Characteristics of litter waste in highway storm runoff

L.-H. Kim*, J. Kang, M. Kayhanian***, K.-I. Gil****, M.K. Stenstrom** and K.-D. Zoh*******

*Dept. of Civil and Environmental Engineering, Disaster Prevention Research Center, Kongju National University, Kongju-si, Chungnam-do 314-701, Korea (E-mail: *leehyung@kongju.ac.kr*)

**Dept. of Civil and Environmental Engineering, University of California, Los Angeles, California 90095-1593, USA (E-mail: *joohyon@ucla.edu*, *stenstro@seas.ucla.edu*)

***Center for Environmental and Water Resources Engineering, Dept. of Civil and Environmental Engineering, University of California, Davis, California 95616, USA (E-mail: *mdkayhanian@ucdavis.edu*)

****Dept. of Civil Engineering, Seoul National University of Technology, Seoul 139-743, Korea (E-mail: *kgil@snut.ac.kr*)

*****Dept. of Environmental & Health, Graduate School of Public Health, Seoul National University, Jongro-Gu, Seoul, 110-799, Korea (E-mail: *zohkd@snu.ac.kr*)

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Abstract Litter characterization is an integrated part of the Caltrans First Flush Characterization Study. These data will provide a basis to develop potential treatment technologies and best management practices to control pollutants in runoff from freeways. During monitoring periods in Southern California areas, the first flush phenomenon was evaluated and the impacts of various parameters such as rain intensity, drainage area, peak flow rate, and antecedent dry period on litter volume and loading rates were evaluated. First flush phenomenon was generally observed for litter concentrations, but was not apparent with litter mass loading rates. Total captured gross pollutants, defined as larger than 0.5 cm, was 90% vegetation with only 10% being litter. The normalized cumulative litter loadings were determined from 1.25 to 13.39 kg/ha for dry litter weight and 0.40 to 8.99 kg/ha for dry biodegradable litter weight. The portions of biodegradable litter to non-biodegradable litter were roughly the same across the entire event. Event mean concentrations were ranged 0.0021 to 0.259 g/L for wet gross pollutants, 0.0001 to 0.027 g/L for wet litters and 0.00007 to 0.018 g/L for dry litters. The mass emission rates should be useful to estimate total litter production for developing total maximum daily loads.

Keywords Best management practice; Caltrans; first flush; highways; litter; stormwater

Introduction

Street litter, such as plastic bags, cups, cigarette butts, and candy wrappers, often is accumulated during dry seasons. It gets swept away with stormwater into storm drains and ends up floating in the ocean or washing up on our beaches. A great deal of street litter is made up of plastic, which takes hundreds of years to break down and become harmless to the environment (US EPA, 1994). Therefore, litter is considered one of the major pollutants when protecting receiving waters for beneficial use. The California Water Resources Control Board has identified in their 303(d) list at least 36 water bodies where trash is considered a pollutant of concern (California State Water Resources Control Board, 1999). Recently Los Angeles Region of the California Regional Water Quality Control Board developed a total maximum daily load (TMDL) standard for trash in the Los Angeles River (California Department of Transportation, 2001). Faced with expected future trash regulation, the California Department of Transportation (Caltrans) is actively assessing the characteristics and potential impacts of litter generated from their surface transportation (California Department of Transportation, 2000a). 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

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entire storm event are evaluated. As part of this study, litter weight and volume were evaluated from six monitoring sites in the Los Angeles area for up to 17 storm events during the 2000–2002 rainy seasons.

Methods

The locations of the monitoring sites in Southern California area are shown in Figure 1. Rainfall, runoff flow rate and runoff quality were monitored at six freeway sites in Southern California over two rainy seasons. The stations were equipped with a rainfall gage, flow meter and flow-weighted composite sampler. Rainfall and flow data were recorded at one-minute intervals. The monitoring sites were designed to capture litter for off-site evaluation. The circular storm drain outfalls were modified by a metal collar extension to mount and secure litter collection bags with 0.5 cm openings.

Gross pollutant samples were collected during storms. Gross pollutants are the combination of litter and vegetation collected initially in the bags. During the storm event, up to four bags were used at each monitoring site. To the extent possible, bags were collected after the first 30 minutes of stormwater flow, after the end of the first hour, and after the end of the second hour of stormwater flow. The fourth and final bag was collected after the storm event. At the completion of each sample interval, the filled collection bag was removed from the outfall and placed inside a plastic trash bag. The trash bag was secured with a large, plastic tie-wrap and labeled with a Tyvek sample tag with the appropriate sample information. Following the storm event, the collected bags were delivered to the laboratory for analysis. Litter analyses were conducted for weight and volume for the following constituents: 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 (California Department of Transportation, 2000b). Litter was defined as material larger than 0.5 cm that is not vegetation. Non-biodegradable litter was 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 for quality control (Kim *et al.*, 2004).

The mean concentration for each event was used to characterize litter loading, which was calculated from the captured litter mass by dividing by discharged runoff volume. EMCs are frequently used to characterize stormwater loadings and can be multiplied by the runoff volume to estimate the mass discharge (Irish Jr. *et al.*, 1998). The mass emission rate is generally greater at the beginning of rainfall, which is often called a first flush effect. The criteria of a first flush can influence the selection of best management practices (BMPs).

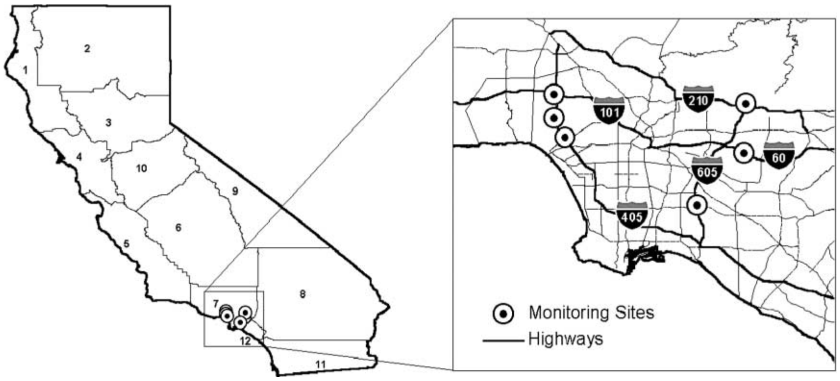

Figure 1 Monitoring sites in Southern California

Results

Continuous flow and rainfall were measured as a minute time interval. Table 1 shows storm event summaries for each monitored event and site. It 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. ADD were observed from 1 day to 190 days and event rainfalls were monitored from 0.28 cm to 15.6 cm during the monitoring periods. The total runoff volume varied from 8 m^3 to 1,420 m^3 among the sites. The gross pollutant and litter data for each site were taken and analyzed for all of the storm events. The results of a statistical analysis for normalized weight and volume by area are summarized in Table 2 for the 2000–2002 monitoring seasons.

In evaluating the raw gross pollutant and litter data for each monitoring site, UCLA 2 and URS23 had the highest relative total weight and volume of gross pollutants. The net volume of litter collected from URS23 was more than 10 times greater than other sites because of the watershed area. However, in the site, URS6-20F and URS8-23C have larger pollutant loading rates compared to other sites. The mean mass loadings for wet gross pollutant are 18.63 kg/ha in URS6-20F and 13.97 kg/ha in URS8-23C. The mean mass for wet vegetation was determined to be 16.59 kg/ha in URS6-20F and 11.51 kg/ha in URS8-23C. This means that most of the wastes of the highway runoff are originated from plants near the highways. Of the monitored sites, a high fraction of biodegradable litter was observed at URS6-20F and a high fraction of non-biodegradable litter at UCLA2.

The hydrograph shows the flow rate, rainfall intensity and the time when a litter bag was collected during a storm event. Since the bags were exchanged at preset time intervals, the hydrograph provides a visual representation of what transpired during the event. A litter bag may be collected prior to, during, or after a peak in storm water flow. Figure 2 shows dry litter concentrations and loading rates for the seasonal first storm event. The concentrations are determined by the dry litter mass by dividing by the total flow volume during the time of the litter sample collection. The litter loading rates were calculated as the dry litter mass divided by the elapsed time of litter collection and catchment area.

The gross pollutants are composed of vegetation and litter. Figure 3 shows fraction of wet vegetation to wet gross pollutant weight for each event and site. The fractions of vegetation for all sites and events are ranged from 70% to 95% of the total gross pollutants weight.

The vegetation in highways comes from plants of the road side and hill side. It is usually pulled out by strong rainfall intensity and sometimes by weathering effect. When it is washed off by storm flow to the nearby stream, it may be floated or deposited at the bottom of the water body. For a long time it can be decomposed into nutrients and other pollutants. The first flush phenomenon was evaluated during monitoring periods and the impacts of various parameters such as rain intensity, drainage area, peak flow rate, and antecedent dry period on litter volume and loading rates were evaluated. First flush phenomenon was generally observed for litter concentrations, but was not apparent with litter mass loading rates.

Wet gross pollutant loading rates for each event and site are shown in Figure 4. It was calculated with wet gross pollutant mass dividing by storm duration and catchment area. It can be useful to determine the amount of washed-off mass during storms to receiving water bodies. Usually the rates depend on antecedent dry days, storm duration, rainfall intensity, total rainfall volume, etc. On Jan. 10, 2001, the loading rates show the highest values of all events although antecedent dry days is very short, around 1.9–2 days except site URS6-20F. However, rainfall intensities on the date are ranged from 18.3 to 32.26 mm/h, which is the highest range of all the events. Also the event rainfalls are

Table 1 Hydrological summary for all monitored events

Event date (m/d/y)	UCLA monitoring sites											
	UCLA1				UCLA2				UCLA3			
	Event rainfall (cm)	Max rainfall intensity (mm/h)	Total flow (m^3)	ADD (days)	Event rainfall (cm)	Max rainfall intensity (mm/h)	Total flow (m^3)	ADD (days)	Event rainfall (cm)	Max rainfall intensity (mm/h)	Total flow (m^3)	ADD (days)
10/26/00	2.39	6.10	260.7	33.6	2.39	5.84	200.8	33.6	2.59	4.06	94.7	33.6
01/08/01	0.38	1.78	43.7	69.4	0.51	1.78	52.2	69.4	0.53	2.03	17.9	69.4
01/10/01	12.70	30.23	1,327.4	1.9	15.60	32.26	1,416.2	1.9	12.85	22.35	481.1	2.0
02/10/01	1.32	7.87	155.2	14.2	–	–	–	–	1.55	4.57	58.6	14.2
02/19/01	0.71	2.79	80.9	5.4	2.39	7.11	261.6	4.8	3.02	12.19	112.4	5.3
02/24/01	1.45	1.78	165.6	1.0	1.91	2.29	241.6	1.0	1.14	2.29	38.1	1.0
03/04/01	1.19	3.05	139.1	4.0	0.89	4.83	140.2	4.0	0.51	2.29	11.4	4.0
04/07/01	–	–	–	–	3.02	5.33	501.9	31.5	2.54	7.62	65.2	31.6
04/20/01	0.81	2.79	79.0	13.2	–	–	–	–	–	–	–	–
10/30/01	–	–	–	–	0.33	2.03	47.5	192.20	0.28	2.29	8.1	192.30
11/12/01	–	–	–	–	1.19	9.91	172.3	12.98	0.74	5.33	24.8	12.99
11/24/01	–	–	–	–	5.03	26.67	737.8	11.69	2.97	14.48	108.7	11.60
12/14/01	–	–	–	–	0.36	2.03	52.0	19.73	–	–	–	–
01/27/02	–	–	–	–	3.18	8.13	445.6	27.13	2.46	5.08	92.2	27.14
02/17/02	–	–	–	–	–	–	–	–	0.74	4.32	25.6	20.31
03/07/02	–	–	–	–	–	–	–	–	0.46	3.30	14.4	17.74
03/17/02	–	–	–	–	0.23	2.29	23.53	10.69	1.04	9.40	37.0	10.70

Table 1 (*continued*)

Event date (m/d/y)	**UCLA monitoring sites**											
	UCLA1				**UCLA2**				**UCLA3**			
	Event rainfall (cm)	**Max rainfall intensity (mm/h)**	**Total flow (m^3)**	**ADD (days)**	**Event rainfall (cm)**	**Max rainfall intensity (mm/h)**	**Total flow (m^3)**	**ADD (days)**	**Event rainfall (cm)**	**Max rainfall intensity (mm/h)**	**Total flow (m^3)**	**ADD (days)**
	URS monitoring sites											
	URS6-20F				*URS8-23C*				*URS23*			
10/26/00	0.89	15.20	33.9	33.0	–	7.60	11.2	–	3.20	–	–	33.0
01/08/01	0.23	3.00	2.0	70.6	0.33	–	–	108.0	0.43	–	–	70.4
01/10/01	7.11	18.30	130.6	72.2	10.26	24.40	168.0	2.0	8.74	27.40	1,673.5	2.0
01/26/01	0.71	6.10	10.7	1.7	1.45	6.10	14.6	1.7	1.19	21.30	156.1	1.7
02/10/01	0.71	6.10	4.3	14.5	1.25	12.20	7.3	2.9	0.79	9.10	152.7	14.6
02/19/01	0.46	6.10	7.9	5.6	0.94	1.50	12.0	5.5	1.04	6.10	117.6	5.7
02/24/01	9.04	9.10	80.8	1.1	6.43	9.10	118.3	0.0	9.55	12.20	1,047.4	5.1
04/09/01	1.55	15.20	21.7	31.8	–	24.40	31.4	28.1	2.29	15.20	564.6	31.8

Table 2 Statistical summary of monitored litter wastes

Parameter	Monitoring sites	Gross pollutants		Litter				Biodegradable		Non-biodegradable	
		Wet		Wet		Dry		Dry		Dry	
		Weight (g)	Volume (ml)	Weight (g)	Volume (ml)	Weight (g)	Volume (ml)	Weight (g)	Volume (ml)	Weight (g)	Volume (ml)
Mean	UCLA2	15,777	18,296	775	6,272	517	4,668	154	1,460	220	1,525
	UCLA3	2,134	5,122	166	911	86	1,040	57	668	38	536
	URS6-20F	4,301	18,833	331	2,156	184	1,956	118	1,073	58	763
	URS8-23C	3,047	4,480	479	1,738	335	1,603	151	711	166	797
	URS23	15,512	44,803	1,581	7,153	871	7,226	389	3,014	367	3,481
Median	UCLA2	6,420	7,550	461	1,822	277	1,458	82	663	71	447
	UCLA3	1,911	4,050	160	650	96	897	50	620	31	495
	URS6-20F	1,770	9,500	198	800	126	1,070	92	580	29	420
	URS8-23C	840	1,200	243	840	151	850	90	425	49	375
	URS23	6,537	25,480	1,050	4,500	549	4,850	171	985	110	1,600
Standard deviation	UCLA2	23,800	22,299	751	11,157	504	6,006	205	2,472	276	2,672
	UCLA3	1,208	3,526	106	751	51	886	33	536	23	504
	URS6-20F	4,755	19,156	391	2,926	235	2,354	147	1,243	71	887
	URS8-23C	4,312	7,714	710	2,601	554	2,398	213	1,016	305	1,151
	URS23	19,069	45,910	1,939	7,811	1,131	7,928	564	4,222	616	4,580

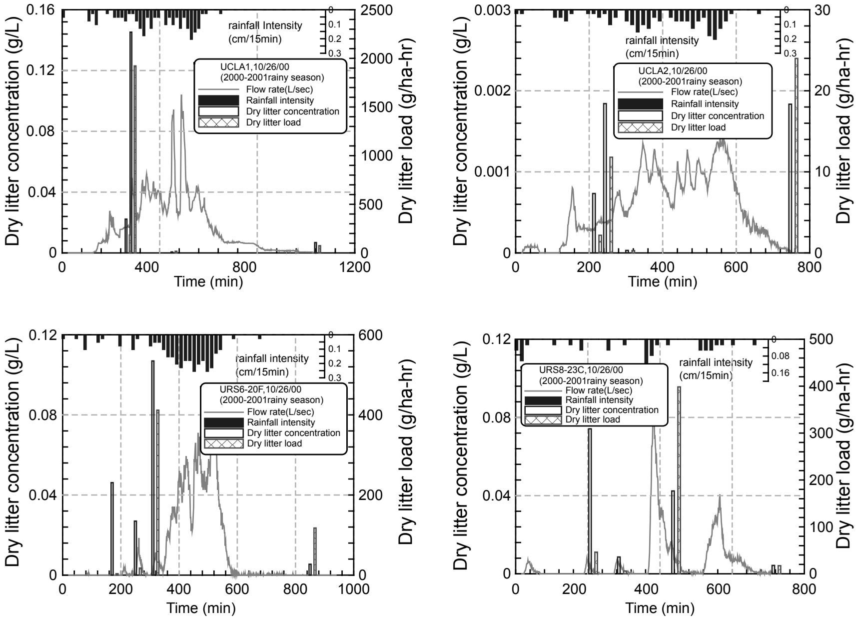

Figure 2 Litter polluto- and load-graphs for first storm event

ranged from 7.11 to 15.6 cm. As a result, it is clear that loading rates are affected by maximum rainfall intensity, event rainfall and total flow.

Litters are finally deposited into receiving water bodies and degraded by microorganism activities for a long time. Therefore it can act on inner pollution sources in the future when the environment such as pH, DO, temperature, etc. between water body and sedimentation layer changes. Figure 5 shows loading rates for wet biodegradable and dry non-biodegradable litters. The loading rates of biodegradable litters are ranged from 1 to 200 g/hr-ha. The ratio of biodegradable and non-biodegradable litters is very similar around 0.5 for all events and sites. The ratio is not affected by maximum rainfall intensity, event rainfall and total flow.

Each pollutant 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

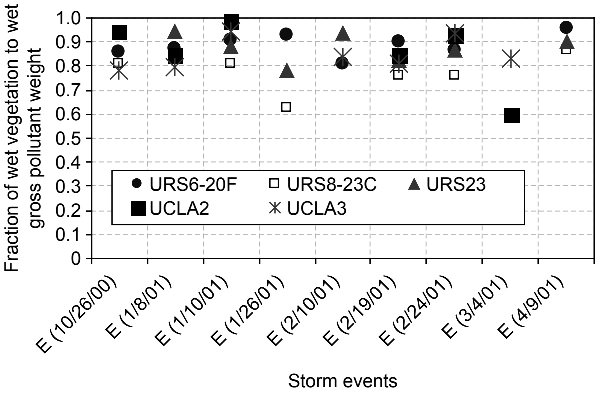

Figure 3 Fraction of wet vegetation to wet gross pollutant weight for each event and site

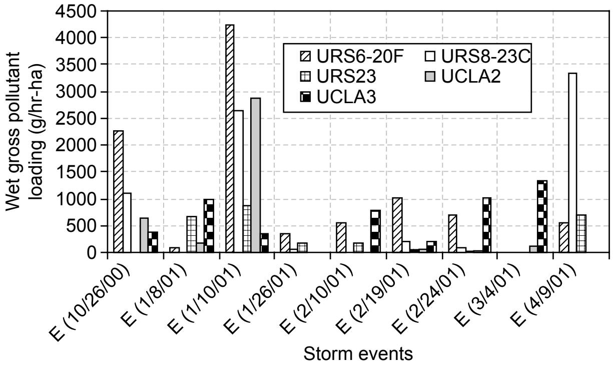

Figure 4 Average wet gross pollutant loading for each event

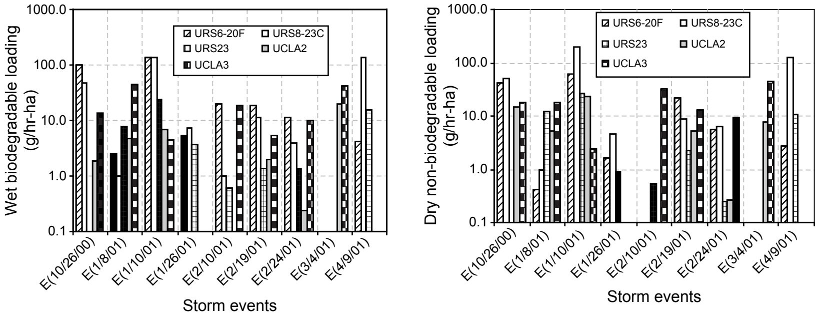

Figure 5 Loading rates for wet biodegradable and dry non-biodegradable litters

mass and volume loadings relationship with affecting parameters. Figure 6(a) shows the mass-based parameters and Figure 6(b) shows the volume-based parameters.

The two lines represent 90% confidence intervals of data. There are no obvious correlations with storm characteristics, such as ADD and total rainfall (TR). The relationship

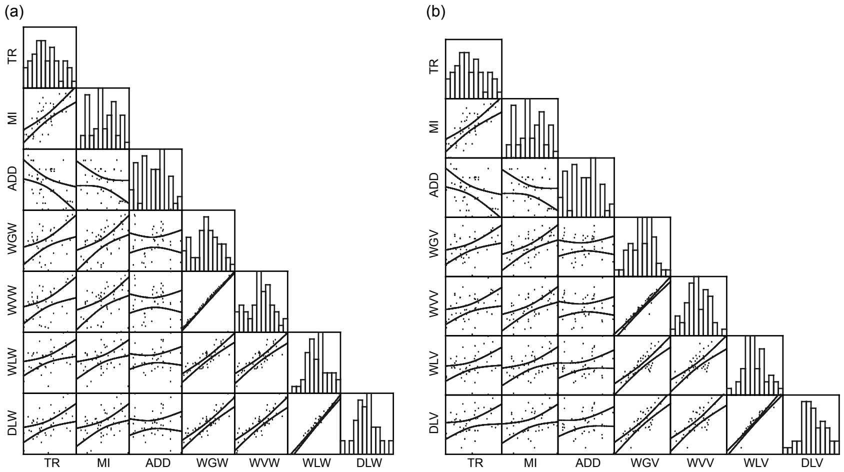

Figure 6 Correlation matrix for mass (a) and volume (b) loading with impacting parameters such as total rainfall, maximum rainfall intensity and antecedent dry days (TR: total rainfall, MI: maximum rainfall intensity, ADD: antecedent dry days, WGW: wet gross pollutant weight, WVW: wet vegetation weight, WLW: wet litter weight, DLW: dry litter weight, WGV: wet gross pollutant volume, WVV: wet vegetation volume, WLV: wet litter volume, DLV: dry litter volume)

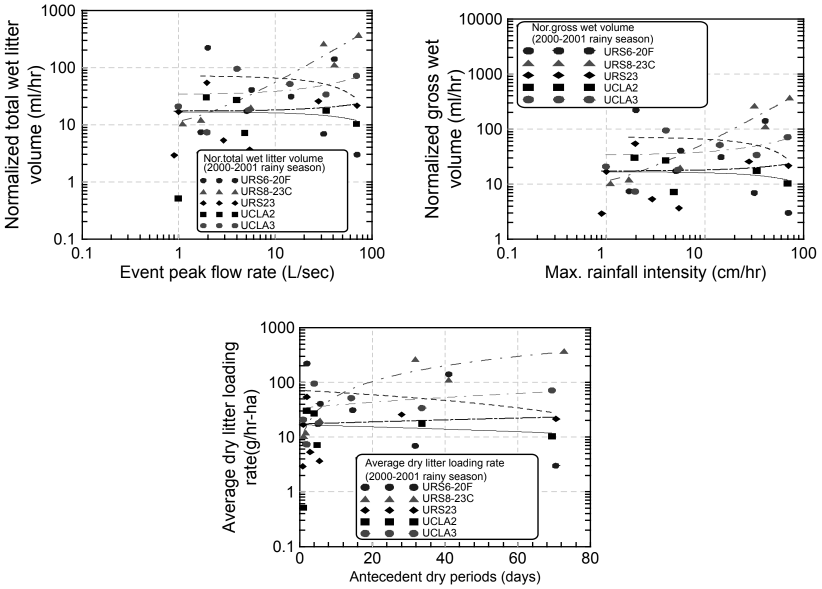

Figure 7 Impact of the hydrological data on loading volume and mass loading

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 are expected.

Figure 7 shows impact of the hydrological data on loading volume and mass loading. The total volume of litter and gross pollutant collected during each storm event were evaluated to determine if there was any potential impact by event peak flow rate, maximum rainfall intensity, and the antecedent dry period. URS8-23C illustrates a possible positive trend that may be present; however, the data of the other monitoring sites are more widely scattered. In previous research (Kayhanian *et al.*, 2002), however, there appears to be a stronger correlation between the normalized total litter volume and the rain intensity for each site. Also the volume of litter collected at a site was closely related to the rain intensity or relative strength of the storm water flow.

Conclusions

As a part of a large non-point source pollution study, the litter study was performed during 2000–2002 rainy seasons at six different freeway sites located in Southern California. Litter pollutants washed-off from highways have harmful effects on drinking water supplies, recreation, fisheries, and wildlife. Therefore the problems of litter wastes have recently attracted very considerable attention due to Total Maximum Daily Load regulations.

The observation of first flush is important for best management practices. According to litter data analysis, a first flush phenomenon was generally observed for litter concentrations, but was not apparent with litter mass loading rates. The size of a monitoring site drainage area did not impact the total litter mass loading rate. Litter volume and loading rates appear to be directly related to peak storm intensity. The ratio of biodegradable litter to non-biodegradable litter was quite variable. However, a slightly greater percentage of biodegradable litter was usually collected in the first flush. The normalized cumulative litter loadings vary from 1.25 to 13.39 kg/ha for dry litter weight, 0.40 to 8.99 kg/ha for dry biodegradable litter weight, and 0.85 to 6.60 kg/ha for non-biodegradable litter weight. Event mean litter concentrations are determined and compared with antecedent dry days, event rainfall and total flow to find a stronger relationship between litter and impact parameters. The EMC distribution does support that higher litter accumulation is associated with longer antecedent dry days. Generally, the large event rainfall and runoff volume decreases the concentrations of litter because of dilution effect. Event mean concentrations are ranged 0.0021 to 0.259 g/L for wet gross pollutants, 0.0001 to 0.027 g/L for wet litters and 0.00007 to 0.018 g/L for dry litters.

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