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Variability of Input Parameters related to Pollutants Build-up in Stormwater Quality Modelling

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***Abstract**: The variability of input parameters is the most important source of overall model uncertainty. Therefore, an in-depth understanding of the variability is essential for uncertainty analysis of stormwater quality model outputs. This paper presents the outcomes of a research study which investigated the variability of pollutants build-up characteristics on road surfaces in residential, commercial and industrial land uses. It was found that build-up characteristics vary highly even within the same land use. Additionally, industrial land use showed relatively higher variability of maximum build-up, build-up rate and particle size distribution, whilst the commercial land use displayed a relatively higher variability of pollutant-solid ratio. Among the various build-up parameters analysed,* D_{50} *(volume-median-diameter) displayed the relatively highest variability for all three land uses.*

***Keywords:** Pollutants build-up, Parameter variability, Stormwater quality modelling, Urban water pollution*

1. INTRODUCTION

The accuracy and reliability of stormwater quality modelling outcomes is important for stormwater management decision making (Egodawatta and Goonetilleke 2007). However, many typical modelling approaches are subject to uncertainties as lumped parameters are used to describe catchment or land use characteristics without adequately representing their distributed nature in terms of pollutant processes. However, embedded uncertainty does not undermine the use of modelling tools if the outcomes are interpreted accordingly. Therefore, undertaking an uncertainty analysis in conjunction with model simulation is important.

The variability of the input parameters is the most important source of overall model uncertainty (Butts et al. 2004). Other uncertainty sources such as model structure or random errors would lead to amplification of the uncertainty associated with input parameters (Haydon and Deletic 2009). A number of researchers have undertaken uncertainty analysis for stormwater quality models (for example Mailhot et al. 1997; Kanso et al. 2005; Gabriele et al. 2008; Gabriele et al. 2009). However, studies specifically focusing on the variability of input parameters are limited. An in-depth understanding of the variability associated with input parameters can provide knowledge on the uncertainty assigned by these parameters and consequently assist in uncertainty analysis of stormwater quality models.

In stormwater quality modelling, input parameters related to pollutants build-up are used to represent different land uses. Although the parameters may be formulated differently in various stormwater quality models, the fundamental definition of these parameters is essentially similar for all models. The accumulated solids load during the antecedent dry period is estimated by the assigned maximum build-up load and build-up rate. In addition, the accumulated solids load is classified into fine and coarse fractions since the wash-off characteristics of these two fractions are different (Miguntanna 2009). Therefore, the particle size distribution has an important influence on stormwater quality modelling outcomes. The other pollutants are simulated as substances attached to the solids. Consequently, the pollutants-solids ratio is a key parameter in simulation.

The input parameters are correlated with each other and are critical to deriving reliable modelling outcomes. Uncertainties can occur due to factors such as the variability in traffic characteristics, road surfaces conditions and anthropologic activities. These site specific characteristics could lead to different pollutant build-up characteristics even within the same land use. In such a scenario, the use of a single set of parameters would result in uncertainties in modelling outcomes.

This paper details the outcomes of an investigation undertaken to analyse the variability relating to pollutant build-up parameters in stormwater quality modelling. Pollutants build-up characteristics on different road surfaces in residential, commercial and industrial land uses were investigated. Variability of build-up parameters were analysed in the context of variability in solids build-up, variability in particle size distribution and variability in pollutant-solids ratio. Uncertainty assigned by input parameters due to their variability and uncertainty in model outcomes were not investigated.

2. METHODS AND MATERIALS

2.1 The build-up equation

A number of equations are commonly used for replicating pollutant build-up such as power, exponential and logarithmic equations (Sartor et al. 1974, Huber and Dichinson 1988, Ball et al. 1998). Build-up expressed as an exponential equation was selected for this study since it has been widely adopted by stormwater quality models such as MIKE URBAN and SWMM. The equation format is shown in Equation (1).

$$M = \frac{A}{D} \times (1 - e^{-Dt}) \qquad \text{Equation (1)}$$

Where, M- accumulated mass of pollutants at time t (g/m^2), t- antecedent dry days (d), A- build-up rate (g/m^2/d) and D- removal coefficient (d^{-1}).

The coefficient D represents the removal of pollutants from the surfaces by various mechanisms such as wind, traffic, street sweeping, biological and chemical degradation and excluding stormwater wash-off. The accumulated mass M will increase until A/D limit is reached and the maximum M is defined as maximum build-up.

2.2 Build-up samples collection and testing

The study sites for build-up sample collection are listed in Table 1 below. For each land use, four road surfaces were selected to include different site specific characteristics such as road surface conditions and traffic conditions. Two solids build-up samples were collected from 3m^2 plots from each road surface representing two different antecedent dry periods. Each sampling plot was located equal distance apart from the kerb and the road centre. Sample collection, transport and storage complied with Australia New Zealand Standards, AS/NZS 5667.1:1998 (AS/NZS 1998). The build-up sample collection was undertaken using a vacuum system. Vacuuming was done three times in perpendicular directions in order to ensure that all the solids were collected. The sample collection efficiency of the vacuuming system has been tested under field conditions and found to have an efficiency of 97% (Egodawatta et al. 2007).

Each build-up sample was tested for total suspended solids (TSS), total dissolved solids (TDS), total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC) and particle size distribution. Sample testing was undertaken according to test methods specified in Standard Methods for the Examination of Water and Waste Water (APHA 2005). The total solids (TS) load was obtained by the summation of the TSS and TDS loads. The unit for TS load is g/m^2. The pollutant-solids ratio was obtained by TSS, TN, TP and TOC loads being divided by the corresponding TS load and was in the units of mg/g.

Table 1 Road surface characteristics

Land use	**Road names**	**Road surface texture (mm)**	**Slope (deg.)**	**TS load (g/m^2)**	
Residential				**8 dry days**	**17 dry days**
	Merloo Drive	0.76	2.24	0.34	1.27
	Yarrimbah Drive	0.86	1.32	2.16	0.87
	Winchester Drive	0.84	2.87	3.52	0.81
	Carine Court	0.80	1.30	2.04	1.17
Commercial				**4 dry days**	**10 dry days**
	Hobgen Street	0.90	Nearly 0	1.62	0.53
	St Paul's Place	0.62	Nearly 0	0.52	0.96
	Via Roma	0.84	Nearly 0	1.07	0.81
	Thornton Street	1.11	Nearly 0	1.74	1.18
Industrial				**4 dry days**	**5 dry days**
	Stevens Street	1.10	5.91	2.99	4.25
	Lawrence Drive	1.05	1.59	1.09	2.16
	Hilldon Court	0.93	0.72	1.94	1.08
	Patrick Road	1.14	1.70	2.19	2.24

2.3 Development of solids build-up parameters

Table 1 gives the TS loads collected from each road surface for the different land uses. The two data sets for each road surface represent two different antecedent dry periods. Both, the build-up rate and maximum build-up were derived from the TS loads for the different road surfaces by fitting the measured TS loads to Equation (1). The larger value of the two TS data points on each road surface (such as 1.27 on Merloo Drive) was considered as the maximum build-up M, whilst the other TS value together with its antecedent dry period (such as 0.34 for 8 antecedent dry days for Merloo Drive) were input into Equation (1) as the solids build-up value at time t to determine the removal coefficient D. The build-up rate A was determined by multiplying the maximum build-up M by the removal coefficient D. Consequently, 12 build-up parameters sets (build-up rate and maximum build-up) were generated for the 12 road surfaces in three land uses. The detailed method for build-up curve development can be found in a previous study (Liu et al. 2010).

2.4 Analysing the variability of build-up parameters

The variability of build-up parameters were expressed using the coefficient of variation (CV). CV describes the data variation and is denoted as a percentage (Hamburg 1994). A high CV value represents a high variation in the dataset. CV is obtained by the standard deviation being divided by mean of the dataset.

3. RESULTS AND DISCUSSIONS

3.1 Variability of solids build-up

Table 2 gives the build-up parameters derived for the different road surfaces. In terms of each land use, both maximum build-up and build-up rate show a variation rather than a single value. The industrial land use has the highest maximum build-up (mean value 2.65 g/m^2) and build-up rate (mean value 1.03 g/m^2/d). In addition, industrial land use also shows the largest variations for both maximum build-up (1.07 g/m^2) and build-up rate (0.86 g/m^2/d). This can be attributed to goods loading-unloading activities, reduced street sweeping, spillage from vehicles, the diversity of industrial activities and the poor condition of the road surfaces. From Table 1, it can be noted that the industrial road surface textures are relatively rougher than at the residential and commercial land use areas. This in turn would also lead to higher variations in solids build-up as the rough surfaces can affect pollutant processes such as the re-distribution of fine particles.

Table 2 Build-up parameters for different road surfaces

Land use	Road names	Maximum build-up (g/m^2)	Build-up rate (g/m^2/d)	D_{50} (µm)
Residential	Merloo Drive	1.27	0.05	10.48
	Yarrimbah Drive	2.16	0.07	103.57
	Winchester Drive	3.52	0.05	6.78
	Carine Court	2.04	0.10	6.63
	Mean	**2.25**	**0.07**	**31.87**
	SD	**0.94**	**0.02**	**47.84**
Commercial	Hobgen Street	1.62	0.06	7.72
	St Paul's Place	0.96	0.19	48.27
	Via Roma	1.07	0.15	163.77
	Thornton Street	1.74	0.20	30.53
	Mean	**1.35**	**0.15**	**62.57**
	SD	**0.39**	**0.06**	**69.48**
Industrial	Stevens Street	4.25	1.29	2.65
	Lawrence Drive	2.17	0.38	190.8
	Hilldon Court	1.94	0.31	8.99
	Patrick Road	2.24	2.13	7.72
	Mean	**2.65**	**1.03**	**52.54**
	SD	**1.07**	**0.86**	**92.21**

The analysis of solids build-up illustrates the high variability of build-up parameters even within the same land use. As such, the conventional approach of estimating build-up parameters based on land use could lead to gross errors in modelling outcomes. Therefore, the variability associated with both maximum build-up and build-up rate should be considered when undertaking uncertainty analysis of stormwater quality modelling outcomes. In relation to the research study undertaken, the range of variation of maximum build-up and build-up rate can be considered as (1.26-3.52 g/m^2) and (0.05-0.10 g/m^2/d) for residential land use; (0.95-1.74 g/m^2) and (0.06-0.20 g/m^2/d) for commercial land use and (1.94-4.25 g/m^2) and (0.31-2.13 g/m^2/d) for industrial land use.

3.2 Variability of particle size distribution

For ease of understanding, the particle size distribution curves for the 24 build-up samples were categorised into 12 classes based on the 12 road surfaces investigated. Figure 1 shows the average volumetric particle size percentages for each road surface. It can be noted that particle size distribution even within the same land use displays high variability. Also, it can be observed from Table 2 that the D_{50} values (volume-median-diameter) of particle size distribution show very high variability for all three land uses. The industrial land use shows the highest standard deviation (92.21 µm), followed by commercial land use (69.48 µm). The residential land use has a relatively low D_{50} (31.87 µm) and standard deviation (47.84 µm).

The high variability of particle size distributions for all land use types illustrate the variability associated with the fine and coarse particle size fractions even within the same land use. Therefore, if a fixed value of particle size is input to a stormwater quality model to represent a given land use, it would lead to error in modelling outputs since the fine and coarse particles display the different transport processes as discussed in Section 1. For assessing the uncertainty of the modelling outputs, the range of variability of D_{50} can be considered as (6.63-103.57 µm) for residential land use; (7.72-163.77 µm) for commercial land use and (2.65-190.8 µm) for industrial land use. Furthermore, the industrial land use shows the highest variation in particle size distribution compared to the commercial and residential land use. This can be attributed to the poor road surfaces conditions and high pollutant generating activities as discussed previously.

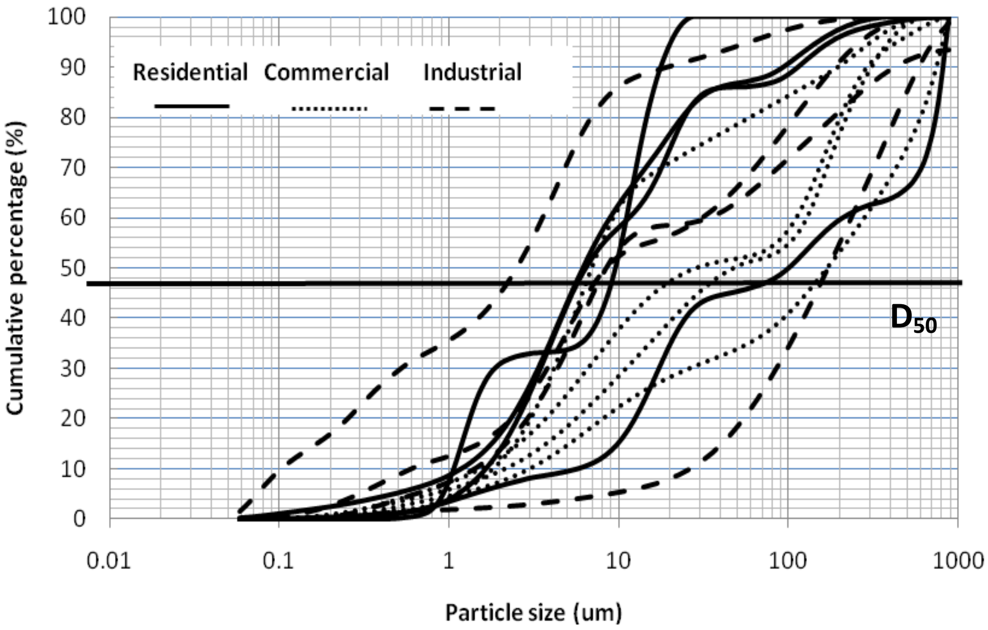

Figure 1 Particle size distributions

3.3 Variability of pollutant-solids ratio

The variations in pollutant-solids ratio were analysed with the use of PROMETHEE and GAIA, which is an unsupervised analytical method for rank-ordering of objects on the basis of a matrix of variables (Keller et al. 1991). PROMETHEE provides the ranking for all objects based on the net out flowing Φ values while GAIA visually presents the PROMETHEE ranking results in the form of a principal components biplot (PC1 vs. PC2). These methods can be applied to investigate the correlations between variables and objects and clusters among objects (Herngren et al. 2006). In the GAIA biplot, the same direction of variable vectors and objects indicate a close relationship between them. A decision axis pi emphasises which objects are predominant (DecisionLab 2000).

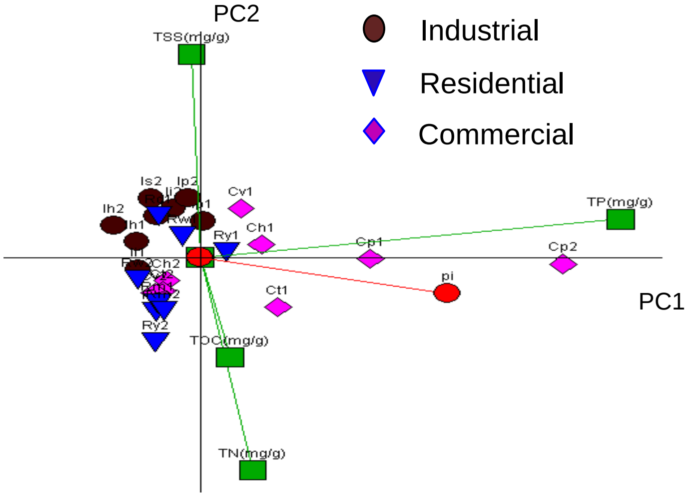

Figure 2 GAIA biplot (Δ=90.14%)

The 24 build-up samples were used to derive four pollutant-solids ratios (TSS-solid, TN-solid, TP-solid and TOC-solid) for analysis. The data matrix (24×4) was submitted to PROMETHEE and GAIA to obtain a PROMETHEE ranking (Table 3) and a GAIA biplot (Figure 2). According to Table 3, the build-up samples from the commercial land use mostly occupy the top positions while the bottom positions are mostly occupied by the industrial land use samples. The residential land use samples scatter in the middle. This indicates that commercial land use relatively has the highest pollutant-solid ratios while these ratios are lower in the industrial land use. The results highlight the highly polluted nature of commercial land use compared with the other two land uses.

Table 3 PROMETHEE ranking

Samples	Φ values	Ranking	Samples	Φ values	Ranking
Cp2	0.2240	1	Ih1	-0.0282	13
Cp1	0.1316	2	Ry2	-0.0296	14
Cv1	0.0787	3	Ip2	-0.0439	15
Ct1	0.0752	4	Rc1	-0.0452	16
Ry1	0.0357	5	Rw2	-0.0460	17
Ip1	0.0349	6	Ct2	-0.0471	18
Ch1	0.0332	7	Rm1	-0.0488	19
Rc2	0.0119	8	Ch2	-0.0499	20
Rm2	0.0045	9	Ii2	-0.0502	21
Rw1	-0.0050	10	Is1	-0.0521	22
Ii1	-0.0145	11	Ih2	-0.0683	23
Cv2	-0.0244	12	Is2	-0.0765	24

Note: In column 1, the first letter indicates land use types (R-Residential; C-Commercial; I-Industrial). The second letter is the first letter of the road name and the digit indicates the sampling episode.

The GAIA biplot displays the correlations between land use and the pollutant-solids ratios. Commercial land use shows a close relationship with the TP-solids ratio; Industrial land use is closely related to the TSS-solids ratio whilst the TOC-solids and TN-solids ratios have close correlations with residential land use. The decision axis pi points in the commercial land use direction, which indicates a higher pollutant-solids ratio and variation, in the commercial land use. Hence, this underlines the need to focus on commercial land use in uncertainty analysis of stormwater quality modelling outputs. It is also noteworthy that the commercial land use data are relatively scattered in the GAIA biplot whilst the industrial and residential land use data are closer together, thus implying that the pollutant-solids ratios have higher variations in the commercial land use than the other two land uses. This is attributed to the diversity and complexity of anthropologic activities in the commercial land use.

Although the outcomes from the PROMETHEE and GAIA analysis can be informative, it is however recommended the further evaluation of the findings should be undertaken using the raw data. Table 4 shows the mean values and standard deviations for the original dataset. In addition, data from past research study undertaken by Miguntanna (2009), which was undertaken in the same study sites as this research project, is also displayed to compare with the original dataset. The commercial land use shows the highest mean values for TP and TOC-solids ratios and the highest standard deviations of all ratios except for TN. Industrial land use has the highest mean value and standard deviation of TSS-solids ratio but is not exceptional in the case of the other three pollutant-solids ratios whilst the residential land use displays the highest mean value and standard deviation of TN-solids ratio. These observations further confirm the conclusions derived from PROMETHEE and GAIA. It also can be noted that TSS and TOC build-up data compare well to the data from Miguntanna (2009). However, TN and TP build-up show much lower values compared to Miguntanna (2009). This can be attributed to the different roads investigated and hence different site specific characteristics. This further confirms the highly variable nature of pollutants build-up even within the same land use.

3.4 Comparison of variability in pollutant build-up parameters

Figure 3 provides a comparison of the CV values derived for build-up parameters for the different land uses. It can be observed that nearly all values show relatively high CV values (more than 25%) except for the TN-solids ratio in commercial land use and TSS-solids ratios in residential and industrial land uses. This further confirms the high variations associated with build-up input parameters even within the same land use as a data set with CV greater than 10% is considered as having a high variation (Hamburg 1994). D_{50} displays the highest CV values, being more than 100%, for all three land uses. This means that the variability of particle size distribution within the same land use is relatively higher than the other build-up parameters. This implies that the particle transport processes would be more complex than other pollutants due to the highly variable nature of particle size distribution and different transport process of fine and coarse particles. Therefore, consideration of the particle size distribution is important in model uncertainty analysis. In terms of pollutants-solids ratios, the different land use characteristics have a significant influence on the variability of the TN-solids ratio and the TSS-solids ratio since the CV values are significantly different among the three land uses, whilst the variability of TP-solids ratio and TOC-solids ratio do not vary significantly with land use. Furthermore, as these parameters are correlated to each other, these parameters in combination would amplify the uncertainty of model outputs.

Table 4 Pollutant-solids ratios for different land use

Land use	Parameters	TSS (mg/g)	TN (mg/g)	TP (mg/g)	TOC (mg/g)
Residential	Data range	691.70-961.71	0.82-3.13	0.31-1.77	12.44-77.98
	Mean	845.13	2.15	0.76	35.71
	SD	99.93	0.74	0.47	21.17
	Miguntanna (2009)	706.7	8.98	2.08	35.11
Commercial	Data range	755.73-1105.41	1.70-2.56	0.52-7.18	18.86-119.81
	Mean	858.67	2.09	2.51	39.93
	SD	114.49	0.34	2.22	33.13
	Miguntanna (2009)	735.9	10.61	5.49	18.67
Industrial	Data range	917.72-1041.01	0.06-2.17	0.06-1.36	10.46-34.52
	Mean	953.62	0.98	0.77	19.25
	SD	37.42	0.74	0.50	8.189
	Miguntanna (2009)	669.9	2.89	4.78	13.12

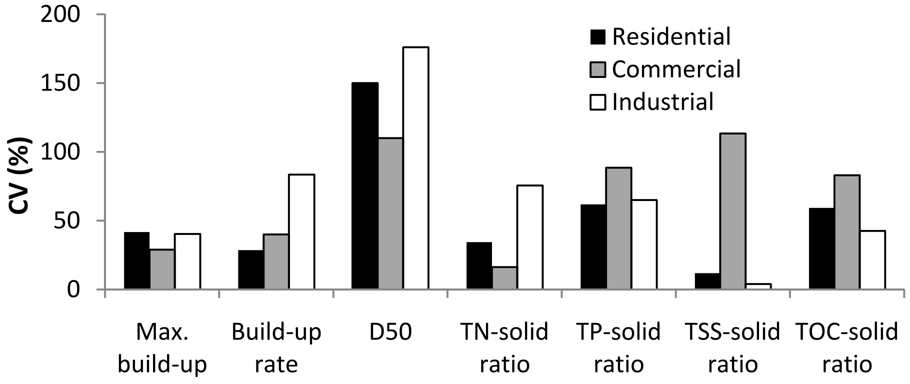

Figure 3 CV of different build-up parameters

4. CONCLUSIONS

The following conclusions were derived from the research study which underlines the uncertainty associated with water quality modelling outcomes:

- Pollutant build-up characteristics vary even within the same land use. This confirms the highly variable nature of build-up not only with land use but also due to site specific characteristics. The combined variability of these parameters would amplify the uncertainty of stormwater quality model outputs.

- Industrial land use has relatively higher variability of maximum build-up, build-up rate and particle size distribution than the other two land uses. However, the commercial land use displayed relatively higher variations of pollutant-solids ratio than the other land uses.
- D_{50} displayed a relatively higher variability for all three land uses than the other parameters. Therefore, particle size distribution should be given greater consideration in model uncertainty analysis as there are different transport processes for fine and coarse particles.

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