Assessment on inflow and infiltration in sewerage systems of Kuantan, Pahang

Hiew Thong Yap and Su Kong Ngien

ABSTRACT

Inflow and infiltration are important aspects of sewerage systems that need to be considered during the design stage and constantly monitored once the sewerage system is in operation. The aim of this research is to analyse the relationship of rainfall as well as inflow infiltration with sewage flow patterns through data collected from fieldwork. Three sewer pipelines were selected at the residential areas of Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas for data collection. Sewage flow data were collected in terms of flowrate, velocity and depth of flow using flowmeters with ultrasonic sensors that utilize the continuous Doppler effect in the sewer pipelines, while rainfall intensity data were collected using rain gauges installed at the study locations. Based on the result, the average infiltration rates of $Q_{peak}$ and $Q_{ave}$ for the locations were 17% and 21%, which exceeded the respective values of 5% and 10% stated in Hammer and Hammer. The flowrate of wastewater in the sewer pipelines was found to be directly proportional to rainfall. These findings indicate that the sewer pipelines in the study areas may have been affected by capacity reduction, whereas the sewerage treatment plants receiving the wastewater influent may have been overloaded.

Key words: drain, infiltration, inflow, rainfall intensity, sewer, wastewater

INTRODUCTION

Kuantan is the capital city of the state of Pahang in Malaysia. The precipitated rainfall in Kuantan ranges from 0.16 m to 19.0 m over a year (Win & Win 2014). Inflow and infiltration become critical when rainfall occurs. This may be due to rainfall inflow into sewer pipelines and the increase in the groundwater table (Ashley et al. 2008). In Malaysia, the separate sewerage system is commonly used. This type of sewerage system functions to transfer only sanitary water to the end treatment plant (Raynaud et al. 2008; Bonakdari et al. 2015) as opposed to combined sewerage systems, which transfer a combination of stormwater and wastewater. However, inflow and infiltration into separate sewerage systems may happen due to differential soil settlement or poor workmanship. And even though there is normally a certain allowable value of inflow and infiltration into separate sewerage systems, this limit has a high probability of exceedance in a tropical country such as Malaysia. The aim of this research is to analyse the relationship between the sewage flow patterns in the separate sewerage systems of Kuantan and rainfall as well as inflow infiltration rate. Flow pattern is very important for checking the trend of flow (Ajeel Fenjan et al. 2016). The scope of the study comprises the evaluation of the effect of inflow and infiltration during wet and dry weather.

INFLOW AND INFILTRATION

Functional efficiency of sewer systems includes the conveyance of wastewater from urban and industrial areas to sewerage treatment plants without inflow and infiltration (Rehan et al. 2014). Inflow is defined as wastewater runoff into the sewerage system from the surface of the ground, such as street water and rainfall (Bizier 2007). Surface waters become inflow into sewer pipelines through damaged manhole covers or combined storm connections. Infiltration is slightly different from inflow and is defined as water from the subsurface that infiltrates into the sewer pipeline through loose joints or pipes with defects (Karpf et al. 2011). One of the main source of infiltration, besides rainfall seepage from the surface of the ground, is sewer pipelines that are inundated by groundwater as can be seen from...
the case of Massachusetts in the United States. Massachusetts has applied one of the highest infiltration rates in the country, within 500 to 1,000 gal/inch/mile/day, and the high infiltration limit was probably due to Massachusetts being located at the seaside where the groundwater level is naturally high (Kirshen 2002). Inflow and infiltration in sewerage systems is a critical issue for municipalities. It is a well-known phenomenon and is a given occurrence at times, but there is proof of resulting occurrences of environmental pollution or public health arising from it. Long term inflow and infiltration in sewer networks brings negative effects to human health and environmental protection (Weiss et al. 2002; Schulz et al. 2005; Bareš et al. 2012). Inflow and infiltration leads to the reduction of the design capacity for sewer pipelines and may overload the sewerage treatment plant processes, leading to reduced productivity and discharge of partially or untreated wastewater to receiving waters (Read 2004). Other than that, inflow and infiltration also contributes to overflow of wastewater from manholes that spill onto the streets or roads. This also results in receiving waters getting untreated wastewater, which ultimately affects the surrounding environment as well as human health. In terms of construction cost, repair and maintenance of an improperly designed sewerage system incurs very high cost (Abdullahi & Garba 2015). Thus, it is necessary to consider inflow and infiltration when designing a sewage system (Rahman et al. 2007).

Researchers Karpf et al. (2007) presented inflow and infiltration data in multiple linear regression form. Their result showed that groundwater is one of the significant factors influencing the water quantity in sewer pipelines. A research on inflow and infiltration was conducted using chemical oxygen demand (COD) mass flux method in Prague and Switzerland and similar results were obtained from both locations, where the discharge of inflow and infiltration was found in excess of the proposed values in Hammer and Hammer (Kracht & Gujer 2005; Bareš et al. 2009, 2012). Based on Karpf et al. (2011), the hydrodynamic model (HYSTEM-EXTRAN) was adopted to simulate inflow, infiltration and exfiltration in the sewerage system of the city of Dresden during a wet period. The simulation result showed that infiltration of groundwater was lower than inflow of surface water during the wet period. Otherwise, exfiltration of wastewater was equivalent to surface water inflow into the monitored sewer. Beheshti et al. (2015) suggested investigating inflow infiltration in Trondheim, Norway using the quantitative flowrate method and qualitative fibre-optic distributed temperature sensing (DTS) method. DTS will detect illegal connections to the storm sewer as well as various temperatures. A more recent study presented an experiment in a coastal area where it found proof that the rainfall would influence the quantity of wastewater in sewerage systems. Multiple regression analysis was implemented to determine the daily sewage flow. The result showed that the inflow and infiltration was at an excess of 40% during rainfall compared to the dry period. The experiment also showed that groundwater infiltration into sewage was more pronounced than surface inflow (Cahoon & Marc 2017). A case study was done at a separate sewerage system of an urban residential area in Columbus using the Barthman-Parsons method. The result showed that 68% was contributed by inflow and infiltration while 25% and 59% tested positive as downspout and lateral flow from 116 houses, respectively (Pawlowski et al. 2014). The authors mentioned that groundwater infiltration was directly related to sewer flow (Bénéđittis & Bertrand-Krajewski 2005). Thorndahl et al. (2016) used two models, MIKE SHE and MIKE URBAN to simulate groundwater transport and sewer flow, respectively, in a sewer pipeline in Frederikshavn, Denmark. They found high groundwater infiltration from their analysis. Meanwhile, Rahman et al. (2005) reported a similar study to this research at residential areas in Skudai, Malaysia that utilized the area velocity method. The results showed the average infiltration rate at 31.3% higher than the design criteria mentioned in Hammer & Hammer (2012).

There is still a gap in inflow and infiltration studies with regards to sewerage systems in Malaysia. In this study, the results were analysed and compared with the recommended values stated in Hammer & Hammer (2012) where the maximum allowable infiltration rate of peak hourly sanitary flow and average flow is 5% and 10%, respectively.

**METHODOLOGY**

**Site study**

This research is more on fieldwork and is divided into several stages such as site information collection, site visit and data collection, with a focus on residential areas. Universiti Malaysia Pahang is currently in collaboration with the national sewage company Indah Water Konsortium Sdn. Bhd. to study inflow and infiltration occurring in the sewerage systems of Kuantan, Pahang. Three residential catchments, namely Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas, were selected and monitored to determine the inflow and infiltration in the respective sewer pipeline. The sewer pipeline (MH 84–MH 85) which catered
to a population equivalent (PE) of 1253 was selected in Taman Lepar Hilir Saujana. In Bandar Putra, the sewer pipeline (MH92a–MH92b), which catered to a PE of 1694, was selected. This sewer pipeline is located near the sewerage treatment plant designated as KUN 285. For Kota Sas, the selected sewer pipeline was between manholes MH 219 and MH 220, which catered to a PE of 3950. The length of the selected sewer pipelines at Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas was 35.2 m, 25.7 m and 89.0 m, respectively, whereas their diameter was 225 mm, 400 mm and 450 mm, respectively.

Criteria of sewer pipeline selection

Several criteria need to be considered in the selection of the stretch of sewer pipeline where data are to be collected in this research. The selected sewer pipelines must be uniform in diameter along their length, straight and with no lateral connection, as the various angles of pipe confluence will affect the flowmeter measurement accuracy (Sharifipour et al. 2014; Ngien & Yap 2017).

Equipment used

Figure 1 shows the two types of flowmeters used in this study, where the left-hand model is known as the ISCO 2150 Area Velocity Flowmeter and the right-hand model is the ISCO 4250 Area Velocity Flowmeter. Once the most suitable stretch of sewer pipeline has been determined from the sewer reticulation plans provided by the national sewerage service provider Indah Water Konsortium Sdn. Bhd. (IWK), the flowmeters were installed separately in the upstream and downstream manholes with assistance from IWK staff, with configurations as illustrated in Figure 2. Each flowmeter was connected to an ultrasonic sensor that applies the continuous Doppler effect to measure flowrate, velocity and vertical depth level of the sewage in the monitored sewer pipelines. As the research covered both wet and dry periods, an ISCO 674 rain gauge was installed in the compound of the nearest sewerage treatment plant to collect rainfall intensity data. All data measurements were taken at 5 minute intervals, since data stored every 5 minutes is more precise compared to measurements done every 10, 15 or 30 minutes (Yap & Ngien 2015; Yap et al. 2017). The data from both flowmeters as well as the rain gauge were retrieved from the respective equipment using the software Flowlink version 5.1 (Teledyne ISCO 2012).

Equipment calibration

The measurement accuracy of the equipment is significant in this study. To prevent inaccurate data from being measured, calibration of the equipment was carried out before installation at each location. The calibration exercises were performed at the Hydrology and Hydraulic Laboratory of Universiti Malaysia Pahang (UMP), Gambang campus, where measurement values obtained through the flowmeters were compared with the readings from the open channel apparatus in which calibration was done. A calibration curve was obtained for each flowmeter after each calibration, and the subsequent data obtained from site will be calibrated based on the calibration curve before being analysed (Yap et al. 2017). Several observations can be made through the equipment calibration exercises. In order to properly record flowrate data using the flowmeters, a lapse of 1 minute is needed after the sensor is placed in the open channel or sewer line. The minimum and maximum flowrate that can be handled by the flowmeter sensors
should also be tested to get a suitable range of flowrates for the equipment. On top of that, it is very important to replace the saturated silica gel beads located in each flowmeter as well as in the rain gauge with fresh dry ones after each data collection in order to prevent equipment breakdown caused by humidity.

**Theory of inflow and infiltration measurement**

The method used to estimate the inflow and infiltration rate in this study is known as the Flowrate method. It is based on the analysis of the daily hydrograph produced from the measured flow data. According to the Flowrate method, the downstream sewer flow should be equal to the upstream sewer flow, so any excess water is considered as water inflow or infiltration into the sewer as shown in Equation (1). Upstream sewer flow is defined as the influent into the selected sewer pipeline, while downstream sewer flow is defined as the effluent from the sewer pipeline monitored.

\[
Q_d = Q_u + Q_{inflow\ and\ infiltration} \tag{1}
\]

where \(Q_d\) is the downstream sewer flow, \(Q_u\) stands for the upstream sewer flow, and \(Q_{inflow\ and\ infiltration}\) is the excess water. The unit used in this equation is \(\text{m}^3/\text{day}\). Based on the Malaysian Sewerage Industry Guideline (MSIG 2009), infiltration rate can be calculated by dividing \(Q_{inflow\ and\ infiltration}\) obtained from Equation (1) with the length and diameter of the sewer pipeline monitored. Hence, the infiltration rate can be measured by using Equation (2).

\[
\text{Infiltration rate} = \frac{(Q_d - Q_u)}{(L_{\text{pipe}} \times \varphi_{\text{pipe}})} \tag{2}
\]

where \(L_{\text{pipe}}\) is the length of sewer pipeline between the two manholes in km and \(\varphi_{\text{pipe}}\) represents the diameter of the sewer pipeline in mm. According to Hammer & Hammer (2012), estimation for the infiltration rate percentage of peak hourly sanitary flow ranges from 3% to 5%, or 10% of the average flow. In order to achieve the purpose of this study, the percentage of \(Q_{peak}\) and \(Q_{ave}\) infiltration rate needed to be determined from the data collected.

**RESULTS AND DISCUSSION**

The first investigation was conducted in the residential area of Taman Lepar Hilir Saujana. Data were collected for 18 days from 30 September 2015 to 17 October 2015. The summarized infiltration rate results are tabulated in Table 1 with the infiltration rates calculated using Equation (2). Peak hourly sanitary flow was measured from the peak flow within each hour of the day. The infiltration rate percentage of \(Q_{peak}\) was calculated using the differences between downstream and upstream infiltration rate to the peak hourly sanitary flow. Meanwhile, the infiltration rate percentage of \(Q_{ave}\) was calculated by dividing the infiltration rate with the upstream infiltration rate. Based on Table 1, the ratio of downstream infiltration rate to upstream infiltration rate has a value of 1.19. Meanwhile, the average infiltration rate calculated ranges from 0.57 \(\text{m}^3/\text{mm}/\text{km/day}\) to 6.25 \(\text{m}^3/\text{mm}/\text{km/day}\).

Figure 3 shows the trend line of the infiltration rate percentage for both \(Q_{peak}\) and \(Q_{ave}\) at Taman Lepar Hilir Saujana. The trend lines for the infiltration rate percentage of \(Q_{peak}\) and for \(Q_{ave}\) are very close to each other. According to Hammer & Hammer (2012), the \(Q_{peak}\) and \(Q_{ave}\) of infiltration rate should not exceed 5% and 10%, respectively. The average infiltration rate of \(Q_{peak}\) was calculated at 16.1%, while the average infiltration rate of \(Q_{ave}\) was measured at 18.6%. The results show that the selected sewer pipeline at Taman Lepar Hilir Saujana is experiencing inflow and infiltration.

The sewer pipeline at Bandar Putra was monitored for 290 hours and 45 minutes. Table 2 shows the summary of infiltration rate results at Bandar Putra. Based on the results shown, average \(Q_{peak}\) was 14.8%, which is three times higher than 5%. This indicated that peak flow occurred in the sewer pipeline together with other sources of wastewater that may have infiltrated into the sewer pipeline. Another comparison was done on the result for average \(Q_{ave}\) of infiltration rate, and 30.3% was obtained, which is three times higher than the 10% mentioned in Hammer & Hammer (2012). Besides that, a comparison of the infiltration rate for downstream flow and upstream flow shows that the total infiltration of downstream flow is 1.3 times higher than the total infiltration rate of upstream flow. This finding provides evidence that the sewer pipeline studied in Bandar Putra is efficient but inflow infiltration is happening. The highest peak hourly flow occurred on 11 March 2016, with an amount of 120.86 \(\text{m}^3/\text{mm}/\text{km/day}\). This may be caused by the value of downstream and upstream infiltration rates being relatively higher compared to other days. Moreover, the highest infiltration also happened on 11 March 2016, with an amount of 28.76 \(\text{m}^3/\text{mm}/\text{km/day}\).

Figure 4 shows the trend line for percentage infiltration rate of \(Q_{peak}\) and \(Q_{ave}\) at Bandar Putra. It is obvious that the line for percentage \(Q_{peak}\) infiltration rate is two times lower.
than the line for percentage $Q_{ave}$ infiltration rate. The values of $Q_{peak}$ and $Q_{ave}$ infiltration rate percentage were relatively small during the early stages. From 4 March 2017, both lines of percentage in filtration rate increased drastically until 6 March 2016. This type of increase is most likely due to rainfall. After that, the percentage of $Q_{peak}$ and $Q_{ave}$ infiltration rate gradually decreased from 6 March 2016 to 15 March 2016 before rising high again on 16 March 2016. After 16 March 2016, both graph lines went on a downward trend until the end of the data collection at Bandar Putra. Overall, the values of percentage $Q_{peak}$ and $Q_{ave}$ infiltration rate were higher than the values given in Hammer & Hammer (2012).

A similar method of calculation was used for data obtained from the residential area of Kota Sas. Table 3 shows the resultant infiltration rate for 5 days at Kota Lepar Hilir Saujana.

![Figure 3](https://iwaponline.com/wst/article-pdf/76/11/2918/210038/wst076112918.pdf)

**Figure 3** | Percentage infiltration rate of $Q_{peak}$ and $Q_{ave}$ at Taman Lepar Hilir Saujana.

<table>
<thead>
<tr>
<th>Date (2015)</th>
<th>Total rainfall (mm)</th>
<th>Downstream infiltration rate ($D$) ($m^3/mm/km/d$)</th>
<th>Upstream infiltration rate ($U$) ($m^3/mm/km/d$)</th>
<th>Infiltration rate ($I$) ($m^3/mm/km/d$)</th>
<th>Ratio $\frac{I}{D}$</th>
<th>Peak hourly flow ($P$) ($m^3/mm/km/d$)</th>
<th>Infiltration rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Sep</td>
<td>0</td>
<td>22.98</td>
<td>17.57</td>
<td>5.41</td>
<td>20.62</td>
<td>26.26</td>
<td>30.83</td>
</tr>
<tr>
<td>2 Oct</td>
<td>0</td>
<td>19.49</td>
<td>16.48</td>
<td>3.01</td>
<td>22.25</td>
<td>13.53</td>
<td>18.28</td>
</tr>
<tr>
<td>3 Oct</td>
<td>0</td>
<td>20.43</td>
<td>16.46</td>
<td>3.97</td>
<td>18.12</td>
<td>21.88</td>
<td>24.09</td>
</tr>
<tr>
<td>5 Oct</td>
<td>0</td>
<td>18.82</td>
<td>16.57</td>
<td>2.24</td>
<td>18.45</td>
<td>12.16</td>
<td>13.53</td>
</tr>
<tr>
<td>6 Oct</td>
<td>0</td>
<td>18.37</td>
<td>16.63</td>
<td>1.74</td>
<td>18.57</td>
<td>9.37</td>
<td>10.46</td>
</tr>
<tr>
<td>7 Oct</td>
<td>0</td>
<td>17.12</td>
<td>16.01</td>
<td>1.11</td>
<td>17.91</td>
<td>6.19</td>
<td>6.92</td>
</tr>
<tr>
<td>8 Oct</td>
<td>0</td>
<td>17.52</td>
<td>16.10</td>
<td>1.43</td>
<td>19.33</td>
<td>7.37</td>
<td>8.85</td>
</tr>
<tr>
<td>9 Oct</td>
<td>0</td>
<td>17.36</td>
<td>16.79</td>
<td>0.57</td>
<td>1.19</td>
<td>21.21</td>
<td>2.71</td>
</tr>
<tr>
<td>10 Oct</td>
<td>0</td>
<td>17.81</td>
<td>16.46</td>
<td>1.35</td>
<td>17.39</td>
<td>7.75</td>
<td>8.19</td>
</tr>
<tr>
<td>11 Oct</td>
<td>0</td>
<td>18.58</td>
<td>16.14</td>
<td>2.44</td>
<td>17.01</td>
<td>14.33</td>
<td>15.10</td>
</tr>
<tr>
<td>12 Oct</td>
<td>0</td>
<td>17.51</td>
<td>15.56</td>
<td>1.95</td>
<td>16.71</td>
<td>11.67</td>
<td>12.53</td>
</tr>
<tr>
<td>13 Oct</td>
<td>36.30</td>
<td>19.91</td>
<td>16.19</td>
<td>3.72</td>
<td>21.60</td>
<td>17.22</td>
<td>22.98</td>
</tr>
<tr>
<td>15 Oct</td>
<td>0</td>
<td>19.79</td>
<td>16.19</td>
<td>3.59</td>
<td>17.85</td>
<td>20.13</td>
<td>22.19</td>
</tr>
<tr>
<td>16 Oct</td>
<td>24.90</td>
<td>21.30</td>
<td>16.32</td>
<td>4.98</td>
<td>18.42</td>
<td>27.02</td>
<td>30.49</td>
</tr>
<tr>
<td>17 Oct</td>
<td>0</td>
<td>21.30</td>
<td>16.61</td>
<td>4.69</td>
<td>20.45</td>
<td>22.95</td>
<td>28.26</td>
</tr>
</tbody>
</table>

**Table 1** | Infiltration result at Taman Lepar Hilir Saujana
Sas from 15 April 2016 to 19 April 2016. Based on the result shown, the overall value of infiltration rate at Kota Sas was lower than that in Bandar Putra. This could be due to the recently developed sewerage system in Kota Sas. Based on the drawing provided by IWK, the length of sewer pipeline chosen at Kota Sas is 89 m, which is 3.5 times longer than the sewer pipeline monitored in Bandar Putra. When the length of sewer pipeline is longer, the infiltration rate will tend to be lower based on Equation (2). The infiltration rate of $Q_{\text{peak}}$ and $Q_{\text{ave}}$ is 20.9% and 15.6%, respectively, exceeding the 5% and 10% stated in Hammer & Hammer (2012). Besides that, the total infiltration rate of downstream flow is only 1.2 times that of the upstream flow infiltration rate.

Figure 5 shows a comparison of the line graphs for percentage infiltration rate $Q_{\text{peak}}$ and $Q_{\text{ave}}$ at Kota Sas from 15 April 2016 to 19 April 2016. The percentage of $Q_{\text{peak}}$ infiltration rate was 25% higher than the percentage of $Q_{\text{ave}}$ infiltration rate. This could be due to the study being conducted during the wet period, as the infiltration rate of $Q_{\text{peak}}$ was higher than $Q_{\text{ave}}$. Both values decreased from 15 April 2016 to 18 April 2016 before gradually increasing over the rest of the study period. It is noted that the infiltration rates for $Q_{\text{peak}}$ and $Q_{\text{ave}}$ at Kota Sas were low compared to the other two locations studied.

Overall, the average percentage of $Q_{\text{peak}}$ and $Q_{\text{ave}}$ infiltration rate for all monitored locations was 17%
and 21% respectively, which is three and two times higher than the values recommended in Hammer & Hammer (2012). It is suspected that the sewer pipelines at all the locations studied may have defects that caused the inflow and infiltration.

**FLOW PATTERN**

Figure 6 shows the upstream and downstream sewage flow-rate patterns as well as rainfall incidence at Taman Lepar Hilir Saujana from 30 September 2015 to 17 October 2015.
2015. It can be seen that the downstream flowrate exceeded the upstream flowrate even though no rainfall occurred for the most part. This could have been caused by extraneous water that infiltrated into the sewer pipeline from sources such as the groundwater table. When rainfall occurred, both the downstream and upstream flowrates were affected in the form of an increase in the flowrate.

Figure 7 shows the downstream and upstream sewage flowrate patterns at the monitored sewer pipeline in Bandar Putra from 26 February 2016 to 23 March 2016. Based on the trend of sewer flow pattern shown during the dry season, there are two peaks constantly located between 7 am to 8 am in the morning and 6 pm to 8 pm evening every day. It can be clearly seen that the flow pattern gradually increased from 6 am to 8 am in the morning, and then gradually decreased from 8 pm to 12 am at night every day. Overall, the flow pattern of the downstream flowrate was higher than that of its upstream counterpart. From the results, it is surmised that the sewer pipeline studied may contain defects that allowed inflow and infiltration into the sewers.

Figure 8 shows the hydrographs of the downstream flow and upstream flow as well as rainfall at Kota Sas. The hydrograph shows the pattern and characteristics of sewer flow during wet and dry periods. It can be clearly seen that the
daily flow pattern was the same throughout the study period, regardless of whether it was during the wet or dry phase. Downstream flow was shown to be nearly constant from 12 am to 5 am in the morning with an average amount of 200 m$^3$/day. Besides that, the downstream and upstream flows were shown to gradually increase from 6 am to 8 am in the morning, while from 9 pm to 12 am midnight the flows decreased. Other than that, the value of infiltration rate was high during the dry period. The cause of high infiltration is likely to be the high water table of the coastal area and inflow via damaged manhole covers. During wet periods, the flowrate increased relatively, showing a peak flow of 959.98 m$^3$/day. This may have occurred due to high rainfall on 19 April 2016. It was indicated that rainfall influences the flow in sewerage systems (Cahoon & Marc 2017).

CONCLUSION

Based on the results from this study, the average infiltration rates of $Q_{\text{peak}}$ and $Q_{\text{ave}}$ for all three locations were 17% and 21%, respectively, which exceeded the 5% and 10% stated in Hammer & Hammer (2012). The excess water could have come from the surface through infiltration or as inflow through defective sewer pipe joints and manholes. This in turn could have repercussions in the form of reduced sewer capacity and overloading of the sewage treatment plant, resulting in untreated wastewater flowing directly into receiving water bodies. It was also found that the flowrate of the wastewaster was directly proportional to the magnitude of rainfall. Inflow and infiltration continues to be a concern, and more detailed studies such as those that include groundwater monitoring are needed. Other than that, observation of the inflow and infiltration for longer durations may be needed to verify the findings in this article.

ACKNOWLEDGEMENTS

The authors would like to thank Indah Water Konsortium Sdn. Bhd. (Pahang branch), which has given technical support in this research. We would also like to acknowledge the financial support given by the Malaysian Ministry of Education in the form of RACE research grant RDU 141302.

REFERENCES


Bareš, V., Stránský, D. & Sýkora, P. 2009 Sewer infiltration/inflow: long-term monitoring based on diurnal variation


