff**	**Depression storage**	**Evapotranspiration**	**Interflow**	**Groundwater flow**
1. Infiltration basin								
2. Barrier system (with natural soil depression / channel)								
3. Greenways (with conservation of natural hydrologic landscape)								
4. Stream reclamation								
5. Vegetated surface channel	**Relation**							
6. Rainwater harvesting								
7. Infiltration basin (man-made basin)								
8. Barrier system (without natural soil depression or channel; man-made / restored)								
9. Narrow street								
10. Rain garden								
11. Greenways (without conservation of natural hydrologic landscape / restored)								
12. Stormwater wetland								
13. Tree canopy cover								
14. Green roof								
15. Disconnection of impervious area								
16. Porous pavement								
17. Soil modification								

Legend:

Similar strategy with yellow colour code but **with** the present of natural / undisturbed biophysical elements

Similar strategy with green colour code but **without** the present of natural / undisturbed biophysical elements (retrofit, restored, man-made)

The strategy have a relation with the hydrology cycle

White colour in the column of hydrology cycle
The strategy does not have a relation with the hydrology cycle

6. Conclusion

In conclusion, a sustainable stormwater management is crucial for a sustainable environmental planning and design. A sustainable stormwater management can be achieved by connecting the strategies of the stormwater management with the hydrology cycles. The hydrology cycles become the fundamental understanding in planning and designing the strategies of stormwater management. The precise basis of stormwater strategies that are based on the scientific knowledge of hydrology cycle can provides clear information to the professionals involved in stormwater management. Likewise, sustainable stormwater strategies can benefit not only in managing the stormwater issues, but provides additional benefit to the society with the beauty of the landscape area and nature.

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