A new approach to stormwater treatment and reuse: Green Gully and its performance measurement

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Abstract: - In order to manage water resources in sustainable manner and to help reduce the necessity for national restrictions in water use, developing methods to recycle and reuse stormwater and effluent waste water has become an important and urgent issue. The current critical shortages of fresh water have highlighted the need for greater reuse and recycling of water resources. This paper presents a new technology known as ‘Green Gully’ that collects, purifies and reuses stormwater throughout an automated network system. A detailed description along with working principals is presented. To determine the performance of Green Gully, preliminary experimental results are provided and discussed. Experimental procedures and performance calculations are also presented.

Key-Words: - Stormwater quality improvement devices, Stormwater management, Litter, Water restriction, Green Gully

1 Introduction

The world is facing water crisis. At present a very large number of people in the world are likely to suffer from lack of clean, fresh water, particularly those who live in hot, arid countries where reliable water supplies are only available during part of the year. Two-thirds of the earth’s surface is covered by water but 97 per cent of it is salty ocean or sea water that is not suitable for drinking, irrigation, industrial, or any other household use. The rest of the water is not easily accessible because nearly three-quarters of it is either frozen in polar ice caps or present as ground moisture. Only less than one per cent of the world’s water is in freshwater lakes and rivers. With the world’s population growing alarmingly, the available fresh water is not sufficient to meet human demands and this is presenting a huge problem [1].

William Cosgrove, Vice President of the World Water Council, told reporters in Tokyo [2]: ‘Thirty per cent of the world is living under water stress – they do not have enough water to live or wash, and if we continue at that rhythm, it will become more than 50% in 2025. It is not sustainable.’. In view of this, urban engineers and planners are beginning to evaluate alternatives to traditional water supply and disposal methods, such as the reuse of stormwater and wastewater. Accordingly, researchers started to think about secondary sources of water. Stormwater can play a vital role as a secondary source to reuse in different household activities as well as in irrigation with purification methods related to category of use. The main incentives for stormwater reuse schemes include [3,4]:

- enhancing the limited primary water source and helping prevent excessive distraction of water from alternative uses (including the natural environment)
- reduction of potable water usage costs, including total treatment and discharge costs
- environmental protection
- reduction or elimination of discharges of treated sewage to receiving waters
- developing ‘Regulation’ of potable water use, and
- raising profile and awareness

Reuse of stormwater offers significant potential savings in potable water use. Typical applications of water reuse include: (a) amenity areas: parks, gardens and golf courses; (b) commercial agriculture: viticulture, floriculture, turf grass, pastures, hay
cropping and vegetable production; (c) irrigation of urban landscapes and recreation areas; (d) residential potable reuse; (e) forestry, particularly plantation forestry; (f) industrial and commercial applications, including reuse within treatment plants, and (g) residential use as part of third pipe developments.

Waste-water 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 [5].

Stormwater pipe systems in Australia 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. A research study was conducted using a neural network (NN) approach to model deterioration in serviceability of concrete stormwater pipes, which make up the bulk of the stormwater network in Australia [6].

Stormwater needs some treatment for use in different sectors. The methods and degree of treatment required for water reuse differ according to the hydraulic and biochemical characteristics of the stormwater and the potential end uses. The level of treatment required depends on the application and risk of exposure to the public. For many applications secondary treatment (i.e. physical treatment to remove solids and biological treatment to remove organics) with disinfection may be adequate. For higher contact applications, tertiary treatment (i.e. secondary treatment plus removal of nutrients) may be required [7]. Ancient stormwater management practices involving the capture and reuse of as much stormwater as possible are the antithesis of modern practice, as described, for example, in ‘Australian rainfall and runoff’ [8], that encourages rapid discharge of stormwater to the environment. It is ironic that sustainable stormwater management practice has rediscovered ancient practices. There are many strategies for the reuse of stormwater at the allotment scale, including [9]:

- directing roof water and stormwater to gardens or lawns rather than the street drainage system;
- capturing overflow from rainwater tanks and stormwater in ponds or underground tanks and reusing it outdoors and in toilets;
- directing roof water and stormwater to a gravel filled infiltration trench (a shallow gravel layer adjacent to or under a garden area will provide passive irrigation to the area [10]), and
- directing roof water and stormwater to water sensitive gardens that may include ponds, swales, infiltration measures and mulching [11].

There is a wide range of tried and tested stormwater reuse methods and techniques used around the world. To apply any reuse method, Stormwater Quality Improvement Devices (SQIDs) play a fundamental role by trapping stormwater pollutants and help to protect creeks, rivers and beaches by trapping or collecting rubbish and pollution that ends up in our stormwater drains. SQID is a collective term to define infrastructure that is designed primarily to improve or protect the health of the city’s waterways [12]. To reduce the pollutant content in stormwater, SQIDs are introduced that filter the run-off before it enters the waterways. SQIDs are vital when it is impossible to prevent significant quantities of pollutants (e.g. litter or sediment) entering the stormwater drainage system and where a reduction in the loads or concentrations of such pollutants is needed. These are always associated with ongoing maintenance costs and often significant construction costs; alternative strategies (i.e. source controls) should be carefully evaluated before committing oneself to the installation of SQIDs. SQIDs are installed to meet agreed Water Quality Objectives for downstream water bodies (e.g. a river or creek), or to simply implement ‘best practice’ stormwater quality management [13].

This paper introduces a new SQID, called ‘Green Gully’ that comprises pollutant trapping processes from stormwater along with an automated network system to reuse stormwater for irrigation. The main objective of the research is to determine the performance (the percentage of water flow through the gully grate) of a laboratory scale gully pit model based on different flow conditions (i.e. flow without litter and flow with different litter). Preliminary laboratory experimental procedures and results are presented and discussed.

2 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 environment pollution, flooding, and reduce 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 is an upgraded and extended road gully device.

The Green Gully fulfils a vital role in water consumption to reuse stormwater. 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 rainwater, make it suitable for irrigation and provide an automated network system to water roadside plants. The 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 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 [14].

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

### 2.1 Description of Green Gully

Green Gully consists of a number of different apparatus shown in Figure 1a and 1b [15]. The components of the Green Gully include:

- a channel member (‘3’ in Figure 1a and 1b);
- a kerb member (‘4’ in Figure 1a and 1b) extending along one side of the channel member;
- a gully inlet (‘7’ in Figure 1a and 1b) 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 1b) 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 1a) associated with the diverter channel to substantially prevent debris from entering the diverter channel (the filter includes a gully grate (‘8’ in Figure 1a and 1b) located at or adjacent to an opening in the diverter channel);
- a removable grill, (‘6’ in Figure 1a and 1b) 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 1b) to collect and direct debris (the V-shaped base wall is located adjacent the channel member);
- the gully inlet (an elongate opening);
- a runnel member (‘9’ in Figure 1a), 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 1b) 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 1a and 1b) 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.

![Figure 1: (a) Schematic diagram of a Green Gully and (b) Section A-A of Figure 1a.](Source: Redrawn from C-M Concrete product manual.)
2.2 Working principal of the Green Gully

The Green Gully is divided in two parts. First, diverting stormwater from roadways to the diverter channel by filtering litter, and second, watering roadside plants with stormwater collected from the diverter channel.

A schematic diagram showing the diversion of water from roadways to the drainage and irrigation unit is shown in Figure 2. With reference to Figure 2, the road gully drainage unit ‘10’ is installed next to the road ‘4’ and is connected to a stormwater drain. The irrigation unit ‘2’ is installed beneath the surface of the ground ‘5’. The road gully drainage unit ‘1’ has a channel portion ‘18’ that abuts the road ‘4’ and a kerb portion ‘7’ that extends along one side of the channel portion ‘6’. The channel portion ‘6’ has a channel opening ‘8’ for allowing stormwater from the road ‘4’ to flow into the stormwater drain that is located below the channel opening ‘8’. A removable channel grate ‘9’ is placed over the channel opening ‘8’. There is an elongate gully inlet ‘10’ formed within the kerb portion ‘7’ and located adjacent the channel portion ‘6’. A diverter channel ‘11’ is formed within a side wall ‘12’ of the gully inlet ‘10’. The opening ‘13’ of the diverter channel ‘11’ is covered by gully grate ‘14’.

A runnel ‘15’ located within the gully inlet ‘10’ is formed to direct water to the stormwater drain or the diverter channel ‘11’. The runnel ‘15’ has an inclined base wall ‘17’ that slopes downwards towards the stormwater drain. The base wall ‘17’ of the runnel ‘15’ has an elongate V-shaped portion ‘16’ that is located next to the channel portion ‘6’. The side of the V-shaped portion ‘16’, near the diverter channel opening ‘13’, supports one side edge of the gully grate ‘14’, and the side wall ‘12’ of the gully inlet ‘10’ supports the opposite side edge of the gully grate ‘14’. Stormwater from the road ‘4’ is directed by the channel portion ‘6’ to enter the gully inlet ‘10’. The stormwater is then directed by the inclined base wall of the runnel ‘15’ towards the diverter channel opening ‘13’. Floatable litter and debris in the stormwater are trapped in the V-shaped portion ‘16’ of the runnel ‘15’ and therefore removed from the water before the water enters the diverter channel ‘11’. The gully grate ‘14’ serves as a filter to reduce the amount of debris entering the diverter channel ‘11’. Stormwater can flow into the diverter channel ‘11’ as well as the stormwater drain that is located downstream from the diverter channel ‘11’. The diverter channel ‘11’ provides an alternate pathway for the stormwater that has entered the gully inlet ‘10’ from the road ‘4’. The stormwater that enters the diverter channel ‘11’ flows to the irrigation unit ‘2’ of the drainage assembly ‘3’.

The irrigation unit ‘2’ has an inner wall ‘18’ and an outer wall ‘19’ that are spaced from each other to form an irrigation channel ‘20’. The inner wall ‘18’ defines a space ‘27’ that is surrounded by the irrigation channel ‘20’. There is an irrigation inlet ‘21’ and an irrigation outlet ‘22’ formed in the outer wall ‘19’. The floor ‘23’ of the irrigation channel ‘20’ has a number of apertures ‘24’ that open into the ground surrounding the irrigation channel ‘20’. A removable top wall ‘25’ is located over the irrigation channel ‘20’ and positioned between the floor ‘23’ and the top of the inner ‘18’ and outer ‘19’ walls. The removable top wall ‘25’ allows access to the irrigation channel ‘20’ for cleaning purposes.

![Figure 2: Schematic diagram of the road gully drainage unit and an irrigation unit of the Green Gully.](Source: C-M Concrete product manual.)

The road gully drainage unit ‘2’ of the drainage assembly ‘3’ are separately manufactured and connected during installation. The road gully drainage unit ‘1’ is directly connected to the irrigation unit ‘2’ by aligning the diverter channel ‘11’ with the irrigation inlet ‘21’. Stormwater from the road gully drainage unit ‘1’ enters the irrigation channel ‘20’ through the irrigation inlet ‘21’. The stormwater drains from the irrigation channel ‘20’ into the ground surrounding the irrigation channel ‘20’ through the apertures ‘24’ of the floor ‘23’. A plant ‘26’ can be grown in the space ‘27’ and the stormwater used to irrigate the plant ‘26’.

During heavy rains, the water in the irrigation channel ‘20’ may rise to a level where water discharges through the irrigation outlet ‘22’. A transfer pipe ‘28’ is connected to the irrigation outlet ‘22’. The transfer pipe ‘28’ has perforations that allow water in the transfer pipe ‘28’ to drain into the ground near the transfer pipe ‘28’. The transfer pipe ‘28’ can be installed to reach areas away from the drainage assembly ‘3’. The internal space ‘27’ is filled with soil and used to grow plants; a removable basket is used within the space to restrict the growth of plant roots. The basket has multiple openings to allow water to pass through a basket wall. It has one or more handles for enabling it to be lifted from the space. The irrigation outlet ‘22’ is relatively higher than
the irrigation inlet ‘21’ in the outer wall ‘19’. A transfer pipe ‘28’ is connected to the irrigation outlet and to an aperture ‘24’ in the floor. It is adapted to irrigate the ground surrounding the irrigation unit. Perforations in the transfer pipe allow water in the transfer pipe to drain into the ground adjacent to the pipe. There is a discharge outlet formed in the inner wall for discharging water from the internal space and preferably to a stormwater drain. The discharge outlet is located at a higher position than the irrigation inlet and irrigation outlet. An irrigation access opening to allow access to the irrigation channel is located adjacent to the irrigation inlet.

In one embodiment of the Green Gully, the cover is fixed to the inner and outer walls and serves as a top wall covering the internal space and the inner and outer walls. In another version of the Green Gully, the cover is removable to provide access to the irrigation channel. In one form of the cover is a grate. The grate is positioned on top of the inner and outer walls. Alternatively, the grate may be positioned at an intermediate level between the base section and the top of the inner and outer walls. The cover has one or more flush ports to enable cleaning of debris collected in the irrigation channel. The cover is adapted to receive a probe that measures the depth of the water in the irrigation channel. It has a cavity formed above the irrigation channel and adapted to accommodate a dipstick. The cavity also accommodates a pH tester. The cover in one type has one or more cover inlets to allow water to enter the irrigation channel. With this version, the cover has an inclined surface to allow water to flow towards one or more cover inlets. The inclined surface slopes from the perimeter of the cover downwards toward one or more cover inlets.

3 Experimental
A schematic diagram of the Green Gully model with dimensions and flow direction is shown in Figure 3. The gully grate was composed of 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.

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.

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.

\[ P = \rho gh = P_2 - P_0 \quad (1) \]

\[ V = \sqrt{\frac{2(P_2 - P_o)}{\rho}} \quad (2) \]

Where, \( h \) = difference in height, m; \( \rho \) = 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 (\( Q \)),

\[ \eta = \frac{Q_2}{Q} \quad (3) \]

4 Results and Discussion

The efficiency of Green Gully as a function of flow rate is presented in Figure 5. It can be seen from Figure 5 that the efficiency of Green Gully decreases exponentially with increases in the flow rate as predicted by the following equation:

\[ \eta = 58.37e^{-28.56Q} \quad (4) \]

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\(^{-1}\).

Figure 6 compares the fluid flow velocity determined by two methods. First, using a Pitot Static Tube and second, using the distance-time method. From Figure 6, it can be seen that the resultant velocity using both methods was identical. Preliminary experiments were done using one type of gully grate.

![Figure 5: Experimental data plot of Green Gully: efficiency vs. flow rate.](image)

![Figure 6: Comparison of velocity: using distance-time method and Pitot Static Tube.](image)

Green Gully is relatively a new approach in stormwater management. Presently Green Gully is in the process of testing through laboratory experiments. After achieving satisfactory level of performance, this gully will be recommended for real life implementations to manage and reuse stormwater. It is to be noted that analysis on Green Gully can be done through modeling using ANSYS program, however, the laboratory experimental data is needed for model validation.

5 Conclusion

A detailed description and performance measurements have been presented. 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. Green Gully will supply water to roadside trees or irrigation areas. It should be noted that this research is in the first year of a two year research project. Over the next year, further research will be undertaken to consider the flow conditions (such as high or low flow) flow with or without litter and using
differing screen sizes in the gully grate. These results may assist in improving the design and function of Green Gully.

References: