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Evaluating quantities of stormwater flow in a gross pollutant trap: an empirical methodology

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ABSTRACT

Urban gross stormwater pollutants are considered ecosystem and wetland stressors. Gross pollutant traps (GPTs) filter the stressors from urban stormwater runoff. Extreme rainfall variability severely impacts on stormwater systems, including GPTs. A proprietary GPT, with unique internal configurations and hydrodynamic filtration characteristics, was evaluated using empirically derived flow quantities. Extreme (adverse) GPT flow operations with fully blocked screens and low/high downstream tidal waters were modelled in a flume. An empirical methodology was developed to collect, analyse and verify the acoustic Doppler velocimeter (ADV) flow data. Between three cross-sections of the GPT—the inlet, buffer and retention area—the fluid exchanges were measured and examined. Velocity profiles, measured with differently oriented ADV probes, were spline interpolated and integrated. The integrated results showed that no more than 18.7% of the volumetric fluid initially enters (and subsequently leaves) the retention area via the inlet. Alternatively stated, at least 81.3% of the gross pollutants are expected to directly exit the GPT via the bypass-channel. Errors observed in the flow results were within 10% of the expected values. The influence of the ADV probe configuration (orientation) and techniques of measuring in narrow spaces were also reported.

1. Introduction

Gross pollutant traps (GPTs) protect the ecological health of receiving waterways and ecosystems, by filtering anthropogenic litter and organic matter, from urban stormwater runoff (Commonwealth of Australia, 2016). Excess gross pollutants are described as a wetland stressor (Stricker, 2010; Kessler, 2006) and their detrimental impact is well documented (Madhani et al., 2009a). Wetland flooding caused by excessive amounts of gross pollutants and the need for more GPTs have been reported in mainstream news ("Council Review Wetland Damage" 2007). The demand for proprietary (patented and registered designs developed by industry) GPTs has been growing since wetlands are frequently being created and restored in urban areas (Suding, 2011; Zhang et al., 2010; Mitsch et al., 2005).

In Australia, the demand has led to an influx of proprietary GPTs and the need for research on these devices is evident (Madhani et al., 2011). This paper contributes to ongoing research on the testing and evaluation of GPTs. The collected hydrodynamic and capture-retention data form a basis for the operation, management and maintenance of these devices, including any future design improvement studies.

The device under the ongoing evaluation, the *LitterBank* manufactured by C-M Concrete Pty Ltd, is a rectangular flow through GPT designed with internal and external screens. The screened compartment (left, Fig. 1), the retention area of the device (Fig. 2), captures and retains the gross pollutants as stormwater enters the GPT. When the retention area is full, the adjacent bypass-channel (right, Fig. 1) enables the incoming gross-pollutants to directly exit the device with stormwater; the free-passage prevents upstream blockage and flooding in the stormwater drainage system. The inlet and buffer (Fig. 2) are additional flow regions in the internal layout of the GPT, their interface being the entry to the retention area. These regions have been labelled to assist in the subsequent stormwater flow analysis.

Unlike the *LitterBank*, current GPTs tend to have an underground chamber (sump) between the inlet and outlet, separating stormwater pollutants by gravity (Madhani et al., 2011). To avoid waste biodegradation in water and the release of toxic substances downstream stormwater paths, the *LitterBank* is designed to be dry

Abbreviations: ADV, Acoustic Doppler velocimeter; CFD, computational fluid dynamic; COR, correlation; GPT, gross pollutant trap; RD, relative density; SNRs, signal-to-noise ratios.

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Fig. 1. *LitterBank* with screened compartment (left) and bypass-channel (right).

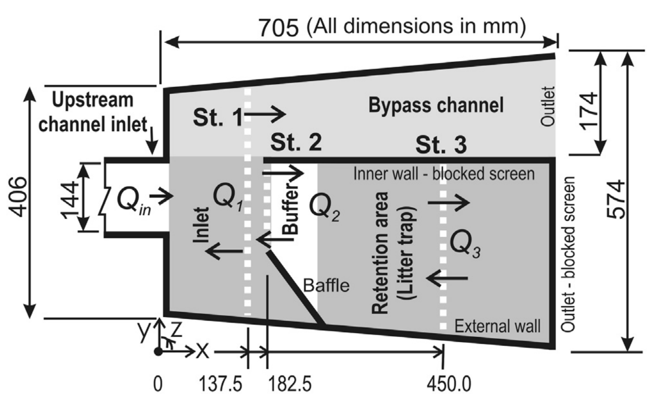

Fig. 2. Plan of upstream channel-inlet and *LitterBank* model. Blocked screens shown in Fig. 3. The superimposed coordinate system (z-axis extends into page), downstream or outflow direction (rightwards arrows) corresponds to the positive x-axis. The dimensions and measurement Stations 1–3 (dash lines) are at St. 1 (x = 137.5 mm), St. 2 (x = 182.5 mm) and St. 3 (x = 450.0 mm). The key flow regions are labelled: inlet, buffer (trap entry), retention area and bypass-channel. The channel-inlet Q_{in} and net flow rate component $Q_i\{i = 1, 2, 3\}$ are illustrated to aid flow analysis (Section 3).

because the floor slightly slopes towards the outlet. Consequently, the installation and excavation costs are less than devices with underground chambers. Costly effluent draining procedures during maintenance (cleanouts) schedules are also avoided. Furthermore, the *LitterBank* discourages the habitation of aquatic life forms and their potential harm during effluent cleanouts.

The *LitterBank* design has unique internal configuration and hydrodynamic separation characteristics that require flow and capture-retention evaluations like all proprietary GPTs. This paper focuses on the evaluations using empirically derived flow quantities. The empirical methodology is a systematic and methodical approach for collecting, analysing and verifying the GPT acoustic Doppler velocimeter (ADV) data.

Fluid exchanges and volumetric quantities of stormwater flow Q_i were measured and examined between three GPT cross-sections, the inlet Q_1, buffer Q_2 and retention area Q_3 (Stations 1–3, Fig. 2). The volumetric flow results were then evaluated as parameters to analyse the GPT capture-retention performance. The empirical flow methodology can either complement or reduce the need for labour-intensive experiments with artificial or real gross pollutants during evaluation (Madhani and Brown, 2014).

Periods of extreme drought and flood cycles have impacted on stormwater management and environmental flows (Tozer et al., 2016). Since GPTs are also impacted, flow data on these devices are equally important in flood management. Subsequently, fully blocked screens, low/high downstream tidal waters and flows below/above the intended GPT design limits were modelled in an experimental flume. Volumetric flows were indirectly measured using differently oriented side and down-looking ADV probes at multi-depth and near-wall positions. The ADV data were of sufficient detail to process (spline interpolate and integrate) the set of velocity profiles at each cross-section and obtain the upstream-downstream (outflows-inflows) flow components of Q_i.

Although ADVs are widely used both in laboratory and field applications, errors associated with wakes produced by the probes have been highlighted (Abad et al., 2004). In the proximity of solid boundaries, stream-wise velocity components have been underestimated when validated with other instruments (Chanson, 2008). Disturbances and dampening effects on flow structures have also been observed (Lemmin et al., 1999; Tyack and Fenner, 1999). Voulgaris and Trowbridge (1998) discuss the advantages of using ADVs compared to other measuring systems. Stormwater contaminated with dirt particles and taking measurements at turbulent flow rates—the criteria for this experimental work—are conditions suited to the robust nature of the ADV probes. Literature on ADV measurements in smaller structures, for example the *LitterBank* GPT, is not well documented.

For this paper, the ADV data uncertainties, attributes and operations in the narrow spaces of the GPT were evaluated with: comparative measurements between the side-looking and down-looking ADV probes; mass conservation compliances between the downstream Q_i^+ and upstream Q_i^- flow components across Stations $\{i = 2, 3\}$; the inlet region ADV processed Q_1 and the independently measured channel-inlet Q_{in}, and lastly, the near-wall signal-to-noise ratio (SNR) behaviour during ADV measurements.

Details of the empirical methodology are presented in the Experimental Methods and Flow Analysis (Data-Processing) Sections 2 and 3. The outcome of this research correlates the capture-retention flow interpretations with the previously collected gross pollutant data from experiments with 40-mm spheres (Madhani and Brown, 2014).

2. Experimental methods

Experiments were performed in the hydraulic laboratory at Queensland University of Technology using the methods described below in the experimental rig, ADV probe details and measurement technique Sections 2.1, 2.2 and 2.3.

2.1. Experimental rig

An experimental rig—a 50% scale *LitterBank* model and an upstream channel-inlet structure—was placed in a square section (19 m long, 0.6 m wide and, 0.6 m deep) tilting flume (Fig. 3). Fully blocked baffle, inner and outlet screens—in the retention area of the *LitterBank* (Figs. 2 and 3)—were modelled with Perspex walls. Inside the flume, water flowed through an upstream channel-inlet of width 144 mm (Fig. 2), the height extended to the full depth of the *LitterBank* model (Fig. 3). The water flow and depth operating conditions were regulated by a weir arrangement at the downstream end of the flume raceway terminus (Fig. 4). An electromechanical rack and pinion arrangement (Fig. 4) adjusted the weir at different heights relative to the flume raceway floor. The constant flow rates (Table 1) were established via controller settings on the centrifugal pumps, circulating the water from underground storage tanks into the flume. A matrix of targeted flow regimes and their designated runs are listed in Table 1. The 1.3-L/s and 3.9-L/s lower targeted flow rates, for Runs 1 and 2, corresponded to a mean inlet velocity