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Best Management Practices for Sustainable Urban Stormwater Management in Uganda

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Abstract—*traditionally, urban storm-water runoff is considered a nuisance that needs to be ridded of immediately. Urbanization creates impervious surfaces leading to increase of runoff from rainfall and cities have to grapple with flood as the cities develop with time. Additionally, urban activities generate numerous pollutants that are washed off during storm-water runoff leading to water quality degradation of the receiving bodies of water. Storm-water best management practices (BMP) are structural and non structural measures or controls that are used to manage the qu8antity and/or improve the quality of storm-water runoff in the most cost effective manner. Structural measures includes: wetlands, swales, sand filters, porous pavements, dry wells, retention and detention basins. Non structural measures include: land use planning, flood plain management, street sweeping, household waste recycling, erosion control at construction sites and public awareness. The paper concluded by advocating the use of these techniques to polity makers, in developing countries, due to their numerous advantages such as flood control, pollutants removal, soil conservation etc. Engineers and technologist have to play a key role in the proper design, construction and maintenance of these systems that are environmentally friendly.*

Keywords—best; management; practices; sustainable; urban; storm-water; management; retention; detention; runoff

1. INTRODUCTION

Disruption of natural water cycle is caused when land is developed. Clearing of land surface reduces the evaporation and transpiration processes that intercept, slow and return rainfall to the air. Depression storage is filled-up; top soil is removed while subsoil is compacted. The construction of impervious surfaces further reduces infiltration and increases runoff. Rainfall that used to infiltrate the ground now runs-off the surface (Steg, 2010) Reference [1]. The total runoff volume now increases dramatically depending on the magnitude of changes to the land surface. These changes cause an increase in the total volume of runoff and accelerate the rate at which runoff flows across land surface.

This effect is further aggravated by artificial drainage systems that are designed to convey runoff to rivers as quickly as possible (McCuen, 2004 Reference [2]; Guo, 2001 Reference [3]). The volume of water infiltrating into the soil is reduced with the development of imperious surfaces, thus reducing the quantity of water available to recharge aquifers and feed-in the base-flow during dry weather period (GSMM, 2001) Reference [4].

In addition to affecting the runoff quantity, urbanization also affects the runoff quality by increasing the concentration of pollutants carried by the storm-water (Methods and Durrans, 2003) Reference [5]. As runoff runs over rooftops, roads, parking lots, domestic, commercial and industrial areas, it picks up a variety of pollutants and transports them to downstream water bodies. The receiving water body is affected by the cumulative impact of urban activities from the entire watershed that drains a stream, and the resultant changes from both storm-water quantity and quality is felt in the downstream waters (Segarra-Garcia and Loganathan, 1992 Reference [6]; Jeng et al., 2005 Reference [7]). Urbanization within a watershed has a number of negative impacts on downstream waters. These impacts include: changes of stream flow and stream geometry, degradation of aquatic habitat caused by water quality impacts (GSMM, 2001 [4]; KCTSMM, 2008 Reference [8]; Steg, 2010 [1]).

2 Historical Perspective Of Urban Storm-water Management

According to Buran et al, (1999) Reference [9], storm-water management could be traced back to history when ancient civilizations grappled with flood prevention and waste disposal in their cities of stone and bricks, long before engineering was recognized profession. Around 3000BC, industrial civilizations construct combined sewers consisting of simple sanitary sewer system with drains to remove storm-water from streets. Other ancient sewer system were constructed by the Mesopotamian empire in Assyria and Babylon (2,500BC) and the Minoans on the island of Crete (3,000-1,000BC), Jerusalem (Circa 1,000BC) and Etruscans around 600BC. Partial underground systems were found around 200AD in ruins of major cities in China. Other examples of ancient sewerage system include the Macedonians, Greeks, under the rule of Alexander the Great and the Persians (Butler and Davies, 2004) Reference [10]. After the Greeks, the cities and towns were taken by the Romans. The Romans were the first to build a carefully planned road system with drained surface in Europe and western Asia from antiquity to the nineteenth century. Specific drainage facilities used by the Romans included the occasional curbs and gutters to direct surface runoff into open channels along the roadways. The channels collected not only the storm-water runoff from road way surfaces, but also sanitary and household waste.

Between 14th and 19th century, there was resurgence in the development of planned sewage system from the disjointed ones of the middle age. The sewers constructed in Europe were simply open ditches and besides conveying storm-water, they became receptacles for trash and other household sanitary wastes which accumulates and causes overflows. To overcome this problem, the channels were covered to form combined sewers (Debo and Reese, 2003) Reference [11]. At the end of 1700s, the outlook was improving for wet weather flow management in Europe. Through the 1800s, society held a brief in progress that is linked to technology. Until the 1820s, European sewers were constructed of cut stones or bricks that contributed to the deposition problems. These were substituted with milestones and cement mortar, thus improving the self cleaning properties and hydraulic efficiency. A variety of new pipe shapes emerged and in the early 1800s, there increase attention to sewer maintenance and the adoption of minimum slope and velocity criteria to provide for flushing during the dry weather period (Burian et al, 1999) Reference [12].

The use of empirical models for the estimation of surface runoff started in the middle of 1800s; among the tools being used include the ill-founded Roes table, Talbot’s formula, among others. The inclusion of meteorological variable in runoff estimation started with the appearance of rational formula during this era (Adams and Papa, 2000) Reference [13]. In the second half of 19th century, hydraulic and hydrologic methods of storm-water conveyance estimation were enhanced through researchers. By the middle to latter part of the twentieth century, US soil conservation service had developed simple but effective methods for runoff estimation for both rural and urban areas (Burian et al.,1999) Reference [12] which was used as models to for design and construction of the storm-water runoff control in Kampala and the artificial reservoirs constructed at the lake Victoria (Entebbe). The development of a digital computer brought about rapid advancement in technical tools and methods for wet weather flow management. The decade of the 1960s witnessed the integration of the hydrologic cycle and simulation of the entire watershed. The computational capabilities of computers enable the engineers to not only design the systems but also to optimize the design through the use of advanced mathematical optimization techniques (Singh and Woolhiser, 2002) Reference [14].

The recognition of the impact of storm-water runoff on receiving water bodies has been the subject of interest and debates in the past few decades. Methods for the control and treatment of urban storm-water have evolved. Among the methods are physical, chemical and biological treatment processes and storage and treatment combinations. Presently, attention is focused on best management practices (BMPs) to control urban storm-water runoff and pollution. The systems being used include swales, porous pavements, dry wells, wetlands, retention and detention basins (DID, 2000 Reference [15], Davis and Birch, 2009 Reference [16],, Urbonas and Glidden, 1983) Reference [17].

3 STORMWATER BEST MANAGEMENT PRACTICES

Storm-water best practices (BMPs) are techniques, measures, or structural controls that are used for a given set of conditions to manage the quantity and/or improve the quality of storm-water runoff in the most cost-effective way (USEPA, 1999a) Reference [18],. There are two basic/main types of storm-water BMPs; these are structural and non-structural storm-water.

- **Structural storm-water BMPs**

These are designed facilities or modified natural environment that help control the quantity as well as improve the quality of urban storm-water. These include various kinds of storm-water ponds, filtration practices, vegetated channels practices, catchment areas and wetlands.

- **Non Structural storm-water BMPs**

These consist of administrative, regulatory or management practices that have positive impacts on NPS runoff (Sharma, 2006) Reference [19]. These are techniques that include land use planning, advocating the proper use of fertilizers or pesticides, flood plain management, street sweeping, and providing information to people to enable them to reduce stormwater pollutants by changing their daily habits, household waste recycling etc. These are less expensive and quite important in the management of stormwater runoff pollution. Howbeit, their effectiveness is not guaranteed as performance depends on the compliance of the recommendations given by the supervisory persons (FHWA, 2006) Reference [20].

Martin et al (2007) Reference [21], conducted a survey to evaluate some BMPs (i.e. detention basins, retention basins, below ground storage tanks, chambers, swales, roads or car parking lots with reservoirs structures, infiltration trenches, over-roof storage and soakaways) with preference to their performance. Results indicates the performance indices such as hydraulic efficiency, pollution retention, operation and maintenance, economic investment, environmental impact, social and sustainable urban living are among the factors influencing the choice of a given BMP. Moreover, the preferences of stakeholders vary according to the different management strategies and vested interest.

Weiss et al (2007) Reference [22], used a 20 years historical data to assess and compare the cost and effectiveness of some of the BMPs in terms of TSS and phosphorus removal efficiencies. The BMPs compared were: wet basins, dry extended detention basins, constructed wetlands, sand filters, infiltration trenches and bio-retention filters. Results show that if land cost is ignored, constructed wetlands are the least expensive. However, land acquisition cost in urban areas could make constructed wetlands more expensive. BMPs being used all over the world are presented as follows below:

3.1 Storm-water wetlands

These consist of a combination of plants and water in a shallow pool designed to both treat and control urban stormwater runoff (Carter, 2005) Reference [23]. Wetlands can be natural or constructed. Constructed wetlands have less biodiversity than natural wetlands (SMRC, 2003) Reference [24]. Wetlands are a widely applied stormwater treatment practice but have limited applicability in highly urbanized areas due to space constraints (Weiss et al., 2007) [22],. They use biological and naturally occurring chemical processes in water and plants to remove pollutants and also help to control the peak flows of a storm event (FHWA, 2006 [20],; Wong et al., 1999) Reference [25]. They also act as pollutant removal systems through vegetative filtering and gravitational setting in the slow moving marsh flow. Stormwater wetlands treatment possesses also include chemical and biological decomposition, and volatilization (Matthews, 2002 Reference [26],; Wong et al., 1999 [25]). Compared to wet ponds; wetlands are relatively shallow, with higher evaporation rates, making it more difficult to maintain the permanent pool of water. Matthews (2002) [26], assessed the functions of a wetland on a forested floodplain of South Buffalo creek, US and found that 1092-1639 g/m^2/yr TSS removal, 15 g/m^2/yr nitrogen removal, 1.5 g/m^2/yr phosphorus removal is obtainable.

3.2 Filtration Practices

Filtration practices are surface or underground practices that reduce the volume of surface runoff and allowing it to infiltrate through the soil (NCHRP, 2003) Reference [27]. They provide performances that are independent of local conditions and have designs available for roadsides and congested urban applications. According to FHWA (2006) [20], bio-retention cells and sand filters are filtration practices commonly used for small to medium catchment basins because their area usually occupies only about 2 to 3% of the drainage area and hence suitable in dense urban setting. Sand and gravel filters are also commonly used filtration practices for the management of urban stormwater (Blazejewski and Murat- Blazejewska, 2003) Reference [28]. Other infiltration practices include pervious pavements etc.

3.3 Bio-Retention Cells

Bio-retention are shallow landscaped depressions, commonly located in parking lots or within residential land-uses designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. Stormwater treatment in a bio-retention cell is achieved through sedimentation, filtration, soil adsorption, micro-biological decay processes, and the uptake of pollutants by plants (Weiss et al., 2007) [22]. Components of bio-retention area include a grass buffer strip, planting soil, plant material, a pounding underground sand bed, an organic layer, and infiltration chamber chambers (VASM, 1999) Reference [29],.

A bio-retention cell uses an organic media filter for treatment purpose. The coarse sediments are captured and removed first bed in order to reduce the likelihood of clogging. Bio-retention cells are designed with an under-drain system, a perforated pipe in a gravel layer placed along the bottom of the bio-retention cell, to collect filtrated runoffs and direct same to the stormwater drain system (FHWA, 2006) [20]. Untreated runoffs from large storms are conveyed from the cells through an overflow structure to the stormwater drain system. The drainage areas of a bio-retention call should ideally be to five (5) acres or less, as larger areas tend to clog cells and have problems with conveyance to flow. They are generally applied to areas which have gentle slopes, but sufficient slope is required to ensure that the runoff that enters a bio-retention area can be connected with the stormwater drain system (SMRC, 2003) [24]. Bio-retention ell, with its trees and shrubs, provide an aesthetic value to the community and reduce stormwater runoff. They can be designed to control both quality and quantity of run-offs (USSBMP, 2001) Reference [30].

3.4 Pervious Pavement

These consist of pavements made with porous blocks or a layer of porous asphalt that permits water to infiltrate through them. Pervious pavements may also be made from impervious blocks that are fit in such a way that water can pass between them. They can be used in surface with light traffic or at car parks. The infiltration rate through the pavement may be as high as 1000mm/hr in new development although this value may reduce to 10% of the original value over the life of the pavement (Butler and Davies, 2004) [10].

3.5 Sand Filters

These are structures constructed in underground vaults, paved trenches at the perimeter of imperious surfaces, or in either earthen or concrete open basins. They are multi-chambered structure designed primarily for quality treatment through filtration

(Weiss et al., 2007) [22]. They have a sand-bed as its primary filter media to remove the finer sediments which escape the fore-bay. They also have an under-drain collection system to carry the runoff to the stormwater drain.

Modifications of the basins sand filter design include surface sand filter, perimeter sand filter, and underground sand filter. Sand filters may be constructed in underground vaults, paved trenches at the perimeter of impervious surfaces, or in either earthen or concrete open basins (VASM, 1999 [29]; GSMM, 2001 [4]).

Surface sand filters can have a drainage area of up to 50 acres while perimeter and underground sand filters are best suited for small sites with a drainage area of about 2 acres (USEPA, 1999a) [18].

Flat terrain might be suitable for perimeter sand filters but other types require a significant drop in elevation to allow the runoff to flow through the filter. Per-treatment, treatment, proper conveyance and landscaping are basic design features in all types of sand filters. Filtering practices, except the perimeter systems, are designed as off-line systems, having only a small amount of the stormwater runoff diverted to them using a flow splitter, which is a structure that bypasses larger flows to the stormwater drain system. Sand filters are generally applied to land uses containing a high percentage of impervious surfaces, as less than 50% imperviousness or high clay/silt sediment loads tend to clog the filter bed. The entire treatment system of the surface sand filter must temporarily hold at least 75% of the stormwater runoff prior to filtration. Sand filters may be surface or underground. Unlike bio-retention cells, the primary function of sand filters is to provide water-quality improvement (Blazejewski and Murat-Blazejewska, 2003) [28].

3.6 Vegetable Open Channel Practices

These are system explicitly designed to treat stormwater runoff in a swale or channel formed by check dams or other means. They usually do not provide quantity control and are combined with other stormwater BMPs to meet regulations. These practices directly receive runoff from an impervious surface and have a temporary pounding time of less than 48 hours and a 6 inches drop onto a protected shelf to minimize the clogging potential of the inlet (GSMM, 2001) [4]. Two different types of vegetated open channel practices include grass swales (dry/wet) and grass channels.

3.7 Grass Swales

According to SAARC Meteorological Research Centre (SMRC) (2003) [24], grass swales are broad, shallow earthen channels designed to treat stormwater runoff using erosion resistant and flood tolerant grasses. Filtering in these practices occurs through vegetation, a subsoil matrix, and infiltration into the underlying soils. Grass swales have small longitudinal slopes with check dams installed perpendicular to be slow and allow the particulates to settle. There are two types of grass swales, dry swales having a filter bed of prepared soil that overlay an under-drain system and wet swales designed to retain moisture conditions that support wetland vegetation (USEPA, 1999a) [18].

Grass swales work best when used to treat small drainage areas of less than five acres with relatively flat slopes. They do not function well in low to moderate density single family residential developments with high volumes and velocities of stormwater because the velocity becomes too great to the runoff in the channel. Therefore, they have limited application in highly urbanized areas, unless used as pre-treatment facilities for other BMPs (VASM, 1999) [29]. Other than flat slope and preferably parabolic or trapezoidal cross sections, grass swales should have dense vegetation to help reduce flow velocities, protect the channel from erosion, and act as a filter to treat stormwater runoff. Swales are usually designed for a 2-years storm event, although they can have the capacity to pass large storms (SAARC Meteorological Research Centre (SMRC)USSBMP, 2001 [30]; Georgia Stormwater Management Manual (GSMM), 2001) [4].

3.8 Grass Channel

Grass channels are pre-treatment practices that provide nominal treatment because they lack the filtered media present in the filter media present in the grass swale. They act by partially infiltrating runoff from small storm events in areas with pervious soil and are therefore best applicable to other structural stormwater BMPs (SMRC, 2003) [24].

They help in reducing the impervious cover and provide aesthetic benefits. Grass channels are designed on relatively flat slopes of less than 4% with infiltration rates greater than 0.27 inches per hour. The stormwater runoff takes 5 minutes on average to flow from the top to the bottom of the channel. For efficient usage, the channels should be used to treat small drainage areas of less than 5 acres and the grass of the channels should be maintained at a height of 3 to 4 inches for the effective removal of particles (GSMM, 2001) [4].

3.9 Detention Ponds

Stormwater detention is the temporary storage of runoff in ponds, basins, or depression and even underground containers meant to control the quantity as well as quality of runoff at the downstream of a catchment (Gayer, 2004 Reference [31]; Paine and Akan, 2004 Reference [32]). Stormwater detention is necessary in new developments because of the increased volume of runoff caused by the increased imperious area such as roads, roofs, sidewalks, etc (Comings et al., 2000) Reference [33]. Increase surface runoff from the urban catchment typically increases the chances of flooding to downstream conveyance structures posing risk to downstream properties. Excess runoff collected in a controlled manner such that downstream flooding and other adverse impacts are prevented or at least migrated (Gribbin, 2002) Reference [34]. Shokoohi (2007) Reference [35] indicted that the incorporation of a detention facility at the upstream of a catchment could reduce the cost of downstream conversional river engineering flood control measures by as much as 40%. In stormwater detention, runoff hydrograph from the catchment area is channeled to the detention pond and the runoff is then released from the pond through a properly sized outlet structure at a controlled rate. This results in the outflow hydrograph from the pond that is considerably flatter than the inflow hydrograph (Methods and Durrans, 2003) [5].

3.10 Other Structural BMPs

Others types of stormwater BMPs include infiltration trenches, dry wells, green roofs, rain barrels, cisterns, artificial marshes, recharge basins, oil/greet separators, catch basins, etc (Tsihrintzis and Hamid, 1997 Reference [36]; Sayre et al., 2006; American Water Works Association (**AWWA**), 2000 Reference [37]; Butler and Davies, 2004 [10]; Perez-Pedini et al., 2005) Reference [38].

3.11 Non Structural Practices

According to US Environmental Protection Agency (USEPA), (1999b) Reference [39], non-structural stormwater BMPs are institutional and pollution prevention practices designed to prevent or minimize pollutants from entering stormwater runoff and/or reduce the volume of stormwater requiring management. The practices work by changing the behaviour of people through government i.e. enabling acts of the Uganda Peoples Parliament in conformity with the presidential assent and execution and do not involve physical facilities. They include the following (Wong and Tailor, 2002 Reference [40]; Butler and Davies, 2004 [10]; Bottcher et al., 1995 Reference [41]):

- Land use planning in-view developments to promote decreasing imperviousness
- Flood plain management
- Street sweeping to reduce the accumulation of pollutants in the catchment areas.
- Household waste recycling
- Erosion control at hither regions and construction sites
- Public awareness on effects of NPS pollution
- Fertilizer and pesticides application control etc.

4 Conclusion

In this paper, various stormwater BMPs commonly used for the treatment and control of urban stormwater have been indicated. The technique are natural and thus offers a whole lots of benefits ranging from groundwater recharge, flood control, stormwater pollutants removal, soil and ecosystem conservation at the least cost. Adopting BMPs in developing nations like Uganda will go a long way in addressing these issues. The systems are environmentally friendly and cheap.

Therefore, it is recommended that the policy makers like the Uganda Peoples Parliament and the Presidency need to work cordially to formulate workable policies and provide platforms to be given so required knowledge on the benefits of BMPs so that they can be able to incorporate same into the required town planning acts and laws. Engineers and Technologists should be encourage to play key roles in BMPs policy formations, designs, constructions, operations and maintenance, so as to be able to achieve the required aim and goal of implementing the practice of BMPs in Uganda as a nation.

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