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Case Studies of Applying Urban Surface Data in Evaluating Stormwater Management Issues

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Abstract

Pollutant load estimation is often required to evaluate stormwater management issues associated with water quality and urban development. Land use (e.g. residential, commercial) is commonly employed as a base to spatially characterize the pollutant generation from urban areas. This paper demonstrates an alternative approach of using surface type (e.g. road, roof, grassed) to define suspended solids loads in runoff from urban catchments. Three case studies are provided to illustrate the potential of using this surface based approach. The case studies analyzed are 1) a comparison of the suspended particle loads generated from residential and commercial land uses, 2) an assessment of the effect of exposed areas of bare soil on suspended particle loads generated from a residential catchment and 3) an evaluation of the effect that widespread adoption of rainwater tanks may have on the suspended particle concentration of residential urban runoff. The case studies demonstrate that the surface based approach provides a fundamental understanding of the main contributors to stormwater pollutant load generated from urban catchments. This level of understanding can not be gained by the more generic and lumped approach of using land use to define the hydrological and pollutant generation impacts of urban catchments. The surface based approach is also GIS compatible as briefly discussed in this paper.

Keywords: Urban runoff, impervious surfaces, suspended solids, stormwater management, non-point source pollution

Introduction

Suspended solids and other pollutants washed from urban catchments during storms can impact on the water quality of downstream aquatic ecosystems. In order to manage these impacts, predicting the mass loading or concentration of suspended solids in urban runoff is often required. Total Suspended Solids (TSS) concentration is conventionally used to quantify the solid particle phase in stormwater and is a common parameter used to set compliance requirements for environmental discharges.

The generation of TSS loads from urban areas is often computed based on the spatial composition of various land uses found within the catchment. The application of land use to estimate pollutant loads is common practice as this data directly relates to a management question that is frequently posed: "What is the expected change in stormwater quality if land use within a catchment is modified?" At a broad catchment scale, using various lands uses such as residential, commercial, rural and forest to define stormwater pollutant generation is a simple and convenient approach.

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A range of GIS-based models are available that have a land use base. A common approach is to simply use GIS to map the spatial distribution of pollutant loads that are directly estimated from land use. Runoff coefficients and Event Mean Concentrations (EMCs) of key pollutants are typically assigned to each category of land use in order to compute the pollutant loads. This approach has a decision support role in catchment management by quantifying the total magnitude and the dominant contributors of diffuse pollutant generation. Recent examples include GIS assessments of the Santa Monica Bay watershed by Park and Stenstrom (2006) and the Las Vegas Valley by Reginato and Piechota (2004).

GIS mapping of pollutant loads derived from land use data is appropriate for regional planning and screening of stormwater management issues, such as pollution hazard identification (Mitchell, 2005). At a local urban scale (up to order 1000ha), recognition is emerging that surface type may be a better measure than land use in the determination of stormwater loads. This recognition is founded on the basis that surfaces including roads, roofs, carparks, driveways, grassed and landscaped areas physically make up the spatial mosaic of urban development, not planning classifications of land use. The Australian Runoff Quality guidelines (Engineers Australia, 2005) outlines the limitations of using land use and offers a method to estimate stormwater loads from ungauged urban catchments using surface composition data (from Phillips and Thompson, 2002). Other models that predict pollutant loads generated from urban surfaces in response to rainfall include SLAMM (Pitt and Voorhees, 2000) and SEWSYS (Ahlman et al., 2005).

There is also an emerging trend of applying management practices distributed throughout a catchment in preference to a smaller number of large ‘end-of-pipe’ systems such as constructed wetlands and detention basins. These distributed practices can be applied at a lot scale (0.1 to 1ha) and are referred to as Low Impact Development (LID), Sustainable Urban Drainage Systems (SUDS) or Water Sensitive Urban Design (WSUD). It is considered that stormwater loads based on specific land surfaces, rather than generically defined land use, would be required to effectively assess the performance of these generally small-scale measures.

This paper will outline three case studies that demonstrate the use of urban surface modeling in evaluating a broad range of stormwater management issues. The purpose of the case studies is to highlight the increased understanding of catchment pollutant generation able to be gained from a surface-based approach, compared to the more commonly applied land use approach.

The examples that are provided apply a mass balance spreadsheet model developed by Brodie (2007). The case studies analyzed are 1) a comparative analysis of the suspended particle loads generated from residential and commercial land uses, 2) an assessment of the effect of exposed areas of bare soil in the suspended particle loads from a residential catchment and 3) an evaluation of the effect that widespread adoption of rainwater tanks may have on the suspended particle concentration of residential urban runoff.

The measure of suspended solids in stormwater preferred in this paper is Non-Coarse Particles (NCP), defined as particles smaller than 500µm in size. NCP is considered to be a better measure than TSS of the readily suspended particle mass in urban stormwater (Brodie 2005) and is based on the Suspended Sediment Concentration (SSC) laboratory method of analysis (ASTM, 2002). The SSC method was endorsed by the US Geological Survey in response to concerns about the TSS method being inaccurate for analyzing water samples containing coarse sediment particles (Gray et al., 2000). The bulk of previous urban runoff studies have utilized TSS data and available data for the alternative SSC (or derivatives such as NCP) is very limited. The lack of measured SSC data means that the case studies in this paper are hypothetical examples for demonstration purposes only.

Methodology

Mass Balance Model

A spreadsheet model was developed to predict the NCP load for a range of urban surfaces in response to a sequence of storms. A mass balance model by Brodie (2007) was incorporated into the spreadsheet to simulate NCP loads generated from impervious surfaces. Development and validation of this part of the model was conducted using monitoring data collected from a galvanized iron roof, a concrete carpark and a bitumen road located in Toowoomba, Australia. Surface particles are separated into highly mobile 'free' particles and less mobile 'detained' particles, depending on the rain power required to initiate wash off. The hydraulic capacity of the drainage system associated with each surface (e.g. roof gutter, road curb) to transport particles is also allowed for by the model.

NCP loads from pervious areas were estimated based on simple regressions provided as Equations 1 and 2, for bare soil and grassed surfaces respectively. These relationships were fitted against loads measured as part of the stormwater monitoring at Toowoomba.

$$L_{BARE} = 1500R \quad \text{if } R\text{<4mm} \qquad \textbf{Equation 1}$$
$$L_{BARE} = 6000 + 435(R-4) \quad \text{if } R\text{>4mm}$$

where L_{BARE} is the NCP load from the bare soil surface (mg/m^2) and R is the runoff depth (mm)

$$L_{GRASS} = 40R \qquad \textbf{Equation 2}$$

where L_{GRASS} is the NCP load from the grassed surface (mg/m^2)

The runoff generated from impervious surfaces is computed based on Equation 3. An adjustment factor F_{IC} was introduced to account for impervious areas that are not connected to the formal stormwater drainage system. This may apply in the case of some types of residential housing that have roof downpipes unconnected to the street drainage. The runoff equation for pervious surfaces is provided as Equation 4. Equations 3 and 4 are also based on the Toowoomba stormwater monitoring results.

$$R = F_{IC} \times (P-1) \quad \text{for impervious surfaces} \qquad \textbf{Equation 3}$$
$$R = Max(0, aP-b) \quad \text{for pervious surfaces} \qquad \textbf{Equation 4}$$

where R is the runoff depth (mm), P is the rainfall depth (mm) and F_{IC} is an adjustment factor to allow for indirectly connected impervious areas (range 0-1), a and b are runoff coefficients for pervious surfaces (a=0.83, b=17 for bare soil, a=0.62, b=12.3 for grassed areas).

The spreadsheet was structured to calculate the NCP load (mg/m^2), the NCP event mean concentration EMC (mg/L) and runoff depth (mm) for five different urban surfaces (roof, road, carpark/driveway, grassed and bare soil) in response to a storm sequence. A series of 36 storms recorded as part of the Toowoomba stormwater monitoring (Brodie and Porter, 2006) was used in the analysis. These storms, with a cumulative rainfall of 659mm, occurred over a 13 month period from December 2004 to January 2005. Individual storm rainfalls ranged from 2.5mm to 64.25mm in depth.

Results and Discussion

Case Study 1: A Comparative Analysis of NCP Loads Generated From Residential and Commercial Land Uses

The first case study demonstrates the use of urban surface data to compare the NCP loads generated from two different land uses. Databases of stormwater TSS data from urban areas have been compiled, most notably in the USA. The US Nationwide Urban Runoff Program (NURP) was conducted by the EPA from 1978 to 1982 and obtained data for 2300 storms from 81 catchments (Althayde et al., 1983). Most of the data relates to residential areas, but incorporated other land use categories. More recently, the US EPA are compiling stormwater measurements obtained as a requirement of the National Discharge Elimination System (NPDES). As at the end of 2003, data from 3770 separate storm events from 66 authorities have been entered into the National Stormwater Quality Database (NSQD) according mainly to the land use of each catchment (Pitt et al., 2004).

Duncan (1999) undertook a statistical overview of stormwater data obtained from over 500 Australian and overseas investigations. TSS concentration data was grouped based primarily on land use, although roof and various road categories were considered separately. A comprehensive stormwater monitoring program of various land uses was also completed by Brisbane City Council (BCC 2004). A summary of TSS concentration statistics for ‘residential’, ‘commercial’ and ‘industrial’ land use categories from the NURP, NSQD, Duncan (1999) and Brisbane studies is provided in Table 1.

Table 1: TSS concentration statistics for Residential, Commercial and Industrial land uses from various stormwater monitoring studies

Study/Statistic	**Residential**	**Commercial**	**Industrial**
Brisbane City Council monitoring 2002/2003 of representative catchments (BCC 2004)			
Number of samples, *n*	209	120	71
Mean (log transformed)	151	144	83
% Effective impervious	37-38	61-71	72-91
Review of word-wide data (Duncan 1999)			
Number of samples, *n*	109	25	12
Mean (log transformed)	141	133	150
NSQD and NURP (Pitt et al., 2004)			
Number of samples, *n*	1075	503	524
NSQD Median (untransformed)	48	43	77
NURP Median (untransformed)	101	69	-
Median %Impervious	37	83	75

The Event Mean Concentration (EMC) statistics from Duncan (1999) suggest that mean EMCs are similar across all land use types. This outcome is partly supported by the stormwater monitoring by Brisbane City Council (BCC 2004) which presented similar TSS EMCs for residential and commercial land uses, but a lower mean EMC for the industrial land use. This was also the case for the NSQD medians, except contrary to the Brisbane data; the industrial median is higher relative to the other land uses.

The magnitudes of the Brisbane TSS EMCs are consistent with the overseas statistics reported by Duncan (1999), but appear significantly higher than the US values. In broad terms, the statistical analysis of the US and overseas data suggests that the TSS concentrations, on average, for stormwater runoff from residential and commercial areas are similar in magnitude. This EMC similarity is present even though the impervious cover in commercial areas (typically of the order of 80%) is substantially greater than residential areas (typically of the order of 40%). TSS concentrations from industrial areas may differ in response to the type, intensity and controls placed on the industrial activities that occur within these catchments.

The consistency in mean or median TSS concentrations of runoff from residential and commercial areas can be demonstrated by use of the surface-specific load data. NCP loads, on a per hectare basis, from both land use types were determined for the Toowoomba sequence of 36 storms from December 2004 to January 2006. The relative proportions of roof, grass, carpark (represented mainly by off street vehicle driveways and parking areas) and road surfaces were selected to reflect typical conditions found in each land use. It was assumed that each land use is established with no bare soil areas.

The surface composition of both land use types are summarised in Table 2. The residential area is a hypothetical example of ‘traditional suburban’ areas within many Australian cities and includes 700m^2 lots with occupancy of 2.6 persons/household and a gross density of 10 houses/ha (Mitchell et al., 2005). The impervious surfaces within the traditional suburban land use equates to 42%, marginally higher than the average values reported in Table 1. By comparison, impervious surfaces represent 70% coverage of the hypothetical commercial area. It was assumed that the impervious surfaces are fully directly connected to the stormwater drainage system.

Table 2: Adopted surface composition (%) for hypothetical Residential and Commercial land uses

Surface	**Residential**	**Commercial**
Roof	20	30
Carpark	10	20
Road	12	20
Grass	58	30
Total impervious	**42%**	**70%**

The adopted surface compositions were modeled as hypothetical 1ha areas in the spreadsheet model and analysed for the Toowoomba storm sequence. Loads and stormwater volumes from the individual surfaces were derived for each storm and summed to provide the total land use loading. NCP EMCs were then calculated from the load and volume predictions. Results compiled for the residential and commercial areas are summarised in Table 3**.** Although direct comparisons between NCP and TSS are not applicable, the results provide information on the relative differences between the two selected land uses.

Table 3: Results of NCP load analysis for hypothetical Residential and Commercial land uses based on Toowoomba December 2004 to January storms, on a per hectare basis

Statistic	**Residential**	**Commercial**
Total runoff volume for 36 storms[1] (kL/ha)	3180	4625 (+45%[2])
% Contribution of each surface to total runoff (Roof -Carpark-Road-Grass)	39%-19%-23%-18%	41%-26%-26%-7%
Total NCP load for 36 storms (kg)	174	268 (+54%[2])
% Contribution of each surface to total NCP load (Roof -Carpark-Road-Grass)	7%-16%-63%-14%	7%-20%-68%-5%
Mean EMC (log transformed)	60	62
EMC Range	15-317	16-327

Note:

1. Total rainfall = 659mm
2. Percentage change from Residential value

The statistics indicate that the predicted mean NCP EMCs for both land uses are very similar, as was the case for the review of TSS data summarised in Table 1**.** Total runoff volume for the commercial area is 45% more than the residential area, and this is accompanied by a 55% increase in NCP load. As both runoff volumes and loads have increased in approximately the same proportion, the net change in mean EMC is minimal. This outcome is consistent with previous studies, such as McLeod et al. (2006) who made a similar postulation based on measured TSS data collected at Saskatoon, Canada.

To further elucidate the differences between the hypothetical residential and commercial areas, the total NCP load (kg) and runoff volume (kL) generated by the subsets of storms within different rainfall ranges were computed. These calculations provide a measure of the contribution that is made by rainfall events of varying magnitude within the sequence of storms. The results are plotted as Figure 1. The commercial area is predicted to generate substantially greater runoff volumes for storm rainfalls more than 6mm. This effect is not as marked in larger rainfalls greater than 40mm. This produces a significant increase in particle loads for storms within the 6 to 40mm range. A graph of the mean EMC associated with each rainfall range is also provided, which clearly shows the negligible difference between predicted residential and commercial NCP concentration across all storms.

In both residential and commercial land uses, the roof surface is a dominant source of runoff volume but makes only a minor contribution to the NCP load as shown by the pie-charts given in

Figures 2 and 3. The road surface generates approximately 60 to 70% of the overall NCP load, but occupies between 12 to 20% of the land depending on the land use.

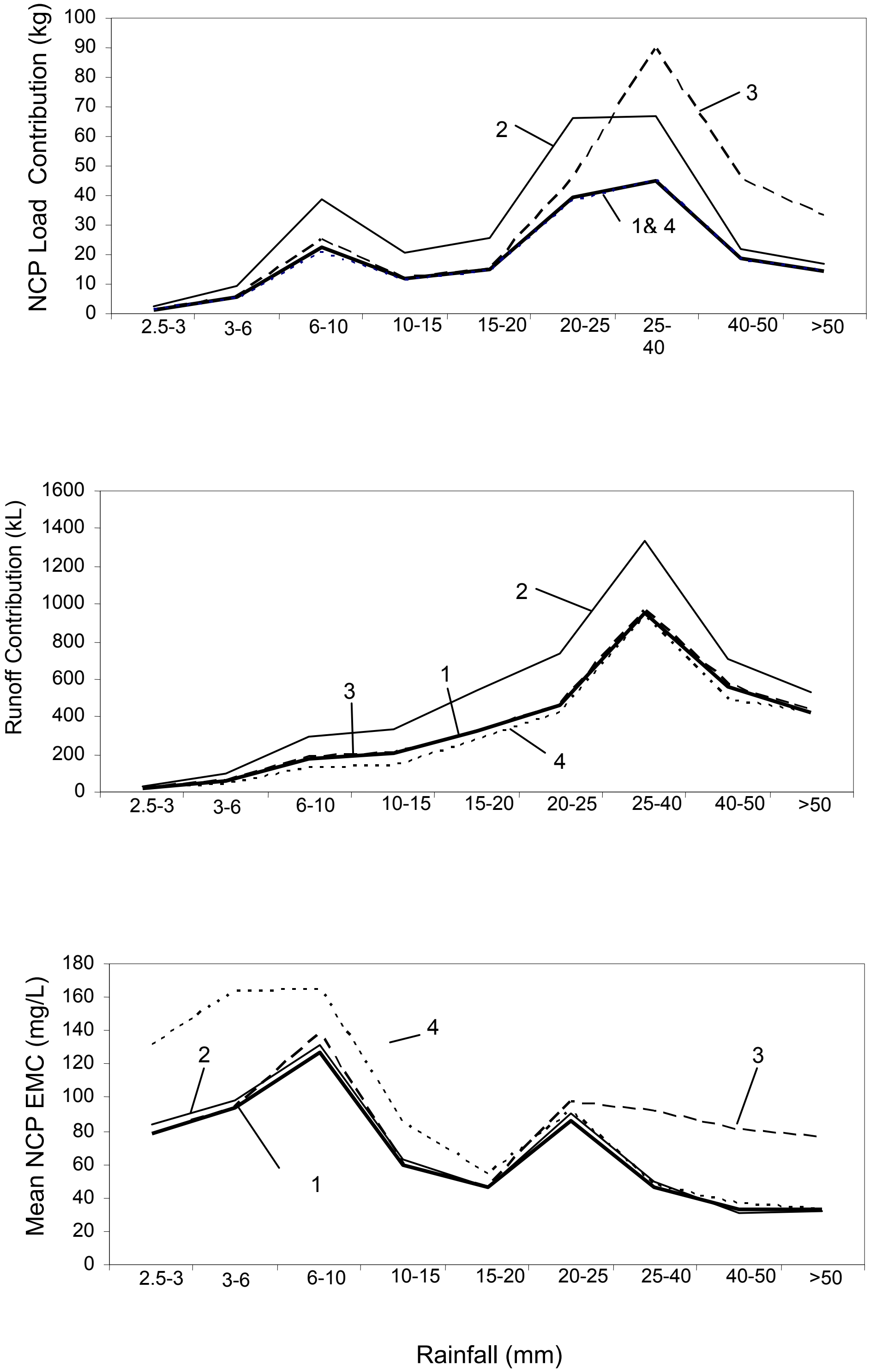


Figure 1: Plots of NCP load contribution, runoff contribution and mean NCP EMC for various rainfall ranges for hypothetical 1ha (1) Residential area; (2) Commercial area;(3) Residential area with 10% bare soil, and; (4) Residential area with rainwater tanks

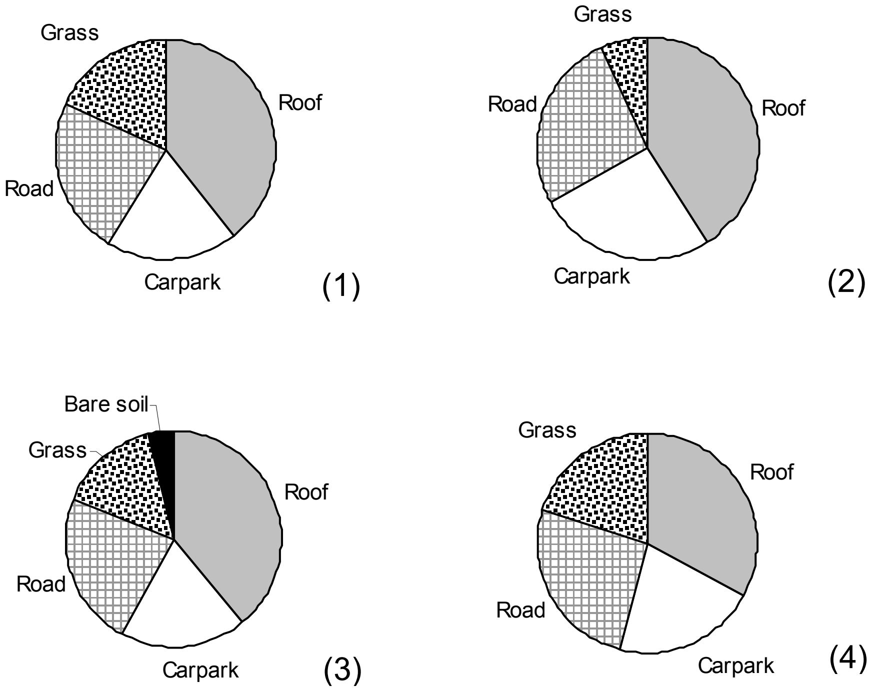
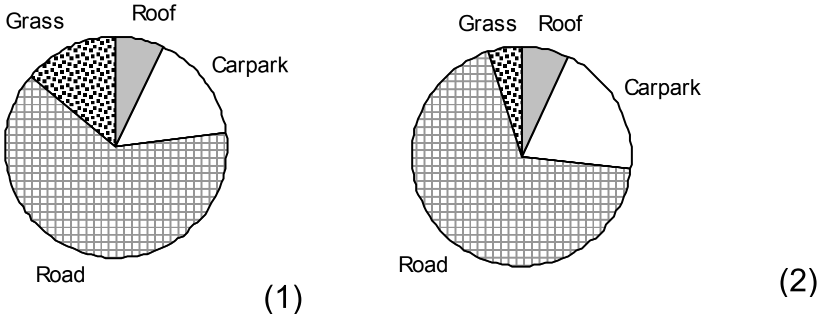


Figure 2: Pie-charts of contribution of each surface (%) to total runoff for hypothetical 1ha (1) Residential area; (2) Commercial area; (3) Residential area with 10% bare soil, and; (4) Residential area with rainwater tanks



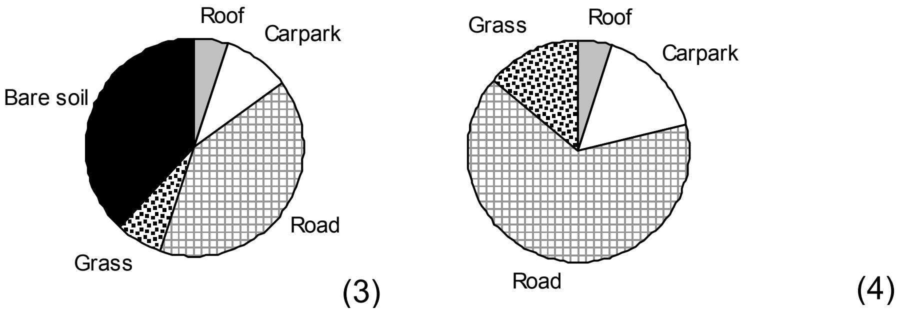


Figure 3: Pie-charts of contribution of each surface (%) to total NCP load for hypothetical 1ha (1) Residential area; (2) Commercial area; (3) Residential area with 10% bare soil, and; (4) Residential area with rainwater tanks

Case Study 2: Effect of Bare Soil Areas on NCP Loads from a Residential Catchment

The previous assessment of residential land use assumes that all pervious surfaces are grassed. This may be the case in long established and well maintained urban development, but in newly constructed or poorly maintained areas, the proportion of the surface exposed as bare soil may be significant. NCP load generated from bare soil during rainfalls exceeding 20mm is relatively high (Brodie and Porter, 2006). To check the significance of this aspect, the mass balance analysis of the typical residential area was repeated with a portion of the pervious area assumed to be bare soil. Specifically, the 58% pervious area in the residential land use was assumed to consist of 48% grassed and 10% bare soil, expressed as percentages of the total area. Results of the bare soil analysis are compiled in Table 4 and the percentage differences between the residential land use with no bare soil component are also provided.

Table 4: Results of NCP load analysis for hypothetical Residential land use with 10% bare soil based on Toowoomba December 2004 to January 2006 storms, on a per hectare basis

Statistic	**Residential + 10% Bare Soil**
Total runoff volume for 36 storms[1] (kL/ha)	3220 (+1%)[2]
% Contribution of each surface to total runoff (Roof -Carpark-Road-Grass-Bare)	39%-19%-23%-15%-4%
Total NCP load for 36 storms (kg)	273 (+57%)[2]
% Contribution of each surface to total NCP load (Roof -Carpark-Road-Grass-Bare)	5%-10%-40%-7%-38%
Mean EMC (log transformed)	75 (+25%)[2]
EMC Range	15-344

Note:

1. Total rainfall = 659mm
2. Percentage change from Residential value

As the runoff characteristics of bare and grassed surfaces are very similar, the total runoff volume has marginally increased. The runoff from bare soil areas is highly concentrated and consequently the total NCP load has increased dramatically by 57%. The increase in mean EMC is not as high but is of the order of 25%. Plots of the NCP load and runoff volume contributions for each rainfall range are provided in Figure 1, together with the variation in mean EMC with rainfall. As presented, the change in runoff due to the introduction of the bare soil is minimal, but significant increases in EMC and hence load is evident for storms greater than 20mm rainfall. As bare soil runoff is initiated only when rainfall exceeds soil infiltration capacity, the effect of bare soil in small-to-moderate storms is largely absent.

As shown in the pie-charts in Figures 2 and 3, the bare soil occupying 10% of the residential area contributed a minor proportion of the total runoff (4%) but approximately matched the NCP load contribution generated from the road surfaces (38%). This result highlights the substantial contribution that bare soil areas can make to urban suspended particle load and reinforces the need to effectively manage disturbed areas such as construction sites and poorly maintained open space with low vegetative cover. The significant potential of exposed bare soil within construction sites to generate high concentrations of suspended sediments has been demonstrated by previous investigations, including Owens et al. (2000).

Case Study 3: Effect of Rainwater Tanks on the NCP Concentration of Residential Urban Runoff

A considerable amount of research has been undertaken on the water supply benefits of installing rainwater tanks. Reductions in mains water use up to 85% can be achieved with tank sizes between 5 to 15 kL, provided that dual water supply is incorporated and the roof water is used for indoor purposes (Coombes et al., 2002a; Mitchell et al., 2005). As a specific example, the installation of two 2.2kL rainwater tanks with mains water trickle top up at a small cottage in Newcastle, Australia was found to have resulted in a 45% reduction in mains water use during a drought (Coombes et al., 2004). When full, the tanks were able to supply total household demand for about 11 days.

The capture of roof water for domestic use reduces the amount of runoff discharging from a housing allotment. An 80% reduction in the one year average recurrence interval peak stormwater discharge was predicted if 10 kL rainwater tanks were adopted in the Parramatta region of New South Wales, Australia (Coombes et al., 2002b). As a consequence, the use of rainwater tanks is a common WSUD feature. However, minimal research has been conducted on the potential quality effects of removing roof water as a component of urban runoff generated from residential catchments.

Roof runoff water has a low NCP concentration but volumetrically is a major component of urban stormwater. As demonstrated by the analysis of a hypothetical residential area in Case Study 1, roof runoff constitutes approximately 39% of the stormwater volume but only 7% of the NCP load. The extraction of roof water from the stormwater flow may result in less dilution of the more highly concentrated particle sources, especially roads, causing a net increase of NCP concentration.

To check the significance of this aspect, the mass balance analysis of the hypothetical residential area was repeated with allowance for storage and use of roof runoff. The analysis was performed on a per hectare basis and a number of assumptions were made, consistent with an assessment of roof water storage requirements for various Australian cities by Mitchell et al. (2005):

- Household use of roof water was assumed to be 1.3 kL/ha/day based on a constant demand of 50 L/person/day, an average household of 2.6 persons/household and a development density of 10 houses/ha. The household demand is based on toilet flushing and some additional component of non-potable indoor use.
- The tank storage was set at 100 kL/ha, equivalent to 10 kL/household. It was assumed that there was no mains water top up of the tanks.
- The roof water contribution to urban stormwater is the overflow from the tank storage. The tank overflow volume was computed for each storm event and the overflow NCP concentration was assumed to be equivalent to the roof runoff concentration. This is a conservative assumption as particle settling is expected to occur within the tank storage.

A simple mass balance approach was used to estimate the tank overflow volume for each storm. A calculation is made of the roof water storage volume S_O that provides a measure of the tank status at the end of the storm (i.e. whether the tank has overflowed or is partly full). Equation 5 is used in the S_O determination.

$$S_o = S_i + R_{roof}$$ **Equation 5**

where S_i is the tank storage volume at the start of the storm (kL) and R_{roof} is the roof runoff (kL) S_i is derived based on the tank storage volume at the end of the previous storm S_a, U which is the household demand (kL/ha/day) and ADP which is the antecedent dry period (hr) in accordance to Equation 6.

$$S_i = Max\left(0, S_a - U \times ADP/24\right)$$ **Equation 6**

After S_O is calculated, it is used to determine the tank storage overflow $R_{overflow}$ and S_a (to determine S_i for the next storm) based on the tank storage capacity S_C in accordance to the rules provided as Equation 7.

If $S_O > S_C$, then tank has overflowed and $R_{overflow} = S_O - S_C$ and $S_a = S_C$ **Equation 7**
If $S_O < S_C$ then tank is partly full and $R_{overflow} = 0$ and $S_a = S_O$

The tank storage and overflow algorithm was included in the mass balance spreadsheet for the hypothetical residential area and the December 2004 to January 2006 storm sequence was reanalysed. Roof surface was assumed to represent 20% (or 2000 m^2) of the 1ha residential catchment, as noted in Table 2. The simulation results are provided in Table 5. Capture and use of the roof water reduced the total stormwater volume generated by the urban land area by 10%. For the sequence of storms analysed, approximately 75% of the roof water overflowed the tank storage and the remaining 25% was available for household use.

Table 5: Results of NCP load analysis for hypothetical residential land use with rainwater tank strategy based on Toowoomba December 2004 to January 2006 storms, on a per hectare basis

Statistic	**Residential + Rainwater Tanks**
Total runoff volume for 36 storms[1] (kL/ha)	2860 (-10%)[2]
% Contribution of each surface to total runoff (Roof -Carpark-Road-Grass)	33%-21%-26%-20%
Total NCP load for 36 storms (kg)	169 (-3%)[2]
% Contribution of each surface to total NCP load (Roof -Carpark-Road-Grass)	5%-16%-65%-14%
Mean EMC (log transformed)	74 (+23%)[2]
EMC Range	23-367

Note:

1. Total rainfall = 659mm
2. Percentage change from Residential value

As the roof runoff has low NCP concentrations, the reduction in the total particle load for the residential area with rainwater tanks is minor. A 23% increase in the mean NCP EMC is predicted and as indicated in Figure 1, this outcome is due to higher runoff concentrations predicted for small to moderate storms less than 20mm. During these storms, the tank storage captures a greater proportion of the roof water and the particle load from the other surfaces is thus less diluted than otherwise would be the case for the no rainwater tank scenario. A concentration increase of particles and associated pollutants for these minor, frequent events may adversely impact some types of aquatic habitats.

The pie-charts provided in Figures 2 and 3 indicate that the percentage contributions of the roof surfaces to total runoff and NCP load have reduced, as expected, due to the operation of the rainwater tanks.

Compatibility of Surface-based Approach to GIS

Using GIS modeling for a direct comparison of the spreadsheet analysis provided in the three case studies is a future project and is not the main focus of this paper. However, GIS has long been identified as necessary to support physically based urban storm water management modeling (Meyer et al., 1993) and the same role of GIS applies to the surface-based approach in estimating stormwater pollutant loads. It was recognized in the early 1990s that the use of nonpoint source pollution severity models was severely limited, but integration with GIS was likely to overcome these problems (Engel et al., 1993) and graphically present model results in simple and intuitive ways (Wong et al., 1997). Haubner and Joeres (1996) found that GIS was increasingly used as a method of preparing, analyzing and displaying data for watershed analysis and modeling in small urban areas in addition to the more common larger watershed hydrology basin scale. Sample et al. (2001) also recognised the value of using GIS in the urban environment and neighbourhood scale, and used an optimization with a mathematical model and GIS to help in making complex decisions in a small scale urban stormwater management project.

As noted in the Introduction to this paper, GIS- based models are available that utilize land use to compute and map stormwater pollutant loads. At a regional planning level, simple estimation methods based on runoff coefficients and EMCs are in common usage. In this context, surface type has the potential to be a direct alternative to land use and this substitution has been introduced in some of the previously cited GIS studies. For example, Reginato and Piechota (2004) included 'Roads/Highways' as a distinct land use in their assessment of the Santa Monica Bay watershed. On this basis, surface type data is as compatible as land use data when used in conjunction with simple GIS techniques.

More complex methods of pollutant load estimation, such as the mass balance model described in this paper, may require a separate interface rather than imbedded within the GIS. Linking a GIS, which provides input data storage and output mapping, with a separate hydrological model is used in a number of applications. An example is BASINS (Better Assessment Science Integrating point and Non-point Sources) available from the US Environmental Protection Agency which integrates a GIS with a range of modeling tools including HSPF (Hydrologic Simulation Program – FORTRAN).

The current widespread usage of land use data in GIS assessment of stormwater management issues is predicated on the easy availability and extensive coverage of this type of spatial information. In the case of USA, the US Geological Survey maintains a nationwide land use/land cover (LULC) dataset sourced from high-altitude aerial photographs. More accurate datasets based on 30m Landsat 5 Thematic Mapper data is compiled in the National Land Cover Dataset (NLCD) (Burian et al., 2002). In comparison, techniques to identify and map the various surface types in urban areas are emerging and are necessary to provide the basic inputs to the surface based approach described in this paper. Developments in remote sensing (Herold et al., 2002 and others) in the identification and mapping of urban surface cover will greatly improve the availability of these basic inputs.

Conclusions

This paper demonstrates that describing urban catchments by their surface composition, rather by a more generic land use, is a useful approach when applied to stormwater planning. The benefit of this approach, as highlighted by the case study analyses, is a greater understanding of the main contributors to stormwater pollution. A surface based model is especially relevant in the context of Water Sensitive Urban Design (WSUD), which has a small-scale and spatially distributed focus to water management. In this context, surface type data provides a physically realistic base to determine stormwater runoff quantities and pollutant loads in local urban assessments up to order 1000ha scale.

Three hypothetical case studies have been provided to illustrate a surface type approach to quantify pollutant generation from urban catchments under different scenarios. The magnitude of the predicted effects associated with each case study are indicative, as the results are specific to the densities of urban development, the relative compositions of various urban surfaces and the adopted historical sequence of storm events.

The first case study compared the mass load and concentrations of Non-Coarse Particles (NCP) in stormwater generated from 'typical' Residential and Commercial areas. Although the amount and composition of impervious surfaces within each land use are markedly different, the Event

Mean Concentrations (EMCs) of NCP were predicted to be very similar in magnitude in both land use scenarios. It was found that the impervious surfaces in the Commercial area increased the NCP mass load, but the runoff volume also increased by approximately the same proportion. This provides an explanatory basis to the findings of previous studies (Pitt et al., 2004; McLeod et al., 2006) who found similarities in Total Suspended Solids (TSS) concentrations obtained from monitored Residential and Commercial urban catchments. The case study analysis also demonstrated that the majority (60 to 70%) of the NCP load in both land use scenarios is associated with road surfaces. This suggests that, to be effective, initiatives to reduce NCP pollution need to focus on the significant contributions made by roads within the urban landscape.

The second case study explored the effect that areas of bare soil may have on NCP loads generated from a Residential catchment. It was assumed that bare soil occupied 10% of the Residential area. Although the increase (1%) in stormwater volume is minor, a significant increase (57%) in NCP load is predicted as runoff from bare soils contains elevated NCP concentrations. The results highlight the need to provide effective stabilisation or erosion controls within disturbed areas such as construction sites and poorly maintained open space with low vegetative cover.

The third case study demonstrated that the widespread application of rainwater tanks to harvest roof water may change the overall stormwater runoff response from Residential areas. The NCP load was predicted to reduce by 3%. A significant increase (23%) in the NCP concentration of urban runoff is predicted, especially for minor, relatively frequent rainfalls less than 20mm. The hydrological effect of harvesting roof water is predicted to be an increase of NCP concentration as less stormwater is made available to dilute the contributions made by the more dominant NCP sources, primarily the road surfaces.

GIS has a key role in providing a framework to acquire, maintain and utilise the necessary spatial information required to perform a surface-based analysis of urban catchments. It is suggested that a surfaced-based GIS would have a number of possible future applications. These applications include evaluating specific urban development proposals to check if stormwater quality targets are met and assessing the pollution generation from existing urban development in order to identify critical source areas.

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