STORMWATER PROGRAM

California State University, Sacramento
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California Department of Transportation (Caltrans)

A Scientific Approach to Evaluating Storm Water Best Management Practices for Litter

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ABSTRACT

The California Department of Transportation (Caltrans) is conducting a Litter Management Pilot Study (LMPS) to assess the effectiveness of several best management practices (BMPs) in reducing litter discharged from Caltrans' storm water conveyance systems. A multi-year effort, LMPS has required the development of litter characteri zation techniques, selection or development of litter BMPs, and extensive field monitoring. This paper describes the definition of litter, litter monitoring protocols, litter characterization, and the study design used to assess BMP effectiveness. Prelim inary data on litter constituents and loading from freeways are also presented.

Introduction

Litter in storm water is an increasing concern along the Southern California coast. Roadside litter causes highway safety problems and is a visual nuisance. Historically, litter has been managed from a solid waste perspective. Now, litter is also being considered from a water pollution standpoint. When transported by storm water conveyance systems and discharged into receiving waters, litter can impair beneficial water uses such as contact and non-contact recreation and wildlife habitat.

To reduce the incidence of waterway degradation and loss of beneficial uses caused by litter, an improved understanding of the litter problem is essential. Litter constituents, sources, loadings and effects on water quality must be determined. Unfortunately, little research has been performed on defining and characterizing litter, determining transport mechanisms, or measuring the effectiveness of various removal techniques. To gain a better understanding of litter as a water pollutant, Caltrans has initiated the Litter Management Pilot Study (LMPS). LMPS is an ongoing, two-year study. The first year's monitoring has been completed, but currently only a small amount of the data is available.

The ultimate goal of LMPS is to identify effective Best Management Practices (BMPs) that will reduce the water quality impacts of litter. To achieve this goal, LMPS had to accomplish four tasks: (1) an operational definition of litter had to be chosen; (2) sampling and monitoring protocols had to be developed; (3) appropriate characterization parameters had to be determined; and (4) a means of measuring BMP effectiveness had to be devised. In this paper, the LMPS study design, monitoring protocols, and characterization methods are described. Preliminary litter characterization and load data are also presented.

Definition of Litter

The LMPS Detailed Study Design and Plan defines litter as manufactured material larger than ¼ -inch that could discharge through the Caltrans freeway storm drain system. Operationally, litter is defined as manufactured materials that fail to pass through a screen with a ¼-inch mesh. The materials covered by this definition include items such as cartons, cups, cans, napkins, and cigarette butts. The definition does not include materials of natural origin such as soil, gravel, and vegetative debris. Material smaller than one-quarter inch was not included because it would be difficult to determine if the material were manufactured or not. An example would be manufactured wood versus a twig from vegetation. As discussed below, sampling was conducted utilizing bags with one-quarter inch mesh. Smaller mesh sizes were rejected for fear that they would impair the hydraulic capacity of the drainage system.

Litter Sampling Protocols

Safety concerns associated with working on freeways during wet weather necessitated sampling litter at drainage outfalls rather than at drain inlets. In the LMPS, litter samples are collected by attaching a ¼-inch mesh bag to the pipe outfall as shown in Figure 1. The mesh bags are attached to the outfall with a metal collar and nylon belt. Litter and organic debris are collected as the storm water drains through the mesh. Clean bags are placed on each pipe before each predicted storm event. At the conclusion of each event, the bags are retrieved and delivered to the litter lab for analysis. At the sites being monitored, pipe diameters range between 12 and 24 inches.

To investigate how litter is conveyed from the drain inlet to the outfall, a set of clearly labeled items are placed in the inlets by hand prior to each storm event. These litter 'spikes' are recovered in the laboratory as part of the characterization of the litter sample. The spikes indicate how fast litter is transported through the piping system. They also provide a quality control check of the sampling equipment and analysis procedures.

Litter Characterization

On arrival at the lab, the samples are removed from the bags and wet weights and volumes are measured. The litter is separated from the vegetative matter and placed on drying racks. After drying on the racks for 24 hours, the litter is sorted and classified into the following 10 categories:

Cardboard/chipboard	Moldable plastic
Paper	Plastic film
Glass	Styrofoam
Metal	Wood debris
Cloth	Cigarette butts

plus "other". These categories are similar to the categories used in Australian litter studies (Allison et al., 1997). Each type of litter is further divided into prior usage categories – food -related, smokingrelated and other. Only three categories are defined because of the difficulties associated with identifying prior use by simply looking at the resulting litter.

At the present time, there is no authoritative guidance or generally accepted view on the most suitable parameter to use as a measure of litter. Therefore, in the LMPS, litter is characterized by weight, volume, and number of items. Air-dried weight is obtained using a digital scale; volume is estimated by placing the litter samples into graduated containers; and the number of items is determined by manual count.

Concurrent Water Quality Monitoring

To determine if a correlation exists between chemical pollution and litter concentrations, water samples are collected concurrently with the litter sampling. Water samples are collected by flow activated automatic samplers. A ½-inch tube conveys water from the invert of the outfall immediately upstream of the litter monitoring bag to a collection bottle located in a weatherproof cabinets. The end result is a flow-weighted composite sample. In addition to the automatic sampling, manually-collected (grab) samples are taken during the early parts of each storm event. These grab samples are obtained by dipping a glass sample container into the flow upstream of the litter collection bag via a specially installed flap.

Temperature and specific conductance are measured in-situ. Other parameters are determined by sending the water samples to a certified laboratory where they are analyzed for phosphorous and nitrogen components, coliform bacteria, oil and grease, total and volatile suspended solids, total organic carbon, hardness, and a range of metals (Cu, Cr, Zn, Cd, and Ni). Lab analyses and sampling were performed in accordance with Caltrans storm water monitoring protocols (Caltrans Environmental Program, 1997).

Flow data are recorded each minute at all the sites being monitored. After each storm, the data are reviewed and quality assurance (QA) procedures are applied. The QA procedures include the generation of hydrographs (from the flume depth data), hyetographs and other summary information (e.g., rainfall intensities, peak flow rate, total flow volume, and event duration). This information could be used to study the transport mechanisms for storm water litter.

BMP Descriptions

Five BMPs are being tested in this study. Three involve structural modifications to standard Caltrans freeway drainage systems, and two involve changes to management practices. These BMPs were selected after an extensive literature search, consultation with a technical advisory group, and other discussions with interested parties. Selections were based on expected performance and ability to fit with existing Caltrans drainage systems.

Street sweeping frequency – The effectiveness of street sweeping is being investigated using mechanical broom sweepers similar to those currently used by Caltrans. In treatment areas, sweeping is done weekly. In the control areas, sweeping occurs monthly. In both cases, sweeper speed is based on the manufacturers' recommended speed of 5 mph. Other parameters such as broom strike and coning also follow manufacturers' recommendations.

Litter pick-up frequency – In the treatment areas, litter is picked up in the right-of-way weekly. In the control areas, litter is picked up monthly (as per the Caltrans Adopt-a-Highway Program). In both cases, workers remove only those items that are large enough to be easily handled by tongs.

Modified inlet – This device is a standard drain inlet modified by the addition of perforated metal plates placed on the inflow perimeter of the inlet. The holes in the perforated plate are approximately 0.25 inch in diameter. The plate is welded to the grate so that it is flush with the freeway surface. The intention is that litter will be retained on the grate surface until removed by a street sweeper.

Bicycle grate – The Caltrans bicycle grate is constructed of a standard parallel-bar grate with the addition of perpendicular bars at 6-inch spacing. The additional bars are intended to prevent larger objects from entering the inlet and retain them until removed by a street sweeper. In the second year of the study, this BMP was replaced by the Litter Inlet Deflector.

Litter Inlet Deflector – The Litter Inlet Deflector (LID) is a novel device developed for the LMPS. It is constructed by changing a drop inlet into a curb inlet and adding a hinged gate that hangs over the open entrance of the inlet (see Figure 2). During the dry season, significant quantities of litter can be transported to and deposited in drain inlets. The goal of the LID is to prevent this dry weather deposition and accumulation. As shown in Figure 3(a), the flap prevents litter from entering the inlet during dry weather. Street sweepers then periodically remove the accumulated litter. The weight of the hanging gate is such that it cannot be opened by the wind forces generated by passing trucks. On the other hand, even small water flows will force the gate open during wet weather (see Figure 3(b)).

Assessment Methodology

BMP assessment is based on a paired-catchment experimental design. Pairs of catchment areas (mini-watersheds) were chosen with minimal differences betwee n them in terms of size, location, and traffic volume. The BMP was implemented on the "treatment" member of the pair; typical Caltrans management conditions continued on the "control" catchment. The freeway surface areas included in the experimental catchments ranged from 0.13 to 0.35 ha (0.32 to 0.87 ac). Four sites were chosen in the Los Angeles region (see Figure 4). Each site had three pairs of catchments for a total of 24 catchments monitored The assessment of BMP effectiveness will be made by com paring the rainfall, flow, and litter data generated for each catchment pair.

Monitoring of BMP performance has been on a "storm event" basis. Accurate storm warnings have been essential to successful sample collection because the team must prepare sampling equipment before the storm, deploy staff during the event, recover samples, and transport the samples to laboratories after the event. A "go/no go" criterion of 80% or better probability of 0.1 inches of rainfall was set during the first year of the study. When these conditions were met, staff would mobilize for monitoring. Because the original criterion didn't always produce adequate runoff, the criterion was changed in the second year a 70% or better probability of 0.2 inch of rain.

The amount of litter monitored in the control and respective treatment catchment are compared to determine the BMP effectiveness. The first step in this comparison is normalizing the data by area. The next step is to calculate the percentage change in the quantity of litter caused by the presence of the BMP. The percentage change is calculated using the following equation:

$$\% \text{ change} = 100*(C-T)/C$$

where C is the amount of normalized litter in the control catchment and T is the amount of normalized litter in the treatment catchment, both expressed as weight, volume, or count per unit of freeway area. A positive percentage change indicates the BMP is reducing the litter load reaching the outfall compared to its control pair. Conversely, a negative percentage change indicates there was more litter found in the BMP catchment than the control. These analyses are performed for each monitored storm event. The distribution of percentage changes are then plotted over the entire monitoring period and statistical tests performed to determine if statistically significant trends exist.

The percentage change is calculated for each parameter measured (i.e., weight, volume, and count). It is possible to calculate different apparent BMP performances, depending on which parameter is used to measure effectiveness. This can make the outcomes of the study confusing and reinforces the need for agreement on which parameter (or combination of parameters) should be used to measure litter quantities. The complete analysis for this study will be performed after the two years of monitoring have been completed.

Preliminary Results

Litter monitoring within the freeway drainage system provides preliminary baseline data on the types and quantities of litter from freeways in the Los Angeles area. Although the study is currently underway, some results are available. Unfortunately, there are still insufficient data to fully analyze the effectiveness of the BMPs.

Litter Characteristics

The analyses performed on the litter samples gave estimates of the ratios of naturally-occurring to manufactured material and the types of litter in the storm water.

Data from the first year of monitoring suggest that between 60 and 80% of the material collected from the storm water runoff is naturally-occurring material, mainly leaves and twigs. This has important consequences in the design of BMPs. Any treatment facilities contemplated must be able to remove large amounts of vegetation in addition to the target litter items.

As noted earlier, after the litter is drained and separated from the vegetation, it is sorted into various categories. Figure 5 shows the breakdown of categories with respect to weight. Slightly less than one third of the material consists of plastic film, moldable plastic, and styrofoam. The remainder of the material is approximately equal portions of paper, cardboard/chipboard, cigarette butts, wood, and miscellaneous items (metal, cloth, and glass etc.).

Figure 6 shows percent composition with respect to volume, where the distribution of material across the various categories is similar to the dry weight analyses with the exceptions of glass and styrofoam. Approximately one third of the litter volume is plastics and styrofoam, and approximately twenty percent is paper.

Categorizing by count, shown in Figure 7, revealed a different distribution of components compared to the weight and volume analyses. Over a third of the litter particles are cigarette butts.

Freeway storm water litter loads

Monitoring the control catchments during this study has yielded unique information on the amount of litter discharged from freeway drains. Table 1 presents the average amount of litter monitored from ten storm events during the 1998/1999 storm season. It should be noted that the loads were distributed throughout the year and no seasonal first flush was observed. Also, the table represents only one year of data for a two-year study and is preliminary. The control sites are used to present loading data from "typical" highway conditions. Based on limited sampling, litter loads vary substantially from site to site and from storm to storm. As shown in Table 1, loading by weight varies by a factor of 2 and loading by volume and count vary by a factor of 3. The load variations might be caused by many site factors, such as different traffic volumes, prevailing wind directions, and highway shoulder conditions.

Table 1 Litter Loads from Control Catchments: Preliminary Data from the 1998/1999 Storm Season

	Air-dried Weight per storm		Volume per storm		Count per storm	
Location	grams/ha	lb/ac	m^3/ha	ft^3/ac	Number/ha	Number/ac
Site 1-E	1150	1.03	0.0114	0.16	1520	615
Site 1-W	786	0.70	0.0089	0.13	1290	522
Site 6	722	0.64	0.0072	0.10	979	396
Site 8	514	0.46	0.0035	0.05	487	197
Averages	793	0.71	0.0077	0.11	1070	433

The performance of the BMPs is still under investigation with data being collected at the time of writing. It was obvious after the first year of monitoring that the bicycle grate did not substantially reduce litter in the discharge. Consequently, it was replaced by the newly-developed LID for the second year of monitoring.

Summary

Considering litter as a water quality parameter is a recent development. Little information is available on constituents, loads, and best management practices to reduce water quality impacts. The Caltrans Litter Management Pilot Study will advance the state of the art in this field. The study is currently underway, with projected completion in Fall 2000.

References

Allison et al. (1997), "Stormwater Gross Pollutants", Industry Report 97/11, Cooperative Research Centre for Catchment Hydrology, Australia.

Caltrans Environmental Program (1997). "Guidance Manual: Storm Water Monitoring Protocols." Prepared by Larry Walker Associates, Davis, CA, and Woodward-Clyde Consultants, Oakland, CA.

Acknowledgements

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Authors

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Figure 1 Litter Sampling Device

Figure 2 Litter Inlet Deflector

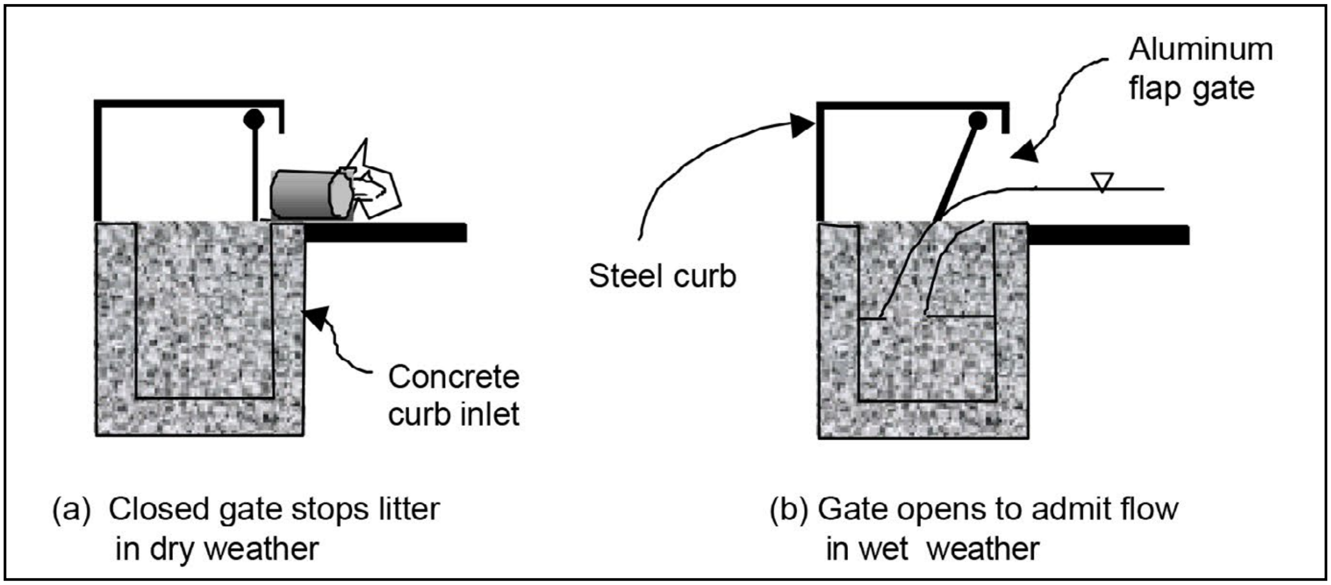
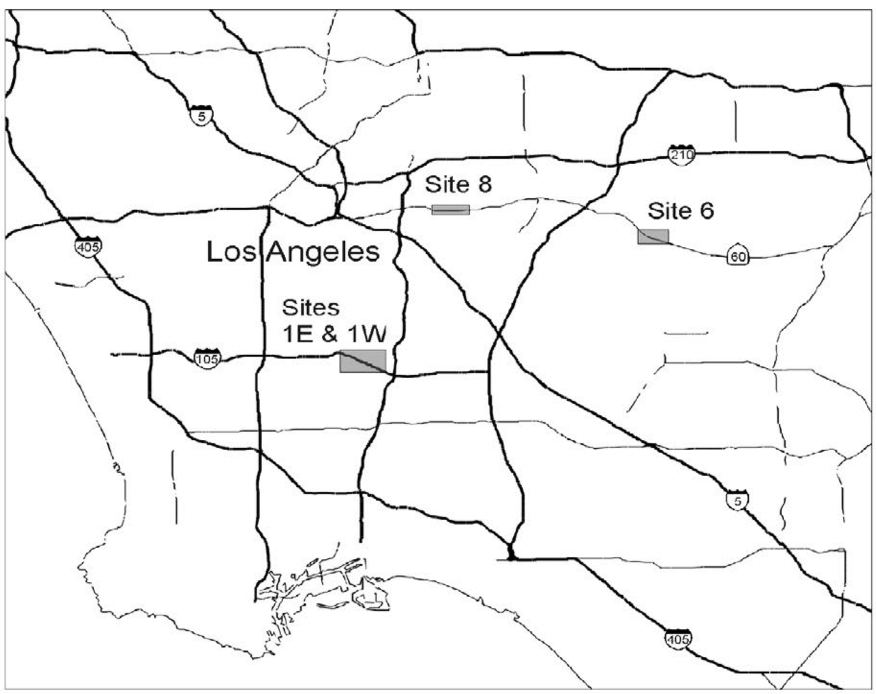


Figure 3 Litter Inlet Deflector Schematic



Site 1E	Manual litter pick-up, I-105 Eastbound (Lynwood) between Gertrude Ave. and Atlantic Blvd. overpass.
Site 1W	Street sweeping, I-105 Westbound (Lynwood) between Atlantic Blvd. and Gertrude Ave. and overpass.
Site 6	Modified inlet grate, Freeway 60 (Hacienda Heights) between Turnbull Canyon undercrossing and Kwis St. overcrossing.
Site 8	Bicycle grate (1989-1999), Litter inlet deflector (1999-2000), Freeway 60 (Montebello and Monterey Park) between Garfield Ave. undercrossing and Fulton Ave.

Figure 4 LMPS Site Locations

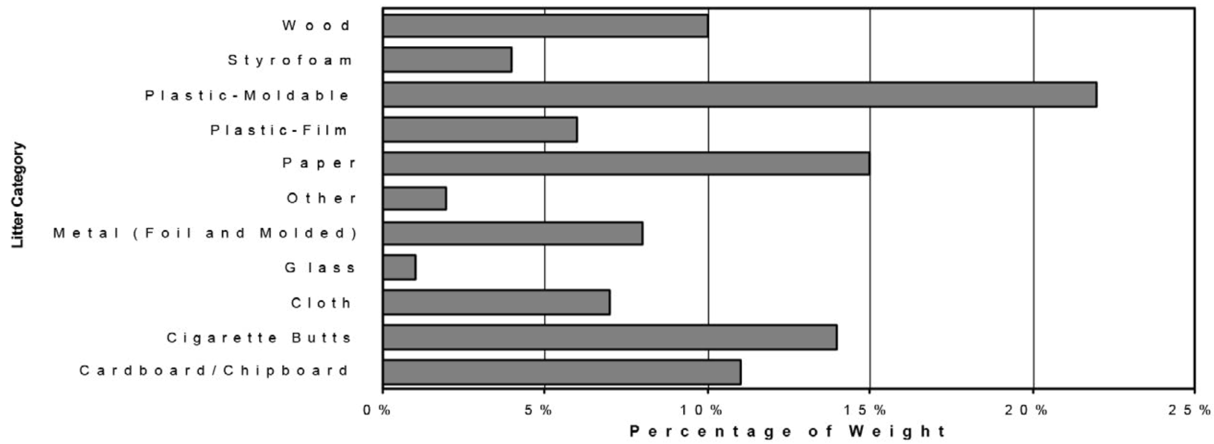


Figure 5 Litter Composition by Weight

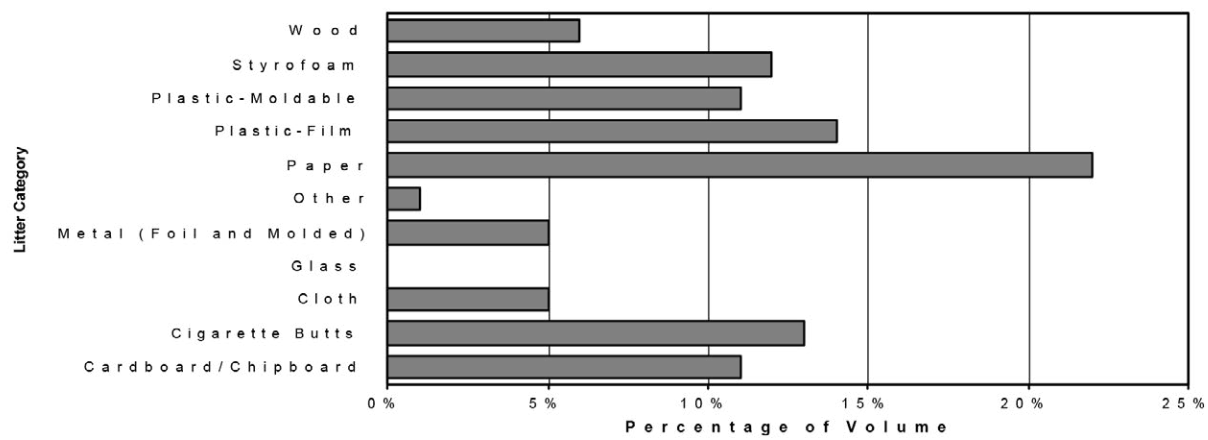


Figure 6 Litter Composition by Volume

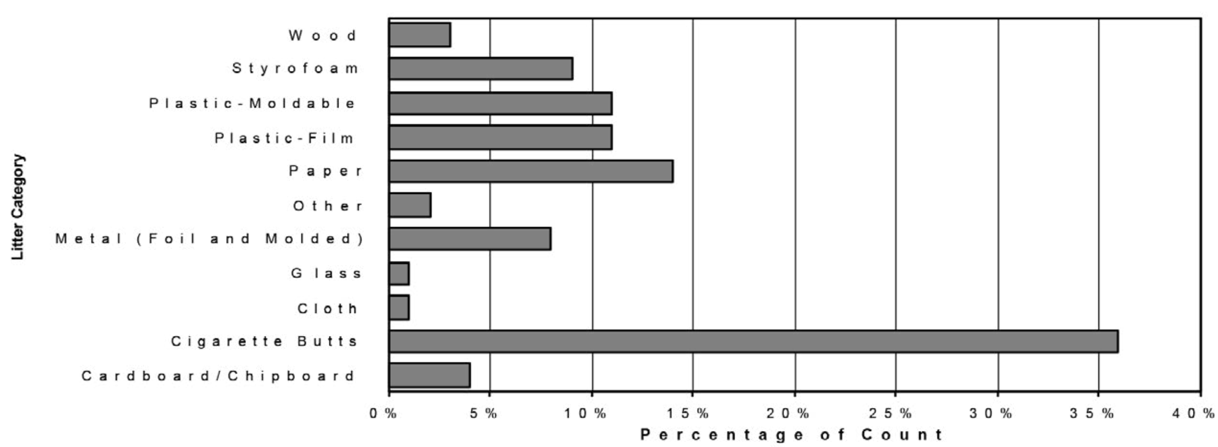


Figure 7 Litter Composition by Count