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California State University, Sacramento (CSUS)

University of California, Davis (UCD)

California Department of Transportation (Caltrans)

A REGRESSION MODEL TO PREDICT LITTER IN URBAN FREEWAY OUTFALLS AFTER RAINSTORMS

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Authors:

Daniel B. Syrek, Institute for Applied Research, Sacramento
Masoud Kayhanian, Caltrans/UCD Environmental Program
Scott Meyer, CSUS Office of Water Programs, Sacramento

Disclaimer:

Storm Water Program
CSUS Office of Water Programs
7801 Folsom Boulevard, Suite 102, Sacramento, CA 95826

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A REGRESSION MODEL TO PREDICT LITTER IN URBAN FREEWAY OUTFALLS AFTER RAINSTORMS

Daniel B. Syrek[1], Masoud Kayhanian[2*] and Scott Meyer[3]

INTRODUCTION

Passage of the Clean Water Act (CWA) amendments in 1972 had profound effects for upgrading wastewater treatment facilities and improving discharge quality. Despite major progress in point source pollution, non-point source pollution remains the nation's largest source of water quality problems in recent time (Horan, 1990; Larsen et al., 1998; Parr et al., 1998). To address the combined effects of point and non-point sources, Section 303(d) of the CWA mandated the implementation of total maximum daily loads (TMDLs). A TMDL is a calculation of the maximum amounts of pollutants that can be discharged to receiving water and still meet water quality standards. The TMDL includes the allocation of loads to the various dischargers and is the sum of the allowable loads of a single pollutant from all contributing point and non-point sources.

In a recent 303(d) list prepared by the California State Water Resources Control Board, at least 36 water bodies were identified where trash or litter is considered a pollutant of concern (CSWRCB, 1999). The first trash TMDL was adopted by the Los Angeles area Regional Water Quality Control Board for the Los Angeles River (CRWQCB, 2001). Other litter TMDLs are being developed for other watersheds.

Concerned with litter accumulation at freeway sites, and in response to the Los Angeles trash TMDL, the California Department of Transportation (Caltrans) is actively assessing the characteristics and potential impacts of litter generated from their freeways (Caltrans, 2000). Caltrans is also evaluating the practical applications and performances of several litter capturing devices (Caltrans, 2001). Litter characterization was an integrated part of the Caltrans First Flush Study where both water quality and litter characteristics during the first flush and the entire storm event were being evaluated (Kayhanian et al., 2002). These data will provide a basis for Caltrans to develop potential treatment technologies and best management practices to control pollutants in runoff from Caltrans roadways. As part of this effort, an attempt was also made to develop a mathematical model to estimate the amount of litter that can be captured from freeway outfalls. The focus of this paper addresses this issue.

Research conducted during the last 25 years has shown that the rate of accumulation of litter along roadsides is a function of such variables as traffic volume, neighborhood income, temperature and rainfall during the accumulation period, and the roadway type or adjacent land use (Syrek, 1986). A recent study of data from 1,400 sample sites in major litter surveys in 15 states has also shown that other factors, such as county population, occupants per vehicle, and the duration of litter control programs significantly influence the rate at which litter accumulates (Syrek, 1998). While the model described by Syrek (1998) characterized the rate of litter buildup along roadsides, additional factors are required to provide estimates of the portion of accumulated litter that would be transported into the drainage system following rainstorm events. These parameters include: total magnitude and intensity of the storm, time elapsed since the previous storm (antecedent dry period), the portion of accumulated litter close enough to the drainage channels to be moved during a storm, and the percentage of litter small enough to pass through the gratings. Earlier estimates indicated that in the U.S., 41 percent of roadside litter is picked up, 42 percent is either

[1] The institute for Applied Research, 840 La Goleta Way, Sacramento, CA 95864

[2*] Corresponding author: Center for Environmental and Water Resources Engineering, Department of Civil and Environmental Engineering, One Shields Avenue, Engineering III, University of California, Davis, CA 95616, (530) 752-8957, mdkayhanian@ucdavis.edu.

[3] Office of Water Program, California State University, 7801 Folsom Blvd., Suite 102, Sacramento, CA 95626

degraded or covered by soil or vegetation, and 17 percent is washed into the drainage system (Miller-Hooks et al., 2000).

This paper describes how a model was developed to incorporate the factors affecting the rate of litter accumulation as well as the fraction of litter that is transported into the drainage system during a rainstorm. The model was evaluated by comparing the predicted rate of litter in runoff at four urban freeway sites in the Los Angeles Area in the Caltrans Litter Management Pilot Study (Caltrans, 2000) and the actual amount measured at freeway outfalls. Based on the results of this comparison of predicted and actual collected litter, recommendations are provided for improving the urban freeway model. The extension of the model to cover rural freeways and roadways is discussed along with its applicability for predicting the amount of litter transported from streets and freeways in urban areas.

MODEL DEVELOPMENT

The estimation of litter collected from freeway outfalls was developed using a multiple linear regression analysis of 100,000 items of litter data measured at 1,400 sites in 15 regional or statewide litter surveys (Syrek, 1998). These data were collected as part of an effort for assessing changes in litter and the effectiveness of litter control systems implemented by government agencies throughout the United States. The flow chart shown in Figure 1 presents the general sequence of calculations that modify the roadside litter estimate to determine the amount that is transported into drainage systems during rainstorms.

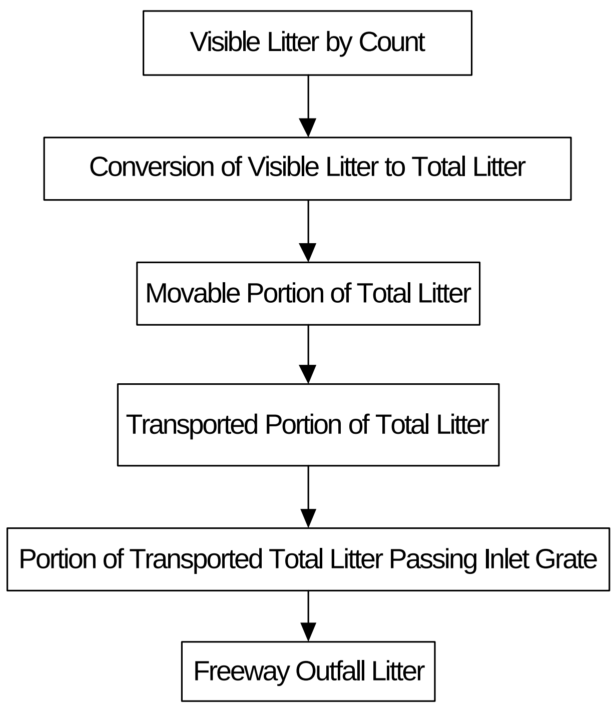


Figure 1
Flow Chart of Litter Calculation Sequence

As shown, the model is divided into six segments: (i) visible litter on the roadside, (ii) conversion of visible litter to total litter, (iii) movable litter, (iv) litter transported to grate, (v) the portion of the litter passing the grate, and (vi) the litter volume at the freeway outfall. Each segment of the calculation is described below in detail.

Visible Litter Prediction

The equation for predicting roadside visible litter is obtained from correlations of accumulated visible litter rates and five independent variables that were found to affect litter rates along urban freeways (Syrek, 1998). These five variables are: (i) weather index (ii) county population, (iii) occupants per vehicle, (iv) litter program year, and (v) average daily traffic.

General visible litter prediction equation derived from these analyses is shown in Eq. 1. This Eq. predicts the amount of visible litter per centerline mile at freeway roadsides (including medians).

$$L_{vl} = -1347 + 156 \times WI + 0.297 \times CP + 7956 \times OPV - 344.1 \times LPY + 0.07 \times AADT \quad (1)$$

Where,
L_v = visible litter per centerline mile
WI = weather index
CP = county population
OPV = occupants per vehicle
LPY = litter program years
AADT = average annual daily traffic

The methodology and analysis performed to derive each of the above model variables is briefly described below.

Weather Index

Because of the complex, non-linear relationship of litter rates to rainfall and temperature (Syrek 1999), a composite index is used to represent the influence of these two parameters on litter accumulation. Syrek (1999) found that for urban freeways, weather index (WI) is best embodied by using daily rainfall and maximum daily temperature averages for the 81 days prior to the date selected for evaluation. The WI can be calculated for a specific storm event using recorded data, or for future predictions, the historical monthly average data. The formulas, which are found to be dependent on the maximum daily temperature and total rainfall, are:

$$WI_{(F<54)} = 2.72^{-4.2+0.06F} - 0.24 \times RF \quad (2)$$

$$WI_{(54<F<75)} = -1.48 + 0.033 \times F - 0.24 \times RF \quad (3)$$

$$WI_{(F>75)} = 1.99 - 0.014 \times F - 0.51 \times RF \quad (4)$$

Where,

WI = weather index
F = maximum daily temperature, degrees Fahrenheit
RF = average daily rain fall, inches

It is important to note that WI is a non-continuous function and that these formulas are a simplified representation of the rapid changes in behavior affected by changes in temperature and rainfall.

County Population

Due its magnitude the value of county population (CP), in relation to the other parameters, heavily influences the L_{vl}. Therefore, the latest estimate for county population should be used for computing the visible litter. The most recent U.S. Census Bureau figure is acceptable if it is only 2 to 3 years old. Otherwise, the current county population estimate for between census years prepared by the Census

Bureau should be obtained. Similar estimates prepared by state organizations such as the California Department of Finance Demographic Research Unit are also acceptable. Note that for large urbanized areas, regional estimates that include the populations of all the adjacent counties with contiguous urban areas should be used. The Census Bureau designates such regions as "metropolitan areas."

Occupants Per Vehicle

For a given county, the average occupants per vehicle ($\overline{OPV}$) can be estimated by first obtaining the total county population and dividing by the number or registered vehicles in the county for the same year. The number of occupants per vehicle for urban freeways and other local areas can be estimated using the following equation (Syrek, 1997):

$$OPV = 0.4 + 0.9 \times \overline{OPV}_{county} \tag{5}$$

Where,

OPV = Occupant per vehicle for an urban freeway

$\overline{OPV}$ = Average occupant per vehicle for the county

Equation (5) is derived by correlating the OPV measured at 62 urban freeway sites during nine litter studies with the OPV estimated from population and motor vehicle registration data (Syrek, 1997). For a specific freeway segment, during a 20-minute vehicle count, separate tally of the number of vehicles with one, two, three or more occupants, will allow for calculation of a OPV value more accurately than provided by Eq. (5).

Litter Program Years

The number of litter program years is obtained for the location or county in question by summing the number of years that an organized litter control program has been in effect in the jurisdiction in which the freeway segment is located. This would include Keep America Beautiful (KAB) and similar local or state programs. Also, the effect of Adopt-A-Highway (AAH) programs should be added to the Keep America Beautiful litter program years using the following formula:

$$LPY = LPY_{KAB} + 0.64 \times LPY_{AAH} \tag{6}$$

Where,

LPY = Litter program years, yr

LPY_{KAB} = Litter program years based on Keep America Beautiful program, year

LPY_{AAH} = Litter program years based on Adopt-A-Highway Programs, year

The factor 0.64 accounts for the fact that Adopt-A-Highway programs have been found to reduce litter by an average of only 64 percent. This was determined from studies in six states where the litter rate for adopted roadway segments was divided by the litter rate for similar unadopted segments (Miller-Hooks et al., 2000).

Annual Average Daily Traffic

The annual average daily traffic (AADT) for a specific urban freeway segment can usually be obtained online from highway department surveys. (In the State of California the average daily traffic values can be obtained from the web site: http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/2000all.htlm). Where the traffic volumes are known to have seasonal variations of more than 15 percent, a more accurate estimate of litter can be obtained by calculating an adjusted annual average daily traffic for the period of 81 days prior to the evaluation date. Because paper and plastic litter was found to be constantly degrading or disappearing, Syrek (1999) found in a series of litter surveys that about 95 percent of all litter at an urban freeway site is estimated to have been deposited in the previous 81 days with 60 percent of this having deposited in the prior 30 days, another 28 percent in 31 to 60 days and 12 percent during 61 to 81 days prior.

The adjusted AADT is weighted using the AADT for 1 to 30 days, 31 to 60 days, and 61 to 81 days prior the evaluation date as shown in Equation (7):

$$AADT_{adjusted} = 0.60 \times AADT_{(1-30d)} + 0.28 \times AADT_{31-60d)} + 0.12 \times AADT_{(61-81d)} \quad (7)$$

Where,

AADT = Annual average daily traffic, vehicle/d
$AADT_{adjusted}$ = Adjusted annual average daily traffic, vehicle/d

Conversion of Visible Litter to Total Litter Count

Equation (1) was developed to estimate the visible fraction of total roadside litter. While this type of count is the most appropriate measure where the visual offensiveness of litter was being assessed, a factor *(K_{vt})* must be used to estimate the total number of items that would be counted in runoff samples performed at freeway outfalls. Therefore, total litter *(L_{tl})* count will be computed using the following equation:

$$L_{tl} = K_{vt} \times L_{vl} \quad (8)$$

Where,

L_{tl} = Total litter, count
K_{vt} = Factor converting visible litter to total litter count, fraction
L_{vl} = Visible litter, count

For urban freeways the conversion factor *(K_{vt})* was found to be 6.7 by evaluating the results of 14 litter surveys in which both visible and total litter were concurrently measured (Syrek, 2000C).

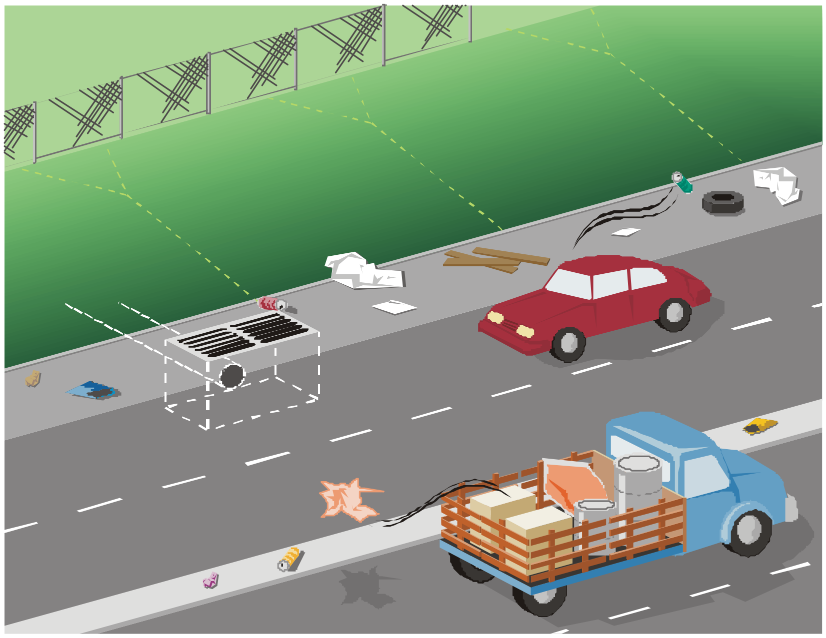
The general equation to estimate movable portion of total litter is as follows:

$$L_{ml} = K_{ml} \times L_{tl} \quad (9)$$

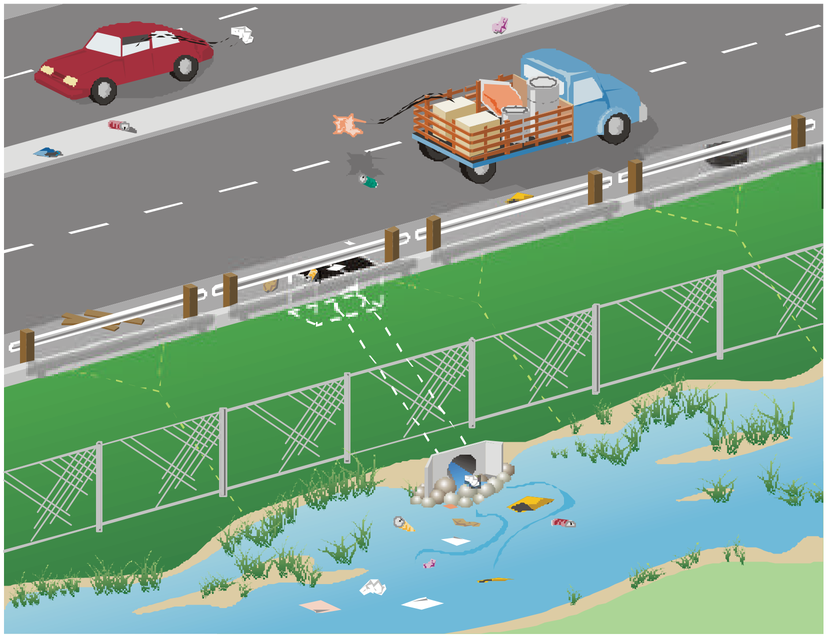
Where,
L_{ml} = Total movable litter, count
K_{ml} = Factor converting total litter to movable litter, fraction

Movable Portion of Total Litter

Accumulation and movement of litter in urban freeways is depends on the physical characteristics of the road and the nature of litter entrapment barriers. Accumulation and movement of litter within two physical configurations of freeway sites are illustrated in Figure 2. Observations of litter movement following rainstorms showed that only the portion of the litter lying within a few feet of drainage surfaces or channels is removed from a typical street or roadway site by runoff (Syrek, 2000).



(a) Cut section



(b) Fill section

Figure 2

Accumulation and Transportation of Litter within two Physical Configurations of Freeway Sites

The estimate of movable litter (L_{ml}) in this paper was derived from a study of accumulated roadside litter for 268 mostly rural sites in Florida (Schert, 1995). Counts were performed at 5-foot intervals from the roadway edge to a maximum of 15 feet from the roadway. Schert (1995) found that 52 percent of these items were within 5 feet of the roadway, an additional 28 percent were within 5 to 10 feet from the roadway, and the remaining 20 percent was more than 10 feet of the roadway. These results were extrapolated to an 80-foot right-of-way for freeways, as shown in Figure 3.

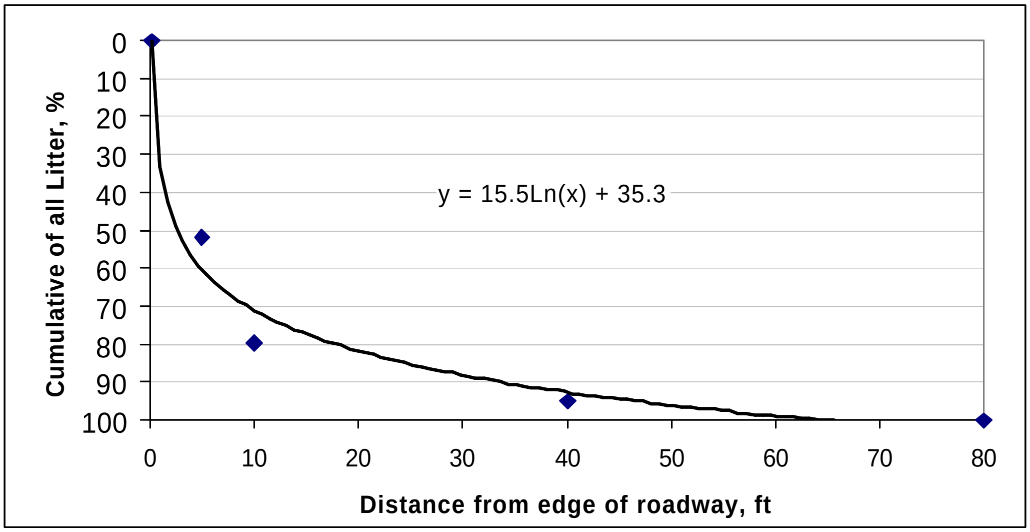


Figure 3
Distribution of Litter along Roadsides

For most locations in level terrain, the results in Figure 3 imply that about 70 percent of all the accumulated litter at a site lying within 10 feet of the roadway could potentially be moved by a rainstorm. However, for sites with adjacent walls or embankments (see Figure 4), the percentage could increase up to 90 percent, depending on the height of the wall or embankment. Where asphalt concrete berms or curbs are located at the pavement edge, it is estimated that only 25 percent of the deposited roadside litter would be free to move into the drainage system (Syrek, 1975). On fill sites or on wide right-of-ways where additional drainage channels are located some distance from the roadway, an additional percentage of litter estimated from the distribution shown in Figure 2 would have to be added.

Transported Portion of Total Litter

The percentage of the potentially movable litter that is actually transported during rainstorms was obtained from a 5-year litter survey at two sites based on approximately weekly intervals (Syrek, 2000a). The analyses from 156 rainstorm events revealed that the changes in the litter rate were influenced by three main factors: (i) the total rainfall occurring between visits, (ii) the maximum rainfall intensity, and (iii) the antecedent dry period.

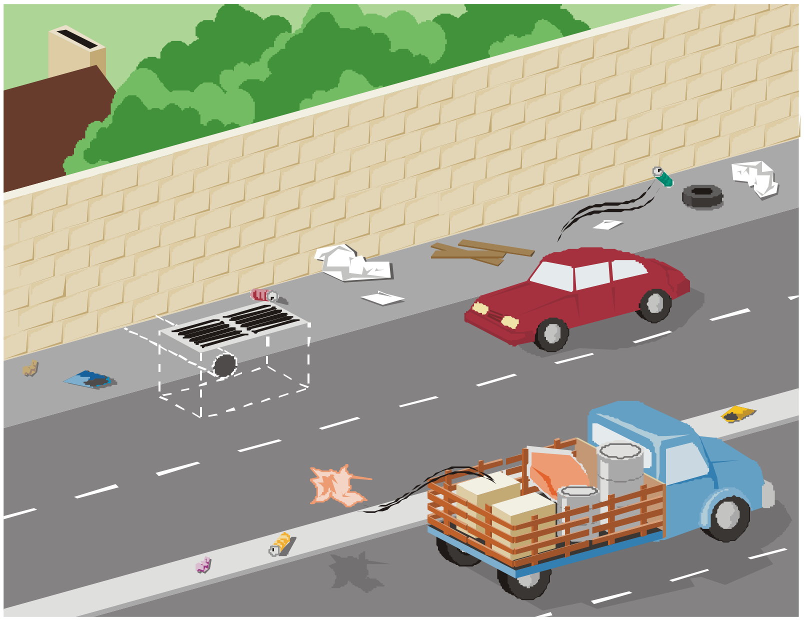


Figure 4
Illustration of the Influence of Sound Wall on Litter Entrapment within an Outfall

Impact of total rainfall

The percent change in litter counts plotted as a function of the total rainfall between counting intervals measured by Syrek (2000a) are displayed in Figure 5. The high degree of variability displayed by the data in Figure 5 is due to the fact that total rainfall between counts is one of the major variables influencing the change in roadside litter. Other factors influencing roadside litter counts include: removal of old litter by wind degradation, cleanup operations, and deposition of new litter. In spite of this, a definite reduction in litter was found, particularly for the storm events with over 2 inches of precipitation. The average reduction measured of 5.94 percent per inch of rain was found to be statistically significant at the 98 percent confidence level.

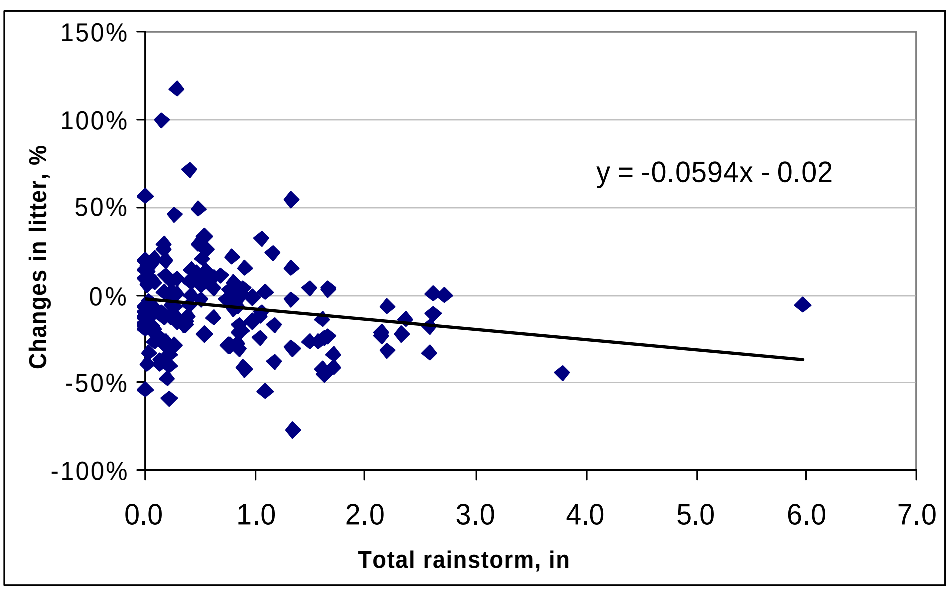


Figure 5
Influence of Total Rainfall on Change of Litter Rate

Impact of maximum rainfall intensity

The change in litter counts performed by Syrek (2000a) as a function of maximum storm intensity (inches per hour) is plotted in Figure 6. The decline in litter of 5.3 percent per inch per hour was not statistically significant, probably because the rainfall intensity was measured at a weather station 8 miles from the litter sample sites. In preparing Figure 6, the data for rainstorm events under 0.15 inches of rainfall per hour was deleted due to the significantly poor correlation observed during relatively light rainstorms. This was consistent with field observations that litter removal increased during peak runoffs as the water level in drainage channels rose and as larger or embedded objects that would not have been moved during lesser periods of flow were transported into the drainage system.

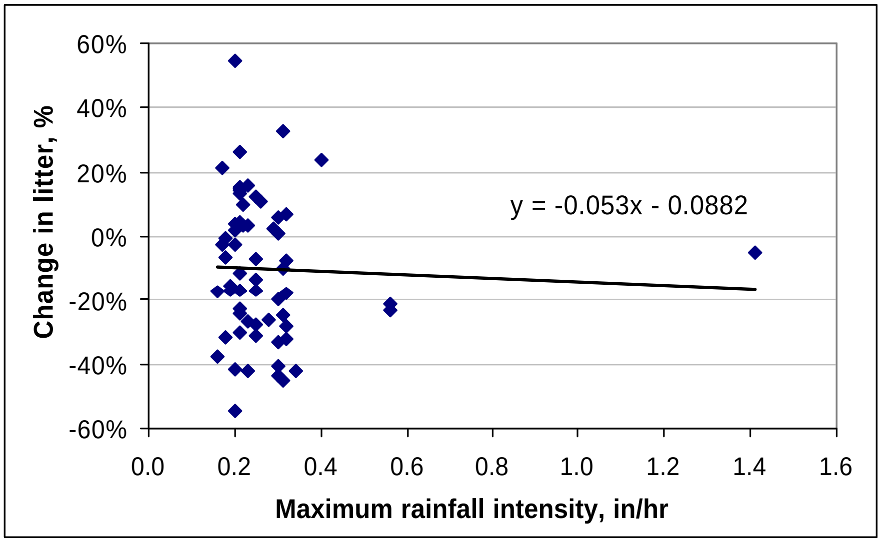


Figure 6

Influence of Maximum Rainfall Intensity on Change of Litter Rate

Impact of antecedent dry period

The amount of litter removed is influenced by the build up of litter occurring during dry periods between storm events. This increased level of litter was partly accounted for in Equation 1 by higher temperatures usually associated with dry periods. However, an additional effect, shown in Figure 7, was detected by Syrek (2000) in that the amount of litter following a storm event declined by 0.14 percent each day in the period since the previous rainstorm. If the two outlier in Figure 7 are excluded, the decline of percent change in litter as antecedent dry days increases, could be statistically more significant at a 96 percent confidence level. Combining the three parameters impacting portion of total movable litter, the percent of the total litter transported to the grate can be computed from the following relationship:

$$L_{tr} = K_{tr} \times L_{ml} = \left[5.94\% \times RF + 5.30\% \times RI + 0.14\% \times ADP\right] \times L_{ml} \quad (10)$$

Where,

L_{tr} = Total litter transported to the grate, count

K_{tr} = Conversion factor converting portion of movable litter transported to the inlet grate, %

RF = total rainfall, in

RI = maximum rainfall intensity, in/hr

ADP = Antecedent dry period, days

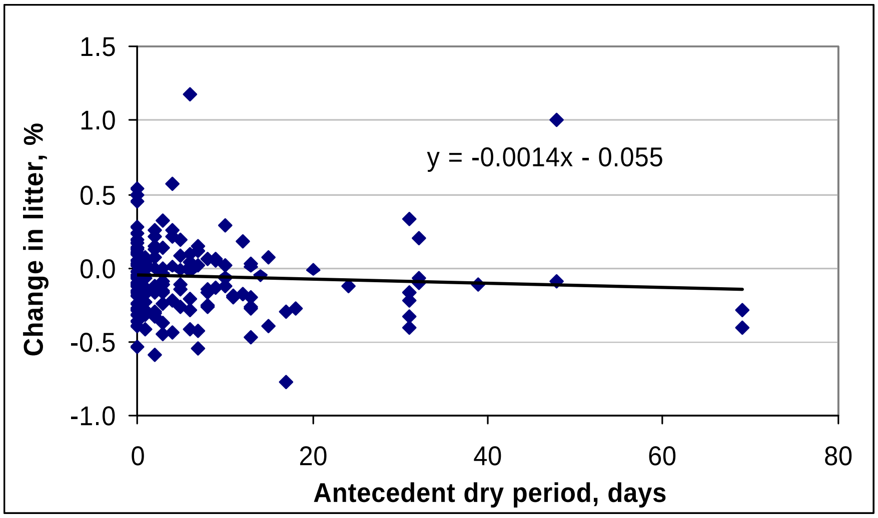


Figure 7
Influence of Duration of Prior Dry Period on Change of Litter Rate

Portion of Transported Total Litter Passing Inlet Grate

Not all of the litter moved from road sites into drainage channels is be able to pass through the openings in the inlet grates. The amount of litter that can pass through inlet grates is estimated using the following general equation.

$$L_{pg} = K_{pg} \times L_{tr} \tag{11}$$

Where,

L_{pg} = Total litter passing through inlet grate, count
K_{pg} = Factor to account percent of transported litter passing through the inlet grate, fraction

An estimate of the different percentages of materials likely to pass through inlet grates is presented in Table 2. The data presented in this table were derived (i) from the litter composition for almost 16,500 items counted at 104 urban freeway sites that was obtained from 13 litter surveys performed in 10 states and 3 Canadian provinces, and (ii) from

Table 2
Estimated percent litter materials passing through inlet grates

Litter material category	Percent of total urban freeway litter	Percent of total litter under 6 sq. in	Percent of category able to pass inlet grate
Misc. Paper	31.5	16.1	51.1
Cigarette Butts	29.3	29.3	100.0
Foam Pieces, Pellets	6.6	4.1	61.5
Plastic Film, Sheet	10.2	5.3	52.4
Hard Plastic Pieces	3.8	2.5	66.2
Tire Pieces	0.1	0.1	70.0
Whole Bottles	1.0	0.0	0.0
Glass Pieces	0.6	0.0	5.4
Aluminum Pieces	6.4	1.9	30.2
Other Metal Pieces	1.9	0.8	42.7
Other Misc.	8.6	2.4	27.5
Total	100.0		62.6

photographs of 914 items of litter picked up at 13 California urban freeway sites (Syrek, 1979 and 1985b). Under this analysis, the litter was grouped into 11 product or material categories and viewed for size fractionation. A judgment made as to whether it was small enough (under 6 square inches) to pass through a 1.5-inch grate opening. As shown in Table 2, it was estimated that 62.6 percent of all urban freeway litter was capable of moving through inlet grates. Another factor to consider in the percentage of litter passing through inlet grates is the zonal distribution along roadsides as determined for 2,508 items of litter in a study in Florida (Schert, 1995). The analyses of these results revealed that, for an average roadside location, smaller items of litter were disproportionately deposited within the first 5 feet of the pavement edge. As a consequence, it was found that a higher percentage of the litter materials, 71 percent, within 5 feet of the roadway edge was likely to pass through inlet grates, contrasted to 57 percent for the zone 5 to 10 ft from the pavement and 52 percent for the zone beyond 10 ft. This is particularly important, since for most urban freeway locations, the primary drainage flow is located within or adjacent to the first zone. Note that in the same manner that the determination of the percent movable for a given location had to take into account the effect of adjacent walls, embankments, mounds and curbs, in trapping the litter close to drainage channels, the same considerations would influence the percent passable.

Freeway Outfall Litter

Combining all previous equations, inserting the value estimated for percent of litter movable, transportable, and passing inlet grates, and the conversion factor relating visible litter to total litter results in the following general relationship for estimating the total litter items collected at freeway outfalls following rainstorms.

$$L_{olc} = K_{pg} \times K_{tr} \times K_{ml} \times K_{vt} \times L_{vl} \tag{12}$$

Where,
L_{olc} = Total outfall litter, count

Visible and total litter item counts are among the most precise measurements of roadside litter (Syrek, 1985a) and are directly related to the visual offensiveness of litter and the cost of picking it up. It is usually easier, however, to measure collected outfall litter by volume. To convert outfall litter count (Eq. 12) for volumetric estimates of outfall litter, two additional factors must be incorporated: K_{tv}**,** the factor for converting total litter count to volume measurement in cubic feet and K_{da}, the density adjustment factor to account for the screening effect of the inlet grates in removing the larger items of roadside litter. The volume of litter that can be collected from a freeway outfall, then, can be estimated from Eq. (13).

$$L_{olv} = K_{da} \times K_{tv} \times K_{pg} \times K_{tr} \times K_{ml} \times K_{vt} \times L_{vl} \tag{13}$$

Where,
L_{olv}= Total outfall litter volume, ft^3
K_{tv}= Factor converting total litter count to volume, fraction
K_{da}= Density adjustment factor, fraction

The value for K_{tv}, the factor for converting total item count to cubic feet was derived from results from six litter studies where both total item counts and volume measurements of accumulated roadside litter were made concurrently (Syrek, 2000c). For urban freeway litter, a factor of 0.0151 cubic feet per item was obtained.

The value for K_{da} the factor for adjusting roadside litter density to outfall litter density was derived by first combining percentage composition from thirteen urban freeway studies and cubic inches per item data from three studies for the same components (Syrek, 2000c). The specific volume of each litter component type was combined with the percentage of each component judged likely to pass through an inlet grate as determined from photographs of 914 items of typical urban freeway litter. The weighted specific volumes of components likely to pass the inlet grate were summed up to yield a density adjustment factor of 33.8 percent.

MODEL VARIABLES SELECTION PROCESS

Based on the assumptions and discussion presented previously, the flow chart shown in Figure 8 is provided to assist in selecting proper model coefficients and the necessary means to compute each model variable. This flow chart can be consulted when an estimation of litter from a single or various segments of a freeway is required.

MODEL PERFORMANCE

The litter model performance was determined by using data obtained from four urban freeway sites in Los Angeles County during a 2-year period and 23 rainstorm events (Caltrans, 2000). The selection of model variables to estimate the visible litter was based on the assumptions and selection process discussed in previous sections and the flow chart presented in Figure 8. The input data and predicted visible roadside litter for the four litter freeway monitoring sites is summarized in Table 3.

Table 3
Summary of variables to estimate visible roadside litter

	Monitoring Sites				
Model Variable	**Unit**	**Site 1E**	**Site 1W**	**Site 6**	**Site 8**
Site length	Miles	0.11	0.11	0.15	0.23
County population	1000's	13,894	13,894	13,894	13,894
Occupants per vehicle	Person	1.54	1.54	1.54	1.54
Litter program years	year	6.3	6.3	6.3	6.3
Annual average daily traffic	vehicles/d	211,000	211,000	216,000	227,000
Avg. prior daily max. temp.	Deg. F	68.4	68.2	69.4	69.4
Avg. prior daily total rainfall	Inches	0.06	0.06	0.05	0.05
Avg. visible roadside litter	count	28,800	28,800	28,000	27,000

To estimate total outfall litter, it is necessary to estimate values for the percentages of litter that are potentially movable from each of the four sites and potentially able to pass through the inlet grates. The first two sites (1E and 1W) have earthen berms that were estimated to trap all of the litter that would normally be deposited within 10 feet of the roadside edge. As shown in Figure 2, it was assumed that approximately 50 percent of the litter normally found in the first two 5-foot zones would be capable of being moved in a rainstorm event, amounting to 77 percent of the normal roadside total litter.

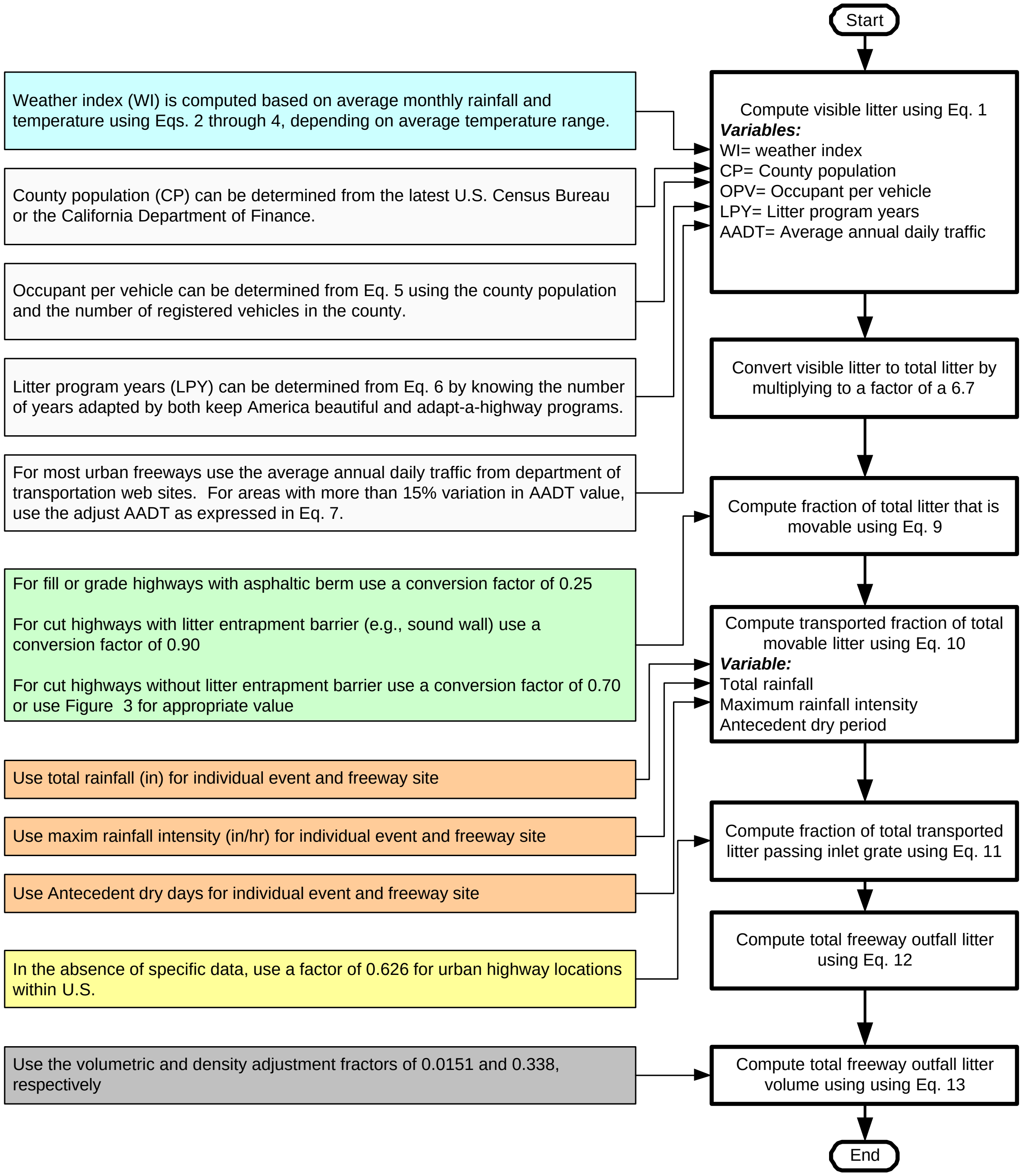


Figure 8
Process to Select Litter Model Variables

Similarly, the size characteristics of the litter in the first two zones at sites 1E and 1W was such that 64 percent of the litter moved and transported to the inlet grates would pass through them. Site 6 had a very tall vertical sound wall that would probably trap an estimated 40 percent of the material normally within the first two 5-foot zones and 20 percent of the material beyond 10 feet resulting in an estimated 89 percent of the littered material being movable in a rainstorm when combined with the factors of Table 2 results in an estimated 61 percent capable of passing the inlet grates. These structures would thus tend to increase the normal percentage of accumulated litter along the roadside that would be removed and transported past the inlet grates during storm events. Site 8 was located on fill and also had a raised asphalt curb at the roadway edge that would tend to prevent most of the litter that landed beyond it from entering the drainage system. Its percent movable litter was estimated at 24 percent and its percent passable at 70 percent. Table 4 summarizes the input data for the four freeway sites.

Table 4
Summary of variables used to estimate freeway outfall litter

Model Variable	Unit	Litter monitoring sites Site 1E	Site 1W	Site 6	Site 8
Movable Litter	%	77.4	77.4	88.7	23.9
Average Rainfall Total	In	0.64	0.6	0.65	0.7
Average Max. Rainfall Intensity	In/hr	1.0	0.9	0.7	0.9
Average Prior Dry Period	Days	7.6	7.6	7.6	7.6
Transported Litter	%	11.1	3.7	3.9	4
Litter Passing the inlet grates	%	63.6	63.6	61.3	70
Conversion Factor	-	6.4	6.4	6.4	6.4

Using the variables presented in Table 4 and the visible litter computed previously (see Table 3), the theoretical amount litter that could be collected from site IE was computed. The correlation between the predicted and actual outfall litter rate at Site 1E for 23 separate rainstorm events is shown in Figure 9. As shown, the model produces a fairly good correlation between the predicted and actual amounts collected.

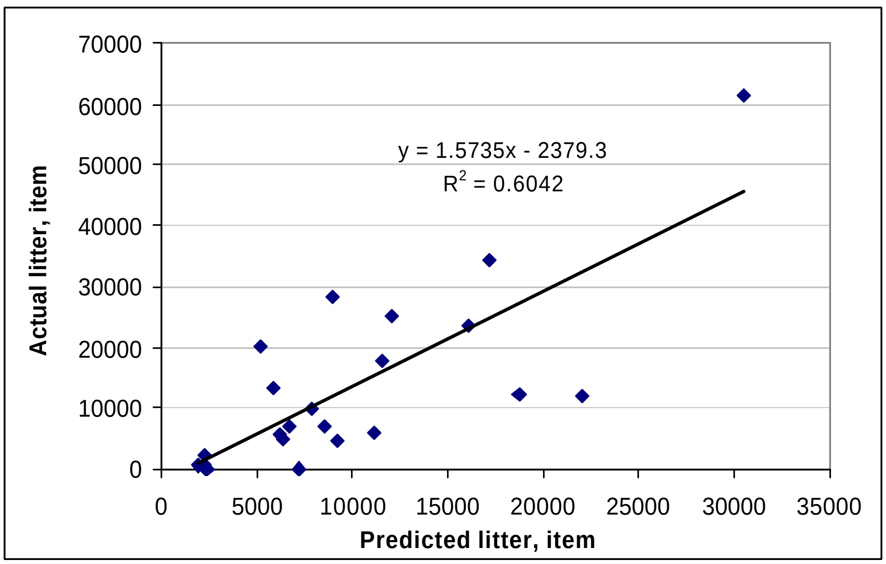


Figure 9
Predicted vs. Actual Total Litter Collected at Freeway Outfall, Site 1E

Similar results were obtained for the other three monitoring sites, as summarized in Table 5. As shown in Table 5, the error in predicting outfall litter totals at the four sites ranged from 12 percent to 25 percent and averaged only 12 percent. This magnitude of error for the individual site predictions would actually be expected, given the high inherent week-to-week variability of actual roadside litter rates measured at the same sites over time. For example, in one litter study conducted by Syrek (2000a), two roadside locations has shown that for rain-free weeks, the week-to-week variability is such that 95 percent of the time litter rates could expect to vary by as much as +/- 51 percent. Thus, for the four sites to show actual differences from predicted levels in collected outfall litter after rainstorms ranging from 12 percent to 25 percent would be well within a reasonable range.

Table 5
Comparison of model output parameters for four monitoring sites

Model Output Parameters	Unit	Site 1E	Site 1W	Site 6	Site 8	All 4 sites
Correlation Coefficient	-	0.60	0.31	0.30	0.10	0.57
Slope	-	1.57	0.93	0.41	0.39	1.05
Y intercept	-	-2,379	-2,099	-3,549	-2,106	-661
Predicted outfall litter	Count	9,679	8,937	9,095	2,833	7,636
Actual total outfall litter	Count	12,850	11,370	7,318	3,206	8,686
Difference actual vs. predicted	%	-24.7	-21.4	24.3	-11.6	-12.1

While the previous discussion is applicable to predictions at individual sites for a season of rainstorm events, the most practical uses of the model would involve predicting the season average or total litter that would be collected at a number of sites for a given jurisdiction or region. As shows in Table 5, the average error calculated from the model predictions of all four sites is only 12 percent, significantly less than for the individual sites alone. Equally important, as shown in Figure 10, the slope of the prediction equation is close to 1.0, indicating the suitability of the model for purposes of predicting seasonal outfall total litter for a given region. Note that predictions of total outfall litter made for a specific jurisdiction or region should be based on a number of randomly selected sample segments that reflect a representative range of traffic volumes and site drainage configurations.

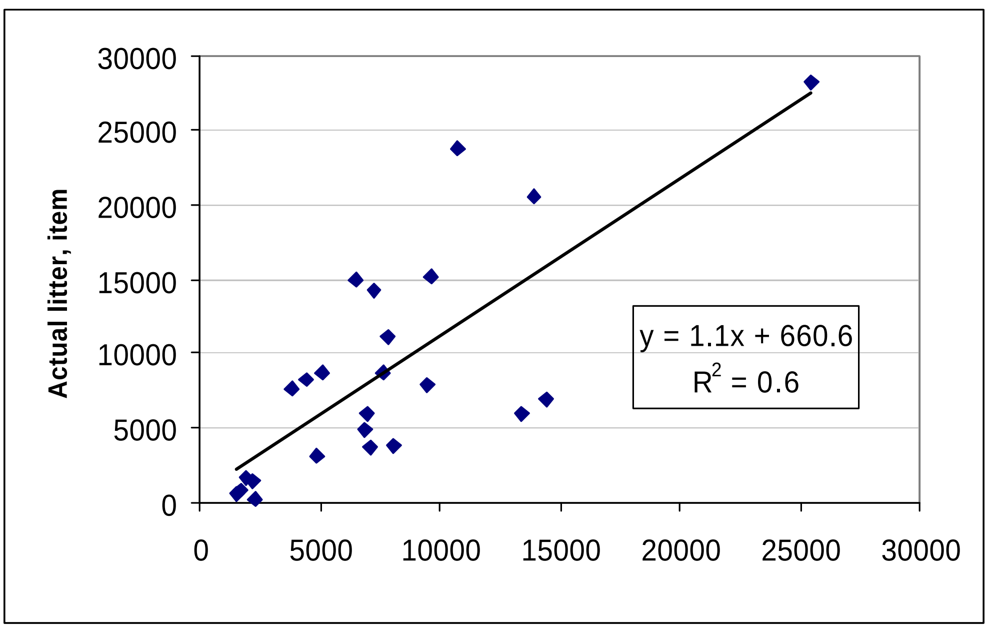


Figure 10
Predicted vs. Actual Total Litter Items Collected at Freeway Outfalls per Centerline Mile for Four Sites Combined

MODEL IMPROVEMENT FOR GENERAL APPLICATIONS

Reliability of the model could be enhanced by conducting various visible litter count monitoring studies for the various roadside edge features, including: top of berm, base of sound wall, and raised asphalt curb. The additional counts of litter in the drainage zone would be added to the portion of litter beyond the berm or sound wall barrier to determine the total deposited litter, increasing the confidence in the model parameters. The percentage of litter in the drainage zone between the pavement edge and the barrier would then be compared with the percent movable estimated for the four sites. The model could be made more robust by extending this visible litter count procedure to a larger random stratified sample of freeway sites where typical roadside drainage characteristics and zones would be evaluated.

A better estimate could be obtained by actually collecting samples of litter in the adjacent litter accumulation zones near selected sites. The standard procedure should be used to collect litter items with minimum size. These samples would then be placed on inlet grates to determine what percentage could pass through and thus verify the basis for the predictions used in this analysis.

A more accurate estimate of the combined percentage movable and passable may be possible by conducting specific color coding litter study prior rain storm and determining litter composition for selected sites. These additional studies using marked samples representing known percentages of freeway litter composition would further refine the litter model variables and hence enhances its performance.

The model developed in this paper applies specifically to urban freeways and limited access expressways. Some modification would be required to adapt it to rural freeways, other rural state highways, rural local roads, and city streets. For rural freeways, rural state highways, and rural local roads different coefficients would have to be used in Equation (1) to predict visible roadside litter. Additional variables, distance to nearest city, for example, would have to be added to implement the additional types of roadways in the litter model.

Similarly, predictions could be made of non-freeway runoff litter from the streets of a specific city by modifying Eq. (1) to include pedestrian traffic volume and neighborhood incomes, both of which factors have been found to significantly affect the litter rate. Some of the factors in Eq. (13) for predicting collected outfall litter would also have to be modified for each roadway type or jurisdiction. These would include K_{pg} (fraction of litter passing the inlet grate), K_{vt} (factor converting visible litter to total litter), K_{tv} (factor converting total litter count to volume) and K_{da} (density adjustment factor).

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