Comparison of pollutant loading estimation using different land uses and stormwater characteristics in Ballona Creek Watershed

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ABSTRACT

Estimation of stormwater pollutant loads using land use based models has been widely used for establishing regulations and management practices. This approach requires land use information to assign the imperviousness or runoff coefficients (RC) and event mean concentrations (EMCs) for the pollutants of interest. This simplistic approach is useful to estimate the total mass emissions. However, different research groups have used various parameters based upon similar data sources, and there are very few validations using actual field data. This study compares the assumptions, methodologies and results of several, independent modelling efforts, and functions as a quality and sensitivity study of the methodologies. The similarity or differences of the various model results serve as a qualitative indicator of the state of art for this type of stormwater modelling.

Key words | event mean concentration, land use, pollutant loads, runoff coefficient, stormwater modelling

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INTRODUCTION

The Ballona Creek Watershed is the largest, urbanised watershed discharging to Santa Monica Bay in Southern California and was recognised as an important source and was given priority for early loads analysis. Stenstrom & Strecker (1993) inventoried land use and estimated pollutant loads. Since then additional and more sophisticated approaches have been developed (Wong *et al.* 1997; Ackerman *et al.* 2005; Barco *et al.* 2008). The modelling or technical approaches vary and some use US EPA models such as Stormwater Management Model (SWMM) and HSPF. Others use an empirical model or mass balance approaches, which all require land use information or another method to assign the imperviousness or runoff coefficients (RCs) and event mean concentrations (EMCs) for various pollutants. In this way the various land parcels that comprise the Ballona Creek Watershed can be assigned an EMC and RC.

doi: 10.2166/wst.2008.259

These can be combined with the rainfall to estimate total pollutant mass, as follows:

$$\text{Pollutant Mass} = \text{EMC} \times \text{RC} \times \text{Rainfall} \times \text{Area} \quad (1)$$

This simplistic approach is useful to estimate the total mass emissions but does not provide more detailed information such as routing, build-up and washoff functions or correlations among pollutants and impacts of storm characteristics such as rainfall intensity, antecedent dry days (ADD), etc. More advanced models such as SWMM and HSPF have greater capabilities in this respect.

As a first step in validating the various approaches used by different modelling groups, it is useful to compare the results of their models. While they are based upon sound principles and similar data sources, these efforts have been performed independently and no specific comparisons were made prior to this effort. The comparison performed in this study serves to evaluate the approaches and can function as a quality assessment. The similarity or differences of the various model results serve as a qualitative indicator of the state of art for stormwater modelling. A well developed and understood scientific approach should produce similar results even when performed by different groups that are working independently.

This study addresses the land use definitions first and compares the results of the different efforts. Next the RCs and EMCs are compared along with a brief description for the basis or background. Finally, the differences of annual mass load are compared and the reasons for the differences in projections are discussed.

METHODOLOGIES

The Ballona Creek Watershed was selected for making comparisons. This watershed includes the majority of the Ballona Creek Watershed, but ends at the Los Angeles County Department of Public Works mass emission station. They currently monitor at this station and there is a USGS flow gauge at this station.

Three approaches by independent research groups were compared (Stenstrom & Strecker 1993; Stein *et al.* 2007; Susilo *et al.* 2006). The key input of the model (Equation 1) is land use definition. Generally, USGS land cover and land use (LCLU) classification system (Anderson *et al.* 1976) is most often used. This system is also used by Southern California Association of Government (SCAG) for land use information of Los Angeles region with some minor differences. According to SCAG's land use information, there are 109 different land uses in Ballona Creek Watershed (SCAG 2001). Each research group condenses 109 land uses into a manageable number of environmentally significant definitions as shown in Table 1.

The comparison of runoff volume was made using 15 inches annual rainfall, which is approximately the 70-year average annual rainfall for the Ballona Creek Watershed. The runoff coefficient is a key factor that impacts the runoff volume and mass load. The runoff coefficient is defined as the average ratio of runoff to rainfall, highly correlated to imperviousness of the area (Wong *et al.* 1997). Many researchers have developed different equations to estimate

Table 1 | Land use definition used for Ballona Creek Watershed models

Stenstrom *et al.*	**Susilo *et al.***	**Stein *et al.***
Single family residential	Single family residential	Low density residential medium – high density
Multiple family residential	Multiple family residential	Residential
Commercial	Commercial	Commercial
Public		Public facilities & institution
Industrial	Industrial	Industrial
		Extraction
Transportation	Other urban	Transportation & utilities
Open	Open	Open space & recreation
	Agriculture	Vacant
		Agriculture
Water		Water & floodways

RCs. The following relationship (Driscoll *et al.* 1990) was used to the RCs for each land use for Stenstrom *et al.* and Stein *et al.* models.

$$\mathrm{RC} = 0.7 \times \mathrm{I} + 0.1 \quad (2)$$

where RC is runoff coefficient, I is impervious fraction. Stenstrom *et al.*'s RC (Stenstrom & Strecker 1993) used the imperviousness assigned by the Los Angeles County Department of Public Works (LADPW) and the imperviousness values were based on Los Angeles County Department of Public Works, NPDES Permit No. CA0061654, Attachment 1, Santa Monica bay Drainage Basin drainage area characterisation. Stein *et al.* used the pervious surface area for each land use, as established by LADPW (DePoto *et al.* 1991). Susilo *et al.*'s RC used the data for each land use type in the Southern California Bight (Ackerman & Schiff 2003).

Event Mean Concentration is an average pollutant concentration during the storm event, defined as the total pollutant mass divided by total runoff volumes (Huber & Dickinson 1988) as follows:

$$\mathrm{EMC} = \frac{M}{V} = \frac{\int_0^T c(t)q(t)\mathrm{d}t}{\int_0^T q(t)\mathrm{d}t} \quad (3)$$

where M is total mass of pollutant during the entire runoff (kg), V is total volume of runoff (m^3), $c(t)$ is time varying pollutant concentration (mg/L), $q(t)$ is time variable flow (L/min), T is total duration of runoff (min). Table 2 shows the EMCs for each land use in the Ballona Creek Watershed used by each group. Stenstrom *et al.*'s EMC data contain nine water quality parameters, i.e. chemical oxygen demand (COD), total suspended solid (TSS), total Kjeldahl nitrogen (TKN), total phosphorus (TP), total copper (Cu), total lead (Pb), total zinc (Zn), and oil and grease related for seven land uses. The method of developing these EMCs is based upon an analysis of all previously collected data for the Santa Monica Bay Watershed (Stenstrom & Strecker 1993). Much of the data were not useful due to differences in protocol, but there were sufficient data to estimate EMCs for TSS, COD, BOD, Cu, and Zn. These were compared to data reported in the Nationwide Urban Runoff Program (US EPA 1983) and were higher than national means, corresponding in most cases to the 90th percentile. For the remaining parameters, except oil and grease, it was assumed they would also correspond to the 90th percentile. Oil and grease measurements collected by Stenstrom *et al.* (1984) for six different land uses in Richmond, CA, were used for oil and grease EMCs.

Stein *et al.*'s EMC data including TSS, TP, Cu, Pb, Zn were collected from seven land use monitoring sites in Santa Monica Bay watersheds. The EMC values shown here are mean EMCs during 2000–2001 except transportation and open land use. EMCs for Transportation land use were measured in a rail park in 2001 and EMCs for open land use

Table 2 | EMC related to each land use for Ballona Creek Watershed

	TSS	TKN	$NO_{2\&3}$	TP	Cu	Pb	Zn	O&G
Stenstrom & Strecker (1993)								
SF Residential	290	4	1.9	0.9	0.095	0.350	0.350	3
MF Residential	210	2	1.0	0.6	0.100	0.440	0.380	22
Commercial	180	2	1.2	0.4	0.072	0.225	0.694	22
Public	180	2	1.2	0.4	0.072	0.225	0.694	22
Industrial	180	2	1.2	0.4	0.072	0.225	0.694	22
Transportation	210	2	1.0	0.6	0.100	0.440	0.380	22
Open	490	3	1.5	0.5	0.055	0.140	0.440	0
Stein et al. *(2007)*								
LD Residential	22			0.3	0.017	0.004	0.059	
HD Residential	25			0.3	0.015	0.007	0.196	
Commercial	15			0.2	0.012	0.004	0.133	
Industrial	130			0.9	0.031	0.018	0.583	
Transportation	13			0.1	0.008	0.002	0.064	
Open	135			0.0	0.008	0.001	0.023	
Agriculture	60			1.3	0.020	0.006	0.130	
Susilo et al. *(2006)*								
SF Residential	65		0.30		0.015	0.005	0.053	
MF Residential	33		0.57		0.012	0.003	0.116	
Commercial	58		0.46		0.019	0.002	0.128	
Educational	58		0.46		0.019	0.002	0.128	
Industrial	81		0.49		0.032	0.004	0.290	
Transportation	81		0.49		0.032	0.004	0.290	
Open	28		1.00		0.004	0.000	0.002	
Agriculture	699		11.3		0.084	0.020	0.247	

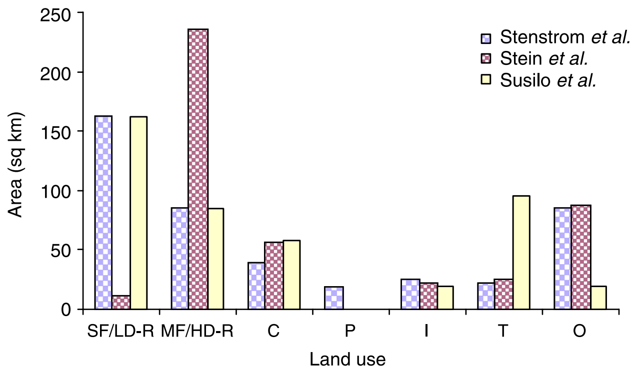

Figure 1 | Land use composition in Ballona Creek Watershed. Note that SF/LD-R is single family or low density residential. MF/HD-R is multiple family or high density residential. C is commercial, P is public, I is industrial, T is transportation or other urban, and O is open land use.

were measured in 2003. Susilo *et al.*'s EMC data include TSS, nutrients such as nitrate, and metals such as Cu, Pb, and Zn. The EMCs were based on LADPW's 1994–2000 flow-weighted composite-sampled land use runoff monitoring data except agriculture, which was developed from Ventura County 1994–2004 land use EMC data.

RESULTS

The land use categories used by each group are different and the division of land uses for the Ballona Creek Watershed is shown in Figure 1. There are large differences in single family (or low density) and multiple family (or medium to high density) residential areas, and transportation (or other urban) and open areas. The differences are due to different grouping methodology. For example, Stein *et al.*'s low density residential areas were regarded as SFR while medium to high density residential areas were regarded as MFR. In this case, MFR also contains high density SFR. Another example is transportation area. Susilo *et al.*'s other land use category was regarded as transportation, which contains land parcels that were considered vacant or open by other groups. It is important to note that we are not treating any of the assumptions as right or wrong or better or worse, only different.

Table 3 | Annual runoff volume for the Ballona Creek watershed calculated using each group's runoff coefficients and land use definitions

Runoff volume (10^6 m^3/yr)	Using uniform land use definition	Using each group's land use definition
Stenstrom *et al.*	74	74
Stein *et al.*	63	76
Susilo *et al.*	69	79

Figure 2 shows the comparison of RCs for the Ballona Creek Watershed. Despite the differences in methodologies, the RCs for each land use are rather similar. Stenstrom *et al.*'s RCs are on average a little greater. Stein *et al.* did not use the public category and UCLA did not use the agricultural category. The greatest difference in RC is for transportation land use, where Stein *et al.* used 0.45 and Susilo *et al.* and Stenstrom *et al.* used 0.64 and 0.66, respectively.

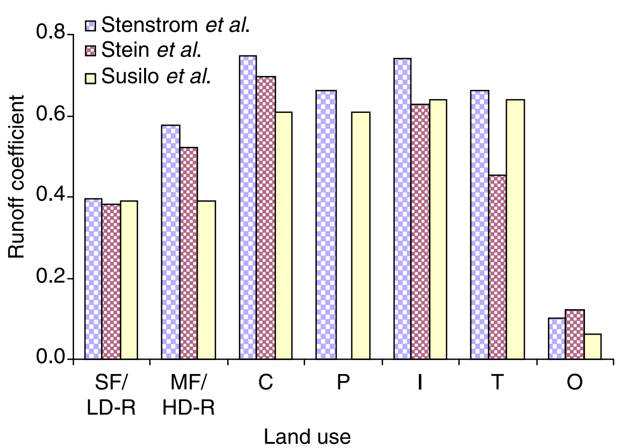

Figure 2 | Runoff Coefficients against land use in Ballona Creek Watershed. Note that SF/LD-R is single family or low density residential. MF/HD-R is multiple family or high density residential. C is commercial, P is public, I is industrial, T is transportation or other urban, and O is open.

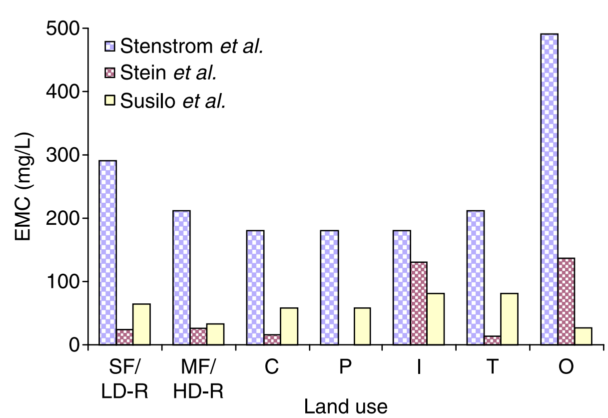

Figure 3 | Comparison of TSS EMC against land use in Ballona Creek Watershed. Note that SF/LD-R is single family or low density residential. MF/HD-R is multiple family or high density residential. C is commercial, P is public, I is industrial, T is transportation or other urban, and O is open.

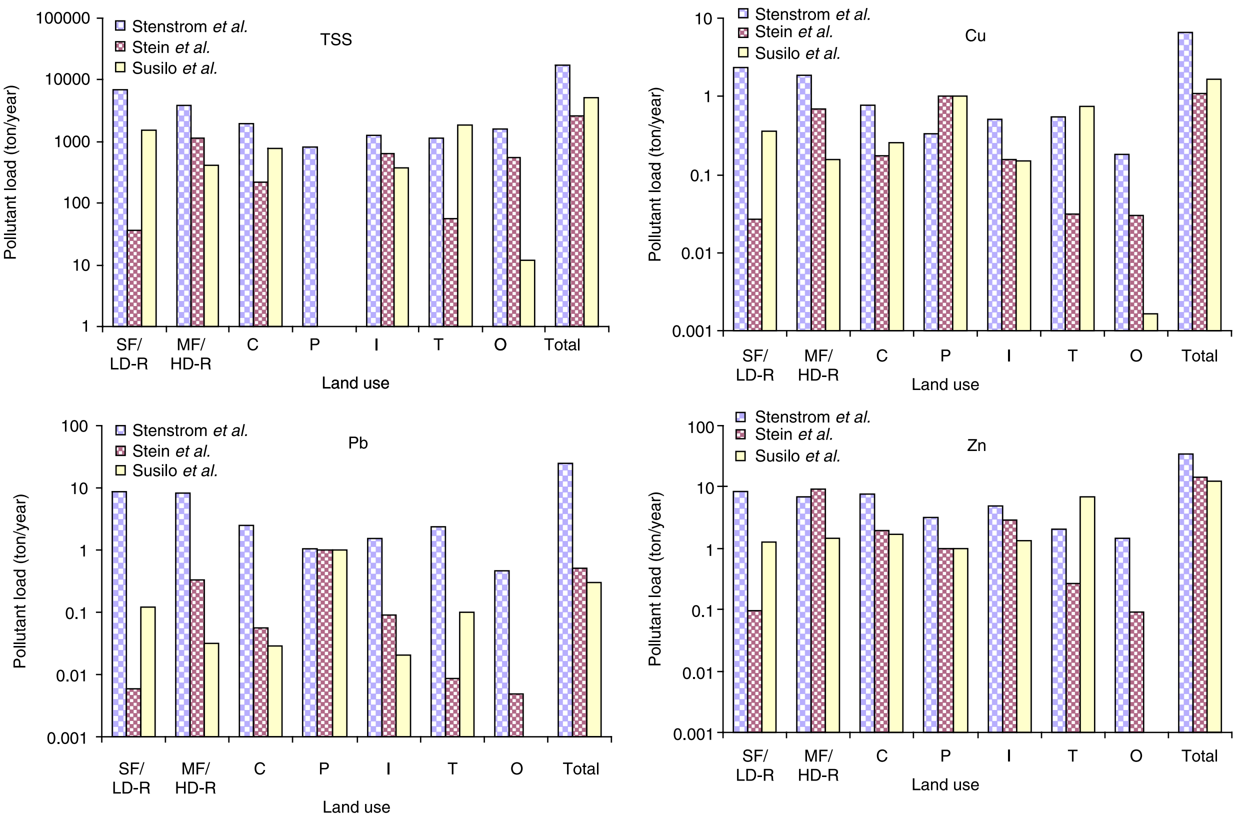

Figure 4 | Estimated Pollutant Loads from each land use in Ballona Creek Watershed. Note that SF/LD-R is single family or low density residential. MF/HD-R is multiple family or high density residential. C is commercial, P is public, I is industrial, T is transportation or other urban, and O is open.

The difference in RCs creates different runoff volumes and will be directly proportional to differences in load estimates. Table 3 shows the differences in annual runoff volume. The second column shows the runoff using each group's RCs with a uniform land use definition (Stenstrom *et al.*'s). The higher RCs generally observed for UCLA in Figure 2 translate into greater runoff. The third column shows the runoff using each group's RCs and land use definitions. In this case, the runoff volume is slightly different.

Figure 3 shows the comparison of TSS EMCs of the watershed. Stenstrom *et al.*'s EMC values are much greater than others. SCCWRP EMC values for transportation area are much lower compared to those used by other groups probably because of the monitoring station. This indicates that the stormwater pollution concentrations in the watershed have declined since 1993.

Using acquired RC and EMC data from each research group, we calculated pollutant loads (PLs) from the Watershed. Figure 4 shows the estimates of annual pollutant loads for selected constituents using different land uses, EMCs and RCs from each research group. The areas of each land use still have a great effect on PL estimates. The result shows that the load estimates with Stenstrom *et al.*'s model are generally higher by 20–80% than using other models.

CONCLUSION

The three groups have slightly different interpretation of land use definition, which can be reconciled quite easily. Runoff coefficients used by the different groups were nearly identical, except for transportation because all of them are based on LADPW's information. EMCs among the groups are quite different and especially EMCs based on 90th percentile of NURP data are far too great compared to others. This may result in part because of genuine pollutant reductions that may have occurred since the Stenstrom and Strecker (1993) database was assembled, such as washout of lead from leaded gasoline combustion products. Alternatively, it should be noted that this database was trongly biased with observations in the late 1980s, when there was a major drought in southern California. The reduced rainfall may have created higher EMCs due to less dilution.

These differences of land uses, RCs and EMCs in predicted pollutant loads assumed by the various modellers, all of whom are experienced and capable, point to the need for verification studies. The empirical spreadsheet models described in this paper, which are also widely used by others and in different areas, are highly sensitive to the assumptions for land use, RC and EMCs. The differences in predictions based upon these assumptions can be larger than the potential impact of applying BMPs.

The most important finding from this exercise is the need to calibrate and verify these models, prior to using them to direct BMP construction programs, which may cost hundreds of times more than the cost of calibrating and verifying the models.

ACKNOWLEDGEMENTS

The authors would like to thank Ken Susilo and Brandon Steets at Geosyntec and Eric Stein and Drew Ackerman at SCCWRP for providing their data for us.

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