INTRODUCTION TO STORMWATER ISSUES

6. Stormwater treatment approaches

6.1 Sedimentation

This section considers the inherent variability of pollutant concentrations in stormwater, the various approaches used to treat or remove sediment and sediment-bound contaminants from stormwater, and issues such as the fall velocity or rate at which sediment settles.

One of the challenges cited in the management of stormwater quality is the inherent variability of pollutant concentrations in stormwater. This variability arises through factors such as:

- Catchment pollutant sources (both vehicular and other);
- Vehicle loads, traffic behaviour, congestion and road surface;
- **Storm size** and frequency;
- Point within the storm (i.e. the **first flush**[2] or higher concentration of contaminants typically occurring earlier within the **hydrograph** as contaminants are washed into the system, but before the concentration of storm flows affects **dilution**);
- Duration of dry spell between storms (intervening **dry spell** can affect first flush characteristics);
- Seasonal factors (e.g. leaf fall in autumn); and
- Mitigating factors (e.g. street sweeping, catch-pit cleaning).

Consequently, the monitoring of discrete pollutant concentrations in stormwater runoff for the purposes of assessing effects, treatment requirements, and even compliance, is fraught, if not meaningless[3], as it implies an accuracy that is not typically available given the base data and sample size[4]. **Sediment fingerprinting** (see C Davis and J Fox, 2009) is a much more useful tool when seeking to ascertain contaminant build-up or the quality of stormwater discharges over time.

Other than to acknowledge first flush (where this exists), monitoring and management practices have conventionally 'set aside' the matter of contaminant variability and instead focussed on the **event mean concentration** (EMC).

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[2] First flush effects (other than for litter and debris) may be more predominant in urban environments than elsewhere and may not always occur in conditions where rainfall is evenly distributed throughout the year. Devices targeted at first flush contaminant removal may therefore not be as effective in some regions or some New Zealand conditions as intended. This does not imply that such devices should not be used, but rather that a degree of realism is applied to their applicability and efficacy.

[3] This is not intended to extend to research that may consider this variability in some detail.

[4] Non-parametric statistical methods can be applied to such data sets, but given the often limiting factors of budget and site constraints, and quality of the underlying data set (itself more often than not constrained by research budget, study timeframes, and storm events/ sample availability) this is of limited practical benefit.

The adoption of, or focus upon, the **EMC** has a number of implications, as follow:

- There will be occasions when concentrations will exceed environmental criteria, as the EMC represents average conditions (and, depending on the sampling programme, may only represent an average within a given storm of a given size at a given time);
- Comparison of both discrete water quality data points and EMCs against environmental or discharge consent criteria, should therefore only be discussed in general terms and never used for compliance purposes; and
- By the adoption of the EMC, inherent within any associated treatment approach is that it, too, will be aimed at the removal of contaminants on average.

Carpark cesspit.

Research into urban stormwater quality shows that, in addition to floating materials (e.g. **litter**) and sediment itself, contaminants in stormwater are predominantly[5] associated with sediment or are in particulate form (refer to **Section 4.1**). Consequently, a second area of generalisation inherent in most treatment approaches is the focus on sediment-bound contaminants.

This does not mean that soluble contaminants have been ignored. The NURP report stated that early studies determined that combined sewer overflows were of significant concern and these were the focus of early remedial strategies. Early New Zealand initiatives followed a similar path. In a similar vein, later initiatives have targeted other soluble contaminants and sources such as wastes from stock trucks. However, the narrower approach does direct attention to the predominant form of contaminants and acknowledges the relatively high cost involved in stormwater quality improvement.

What the focus on sediment-bound contaminants does mean is:

- The scientific principles behind sediment removal are important;
- Particle size distribution and the relative contaminant partitioning, is therefore relevant; and
- Aside from any limitations relating to the site, device form (and therefore function) will be determined by sediment settling requirements in the first instance.

For practitioners this means that a number of interlaced strategies are likely to be required to augment treatment devices, based on the principles encapsulated within NURP. These strategies might include:

- Planning and management (e.g. to target land use, transportation networks, road usage, source control);
- Maintenance and operational strategies (e.g. street sweeping, pavement type, effluent and spill containment points);
- Emergency response (e.g. means of managing a spill of **miscible** liquid).

Given this, **SQIDs** then become focussed on long term average contaminant conditions' rather than exceptions, in an approximation of the '80/20 rule'.

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[5] A notable exception being zinc, which can also be present in high concentrations in the soluble form.

Sediment and 'Settleability'

While a range of pollutant removal processes may be involved in a SQID (e.g. adsorption, plant uptake, biodegradation), given the prevalence of sediment and sediment-bound contaminants in stormwater, priority is typically given to approaches that remove sediment first and foremost. Much work has been undertaken (e.g. Leersnyder, 1993; J Zanders, 2005; Landcare Research, 2008) to characterise sediments and, more particularly, **particle size distribution** (**PSD**) in stormwater (refer to Figure 6.1.1).

The research undertaken by Leernsyder (1993) found that approximately 50% – 80% of particles were smaller than 63 µm (0.063mm) while Zanders indicated roadside sediments were predominantly smaller than 250µm (i.e. less than 0.25mm). The Landcare work found sediments in catchpits and road sweepings to have similar characteristics (with 30% – 50% of sediments being less than 0.5mm in size), but that road dust was finer (with approximately 70% of sediments being less than 0.5mm). This generally corresponds with data for eight Auckland City sites presented in the NZTA *Stormwater Treatment Standard for State Highway Infrastructure* (2010); refer to Figure 6.1.2.

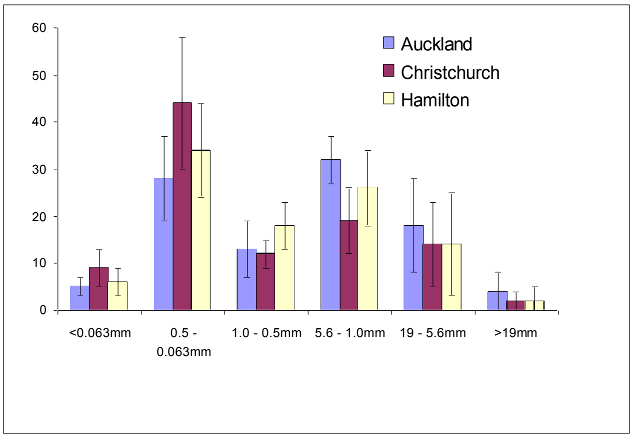
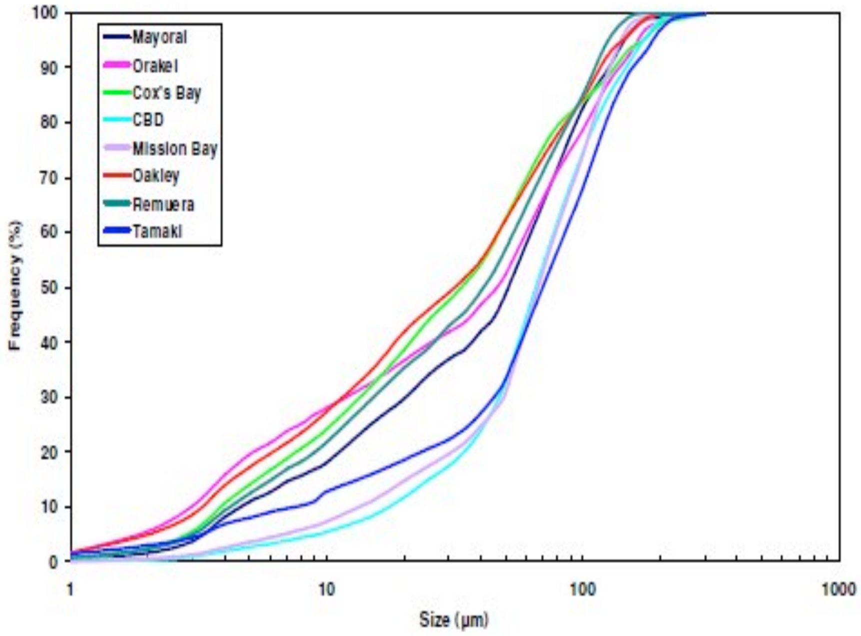


Figure 6.1.1: Sediment Size in Road Run-off
Source: Landcare Research from RCA Forum Stormwater Group Workshop Series (2008).

Figure 6.1.2: Particle Size Distribution of Suspended Solids from Auckland Sites
Source: Stormwater Treatment Standards for State Highway Infrastructure (NZTA, 2010).



This is also consistent with the summary of data presented by the Auckland Council in a recent review (refer to Figure 6.1.3), which highlighted generally consistent findings from a number of researchers. This same review provides a useful overview of one of the key areas of generalisation underpinning **SQID** design and treatment management approaches: 'settleability'.

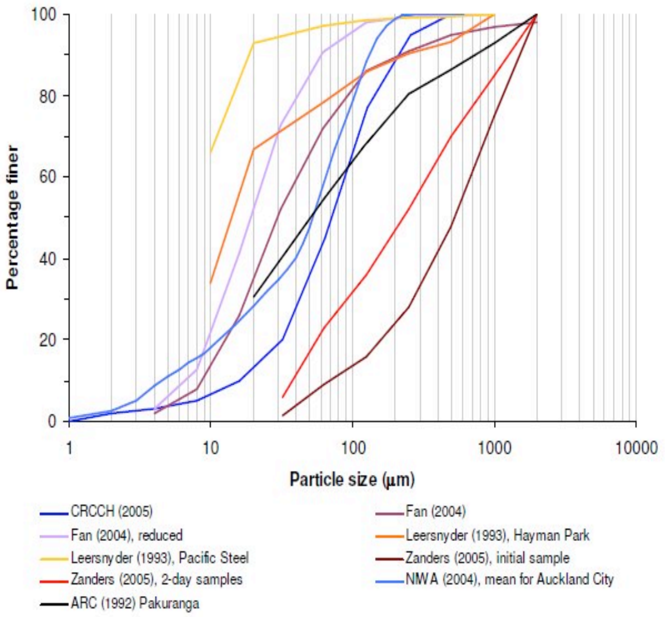


Figure 6.1.3: Particle Size Distribution in Stormwater
Source: Fall Velocities of Stormwater Sediment Particles: Literature Review (AC, 2009).

It is well understood (through application of Stokes Law and Reynolds numbers, etc), that heavier particles will tend to settle out more readily than smaller ones. Crudely, this is the basis of pond or detention based SQIDs. However, this rate of settlement is affected by a wide range of variables, such as, but not limited to:

- Particle shape and buoyancy;
- Hydraulics (e.g. water velocities, flow patterns, turbulence, wall effects[6]);
- Physical conditions (e.g. wind effects, temperature);
- Chemical effects (including sediment concentrations) and /or biological factors;
- Contributing land use and geology;
- Sampling variables (e.g. techniques and timing within the hydrograph).

Methods for establishing the rate of settlement have been subject to debate. The dynamic settling equation proposed by Fair and Gayer (1954) found favour in some quarters as a means of estimating settling times (e.g. MOE, 1994[7]), but has more recently been challenged (e.g. Krishnappan, et al., 1999; Brown, and Lawler, 2002). The more common approach now uses the method adopted by NURP (e.g. Auckland Council's TP10): the collation and comparison of data derived from settling tube tests (Leernsyder, 1993). These settling simulations are still limited, however, as they assume quiescent conditions (i.e. still conditions occurring during intervening dry spells), and do not consider the interface with dynamic settling (which might occur during the rain storm itself (Sear and Rayborn, undated). Nonetheless, settling column tests such as those used by Leersnyder have been established as standardised laboratory methods in the assessment of water and wastewater.

The matter of "fall velocity" (sediment settlement rates in SQIDs) does, however, appear to be an area of focus and rapidly progressing debate. Questions are being raised about empirical models, and the appropriateness of methods. For practitioners, however, this debate will have very little meaning or effect.

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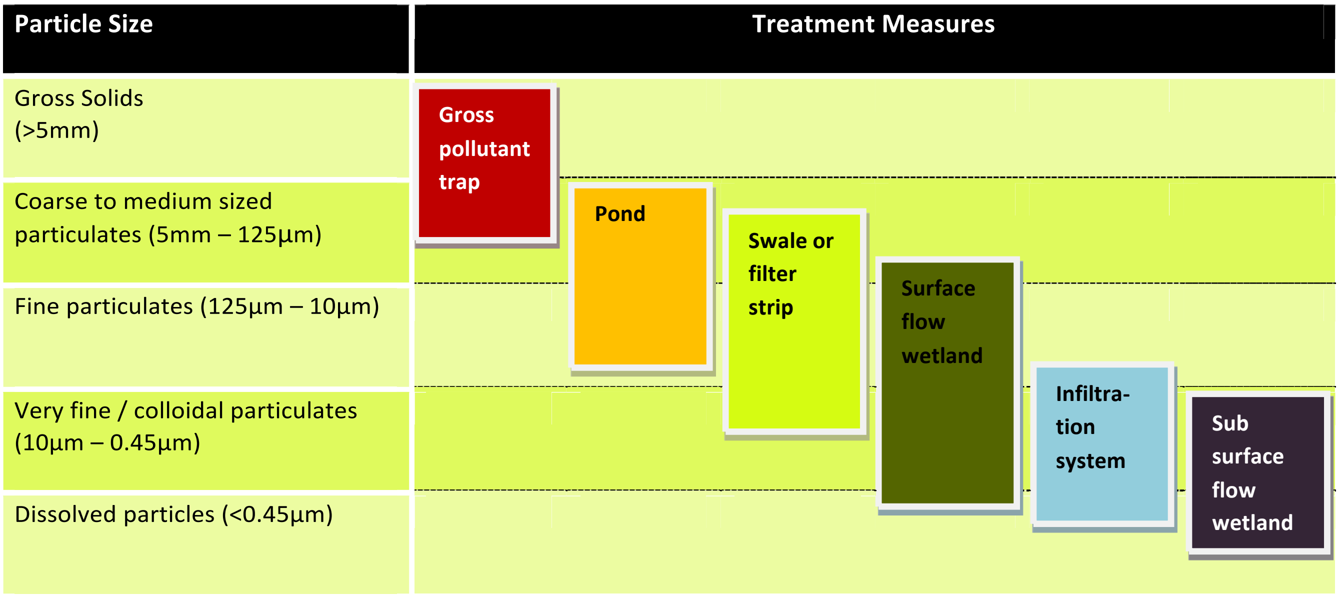
[6] More commonly affecting settlement experiments, but can be a factor in some devices.

[7] As cited by Krishnappan et al., (1999).

Changes to fall velocity may affect calculations of device detention / **residence times** and /or preferred device flow-through velocities. While there may be some change to the theoretical device efficiency, this level of accuracy will be immaterial in practice, given the number of variables; at the end of the day, pond efficiency will still be a factor of whether a given particle can settle out within the device and then stay entrained within the system.

Changes to thinking around fall velocities may underline the importance of vegetation and devices using biological processes to assist in the removal of finer sediments. A summary of device appropriateness based on sediment size is given in Figure 6.1.4.

Figure 6.1.4: Target Sediment Particle Sizes for Stormwater Quality Improvement Devices



Source: *AustRoads. Guidelines for Treatment of Stormwater Runoff from the Road Infrastructure (after Wong, 2000). 2003.*

There is one additional consideration for sediment and ‘settleability’, which relates to the adoption of the ‘treatment train’ approach. A treatment train refers to the combined use of multiple strategies and devices to improve stormwater quality. This might, for example, include applying planning mechanisms, source controls, operational strategies, **swales**, **ponds**, and **riparian** enhancement for a given discharge point. Where treatment devices are used that focus on sediment removal as the primary treatment function, there is possibly no actual benefit in establishing SQIDs in series, particularly if there is no additional contaminant load contribution to the secondary device(s).

The issue is summarised within Figure 6.1.5. Whilst Figure 6.1.5, which assumes three ponds with the same design parameters (i.e. volume, flows, attenuation) and no additional inflows, is a simplified depiction, it is aimed at demonstrating that treatment will not be significantly improved by locating devices in series unless the down-gradient device increases the settling time or changes the conditions in some other way (e.g. introduction of more extensive wetland / infiltration, etc). If a larger device is able to be constructed in the furthest down-gradient position, then the upper devices may be of little benefit other than to reduce loadings in the lower devices.

In reality, there are usually additional flows that will be intercepted by lower devices. Rather than have treated stormwater from up-gradient passing through another device where it might re-suspend or otherwise disturb treatment processes, it is usually preferable to **by-pass** flows around subsequent devices or build devices “off line” (out of the primary flow or stream, which would be considered to be an “on line” device).

This has the added benefit of reducing construction impacts and **fish passage** issues, amongst other things.

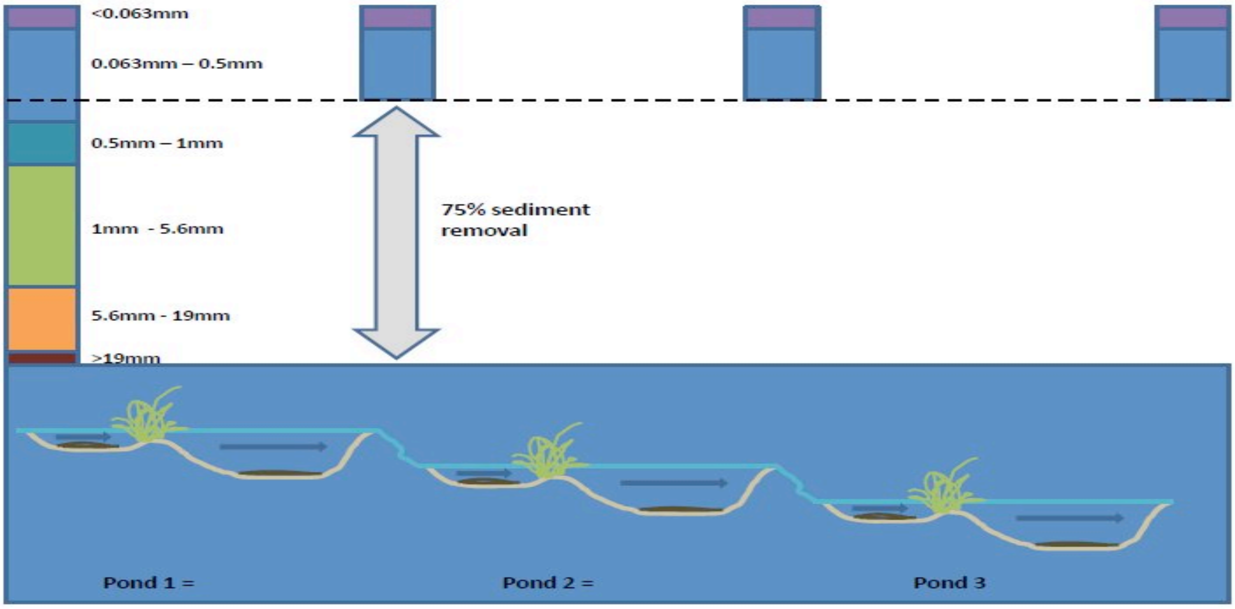


Figure 6.1.5: Efficiency of Ponds in Series

The key points with regard to sediment and 'settleability' are considered to be as follows:

- Many means of determining device size and efficiency are based on NURP and interpolated data for fall velocities;
- This does not take into account local variables such as geology or land use, nor a host of other variables that could affect **fall velocities**;
- Some verification of settling rates / fall velocities may be prudent in areas where this validation has not been undertaken;
- There may be changes to management principles in the future as thinking around the empirical methods in deriving and applying fall velocity calculations progresses; and
- Care is needed when establishing devices in series.

Pollutant Partitioning

It is generally expected that higher concentrations of contaminants would be found in association with the finer sediment particles. This is based on the simple relationship between binding properties and available surface area. Data reported by AustRoads (2003) confirms this relationship (refer to Table 6.1.1), as does research undertaken by Leernsyder and Landcare (refer to Table 6.1.2). However, larger particles may have high internal surface areas which increase the available area for chemical **adsorption**. It is the total surface area available, rather than the specific surface area, that is the important consideration in chemical distribution.

As discussed above, most sediment in stormwater is expected to be smaller than 250µm or 0.25mm. Not surprisingly, this also corresponds with the highest concentrations of heavy metals. Therefore, in order for stormwater quality improvement to be effective, the device needs to have sufficiently low throughput (i.e. low velocities, long detention times) to allow fine sediment in suspension to settle. Figure 6.1.4 provides some guidance on the SQIDs best suited to this task.

Table 6.1.1: Pollutant Association with Sediment Size

Particle Size	Percentage Pollutant Associated with Particle Size		
	Copper	Zinc	Lead
<74µm (0.074mm)	8	25	14
<105µm (0.105mm)	21	62	34
<250µm (0.25mm)	**92**	**90**	**56**
<840µm (0.84mm)	98	100	88
<2000µm (2.0mm)	100	100	95

Source: *AustRoads. Guidelines for Treatment of Stormwater Runoff from the Road Infrastructure. 2003.*

Table 6.1.2: Sediment Size in Road Runoff

Particle Size	Total Metal Concentration (mg/kg)					
	Copper		Zinc		Lead	
	Hayman Park[#]	Landcare*	Hayman Park	Landcare	Hayman Park	Landcare
0 – 63µm (clay)	-	189	1478	1889	1335	319
63 – 125µm (silt)	-	212	1653	1628	1205	334
125 – 250µm	-	184	1754	1073	1047	251
0.25 – 0.5mm	-	85	1639	507	805	193
0.5 – 1mm	-	26	1592	268	609	323
1– 2mm	-	21	1071	226	387	36
Whole sample	-	124	-	962	-	249

Source: [#]*Leernsnyder, 1993.*

**Landcare Research, 2008.*