A comparative review of stormwater treatment and reuse techniques with a new approach: Green Gully

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Abstract: - Water restrictions are currently in place in most of the major cities of Australia in response to the severe drought. In order to manage water resources in a sustainable manner and to help reduce the restrictions, developing methods to recycle and reuse the stormwater and effluent water/waste water has become an important and urgent issue. 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. The component of Green Gully along with experimental set-up and procedures are described. Preliminary experimental result on performance of Green Gully is provided and discussed. 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, Stormwater quality improvement device (SQID), Pollutant, Water restriction, Road Gully, Green Gully.

1 Introduction

In recent years there has been increasing interest in the use of water resources generated within the urban boundary for potable supply substitution, as a means of augmenting current supply capacity. These urban water resources include roof runoff and stormwater. Stormwater utilisation has become a high profile potable water substitute.

'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, while others 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 western 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, together with concerns about climate change, have highlighted the need to manage water resources in a more sustainable manner. Expanding the use of stormwater to add to the water supply and reducing 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 [3].

Road rain/stormwater harvesting (RWH) is now a familiar term for reusing stormwater as a secondary source. Road rainwater harvesting has great potential and needs to be encouraged to bridge the demand supply gap of water requirements in this country. The systems for urban roads located in built up as well as open areas, as discussed in this paper, may be adopted with suitable modifications to meet the requirements of a specific place. A RWH system beside a road should be provided in such a manner that the harvested water does not enter into the pavement structure / other adjoining structures to avoid damage to them. This is also helpful in providing solution to the problems associated with flooding of roads during rainy season [4].

Highway stormwater runoff is discontinuous in time, not concentrated at one specific location, and responsive to changes in climatic conditions, and hence is a classic non-point pollutant source. The sources of the water quality constituents found in highway stormwater runoff are varied and may be attributed to: traffic deposition (e.g., tyre wear, brake linings, and leakage of oil and lubricants), dust fall from the surrounding environs, pavement wear (the breakdown of asphalt and/or concrete surfaces), maintenance operations (e.g., application of de-icing compounds, pesticides and herbicides), accidental spills, and littering. Given the attributes of this non-point source, it is not surprising to observe the high variability of the many water quality constituents found in highway stormwater runoff. It is this variability that hinders our ability to accurately predict these constituents from site to site, or between runoff events at a single site. Nevertheless, the prediction of constituents in highway stormwater runoff is a necessity for the planning and assessment of proposed or existing highway corridors. To enable accurate prediction of the various constituents, a comprehensive understanding of the constituents of highway stormwater runoff, and more importantly, how these constituents vary both temporally and spatially, is required [5].

Stormwater pipe systems are designed to convey water from rainfall and surface runoff only and do not transport sewage. Any blockage can cause flooding events with the probability of subsequent property damage. Proactive maintenance plans that can enhance their serviceability need to be developed based on a sound deterioration model [6].

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 [7]:

- *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). Storage is sometimes a limiting factor in utilising stormwater as available open space in cities is limited. It is for this reason that underground aquifers have been considered for storage of the water. Factors to consider for storage stormwater:
  - Maintaining the health of urban watercourses with ecological values.
  - The highly variable nature of stormwater flow means that only some flow can be economically harvested.
  - Infrastructure to divert adequate stormwater volumes
  - Volume needed to store between peak supply (winter) and highest demand (summer)
  - Land availability for surface storages on the Adelaide Plains
  - Variability in water quality (eg stormwater captured immediately after a dry period will carry far more pollutants than water captured at the end of a long wet period)
  - Feasibility of using established reservoirs
  - Recharge rate and holding capacity of aquifers.

- *Treatment*. Captured water is treated to reduce pathogen and pollution levels, and thus the risks to public health and the environment, or to meet any additional requirements of end-users. Factors to consider for treatment:
  - Raw and treated water quality needs (for consumer, and for ASR storage).
  - The level of treatment that is required for the intended use, either with wetlands or other processes.
  - Availability of space for wetlands or other treatment facilities

- *Distribution*. The treated stormwater is distributed to the area of use. Factors to consider for distribution:
  - Distance between the user and the water source/storage site will increase the distribution cost.

- Number of users and how much they need.
- Potential for contamination of other water systems.
- In established areas, requirements for modifications to public infrastructure and individual properties.

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 [8]. 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 [9].

This paper presents a comparative study of available stormwater treatment measures with respect to advantages, disadvantages and pollutant trapping efficiency. A new technology of stormwater management known as 'Green Gully' that collects, purifies and reuses stormwater throughout an automated network system have been introduced with its preliminary laboratory result. Current stormwater reuse techniques are discussed to reduce the water crisis.

2 Stormwater Quality Improvement Devices (SQIDs)

The Stormwater Quality Improvement Device (SQID) is a relatively inexpensive guard against pollutants and other debris being washed to our oceans via our ecologically fragile rivers and streams. The SQID line of products is designed to provide an economical, hydraulically efficient, easy to install and simple to maintain device, which aids in improving stormwater quality by the removal of litter and sediment pollutants, which have historically been transported to our sensitive aquatic ecosystems [10].

The benefits to the community and environment are immeasurable. Many of these have been discussed in lengthy papers and reported by environmental agencies over time. Some of these include the reduction of discarded and trimmed vegetation that depletes the oxygen levels in water as it decomposes, thus contributing to the blue green algae problem. Cigarette butts are stopped at the source. These cause immeasurable damage to the ecosystem as they have life expectancy far exceeding that of natural components. Plastic bags, broken bottles, discarded wrappers, and all forms of litter otherwise known as gross pollutants are stopped at the source. All these items have been found to be trapped by the SQID systems. It has been found with field observation and experiments that as the litter and sediment is trapped, there is a tendency for pollutants such as nutrients, trace metals, free oil and grease as well as smaller particles less than 2 mm to be entrapped in the litter, thus reducing further pollutants to the ecosystem (Table 1).

Table 1: Pollutant Table

(Source: Design Guidelines for Stormwater Quality Improvement Devices, Brisbane City Council, 1999)

Pollutant Description	**Possible Pollutant Source**
Gross Pollutants (Litter and Debris)	• Pedestrians and vehicles • Waste collection processes • Large vegetative matter • Lawn Clippings
Sediment	• Soil erosion – wind and water • Pavement and vehicle wear • Atmospheric deposition • Organic matter • Car washing • Weathering of buildings and structures
Oxygen Demanding Substances	• Organic matter decay • Atmospheric deposition • Animal faces
Nutrients	• Organic matter • Atmospheric deposition • Animal faces

The SQID range of products is designed with durability and UV stability built-in. Constructed of polyethylene and stainless steel, these products are designed to last. Once manufactured and installed, these products contribute no more pollution to the environment, and are made of 100 percent recyclable materials. Authorities have begun to act to ensure that stormwater pollutants are captured at the source. With this in mind, the SQID ranges of litter and sediment traps (LST) were developed. The SQID litter and sediment traps would become an integral part of a stormwater treatment plan that councils are being urged to implement. It is envisaged that this will help reduce the impact of urban development on the ecosystem. This will greatly improve the likelihood of sustainable development. Developers will also benefit by installing the SQID systems, as this may facilitate development plans if they are seen to be ecologically sound. The systems are primarily designed to capture and maintain sediment and pollutants from areas such as industrial areas, car parks, courtyards, driveways and kerbside channelling. There are many various applications in which the SQID systems may be useful.

3 A New SQID Concept: Green Gully

Among several SQIDs, road gully is one of the devices that is installed in roads to direct stormwater from roadways into a storm drainage system. Generally, stormwater from roads is directed to gutters and passed through stormwater drains. The road gully drainage unit efficiently directs water from the gutter and roadways to avoid environmental pollution, flooding, and reduces the risk of accidents caused by the build-up of water on the road and in the gutters. The water passing through the stormwater drains is discharged from outlets into waterways. Green Gully (shown in Figure 1) is an upgraded and extended road gully device.

Figure 1: Green Gully

Green Gully fulfils a vital role in water consumption to reuse stormwater. It resides in a road gully drainage unit for directing water from a road gutter. The main objective of Green Gully is to collect rainwater, make it suitable for irrigation and provide an automated network system to water roadside plants. Green Gully includes a gully grate or a runnel with a V-shaped base wall for filtering litter from stormwater before it 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. This is useful in the CBD (Central Business District) where the growth of plant roots must be controlled in order to prevent damage to paved areas. The irrigation system includes a self-watering system for irrigating an area like a park, utilising stormwater from roadways [11].

The working principle 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 [12]

The concept of Green Gully is relatively new compared to other techniques and methods of stormwater reuse and treatment. As a new technology, Green Gully provides support to:

- reduce water restrictions
- treat stormwater according to plant requirements
- avoid continuous manpower watering requirements, and
- lower installation and maintenance costs (it is easily installed in both the CBD and rural areas).

3.1 Description of Green Gully

Green Gully consists of a number of different apparatus shown in Figure 2a and 2b [12]. The components of the Green Gully include:

- a channel member ('3' in Figure 2a and 2b);
- a kerb member ('4' in Figure 2a and 2b) extending along one side of the channel member;
- a gully inlet ('7' in Figure 2a and 2b) formed within the kerb member and adjacent to the channel member — this gully inlet directs water into a stormwater drain;
- a diverter channel ('11' in Figure 2b) formed within a side wall of the gully inlet before the stormwater drain (the diverter channel provides an alternative passageway for the water;
- a filter ('10' in Figure 2a) associated with the diverter channel to substantially prevent debris from entering the diverter channel (the filter includes a gully grate ('8' in Figure 2a and 2b) located at or adjacent to an opening in the diverter channel);
- a removable grill, ('6' in Figure 2a and 2b) positioned behind the gully grate to alter the size of the apertures of the gully grate (the grill has fan-like blades to direct water into the diverter channel);
- the filter, which includes an elongate and V-shaped base wall ('13' in Figure 2b) to collect and direct debris (the V-shaped base wall is located adjacent the channel member);
- the gully inlet (an elongate opening);

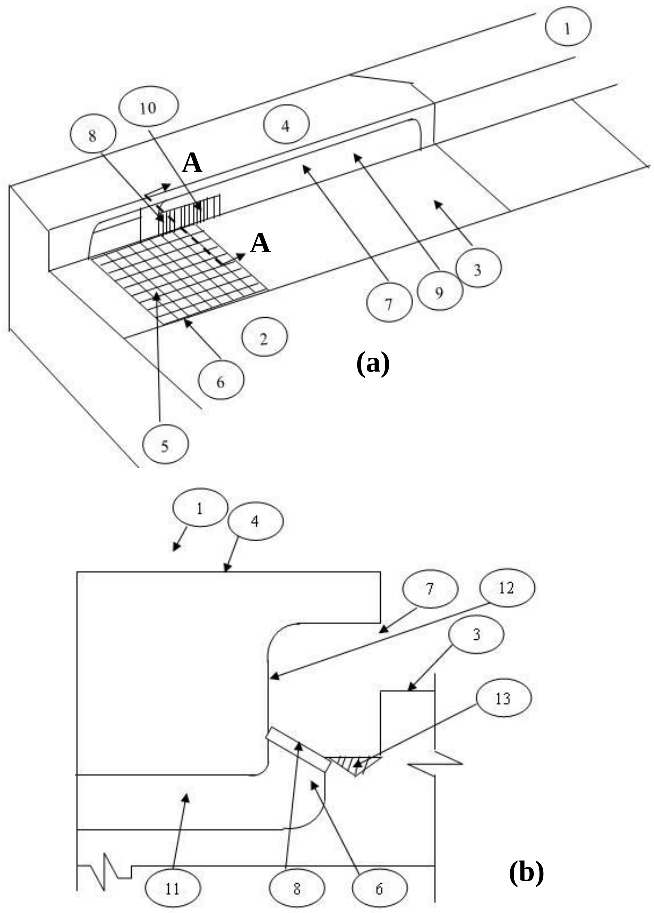

Figure 2: (a) Schematic diagram of a Green Gully and (b) Section A-A of Figure 2a.
(Source: Redrawn from C-M Concrete product manual.)

- a runnel member ('9' in Figure 2a), located within the gully inlet wherein the runnel member is adapted to direct water to the stormwater drain or diverter channel (the runnel member has an inclined base wall that slopes downwards toward the stormwater drain or diverter channel; the base wall has a V-shaped portion for collecting and passing debris);
- a V-shaped side portion that supports one side edge of the gully grate, and the side wall ('12' in Figure 2b) of the gully inlet that supports an opposing side edge of the gully grate;
- the channel member that has the channel opening ('6' in Figure 2a and 2b) providing access to the stormwater drain (alternatively, the kerb members have a kerb opening providing access to the stormwater drain). There is a removable grate positionable over the kerb of the channel opening.

3.2 Laboratory Experiment with Green Gully

To determine the performance of Green Gully, a laboratory experiment was conducted with a Green Gully model. A schematic diagram of the Green Gully model with dimensions and flow direction is shown in Figure 3. The gully grate was composed of a cross-diagonal screen made of steel wire. The size of the grate was 90mm high and 210mm wide. The main objective of the experimental work in the laboratory was to determine the performance of the Green Gully pit model using different flow conditions. A schematic diagram of the experimental setup is shown in Figure 4. The experiments were performed at the Central Queensland University's (CQU) fluid mechanics laboratory. A full scale Green Gully model was set up at the middle section of the laboratory's existing flume. The flume length, height and width are 7.76m, 0.45m and 0.297m respectively. Water was supplied to the flume by a pump of capacity 10HP with a 10m head. The flow pipe of the pump is 16cm diameter with a capacity of 5 litres.

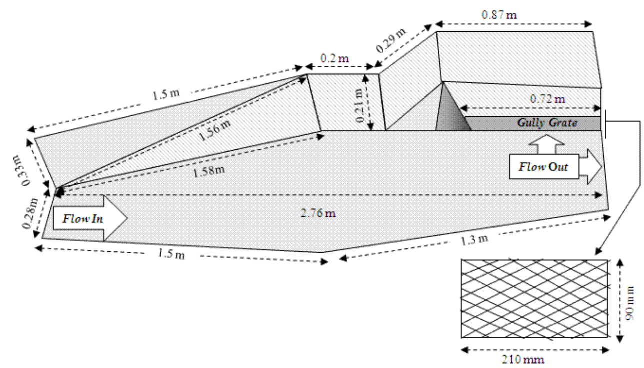

Figure 3: Schematic diagram of the Green Gully model with gully grate.

Experiments were performed using fresh water without litter. Three flow rates were measured: total flow from the pump (i.e. flow at the Green Gully entry (Q)), flow through the downstream of the Green Gully (Q_1), and flow through the gully grate (Q_2). A Pitot static tube was used to determine the upstream fluid flow velocity. The Pitot tube measures a fluid velocity by converting the kinetic energy of the flow into potential energy. The Pitot tube consists of two tubes: (1) an outer tube, with holes perpendicular to the direction of flow, which senses static pressure only, and (2) an inner tube, which faces into the direction of flow and senses the static pressure plus the pressure increase due to fluid striking the tube opening (dynamic pressure). The dynamic pressure is greater than the static pressure and the pressure difference is proportional to the velocity. A differential manometer was used with the instrument.

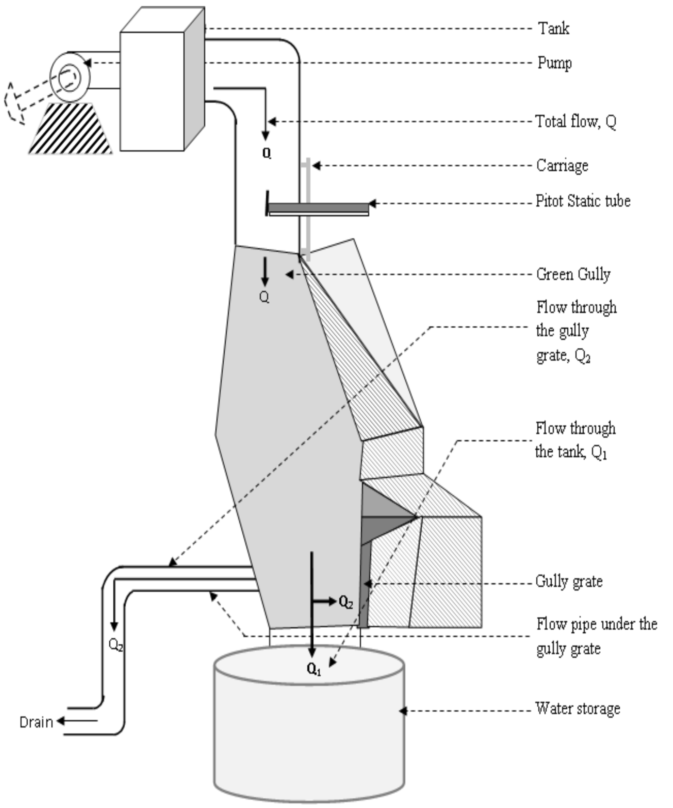

Figure 4: Schematic diagram of laboratory Green Gully setup.

The difference in height of the indicating fluid in the manometer was converted to pressure difference using Equation 1. Velocity was calculated using pressure difference by the Equation 2. The fluid flow velocity was also measured by the distance-time method. Using this method, distances of a floating object were measured over time. Upstream flow rate (Q) was determined by multiplying the velocity by the cross-sectional area.

$$P = \rho g h = P_s - P_o \qquad (1)$$

$$V = \sqrt{\frac{\{2(P_s - P_o)\}}{\rho}} \qquad (2)$$

Where, h = difference in height, m; ρ = density of water, kg m^{-3} and g = gravitational force, m s^{-2}

Flow through the gully grate (Q_2) was measured by collecting water in a tank for certain time. Flow rate was calculated by dividing the volume of water by time. Flow through the downstream (Q_1) was determined by subtracting Q_2 from Q. The efficiency of the Green Gully is defined as the ratio, expressed as a percentage, of the flow rate through the gully grate (Q_2) to the total flow rate (Q) ,

$$\eta = \frac{Q_2}{Q} \qquad (3)$$

3.3 Results and Discussions

Preliminary results of the laboratory experiment on the Green Gully model to determination the performance (expressed as efficiency) is presented through a graph in Figure 5. The efficiency of the Green Gully is expressed as the function of flow rate. It can be seen from Figure 5 that the efficiency of the Green Gully decreases exponentially with increases in the flow rate as predicted by the following equation:

$$\eta = 58.37 e^{-28.56Q} \qquad (4)$$

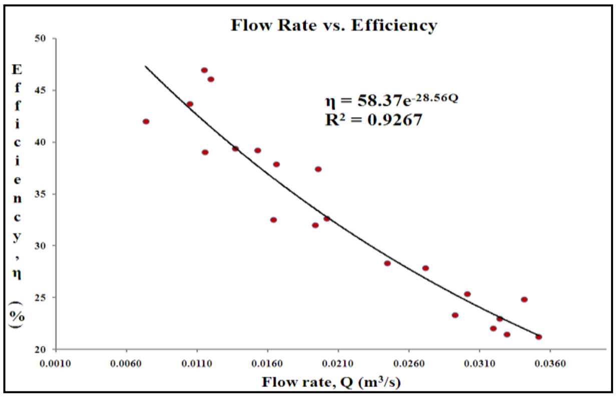

Figure 5: Experimental data plot of Green Gully: efficiency vs. flow rate.

However, the efficiency of about 47% was achieved at a flow rate of 0.0115 m^3 s^{-1} and 21% at a flow rate of 0.0352 m^3 s^{-1}.

It was found that the efficiency of the Green Gully varies with flow rate, as expected, exponentially, that is; the higher the flow rate the lower the efficiency.

4 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 [9]:

- *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 [7], 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.

Table 2 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 [7, 8, 12, 13].

Table 2: 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
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

Treament Measures	Description	Advantages	Disadvantages	Pollutant Trapping Efficiency
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
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
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) Needs to be regularly cleaned with safety hazard	Litter: L-M Oxygen demanding material: L Sediment: M Oil & grease: M Nutrient: L Bacteria: L

Treatment Measures	Description	Advantages	Disadvantages	Pollutant Trapping Efficiency
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) Diverts stormwater from the roadways to the diverter channel by filtering litter b) Waters roadside plants with stormwater collected from the diverter channel c) Provides 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 low maintenance requirements and relatively low installation costs.

5 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 [14]. The main benefits that can be gained from a successful stormwater reuse scheme are reductions in:

- demand for mains water
- stormwater volumes, flows and the frequency of run-off and
- 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:

- the local climate, particularly rainfall
- catchments' land use, which influences run-off quality and quantity
- the condition of the sewerage system, which affects sewer overflows to stormwater
- the demand for reuse water, in particular the flow rates and any seasonal variations and,
- the design of the scheme, particularly how the flow is to be diverted to the scheme and the storage volume provided

Wastewater management is the last step in the chain of water management and economising. An important task with this respect is to be done by cleaning facilities. Either large (some sort of production units) or small (becoming indispensable for everyday usage). The analysis and design of wastewater management facilities to reduce or eliminate the constituents found in wastewater involves consideration of those factors and issues that will affect the sizing, performance, and reliability of these facilities they are both of the same importance [15].

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 [16]. Different standards for stormwater uses apply [17, 18]:

- 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;
- Water straight from rainwater tanks is recommended for flushing toilets, watering gardens and washing cars;
- Treated to less stringent standards, recycled water is used by local councils and businesses for irrigation, watering grounds, construction, flushing sewers and recharging groundwater
- 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 [19, 20]. There is a wide range of tried and tested stormwater reuse techniques from around the world that can be used for this purpose.

5.1 Aquifer Storage and Recovery

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. It has considerable potential to utilise excess surface water – including urban stormwater runoff and treated wastewater – and where the aquifers are suitable it offers a comparatively low cost method of storing water as an alternative to surface storage [23, 24, 25]. In terms of water storage, it can be used for:

- Seasonal storage and recovery
- Long-term storage
- Emergency storage
- Diurnal storage (to enhance base stream flows)
- Storage of reclaimed water

5.2 Urban Lakes

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. The lakes also improve urban amenity and provide habitats for flora and fauna. Stormwater can also be captured in urban lakes or housing cluster scale tanks for reuse in toilets and gardens in households. This water also often supplies and enhances the benefit to local area amenities, through aesthetic appreciation and habitat provision [21, 24].

5.3 Constructed Wetlands

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. Stormwater wetlands temporarily store runoff in shallow pools that support conditions suitable for the growth of wetlands plants. Similarly to urban lakes, water stored in wetlands can also be directly reused for irrigation and local area lawn watering [21, 25]. Constructed wetlands are universally recognised as an ecologically sustainable and cost effective stormwater management tool given their ability to:

- Significantly reduce stormwater pollutants
- Provide a buffer to natural aquatic ecosystems
- Create habitat for flora and fauna
- Provide an attractive public amenity

5.4 Rainwater Tanks

Rainwater tanks refer to storages used for the collection and possible reuse of roof water. These storages can be used on an individual household basis, or alternatively larger storages can be constructed to collect roof water runoff from several houses. There are numerous ways in which such tanks can be configured, ranging from the well recognised above ground corrugated iron or concrete tanks, seen around much of rural Queensland, to more sophisticated roof eave based rainwater tanks that have recently been proposed. Water stored in rainwater tanks can serve a wide range of reuse applications. In many areas of the world, water in rainwater tanks constitutes the only source of water, and consequently serves all potable and non-potable uses. Rainwater tanks can also supply water for toilet flushing purposes [26].

5.5 Water Sensitive Urban Design (WSUD)

Water Sensitive Urban Design is the application of a wide range of within catchment measures to manage the impacts of urban development on the total water cycle. Consistent with the *Urban Stormwater: Best Practice Environmental Management* guidelines, the key principles of WSUD from a stormwater management and planning perspective are to [21 - 30]:

- Protect natural systems
- Protect water quality
- Integrate stormwater treatment into the landscape
- Reduce runoff and peak flows
- Add value while minimising development costs

- Reduce potable water demand

5.6 Water Harvesting

Stormwater harvesting involves the collection and reuse of rainwater entering the stormwater drainage system, which would otherwise end up in the ocean. This complements other urban local or household management practices such as greywater reuse systems, water recycling and the use of rainwater tanks. Within residential areas, stormwater harvesting can be effective in supplementing supply and reducing the demand on our dams and groundwater supplies [21]. While stormwater harvesting may differ between locations, these projects generally involve:

- the collection of rainwater from drains, creeks or ponds;
- temporary storage of stormwater in small dams or tanks;
- treatment to remove contaminants such as pathogens and pollutants
- distribution to users.

5.7 Industrial Reuse

Collected and treated stormwater may be used by industries for processes that do not require water of potable quality [21]. Examples in this regard include the following:

- evaporative cooling water
- boiler feed water and
- process water

5.8 Unplanned Reuse

As well as the range of 'planned' or purpose-developed reuse discussed in earlier sections of this paper, there is also widespread unplanned stormwater reuse and unplanned groundwater recharge which exists in our urban areas [31]. Examples of such unplanned reuse include the following:

- roof drainage directed to gardens and lawns;
- runoff from roads and paved areas directed onto grassed areas;
- overflowing gutters and storm systems under heavy rainfall; and
- infiltration to subsurface aquifers from open drainage channels and exfiltration from storm sewers.

Studies [31] 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:

- reduction in potable water usage
- increased environment protection, and
- profile and awareness rising.

The disadvantages of reuse are:

- cost
- extra maintenance, and
- 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.

6 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. This paper introduced a new SQID, Green Gully with its preliminary laboratory experiment results to determine its performances.

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