An impact assessment for urban stormwater use

Lian Lundy*, J Bryan Ellis and D Michael Revitt

Urban Pollution Research Centre, Middlesex University, Hendon, London. NW4 4BT, UK.
**Corresponding author's e-mail: l.lundy@mdx.ac.uk*

Abstract

The adoption of stormwater collection and use for a range of non-potable applications requires that the perceived risks, particularly those associated with public health, are addressed. Pollutant impacts have been assessed using *E. coli* and a scoring system on a scale of 0 to 5 to identify the magnitude of impacts and also the likelihood of exposure to stormwater during different applications. Combining these identifies that low or medium risks are generally predicted except for domestic car washing and occupational irrigation of edible raw food crops where the predicted high risk would necessitate the introduction of remedial actions.

Keywords: stormwater collection, non-potable uses, *E. coli*, risk, public health.

Introduction

Water scarcity is a growing global concern leading to the identification of water reuse as a top priority objective in many countries. For example, the EU Water Framework Directive (EU WFD, 2000) identifies water reuse as a key supplementary measure to be considered within the development of river basin management plans in order to maximise Europe's water resources (European Commission, 2012). As much as 50% - 80% of average domestic water consumption does not require water to be of a potable water quality and thus the use of collected stormwater as a substitute source comprises a potentially sustainable and economic option. In addition, stormwater use would lead to a reduction in urban flood discharge volumes, enhanced receiving water quality and ecological improvements (Hatt *et al*., 2006). The range of applications for which stormwater can be used as an alternative source of water, together with the scale at which the practice is commonly applied and an indication of key areas of concern are identified in Table 1. Many of the uses can involve either or both non-occupational and occupational exposure and the potential health risks associated with such uses need to be assessed to identify the level of risk associated with the various uses/receptors. This paper evaluates the risks associated with using stormwater to supplement the non-potable supply using an impact assessment approach.

The principal water quality concern for stormwater use in relation to the public health risk is the potential for microbial contamination (Davies *et al*., 2008). Although water quality guidelines are available for total and faecal coliforms and enterococci in a variety of contexts those quoted for *E. coli* are currently the most adaptable to the different applications for stormwater use and additionally this microbial parameter is often reported in stormwater data sets. Guideline standards, as a measure of public health risk, have been developed for different types of treated wastewaters but only Australian guidelines (NSW Department of Environment and Conservation, 2006) apply specifically to stormwater use (Table 2). Perceived differences in the guideline standards for stormwater reuse exist according to whether the stormwater use is to be restricted or unrestricted and subjected to occupational or non-occupational exposure. Differences of one or two orders of magnitude in the recommended values have been reported and therefore a balance

Table 1. Potential applications for collected stormwater, common scale of application and key limitations/concerns for water quality

Land Use	Application	Household (site) scale	Sub-catchment (neighbour-hood) scale	Catchment (district) scale	Limitations / concerns
Urban (non - irrigation)	Toilet flushing (R; NO)	√			Dual distribution and costs of dual plumbing in domestic environments; problems due to cross-connections; public health risks; lack of relevant legislation
	Firefighting (U; **O**/NO)	√	√		
	Vehicle washing (R:O/**NO**)	√	√		
	Street Cleaning (U; **O**/NO)		√		
	Dust control (U; **NO**)		√		
	Water features (U; O/NO)	√	√		
Irrigation	Lawns, flowers/shrubs (U; O/NO)	√	√		Variation in seasonal demands; adverse impacts on plants / crops; public health risks; lack of relevant legislation
	Parks, playgrounds, public open space (U; **O**/NO)		√		
	Sports grounds, golf courses etc. (R; **O**/NO)		√	√	
	Nurseries (R; **O**/NO)		√		
	Agricultural crops* (R; **O**/NO)		√	√	
	Orchards* (R; **O**/NO)		√		
	Allotments* (U; O/NO)		√		
Habitat, aesthetics and recreation	Ornamental / recreational waterbodies (U; O/NO)	√	√		Occurrence of algal growths; adverse ecological impacts; public health risks; lack of relevant legislation
	Detention/retention basins (U; N/NO)		√	√	
	Wetlands (U; O/NO)		√	√	
Water supply/ recharge	Surface reservoirs		√	√	Potential impact on and prejudice to groundwater
	Groundwater recharge	√	√	√	

Key: R=restricted/controlled access; U=unrestricted/open access; O= occupational exposure; NO=non-occupational exposure [where both occupational and non-occupational exposure are indicated, bold type indicates where a predominant exposure route exists]

* food products may or may not be processed prior to human consumption.

needs to be achieved when establishing appropriate end use water quality standards. In addition, the guideline standards need to be supported by evidence-based epidemiology in relation to the different stormwater source types and end-uses. The available *E. coli* standards (Table 2) are up to several orders of magnitude lower than the levels typically found in stormwater depending on the intended use. Measured *E. coli* median levels in urban stormwater from non-industrial catchments have been quoted in the range from 290 to 19,496 cfu/100ml with a calculated median value of 3037 cfu/100ml (Ellis and Mitchell, 2006; McCarthy et al., 2012).

There are substantial difficulties associated with quantifying the potential stormwater volumes that might be available for further use applications at both local and district scales in comparison to those associated with greywater or treated wastewater. Total discharge volumes will be dependent on the occurrence and timing of rainfall-runoff in relation to local demands as well as the ability to collect and store stormwater and to coordinate this alternative water supply with other water sources. The total amount of stormwater is also a function of contributing catchment area. GIS scenario analysis of the Greater London metropolitan region suggested that some 70% of rainfall associated with the 30 year storm event might be captured by all types of at-source sustainable drainage systems (SuDS) devices, but that this decreased to below 50% if on-site water

Table 2. *E. coli g*uideline values associated with different occupational and non-occupational stormwater uses.

Application category		Median E. coli guideline values (cfu/100ml)
Residential /Commercial activities	Toilet flushing Garden watering Car washing	≤ 1[a]
Open access urban exposure	Firefighting Dust control; street cleaning; irrigation of public open spaces / parks Ornamental water bodies	≤ 10[a]
Controlled access urban exposure	Irrigation of sports grounds and nurseries	≤ 100[a]
Agricultural irrigation (including allotments)	Raw foods Processed foods Non-food crops	≤ 1[b] ≤ 100[b] ≤ 1000[b]
Potable water supply	Surface reservoirs Aquifer recharge (via surface spreading or direct injection)	0[c] Below the limit of detection[c]

[a] NSW Department of Environment and Conservation, 2006; [b] JRC, 2016; [c] EU Drinking Water Directive

butts/tanks and raingardens were removed from the scenario (Todorovic and Breton, 2016). The ability of SuDS to capture and attenuate storm runoff from high frequency, low magnitude rainfall events is complemented by pollutant loading reductions due to sedimentation, filtration and degradation processes. However, efficient treatment requires ongoing management, monitoring and maintenance to ensure effective and safe further use practices at neighbourhood and catchment scales.

Methodology

To assist in the development of an impact assessment for stormwater use, a diagrammatic source-pathway-receptor model is presented in Figure 1. In addition to direct human interactions the main receptors are identified as plants, soil and receiving waters all of which can have indirect impacts on human health. Plants for human consumption can be contaminated by direct contact with irrigating waters as well as through uptake from soils. Surface reservoirs (through direct inflow) and aquifers (through recharge following surface spreading or direct injection) are examples of receiving waters which may be affected although in both cases there will be dilution followed by water treatment prior to achieving potable water of a standard fit for human consumption. The direct human interaction with stormwater will be influenced by whether this involves occupational or non-occupational exposure and whether the use relates to a residential/commercial activity, to an open access urban activity (unrestricted) or to a controlled access urban activity (restricted). These categories are further developed with respect to *E. coli* guideline values in Table 2.

The level of risk posed by stormwater collection and use is the product of the likelihood of exposure to occur multiplied by the magnitude of impact following exposure. The allocation of scores (in the range of 0 to 5) to each of these parameters together with an explanation of their meaning is shown in Table 3. The maximum score of 5 in both cases indicates that exposure is highly likely to occur and that the resulting exposure is highly likely to exert an impact. The lowest score of 0 suggest that exposure is not feasible and that no impact would be expected as

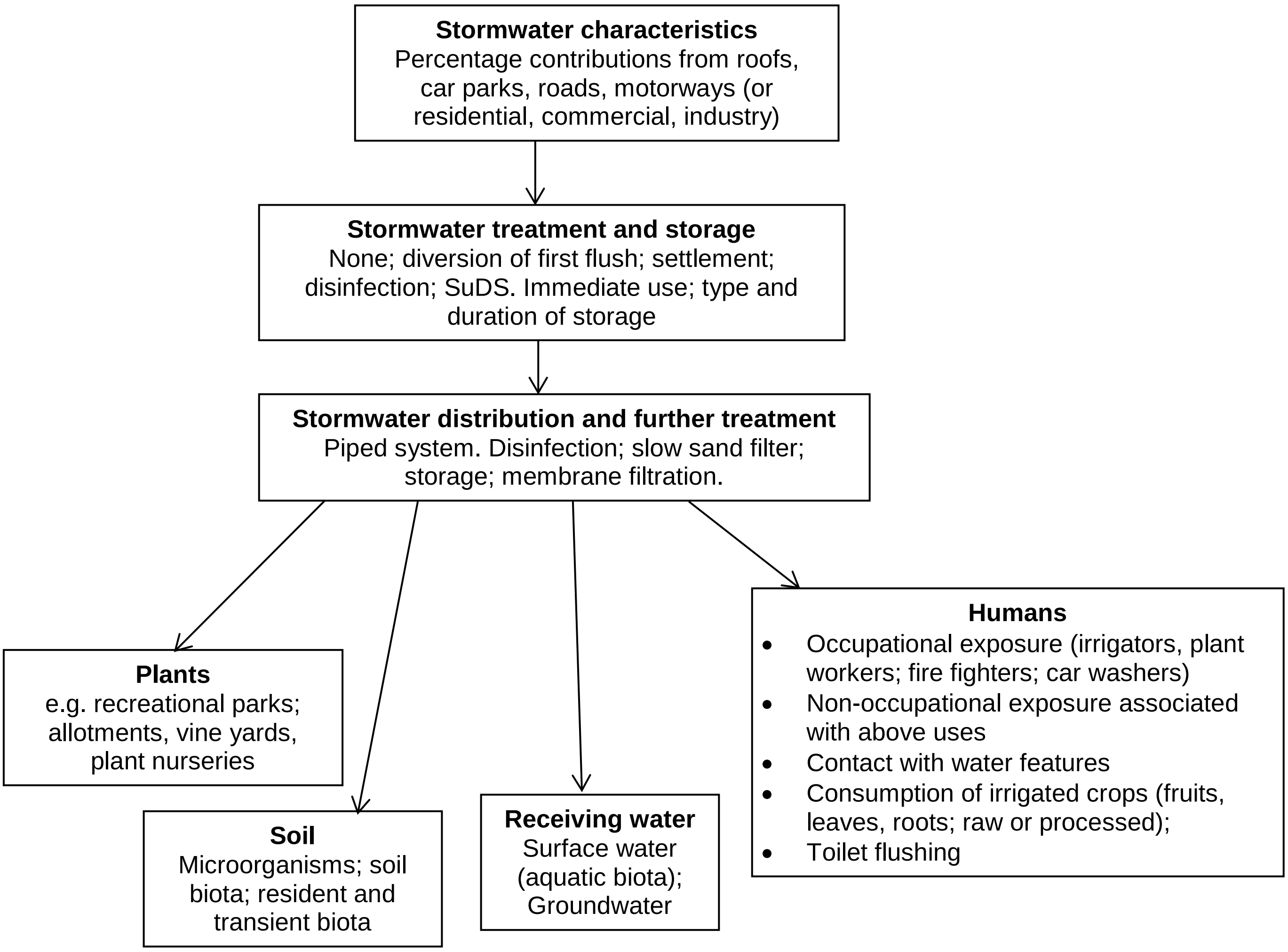

Figure 1. Source - pathway - receptor model identifying routes from stormwater collection to human health and environmental health receptors

compliance with the guideline standard exists. The likelihood of exposure is independent of the pollutant type and is influenced solely by the contact between the stormwater and the human receptor. The magnitude of impact following exposure is entirely dependent on the nature of the pollutant and in the case of *E. coli* is determined by the relative magnitude of the median stormwater level (3037 cfu/100ml) to the guideline standards for the different uses of stormwater. The greater the exceedance the higher the score as shown by logarithmic-linear relationship represented in Table 4.

Results and Discussion

The overall level of risk is the product of the likelihood of exposure to occur multiplied by magnitude of impact following exposure, where a value of 1-4 = low risk (acceptable); 5-14 = medium risk; 15-25 = high risk (unacceptable; needs to be managed). Applying this approach to the different stormwater uses identified in Table 2 produces the risk matrix shown in Table 5. The overall risk score compartments are coloured according to the derived level of risk with green indicating that only a low risk is predicted whereas red identifies situations where the level of risk is unacceptable and if the associated practices are unavoidable, actions should be instigated to reduce the overall level of risk. In contrast to the impact magnitude scores which are based on

Table 3. Example descriptors of incrementing likelihood of occurrence and magnitude of impact

Score	Likelihood of exposure to occur	Magnitude of impact following exposure
5	Highly likely to occur	Highly likely to exert an impact
4	Likely to occur	Likely to exert an impact
3	Possible (may occur sometimes)	Possible impact (may occur sometimes)
2	Unlikely (uncommon but known to be possible)	Unlikely (uncommon but impact may occur)
1	Rare (lack of evidence for exposure occurring)	Rare (little possibility of impact)
0	Exposure not feasible	No impact expected following comparison with guideline values

Table 4. Score allocation according to ratio of median stormwater E. coli level to guideline level

Ratio of median stormwater level to guideline level	Score
≥ 10000	5
≥ 1000	4
≥ 100	3
≥ 10	2
≥ 1	1
≤ 1	0

quantitative values, the likelihood of exposure scores are evaluated from a consideration of the potential for human contact to be made with used stormwater and may, to some extent, be subjective. Potential routes for the exposure of humans to stormwater during its use include inhalation, ingestion and dermal contact (Sinclair *et al.*, 2016; WHO, 2006). Thus in the residential/commercial activity category it is postulated that exposure as a consequence of toilet flushing will be limited to occasional spray inhalation with a lesser chance of skin contact and therefore exposure would be unlikely (score:2). Aerosol production will be dependent on flush energy but Quantitative Microbial Risk assessment results for viral infections have identified a risk value below the US EPA annual risk benchmark of $\leq 10^{-4}$ per-person-per-year for toilet flushing using treated stormwater (Lim *et al.*, 2015). In contrast, garden watering (occupational and non-occupational) and car washing render operatives more susceptible to spray inhalation/ingestion and skin contact (where full protective clothing is not used) leading to the possibility of exposure (score: 3). Using a chemical tracer in simulated high pressure spray car washing experiments, Sinclair *et al*. (2016) demonstrated that the predominant intake role was through ingestion/inhalation with negligible skin absorption. The increased direct dermal contact experienced by private car washers (non-occupational) would also make exposure likely to occur (score 4).

In both open access and controlled access environments the likelihood of exposure is considered to be higher in occupational situations due to the use of pressurised spray systems during firefighting, street cleaning, dust control and irrigation of parks and sports grounds etc. leading to elevated inhalation risks and the possibility of skin contact (scores: 4 or 3). The presence of fountains in ornamental water bodies can lead to spray inhalation and limited skin contact for both directly involved workers and the general public (score:3). The irrigation of food crops presents an elevated exposure at the occupational level as a consequence of both inhalation and skin contact as well as the potential for ingestion of freshly picked raw foods (score:5). The retention of water on crop surfaces during irrigation enhances the potential for contamination when freshly eaten (Hamilton *et al*., 2006). The general public will also be exposed through the

Table 5. Risk matrix developed showing scores associated with stormwater use in a range of occupational and non-occupational contexts

Application category		Score relating to magnitude of impact	Scores relating to likelihood of exposure		Risk score	
			Occupational	Non-occupational	Occupational	Non-occupational
Residential /Commercial activities	Toilet flushing	4	-	2		8
	Garden watering		3	3	12	12
	Car washing		3	4	12	16
Open access urban exposure	Firefighting	3	4	1	12	3
	Dust control; street cleaning; irrigation of public open spaces / parks		3	2	9	6
	Ornamental water bodies		3	3	9	9
Controlled access urban exposure	Irrigation of sports grounds and nurseries	2	3	1	6	2
Agricultural irrigation (including allotments)	Raw food	4	5	3	20	12
	Processed foods	2	3	1	6	2
	Non-food crops	1	3	1	3	1
Potable water supply	Surface reservoirs	4*	2	1	8	4
	Aquifer recharge (via surface spreading or direct injection)	4*	2	1	8	4

* if not treated

intake of raw foods but the delay between irrigation and eating would be expected to lead to a decrease in *E. coli* levels (score:3). In the case of processed food the likelihood of exposure to *E.coli*, both occupationally and non-occupationally, will be reduced and are hence allocated scores of 3 and 1, respectively. Exposure through water supply sources will be rare for the general public (score:1) with occupational exposure limited to possible skin contact (surface reservoirs) or spray inhalation through surface spreading during aquifer recharge (score:2).

The magnitudes of the impacts which can result from the exposure to *E. coli* in stormwater have been derived by comparing the possible levels in stormwater with the microbial guidelines which currently exist for different applications of stormwater use. Likely impacts (score:4) are predicted for residential/commercial activities (toilet flushing, garden watering, car washing), consumption of raw foods, and the ingestion of untreated waters from surface reservoirs or aquifers. However, exposure through human intake of untreated water from either of these sources is unlikely as initial dilution combined with treatment would result in a low overall risk score for the general public. This increases to a medium risk classification for occupational use due to additional exposure routes. When the high impact potential posed by car washing is combined with the likelihood of exposure which exists with the hand washing activity practised by many car owners, an overall high risk is predicted for this non-occupational activity. Therefore as a precaution it would be advisable to recommend that untreated stormwater should not be used for this purpose.

Agricultural irrigation can result in exposure for all workers directly involved in these procedures. However, the potential impact arising from exposure to stormwater containing *E. coli* at identified levels is only elevated in the situation where the workers are directly ingesting raw foods which have the possibility of being contaminated. The resulting high overall occupational risk factor (score:20) would be ameliorated if the practice of directly eating the crops was avoided and reduced considerably if washing and preferably some form of processing were practised. It is clear from the overall risk scores presented in Table 5 that occupational risks are generally higher with a typically medium risk being identified. In comparison, the same stormwater use applications in a non-occupational context are predominantly associated with low risk when exposed to stormwater containing *E. coli* at identified levels.

The impact scores resulting from the risk matrix methodology are based solely on the consequences of potential public health exposure and do not consider wider ecological or technological consequences dependent on receiving water ecology, mitigation measures or on other secondary/tertiary consequences such as commercial, policy, community interests. However, the primary health impacts are clearly of the highest priority in any decision-making water reuse schemes. It is possible that the quasi-quantitative risk characterisation presented here incorporates conservative safety margins which are commonly associated with scoring allocations of risk magnitude (Dominguez-Chicas and Scrimshaw, 2010). Nevertheless, the utility and flexibility of the risk characterisation and impact methodology serves to support the consideration of appropriate action levels and appropriate source treatment options.

Conclusion

Given the frequently highlighted public health concerns associated with the collection and use of stormwater, this paper has established an impact assessment methodology in which stormwater data sets are compared to available *E. coli* standards/guidelines for different stormwater uses allowing a scoring system for different levels of impact to be developed on a scientific basis. However, by necessity, the scores allocated to increasing likelihood of exposure have a subjective basis, and there is a need for a robust epidemiological understanding of stormwater use to enable these scores to be evidence-based. This would enable a more confident prediction of the use of collected stormwater as an alternative water resource in a range of non-potable applications and would ultimately support future uptake and intensification of the practice.

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