Estimating Pollutant Mass Accumulation on Highways during Dry Periods

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Abstract: For determining the accumulated pollutant mass on highways, two years of monitoring data were used from eight highway sites in southern California. Buildup over antecedent dry days was calculated from mass washed off from the following storm and retained pollutant mass. Mass accumulation rates were determined for total suspended solids (TSS), chemical oxygen demand (COD), oil and grease, total Kjeldahl nitrogen, and total phosphorus, and are reported in g/m^2-day. A revised buildup model is proposed using an alternative modeling approach to describe buildup during dry days between storms. The result shows that, between 1 and 10 antecedent dry days, the pollutant mass buildup rates are determined to be 0.544 g/m^2-day for TSS, 0.114 g/m^2-day for COD, and 0.0113 g/m^2-day for oil and grease. Buildup rates decline in subsequent periods rates decreased by 79% for TSS, 78% for COD, and 61% less for oil and grease in the following 10–70 day period.

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Introduction

Many of the waters of the United States are classified as impaired because of pollutant inputs from point and nonpoint sources. The Nationwide Urban Runoff Program (NURP) expanded the state of knowledge of urban runoff pollution by instituting data collection at many different sites [Driscoll et al. 1990; USEPA 1994, 1995, 1996]. The study showed that significant quantities of organics, nutrients, pesticides, herbicides, and heavy metals are contained in runoff and caused the USEPA, using the authority of Section 208 of the Clean Water Act, to require that regional urban planning agencies develop ways to reduce pollution from nonpoint sources.

Many plans developed to minimize nonpoint-source pollution use total maximum daily loads (TMDLs) as a control mechanism. A TMDL is 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 still be used for its designated purpose (e.g., drinking water supply, contact recreation, etc.). The success in developing and implementing a TMDL depends largely on a better understanding of nonpoint sources, because most point sources (e.g., domestic wastewater treatment plants) have already been addressed. Between 40 and 80% of the total annual organic pollutant loading that enters receiving waters from a typical city originates from nonpoint sources (USEPA 1995, 1996). Other pollutants also have high fractions originating from nonpoint sources.

The origins of pollutants from nonpoint sources are varied and range from illegal discharges to washoff of natural substances to atmospheric deposition. Buildup of pollutants from various deposition sources is of interest, and a better understanding may assist in best management practices (BMP) selection or justification.

This paper analyzes the buildup of pollutants from eight highway sites in southern California over two years of monitoring. Estimates are made for six water quality parameters, and a revised buildup model is proposed.

Background

The sources of urban runoff pollution can be categorized as follows: wet and dry atmospheric deposition; street refuse deposition including litter, street dirt, vegetation, and organic residues; traffic emissions; erosion; and road deicing chemicals. Dry deposition includes dust particles that arise from unpaved roads, parking lots, construction and demolition sites, urban refuse (litter or garbage), surrounding soils, and industrial activities. A significant portion of pollutant loadings from urban areas can be attributed to rain or snowfall. This is especially true for nitrogen, and precipitation is one major source of nitrogen (Crittenden 1998).

Yuzhou et al. (2002) measured wet and dry atmospheric nitrogen deposition on the East Coast of the United States. The mean values were 0.611 and 3.37 mg N/m^2-day for wet and dry deposition, respectively. Lang et al. (2002) estimated 0.186 and

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0.814 ug/m^2-day for wet and dry polycyclic aromatic hydrocarbons (PAHs) deposition, respectively, in metropolitan Miami. Park et al. (2002) also measured atmospheric wet and dry deposition for PAHs in urban areas in Texas. The authors found values of 0.499 and 0.185 ug/m^2-day for wet and dry deposition, respectively.

Deposition from automobile exhausts is composed of dust-sized particles (<60 um), but is not the only source of traffic-related pollution. Tire wear, solids carried on tires and vehicle bodies, wearing parts such as brake pads, and loss of lubrication fluids add to the pollution input attributed to traffic. Shaheen (1975) estimated that approximately 0.7 g/axle-km of solids were directly attributed to traffic. Direct traffic emissions were reported to be 0.2 g/vehicle-km from tire wear (USEPA 1977). Bannerman et al. (1984) estimated atmospheric dry deposition of solids in urban watersheds as 50 mg/m^2-day. Organic content was 40% of the atmospheric dry deposition rate.

The dust mass on highway surfaces should increase with the duration of the dry period before rainfall events. This means that pollutant mass washed off during a storm event should depend on antecedent dry days (ADD); however, the role of ADD in the process of pollution generation has been questioned. Sartor and Boyd (1972) found a weak exponential relationship between ADD and mass of solids accumulated on an asphalt surface using data obtained by vacuum cleaning paved surfaces. The buildup depends on the season, ADD, wind speed, land use, and traffic. Wash off may be a function of rainfall intensity, bottom shear stress, and other factors (Mostaghimi et al. 1997; Ristenpart 1999; Kim et al. 2004, 2005). Osuch-Pajdzinska and Zawilski (1998) and Novotny et al. (1985) considered a loss coefficient, street sweeping and mass accumulation rate, in their buildup models.

Grottker (1987), after experimenting on impervious surfaces, suggested that buildup should be related to ADD, washoff and site-specific parameters such as street cleaning, wind speed, and traffic intensity. Deletic and Maksimovic (1998) compared event mean concentrations (EMCs) to ADD and concluded that they were weakly related; they suggested that buildup and washoff models should be related, even though the exact mechanism or relationship is not presently known.

Most previously published buildup models are based on ADD, and the buildup models have been expressed as a linear, power-law, exponential, or other function of time. Many models adapt the exponential representation because it is simple and can be derived as a first-order process. Grottker (1987) proposed the following buildup model:

$$M_t = M_0[1 - \exp(-k_1 \cdot t)] \tag{1}$$

where t=time in days; M_t=accumulated pollutant mass on the watershed during the dry period; M_0=maximum possible pollutant mass accumulated on the watershed; and k_1=buildup coefficient (d^{-1}). This equation only considers buildup between storm events as a function of dry days.

Charbeneau and Barrett (1998) proposed the following model, which accounts for masses not washed off during previous rainfall events:

$$M_t = M_2 + (M_0 - M_2)[1 - \exp(-k_1 \cdot t)] \tag{2}$$

where M_2=pollutant mass not washed off from the previous rainfall event, which can be called "the initial mass for the dry period."

Ball et al. (1998) tried to find a more reasonable buildup model using regressions of ADD. Of several regression functions including linear, exponential, power, reciprocal, and hyperbolic, they concluded that the power and hyperbolic functions best fit pollutant buildup.

The challenge of using the previously mentioned models is estimating the initial mass after a previous storm event and the pollutant accumulate rate during dry days. Experiments are required but are cumbersome, because the experiments must be continued until the next rainfall event, which is generally unknown and may occur at inconvenient times. It is also necessary to obtain data over a range of dry days, which means that the rainfall frequency must accommodate the experimental design, which can only occur with fortuitous conditions. It is believed that accumulation occurs most rapidly during the first few days after a rainfall event (Grottker 1987), and short and long ADDs would be needed to verify this assumption. As a consequence, it is difficult to characterize buildup, and several seasons may be needed. Other issues such as street cleaning, construction, shock pollutant spills, and wind speed must be controlled, and these complicate the experimental design.

Using two years of stormwater monitoring data, we found a weak relationship between ADD and various pollutant EMCs (Ma et al. 2002; Kim et al. 2004, 2005). Using a different definition of mass, total mass, which includes washed-off mass and retained mass, shows a stronger correlation with ADD. Thus, using total mass can be a reasonable approach to estimate the mass accumulation during dry periods. Additionally, when the remaining mass is linked with total washed-off mass for a storm event, the mass accumulation can be estimated. This method is a new approach for mass accumulation model based on combined buildup and washoff models.

Methods

As stated earlier, direct measurement of mass accumulation on a watershed, especially highways, is very difficult because of high traffic, random street sweeping, shock pollutant spills, and other uncontrolled conditions. Therefore, it is preferred that an indirect estimation method be developed, which may be general (Deletic and Maksimovic 1998). Accumulated pollutant mass can be inferred from the amount of pollutant that is washed off during storm events. Some of the pollutant mass is washed off the watershed, but some mass remains on the watershed and contributes to the buildup for the next dry period (Charbeneau and Barrett 1998; Deletic and Maksimovic 1998; Fraser et al. 1999; Kim et al. 2004, 2005). The monitoring results obtained in our study provide an opportunity to estimate buildup from washed-off mass, which is an indirect method.

Monitoring Area

Rainfall, runoff flow rate, and runoff quality were monitored at eight highway sites in southern California (Fig. 1) over two rainy seasons. The stations were equipped for recording with a flow meter, rain gauge, and flow-weighted composite sampler. Grab samples (generally 8–12 per event) were also collected and compared to composite samples. A total of 41 storm events were monitored. Detailed summaries of the sites and events are given in Table 1. The table shows the area of each site, event date, average daily traffic (ADT), ADD, event rainfall, storm duration, total runoff volume, and runoff coefficients for each storm event. The runoff coefficient was calculated by dividing the total runoff

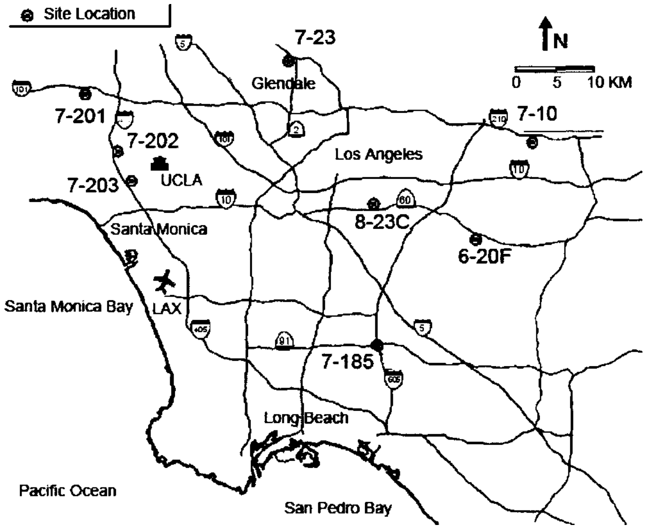

Fig. 1. Monitoring area in southern California

by the product of the total rainfall and site area. More information on the methodologies is available in other papers (Stenstrom et al. 2001; Ma et al. 2002; Kim et al. 2004, 2005).

Derivation of New Buildup Model

Two mechanisms are proposed for the buildup model. The first is a buildup mechanism that should be related to ADD, ADT, and other factors that affect pollutant input but is independent of accumulated pollutant mass. The second mechanism accounts for pollutant reduction; it should include factors such as wind, degradation, street sweeping, etc.; and is a function of accumulated pollutant mass. The individual factors for buildup and reduction are lumped into single terms for simplicity. Fig. 2 shows the approach of mass buildup and washoff phenomena. Eq. (3) shows the mass changes with time

$$\frac{dM}{dt} = \xi P \cdot A - \psi \cdot M \tag{3}$$

where M=pollutant mass (mg) accumulated on the watershed surfaces at time t; P=pollutant mass fallen on the watershed surface from air and vehicles ($\mathrm{mg \cdot m^{-2} \cdot day^{-1}}$); ξ=capture coefficient (dimensionless); ψ=loss coefficient ($\mathrm{day^{-1}}$); and A=catchment area ($\mathrm{m^2}$).

Rearranging Eq. (3), we obtain

$$\int_0^{Ma_i} \frac{dM}{\xi P \cdot A - \psi \cdot M} = \int_0^{T_i} dt \tag{4}$$

where T_i=dry period to the next storm event, i; and Ma=accumulated mass during the dry period.

After integration we obtain

$$\left(-\frac{1}{\psi}\right) \ln(\xi P \cdot A - \psi \cdot M)\Big|_0^{Ma_i} = T_i \tag{5}$$

$$\ln\left[\frac{\xi P \cdot A - \psi \cdot Ma_i}{\xi P \cdot A}\right] = -\psi \cdot T_i \tag{6}$$

Rearranging Eq. (6), we obtain

$$Ma_i = \frac{\xi P \cdot A}{\psi} \cdot [1 - \exp(-\psi \cdot T_i)] \tag{7}$$

Therefore, the total mass accumulation during dry periods on a catchment can be determined by adding the retained mass from a previous rainfall event and the accumulated mass after an event. The total mass (Ma_T) available for the next storm can be described as follows:

$$Ma_T = Mr_{i-1} + Ma_i = Mr_{i-1} + \frac{\xi P \cdot A}{\psi} \cdot [1 - \exp(-\psi \cdot T_i)] \tag{8}$$

where Mr_{i-1}=retained mass that is not washed off by the previous storm.

Eq. (8) has two parameters, ψ, and ξP, which can and ideally would be measured directly, or correlated to measurable parameters such as wind velocity. They were not measured in this study, because it was not in the original scope of effort. We are hopeful that the parameter values calculated for these sites can be used in future monitoring programs to predict loads.

Close examination of Eqs. (2) and (8) shows that they are mathematically identical if one rearranges and redefines the parameters. The principal difference is that the maximum buildup, represented by M_o in Eq. (2), is not a parameter in Eq. (8), but rather an equilibrium state obtained when the rates of accumulation and losses are equal. It is hoped that this formulation is more realistic and will allow the parameters to be estimated from direct measurements.

Results

Monthly and cumulative rainfall during the monitoring periods is shown in Fig. 3. The vertical bars show the 43-year monthly average and the observed rainfall during the study period. The lines show the cumulative rainfall for the same conditions. The number of dry days per month ranges from 23 to 31 days; therefore, even in the wet season, the highways are usually dry. The first year of the research period was an average year, while the second was a wet year, having nearly 50% more rainfall than average.

Monitored Event Descriptions

Table 1 summarizes the site information and event descriptions. Monitoring was performed for all events having at least one antecedent dry day. The average daily traffic (ADT) was very high, ranging from 122,000 to 328,000 cars/day. Table 1 also summarizes selected event characteristics such as date, ADD, rainfall duration, total rainfall, runoff volume, and runoff coefficients. Event rainfall varied from 0.3 to 5.64 cm, and antecedent dry days varied from 1 to 70 days. The smallest watershed site, 6-20F, is 1,700 $\mathrm{m^2}$ and the largest area, 7-10, is 48,100 $\mathrm{m^2}$. The runoff coefficients vary from 0.35 to 0.96, with lower values occurring during smaller events. The lower coefficient reflects infiltration and evaporation during the event, which are more significant in smaller events. Antecedent dry periods are also known to affect runoff coefficients.

Table 1. Site and Event Descriptions

Site	Event date (month/day/year)	Average daily traffic (cars/day)	Watershed area (m^2)	Antecedent dry days (days)	Storm duration (h:min)	Total rainfall (cm)	Total volume of runoff (m^3)	Runoff coefficient
7–201	01/25/00	328,000	12,800	8.00	19:21	1.68	213.18	0.87
	02/27/00			3.90	4:26	0.30	16.14	0.37
	10/26/00			33.60	10:57	2.34	255.20	0.85
	01/08/01			69.40	6:34	0.38	43.70	0.90
	02/19/01			5.40	4:08	0.71	80.86	0.89
	03/04/01			4.00	10:32	1.17	136.13	0.91
7–202	01/25/00	260,000	16,900	7.90	19:23	2.36	396.70	0.92
	02/10/00			9.90	19:01	0.69	106.47	0.92
	04/17/00			39.80	8:34	4.42	300.78	0.40
	10/26/00			33.60	10:57	2.31	194.41	0.50
	01/08/01			69.40	4:18	0.48	49.60	0.61
	03/04/01			4.00	5:05	0.89	140.17	0.93
7–203	01/25/00	322,00	3,900	8.20	7:53	1.75	68.02	0.96
	02/12/00			1.10	4:42	1.78	59.46	0.86
	03/04/00			5.00	1:33	0.58	20.50	0.75
	10/26/00			33.60	11:47	2.59	94.53	0.94
	02/19/01			5.30	6:56	2.97	110.53	0.95
	02/24/01			1.00	11:36	1.12	37.29	0.86
	04/06/01			31.60	10:46	2.16	55.43	0.66
7–10	01/25/00	176,000	48,100	25.20	10:04	1.50	557.23	0.77
	02/12/00			2.10	2:50	2.31	950.31	0.85
	02/20/00			3.20	13:05	5.64	2598.24	0.96
	02/23/00			2.10	13:00	4.24	1737.42	0.85
	02/27/00			4.00	5:45	1.09	400.49	0.76
	03/08/00			1.00	10:06	2.74	1145.46	0.87
	04/17/00			38.90	7:20	4.24	1745.43	0.86
7–185	01/25/00	220,000	2,300	25.00				
	02/12/00			2.00	2:30	1.88	36.98	0.86
	02/23/00			2.00	9:35	2.49	56.53	0.96
	02/27/00			4.00	1:05	0.38	4.00	0.46
	03/08/00			3.00	8:45	2.06	45.70	0.95
	04/17/00			39.00	6:55	3.18	70.39	0.96
6–23	01/26/01	122,000	29,100	33.00	7:48	0.89	95.61	0.37
	02/10/01			14.60	9:12	0.99	120.42	0.42
	02/19/01			5.70	6:24	0.94	116.82	0.43
6–20F	10/26/00	216,600	1,700	33.00	10:00	3.18	33.13	0.61
	01/26/01			33.00	7:18	1.19	10.53	0.52
	02/10/01			14.50	6:36	0.51	2.75	0.32
	02/19/01			5.60	5:40	1.04	7.72	0.44
8–23C	01/26/01	229,000	2,500	33.00	12:48	0.53	6.59	0.49
	02/19/01			5.50	7:12	0.43	10.66	0.94

Comparison of Monitored Pollutant Concentrations

Fig. 4(a) shows a concentration correlation matrix of water quality parameters. The ellipses indicate 90% confidence ranges. The confidence ellipse is a Gaussian bivariate confidence interval on the centroid. The correlations are represented by the middle line, with the 90% confidence intervals represented by the bordering lines. All statistics were calculated using Systat 9 (SPSS Corp., Chicago). Chemical oxygen demand (COD) shows strong corre-

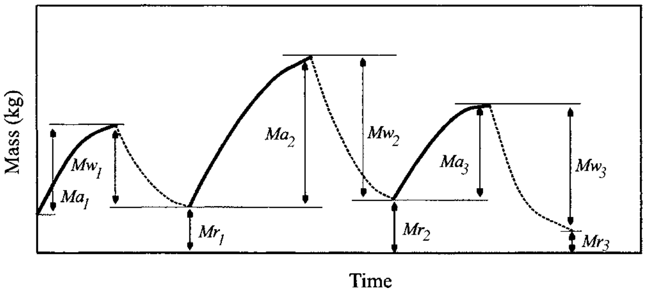

Fig. 2. Mass accumulation and washoff model approaches

lations with all parameters except total phosphorus. Statistical summaries for the monitored concentrations are shown in Fig. 4(b). The number of observations for each parameter range from 451 to 785.

Calculation of Accumulated Pollutant Mass during Dry Days

The retained mass is assumed to be the product of the final runoff concentration and the retained water. The retained water is equal to the total rainfall times one minus the runoff coefficient. The buildup mass can be quantified by the washed-off mass in the following rainfall event, as shown in Fig. 2. The retained mass for the next event is calculated as before. The analysis can be performed after the second event. Thus, the mass accumulated on highway surface can be calculated by following Eqs. (9) and (10):

$$Ma_2 = Mw_2 - (Mr_1 - Mr_2) = Mw_2 + Mr_2 - Mr_1 \quad (9)$$

$$Ma_3 = Mw_3 - (Mr_2 - Mr_3) = Mw_3 + Mr_3 - Mr_2 \quad (10)$$

$$\vdots$$

$$Ma_n = Mw_n - (Mr_{n-1} - Mr_n) = Mw_n + Mr_n - Mr_{n-1} \quad (11)$$

where $Ma_{1,2,3, \text{ and } n}$=mass accumulated on the catchment during dry periods between events (kg); $Mw_{1,2,3, \text{ and } n}$=mass washed off by a storm event (kg); and $Mr_{1,2,3, \text{ and } n}$=mass retained in the catchment after an event (kg).

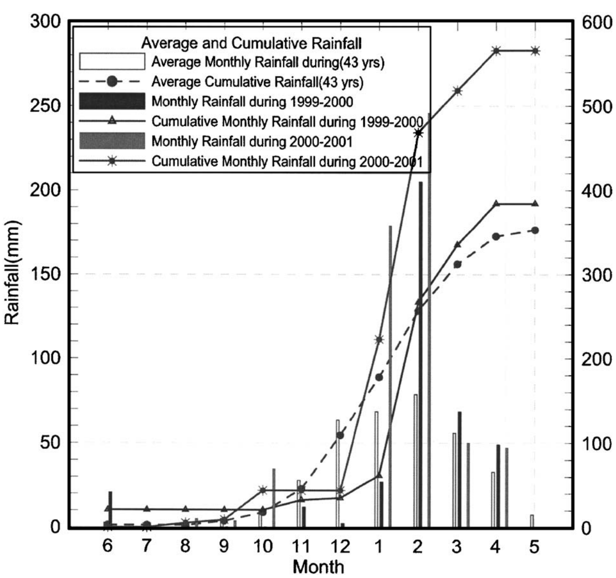

Fig. 3. Monthly rainfall for research periods and 43 years

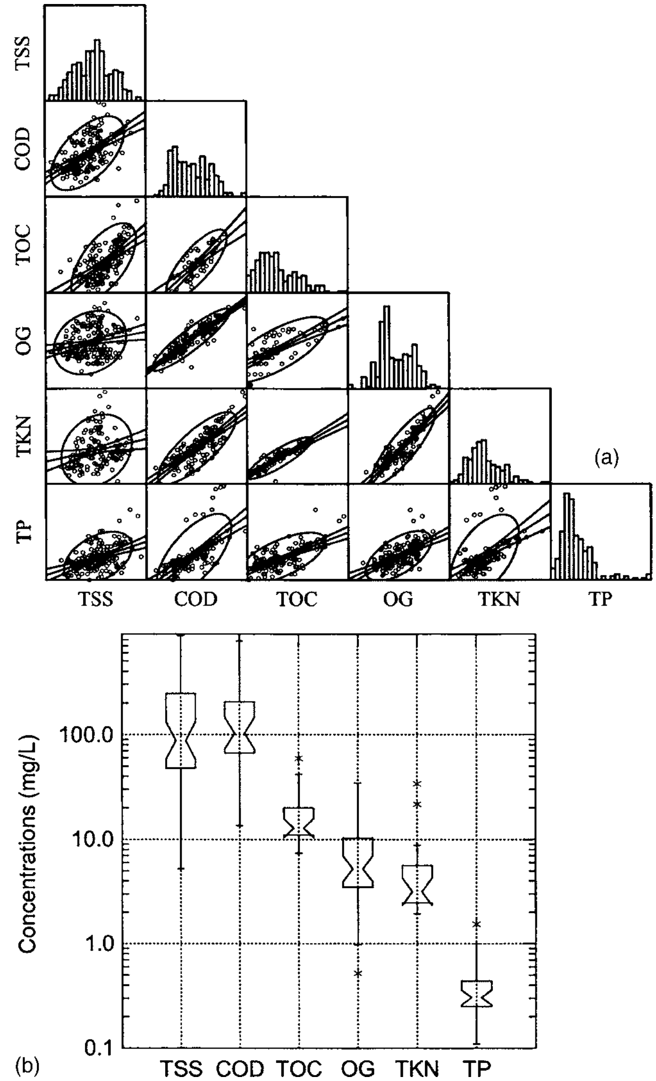

Fig. 4. (a) Correlation matrix; (b) notched box plots for concentration distribution. In Fig. 4(a), the ellipse means the confidence ellipse at p=0.95, and upper/lower lines near a regression line mean 95% confidence intervals. The parameters shown are TSS (total suspended solids), COD (chemical oxygen demand); TOC (total organic carbon), OG (oil and grease), TKN (total Kjeldahl nitrogen) and TP (total phosphorus).

Fig. 5(a) shows a correlation matrix for accumulated pollutant masses for the five pollutants calculated using Eqs. (9)–(11). Fig. 5(b) shows a statistical summary for accumulated pollutants using notched box plots. The accumulated masses are normalized per unit area for all eight sites. Fig. 6 shows the accumulated masses versus ADD, and the buildup trends are apparent. There are fewer total Kjeldahl nitrogen (TKN) observations, because TKN was not measured at sites 7-201, 7-202, and 7-203 in the first year.

Model Application Using Normalized Accumulated Mass

Eq. (7) can be applied to the data shown in Fig. 6 and used to fit the parameters ξP and ψ. These two parameters were estimated using nonlinear, least squares regression. The results are shown in

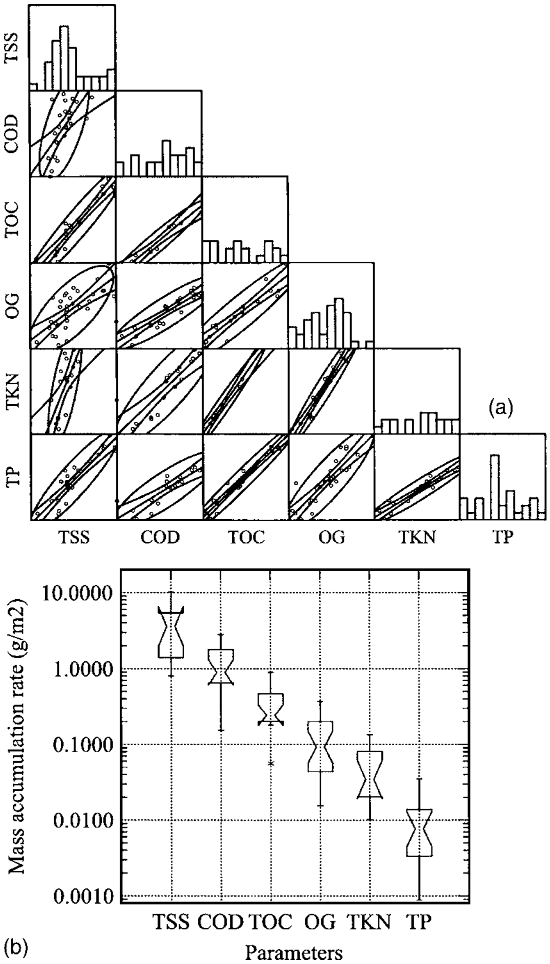

Fig. 5. (a) Correlation matrix; (b) notched box plots for accumulated pollutant mass rate

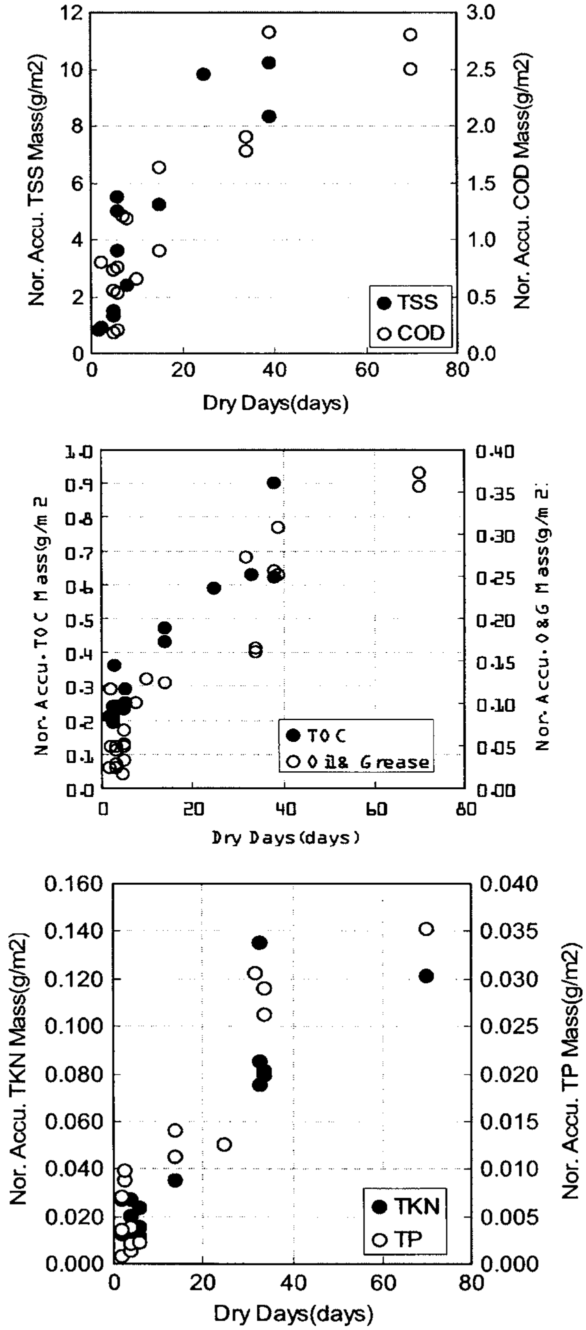

Fig. 6. Normalized accumulated pollutant mass for model application

Table 2, which summarizes the model fit and presents R^2, F, other statistical parameters, and the Durbin-Watson parameter for autocorrelation. Small values of the Durbin-Watson statistic indicate the presence of autocorrelation. Usually a value less than 0.80 indicates that autocorrelation. The R^2 values for all parameters are greater than 0.8, suggesting that the model and data are well matched. The "adjusted coefficient of multiple determination (Ra^2)" is an R^2 statistic adjusted for the number of parameters in the equation and the number of data observations. It is a more conservative estimate of the percent of variance explained, especially when the sample size is small as compared to the number of parameters. It is defined as follows:

Table 2. Statistical Comparison between Modeled and Measured Mass Rate

Parameters	Number of events	Standard error of estimate	Maximum deviation for any event	R^2	R_a^2	F value	Durbin-Watson test for autocorrelation
TTS	13	1.33	2.36	0.85	0.84	64.27	2.09
COD	17	0.37	0.61	0.82	0.81	69.69	1.47
TOC	18	0.10	0.21	0.80	0.79	64.73	1.21
Oil and grease	24	0.04	0.09	0.88	0.88	165.80	1.89
TKN	14	0.02	0.05	0.85	0.83	65.93	2.55
TP	18	0.00	0.01	0.86	0.85	95.16	2.37

Table 3. Determined Model Parameters and Statistical Summaries

Parameters	Mass accumulation rate				Loss coefficient			
	ξP (g/m^2-day)	Standard error	t	Prob(t)	ψ (1/day)	Standard error	t	Prob(t)
TSS	0.6525	0.1240	5.27	0.00026	0.062	0.019	3.280	0.007
COD	0.1245	0.0220	5.78	0.00004	0.045	0.012	3.850	0.002
TOC	0.0678	0.0110	5.94	0.00002	0.021	0.007	2.900	0.008
Oil and grease	0.0096	0.0010	6.74	0.00001	0.097	0.022	4.390	0.000
TKN	0.0039	0.0008	4.90	0.00037	0.026	0.012	2.180	0.050
TP	0.0009	0.0002	5.59	0.00004	0.025	0.010	2.480	0.024

$$R_a^2 = 1 - \frac{n-1}{n-N_p} \cdot (1-R^2) \tag{12}$$

where n=number of observations; N_p=number of parameters; and R^2=unadjusted coefficient of multiple determination.

Model Parameters

As stated earlier, it is difficult to measure mass buildup rates because of the difficulty in controlling conditions or accessing sites. Deletic and Maksimovic (1998) proposed indirect estimation methods. They correlated event mean concentrations (EMCs) with antecedent dry days and found only a weak relationship.

The technique used here is also an indirect method. The modeled mass accumulation rate (ξP) and loss coefficient (ψ) are summarized in Table 3. The mass accumulation rates are 0.653 g/m^2-day for TSS, 0.125 g/m^2-day for COD, and 0.0096 g/m^2-day for oil and grease. The table also shows standard errors, t, and Prob(t) for all parameters. The table also shows the "t" statistics, which is computed by dividing the estimated value of the parameter by its standard error. This statistic is a measure of the likelihood that the actual value of the parameter is not zero. The larger the absolute value of t, the less likely that the actual value of the parameter could be zero. The "Prob(t)" value is the probability of obtaining the estimated value of the parameter if the actual parameter value is zero. The smaller the value of Prob(t), the more significant the parameter and the less likely that the actual parameter value is zero. The Prob(t) values of Table 3 are very small (mostly $<0.03\%$), which suggests a nonrandom relationship.

The values of mass accumulation rate and loss coefficients are different for each water quality parameter. This is to be expected, because each pollutant has different transport and transformation behavior.

An alternate method for estimating buildup is to use only the early part of the data shown in Fig. 6. The data between 1 and 10 ADD show nearly linear buildup. Also, the proposed model has nearly linear buildup during this period, in that the product of the loss coefficient and accumulated mass are small. Table 4 shows the slopes of the buildup between 1 and 10 ADD and compares them to the model parameters presented in Table 3. The linear buildup coefficients are less than the model parameters, and the agreement is good. The mass buildup rates were 0.544 g/m^2-day for TSS, 0.114 g/m^2-day for COD, and 0.0113 g/m^2-day for oil and grease from 0 to 10 days. After 10 days, the mass buildup rates decreased to 0.113 g/m^2-day (79% less than the buildup rate before 10 days) for TSS, 0.0252 for COD (78% less), and 0.0044 for oil and grease (61% less) in the ADD range of 10–70 days.

Table 4. Mass Accumulation Rate Using Linear Assumptions

Parameters	Mass accumulation rate (g/m^2-day)		
	0–10 days	10–70 days	Percent decrease
TSS	0.544	0.1133	0.79
COD	0.114	0.0252	0.78
TOC	0.059	0.0122	0.79
Oil and grease	0.0113	0.0044	0.61
TKN	0.0037	0.0013	0.65
TP	0.0011	0.0004	0.64

Total suspended solids (TSS) are often used as a master parameter in stormwater modeling. The individual measurements of COD, TOC, oil and grease, TKN, and TP are correlated to TSS, with R^2 ranging from 0.65 (TKN) to 0.83 (TOC). The correlation ratio of the parameters to TSS and the ratio of the buildup coefficients to the buildup coefficients for TSS are poor. Therefore, one does not expect the relationship among pollutant concentrations to be useful in predicting buildup coefficients.

Table 3 also summarized values and statistics of loss coefficients for each parameter and ranged from 0.025 to 0.062 day^{-1} for all parameters. The Prob(t) is less than 2.4%, except for TKN.

Sensitivity Analysis with Changes of Model Parameters

The mass accumulated on the catchment during dry days can be predicted using the new buildup model. The model has several parameters, which include measurable variables such as area, ADD, etc., and two fitting parameters. The product of the capture coefficient with the pollutant accumulation rate and loss coefficient will affect the rate of mass buildup. A sensitivity analysis of the loss coefficient is shown in Fig. 7. The final buildup is impacted by the value of the coefficient as well as the rate of buildup. The net mass accumulation of TSS becomes nearly constant after 20–40 days. For COD, the net mass accumulation continues to increase until 100 days. For pollutants that have a high loss coefficient, BMPs such as street sweeping must be performed often if the mass capture is to be maximized. Also, the model could be used to assist in comparing the cost of various BMPs, such as the frequency of street sweeping.

Conclusions

Pollutant buildup over dry days between storms was investigated using data from a 2-year monitoring program and fit with a new model. The following conclusions were made:

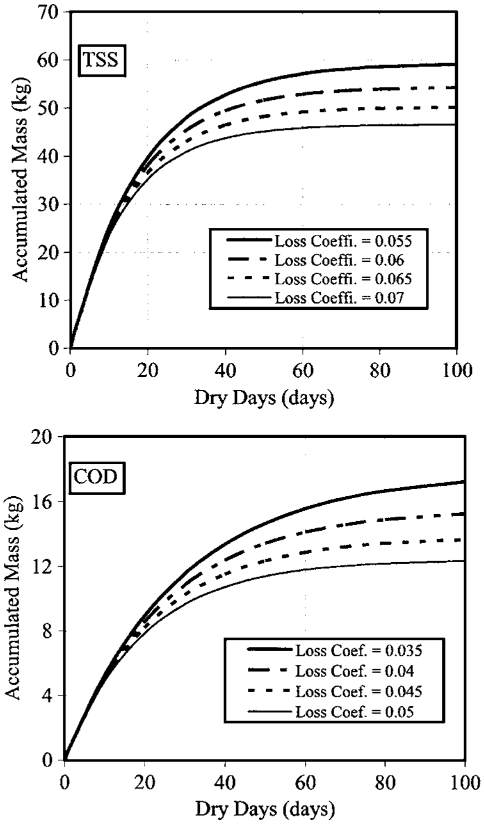

Fig. 7. Sensitivity analysis for TSS and COD with changes of loss coefficient (ψ) at 5000 m^2 area

1. Pollutants on highways build up over time. The concentrations of organic constituents (e.g., chemical oxygen demand, total organic carbon) are correlated, and they are more correlated to each other than to total suspended solids. The various pollutants also accumulate at different rates.
2. Pollutant buildups over 41 storm events at eight sites were calculated from washoff data and show good agreement with a new buildup model using two calibration parameters. The model can be used to assist in best management practice selection and may be useful in predicting their cost effectiveness.
3. The mass accumulation rate was 0.653 g/m^2-day for TSS, 0.125 g/m^2-day for COD, and 0.0096 g/m^2-day for oil and grease. The parameters were statistically significant at a 0.03 confidence level. Results are also presented for total Kjeldahl nitrogen, total phosphorus, and total organic carbon.
4. An alternate method for estimating buildup using a simple linear assumption was also presented. Between 1 and 10 antecedent dry days, the mass buildup rates were 0.544 g/m^2-day for TSS, 0.114 g/m^2-day for COD, and 0.0113 g/m^2-day for oil and grease. Between 10 and 70 days, the buildup rates decreased by 79% for TSS, 78% for COD, and 61% for oil and grease.
5. The loss coefficient ranged from 0.025 to 0.062 day^{-1} for all parameters. The significance was less than 0.024 except for TKN, which was 0.05.

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