Original Research

Suspended Solids Concentration in Highway Runoff during Summer Conditions

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Abstract

One treatment practice for storm water is detention of the initial part of the runoff that is considered to contain the highest concentration of pollutants. This study has evaluated the concentration of total suspended solids (TSS) in 44 consecutive runoff events from a highway watershed. The effluent TSS standard for wastewater of 60 mg/l applied in the EU was used to assess the required treatment. In 35 of the runoff events the TSS partial event mean concentration exceeded 60 mg/l for the duration of the runoff event. Thus, a partial capture of the runoff volume should not be used as a treatment option in similar conditions that prevailed in this study.

Keywords: discharge value, event mean concentration, first flush, storm water

Introduction

Numerous studies have been performed in regards to pollutant transportation and physical characteristics of pollutants in runoff, e.g. [1, 3-5]. Most pollutants have a strong affinity to suspended solids [6] and show seasonal variation [7]. In EU directive 1991/271/EEC, runoff water or storm water is defined as sewage water. For domestic wastewater, the directive gives a discharge concentration of 60 mg/l for total suspended solids (TSS). This value, in lieu of similar discharge limits relating exclusively to runoff water, could be useful as a reference when evaluating the requirements for treatment.

One common term used to describe the mass transport pattern in runoff is “first flush” [1, 3, 7]. Studies have been made on different types of catchment areas between 211 m^2 [8] and 6.000 km^2 [8] with results indicating that the mass transport behaviour varies significantly even between similar catchment areas during comparable runoff events. The pollutant load may increase dramatically during the winter season when de-icing agents are utilized [10]. Runoff from urban roadways often contains significant loads of metal elements, particulate and dissolved solids, organic compounds and inorganic constituents [1, 2]. Studded tyres are the main contributor to the wear of the asphalt pavement [11, 12]. High pollutant load are related to elevated traffic flows, according to Barrett et al. [13].

It is therefore evident that there is a need for removal of pollutants from areas with elevated traffic loads. The most common method for treatment is sedimentation, which is justified by the pollutants’ predominant affinity to particulate matter. Studies have indicated that a 250 m^2 sedimentation surface per hectare watershed area would be sufficient for treatment of highway runoff [14]. However, in urban areas, the land use and/or investment cost restricts the construction of sedimentation basins. It is important to investigate the possibilities of reducing land use by optimizing the treatment of runoff water. This could be executed by a batch-wise sedimentation of a part of the runoff volume, the precondition for this being an emphasized first flush. A study during winter suggested that a capture of the initial part of the runoff for subsequent treatment was less applicable [15]. It is therefore of interest to investigate the watershed during summer conditions.

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The present study was conducted between 3 May 2005 and 23 October 2005 in Stockholm, Sweden, when studded tyres and salt are not used on the roads. The aim was to examine the TSS concentration in the runoff event with regards to the EU wastewater effluent standard of 60 mg/l, and use TSS monitoring to assess the possibility of treating part of the runoff volume in contrast to total runoff volume.

Study Area

An area located at the northern exit of Stockholm City was selected for the study. A six-lane highway (E4) that has an annual average daily traffic (AADT) load of 120,000 and a speed limit of 70 km/h dominates the area. The highway passes through the 235 m long Eugenia road tunnel. Data on drainage area and land use are presented in Table 1.

Four separate areas with regard to the pipe network can describe the watershed: Southwest 1 (SW1), Southwest 2 (SW2), Southeast (SE) and Northwest (NW) as shown in Table 1 and depicted in Figs. 1 and 2. SW1 receives some runoff water from a pedestrian walk. SW2 includes Solna Bridge, which is a local street passing over the highway. The runoff water from Solna Bridge and a parking lot is discharged via a sand trap into the pipe network. SE includes runoff water from a park area and pedestrian walk. NW receives water exclusively from the highway.

In order to reduce pollutant load from the catchment area, a treatment plant was constructed and commissioned in 1991. The treatment plant, named Eugenia, is located below ground and the runoff is transported by gravity to the intake chamber. The tunnel section, however, has a separate collecting pump sump from which the water is pumped intermittently to the intake chamber. The runoff then overflows to a step screen and passes through two separate Parshall flumes before it discharges to the retention basin for sedimentation. The measuring equipment for this study was placed in the intake chamber.

Fig. 1. Southwest (2) catchment area.

Fig. 2. Northwest catchment area.

Methods

Measurement of Total Suspended Solids

Continuous measurement of suspended solids was carried out using a Cerlic ITX suspended solids meter. The measuring wavelength for the instrument was 880 nm. The data from the TSS measurements was collected with a Campbell Scientific CR10X data logger every 60 s. The measuring probe was located in the intake chamber. The intake chamber is constructed as a separate compartment with a constant water level. The volume of the intake chamber is approximately 1 m^3 with a water depth of 0.8 m. Cleaning of the measuring probe was executed automatically every 50 min for a duration of 120 s with compressed air.

An *in situ* calibration of the instrument was achieved by correlating the analyzed TSS concentration with the registered value from the Cerlic ITX instrument. Seven water samples were collected and analyzed for the purpose of calibration. Analysis of TSS was performed at a certified (SWEDAC ISO/IEC 17025) laboratory using a standard method (SS-EN 872). The concentrations of TSS ranged from 38 mg/l to 970 mg/l. These data were compared to the collected logger data from the probe. The linear correlation r^2 was 0.92.

Table 1. Description of the four parts of the catchment area.

Part of catchment area	Total area (m^2)	Asphalt surface (m^2)	Green areas (m^2)	Inclination (‰)	Main pipe diameter (mm)	Gully pot pipe diameter (mm)
Southwest 1	6,900	5,900	1,000	40	300	225
Southwest 2	26,000	21,000	5,000	20	400	225
Southeast	1,500	1,500		30	225	225
Northwest	32,600	25,600	7,000	20	400/500	225
Sum	67,000	54,000	13,000			

Flow Measurement

Flow was measured with two Parshall flumes designed for flows between 1 l/s to 20 l/s and between 20 l/s to 600 l/s respectively. The flow between 0 l/s to 20 l/ s was registered with a Chanflo Open Channel (Danfoss) flowmeter (0 m to 0.3 m) with a Sonolev sensor (100 KHz). The flow between 20 l/s to 600 l/s was registered with Chanflo Open Channel (Danfoss) flowmeter (0 m to 1 m) and also with a Sonolev sensor (100 KHz). The data from the flow measurements was collected every 60 s during the runoff event with a Campbell Scientific CR10X data logger.

Precipitation Measurement

A rain gauge was located 6 m above the ground level in the central part of the watershed close to the Eugenia treatment facility. The rain gauge registered every 0.5 mm rain.

Runoff Volume and Event Mean Concentration (EMC) of TSS

During the runoff event, the flow and concentration of suspended solids were measured and sampled with an interval of 60 s (Δt). The flow, Q, and concentration of TSS, *C*, could be approximated by a linear relationship between two sampling points. Total runoff volume, V_{tot}, could be calculated according to (1) and total mass of suspended solids, $TSS_{tot,}$ and (2)

$$V_{tot} = \sum_{i=1}^{N} Q_i \cdot \Delta t \qquad (1)$$

$$TSS_{tot} = \sum_{i=1}^{N} Q_i \cdot C_i \cdot \Delta t \qquad (2)$$

$$N = \frac{TotTime}{\Delta t} \qquad (3)$$

where N is an integer representing total number of measurements during total time, TotTime, for the duration of the runoff event.

The TSS EMC was calculated according to (4).

$$EMC = \frac{TSS_{tot}}{V_{tot}} \qquad (4)$$

EMC Variations and Runoff Volume

In order to evaluate the possibility of bypassing a part of the runoff volume, the EMC variations over the runoff event was evaluated in regards to total runoff volume. The partial EMC, PEMC, was calculated from the end of the runoff event according to (5).

$$PEMC_k = \frac{TSS_{tot} - \sum_{i=1}^{N-k} Q_i \cdot C_i \cdot \Delta t}{V_{tot} - \sum_{i=1}^{N-k} Q_i \cdot \Delta t} \qquad (5)$$

where k = 1, …, N

The fraction of the total runoff volume, X_V, was calculated according to (6).

$$X_{Vk} = 1 - \frac{\sum_{i=1}^{N-k} Q_i \cdot \Delta t}{V_{tot}} \qquad (6)$$

To find the fraction of the volume containing less than the reference value of 60 mg/l, X_{Vk} and $PEMC_k$ was calculated for k=1,…,N or more precisely the points (X_{Vk}, $PEMC_k$) as exemplified graphically in Figs. 3 and 4.

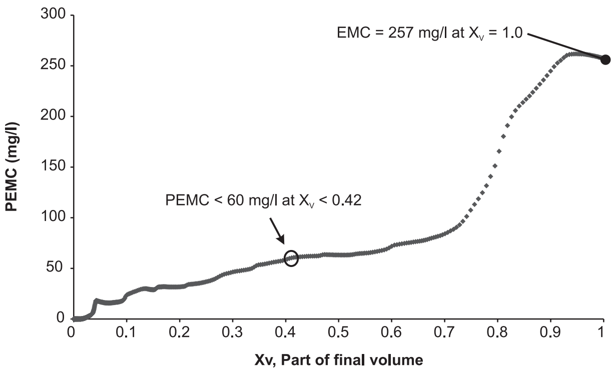

Fig. 3. X_V plotted against PEMC during the runoff event 2005-06-12. At X_V = 0.42 the PEMC was 60 mg/l. EMC for the runoff event was 257 mg/l.

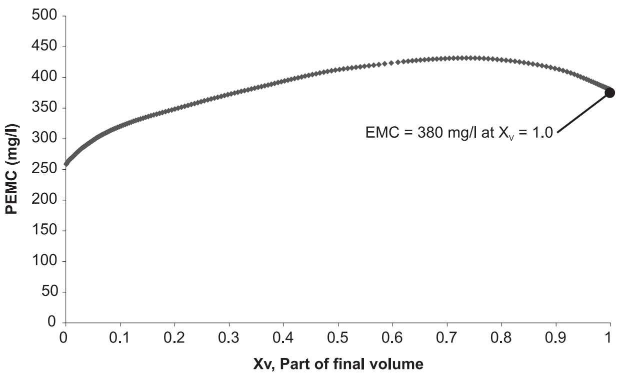

Fig. 4. X_V plotted against PEMC during the runoff event 2005-05-31. EMC for the runoff event was 380 mg/l.

Table 2. Studied runoff events May 2005 to October 2005. (ADP = Antecedent dry period).

Date	ADP (h)	Duration (h)	TSS EMC (mg/l)	Runoff volume (m^3)
3May2005	430.0	13.0	906	1,985
24May2005	496.0	3.0	440	71
28May2005	105.0	12.6	830	875
30May2005	36.3	4.0	616	231
31May2005	22.4	3.5	380	98
4June2005	82.6	5.5	413	823
5June2005	18.4	6.3	136	403
10June2005	123.0	9.5	353	792
12June2005	22.5	11.1	257	1,670
22June2005	231.0	8.4	835	719
27June2005	130.0	2.0	349	261
28June2005	21.6	2.2	225	196
16July2005	417.0	3.3	267	175
17July2005	27.1	3.5	980	1,034
19July2005	44.3	3.8	288	209
20July2005	10.9	6.2	166	597
21July2005	22.9	2.2	182	140
21July2005	9.7	1.5	158	106
22July2005	4.6	6.0	83	348
22July2005	1.6	35.8	121	3,496
26July2005	49.6	32.3	218	2,505
30July2005	83.9	6.1	58	245
1August2005	34.3	2.6	102	107
4August2005	71.6	1.4	209	178
6August2005	47.6	2.8	223	195
6August2005	2.6	5.7	175	672
7August2005	1.9	6.7	49	348
10August2005	61.3	16.9	67	1,602
11August2005	8.6	3.9	79	142
11August2005	4.1	2.4	115	42
11August2005	1.0	2.8	193	80
15August2005	79.3	2.1	314	167
25August2005	261.0	12.0	326	1,397
28August2005	45.0	3.0	80	65
7September2005	247.0	1.5	218	72
12September2005	119.0	1.7	235	147
14September2005	35.0	3.1	64	26
15September2005	27.6	2.3	206	172
28September2005	306.0	1.7	238	34
28September2005	11.1	1.3	271	33
22October2005	561.0	4.9	416	709
22October2005	1.4	3.3	317	236
23October2005	8.0	6.2	93	257
26October2005	53.7	19.0	201	1,346

Result and Discussion

Runoff Events

A total of 44 consecutive runoff events were evaluated from 3 May 2005 to 25 October 2005 as shown in Table 2. The average measured precipitation for the events was 6.6 mm, ranging from 0.5 mm to 32 mm. The average duration of the precipitation was 6.0 h with a minimum duration of 1 hour and a maximum duration of 36 h. The average antecedent dry period was 100 hours with a minimum of 1 hour up to 561 hours.

EMC and PEMC during the Runoff Event

A PEMC below 60 mg/l was found in nine runoff events as presented in Table 3. In two of the runoff events, the EMC was below 60 mg/l while in seven events a PEMC below 60 mg/l was found in 94%, 86%, 42%, 36%, 30%, 21% and 19% respectively of the latter part of the runoff volume. At only one occasion, 2005-06-12, a significant first flush, according to Bertrand-Krajewski et al. [3], was evident when over 80% of the total mass of TSS was transported in 30% of the runoff volume (Fig. 3, Table 2, Table 3). This runoff occasion also displayed the maximum registered precipitation depth of 32 mm during the study period.

As shown in this study the majority of the runoff events displayed elevated TSS PEMC for the duration of the runoff event in regard to the selected criteria of 60 mg/l (Fig. 4, Table 2, Table 3). This shows that a treatment system should be designed to treat the complete runoff volume during summer from similar catchment areas. Furthermore, the findings of Hallberg and Renman [15] also suggest that the entire runoff volume should be treated during winter in this type of watershed. The prevailing method for removal of the particulate matter in runoff is sedimentation. According to Barret et al. [13] many storm water treatment systems are designed to capture the initial

Table 3. Runoff events with EMC or PEMC below 60mg/l and portion of the final part of total volume (X_V).

Date	X_V (TSS PEMC < 60mg/l)	Total runoff volume (m^3)	TSS EMC (mg/l)
12June2005	0.42	1,670	257
22July2005	0.86	3,496	121
30July2005	1.00	245	58
6August2005	0.21	672	175
7August2005	1.00	348	49
10August2005	0.94	1,602	67
11August2005	0.30	142	79
28August2005	0.19	65	80
23October2005	0.36	357	93

runoff from storms and thus remove and treat the runoff that contains the highest concentrations of pollutants. However, earlier studies have indicated large variations in pollutant transport, e.g. first flush [3, 8, 9], implying a corresponding uncertainty in designing treatment systems for storm water. The EU directive considers runoff water as a source of pollution in domestic wastewater in combined sewer systems. It is therefore of interest to assess treatment of runoff water using the directive as a guideline for discharge limits. This, in combination with the study of the PEMC, constitutes in our study a different approach with regards to earlier work.

Conclusion

The majority of the events in this study had a higher PEMC than the reference value of 60 mg/l during runoff. The findings indicate that the entire runoff volume must be treated from similar watersheds. The use of first flush as a design criterion is less applicable for the summer period for this kind of urban study area with a high traffic load and a surface asphalt covering over 80% of the watershed area.

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