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# STORM RUNOFF QUALITY IN A RESIDENTIAL CATCHMENT IN MALAYSIA

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*This paper examines the storm runoff quality from a medium cost residential area in south Johor, Malaysia. The quantity and quality of storm runoff during nine storm events were investigated. A total of 101 storm runoff samples were analyzed for total suspended solids (TSS), biochemical oxygen demand (BOD5), chemical oxygen demand (COD) and oil and grease (O&G). The ranges of event mean concentration (EMC) were 2.09-70.27 mg/L for TSS, 2.27-15.21 mg/L for BOD5, 15.86-47.93 mg/L for COD, and 1.25-5.55 mg/L for O&G. These gave site mean concentrations of 40.62 mg/L, 6.67 mg/L, 27.53 mg/L, and 3.07 mg/L for TSS, BOD5, COD and O&G, respectively. The pollutographs of all pollutants showed peak concentrations preceded the peak flow of runoff. EMCs for all constituents also show large inter event variation. Correlation analysis showed that only rainfall intensity has significant influence on the EMC of O&G and TSS in storm water runoff. The EMCs of BOD and COD were influenced by antecedent dry days. All pollutant constituents show the occurrence of first flush, indicating that higher mass loading was delivered during the early part of the storm runoff.*

## INTRODUCTION

Urban storm water runoff has been recognized as one of the major sources of non point pollution, contributing to the potential degradation of the quality of receiving waters (Carmen, 1997). The focus on water pollution control had shifted from point sources to non-point sources especially resulting from urban runoff (Ellis, 1989; Yamada, 2007). As most stormwater is discharged directly into receiving waters through stormwater drainages, it is important to know the magnitude of pollutant loading in order to protect or preserve urban rivers.

Impervious areas, especially road surfaces, are important in the management of urban water ecosystems because they contribute a considerable amount of runoff even during less intense frequent storm events (Ball et al., 2000). A wide range of pollutants such as particulates, heavy metals and petroleum hydrocarbons which primarily originate from land transportation activities can accumulate on the road surfaces (Gan et al., 2007). During storm events, they are washed off and discharged into receiving waters. The extent by which these materials are polluting stormwater runoff and the ultimate receiving waters is largely unknown. It was found that hydrocarbon compounds in stormwater are typically measured as "oil and grease (O&G)", which can include animal fats, vegetable oils, soaps, and other biological oils, in addition to petroleum constituents. Oil and grease from different land use sites have been reported to be primarily associated with used crankcase oil (Latimer et al., 1990). Other sources of oil and grease in runoff include hydraulic fluid leaks from vehicles, lubricant leaks from construction sites, and illegal disposal of used oil from industry, farm and other off-road or heavy equipment. While the amount of oil leaked from vehicles is not known, one model developed in New Zealand estimated that the rate of oil lost to roadways was 2.8 ml of lubricating oil per 1,000 kilometers driven for cars and light commercial vehicles, and 2.1 ml per 1,000 kilometers for most buses (Kennedy et al., 2002). Stormwater quality can show considerable variability but typical concentrations of oil and grease in runoff samples are generally less than 5 mg/l, and seldom exceed 10 mg/l (OEHHA, 2006).

O&G and other major pollutants can cause various water problems, ranging from toxicity to aquatic life, depressed dissolved oxygen concentration, odors, and unsightly conditions to loss of use. The development of environmentally acceptable and cost effective technologies for the control of urban stormwater runoff is of significant concern for improving the receiving water quality. This paper reports the quality of stormwater runoff from a residential catchment in south Johor, Peninsular Malaysia. The influence of the rainfall characteristics on storm runoff quality and correlations among the quality constituents are also examined.

## METHODOLOGY

### Site description

The study site is located in Taman Impian Emas in Skudai, Johor (Figure 1). This study site is typical of high density medium cost residential areas in Malaysia. The catchment area is 32.77 ha. A total of 7811 vehicles per day were recorded during an average daily traffic day. Double story detached houses constitute 44% of the homes, whereas the remaining 56% are single story detached houses.

### Sample collection and chemical analysis

Stormwater runoff was sampled at the outlet of the catchment. Discharge was measured by the velocity area method using a SWOFFER 2100 current meter. A stage-discharge rating curve was

Table 1. Characteristics of the study site.

| Characteristics | value |
|---|---|
| Area (ha) | 32.77 |
| Land use: | |
| residential | 29.97 |
| Lawn/park | 2.8 |
| Sewer type | Separated sewer |
| Percent impervious (%) | 90 |
| Channel slope | 1 : 530 |

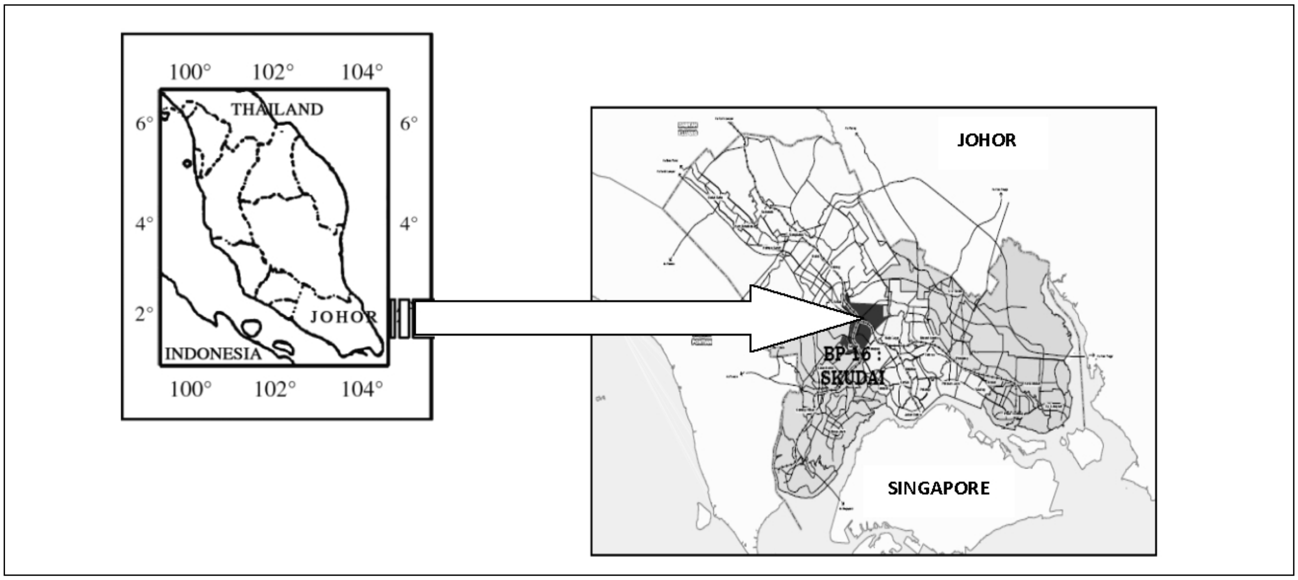


Figure 1. Location of the study site.

developed to convert water level into flow. During storm events, the storm water samples were collected manually by grab techniques. Depending on the rain intensity and the discharge, the samples were collected between 1 and 10 minute intervals on the rising limb of the hydrograph and 10 and 20 minute intervals on the falling limb. This manual sampling method is chosen because more samples can be collected on the rising limb of the hydrograph which is crucial for assessing first flush occurrence.

A total of 101 storm water samples were analyzed according to the standard methods for the examination of water and waste water (APHA, 1998): total suspended solids (TSS) by method 2540D, 5-day biochemical oxygen demand ($BOD_5$, method 5210B), chemical oxygen demand (COD, method 5220 B) and oil and grease (O&G, method 5520 B). The required sample volume, bottle type, and preservative requirements also followed these standard methods.

## DATA ANALYSIS

### Event Mean Concentration (EMC)

The widely used method for estimating storm water pollutant loads is based on the Event Mean Concentration (EMC). The EMC is defined as total constituent mass *M* discharged during an event divided by total volume, *V* of discharge during the event (Huber, 1993). Mathematically,

$$EMC = \overline{C} = \frac{M}{V} = \frac{\int C(t)Q(t)dt}{\int Q(t)dt} \qquad (1)$$

where $M$ is total mass of pollutant during the entire runoff (kg); $V$ is total volume of runoff ($m^3$); $C(t)$ is time varying pollutant concentration (mg/L); $Q(t)$ is time variable flow (L/min); and $t$ is total duration of runoff (min).

## First flush concept

In general the term "first flush" has been utilized to indicate a disproportionately high delivery of either concentration or mass of a constituent during the initial portions of a rainfall-runoff event (Sansalone & Cristina, 2004). Equations (2) and (3) represent the first flush phenomenon:

$$L = m(t)/M \tag{2}$$

$$F = v(t)/V \tag{3}$$

where $L$ is dimensionless cumulative pollutant mass and $F$ is dimensionless cumulative runoff volume. A first flush exists at time $t$ if the dimensionless cumulative pollutant mass $L$ exceeds the dimensionless cumulative runoff volume $F$ at all instances during the storm events. A 1:1 line, on a plot of $L$ vs. $F$, indicates that pollutants are uniformly distributed throughout the storm events. If the data for a particular storm falls above the 1:1 line, a first flush is suggested (Deletic, 1998; Bertrand-Krajewski et al., 1998, Larsen et al., 1998).

# RESULTS AND DISCUSSION

## Storm characteristics

Nine storm events were sampled between March 2008 and November 2008. The characteristics of the storm events are shown in Table 2. The storm size varies from 1.8 mm to 53.2 mm while the intensity ranges from 2.69 mm/hr to 99.6 mm/hr.

## Fate and transport of pollutants

In all the storm events, the maximum concentrations of TSS, O&G, BOD and COD occurred before the peak flow. The time lags between peak concentration and peak flow are summarized in Table 3. O&G showed the shortest time lag (average 9 minutes) and BOD the longest (average 14 minutes). Rainfall intensity plays an important role in determining the time lag between peakflow and peak concentration of various pollutants. A longer time lag between peak concentration and peak flow suggests a higher pollutant loading at the early part of the episode.

## Event Mean Concentration

The EMC values calculated using Equation (1) show considerable variation between events (Table 4). Their statistical summary is presented in Table 5. The site mean concentrations (SMC) which are the average EMCs of all storm events are 40.62 mg/L, 3.07 mg/L, 6.67 mg/L and 27.53 mg/L for TSS, O&G, BOD and COD, respectively. The SMC ratio of $BOD_5$ to COD is about 1:4, indicating that most of the organic matter in the stormwater runoff is non biodegradable. The differences between the arithmetic mean and median values are 2.2% for TSS, 23% for O&G, 6.7% for BOD and 19% for COD. The ranges of concentration for TSS and BOD were large, which indicate that the concentrations varied during the storm episode. When compared with the interim national water quality standard for Malaysia (DOE, 2000), the SMCs of all constituents fall in class II, except for BOD which was in class III. The new designs of underground stormwater drainage systems at the study site have improved the quality of stormwater runoff. In addition street sweeping activities may further reduce the accumulation of pollutants on the road surfaces.

Table 2. Rainfall characteristics for monitored storm events.

| Storm Events | Total Rainfall Depth (mm) | Rainfall Duration (hour) | Mean Rainfall Intensity (mm/hour) | Antecedent Dry Days (Day) | Max 5 Min Rainfall Intensity (mm/hour) |
|---|---|---|---|---|---|
| 12 -03-08 | 36.2 | 2.48 | 14.6 | 0.765 | ND |
| 28-03-08 | 10.6 | 1.05 | 10.1 | 0.981 | 28.8 |
| 01-06-08 | 47.2 | 0.6 | 78.7 | 2.11 | 180 |
| 18-06-08 | 43.8 | 0.44 | 99.6 | 0.833 | 151.2 |
| 23-07-08 | 3.4 | 0.87 | 3.92 | 1.62 | 12 |
| 03-09-08 | 10.8 | 1.17 | 9.23 | 0.779 | 31.2 |
| 09-10-08 | 53.2 | 1.2 | 44.3 | 1.967 | 117.6 |
| 29-10-08 | 1.8 | 0.67 | 2.69 | 1.952 | 9.6 |
| 10-11-08 | 6.6 | 0.63 | 10.5 | 0.963 | 19.2 |

Table 3. Time lag between the peak concentration of constituents and peak flow appearance.

| Storm event | Range of Interval time (min) | Average Interval Time (min) |
|---|---|---|
| TSS | 0 - 32 | 12 |
| O & G | 0 - 17 | 9 |
| BOD | 2 - 32 | 14 |
| COD | 2 - 27 | 12 |

Table 4. EMCs of various pollutants during nine storm events.

| No | Storm event | TSS | O & G | BOD | COD |
|---|---|---|---|---|---|
| 1 | 12/03/08 | 26.77 | 2.16 | 6.22 | 15.86 |
| 2 | 28/03/08 | 60.44 | 1.89 | 7.40 | 46.40 |
| 3 | 01/06/08 | 41.53 | 4.69 | 15.21 | 47.93 |
| 4 | 18/06/08 | 70.27 | 3.69 | 3.23 | 17.79 |
| 5 | 23/07/08 | 2.09 | 1.25 | 7.15 | 23.08 |
| 6 | 03/09/08 | 26.87 | 5.55 | 2.63 | 20.99 |
| 7 | 09/10/08 | 47.10 | 2.37 | 2.27 | 31.49 |
| 8 | 29/10/08 | 50.61 | 1.61 | 10.90 | 22.24 |
| 9 | 10/11/08 | 39.93 | 4.40 | 5.02 | 21.99 |

Table 5. Statistical summary of the EMC values.

| | Statistical summary (mg/L) | | | |
|---|---|---|---|---|
| Constituent | TSS | O & G | BOD | COD |
| Minimum | 2.09 | 1.25 | 2.27 | 15.86 |
| Maximum | 70.27 | 5.55 | 15.21 | 47.93 |
| Median | 41.53 | 2.37 | 6.22 | 22.24 |
| Arithmetic mean | 40.62 | 3.07 | 6.67 | 27.53 |
| Standard Deviation | 19.09 | 1.46 | 3.97 | 11.25 |

Table 6 compares the EMCs of selected pollutants at the study site with other residential catchments. The EMCs for TSS, COD and BOD at the present site are lower than those reported in Malaysia and Korea. However, the EMC for O&G is higher than a reported value in Kuala Lumpur and comparable with the average in the USA.

## Rainfall influence on the EMC

Table 7 shows the correlation between the EMCs of the four pollutants and storm characteristics, i.e. rainfall depth (R, mm), rainfall duration ($R_{Dur}$, hour), runoff volume (Q, $m^3$), rainfall intensity (RI, mm/hour), maximum 5 min rainfall intensity ($RI_{max5,}$ mm/hour), antecedent dry day (ADD, day) and mean intensity of the preceding storm ($RMI_p$, mm/hour). No strong correlation was found between the storm characteristic and the EMC values. However, significant relationships ($p<0.05$) were found between $EMC_{O\&G}$ against mean rainfall intensity ($r=0.38$) and maximum 5 min rainfall intensity ($r=0.35$). This suggests that storm intensity is important in flushing accumulated O&G on the road surfaces into storm drains. The negative correlation with rainfall duration suggests that a longer storm will result in a smaller $EMC_{O\&G}$. The mean rainfall intensity also correlates well with $EMC_{TSS}$ ($r=0.51$), which explains that rainfall intensity is the main factor that influences the concentration of TSS. BOD was diluted with runoff volume resulting in smaller EMC during large storms. This is evident as $EMC_{BOD}$ and runoff volume were negatively correlated. A longer antecedent dry days tended to accumulate more organic matter on the road surfaces, thus it was expected to cause higher EMC in the stormwater. However, only BOD and COD showed positive correlations with ADD whereas TSS and O&G showed negative correlations. Such discrepancies might suggest dilution of TSS and O&G toward the end of the storm episodes.

## First flush phenomenon

Figure 2 shows plots of normalized cumulative loadings of TSS, COD, BOD and O&G against normalized cumulative volume of storm runoff. Points above the 1:1 line indicate the occurrence of first flush. It is obvious that first flush occurred for all constituents. The strongest effects were observed for COD and BOD with all events showing first flush phenomena. O&G also showed a strong occurrence of first flush with the exception of two events on July, 23 and October, 29 which produced weak first flush phenomena. These events have low rainfall intensity (3.92 mm/hour and 2.69 mm/hour) thus lacking strength to flush pollutants from roads and other impervious surfaces. The strengths of first flush are in the order BOD>O&G>COD>TSS. Strong occurrences of first flushed, especially in small catchments, were also observed by others (Lee et al., 2004; Yusop et al., 2005; Nazahiyah et al., 2007).

Table 6. Comparison of EMCs with other studies (mg/L).

| Constituent (mg/L) | Malaysia This study | USA Nationwide[a] | USA La Mirada[b] | Malaysia Serdang[c] | Malaysia Kuala Lumpur[d] | Korea ChongJu[e] |
|---|---|---|---|---|---|---|
| O & G | 3.07 | 3.9 | ND-3.0 | - | 2.0 | - |
| TSS | 40.62 | - | - | 126.5 | 102 | 146 |
| BOD | 6.67 | - | - | 29 | 16.8 | 76 |
| COD | 27.53 | - | - | 120 | 95 | 211 |

[a] Pitt et al., 2004 [b] La Mirada, 2005 [c] Mamun, 2005 [d] DBKL, 2003 [e] Choe et al., 2002

Table 7. Correlation coefficient (r) for EMCs and storm characteristics.

| | $EMC_{TSS}$ | $EMC_{O\&G}$ | $EMC_{BOD}$ | $EMC_{COD}$ | R | $R_{Dur}$ | Q | RMI | $RI_{max5}$ | ADD | $RI_p$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $EMC_{TSS}$ | 1.00 | | | | | | | | | | |
| $EMC_{O\&G}$ | 0.073 | 1.00 | | | | | | | | | |
| $EMC_{BOD}$ | -0.022 | -0.132 | 1.00 | | | | | | | | |
| $EMC_{COD}$ | 0.297 | -0.022 | 0.559 | 1.00 | | | | | | | |
| R | 0.302 | 0.186 | -0.044 | 0.208 | 1.00 | | | | | | |
| $R_{Dur}$ | -0.344 | -0.250 | -0.134 | -0.124 | 0.167 | 1.00 | | | | | |
| Q | -0.058 | 0.102 | -0.355 | 0.340 | 0.597 | 0.45 | 1.00 | | | | |
| RI | 0.508 | 0.377 | 0.042 | 0.182 | 0.742 | -0.464 | 0.106 | 1.00 | | | |
| $RI_{max5}$ | 0.381 | 0.351 | 0.158 | 0.309 | 0.945 | -0.317 | 0.360 | 0.952 | 1.00 | | |
| ADD | -0.124 | -0.306 | 0.558 | 0.355 | 0.234 | -0.230 | 0.055 | 0.145 | 0.278 | 1.00 | |
| $RI_p$ | 0.389 | -0.120 | 0.109 | -0.451 | -0.027 | -0.249 | -0.695 | 0.252 | 0.084 | 0.038 | 1.00 |

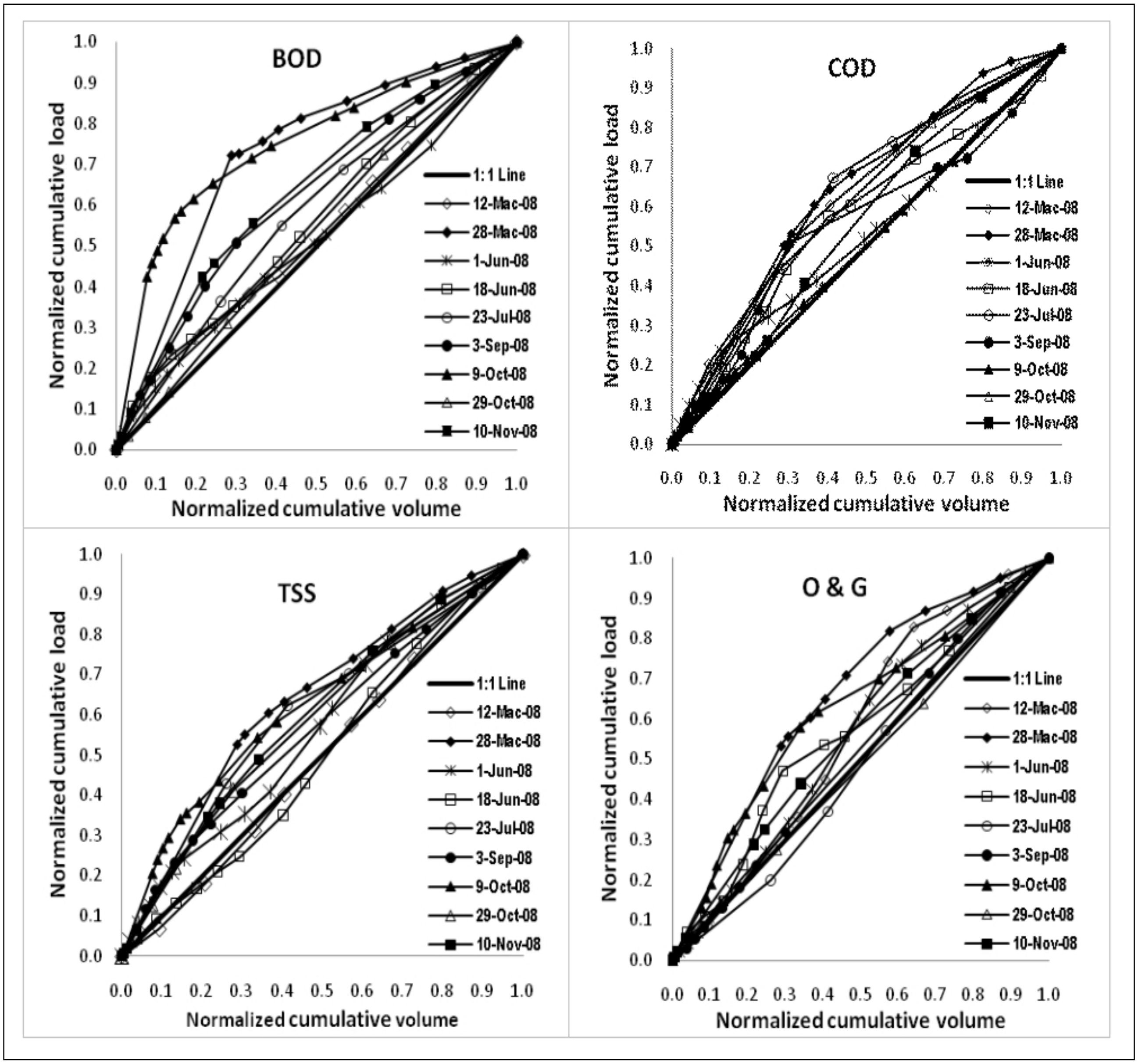


Figure 2. Normalized cumulative loadings of BOD, COD, TSS and O&G for all storm events.

## CONCLUSIONS

This study provides a better understanding of the mechanism of pollutant transport in a typical medium cost residential catchment in Malaysia. Such information is still scarce and is thus useful for improving the control and management of urban runoff pollution in the tropics. Major conclusions of this study are as follows:

1. Event mean concentrations (EMCs) of O&G, TSS, BOD and COD show large inter event variation but the site mean concentrations (SMCs) were generally lower than other local values.

2. EMCs show poor correlation with storm characteristics. The only characteristics that are significantly correlated with $EMC_{O\&G}$ and $EMC_{TSS}$ are average rainfall intensity, while for $EMC_{BOD}$ and $EMC_{COD}$ it is antecedent dry days.

3. In most events, the peak pollutant concentration preceded the peak flow, indicating strong first flush phenomena. The EMC strengths of the first flush are BOD>O&G>COD>TSS.

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