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Event mean concentration and loading of litter from highways during storms

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Abstract

Total captured gross pollutants in stormwater runoff were monitored at six Southern California highway sites over 2 years. Gross pollutants were defined as larger than 0.5 cm and were classified into three categories. The gross pollutants were 90% vegetation and 10% litter. Approximately 50% of the litter was composed of biodegradable materials. Event mean concentrations and mass emission rates are presented. No statistically significant correlations of litter production were noted, although the event mean concentrations show an increasing trend with antecedent dry days and a decreasing trend with total runoff volume or total rainfall. The mass emission rates will be useful to estimate total litter production for developing total maximum daily loads.

Keywords: Event mean concentration; Highways; Litter; Nonpoint sources; Stormwater

1. Introduction

Since the passage of the Clean Water Act Amendments in 1972, great progress has been achieved in treating wastewaters from municipalities and industries. In the Los Angeles area, all treatment plants now have secondary treatment or better. In spite of this progress the aquatic environment is still impacted due to pollution from diffuse, or non-point sources. Currently, non-point source pollution remains the Nation's largest source of water quality problems (Horan, 1990; Larsen et al., 1998; Parr et al., 1998).

To address the combined impacts of point and non-point sources, Section 303(d) of the Clean Water Act mandated the implementation of total maximum daily loads (TMDL). A TMDL is a calculation of the maximum amount of pollutant that can be discharged to receiving water and still meet water quality standards. The TMDL includes the allocation of loads to the various dischargers to meet the goal. The process requires the identification of the uses for each receiving water (e.g.

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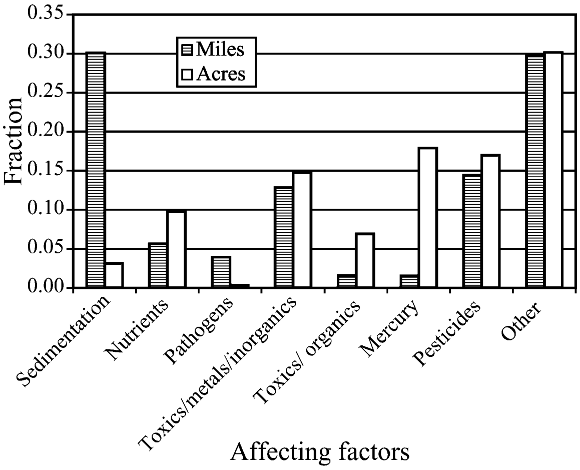

Fig. 1. Percentage of 8 impacting parameters to waters in California.

drinking water supply, contact recreation, and aquatic life support) and the scientific criteria to support that use. A TMDL becomes the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The calculation must include a margin of safety to ensure that the receiving water can be used for the designated purposes, and must also account for seasonal variation in water quality.

The California State Water Resources Control Board has identified in their 303(d) list at least 36 water bodies where trash or litter is considered a pollutant of concern (California State Water Resources Control Board, 1999). The first TMDL adopted by the Region 4 (Los Angeles area) of the California State Water Quality Control Board was for trash in the Los Angeles River (California Regional Water Quality Control Board, 2001), and other litter TMDLs are being developed for other watersheds. Fig. 1 shows the parameters that impact California waters and lists them by percentage of total area or linear miles impacted. Litter is included in 'sedimentation' and 'other' categories and can potentially affect approximately 60% of receiving waters.

The California Department of Transportation (Caltrans) is actively assessing the characteristics and potential impacts of litter generated from their highways (Caltrans, 2000a). Caltrans is also evaluating the practical application and performance of several litter capturing devices (Caltrans, 2001). Currently, litter characterization is an integrated part of the Caltrans First Flush Characterization Study (FFCS) where both water quality and litter characteristics during the first flush and the entire storm event are being evaluated. These data will provide a basis for Caltrans to develop potential treatment technologies and best management practices (BMPs) to control pollutants in runoff from Caltrans freeways. As part of this study, gross pollutants were captured and analyzed at 6 monitoring sites in the Los Angeles area for 17 storm events during the 2000–2002 rainy seasons. Gross pollutants (defined as being larger than 0.5 cm) were collected and divided into vegetation, biodegradable litter and non-biodegradable litter. This paper presents the results, including mass emission rates, event mean concentrations, and correlations to site-specific conditions.

2. Methodology

2.1. Study area

The first flush characteristic study (FFCS) was developed to obtain first flush water quality and litter data from representative stormwater runoff from standard highway drainage outfalls in the Los Angeles area. The locations of the FFCS monitoring sites are shown in Fig. 2, and their characteristics are summarized in Table 1. Table 1 shows average daily traffic (ADT), catchment area and approximate site imperviousness. Each site was equipped with a rainfall gage, flow meter and flow-weighted composite sampler. Rainfall and flow data were recorded at 1-min intervals. Each site generally had a corrugated or reinforced concrete pipe that discharged stormwater from grated drain vaults located along the edge of the highway. The circular storm drain outfalls were modified using a metal collar extension to mount and secure litter collection bags with 1/2 cm openings.

2.2. Litter collection procedure

Gross pollutant samples were collected in accordance with the procedures detailed in the FFCS

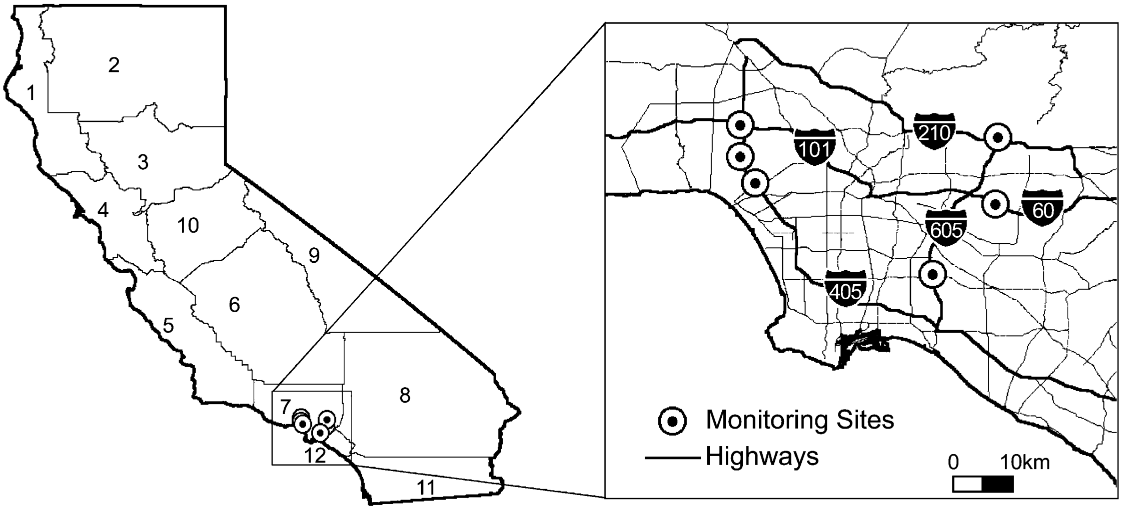

Fig. 2. Monitoring sites in Southern California.

Sampling and Analysis Plan (SAP) (Caltrans, 2000b). Gross pollutants refer to the combination of litter and vegetation that is initially collected in the bags. Samples were collected throughout each storm event, with particular emphasis on the first flush of storm water flow. Prior to the start of a storm event, a new collection bag was securely fastened to the outfall. During the event, up to four bags were used at each site. The bags were collected 1/2, 1 and 2 h after the beginning of runoff. The fourth and final bag was collected after the storm event. The collection bags were removed at the appropriate times, secured inside a plastic trash bag with labels and delivered to the laboratory for analysis.

2.3. Gross pollutant analysis

The collected material was analyzed for gross pollutants, vegetation, wet litter, dry litter, biodegradable dry litter, and non-biodegradable dry litter according to the procedures specified in Caltrans Litter Monitoring Guidance Manual (Caltrans, 2000c). Litter was defined as non-vegetation larger than 1/2-cm. The weight and volume of the gross pollutants were initially measured. The gross pollutants were then emptied into a tray, where vegetation was separated. The wet weight and volume of litter and vegetation were measured and recorded. The wet litter fraction was then air dried for a minimum of 24 h. After drying, the litter dry

Table 1
Descriptions of monitoring sites

Site name	Site location	Post (km)	ADT (cars/day)	No. of drain inlets	Catchment area (ha)	Approx. percent impervious (%)
UCLA1	101 Freeway	29.2	328 000	1	1.3	100
UCLA2	405 Freeway	53.6	260 000	1	1.7	95
UCLA3	405 Freeway	49.7	322 000	1	0.4	100
URS6-20F	60 Freeway	8.2/25.1	216 600	1	0.2	100
URS8-23C	605 Freeway	9/9.6	229 000	1	0.3	100
URS23	210 Freeway	29.8	122 000	20	2.9	100

weight and volume were measured and recorded. The dry litter fraction was then sorted into non-biodegradable and biodegradable fractions and weighed. Non-biodegradable litter is defined as litter that does not naturally degrade in the environment, such as metals and plastics. Biodegradable litter consists primarily of paper products. Mass balances were used to for quality control. Twenty percent of the samples were remeasured, and the replicates were generally less than 15% different in volume and 5% different in weight.

2.4. Calculation of event mean concentrations and emission parameters for litter

The classical event mean concentration was used to characterize litter loading as shown in Eq. (1):

$$\mathrm{EMC}_T(\mathrm{g/l}) = \frac{\text{Captured litter mass}}{\text{Discharged runoff volume}} = \frac{\int_o^T M(t)\mathrm{d}t}{\int_o^T Q_{T\mathrm{Ru}}(t)\mathrm{d}t} \quad (1)$$

where EMC is event mean concentration, $M(t)$ is captured litter weight, $Q_{T\mathrm{Ru}}(t)$ is runoff volume during integration interval, and T is the period of the storm. The equation can also be applied to portions of the storm by applying the appropriate integration limits. EMCs are frequently used to characterize stormwater loadings and can be multiplied by the runoff volume to estimate the mass discharge (Corwin and Vaughan, 1997; Irish et al., 1998).

Pollutant concentrations often decline over time, and it is generally believed that the first runoff is the most polluted. The emission rate is generally greater at the beginning of rainfall. This phenomenon is often called a ‘first flush’, and the existence of a first flush can influence the selection of best management practices (BMPs). The decline in concentration is sometimes off-set by an increasing runoff rate as a storm progresses. Mass emission based definitions of first flush have been proposed (Ma et al., 2002). In this article, the first flush of litter refers to the mass collected during the first 2 h of the event. This corresponds to the first three bags.

Site and event specific parameters were calculated in order to investigate the sources or nature of litter emissions. Factors such as average daily traffic (ADT), antecedent dry days (ADD), total rainfall and runoff volume were correlated with litter emission rates and first flush masses. Dividing by catchment area normalized litter emission.

3. Results and discussion

3.1. Hydrologic data

Table 2 shows storm event summaries for each monitored event and site, which includes event rainfall, maximum rainfall intensity, total runoff volume and antecedent dry days (ADD). The hydrologic data were used to prepare hydrographs and to calculate event mean litter concentrations. During the monitoring periods, antecedent dry days were observed from 1 to 190 days and event rainfalls were monitored from 0.28 to 15.6 cm. The total runoff volume varied from 8 to 1420 m^3 among the sites. The 2000–2001 season was a normal rainfall year with total rainfall nearly equal the mean 43-year record; the 2001–2002 season was a dry year, with approximately 25% of mean rainfall.

3.2. Statistical summary

The results of a statistical analysis for normalized weight and volume by area are summarized in Table 3 for the 2000–2002 monitoring seasons. URS23, the largest site, had the highest total weight and volume of gross pollutants and litter collected over the storm season. The net volume of litter collected from URS23 was greater than observed at other sites, but less when normalized by area. Sites URS6-20F and URS8-23C had larger specific pollutant loadings compared to other sites. The mean mass loading for wet gross pollutant in URS6-20F was 18.63 kg/ha and volume loading was 73.46 l/ha. Comparatively UCLA3 and URS23 sites had smaller mean mass and volume loadings, which were 5.34 kg/ha and 12.81 l/ha

Table 2
Event summary for all monitored events

Event date (month/date/year)	UCLA monitoring sites UCLA1					UCLA2					UCLA3				
	Event rainfall (cm)	Storm duration (h)	Max. rainfall intensity (mm/h)	Total flow (m^3)	ADD (days)	Event rainfall (cm)	Storm duration (h)	Max. rainfall intensity (mm/h)	Total flow (m^3)	ADD (days)	Event rainfall (cm)	Storm duration (h)	Max. rainfall intensity (mm/h)	Total flow (m^3)	ADD (days)
10/26/00	2.39	11.0	6.1	260.7	33.6	2.39	11.0	5.84	200.8	33.6	2.59	11.7	4.06	94.7	33.6
01/08/01	0.38	6.5	1.78	43.7	69.4	0.51	4.2	1.78	52.2	69.4	0.53	4.4	2.03	17.9	69.4
01/10/01	12.7	16.3	30.23	1327.4	1.9	15.6	17.2	32.26	1416.2	1.9	12.85	14.5	22.35	481.1	2
02/10/01	1.32	7.2	7.87	155.2	14.2						1.55	5.7	4.57	58.6	14.2
02/19/01	0.71	4.1	2.79	80.9	5.4	2.39	9.0	7.11	261.6	4.8	3.02	7.0	12.19	112.4	5.3
02/24/01	1.45	19.0	1.78	165.6	1	1.91	19.1	2.29	241.6	1	1.14	11.5	2.29	38.1	1
03/04/01	1.19	10.3	3.05	139.1	4	0.89	5.0	4.83	140.2	4	0.51	3.7	2.29	11.4	4
04/07/01						3.02	9.2	5.33	501.9	31.5	2.54	10.8	7.62	65.2	31.6
04/20/01	0.81	6.2	2.79	79	13.2										
10/30/01						0.33	4.3	2.03	47.5	192.2	0.28	4.3	2.29	8.1	192.3
11/12/01						1.19	1.7	9.91	172.3	12.98	0.74	1.4	5.33	24.8	12.99
11/24/01						5.03	4.4	26.67	737.8	11.69	2.97	4.4	14.48	108.7	11.6
12/14/01						0.36	4.0	2.03	52	19.73					
01/27/02						3.18	8.6	8.13	445.6	27.13	2.46	8.6	5.08	92.2	27.14
02/17/02											0.74	2.1	4.32	25.6	20.31
03/07/02											0.46	1.5	3.3	14.4	17.74
03/17/02						0.23	1.0	2.29	23.53	10.69	1.04	1.6	9.4	37	10.7
	URS monitoring sites[a] URS6-20F					URS8-23C					URS23				
10/26/00	0.89	10.0	15.2	33.9	33		15.3	7.6	11.2		3.2	9.7			33
01/08/01	0.23	2.1	3	2	70.6	0.33	3.0			108	0.43	3.8			70.4
01/10/01	7.11	18.8	18.3	130.6	72.2	10.26	18.5	24.4	168	2	8.74	21.1	27.4	1673.5	2
01/26/01	0.71	7.3	6.1	10.7	1.7	1.45	6.2	6.1	14.6	1.7	1.19	7.8	21.3	156.1	1.7
02/10/01	0.71	6.6	6.1	4.3	14.5	1.25	6.4	12.2	7.3	2.9	0.79	9.2	9.1	152.7	14.6
02/19/01	0.46	5.7	6.1	7.9	5.6	0.94	6.5	1.5	12	5.5	1.04	6.4	6.1	117.6	5.7
02/24/01	9.04	9.7	9.1	80.8	1.1	6.43	9.1	9.1	118.3	0	9.55	10.5	12.2	1047.4	5.1
04/09/01	1.55	8.2	15.2	21.7	31.8		15.3	24.4	31.4	28.1	2.29	10.0	15.2	564.6	31.8

[a]Due to low rainfall in 2001–2002 rainy season, limiter litter data were available from the URS sites.
*The missing data in UCLA sites are due to collection failure.

Table 3
Statistical summary of normalized litter for all data during the 2000–2002 monitoring seasons

Parameters	Monitoring sites	Gross pollutants		Litter				Biodegradable		Non-biodegradable		Vegetation	
		Wet		Wet		Dry		Dry		Dry		Wet	
		Weight (kg/ha)	Volume (l/ha)	Weight (kg/ha)	Volume (l/ha)	Weight (kg/ha)	Volume (l/ha)	Weight (kg/ha)	Volume (l/ha)	Weight (kg/ha)	Volume (l/ha)	Weight (kg/ha)	Volume (l/ha)
Minimum	UCLA2	0.302	0.412	0.020	0.088	0.010	0.082	0.005	0.000	0.005	0.000	0.280	0.323
	UCLA3	0.625	1.875	0.221	0.000	0.104	0.000	0.036	0.000	0.034	0.000	0.625	1.875
	URS6-20F	0.350	2.400	0.033	0.500	0.012	0.400	0.010	0.249	0.000	0.100	0.305	1.400
	URS8-23C	0.497	2.833	0.172	0.900	0.084	0.934	0.053	0.600	0.031	0.334	0.313	1.834
	URS23	0.407	1.793	0.066	0.345	0.030	0.145	0.008	0.072	0.007	0.072	0.335	1.448
Maximum	UCLA2	49.42	35.76	1.38	22.94	0.90	10.00	0.37	4.41	0.39	4.71	48.65	33.84
	UCLA3	11.45	32.50	0.88	5.75	0.40	7.00	0.35	5.00	0.21	4.75	10.75	31.00
	URS6-20F	80.00	292.00	6.80	52.00	4.17	39.30	2.60	19.70	1.15	12.80	72.50	234.00
	URS8-23C	43.33	82.33	7.70	27.73	6.07	26.37	2.30	11.33	3.31	12.37	35.00	53.00
	URS23	20.77	50.00	2.22	8.97	1.30	8.97	0.58	4.14	0.63	4.66	18.22	40.34
Median	UCLA2	3.78	4.44	0.27	1.07	0.16	0.86	0.05	0.16	0.04	0.15	3.30	3.29
	UCLA3	4.78	10.13	0.46	1.63	0.25	2.24	0.12	1.05	0.08	0.56	4.24	7.25
	URS6-20F	5.81	35.00	0.66	2.37	0.26	2.68	0.14	1.72	0.08	0.92	5.40	33.08
	URS8-23C	6.60	10.58	1.27	4.48	0.72	4.50	0.30	1.97	0.36	2.36	5.27	6.10
	URS23	2.25	8.79	0.26	1.55	0.14	1.67	0.05	0.33	0.02	0.24	2.11	5.69
Mean	UCLA2	9.28	10.76	0.46	3.69	0.30	2.75	0.09	0.57	0.13	0.60	8.78	7.06
	UCLA3	5.34	12.81	0.49	2.28	0.25	2.60	0.14	1.31	0.10	1.05	4.88	10.36
	URS6-20F	18.63	73.46	1.58	10.03	0.85	8.38	0.54	4.86	0.24	2.62	16.59	60.94
	URS8-23C	13.97	23.78	2.31	8.66	1.62	7.90	0.67	3.45	0.85	3.93	11.51	14.83
	URS23	5.88	17.65	0.59	2.63	0.33	2.69	0.14	1.09	0.13	1.25	5.21	11.59
Standard deviation	UCLA2	14.00	13.12	0.44	6.56	0.30	3.53	0.12	1.23	0.16	1.33	13.76	9.56
	UCLA3	3.02	8.82	0.22	1.88	0.10	2.22	0.08	1.37	0.06	1.25	2.95	8.33
	URS6-20F	26.70	93.71	2.29	17.63	1.41	13.29	0.88	6.94	0.39	4.24	24.13	73.93
	URS8-23C	17.22	30.85	2.88	10.43	2.30	9.67	0.88	4.09	1.26	4.59	14.18	19.89
	URS23	7.45	17.54	0.77	3.07	0.45	3.12	0.21	1.57	0.23	1.70	6.58	14.20

*Litter collection of some events at UCLA1 failed.

for UCLA3 and 5.88 kg/ha and 17.65 l/ha for URS23.

Table 4 shows the cumulative litter parameters for the 2000–2001 season, normalized by site area. The site UCLA1 is missing due to collection failures. The normalized litter values vary for each site range from 2.69 to 17.35 kg/ha for dry litter weight, 0.40–8.99 kg/ha for dry biodegradable litter weight, and 0.85–6.61 kg/ha for non-biodegradable litter weight. The ratio of net weight of biodegradable to non-biodegradable litter at UCLA3, URS8-23C, and URS23, was very similar, approximately 1–1. A higher fraction of biodegradable litter (up to two times) was observed at URS6-20F and a higher fraction of non-biodegradable litter (up to two times) at UCLA2.

3.3. Litter fraction

The fractions of each parameter are shown in Fig. 3. The notched box plots show the median value and inter-quartile range with flared sides that terminate at the 95% confidence limit. The data used for this comparison was the combined data from all sites and events. The mean fraction of wet litter weight was approximately 12% of the wet gross pollutant weight while the remainder was vegetation. Mean wet litter volume was 21% of the total gross pollutant volume, but varied widely, from 3 to 45%. The mean portions of biodegradable dry litter weight and volume were approximately 50% of the dry litter weight and volume; the fractions of biodegradable and non-biodegradable were nearly equal.

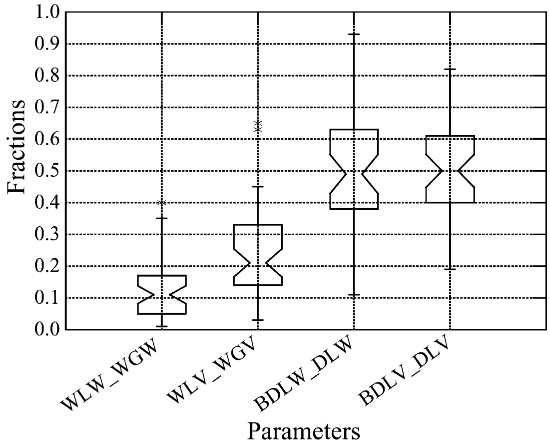

Fig. 3. Fractions of litter for all monitoring data (WLW_WGW = wet litter weight/wet gross weight, WLV_WGV = wet litter volume/wet gross volume, BDLW_DLW = biodegradable dry litter weight/dry litter weight, BDLV_DLV = biodegradable dry litter volume/dry litter volume).

3.4. Litter polluto- and load-graphs

Gross pollutant and litter data were evaluated as polluto-graphs (concentration vs. time) and load-graphs (mass loading rate vs. time) for each event and site. The litter concentrations were calculated as the dry litter mass divided by the total flow

Table 4
Normalized litter as function of catchment area during 2000–2001 monitoring season

Parameter / Monitoring sites				Cumulative pollutant UCLA2	UCLA3	URS6-20F	URS8-23C	URS23
Gross pollutants	Wet	Weight	(kg/ha)	64.8	36.4	329	121	48
		Volume	(l/ha)	56.1	78.6	1440.00	178	138
Litter	Wet	Weight	(kg/ha)	1.8	4	25.3	19.1	4.87
		Volume	(l/ha)	6.25	18.1	165	69.3	22.1
	Dry	Weight	(kg/ha)	5.8	17.35	14.1	13.3	2.69
		Volume	(l/ha)	1.3	1.8	149	63.7	22.3
Biodegradable	Dry	Weight	(kg/ha)	0.4	0.8	8.99	6.01	1.1
		Volume	(l/ha)	2.8	9.5	82.3	28.3	8.28
Non-biodegradable	Dry	Weight	(kg/ha)	0.85	0.85	4.4	6.61	1.01
		Volume	(l/ha)	3	7.8	58.3	31.7	9.55

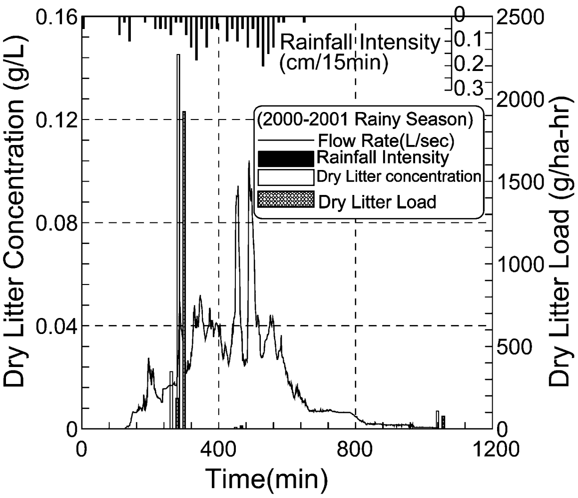

Fig. 4. Litter polluto- and load-graphs for first storm event (with hydrograph shown in background).

volume during the time of the litter sample collection. The litter mass loading rates were calculated as the dry litter mass divided by the elapsed time of litter collection, and normalized by the catchment area. These plots were compared to the respective hydrographs to determine the potential relationships to flow intensity and storm duration. The plots were also used to determine whether a first flush effect (i.e. relatively higher litter concentrations early in the event, followed by a decrease in concentration after a period of time) was present. Fig. 4 shows an example of combined litter polluto-graph and load-graph for the first event of the season. The first event of the season at site UCLA1 shows very high dry litter concentration and load in 1 h.

3.5. First flush

Caltrans' first flush criteria for litter is defined as the litter mass fraction within the first 2 h of the storm event. If more than 50% of the mass is emitted during the first 2 h, it is called a first flush. The litter first flush observation based on the litter ratio is presented in Table 5 for selected events. The occurrence of a first flush was not consistently observed at all monitoring sites during the same storm event. Similarly, review of the litter polluto-graphs and load-graphs indicate that the first flush phenomenon was occasionally

Table 5
Fraction of litter occurring in the first 2 h of runoff [a]

Parameters		GrossLitterLitterLitter			airLitter		airBiodegradableBiodegradable		
		pollutant wet weight	pollutant wet volume	wet weight	wet volume	dry Weight	dry volume	dry weight	dry volume
UCLA2	10/26/01	0.02	0.03	0.04	0.05	0.03	0.06	0.03	0.04
	1/8/01	0.98	0.95	0.98	0.97	0.96	0.97	0.97	0.98
	1/10/01	0.05	0.11	0.53	0.39	0.48	0.5	0.5	0.63
UCLA3	10/26/01	0.92	0.73	0.85	0.62	0.81	0.61	0.64	0.4
	1/8/01	0.94	0.9	0.98	0.96	0.98	0.96	0.98	0.95
	1/10/01	0.2	0.27	0.59	0.31	0.38	0.34	0.49	0.37
	2/10/01	0.25	0.26	0.15	0.13	0.12	0.1	0.15	0.1
	2/19/01	0.61	0.57	0.85	0.71	0.92	0.74	0.75	0.57
URS6-20F	10/26/00	0.23	0.29	0.33	0.35	0.29	0.34	0.24	0.31
	1/10/01	0.98	0.96	0.94	0.96	0.96	0.94	0.97	0.94
	1/26/01	0.87	0.88	0.94	0.96	0.96	0.96	1	0.93
	2/10/01	0.97	0.95	0.99	0.93	0.99	0.94	0.99	0.93
URS8-23C	10/26/00	0.19	0.2	0.14	0.12	0.12	0.12	0.16	0.14
	1/10/01	0.77	0.68	0.58	0.7	0.53	0.62	0.77	0.7
	2/24/01	0.22	0.32	0.37	0.43	0.37	0.33	0.46	0.33

[a] Due to low rainfall in 2001–2002 monitoring season, limited litter data were available.

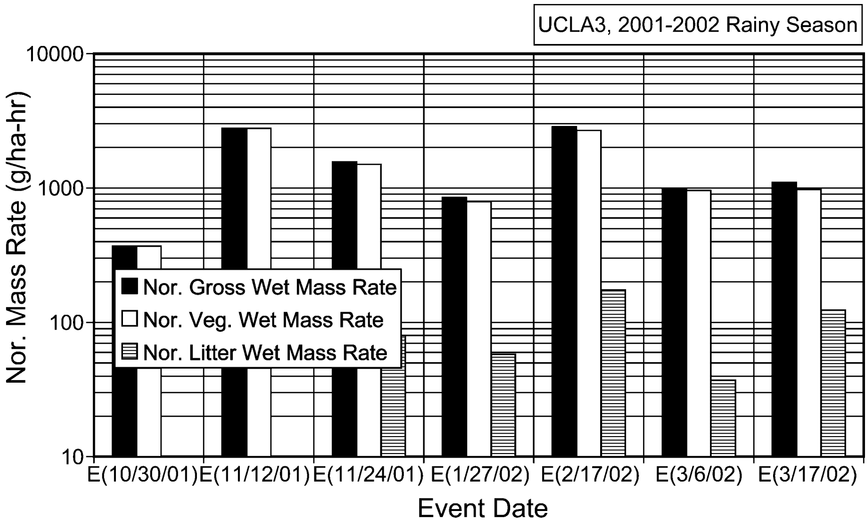

Fig. 5. Normalized mass rates as function of catchment area and storm duration.

observed in all sites during certain storm events. Table 5 shows that site URS 6-20F most consistently exhibited a first flush. During the storm event of January 10, 2001, URS6-20F, URS8-23C and URS23 showed significant first flush effects, but there was none present for UCLA2 and UCLA3. This storm event also had the highest relative rainfall intensity of the season.

Evaluation of the litter load-graphs, however, presented no clear observations of a first flush phenomenon. In many instances, the litter mass loading rates was not highest during the first

Table 6
Correlation matrix with impacting parameter for (a) mass loading and (b) volume loading

	Pearson correlation matrix							
	Volume	TR	MI	ADD	WGV	WVV	WLV	DLV
Matrix of Bonferroni Probabilities	TR	1	0.76	−0.21	0.48	0.44	0.26	0.25
	MI	0.00	1	−0.18	0.59	0.64	0.42	0.43
	ADD	1.00	1.00	1	−0.08	−0.06	0.08	0.08
	WGV	0.09	0.01	1.00	1	0.93	0.86	0.87
	WVV	0.23	0.00	1.00	0.00	1	0.87	0.88
	WLV	1.00	0.30	1.00	0.00	0.00	1	0.99
	DLV	1.00	0.28	1.00	0.00	0.00	0.00	1
	Mass	TR	MI	ADD	WGW	WVW	WLW	DLW
	TR	1	0.76	−0.21	0.608	0.60	0.32	0.38
	MI	0.00	1	−0.18	0.70	0.69	0.51	0.56
	ADD	1.00	1.00	1	−0.10	−0.10	0.04	0.06
	WGW	0.00	0.00	1.00	1	0.99	0.63	0.66
	WVW	0.00	0.00	1.00	0	1	0.57	0.61
	WLW	1.00	0.06	1.00	0.00	0.01	1	0.99
	DLW	0.58	0.02	1.00	0.00	0.00	0.00	1

TR: total rainfall, MI: maximum rainfall intensity, ADD: antecedent dry days, WGV: wet gross volume, WVV: wet vegetation volume, WLV: wet litter volume, and DLV: dry litter volume.

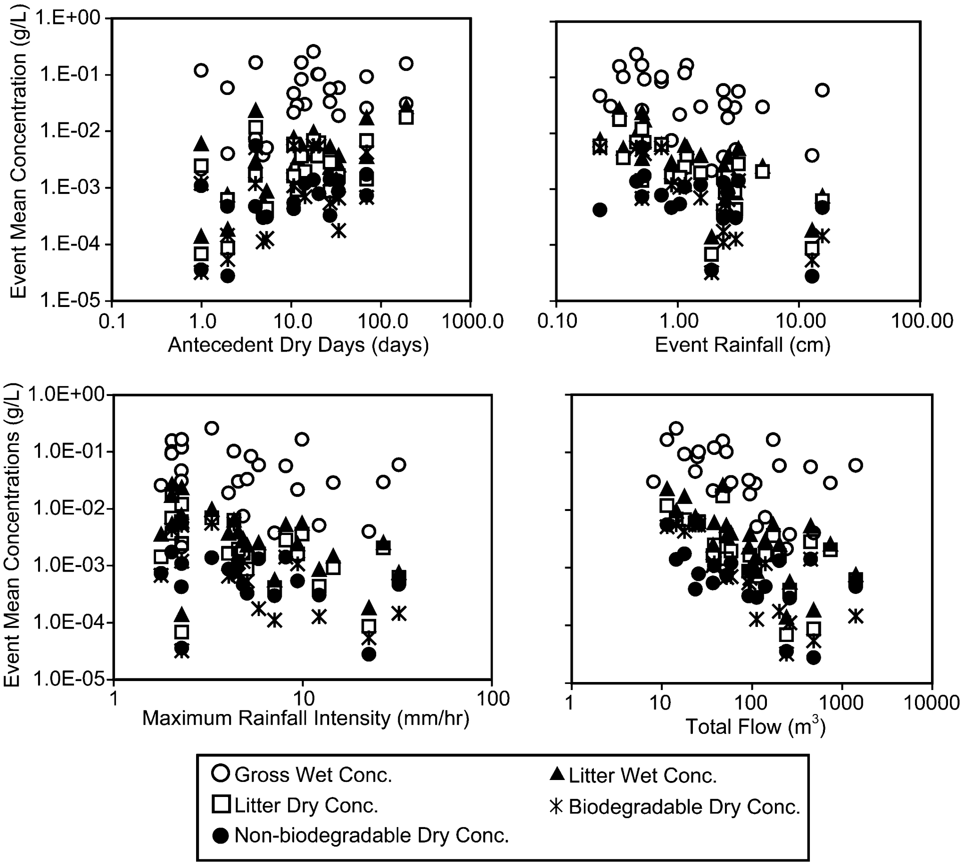

Fig. 6. Correlation between event mean concentrations and impacting parameters (ADD, event rainfall, maximum rainfall intensity and total flow).

portion of a storm event; the highest litter mass loading rate was observed later in the storm event, after the peak flow had occurred.

Gross pollutant and litter data were also reviewed and compared on a multi-event basis to evaluate a potential effect of the first storm event of the season. It was hypothesized that the first storm event of the season would have the highest relative amount of litter mass, volume and mass loading compared to subsequent storm events. Table 5 shows that the first monitored storm event of the season did not produce a relatively greater amount of litter when compared to the subsequent storm events. The existence of a first flush and the mass of gross pollutants may be a function of the total or maximum intensity of rainfall. Gross pollutants are retained on the surfaces and in catch basins and pipes, and a minimum flow may be required to mobilize them. If the first rainfall of the season is large but lengthy with low intensity, gross pollutants may not be mobilized. Conversely, a short, intense rainfall may mobilize more pollutants. The amount of runoff to mobilize gross pollutants is a question for future research, but may be important for designers, since it may be possible to change stormdrain designs to impact litter mobilization.

The ratio of biodegradable to non-biodegradable litter was calculated for each event and site. The values varied considerably during each storm event. Site URS6-20F, the site with the highest normalized litter mass loading, consistently had

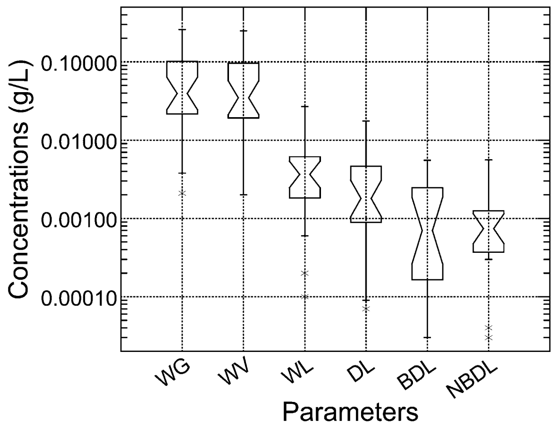

Fig. 7. Notched box plot for event mean concentrations (WG: wet gross, WV: wet vegetation, WL: wet litter, DL: dry litter, BDL: biodegradable dry litter, NBDL: non-biodegradable dry litter).

higher amounts of biodegradable litter. Site UCLA2 had more non-biodegradable litter. On average for all sites, a slightly greater percentage (approx. 60%) of biodegradable litter was measured in the first flush of the storm events. This was consistent with individual storm event observations where lighter biodegradable litter appeared to be washed out first, leaving the relatively heavier non-biodegradable litter to wash out with the remainder of the storm event during the peak flow periods.

Fig. 5 shows the normalized wet gross, vegetation and litter rates for each event at UCLA3 site. The storm event, October 30, 2001, is the first storm at UCLA3 site. The mass rate is not higher compared to other events. The mass rates vary to event-to-event and influenced by several factors as discussed below.

3.6. Factors affecting litter production

Each parameter normalized by area was compared with potential affecting factors such as total rainfall, maximum rainfall intensity and antecedent dry days to determine whether there are any potential relationships. The matrix of small figures represents mass loading relationship with affecting parameters. Table 6 shows the matrices of mass-based parameters and volume-based parameters. There are no obvious correlations with storm characteristics, such as ADD and total rainfall (TR). The relationship between wet gross pollutant mass or volume and wet vegetation mass or volume is striking. The wet gross pollutant mass is primarily vegetation. There are also significant relationships between wet and dry volumes, which is expected.

Fig. 6 shows the litter EMC as a function of ADD and event rainfall. The wet gross pollutant weight shows no trend with ADD or rainfall; however, the EMC shows a slight increasing trend with ADD for litter, suggesting accumulation during dry periods. The EMCs for litter show a small decreasing trend with total rainfall. This has been observed for other pollutants and suggests that the large rainfall has washed out sufficiently large masses of litter from the catchment so that the concentration decreases.

The figure also shows the litter EMC as a function of maximum rainfall intensity. There is no obvious trend; also the rainfall intensity is correlated with total rainfall (see Table 6) so that any trends may be due to total rainfall or maximum intensity. The figure also shows the total runoff volume and total rainfall are related by the runoff coefficient.

Fig. 7 shows EMCs represented by notched box plot for the six previously defined litter parameters. The EMCs can be used to estimate litter production in planning models. The variability of litter emission is 2 orders of magnitude in some cases.

3.7. Regression model for event mean concentrations of litter

In order to predict the litter EMC to measurable or predictable rainfall parameters and power regression was performed using the following equation:

$$\mathrm{EMC}_{\mathrm{litter}} = \varepsilon(\mathrm{ADD})^{a}\ (\mathrm{TR})^{b} \qquad (2)$$

where ADD is antecedent dry days (days) and TR is total rainfall (cm). ε, a and b are fitting parameters.

Table 7
Coefficient determination and statistical summaries

Parameters	ε	A	B	R^2	Durbin–Watson D
Wet gross pollutant	0.0239	0.206	−0.408	0.500	2.009
Wet vegetation	0.02056	0.215	−0.387	0.490	1.964
Wet litter	0.0016	0.360	−0.683	0.790	1.933
Dry litter	0.00095	0.354	−0.694	0.770	2.061
Dry biodegradable litter	0.00061	0.245	−1.034	0.570	1.676
Dry non-biodegradable	0.00032	0.336	−0.408	0.590	2.252

The regression in Eq. (2) explains approximately 40–80% of the variability as shown in Table 7. The fitting parameters are also shown. The value of fitting parameter, *a*, is positive, suggesting that EMC increases with increasing ADD. The parameter *b* is negative, suggesting that EMC decreases with total rainfall or runoff. These two model parameters match the results presented earlier in the paper indicating that the litter will build up over dry days, and the high rainfall or runoff will washout litter from the catchment, reducing the concentration.

4. Conclusions

This article presents the results of total gross pollutants and litter observations at 6 highway sites in Southern California over 2 years. Both pollutants have become important aspects of stormwater pollution prevention. Litter is observable by the public and has attracted increased interest. The first TMDL for Southern California was for litter. There is less information about litter since it has not been considered a traditional water pollutant. The conclusions that can be drawn from this study are summarized as follows.

1. Vegetation composed almost 90% of the total gross pollutants (>0.5 cm) captured in litter traps. Litter composed the remaining 10%.
2. The normalized litter loadings vary from 2.69 to 17.35 kg/ha for dry litter, 0.40–8.99 kg/ha for dry biodegradable litter, and 0.85–6.61 kg/ha for non-biodegradable litter.
3. The event mean concentration for total gross pollutants ranged from 2.1 to 259 mg/l (wet basis). The concentrations of non-biodegradable (metals, plastics, etc.) and biodegradable litter (paper, etc.) were nearly equal and ranged from 0.03 to 5.5 mg/l (dry basis).
4. There were few meaningful correlations of litter parameters with storm parameters such as total rainfall, antecedent dry days, etc. A decreasing trend in litter EMC was observed with total rainfall or total runoff volume. An increasing trend of EMC was observed with antecedent dry days.
5. An empirical power series model was developed that can be used to estimate litter production. The trend observations and the model are considered developmental and need verification.

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