Experimental study of hydraulics and sediment capture efficiency in catchbasins

Yangbo Tang, David Z. Zhu, N. Rajaratnam and Bert van Duin

ABSTRACT

Catchbasins (also known as gully pot in the UK and Australia) are used to receive surface runoff and drain the stormwater into storm sewers. The recent interest in catchbasins is to improve their effectiveness in removing sediments in stormwater. An experimental study was conducted to examine the hydraulic features and sediment capture efficiency in catchbasins, with and without a bottom sump. A sump basin is found to increase the sediment capture efficiency significantly. The effect of inlet control devices, which are commonly used to control the amount of flow into the downstream storm sewer system, is also studied. These devices will increase the water depth in the catchbasin and increase the sediment capture efficiency. Equations are developed for predicting the sediment capture efficiency in catchbasins.

Key words | catchbasin, inlet control device, sediment capture efficiency, stormwater, sump

INTRODUCTION

Stormwater sediments can cause many negative impacts on the receiving water bodies. High levels of sediment concentration contribute to higher turbidity which limits sunlight penetration, thereby prohibiting the growth of aquatic plants (Aryal & Lee 2009). Sedimentation can also clog fish spawning grounds and reduce the conveyance capability of the streams or rivers receiving water from storm sewer system. Additionally, pollutants adhering to sediment, including heavy metals, salt, hydrocarbons and high concentration of nutrients (e.g. total nitrogen and total phosphorus), pose direct threats to aquatic life and water quality (US Environmental Protection Agency 1993; The City of Calgary 2011). In order to remove sediment, various sediment control practices have been adopted recently (Wilson et al. 2009; He & Marsalek 2014; Gu et al. 2016). Catchbasins receive surface runoff and can potentially retain sediment, grit and detritus before these are flushed into the storm sewers (Aronson et al. 1983). In the United States and Canada, circular and rectangular catchbasins with an average depth of 182 cm are used, mostly with sumps (Lager 1987).

A number of factors impact on the sediment capture efficiency in catchbasins. One important factor is the sediment characteristics. Generally, sediment entering catchbasins is inorganic and non-cohesive, with a specific gravity ranges from 2.60 to 2.80 (Clegg et al. 1992). However, small particles (with a size less than 50 μm) tend to be silt or clay with a significant organic component and can have a specific gravity as small as 1.1 (Roesner & Kidner 2007; Burt 2011). Inflow sediment concentration also affects the sediment capture efficiency. The sediment size is the key variable to determine sediment settling ability. The particle median size d50 is usually treated as the characteristic size of a group of particles. Sediment in storm sewer systems can be transported as suspended sediment or bedload sediment, or settle to form sediment deposits. The sizes of suspended sediment vary from less than 1 μm to over 600 μm with a value of d50 between 8 μm and 100 μm (Selbig & Bannerman 2011; The City of Calgary 2011; Goncalves & Van Seters 2012; Boogaard et al. 2014). Bedload sediments usually are characterized by bigger sediment sizes. Several studies reported that in storm sewers bedload sediment d50 value varies between 0.25 mm and 1 mm (Grottker 1990; Sansalone et al. 1998; Almedeij et al. 2010; Bong et al. 2014). Note that hydraulic conditions also affect whether a certain size particle will become suspended sediment or bedload sediment. In northern climates, large particles such as gravel as large as 5 mm are used for winter road de-icing, and some of these particles can be flushed into the catchbasin and become an important...
sediment source. Although these larger particles may only occupy a part of the overall sediment load, their presence can lead to significant blockages in the receiving storm sewer system if they are not captured prior (The City of Calgary 2011).

The earliest research about the sediment capture efficiency of catchbasins was conducted by Lager et al. (1977). Lager et al. measured the sediment capture efficiency under laboratory conditions for various scenarios (i.e. flow rates ranging from 7 to 178 L/s, particle sizes from 0.1 to 2 mm, and various catchbasin designs, albeit all with sumps). With respect to the sediment capture efficiency, it was found that catchbasins can remove medium to coarse sands very efficiently over a wide range of flow rates (i.e. the capture efficiency can reach 65 to 90%). At the maximum flow rate, the capture efficiency was reported to reach 35%. However, a negative capture efficiency may appear when the sediment deposition in a catchbasin is over 40 to 50% of the sump depth which is mainly caused by scouring. Although they observed the sediment capture efficiency in specific catchbasins with various designs, they did not produce a general prediction method. Aronson et al. (1983) collected field data to evaluate the performance of catchbasins in controlling pollution. More than 40 sites were investigated showing 60 to 97% capture efficiencies for total suspended solids. However, this study focused more on the removal of chemical substances. In 1995, Butler & Karunaratne (1995) studied solids trap efficiency in a roadside gully pot and reported capture efficiencies ranging from 15 to 95%.

Wilson et al. (2009) introduced the use of the Péclet number (expressed as a ratio of convective particle transport by settling to transport by turbulent diffusion) from reservoirs to stormwater treatment facilities including catchbasins and ‘standard sumps’ (a cylindrical tank with a vertical axis connecting two horizontal pipes). This work provided a fundamental approach to predict the sediment capture efficiency. Howard et al. (2012) measured the sediment capture efficiency of several standard sumps under laboratory conditions and successfully developed an equation to predict the sediment capture efficiency based on the methods from Wilson et al. (2009). Standard sumps are similar to catchbasins, thus their analytical method can be partly adapted for the analysis of sediment removal in catchbasins.

The configuration of catchbasins also affects the flow hydraulics and sediment capture efficiency. Municipalities typically have their own design guidelines. In Calgary, Canada, catchbasins do not have sumps (The City of Calgary 2011). In the 1940s and 1950s, from the City of Calgary’s point of view, catchbasin sump cleaning and maintenance required too much effort. Hence, sumps were removed from design practice while existing sumps were filled in. In addition, since the late 1980s, the drainage systems in new subdivisions in Calgary have been designed based on the dual drainage principle with installation of inlet control devices (ICDs) in catchbasins. During the major storm events, these ICDs will control the amount of the flow into the downstream pipes to reduce the potential of overloading the storm sewer system. An ICD is usually a steel plate with a small opening, installed at the entrance to the storm sewer to control the amount of the flow to be released into the storm sewer system (The City of Calgary 2011).

In this study, we examine the effectiveness of the current catchbasins of the City of Calgary in sediment capture using a full size laboratory model. The effect of a bottom sump and the installation of ICDs will be examined as well. A wide range of sediment sizes will be tested including large winter de-icing gravels as well as fine solids. General equations will be developed for predicting the sediment capture efficiency. Such prediction equations are important in the design of storm sewers.

**METHODS**

Experiments of a full-size catchbasin configuration were conducted in the T. Blench Hydraulic Laboratory at the University of Alberta. The setup, from upstream to downstream, consisted of a sand and water feeding system, catchbasin and outlet pipe (see Figure 1). Water was supplied by a pump, and the flow rate was measured using a magnetic flow meter with a test range from 5 to 28 L/s. Although this range was relatively small due to the experimental constraints, a wide range of flow conditions can be simulated by using particles of various settling velocities (0.002 to 0.17 m/s, see Table 1). Combined with a general analysis, it is possible to predict the flow and sediment behavior under a large flow rate. A sand feeder (Vibra Screw Inc., Model SCR-20) was used to control the sand feeding rate (g/s) by adjusting its rotational speed (rpm). Sand was added into the water flow through an opening on the crown of the inlet pipe, which had a diameter of 150 mm. At the end of the inlet pipe, a 90° elbow was installed to force the water flow to impinge onto the center of the catchbasin. The use of the elbow for the inflow will likely result in a larger inflow velocity compared to the actual catchbasin; however, our preliminary tests showed that this has
negligible effect on sediment removal efficiency. The catchbasin was 0.9 m square and 1.8 m deep. A false bottom could be added in the catchbasin to represent a catchbasin without a bottom sump. The outlet pipe was a 250 mm diameter Plexiglas pipe. At the entrance of the outlet pipe, an ICD could be installed. The ICD (see Figure 2) was a steel plate with a small opening to control the amount of the flow to be released downstream. The opening of the ICDs consisted of one circular hole and one rectangular area. The circular size of ICD was denoted by its center hole diameter \( D \). Three opening sizes of \( D = 50, 70 \) and 100 mm were studied in this paper (ICD D50, D70, and D100).

Six size groups of sediment were used in the tests (see Table 1 for detailed information). The finest sediment used was BT-13 glass beads (Manus Abrasive System Inc.) with a \( d_{50} \) of 62 \( \mu \)m. The 100 \( \mu \)m size group sand was sieved to be between 75 and 150 \( \mu \)m, and 200 \( \mu \)m size group sand was sieved to be between 150 and 250 \( \mu \)m. Relatively coarse sands Sil 4 \( (d_{50} = 250 \mu m) \), Sil 7 \( (d_{50} = 450 \mu m) \) and Sil 8/16 \( (d_{50} = 1,800 \mu m) \) (Sil Industrial Minerals Inc.) were also used in the experiments. Sil 4, Sil 7, and Sil 8/16 sand are relatively uniform, since their uniformity coefficients \( C_u = d_{60}/d_{10} \) (Yalkowsky & Bolton 1990) are calculated as 1.9, 2.2, and 2.6. A total of six size groups provide a relatively large sand size range for this study. All sands had a 2.65 specific gravity and the glass beads have a 2.51 specific gravity.

Three catchbasin scenarios were studied: (1) without sump and without an ICD (named ‘Without Sump’); (2) without sump and with an ICD (named ‘With ICD’); and (3) with a sump (50 cm depth) and without an ICD (named ‘With Sump’). In each scenario, the test procedures were the same. The test procedures followed a standard method for estimating removal efficiency of sumps and hydrodynamic separators (ASTM International 2012). The first step was to run water until steady state conditions set in and record the relevant hydraulic parameters including the water flow rate, water depth in the inlet pipe (by a tape ruler), water depth in the catchbasin, and the water depth in the outlet pipe (based on photos). Then, the sand adding rate was determined to limit the sand concentration to be less than 0.15 mg/L, a value reported as the normal suspended sediment concentration in storm sewers (Ab Ghani 1993). Since this study only focuses on pure sediment settling without the scour of a previously deposited sediment layer, the chosen small concentration was only able to form a thin sand bed deposited on the catchbasin bottom.

![Figure 1](https://iwaponline.com/wst/article-pdf/74/11/2717/457546/wst074112717.pdf)

**Figure 1** | Experimental setup and flow observations.

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Subsequently, the sand feeder was set by adjusting the rotational speed to obtain the required sand feeding rate. The feeder was run for 5 min for each experiment. Tests with a 10-min duration were also conducted which showed a difference of less than 5%. After each test, the sediment captured at the bottom of the catchbasin was collected, dried and weighed. The capture efficiency of the catchbasin was obtained from the ratio of the amount of captured sand to the amount of sand added. The test flow rates were 5, 7, 14, 21, and 28 L/s, and six types of sand were tested for each flow rate.

RESULTS AND DISCUSSION

Hydraulics of the flow in the catchbasin

In general, two types of flow conditions can be distinguished in this experiment. For the ‘Without Sump’ and ‘With Sump’ scenarios, the flow in the outlet pipe was relatively tranquil even at the largest flow rate (28 L/s). For the ‘With ICDs’ scenario, the flow in the outlet pipe appeared to be wavy and could not attain a tranquil flow state because of the high speed outflow through the ICD, even for the combination of a small flow rate (7 L/s) and the largest ICD (ICD D100) (see Figure 1). The water depth measurements were recorded by a camera. The water depth above the outlet pipe bottom in the catchbasin for the ‘Without Sump’ and ‘With Sump’ scenarios increased from about 10 cm to 24 cm as the flow rate increased from 5 L/s to 28 L/s. The two sets of depths were quite close at the

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Sand information</th>
</tr>
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<tbody>
<tr>
<td>Sand type</td>
<td>Size range (μm)</td>
</tr>
<tr>
<td>BT-13</td>
<td>44–88</td>
</tr>
<tr>
<td>100 μm</td>
<td>75–150</td>
</tr>
<tr>
<td>200 μm</td>
<td>150–250</td>
</tr>
<tr>
<td>Sil 4</td>
<td>40–1,000</td>
</tr>
<tr>
<td>Sil 7</td>
<td>40–1,000</td>
</tr>
<tr>
<td>Sil 8/16</td>
<td>40–2,400</td>
</tr>
</tbody>
</table>

Figure 2 | An ICD installed in the outlet pipe, and ICD dimensions.
same discharge rate (see Figure 3). This indicates that the configuration of the outlet structure governed the water depth in the catchbasin rather than the presence of a sump. The water depth in the catchbasin for the ‘With ICD’ scenario was significantly different from the previous two scenarios: as to be expected, with an ICD, the water level rose quickly with the flow rate. The outflow from the catchbasin corresponded to orifice flow conditions, rather than the open channel flow condition as in the previous scenarios. In particular, with an ICD D50, the water level reached a height of about 90 cm for a relatively small water discharge of 15 L/s.

For orifice flows, the discharge $Q$ can be expressed as:

$$Q = C_d A \sqrt{2gy}$$

(1)

where $y$ is the water depth above the center of the orifice, $A$ is the orifice area, $g$ is gravitational acceleration, and $C_d$ is the discharge coefficient. To simplify the analysis, we treat the ICD as the combination of a circular orifice (with a diameter $D$) and a rectangular orifice (with a width $a$, and a height $b$), see Figure 2. Thus, when the water surface position in the catchbasin is about 20% above the opening (Reader-Harris 2015), the discharge $Q$ can be estimated as:

$$Q = C_d \left[ \frac{1}{4} \pi D^2 \sqrt{2g(h - 0.5D)} + ab \sqrt{2g(h - 0.5b)} \right]$$

(2)

where the depth of water in the catchbasin above the invert of the outlet pipe is $h$, the depth to the center of the circular orifice is $(h - 0.5D)$ and that to the rectangular orifice is $(h - 0.5b)$.

For the ICDs, $a = 3$ cm, $b = 9$ cm, and $D = 50, 70,$ and $100$ mm for ICD D50, D70, and D100, respectively. The measured results in Figure 3 are then used to fit a discharge coefficient $C_d$: $C_d = 0.82, 0.82,$ and $0.73$ for ICD D50, D70, and D100, respectively. It is clear that the discharge coefficient $C_d$ is consistently larger than the $C_d$ value of about 0.61 for an idealized orifice (Reader-Harris 2015). Given the complicated nature of the flow in the catchbasin and our simplified model, the orifice type of equations work quite well and can be used for design purposes.

The energy loss caused by a catchbasin and the water drop can be calculated from the energy difference between the inlet section and the outlet section as follows (see Figure 1 for notations):

$$\Delta H = (H - h') + \left( \frac{V_{in}^2}{2g} - \frac{V_{out}^2}{2g} \right)$$

(3)

where $H$ is the height of the inlet from the datum at the invert of the outlet pipe (see Figure 1), $h'$ is the water depth in the outlet pipe, $V$ is the mean flow velocity, and $\Delta H$ is the head loss between the two sections. The subscripts ‘in’ and ‘out’ refer to the inlet and outlet sections of the structure. The relative energy loss ($\eta_E$) can be calculated by:

$$\eta_E = \frac{\Delta H}{H + \frac{V_{in}^2}{2g}}$$

(4)

The energy loss results are shown in Figure 4. The relative energy loss is quite high, mostly over 60%. It decreases as the discharge increases.
Sediment capture efficiency

Ferguson & Church (2004) provided an equation for calculating particle settling velocity ($V_S$):

$$V_S = \frac{(\rho_P - \rho_w)gd^2/\rho_w}{C_1v + (0.75C_2(\rho_P - \rho_w)gd^3/\rho_w)^{0.5}}$$

where $C_1 = 18$ and $C_2 = 1.0$ for particles in this study; $v$ is kinematic viscosity (at 20°C measured in laboratory); $d$ is particle size, usually using $d_{50}$; $\rho_P$ is particle density; and $\rho_w$ is water density. Based on the different $d_{50}$ values used in the experiments, the calculated sediment settling velocity is 0.18, 0.47, 1.71, 2.50, 5.61, and 16.56 cm/s, respectively, for the six types of sands, from fine to coarse (see Table 1).

For the ‘Without Sump’ scenario (see Figure 5(a)), most of the larger particles can be captured at smaller flow rates. The sediment capture efficiency is high for large particles (i.e. over 1 mm in size) for the catchbasin without a sump when flow rate is less than 14 L/s. This is mainly caused by the low flow velocity which is hard to transport sediment. When flow rate is increased, the sediment capture efficiency decreases significantly. For example, the capture efficiency for the particles of $d_{50} = 1,800 \, \mu$m is over 95% for a flow rate less than 15 L/s. This is mainly caused by the particles’ large settling velocity. However, when the flow rate increases, the increased velocity in the catchbasin will carry more particles out of the catchbasin, and the capture efficiency drops to about 48% at a discharge of 28 L/s. For the sands of $d_{50} = 400 \, \mu$m, the capture efficiency decreases from over 83% to less than 28% over the same flow range. The capture efficiency for 200 $\mu$m $d_{50}$ sand decrease from 48% to 22% over this flow range, and for the 100 $\mu$m $d_{50}$ sand, it decreases from 33% to 18%. For 62 $\mu$m $d_{50}$ glass beads, the capture efficiency decreases from 24% to less than 10%. While the sediment capture efficiency is high for large particles (i.e. over 1 mm in size) for the catchbasin without a sump, the increase in the flow rate will quickly reduce this efficiency. For particles of about 60 $\mu$m, the capture efficiency is low and does not vary much with the flow rate.

The sediment capture efficiency for the ‘With Sump’ scenario is shown in Figure 5(b). In general, for smaller flow rates the sediment capture efficiency for all six size groups is similar to the case of ‘Without Sump’. However, the capture efficiency does not decrease when the flow rate increases, as these particles are settled into the sump. Once settled, it is difficult to re-suspend these particles in the test flow rate range. For example, the capture efficiency for the sand of $d_{50} = 1,800 \, \mu$m remains high at 95% over the entire flow range. For sand with 250 $\mu$m $d_{50}$, the effect of the sump is noticeable at large flow rate (28 L/s) where the capture efficiency increases from 24% to 64%. But when the particles are small, the effect of the sump is limited.

With an ICD, the water depth in the catchbasin increases. A deep water pool in the catchbasin helps in settling the particles. The results of the sediment capture efficiency with an ICD D100 are shown in Figure 5(c). It can be seen that the ICD had no impact on the sediment capture efficiency for the 62 $\mu$m $d_{50}$ glass beads (i.e. see the similar curves in Figure 5(a) and 5(c)). For sands having a 100 $\mu$m
and 200 μm $d_{50}$, the presence of the ICD slightly increases the sediment capture efficiency. For sands with over a 250 μm $d_{50}$, the sediment capture efficiency slightly decreased for a flow rate less than 15 L/s and then moderately improved compared to the ‘Without Sump’ scenario.

In general, the most important factor influencing the sediment capture efficiency is the sediment size or settling velocity. Small sands (62 μm $d_{50}$ glass beads, 100 μm and 200 μm $d_{50}$ sand) display small sediment capture efficiencies and can be relatively easily flushed out of any catchbasin, even at a very low discharge rate. 400 μm and 250 μm $d_{50}$ sands have moderate sediment capture efficiencies but display a relatively large sediment capture efficiency variation (i.e. over 60%) when the discharge changes. 1,800 μm $d_{50}$ sand is relatively hard to be flushed out, hence has the largest retention efficiency. The addition of a catchbasin sump or ICDs has similar beneficial effects on the sediment capture efficiency because of the increased water depth compared to the ‘Without Sump’ scenario. However, a sump is more effective than the provision of ICDs.

**Model for predicting sediment capture efficiency**

Wilson et al. (2009) proposed an equation for predicting the sediment capture efficiency in hydrodynamic separators (see Equation (6)), which is a function of the Péclet number ($P = V_l I W / Q$, the ratio of the particle settling velocity and the mean flow velocity in horizontal direction, where $I$ is the total flow depth from water surface to structure bottom in the sump and $W$ is the sump width) and some coefficients ($a$ and $b$).

$$
\eta_s = \left[1 + \frac{1}{(aP)^b}\right]^{-1/b}
$$

(6)

Howard et al. (2011) studied the sediment capture efficiency in storm sewer sumps and incorporated the inflow jet Froude number into the equation, as follows:

$$
\eta_s = \left[1 + \frac{1}{(aP/F)^b}\right]^{-1/b}
$$

(7)

where $F$ is inflow jet Froude number ($F^2 = V_l^2 / gD_{in}$), $D_{in}$ is inlet jet diameter, and $a$, $b$ are coefficients.

Equation (6) of Wilson et al. (2009) correlates the sediment capture efficiency as a sole function of Péclet number. Equation (7) of Howard et al. (2011) also incorporates the inlet jet Froude number to the Péclet number. However, it is believed that sediment traveling distance and settling time are also important parameters for sediment capture efficiency. In this study, a dimensionless traveling distance ($l/D_{out}$) is also incorporated into Equation (8). As standard catchbasins do not have a well-defined inlet pipe, use of the inflow jet Froude number is avoided in this study. Note that the mean flow direction in catchbasins is in a downwards direction which is different from the horizontal mean flow in storm sewer sumps. Therefore, the Péclet number $P$ is restated as $V_e/V_r$, where $V_r$ ($= Q/WV$) is the vertical mean velocity in the catchbasin. As a result, the proposed equation is:

$$
\eta_s = \left[1 + \frac{1}{(aP D_{out}^b)^{1/b}}\right]^{-1/b}
$$

(8)

According to Equation (8), the term $PD_{out}/l$ can be expressed as $V_S D_{out}/V_r l$. $V_r$ and $l$ are functions of $Q$. Thus, in a catchbasin with a constant $W$, the sediment capture efficiency is a function of the flow rate, settling velocity and outlet diameter ($Q$, $V_S$, $D_{out}$). Notice that the selection of $D_{out}$ as a length scale is somewhat arbitrary. More studies will be needed to develop a general form of the equation. In general, larger flow rates will result in a lower sediment capture efficiency since the larger flow rate reduces the sediment residence time. By contrast, larger settling velocities and larger outlet diameters will lead to higher sediment capture efficiencies.

The experimental data of the ‘With Sump’, ‘Without Sump’, ‘With ICDs’ scenarios as well as other scenarios from the literature (Lager et al. 1977; Howard et al. 2012; Ma & Zhu 2014) are plotted in Figure 6, with $\eta_s$ on the vertical axis and $PD_{out}/l$ on the horizontal axis. When $PD_{out}/l$ approaches positive infinity, the capture efficiency can approach 100%. When the range of $PD_{out}/l$ varies from 0.01 to 10, it represents large variations in flow rates (7–178 L/s), water levels (0.1–1.8 m), and particle sizes (62 μm–1.8 mm). Reflecting this considerable parameter range, it is believed that this model can be applied to represent a wide range of design conditions.

Figure 6 illustrates that the fitted curves of the experimental data have similar trends even for different set-ups. The different symbols represent the various structures tested; specifically, the triangle, square, diamond, and circle symbols represent the ‘storm sewer standard sump’, ‘catchbasin with sump’, ‘catchbasin without sump’, and ‘catchbasin with
ICD’ scenarios, respectively. For all curves, the sediment capture efficiencies increase from about 0 to over 92% covering the entire test range. The gradient of the change in the sediment capture efficiency varies from small to large and finally returns to small, which represents that the sediment capture efficiency is relatively stable at very small or large values of flow rates, settling velocities and outlet diameters but changes rapidly between them. For example, in the case of the ‘catchbasin with sump’ scenario, for coarse sand ($d_{50} = 1\, \text{mm}$), the sediment capture efficiency changes from 50 to 99% (49% difference), when the flow rate changes from 178 to 7 L/s. For fine sand ($d_{50} = 0.1\, \text{mm}$), the sediment capture efficiency only has a 44% difference, during the whole flow rate range. However, for the median size sand ($d_{50} = 0.4\, \text{mm}$), the change is from 15 to 97% (82% difference) for the same flow rate variation.

A general curve for all cases is shown in solid line. This curve has an $R^2 = 0.85$ and a 10% root mean square error (RMSE), which has relatively good fitting and can generally describe the sediment capture efficiency change among different conditions. Although this curve might not able to predict sediment capture efficiency precisely among specific configurations, it reflects the sediment capture efficiency patterns in all catchbasins. Thus, it can provide an approximate sediment capture efficiency for newly planned catchbasins regardless of its configurations. The four curves represent the sediment capture efficiency for the four different scenarios displayed. For the ‘storm sewer standard sump’ (Howard et al. 2012; Ma & Zhu 2014), ‘catchbasin with sump’ (Lager et al. 1977; current study data), and ‘catchbasin without sump scenarios’ (current study data), the correlation coefficient $R^2$ value is over 0.96 while the RSME value is less than 6%. This confirms that the newly developed expression of Equation (8) works well to represent these scenarios. However, for the ‘catchbasins with ICD’ scenario, while the curve still displays a similar pattern, it is not quite as accurate (with 7% RMSE and $R^2 = 0.87$). This might be caused by the $D_{\text{out}}$ value ($D_{\text{out}}$ is chosen as being equal to the diameter of the ICD circular hole), since the ICD is in fact not composed of solely a circular hole but a combination of rectangular and circular hole instead. A summary of these curves (equation, RMSE, and $R^2$) is summarized in Table 2.

**CONCLUSIONS**

In this study, the hydraulics and sediment capture efficiency are studied for three different catchbasin structures: ‘Without Sump’, ‘With Sump’, and ‘With ICD’. With respect to the hydraulic features, compared to a catchbasin without a sump, a sump does neither change the water depth in the catchbasin relative to the invert of the outlet pipe nor change the water depth in the outlet pipe. However, the presence of ICDs increases the water depth significantly. Orifice-type equations represent the ‘With ICD’ scenario.
appropriately and can therefore be used for design purposes. As to energy dissipation, the amount of dissipation decreases with increasing discharge rate. However, given that it is over 60% in all cases, the energy dissipation is relatively high.

About sediment capture efficiency, as to be expected, it decreases as the discharge rate increases, and is greatest for coarser sediments. 1,800 μm d50 sand is easily captured. Sands of 250 μm and 400 μm d50 both have an over 60% decrease in the sediment capture efficiency, when the discharge increases from 7 to 28 L/s. Smaller particles of 62 μm d50 glass beads, 100 μm and 200 μm d50 sands are easier to be flushed out of any catchbasin, even at low discharge rates. The presence of a sump improves the sediment capture efficiency, especially for larger particles. The presence of ICDs has a minor influence on the sediment capture efficiency for the smaller particles (62 μm d50 glass beads, 100 μm and 200 μm d50 sands) at small discharge rates. When the discharge rate is more than 20 L/s, the sediment capture efficiency for all type of sands improves when catchbasin are equipped with an ICD.

A new general expression was developed for predicting sediment capture efficiencies, adapted from previous studies (Wilson et al. 2009; Howard et al. 2012). This expression was used to generate four separate functions reflecting the three scenarios examined as well as the earlier studies, all of which have relatively high correlation coefficients and small RMSE. The new expression can be applied for a wide range of flow rates, water levels and particle sizes. In general, the new expression is clear and simple since it only requires direct physical parameters including W, Q, l, D_{out} and V_s thus making it quite convenient to be applied in urban drainage design.

The proposed equation appears to work well for the data obtained in this study, as well as previous data, as shown in Figure 6. However, using a simple Péclet along with a simple dimensionless travel distance will likely over-simplify the complicated sediment transport and sedimentation in various types of catchbasins and sumps. It is expected that the turbulence levels in these structures are likely to be very much geometry and flow dependent. In addition, various sediment size distributions and concentration will also affect the results. Future studies will need to be carried out to test high sediment concentrations (as in major storm scenarios) since the sand concentration is relatively low in this study. Also, the effects of sediment composition, cohesive and non-cohesive sediment, as well as sediment deposition need to be studied. Large flow rate and different catchbasin geometry should also be tested in future. Also, note seasonal water temperature difference might also result in a sediment capture efficiency.

### ACKNOWLEDGEMENT

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### REFERENCES


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**Table 2** A summary of sediment capture efficiency curves (including equation, RMSE, and $R^2$)

<table>
<thead>
<tr>
<th>Curve type</th>
<th>Equation</th>
<th>RMSE</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>$\eta_s = \left[ 1 + \frac{1}{(9.23P D_{out}^{0.69})} \right]^{-1/0.69}$</td>
<td>10%</td>
<td>0.85</td>
</tr>
<tr>
<td>Standard Sump</td>
<td>$\eta_s = \left[ 1 + \frac{1}{(2.72P D_{out}^{1.54})} \right]^{-1/1.34}$</td>
<td>4%</td>
<td>0.98</td>
</tr>
<tr>
<td>With Sump</td>
<td>$\eta_s = \left[ 1 + \frac{1}{(6.23P D_{out}^{0.97})} \right]^{-1/0.97}$</td>
<td>5%</td>
<td>0.96</td>
</tr>
<tr>
<td>Without Sump</td>
<td>$\eta_s = \left[ 1 + \frac{1}{(3.02P D_{out}^{0.98})} \right]^{-1/0.88}$</td>
<td>6%</td>
<td>0.96</td>
</tr>
<tr>
<td>With ICD</td>
<td>$\eta_s = \left[ 1 + \frac{1}{(24.73P D_{out}^{0.91})} \right]^{-1/0.51}$</td>
<td>7%</td>
<td>0.87</td>
</tr>
</tbody>
</table>


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