Stormwater treatment and reuse techniques: A review

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Abstract: - The elementary importance of improved management of stormwater for urban centres, irrigation, industrial, domestic, and stock uses across the world cannot be overemphasised. This paper presents a review of the available stormwater treatment and reuse techniques and introduces a new technology known as 'Green Gully' that collects, purifies and reuses stormwater throughout an automated network system. A comparative study of available treatment measures with respect to advantages, disadvantages and pollutant trapping efficiency is presented and discussed. This paper also highlights the current stormwater reuse techniques to reduce the water crisis. Conclusions based on a comparative study of stormwater treatment measures and reuse techniques are presented, which will be useful for stormwater researchers, planners and stormwater management in general.

Key-Words: - Stormwater management, Stormwater treatment, Stormwater reuse, Water restriction, Road Gully, Green Gully.

1 Introduction

'One person in six lives without regular access to safe drinking water; over twice that number—2.4 billion—lack access to adequate sanitation' (Kofi Annan, secretary-general of the United Nations (UN)) [1]. Globally, water supplies are unevenly distributed. Some countries experience a plentiful water supply. Other's experience severe water shortages. A 1997 UN assessment of freshwater resources found that one-third of the world's people experience moderate to high water stress. Moderate water stress levels are said to occur when water consumption exceeds renewable freshwater supply by 10 per cent. The problems are most severe in Africa and west Asia. The UN expects the global water situation to get considerably worse over the next 30 years. It estimates that by 2025 the proportion of the world's population experiencing moderate to high water stress will rise to two out of three people [2].

The recent drought in Australia and concerns about climate change has highlighted the need to manage water resources in a more sustainable manner. Expanding the use of stormwater to add to the water supply and reduce water pollution are important objectives in the face of the water crisis. Stormwater is now acknowledged as a valuable resource, rather than an irritation to be disposed of quickly, especially in large urban centres. Over recent years, stormwater harvesting and reuse have emerged as new fields of sustainable water management. Harvesting and reusing stormwater offers both a potential alternative water supply for non-drinking uses and a means to further reduce stormwater pollution in our waterways. Rapid population growth, emerging contaminants, aging infrastructure, urbanisation, and increased concerns about water quality are all factors emphasising the importance of stormwater treatment for reuse, the method of which depends on the reuse category.

Stormwater harvesting and reuse can be defined as the collection, treatment, storage and use of stormwater run-off from urban areas. The characteristics of stormwater harvesting and reuse schemes vary considerably between projects, but most schemes have the following elements in common [3]:

Collection. Stormwater is collected from a drain, creek or pond.

Storage. Stormwater is temporarily held in dams or tanks to balance supply and demand. Storages can be on-line or off-line (constructed on, or some distance from the creek or drain).

Treatment. Captured water is treated to reduce pathogen and pollution levels, and hence the risks to public health and the environment, or to meet any additional requirements of end-users.
Distribution. The treated stormwater is distributed to the area of use.

Treatment is the most important issue before reuse of stormwater for any purpose. A hierarchy of stormwater treatment levels based on the dominant treatment processes are: (1) Primary, (2) Secondary, and (3) Tertiary level treatment. Generally, the greater the level of treatment the greater the reduction in pollutants, and the less restrictions there are on the potential reuses. Primary treatment normally involves screening out gross pollutants and sediment to remove coarse particulate matter. Secondary treatment removes organic matter and lighter solids by biological and mechanical means. Tertiary treatment removes nutrients and finer suspended particulate matter by one or more means, including: carefully-controlled biological processes, chemical processes, and filtration [4]. In most situations, the use of a combination of different treatment measures that reduce pollutants through different processes should provide the best overall treatment of runoff [5].

This paper compares primary level treatment measures with respect to their advantages, disadvantages and pollutant-trapping efficiency. A new technology called ‘Green Gully’, which collects, purifies and reuses stormwater through an automated system, is introduced. Reuse techniques that are outlined in the literature are discussed.

2 Stormwater Treatment Measures: A Comparative Study

Stormwater treatment is only one of a number of factors that should be considered in stormwater management. Other factors include streamflow, and riparian vegetation and aquatic habitat management. Further, the context of stormwater quality management can be based on the following hierarchy [5]:
Preserve and restore (if required) existing valuable elements of the stormwater system (e.g. natural channels, wetlands, riparian vegetation).
Manage the quality and quantity of stormwater at or near the source, which will involve a significant component of public education and community involvement.
Install ‘structural’ stormwater management facilities, such as stormwater treatment measures and retarding basins, for water quality and stream flow control.

The stormwater treatment system should be based on some key considerations [3], including:

- Adopting stormwater quality criteria that: (a) minimises public health risks for the adopted public access arrangements, (b) minimises environmental risks and (c) meets any additional end-use requirements.
- Designing appropriate stormwater treatment techniques to meet the adopted objectives.

Among several stormwater quality improvement devices (SQIDs), a road gully is one of the devices that is installed in the road to direct stormwater from the roadways into a storm drainage system. Generally, stormwater from roads is directed to gutters and passed through stormwater drains. Green Gully (shown in Figure 1) is an upgraded and extended type of road gully.The Green Gully provides a vital role in stormwater collection and reuse. Green Gully resides in a road gully drainage unit for directing water from a road gutter. The main objective of the Green Gully is to collect rain or stormwater, make it suitable for irrigation, and provide an automated network system to water roadside plants and irrigate land. The Green Gully includes a gully grate or a runnel with a V-shaped base wall for filtering litter from the stormwater before the stormwater enters the diverter channel. The irrigation unit of the Green Gully includes a pathway for the flow of stormwater in order to irrigate plants grown in the vicinity of the irrigation unit. The irrigation system includes a self watering system for irrigating an area (like a park) utilising stormwater from roadways. The working principal of the Green Gully is divided in two parts. First, diverting stormwater from roadways to a diverter channel by filtering litter and second, watering road side plants with the stormwater that is collected from the diverter channel [6]

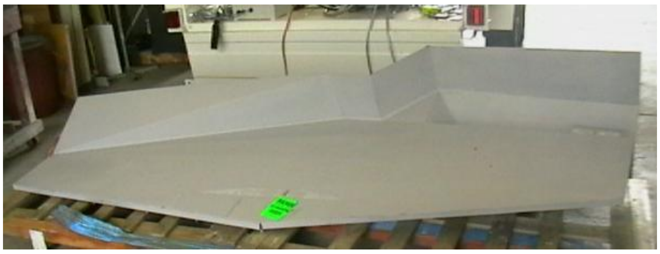

Figure 1: Green Gully

Table 1 presents a comparative study of available stormwater treatment methods and techniques (including Green Gully). For each technique, a description, advantages, disadvantages and an assessment of its pollutant trapping efficiency are included [3, 4, 6, 7].

Table 1: A Comparative study of stormwater treatment measures

Treament Measures	Description	Advantages	Disadvantages	Pollutant Trapping Efficiency
Litter Baskets and Pits	A wire or plastic ‘basket’ installed in a stormwater pit to collect litter from a paved surface (litter basket) or within a piped stormwater system (litter pit).	a) Can be retrofitted in existing areas with high litter loads b) Low downstream maintenance c) Installed underground to minimise visual impacts. d) Litter basket are applicable for small areas (<1–2 ha) and pits can be used for larger catchments (150 ha)	a) Potential for litter pits to aggravate upstream flooding if blocked by litter and vegetation b) Potential for litter baskets to reduce pit inlet capacity if located close to inlet c) Hydraulic head loss occurs for litter pits d) Potential loss of pit inlet capacity due to litter basket on steeper slopes	Litter: M Oxygen demanding material: M Sediment: L Oil & grease: N Nutrient: N Bacteria: N
Trash / Litter Racks	Litter racks (or trash racks) are a series of metal bars located across a channel or pipe to trap litter and debris.	a) Can be used to trap litter upstream of other stormwater treatment measures b) Appropriate for retrofitting into existing areas c) Low downstream maintenance d) Applicable for areas between 8 and 20 ha	a) Racks have a tendency to be blocked by debris b) Collected litter can move upstream along a tidal channel due to tidal sway c) Potential odours and health risk to workers when handling litter d) Possible safety risk when installed in channels and difficult to clean/ maintain	Litter: M Oxygen demanding material: L Sediment: L Oil & grease: N Nutrient: N Bacteria: N
Sediment Trap	Sediment traps (known as sediment basins or sediment fore bays) are designed to trap coarse sediment and can take the form of a formal ‘tank’ or a less formal pond.	a) Trap coarse sediments upstream such as a wet basin or constructed wetland b) Reduce coarse sediment loads to stormwater systems or receiving waters c) Can be installed underground d) Applicable for areas greater than 5 ha	a) Limited removal of fine sediment, and pollutants can be remobilised b) Above ground sediment traps can be visually unattractive c) Trapping of excessive sediment can result in downstream channel erosion d) Potential for mosquito breeding	Litter: N Oxygen demanding material: L Sediment: H Oil & grease: N Nutrient: N Bacteria: N
Gross Pollutant Trap	A gross pollutant trap (GPT) is a sediment trap with a litter (or trash) rack, usually located at the downstream end.	a) GPTs trap coarse sediments before they enter into the waterway b) Collect litter at a single location for removal c) Appropriate for retrofitting into existing urban areas d) Traps can be located underground, minimising visual impacts e) Suitable for catchments greater than 6–8 ha	a) Litter rack has a tendency for blockage b) Potential to aggravate upstream flooding c) The appearance of the trap and litter can be obtrusive d) Potential odours and health risk to workers when handling litter e) Possible safety risk when installed in channels f) Difficult and expensive to clean	Litter: M Oxygen demanding material: L Sediment: M-H Oil & grease: N Nutrient: L Bacteria: L

Treatment Measures	Description	Advantages	Disadvantages	Pollutant Trapping Efficiency
Litter Booms	Litter booms are floating booms with mesh skirts placed in channels or creeks to collect floating litter and debris.	a) Used to remove floating litter/debris b) Enhance aesthetic appeal and recreational potential of downstream waterways c) Collects litter at a single location d) No hydraulic head loss e) Boom can rise and fall with changing level	a) Traps floating litter/debris b) Large objects such as branches or boats can reduce boom effectiveness c) Litter can be blown over the boom's collar in wind d) Potential for vandalism e) Possibility of sinking due to marine growth f) Low visual amenity	Litter: L Oxygen demanding material: N Sediment: N Oil & grease: L Nutrient: N Bacteria: N
Catch Basin	A catch basin is a stormwater pit with a depressed base that accumulates sediment.	a) Can be used upstream of other stormwater treatment measures to enhance performance b) Good for retrofitting into existing areas c) Installed below ground and therefore unobtrusive d) Generally apply to small catchments (< 1–2 ha)	a) Potential resuspension of sediments b) Potential release of nutrients and heavy metals from sediments c) Needs regular maintenance	Litter: L Oxygen demanding material: L Sediment: L-M Oil & grease: L Nutrient: N Bacteria: N
Oil/Grit Separators	Oil/grit separators, also known as water quality inlets, generally consist of three underground retention chambers designed to remove coarse sediment and hydrocarbons.	a) Appropriate for treating stormwater from areas expected to have significant vehicular pollution (e.g. parking) b) Can also trap litter c) Can also be used for treating stormwater from areas storing or handling petroleum products d) Can be appropriate for retrofitting into existing areas	a) Limited removal of fine or soluble pollutants b) When turbulent stormwater enters the chambers, this action may resuspend particulates or entrain floating oil c) Trapped debris is likely to have high concentrations of pollutants, possibly toxicants d) Need to be regularly cleaned with safety hazard	Litter: L-M Oxygen demanding material: L Sediment: M Oil & grease: M Nutrient: L Bacteria: L
Green Gully	Green Gully is a road gully that collects water from stormwater or rain, makes it suitable for irrigation and offers an automatic network to irrigate land and water plants.	a) Diverting stormwater from the roadways to the diverter channel by filtering litter b) Watering roadside plants with stormwater collected from the diverter channel c) Provide an automated road network system to irrigational land and water roadside plants d) Suitable for urban and rural areas	a) Only traps floating litter and debris b) Limited removal of fine sediment or soluble pollutants c) Possible safety risk when installed in roadside d) Needs to be regularly cleaned to maintain work performance	Litter: H Oxygen demanding material: N Sediment: L Oil & grease: N Nutrient: N Bacteria: N

Efficiency level: H, high efficiency (75–100 % removal); M, moderate efficiency (50–75% removal); L, low efficiency (10–50% removal); N, negligible (0–10% removal).

This comparative study provides important information on primary stormwater treatment measures for engineers, planners and researchers. The study will help users to take quick decisions about the most efficient and cost effective measures. It is apparent that most of the treatment measures use technologies designed for general stormwater pollution control and very few of them have advanced treatment components at the end of the treatment train. This study will help potential users to decide on the best procedure to apply for a particular use and situation. Some measures need continuous maintenance. Green Gully, however, has a low maintenance requirements and relatively low installation costs.

3 Stormwater Reuse

Water reuse is becoming a key component of the water cycle management. The prerequisite of sufficient and safe water supplies for human and environmental needs is a difficult challenge in many parts of the world, especially in arid regions. In order to manage water resources in an efficient and sustainable way, a wide range of tools and techniques are required [8]. The main benefits that can be gained from a successful stormwater reuse scheme are reductions in: (a) demand for mains water, (b) stormwater volumes, flows and the frequency of run-off and (c) stormwater pollution loads to downstream waterways.

The extent of the benefits from a particular stormwater harvesting and reuse scheme depends on a range of factors, including: (a) the local climate, particularly rainfall; (b) catchments' land use, which influences run-off quality and quantity; (c) the condition of the sewerage system, which affects sewer overflows to stormwater; (d) the demand for reuse water, in particular the flow rates and any seasonal variations and, (e) the design of the scheme, particularly how the flow to diverted to the scheme and the storage volume provided

The potential limitations and disadvantages to stormwater harvesting and reuse schemes depend largely on the nature of the scheme and the local environment. The major limitations are variable rainfall patterns, the environmental impact of storage, potential health risks and the high relative unit costs of treated stormwater [9]. Different standards for stormwater uses apply [10, 11]: (a) Recycled water for home use is treated to a very high standard and can be used for flushing toilets, watering gardens, washing cars, ornamental ponds, recreation without personal contact, and fire fighting; (b) Water straight from rainwater tanks is recommended for flushing toilets, watering gardens and washing cars. (c) Treated to less stringent standards, recycled water is used by local councils and businesses for irrigation, watering grounds, construction, flushing sewers and recharging groundwater, and (d) Untreated household greywater from showers, baths and washing machines can be reused for watering gardens using subsurface irrigation.

Stormwater harvesting and reuse schemes can be developed for existing urban areas or new developments and are mainly suitable for non-potable purposes such as: residential uses, irrigation, industrial and commercial uses and ornamental ponds and water features [12, 13]. There is a wide range of tried and tested stormwater reuse techniques that have been used around the world.

- *Aquifer Storage and Recovery [14–16]:* Aquifer Storage and Recovery (ASR) is a method of enhancing water recharge to underground aquifers by gravity feeding or pumping excess water into aquifers for later use in times of peak demand.
- *Urban Lakes [14, 17]:* Urban lakes are usually constructed lakes within the urban area that are used to capture, store and treat stormwater for outdoor reuse on gardens and lawns.
- *Constructed Wetlands [14, 18]:* Stormwater wetlands are constructed wetland systems designed to maximise the removal of pollutants from stormwater runoff via several mechanisms: microbial breakdown of pollutants, plant uptake, retention, settling and absorption.
- *Rainwater Tanks [19]:* Rainwater tanks refer to storages used for the collection and possible reuse of roof water. Water stored in rainwater tanks can serve a wide range of reuse applications.
- *Water Sensitive Urban Design (WSUD) [20-23]:* WSUD is the application of a wide range of within catchments measures to manage the impacts of urban development on the total water cycle.
- *Water Harvesting [14]:* Water harvesting refers to the collection and storage of water during times of significant stream flow, with reuse at later times when less water is available.
- *Industrial Reuse [14]:* Collected and treated stormwater may be used by industries for processes that do not require water of potable quality.
- *Unplanned Reuse [24]:* As well as the range of 'planned' or purpose-developed reuse methods discussed in earlier sections of this paper, there is also widespread unplanned stormwater reuse and unplanned groundwater recharge which exists in our urban areas.

Studies [24] have shown that up to 50% of the impervious areas of urban catchments are not effective in terms of stormwater runoff potential. That is, runoff from these areas does not directly or rapidly enter receiving waters via trunk drainage systems, presumably due to the abovementioned unplanned reuse. The benefits of stormwater reuse discussed in this paper are: (a) reduction in potable water usage, (b) increased environment protection, and (c) profile and awareness rising. The disadvantages of reuse are: (a) cost, (b) extra maintenance, and (c) potential public health issues. Appropriate stormwater management and reuse is essential, with the application of simple and effective stormwater harvesting techniques, such as the use of domestic rainwater tanks and local area reuse being potentially powerful management tools.

4 Conclusion

Stormwater treatment and reuse is important for improving urban water cycle management, given the current and increasing stresses on water resources all over the world. There is a requirement for the development of innovative technologies (or modification of existing technologies) for the collection, treatment, storage and distribution of stormwater. Without this, it is likely that stormwater recycling will be limited to smaller scale, less complex systems. Design standards for stormwater treatment for the purposes of reuse, based on targeted research, are also needed. Successful research into the reuse of stormwater will provide significant benefits in terms of protecting receiving waters from pollution, and reduction in potable water demand. The comparative study presented in this paper clearly outlines the relative advantages, disadvantages and pollutant trapping efficiency of different treatment measures and reuse techniques and is a useful document for stormwater researchers, planners and stormwater management authorities.

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