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The capture and retention evaluation of a stormwater gross pollutant trap design

Jehangir T. Madhani *, Richard J. Brown

School of Chemistry, Physics and Mechanical Engineering, Science and Technology Faculty, Queensland University of Technology, 2 George St., Brisbane, QLD 4000, Australia

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ABSTRACT

Gross pollutant traps (GPT) are designed to capture and retain visible street waste, such as anthropogenic litter and organic matter. Blocked screens, low/high downstream tidal waters and flows operating above/below the intended design limits can hamper the operations of a stormwater GPT. Under these adverse operational conditions, a recently developed GPT was evaluated. Capture and retention experiments were conducted on a 50% scale model with partially and fully blocked screens, placed inside a hydraulic flume. Flows were established through the model via an upstream channel-inlet configuration. Floatable, partially buoyant, neutrally buoyant and sinkable spheres were released into the GPT and monitored at the outlet. These experiments were repeated with a pipe-inlet configured GPT. The key findings from the experiments were of practical significance to the design, operation and maintenance of GPTs. These involved an optimum range of screen blockages and a potentially improved inlet design for efficient gross pollutant capture/retention operations. For example, the outlet data showed that the capture and retention efficiency deteriorated rapidly when the screens were fully blocked. The low pressure drop across the retaining screens and the reduced inlet flow velocities were either insufficient to mobilise the gross pollutants, or the GPT became congested.

1. Introduction

Stormwater runoff, and its transported pollutants from impervious surfaces, is a key contributor to the collapse of healthy freshwater ecosystems (Roy et al., 2008). There is also a growing interest to recycle stormwater that enters the ocean via urban drainage systems and receiving waterways; only 4% of rainwater and stormwater is currently recycled in Australia (Hatt et al., 2006). Ecosystem preservation and stormwater recycling require water maintenance or devices that purify stormwater for safe use. In the urban planning and managing of water resources, ponds, wetlands and biofilters have been deployed (Zinger et al., 2013; Zhang et al., 2010; Kazemi et al., 2009). The filtration process in these devices is generally susceptible to clogging and damage when larger (gross) stormwater pollutants are intercepted. Subsequently, gross pollutants traps (GPTs or litter traps) are used as part of the pre-stormwater treatment train. They use internal retaining screens to trap the gross pollutants, dimensionally greater than 5 mm, prior to the release of stormwater.

Visible street waste such as anthropogenic litter and organic matter (sediments, leaves and grass clippings) are classed as gross pollutants. The estimated volume ratio of organic matter to anthropogenic litter typically found on streets and stormwater drains (residential and commercial areas) in Queensland, Australia can vary from 20% to 80% and vice versa (Madhani et al., 2009a). In this investigation, the most frequently discarded litter items were cigarette butts, while paper and plastic accounted for the largest volume. Plastering of grass clippings against the internal screens of the GPTs was also observed, forming a matted layer.

Gross pollutants can exhibit varying degrees of physical and material properties such as structure/firmness, shape, size and density. For example, the largest dimension of a cigarette butt, an average size between 30 and 40 mm, is similar to a table tennis ball (sphere). The initial approach to conducting capture and retention experiments was simplified by using a sphere to model the generic shape of the most discarded litter, in terms of item and volume. This paper contributes to the engineering research of gross pollutant capture and retention.

Fig. 1 shows a plan view of a linear screening GPT recently developed by C-M Concrete Pty Ltd. in Australia, the LitterBank.

Abbreviations: GPT, gross pollutant trap; RD, relative density.

* Corresponding author. Tel.: +61 403908914.
E-mail addresses: jtmadhani@gmail.com (J.T. Madhani), richard.brown@qut.edu.au (R.J. Brown).

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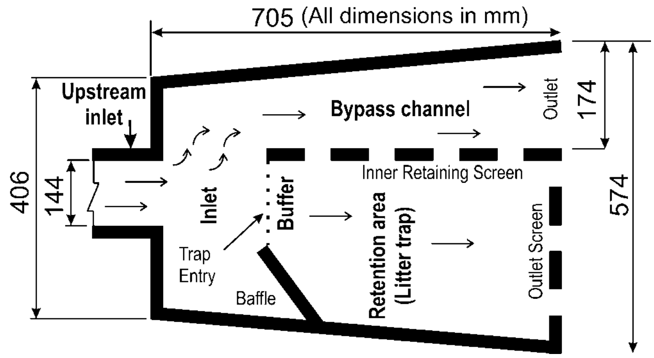

Fig. 1. Plan view of the GPT (LitterBank) with labelled key flow regions inlet and buffer/mixing, trap entry, retention area, bypass channel and upstream inlet.

The key flow regions in the GPT (Fig. 1) are referred to as the inlet, buffer/mixing, retention area, bypass channel and upstream inlet. The trap entry is defined as the invisible boundary between the inlet and buffer regions. The GPT can also be fitted with clay linings to absorb oily pollutants (not within the scope of this investigation).

Despite the number of GPT designs available, scientific investigation on these devices is surprisingly limited (Madhani et al., 2011). Newly-built GPTs are also rarely tested for adverse operations such as screen blockages, downstream tidal waters and operating above/below their intended design flow rates prior to commissioning. In this paper, the adverse operating scenarios have been investigated on the LitterBank under two inlet configuration designs, namely the pipe and channel. The capture and retention efficiencies of the GPT were evaluated, using the spheres to emulate floatable, partially buoyant, neutrally buoyant and sinkable gross pollutants. As subsequently shown below, key findings from the experiments were of practical significance to the design, operation and maintenance of the GPTs. These involved an optimum range of screen blockages and potentially an improved inlet for efficient GPT gross pollutant capture/retention operations.

2. Experimental method

2.1. The experimental GPT rig and setup

The experimental GPT rig (50% scale model) was placed in a square section (19 m long, 0.6 m wide and 0.6 m deep) recirculating flume (Fig. 2). The constant flow rates (Table 1) were established through the rig via controller settings on the centrifugal pumps which circulated the water from underground storage tanks into the flume. Inside the flume, flow into the LitterBank was through an upstream rectangular channel, its height extended to the full depth of the experimental rig (Fig. 2); the width of this inlet was 144 mm. Experiments were also conducted with an upstream pipe inlet, a 100 mm circular cross-section terminating with a small invert level of 40 mm at the inlet, above the GPT floor. Both the pipe and channel inlet configurations are commonly used in stormwater applications.

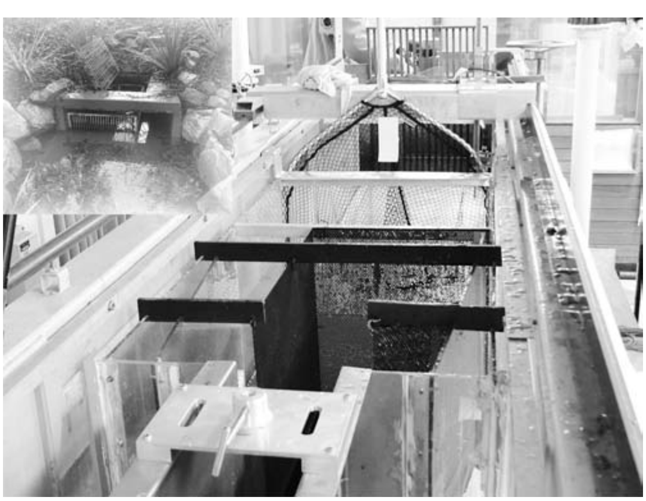

Fig. 2. Experimental GPT rig (50% scale model) placed inside the flume. Fishing net installed downstream at end of raceway capturing exiting spheres. Top left, a view of the GPT LitterBank in situ with high downstream tidal waters.

The flow regimes in Table 1 were centred on the manufacturer's design flow rate of 20 L/s, with the highest flow rate of 35 L/s representing approximately 80% of the maximum capacity prior to the GPT flooding. The lower flow rates of 1.3 L/s and 3.9 L/s (runs 1, 2 of Table 1), with a mean inlet velocity of 0.09 m/s, have corresponding weir heights set in the flume to 0.1 m and 0.3 m to model tidal downstream levels of the receiving waterway that are elevated relative to the GPT outlet. Runs 3 and 4 did not require the weir, since the level of the receiving waterway was below the GPT outlet flow.

At the GPT outlet and inside, various materials were used to model blocked screens. The percentage screen blockages were based on the amount of material obstructing the flow path, and no screens represented 0% blockage. Standard GPT screens were replaced with Perspex solid walls to model fully blocked screens. Perforated walls with 3 mm circular and 5 mm rectangular holes modelled 68% and 33% screen blockages, respectively. The screen used to represent 33% blockages is similar to the standard design internal fittings of the LitterBank.

2.2. Gross pollutant capture and retention experiments

Each experimental run consisted of a GPT inlet configuration (channel or circular pipe), a flow rate (Table 1), a screen blockage (33%, 68% and 100%), a relative density (RD) of the gross pollutant (floatable, partially buoyant, neutrally buoyant and sinkable), and a feeding method (step stimulus function or intermittently). Experiments with the circular pipe were only conducted with two of the four flow rates (runs 1, 3 in Table 1) owing to its limitations in volume discharge capacity. The experiments were conducted with large (≈40 mm) celluloid spheres (table tennis balls). The densities of the spheres were carefully prepared to represent the hydrodynamic characteristics of positive, neutral and negative buoyant gross pollutants. This was achieved by filling the partially (0.9 RD) and neutrally buoyant (1.0 RD) spheres with tap water, while the floatables (0.1 RD) were left empty. The sinkable (1.1 RD) spheres were filled with salty water (100 gm of NaCl per L of H_2O). In order to provide reliable statistical data, each RD density batch consisted of a total of 300 spheres, sufficient to fill the retention area of the GPT.

Each sphere was numbered, repeatedly measured and filled to its correct weight and the desired density, with an estimated error of ±2% (de Souza and Brasil, 2009). The external diameter was measured to ±0.01 mm and weighed to within ±0.001 g. To fill the spheres to the required density, two types of syringes were used (30 cc and 5 cc), the larger for the initial filling and the smaller to

Table 1
Setup of experimental flow regimes in the GPT, water depth (WD) and flow rate (Q) and their designated runs.

Run	WD in GPT (m)	Flow rate (L/s)
1	0.1	1.3
2	0.3	3.9
3	0.1	6.1
4	0.3	35.4