A LITERATURE REVIEW ON RESEARCH METHODOLOGIES OF GROSS POLLUTANT TRAPS

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Abstract: This paper presents a comprehensive review of scientific and grey literature on gross pollutant traps (GPTs). GPTs are designed with internal screens to capture gross pollutants—organic matter and anthropogenic litter. Their application involves professional societies, research organisations, local city councils, government agencies and the stormwater industry—often in partnership. In view of this, the 113 references include unpublished manuscripts from these bodies along with scientific peer-reviewed conference papers and journal articles. The literature reviewed was organised into a matrix of six main devices and nine research areas (testing methodologies) which include: design appraisal study, field monitoring/testing, experimental flow fields, gross pollutant capture/retention characteristics, residence time calculations, hydraulic head loss, screen blockages, flow visualisations and computational fluid dynamics (CFD). When the fifty-four item matrix was analysed, twenty-eight research gaps were found in the tabulated literature. It was also found that the number of research gaps increased if only the scientific literature was considered. It is hoped, that in addition to informing the research community at QUT, this literature review will also be of use to other researchers in this field.

Key words: gross pollutant trap, GPT, literature review, testing, research gap, stormwater.

1 INTRODUCTION

During a rain event, pollutants are collected by stormwater on the urban runoff path and discharged into receiving waterways (Madhani, 2010). Unmanaged, stormwater pollution can result in considerable damage to the aquatic and terrestrial ecosystem. Stormwater pollutants can inflict physical, chemical and/or biological damage. The detrimental impact of stormwater pollutants are well documented (Madhani, 2010). The visible impact of gross accumulated pollutants—organic matter and anthropogenic litter—in waterways is generally perceived to indicate poor water quality. Findings from field work also showed that gross pollutants, especially with water absorbing surfaces such as leaves and paper, are also potential carriers of the finer and more harmful pollutants (Madhani, 2010). Consequently, gross pollutant traps (GPTs) play an important role in preventing visible street waste—gross pollutants—from contaminating the environment.

Gross pollutant traps, including patented and registered designs developed by industry, have specific internal configurations and hydrodynamic separation characteristics which demand individual testing and performance assessments. Despite the introduction of new GPT designs over the past decade due to stormwater pollution concerns, scientific literature is surprisingly limited. It is not clear whether this lack of GPT data is due to cost factors, insufficient resources and government standards, or to the reluctance of manufacturers in sharing their GPT data. For example, a local city council in Australia listed over fifteen types of GPTs available for purchase. However, despite the availability of the GPTs, evaluation data pertaining to their gross pollutant capture/retention performance is scant (Madhani, 2010).

To compensate for the lack of scientific data, this review also embraced other non peer-reviewed or grey literature sources. These sources consisted of professional societies, research organisations, local city councils, government agencies and the stormwater industry involved in the design, manufacture and testing of GPTs.

Apart from the conventional (trashracks) and linear/radial GPTs, other stormwater quality improvement devices (SQIDs) which are well documented in literature were also included in this review to establish a common testing framework. Such devices included storage/detention tanks and vortex/hydrodynamic separators. The outcome of this review is presented and discussed in this paper.

2 METHODOLOGY

A literature review of GPTs and listed devices was performed using bibliographic databases, citation indexes and the internet sites of professional bodies and research organisations. In this paper, these references are defined as primary, secondary and tertiary literature sources that are for journals, conference proceedings and unpublished/non peer-reviewed manuscripts, respectively. The literature was organised under five types of articles (Tab. 01).

TABLE 01: Classification of scholarly and professional manuscripts

Item	Articles	Sources	*PR (Y/N)
1	Journals	primary	Y
2	Conference proceedings	secondary	Y
3	Scholarly Books	secondary	Y
4	Miscellaneous	tertiary	N
5	Fact sheets	tertiary	N

*Peer-reviewed (PR)

Journals and conference proceedings (See items 1 and 2 in Tab. 01), which have undergone a stringent peer-reviewed process are defined as scientific literature. The Australian Research Council has developed a program [the Excellence in Research for Australia (ERA) initiative] to rank a scientific article according to class, A−C. Class A is considered the highest source of literature (http://www.arc.gov.au/era/default.htm). Scholarly books from scientific research organisations were also considered as peer-reviewed. All non peer-reviewed articles were categorised as either miscellaneous or fact sheets. These items were mostly from professional societies, local city councils, government agencies and the stormwater industry.

3 RESEARCH GAP ANALYSIS

The literature reviewed has been classified into six main treatment devices (A−F) as listed in Tab. 02. Devices A−C are linear, radial and conventional (trashracks) type GPTs. Storage detention tanks and vortex/hydrodynamic separators (Device E and F) have also been included in the review, since these devices are used in the treatment of stormwater pollutants and have received considerable scientific interest in the past.

Tab. 03 records the research methodologies used for the investigation of these devices. A paper might contain one or several records. Hence, the sum of the records may exceed the total number of citations for a particular device (columns A−F, Tab. 03). A high record number denotes considerable scientific interest, while zeros in Tab. 03 signify research gaps. A four page tabulation with the authors names instead of the records has been listed elsewhere (Madhani, 2010). For the sake of brevity this tabulation has not been repeated here.

TABLE 02: Key devices (See Tab. 03)

Device	Description
A	Linear GPTs with dry sump—*LitterBank*
B	Linear GPTs with wet sump
C	Radial GPT, continuous deflective separation (CDS)
D	Conventional GPTs—trashracks
E	Storage detention tanks
F	Vortex/hydrodynamic separators

TABLE 03: Number of papers cited for devices defined in Tab. 02

No.	Research Methodology	Devices (See Tab. 02)					
		*A	B	C	D	E	F
1	Design	0	7	6	19	4	11
2	Field work	1	3	12	10	2	8
3	Blockage	1	0	2	1	0	0
4	Flow field	3	0	0	2	3	2
5	Visualisation	1	0	0	0	0	1
6	CFD	2	0	1	0	9	11
7	Head loss	1	1	1	1	0	1
8	Capture	2	0	0	0	2	5
9	Dye	2	0	0	0	2	5

***Column A (items 1-9) was initially filled with zeros. The identified research gaps were mostly filled by a study following this literature review (Madhani, 2010).

The research gap analysis was based on devices B−F. Device A is a recently developed proprietary GPT. The main purpose of this review was to identify the research gaps for this GPT. Since the completion of this literature review, the GPT (device A) has been comprehensively investigated using the research methodology, items 2−9, in Tab. 03.

Gross pollutant traps were first commissioned in Canberra, Australia in 1979 (Madhani, 2010). These were the conventional and non-proprietary GPTs, designed to trap larger gross pollutants and sediments in open stormwater detention areas.

A similar but smaller non-proprietary GPT—located in a Brisbane suburb (See Fig. 01), was primarily constructed to treat urban drainage catchments or large areas commonly termed 'non-point' or 'diffuse source'.

A conventional open GPT structure (See Fig. 01) typically consists of a large concrete wet basin, weir and trashrack to screen gross pollutants. The sedimentation basin is designed to reduce the velocity of the incoming stormwater flow by its large dimensional width. Within the basin, the reduced velocities encourage the deposition of sediments. Downstream, across the basin, atop a weir, the vertical or horizontal bars of the trashrack capture the larger pollutants. Bars are typically spaced between 40 to 100 mm apart.

Conventional GPTs, like most SQIDs that use trashracks, require frequent cleaning, especially after a storm event. Trashrack devices are associated with frequent maintenance and the cleaning is labour-intensive. These devices are susceptible to hydraulic head losses and blockages which often lead to upstream flooding (Madhani, 2010). Moreover, when the trashrack screens are blocked, without a separate bypass channel, the captured pollutants are often scoured from within the retention area and transported downstream during major storm events.

FIGURE 01: An open GPT consisting of a basin, a trashrack with vertical bars atop a weir located at Bedivere Street, Carindale on the outskirts of Brisbane (November, 2008).

The demand for more compact and efficient GPTs produced an influx of mostly proprietary devices (Madhani, 2010). The newer and more recent devices were designed to only remove gross pollutants. Hence, the velocity of the incoming stormwater flow was not considered to be an important design consideration as it had been with the sediment basins. The installation of modern smaller-footprint GPTs was not restricted to large open spaces, since a sedimentation basin was no longer required.

Also, unlike the exposed trashracks, the more recent GPT designs had finer screens and the trapped contents were concealed, thus preventing odour problems during dry periods (Madhani, 2010).

The more recent and newer GPTs are classified as either radial or linear fluid motion devices used to capture gross pollutants from stormwater.

In contrast to the linear GPT designs, continuous deflective separation (CDS) GPTs and vortex/hydrodynamic separators—devices C and F in Tab. 03—use radial fluid motion for capturing/retaining pollutants.

The use of vortex/hydrodynamic separators for treating combined sewer overflow (CSO) effluent in urban drainage was first documented in the early 1960s (Andoh & Saul, 2003). These separators were the modified original hydro-cyclones which were used in the coal, food, paper and petroleum industries (Bergström & Vomhoff, 2007). Here, the hydro-cyclones were deployed to separate solids, liquids or gases of different densities by gravity.

The tapered body of the hydro-cyclone was modified to incorporate a wider constant cross section insert to treat sewer and stormwater effluent. Depending on the design, either baffle/deflection plates or screens were fitted to capture the incoming pollutants.

The design of the vortex/hydrodynamic separator was further modified for the stormwater industry. For example, the continuous deflective separation (CDS) device uses circular internal retaining screens to capture/retain stormwater pollutants (Wong, 1997).

The Australian designed CDS has received considerable scientific interest in comparison to linear GPTs (Madhani, 2010).

Although several design variants of linear GPTs (See devices A and B, Tabs. 01and 02) exist, data is scant for these linear fluid motion devices (Madhani, 2010). Furthermore, the current data shown in Tab. 01 relates to water retaining GPTs (device B), which is similar to the other devices listed in this table. Data for GPTs which do not retain water (dry sump) was not available prior to this literature review. It is unclear whether the modelling complexity involved in performing scientific investigations on a GPT with a dry sump is a deterrent (Fig. 02). For example, it is necessary to devise an experimental methodology to perform fluid measurements in this type of GPT, which requires a minimum depth of water.

A dry sump GPT was recently developed by C-M Concrete Pty Ltd. This GPT, the *LitterBank,* uses retaining screens (Fig. 02) to collect gross pollutants prior to the release of stormwater into natural waterways. Currently there are approximately 20 *LitterBanks* operating at strategic stormwater locations throughout Queensland, Australia.

FIGURE 02: GPT—*LitterBank* in situ.

With regard to wet sump GPTs, there are issues due to waste biodegradation in water. Wet GPT systems generally require frequent cleaning as waste biodegradation in water releases toxic substances downstream through a biological and chemical decomposition process. Biodegradation of organics in a GPT is also capable of producing strong odours during cleanouts, prompting residents to complain (Madhani, 2010). Brisbane City Council (2004) also reports similar anaerobic conditions for their devices in which ammonium nitrogen is produced.

Wet sump GPTs also require costly maintenance schedules due to the procedure to drain and remove the captured pollutants. Additionally, informal reports by local residents indicate many of the aquatic inhabitants are killed during cleanouts. Both issues would be a cause for public concern. Overall, data on the problems with wet sump GPTs are lacking in scientific literature.

Floating booms are also classed as GPTs. These devices operate in water and to date have received little interest. They comprise a string of partly submerged booms located across waterways and were originally designed as oil slick retention devices suitable in slow moving waters. Consequently, these devices are highly suited for the retention of buoyant articles such as plastic bottles and polystyrene. However, they were omitted from Tab. 02, due to the lack of available scientific data.

To compensate for the general lack of GPT data, literature on similar devices which may have common investigating methodologies have been included in Tab. 03. These devices include vortex/hydrodynamic separators and storage/detention tanks which have been deployed in sewer networks (Andoh & Saul, 2003; Stovin & Saul, 1994).

Sedimentation and settling basin/detention tanks have received considerable interest since 1904 (Hazen, 1904). Here, the velocities of the incoming effluent are reduced and the settling of pollutants is achieved through gravity. The more recent investigations of the storage/detention tanks which separate both gross and fine sewer solids are included in Tab. 03.

3.1 Research methodologies for testing GPTs

Gross pollutant traps, including patented and registered designs, have some specific internal configurations and hydrodynamic separation characteristics which demand individual testing and performance assessment. Despite this demand, little scientific data on evaluating the performance of GPTs exists. However, data from the literature revealed that water treatment devices have been generally investigated using one or more of the methodologies listed in Tab. 03 (See nos. 1−9). The research methodologies are design appraisal studies, field testing, blockage investigations, experimental capture of flow field/velocity profiles, flow visualisations, head loss, computational fluid dynamics (CFD), capture/retention experiments using real or artificial pollutants and tracer dye measurements.

3.1.1 Design/overview studies

Design/overview studies (See no. 1, Tab. 03) contain literature pertaining to the review of new devices or qualitative experiments for evaluating their designs.

3.1.2 Field work

There are currently no recognised standard procedures for either field (See no. 2, Tab. 03) or laboratory testing of GPTs in Australia. As shown in Tab. 03, research methodologies 3−9 are mainly performed in the laboratory. Although, design guidelines for GPTs in Australia have recently been documented (Wong et al., 2006), these guidelines do not take into account recent field and laboratory findings such as typical performance data (Madhani, 2010).

In Australia, evaluation/verification programs for new devices in the stormwater industry are not well established. Overall, these programs rely largely on field evaluations. In this regard, field monitoring and comparative investigation of proprietary GPTs which have been previously reported, follow no specific testing procedures. Several authors concluded that comparative investigations are only possible if the testing procedures are standardised, regardless of their unique stormwater treatment application (Madhani, 2010).

To regulate the performance of newly developed stormwater treatment devices, field testing verification programs have been established in the USA (Madhani, 2010). The programs are usually carried out by the environmental protection agencies (EPAs), professional bodies and water research centres. The American Society of Civil Engineers (ASCE) and the Environmental Water Resource Institute (EWRI) are examples of professional and research organisations actively involved in these evaluation/verification programs. Recently, the American Society of Civil Engineers (ASCE)/Environmental and Water Resource Institute (EWRI) went a step further by forming a task committee to review the current regulations and to propose new guidelines for the certification of manufactured stormwater best management practices (BMPs).

The new guidelines shifted the earlier focus on field monitoring assessments to evaluation methodologies such as laboratory testing (Madhani, 2010).

This shift is understandable because the collection of field data is site specific and dependent on weather conditions, with a single test taking years to complete (Madhani, 2010).

Most field results also lack meaningful performance assessments of GPTs, since it is only the captured pollutant data that is recorded and not the removal efficiencies (Madhani, 2010). To determine the removal efficiencies of the GPT, the escaped pollutants should also be monitored. Consequently, laboratory testing is considered to be more effective, rapid and less costly than the conducting of numerous field trials (Madhani, 2010).

The inclusion of laboratory testing in the evaluation/verification of the performance on newly developed GPTs is supported by researchers and the stormwater industry. The advantage of laboratory testing usually outweighs field monitoring assessments of GPTs for a number of reasons. For example, logistics, resources, non-site specifics, non-weather dependence, and cost as demonstrated by Madhani (2010).

3.1.3 Blockages

Field observations have shown that internal retaining screens are commonly blocked with organic matter due to infrequent cleaning (Madhani, 2010). Blocked GPTs can cause upstream flooding, resulting in the stormwater system becoming inoperable.

A bypass is a necessary design feature of the GPT, to allow the incoming pollutants to escape—short-circuiting—when the device is blocked (Madhani, 2010). Subsequently, the study of devices operating under adverse conditions becomes even more important.

Blockages in a GPT/trashrack impacted by flooding have been previously studied (Abt, Brisbane, Frick & McKnight, 1992). Experimental and CFD flow field were used to investigate blocked hydrodynamic separators used for CSO systems and a radial GPT (Ismail & Nikraz, 2009; Tyack & Fenner, 1999). Recently, the performance of a linear GPT (device A) with various screen blockages has been evaluated using hydrodynamic and head loss research methodologies (See nos. 4−7, Tab. 03). Hydrodynamic investigations consist of velocity measurements and CFD to capture global and local flow field data (See nos 4−6, Tab. 03).

3.1.4 Hydrodynamic investigations

Hydrodynamic investigations of SQIDs have been undertaken to understand their removal, capture and retention characteristics. For example, flow field data obtained by CFD simulations have been used to complement measurements and provide detailed flow insights (Madhani, 2010). Experimental and CFD near wall modelling of flow features have also been recently undertaken (Madhani, 2010). Best practise guidelines for CFD studies are well documented (Casey & Wintergerste, 2000). Such guidelines have been used in this research for performing theoretical hydrodynamic studies using CFD.

Examples of insights gained from hydrodynamic studies include the identification of areas relating to high and low velocity, and regions of flow re-circulation. These flow features can cause erosion, containment and/or mobilisation of pollutants respectively (Madhani, 2010). The deposition patterns of particles have been shown to be directly related to the flow patterns observed on the surface of the water (Stovin, Saul, Drinkwater & Clifforde, 1999).

The presence of low velocity regions in vortex/hydrodynamic separators encourages the formation and settling of large particles, thereby improving the separation efficiency (Tyack & Fenner, 1999). Flow patterns are used to determine characteristics conducive to the removal or retention of particles in stormwater treatment chambers (Faram & Harwood, 2002) .

Velocity measurements using the Acoustic Doppler Velocimeter (ADV) and CFD have also been used to study flow patterns with a view to identifying important features such as short-circuiting in vortex stormwater separators, sewer structures, sedimentation basins, dissolved air floatation (DAF) tanks and aquaculture raceways (for a list of authors, see Madhani, 2010). Short-circuiting in GPTs plays an important role when the device is blocked. In other devices, short-circuiting denotes a lack of mixing such as in ponds and wetlands.

The analysis of flow features with a view to understanding the capture/retention characteristics of GPTs, particularly ones with blocked screens, has received limited scientific interest to date. More specifically, experiments using velocity measurements, flow visualisation techniques and CFD data (Tab. 0.2) are scarcely reported. Recent studies have demonstrated the use of such techniques for investigating the performance of Device A (Madhani, 2010).

Image based flow visualisation techniques using the hydrodynamic particle image velocimetry (PIV) dataset collected from device A have also been recently reported (Madhani, 2010). A set of flow patterns was obtained and visualised through an image-based line integral convolution (LIC) algorithm producing a dense representation of streamlines. Such visualisations which are superior to conventional hedgehog or arrow plots were used to detect differences between the shallower and deeper water flow patterns in the retention area of the GPT. The visualised PIV flow patterns clearly showed superior flow domain coverage than the previous ADV measurements.

3.1.5 Gross pollutant capture/retention experiments

Capture/retention experiments (See item 5 under device B, Tab. 01) with GPTs have been conducted using mostly real floating litter items (Phillips, 1999) and artificial pollutants (Armitage & Rooseboom, 2000). In those experiments, artificial pollutants were chosen for their settling velocities; often, a single type was used for simulating sediments. The use of plastic pollutants with different densities has been reported elsewhere but no details were given (Armitage & Rooseboom, 2000). However, customised variable density spherical objects (artificial pollutants) filled with liquid were recently used to investigate the capture/retention characteristics of a GPT (Madhani, 2010). Since the GPT is designed to treat a range of gross pollutants, these objects were classified into floatable, partially submerged, neutrally buoyant and sinkable objects in experiments. The experimental results were used in conjunction with hydrodynamic measurements to describe the positive and negative attributes both of the capture/retention characteristics and the design of a GPT.

Custom made pollutants with different densities require lengthy preparation. Thus, tracer dye has also been used to study the removal efficiency of SQIDs such as hydrodynamic separators, ponds and wetlands (Persson & Wittgren, 2003; Phipps, Alkhaddar, Loffill, Andoh & Faram, 2008). However, dye is limited in its representation of pollutants of varying densities (Madhani, 2010).

The dye investigations did not include factors such as the concentration and remobilisation of pollutants; the hydrodynamic forces due to pressure, inertia and drag; or the interaction with neighbouring pollutants and the boundary walls. For larger pollutants, the process of accumulation rapidly transforms the free space in the GPT into solid boundaries, which in turn changes the fluid path motion. The particle/coupling mechanism in CFD simulation to address these factors and modelling issues is a relatively new concept.

Alternatively, the decoupling approach to CFD simulation of the separation of fine sediments and suspended gross solids is well established; nevertheless, the outcomes are not always successful (Stovin, Saul, Drinkwater & Clifforde, 1999). Consequently, gross pollutant capture/retention experiments are still necessary despite their lengthy preparation. For this reason, tracer dye experiments are still used as an alternative option.

3.1.6 Tracer dye

Tracer dye experiments are rarely reported for the devices shown in Tab. 02, and none for GPTs. The tracer dye studies shown in the table for vortex/hydrodynamic separators are based on CFD simulation.

The dye experiments are useful to study flow characteristics in fluid systems (Lapidus, 1957). For example, fluids entering dead zones have very long residence times and a high percentage of suspended and buoyant particles are held here indefinitely (Madhani, 2010). The output time series data (dye concentration versus time curves of the effluent) was used to determine the residence time distribution (RTD) and the average time the fluid takes to pass through the boundary systems (Levenspiel, 1999).

The relationship between the fluid residence time and pollutant removal in SQIDs has been investigated (Persson & Wittgren, 2003). The pollutant removal efficiency of vortex devices was shown to be strongly related to the RTD in wastewater and stormwater treatment processes (Alkhaddar, Higgins, Phipps & Andoh, 2001).

Existing methods of tracer dye experiments tend to rely on non-continuous grab samples or sampling at low frequencies. Probes used to detect dye concentrations in open waterways (rivers, ponds, wetlands etc.) tend to be bulky, and the sampling frequencies are much lower (Madhani, 2010).

Furthermore, most studies only report the results of the outlet tracer concentrations. Hence, the mass balance error with the inlet is unquantifiable. The mass balance error is an important confidence level indicator of the data sampled (Madhani, 2010). The inlet data also indicates the homogeneity of the dye and water mixture in order to achieve consistency in the measured concentrations.

Custom built tracer dye (Komori) probes have been recently used in device A for performing residence time measurements in conjunction with gross pollutant capture/retention experiments (Madhani, 2010). These probes were designed to fit into confined spaces. The results compared favourably with CFD data.

4 RESULTS AND DISCUSSION

The outcome of the reviewed literature review as tabulated in Tab. 03 provided a framework for comprehensively investigating a GPT (Madhani, 2010). The forty-five item matrix in Tab. 03 revealed that there are twenty-eight research gaps (including the eight gaps for device A)—represented by the total number of zeros in this table. The gaps were found from the analysis of 113 papers which were grouped according to their citation details. The details refer to peer- review and the total number of papers cited for each device is displayed in the form of a histogram (Fig. 03).

For most of the devices listed, a large number of studies refer to the design appraisal study and field work methodologies (See Tab. 03). It is noted that these methodologies are currently used as standard testing techniques by the stormwater industry.

It was also observed from the reviewed literature that a wider range of testing strategies has been applied to vortex/hydrodynamic separators than on other devices. For example, only one research gap exists for vortex/hydrodynamic separators (See No. 3, Tab. 03). This is followed by three gaps for the storage detention tanks.

Storage detention tanks are associated with sedimentation and settling basin/detention, ponds and wetlands. Such devices continue to receive considerable scientific interest. For the sake of brevity, only storage detention tanks were considered for this literature review.

With the advancement of technology and new affordable techniques for measuring and predicting fluid velocities, CFD modelling techniques are also predominant in the literature for some SQID devices such as vortex/hydrodynamic separators and storage detention tanks. This also applies to the physical modelling of these devices which includes a set of measurements in the laboratory (See Research Methodology nos. 3−9, in Tab. 03).

The successful outcomes of these investigations are forcing the stormwater industry to re-evaluate its testing strategy with the added incentives of logistics and cost.

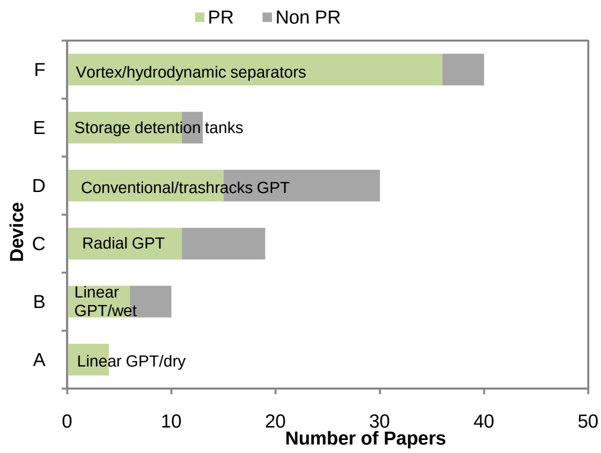

FIGURE 03: A histogram of papers cited for the devices

Unlike GPTs, literature on the storage detention tanks and vortex/hydrodynamics consists mainly of peer-reviewed articles. In case of the older GPTs (conventional/GPTs), non peer-reviewed manuscripts contributed as much as 50 per cent of the literature. Furthermore, this type of GPT has received more scientific publications than the more recent—the linear and radial—GPTs (Fig. 03).

It is unclear whether the lack of publications on the recent GPTs is due to the manufacturers' reluctance to share data on their development. In view of this, grey literature can play a supporting role in providing additional scientific data or fill research gaps. In Tab. 03, grey literature covered less than 10 per cent of research gaps. However, grey literature was found to fill other gaps where scientific data has been scant, such as results from varied testing locations. For example, an unpublished report from Brisbane City Council provided data in Queensland where scientific data on GPTs is scant (Brisbane City Council, 2004).

The applied nature of GPTs involves professional societies, research organisations, local city councils, government agencies and the stormwater industry, with bodies often in partnership with one another. In the procurement and operations of SQIDs, these bodies have solid knowledge and experience which is often reflected in their non peer-reviewed manuscripts. Consequently, they were included in the literature review of GPTs.

Overall, the result of the literature review showed that testing of GPTs is not well established and limited to field testing. There is little data on the adverse operating conditions such as blocked screens. Scientific data for the dry linear GPTs was scant.

This led to a comprehensive investigation of this device, see column device A in Tab. 02 (Madhani, 2010).

5 CONCLUSIONS

A comprehensive literature review pertaining to GPTs was undertaken. The applied nature of GPTs involves professional societies, research organisations, local city councils, government agencies and the stormwater industry. In view of this, non peer-reviewed manuscripts from these bodies were included in the literature review which covered 113 cited articles from various sources. Where scientific data was lacking, it was found that non peer-reviewed manuscripts contributed to at least 50 per cent of the scientific literature and in some cases filled the research gaps.

The outcome of the literature review revealed twenty-eight research gaps. This led to a comprehensive investigation of a particular GPT in which eight of the research gaps were successfully filled.

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