ROLE OF STREET SWEEPING IN REDUCING ROAD RUNOFF POLLUTION

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1 Introduction

Runoff from urban surfaces such as roads contributes sediment and heavy metal pollution into our waterways, causing both immediate and long-term adverse impacts on aquatic ecosystems. Street sweeping is a key tool that can be used to minimise the amount of pollutants that can reach the waterways from road runoff.

A multi-phase project was undertaken by Christchurch City Council (Council) and University of Canterbury to guide the optimisation of Council's street sweeping practices, as part of meeting their Comprehensive Stormwater Network Discharge Consent (CSNDC) conditions. The CSNDC schedule 4 includes requirements for a cost-benefit analysis of options for carrying out a targeted trial for contaminant reduction from the increased level of selective street sweeping, and if shown to be warranted, field trials are to then be undertaken.

2 Phase One: Cost-benefit analysis of street sweeping

A number of cleaning regime options were identified to evaluate the cost-benefit of contaminant removal, including:

a) street sweeping within the catchments draining to a StormFilter™ treatment unit, with a view to extending the time between filter cartridge changes,
b) comparing the unit cost of zinc removal via street sweeping or a rain garden,
c) evaluation of removal rates and the composition of swept material (TSS and metals), and
d) evaluation of improved street sweeping equipment for greater effectiveness.

Of the above cleaning regime options, a cost-benefit comparison was established between:

i. StormFilter™ versus street sweeping:
A council owned StormFilter™ was chosen for comparison of sediment removal costs from a StormFilter™ unit versus removing sediment from the road edge via street sweeping. StormFilters™ treat runoff several catchments (total of 273 hectares) with an estimated sediment accumulation of 30 tonnes in six months. Similarly, the cost of sediment removal by street sweeping was estimated based on the assumptions made by Depree (2008): three weekly sweeping cycle, similar sediment accumulation for Christchurch as was reported for Auckland, 3.8 to 5.5 kg/kerb-km/day accumulation on the target roads, <100% of the kerb length can be swept due to parked cars, 90-95% sweeper effectiveness, and estimated total road length of 10 km.

ii. Sweeping versus Rain Garden
Sweeping and rain gardens both remove sediment, heavy metals and other contaminants from stormwater flows. The cost benefit analysis has been carried out by considering the cost to remove two important contaminants from the stormwater runoff, sediment and zinc.

The desktop analysis indicated that it would be worthwhile carrying out trials into the benefits of street sweeping for a number of reasons, including street sweeping's potential as a pretreatment for a StormFilter™ or raingarden, and that street sweeping may capture sediment at significantly less cost and zinc at a comparable cost than a rain garden depending on the volume collected.

3 Phase Two: Literature review to identify key factors that influence street sweeping performance

3.1 Overview of factors

Previous studies have identified a range of factors that influence road runoff quality following street sweeping. These factors can be broadly categorised into: surface factors, pollutant characteristics, climate characteristics (how it rains) and technology factors (street sweeper type and operation) (Figure 1).

Some of the factors affect the build-up and physico-chemical characteristics of the pollutants, and therefore how they can be captured by street sweepers (Amato et al., 2010; Calabrò, 2010; Hixon & Dymond, 2018; Kang et al., 2009; Kim et al., 2014; Pitt, 1979; Selbig & Bannerman, 2007; Sutherland & Jelen, 1997; Walker et al., 1999). Other factors influence the wash off of the remaining (post-sweeping) particles and therefore the resultant post-sweeping runoff (Egodawatta et al., 2007).

3.2 Factors influencing the ability of street sweeping to remove particles from the road surface

The length of antecedent dry period has been demonstrated to drive the rate of pollutant build up on a surface in dry weather (Wicke et al., 2012), with maximum build up reached typically reached after 6-7 days on road and carpark surfaces (Egodawatta & Goonetilleke, 2006; Sartor et al., 1974; Wicke et al., 2012). Therefore, any field trials should aim to be undertaken with an antecedent dry period of ≥4 days to ensure a reasonable accumulation of sediment on the road.

Traffic intensity influences both the amount (load) and nature of the pollutants on a road surface. Therefore, it is important to assess a range of road surfaces to capture variation in sweeping performance associated with the variability of pollutant loading and particle size distribution.

3.3 Factors influencing runoff quality post-sweeping

Sweeper type and speed of operation were found to be the key factors influencing sweeping efficiency. The number of passes has not been found to improve efficiency.

Particle size analysis of road sediment in literature (from both unswept and swept roads) shows a wide range of distribution across particle size fractions, reflecting the diversity of sediment build up and wash off conditions. Direct comparisons within individual studies of unswept and swept PSDs consistently show finer PSDs for runoff from swept roads, indicative of how coarser particles have likely been captured by the street sweeper and removed from the road surface.

Factors that influence particle size distribution include street sweeping technology and rainfall intensity (the ability to mobilise the particles), as coarser particles require more energy (intensity) to be washed off the road surface. Sweeper types differ in efficiency for the various size fractions. Vacuum-assisted and regenerative-air sweepers are better at removing fine particles (<100 um), while mechanical sweepers are more effective for larger particles (>100-125 um) (Amato et al., 2010; Calabrò, 2010). Overall, vacuum-assisted broom and regenerative air sweepers can be expected to be more effective than mechanical broom sweepers (Wang et al., 2020), due to the expected particle size distribution of road-deposited solids (RDS) (Charters et al., 2015).

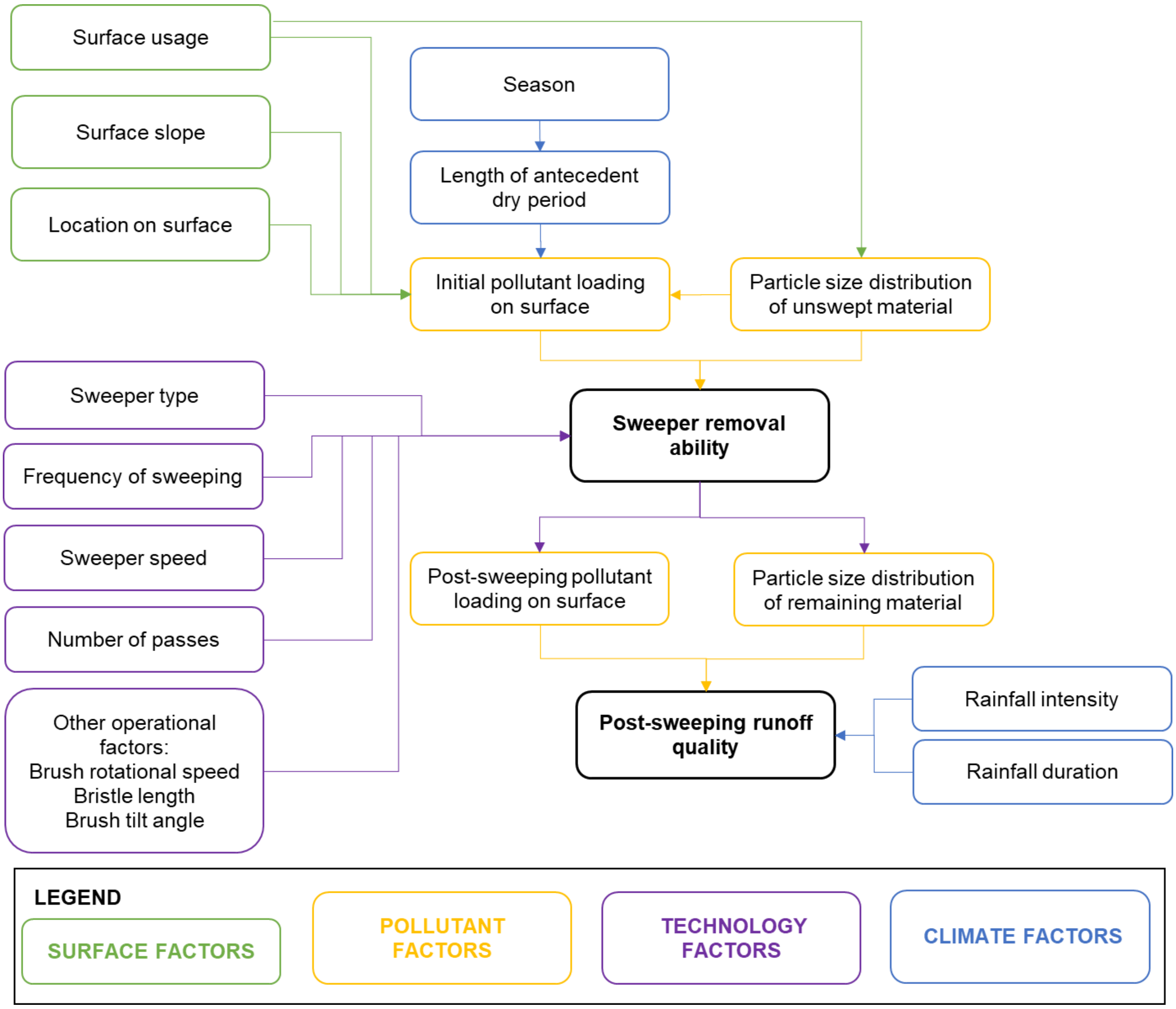

Figure 1: Factors that influence street sweeping performance and their inter-connections

4 Phase Three: Field trials of pre- and post-sweeping runoff quality

4.1 Methodology

Five sites were selected to develop a road runoff quality dataset representative of a range of traffic intensities and catchments: a low trafficked residential road, a moderately trafficked commercial road, a moderately trafficked residential road, a moderately trafficked industrial area, and a highly trafficked central city road. The sites also represent locations that are in close proximity to CCC's monthly surface water quality monitoring programme sites, wet weather monitoring programme sites or other water quality-related projects.

A rainfall simulator was used for all field trials. This enables better control of applied rainfall intensities (all trials could be run under selected intensities to enable comparisons between sites for the same intensity conditions), as well as enabling dry weather field work, instead of having to anticipate natural rain events.

For each site, seven trials were run, where rainfall was applied to the road surface and runoff collected from a 1 m^2 sampling plot set under the simulator. The trial conditions were: unswept conditions at 11 mm/hr (Trial 1), post-vacuum-swept conditions at 11, 22 and 33 mm/hr (Trials 2-4 respectively) and post-regenerative-swept conditions at 11, 22 and 33 mm/hr (Trials 5-7 respectively). All trials were run with ≥4 days antecedent dry period (as per Section 3.2).

Samples were collected over a 20-minute period from the plots, and analysed for totals suspended solids, total and dissolved zinc and copper and particle size distribution.

4.2 Results

Results to date show a noticeable first flush effect in the runoff quality for both sediment and heavy metals, with elevated pollutant concentrations at the start of runoff compared to later in the trial period. TSS concentrations ranged between 50-410 mg/L, TZn between 220-780 ug/L and total copper between 140-210 ug/L. Copper ranged between 57-87% dissolved for the unswept plot, but only 15-59% for the swept plot. Zinc ranged from 89-100% dissolved for the unswept plot, and 30-83% dissolved for the swept plots. PSD analysis confirms that the majority of available fine particles on the surface are washed off in the early stages as they are readily mobilised. The higher intensity trials also showed that coarser particles were being washed off earlier in the trial period, due to the increased ability of the rainfall to entrain and wash off of the larger particles. The unswept plot had a coarser PSD, considered to be due to the street sweeper preferentially removing the coarse particles.

5 Conclusions

Key findings include:

- Literature confirms the potential of street sweeping as an economical pre-treatment for both Stormfilter™ or raingardens (as representative down-catchment treatment systems)
- The key influencing factors for street sweeping efficiency include traffic intensity (available contaminants), sweeper type, sweeper speed and rainfall intensity.
- A strong first flush effect is observed for unswept and swept conditions, at all sites and applied rainfall intensities, for sediment and heavy metals.
- Sweeping is shown to be effective at removing coarse particles. However, TSS and metal concentrations still remain high in post-swept runoff.

The study assists Council to quantify pollutant removal per frequency of sweeping, and the relative influence of sweeping type and local climate conditions, and informs effective decision-making on sweeping frequency for maximum removal of contaminants. The long-term benefit of this research is to yield overall improvements in Christchurch's stormwater quality.

References

Amato, F., Querol, X., Johansson, C., Nagl, C., & Alastuey, A. (2010). A review on the effectiveness of street sweeping, washing and dust suppressants as urban PM control methods. *Science of The Total Environment, 408*(16), 3070-3084.

Calabrò, P. (2010). Impact of mechanical street cleaning and rainfall events on the quantity and heavy metals load of street sediments. *Environmental technology, 31*(11), 1255-1262.

Charters, F. J., Cochrane, T. A., & O'Sullivan, A. D. (2015). Particle size distribution variance in untreated urban runoff and its implication on treatment selection. *Water research, 85*, 337-345.

Depree, C. (2008). *Contaminant characterisation and toxicity of road sweeping and catchpit sediments: Towards more sustainable reuse options*.

Egodawatta, P., & Goonetilleke, A. (2006). Characteristics of pollutants built-up on residential road surfaces. Proceedings of the 7th International Conference on Hydroscience and Engineering: ICHE 2006,

Egodawatta, P., Thomas, E., & Goonetilleke, A. (2007). Mathematical interpretation of pollutant wash-off from urban road surfaces using simulated rainfall. *Water research, 41*(13), 3025-3031. https://doi.org/10.1016/j.watres.2007.03.037

Hixon, L. F., & Dymond, R. L. (2018). State of the practice: Assessing water quality benefits from street sweeping. *Journal of Sustainable Water in the Built Environment, 4*(3), 04018007.

Kang, J.-H., Debats, S. R., & Stenstrom, M. K. (2009). Storm-water management using street sweeping. *Journal of Environmental Engineering, 135*(7), 479-489.

Kim, D.-G., Jeong, K., & Ko, S.-O. (2014). Removal of road deposited sediments by sweeping and its contribution to highway runoff quality in Korea. *Environmental technology, 35*(20), 2546-2555.

Pitt, R. (1979). *Demonstration of nonpoint pollution abatement through improved street cleaning practices* (Vol. 1). Environmental Protection Agency, Office of Research and Development ….

Sartor, J. D., Boyd, G. B., & Agardy, F. J. (1974). Water pollution aspects of street surface contaminants. *Journal of the Water Pollution Control Federation, 46*(3).

Selbig, W. R., & Bannerman, R. T. (2007). *Evaluation of street sweeping as a stormwater-quality-management tool in three residential basins in Madison, Wisconsin*. US Geological Survey Reston, VA, USA.

Sutherland, R. C., & Jelen, S. L. (1997). Contrary to conventional wisdom, street sweeping can be an effective BMP. In *Advances in modeling the management of stormwater impacts* (pp. 179-190). CRC Press.

Walker, T., Wong, T., & Wootton, R. (1999). *Effectiveness of street sweeping for stormwater pollution control*. CRC for Catchment Hydrology.

Wang, Q., Zhang, Q., Wang, X. C., Huang, J., & Ge, Y. (2020). Impacts of key factors on heavy metal accumulation in urban road-deposited sediments (RDS): Implications for RDS management. *Chemosphere, 261*, 127786.

Wicke, D., Cochrane, T. A., & O'Sullivan, A. (2012, Dec). Build-up dynamics of heavy metals deposited on impermeable urban surfaces. *Journal of Environmental Management, 113*, 347-354.