INTRODUCTION TO STORMWATER ISSUES

5. Stormwater treatment

Fundamentals of device performance

Whilst sediment-adsorbed contaminants are not the only road related contaminants of concern, conventional treatment approaches focus on **sediment** removal and assume the removal of other contaminants bound to the sediment. The 'rules' of chemistry therefore apply to any treatment device and will affect performance.

Henley Lake filled with muddy water
Source: Masterton District Library

Sediment with a given particle size distribution and density will settle in water at a given rate when conditions are conducive to do so. The physical performance may be affected by chemical characteristics such as particle charge (important when managing clay particles that are both charged and **colloidal**), the presence of other contaminants (e.g. an oil spill that may affect matters such as water **viscosity**, friction, or coagulation), or whether the system has been otherwise 'dosed' (e.g. chemical flocculation, as often occurs on stormwater discharges from large earthworks sites, or simply from **saline intrusion**). Similarly, sediment of a certain size will be able to be entrapped and filtered using different media, such as soils of differing sizes (e.g. in **swales**, **rain gardens**, or **sand filters**). Less commonly, chemical properties of different media may be used to assist contaminant removal, such as through the use of compost or other media within **infiltration trenches** and 'sand' filters. These approaches are explored further in **Section 6.**

However, as noted above, sediment and sediment-adsorbed contaminants may not be the only factors affecting stormwater quality from a **road**. Oils, faecal matter from stock trucks, stock crossings and stock droving, spills of anything transported on the roads and other contaminants from adjacent properties can all enter run-off from roads. Many of these may be soluble or at least partially able to mix with water (**miscible)**. This includes many **hydrocarbons,** such as petrol and diesel which are partially miscible, and oils that may have **emulsified** (e.g. through bitumen application processes or by the use of high pressure hoses to wash them off the road surface - such as those often used by emergency services). Contaminants such as these may simply pass through many conventional stormwater treatment devices (including **oil separators**).

Deposited litter in a dry stormwater detention pond
Source: Fairfax County

It is therefore important to:

- Select a device that best matches likely contaminants (and their chemistry);
- Recognise the performance limitations of a treatment device (given the likely contaminants and chemistry); and
- Recognise that contaminants for which the device was not primarlity designed will either not be effectively treated or may affect the effectiveness of the device.

Storm size and device performance

The effectiveness of any given stormwater quality improvement device (**SQID)** will depend on a range of factors, such as the **contaminant** loadings, type of contaminants, type of device, and **storm size** (amongst other matters). As with a reticulated **stormwater** system that may be designed to convey a 5 or 10 year annual recurrence interval (**ARI**) event, a SQID will also have a design limit, above which flows will **by-pass** the treatment system, regardless of what that is, and a reduced level of treatment will occur.

The **design storm** or storm size that any given device will treat depends upon the design manual or specifications for the system. For systems sized in accordance with either **TP10** or **TP90**, for example, sediment settling velocities have been assessed and designed around the 5 year **ARI**. The **AustRoads standards** (*APR – 232: Guidelines for Treatment of Stormwater Runoff from the Road Infrastructure*. AustRoads, 2003), suggests that the design storm for treatment devices can even be smaller than this:

> *"The impacts of poor stormwater quality on aquatic ecosystem health are associated with cumulative frequency of aquatic ecosystem exposure to poor water quality. Pollutant loads delivered to receiving waters from many small storm events (e.g. event of magnitude less than the 3 month ARI) constitute in excess of 90% of the annual volume of stormwater discharge and thus hydrologic and hydraulic design standards for most runoff quality treatment measures need only be designed for a relatively small event ARI... (...Wong, 1997)."*

Flooding – Ngauranga Gorge
Source: Wellington City Council (1997)

Excess flows are therefore typically designed to be by-passed to prevent **scour** and/or **sediment** re-entrainment or re-suspension. Likewise very small storm flows may not be suitably attenuated within the device and a reduced level of treatment may also occur. These, and other factors such as **first flush**, length of **dry spell**, and maintenance requirements, all affect the overall efficacy of a **SQID**. This is why guidance such as TP10 refers to treatment efficiency on a long-term average basis. The measurement of discharge quality from any given storm event may have no overall relationship to the **design efficiency** and is meaningless when undertaken for the purposes of assessing compliance against a given discharge standard.

The physical and chemical 'rules', and engineering principles that establish contaminant and treatment device 'behaviour' do need to be considered in device selection, and in considering the effectiveness of that device relative to discharge criteria or performance standard. It is preferable to address these constraints up front rather than find out through monitoring that the discharges do not comply with a performance target or consent condition that was possibly unrealistic.

To sum up the basic things to remember about any stormwater quality improvement device:

- a SQID will be as efficient as it is designed to be;
- 100% contaminant removal is not practicable;
- Sediment (and therefore any adsorbed contaminants within it) settles at a certain rate given the physical and chemical conditions of the water it is in;
- Many devices are not designed to treat mixed or dissolved contaminants;
- Storm size affects device performance; and
- Device efficiency and discharge quality can fluctuate depending on a wide range of factors.

If a SQID has been selected, designed, constructed and maintained in accordance with the specifications and design approach, then the device should be able to perform optimally. If that performance is still short of receiving environment needs, then other mechanisms may need to be adopted. However before leaping immediately to additional source control or off-set mitigation, two further aspects need to be considered.

Storm size and discharge relativity

One of the points rarely considered in performance standard based consent conditions is storm size. All too often consent conditions read along the lines of *"Total suspended solids concentrations shall not exceed 100ppm"*. Technically this requires the discharges to comply with the standard in all events: the annual storm, the 100 year ARI storm, the maximum probable flood event; and irrespective of other natural occurrences or sediment loadings tolerated by the receiving system (refer also to the preceding quote from the AustRoads standards).

Lahar flows down the Whangaehu River
Source: Geological and Nuclear Sciences (1995)

Often a device is only designed to treat the 5 year **ARI**. The stormwater system that conveys flows to the device is usually designed for the 10 year ARI. The adjacent watercourse may be laden with silt as naturally occurs during larger events or for other reasons, and yet a finite discharge standard is required to be complied with. This sets up a situation whereby a device may be optimised and performing as designed, was the best practicable option, but the consent holder is deemed to be in breach of the **consent**. This can be emotive, expensive to resolve, and futile if no further options exist, and/or the receiving environment was unaffected. In the least, therefore, consent conditions should be carefully reviewed to reflect the adopted design constraints.

Debris at the Puha Bridge
Source: Gisborne District Council (2005)

The best practicable option for a treatment device

Many stormwater related studies[5] show aspects of stormwater 'behaviour' to be **asymptotic** when plotted (see Figures 5.1 and 5.2). This includes storm size and capture, as well as sediment settleability and treatment. As a consequence of this behaviour, many stormwater design guidelines use the law of diminishing returns to identify the best balance between performance and device size or retention. In Auckland, for example, 75% treatment[6] over a long-term average basis is considered the best overall balance of treatment[7].

[5] Refer to Schueler (1987), Beca Carter Hollings and Ferner Ltd (1992), Wong (1997), amongst others.

[6] This applies to long term discharges only and not those from construction sites.

[7] The assessment and justification of the adopted 75% is set out within Auckland Council Technical Publication 4 (TP4) *Selection of Stormwater Treatment Volumes for Auckland*, 1992. 75% treatment over a long term average basis is then assumed to be the Best Practical Option for device efficiency within TP10 *Design Guideline Manual: Stormwater Treatment Devices* (2003). The applicability of TP10 to areas outside the Auckland Region is discussed later in this section.

Clearly this attends to only one of the points that may be considered under the **RMA**. Factors such as land availability and the financial implications of the treatment, as well as receiving environment sensitivity (amongst other matters) may also be considered. Consequently, a specified performance standard (i.e. 75% efficiency) for a **SQID** is similar to specifying water quality criteria in that a definitive standard must be achieved without regard to other constraints of considerations. In both instances the RMA provides for a broader approach than these approaches provide at first glance.

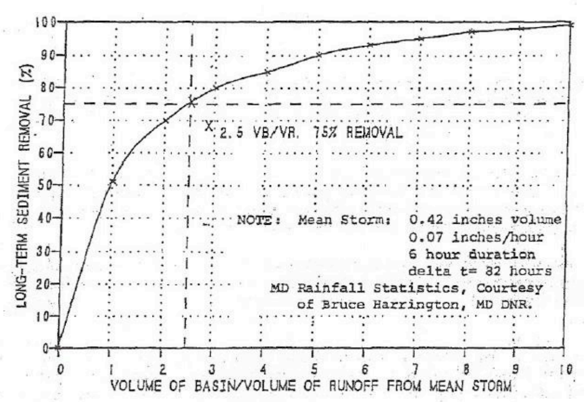

Figure 5.1: Example of Basin Sizing
Source: Auckland Regional Council TP4 (1992) from Schueler (1987).

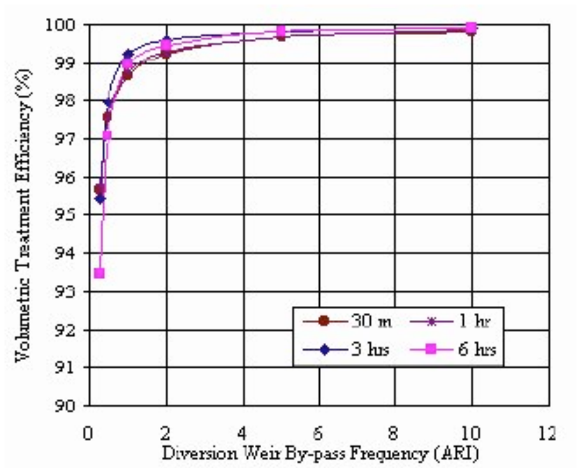

Figure 5.2: Volumetric Treatment Efficiencies versus Design Standard for Stormwater Quality Treatment Measures
Source: AustRoads standards AP – R232 (2003) from Wong (1997).

Unlike industrial processes, or potable water and wastewater treatment, stormwater quality is highly variable and static discharge criteria may not be appropriate. For an RCA, it is necessary to find the balance between receiving environment requirements, community expectations, competing funding demands, limited land availability (especially given the invariably narrow road corridors), and other relevant considerations.

Stormwater treatment device construction, Auckland
Source: NZTA

When faced with discharge standards, or performance expectations for a device, it is important to consider whether these are achievable given the fundamentals associated with chemistry, design storm, and other factors outlined above. If the fundamentals are considered collectively at the outset, an RCA may be able to demonstrate that, if a device is designed, constructed, and maintained in accordance with a specified set of criteria or design approach, monitoring the discharges may not be necessary. The device will have a given design-performance efficiency based on a long-term average; varying with storm-event size and other environmental factors. Monitoring of the discharge is therefore unlikely to produce information that will lead to a change in behaviour, a change in the device itself, or other changes that would improve the discharge[8]. As such, it can be useful to question the need or the level of comfort derived from the monitoring of discharges. Rather, a RCA may be able to redirect compliance monitoring costs to physical works, and simplify the prioritisation and delivery of its stormwater quality related projects.

[8] This is very different from state of the environment monitoring, the monitoring of a new or untried device, or a conventional device in particularly different conditions (e.g. soil type).

Rainfall Capture

Rainfall aspects associated with flood **attenuation** and the mitigation of **channelisation** (stream bank erosion) are addressed within **Section 2**. The overview that follows in this section considers the background assumptions that are commonly used to estimate the sizing of the **water quality volume** and therefore SQID size. Where water is stored for attenuation and flood mitigation purposes, there may also be some water quality benefit. As any benefit will depend on factors such as residence time, quiescent conditions within the pond, and the presence of wet storage (i.e. where sediment may be retained within the system), the combined function and design requirements should be considered conjointly if a device is required to address both quantity and quality aspects.

The overall direction taken in determining an appropriate rainfall event is underpinned by the NURP and the underlying assumptions and generalities as described above and, in particular, the adoption of the **event mean concentration** (EMC) and focus on the long-term average removal of contaminants. The NURP philosophy basically takes the logarithmic behaviour of sediment 'settleability', rainfall capture, and pond performance and identifies the asymptote or point of diminished return.

Motueka River Plume
Source: Landcare Research

A review of this approach was undertaken for the Auckland region in 1992 as part of the background development for TP10 (refer to TP4. ARC, 1992). A number of sizing rationales were considered; all of which broadly drew upon the NURP approach, thus:

- Various measures of treatment effectiveness can be used, but one of the simplest is the fraction of storm events a device may treat or capture;
- In the 1990s, Canada used daily rainfall data to determine a rainfall depth and percentage capture;
- An alternative approach is to use storm rainfall in which the rainfall record is divided into storm, rather than daily, events;
- The use of storms was identified as preferable to daily data, because "*the design of device is more closely related to how much rainfall comes from the storm ... rather than how much runoff occurs over a day*.";
- TP4 recommends:
  - That it is preferable to analyse the fraction of runoff or rain depth captured rather than the storm fraction on the basis that larger storms carry larger contaminant loads and the fraction of rain depth is a better measure of contaminant load;
  - Devices designed to capture runoff volume will tend to capture a larger fraction of the runoff volume than that indicated on a cumulative runoff diagram because the device will capture the first part of the runoff before bypassing flows;
  - The first 2mm of rainfall should not be considered as any rainfall would be captured in depression storage (i.e. no runoff is generated); and
  - A design storm depth of 25mm be used (refer to Figure 3.15) but that adjustments relating to rainfall / runoff relationships, device type, and other factors are required (and are set out within TP10 as part of SQID design guidance).

Within the 2003 revision of TP10, allowance was made for site specific variability in rainfall and instead the design storm (S_d) was derived from the 2 year ARI annual rainfall depth and expressed as:

S_d = (2 year 24 hour rainfall depth at site) / 3.

This equates to the capture of approximately 80% of the runoff volume.

A similar approach has been more recently outlined within the *Guidelines for Treatment of Stormwater Runoff from the Road Infrastructure* (AustRoads, 2003), which cites studies by Wong (1997; refer to Figure 5.3), and notes:

> *"Pollutant loads delivered to receiving waters from many of the small storm events (e.g. magnitude less than the 3 month ARI) constitute in excess of 90% of the annual volume of stormwater discharge and thus ... treatment measures need only be designed for a relatively small event ARI...There is thus a significant difference in the design standards applied to stormwater quality improvement measures compared with stormwater drainage systems, which are often designed to convey flows of much higher average recurrence intervals (e.g. 5 year or 10 year ARI)."*

The relevance and applicability of the design storm size is an aspect that does need to be assessed on a region by region basis. For most parts of the country (outside Auckland, where a storm size is specified), the use of one third the 2 year storm has been proposed as a default (NZWERF, 2004). Rainfall data are usually derived from **HIRDS** (NIWA's national rainfall database) or from local rainfall data.

However, this approach is not always practicable, given the high annual rainfall and large storm sizes in some parts of the country. These areas also tend to be some of the more remote parts of the country (West Coast, East Cape) and whilst these may be environmentally sensitive, arguably the mass loading of intractable contaminants are also relatively reduced. Sediment and nutrients may, however, still be an issue, so any expected lower load of heavy metals should not automatically be used to infer that contaminants are "not an issue" in these areas. NZTA (2009) recommends high rainfall areas, or "*those areas having a 90% storm greater than 35mm of rainfall*" adopt "*20mm of rainfall for design purposes*".

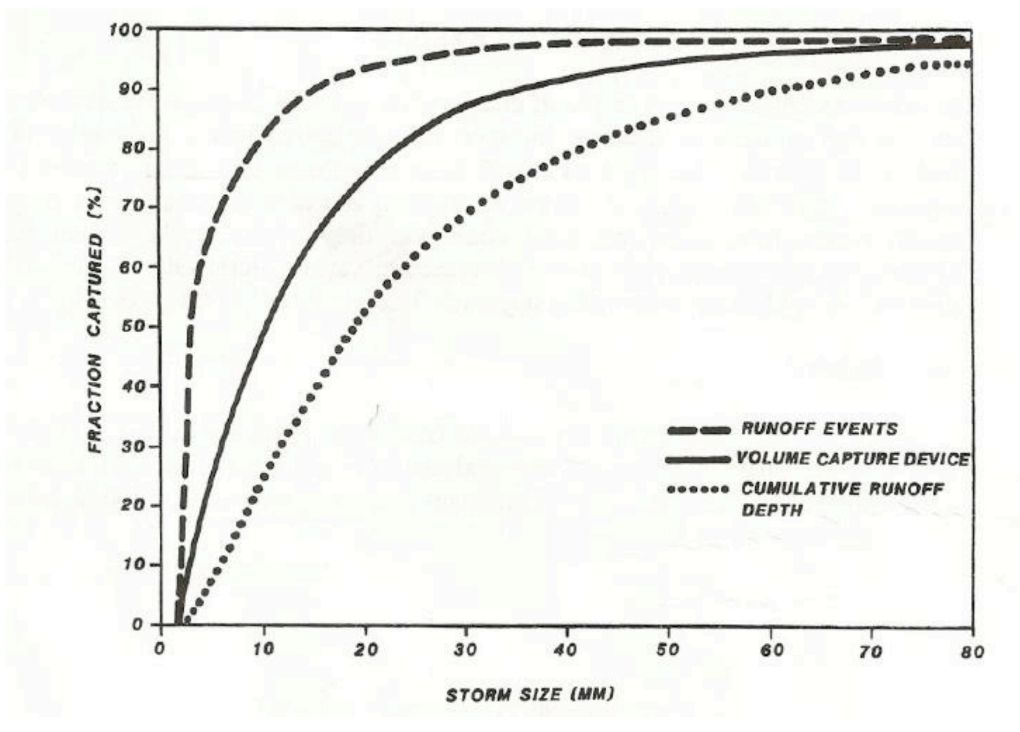

Figure 5.3: Frequency distribution of runoff events
Source: ARC, 1992a.

Feedback from RCAs operating in high rainfall zones would be useful to test this recommendation and to document lessons learned from any stormwater treatment case studies undertaken. This section could then be updated to include some more specific guidance or to share experiences for these high rainfall areas.

Since the release by the former ARC of the *Stormwater Treatment Devices Design Guideline Manual* Technical Publication N^{o}. 10 (**TP10**) in 1992, there has been debate about its applicability to other parts of the country. A variety of reasons have been cited for and against its general adoption and range from the application of the 75% treatment objective, use of the best practical option or specific performance criteria, variations in soil types, local geology and topography, differences in coastal or litoral landform, and the applicability of assumed values (e.g. design storm values).

What is clear is that TP10 follows approaches from overseas studies, particularly NURP, and seeks to tailor this to Auckland conditions. It takes on board the generalities and assumptions of the approach, as discussed in previous parts of this section and, as such, provides a 'cook book' means of working through the design requirements of a SQID.

While there may be models or other means of working through this process, TP10 does provide a simplified approach (based on international practice) that enables treatment to be implemented without the need for extensive and expensive investigations or analyses.

Stormwater pond
Source: Tasman District Council

Soon after the introduction of TP10, tests were still undertaken to check that sediment settling behaviour was consistent with the NURP data and therefore the associated assumptions in TP10. This was later dispensed with when the data showed a general alignment of soil settling across sites. Settling tests and adjustments to storm size were also used when following the calculation methods set out within TP10 for other parts of the country. Until such time as other regions have established calibration records or other data, then such checks on the underlying inputs and assumptions within TP10 are appropriate; the specifics of this are well canvassed within the *On-Site Stormwater Management Guidelines* (NZWERF, 2004).

The former ARC began a review of TP10 in 2009 after recognising that TP10 was too prescriptive and inflexible in many parts, and inappropriate to be applied in other regions without careful attention to local environmental sensitivities and variables. ARC was working towards the 1 November 2010 amalgamation of Auckland councils and the review of technical papers was delayed by this process. TP10 will become Guidance Document 01 (GD01), released as volumes 1, 2a, 2b, 3, 4 and 5; each topic area within these volumes is being released as a technical report, with new technical reports on wetlands, green rooves, rain-gardens, permeable paving and swales. Volume 1 deals with stormwater management issues. Volume 2 deals with stormwater treatment devices design, while volume 3 deals with their construction and vloume 4 deals with their operation and maintenance. Volume 5 deals with landscaping, biodiversity and biosecurity.

Differences between Short and Long Term Treatment Philosophies

Stormwater treatment primarily focuses on the removal of **sediment** and sediment adsorbed contaminants. Consequently, the *broad* principles regarding sediment removal should not differ between solutions targeted at the short term (i.e. on-site stormwater management during construction) and those aimed at providing long-term management. However, factors such as **design storm**, application of **discharge standards**, and availability of suitable space all influence the application of those principles. The calculation of the design storm, catchment area and appropriate catchment proportion for a treatment pond, as well as performance requirements and choice of outlet type will tend to differ between a short-term and a long-term response. These differences have caused some confusion in the establishment of resource consent conditions and during discussion with potentially affected parties.

Depending on the statutory framework operating within a region, the key differences in approach between short and long term stormwater treatment may be summarised as follows in Table 5.1:

Table 5.1: Comparison of short-term and long-term treatment approaches

Aspect	Temporary Sediment Control	Long Term Stormwater Treatment
Design Storm	**5% annual exceedance probability (20 year annual recurrence interval).**	**2 year 24 hour annual recurrence interval event**
Pond size	**2 – 3% of contributing catchment.**	**Approx 1 – 2% catchment (depending on calculation method).**
Treatment efficacy	**Unspecified. Depends on soil types, pond size, and other factors. Treatment has been measured at around 90% without chemical flocculation (Winter, 1998) but is not typically calculated.**	**Calculated theoretical efficiency. Frequently targets 75% sediment removal on long term average basis.**
Outlet type	**Floating decant (or similar)**	**Fixed spillway / weir system (or similar)**
Targeted contributing catchment size	**0.3 – 5ha**	**Larger catchments. Typically limited by land availability.**
Target pond life	**Less than 2 years.** **Ponds may be modified and converted to long term treatment structures.**	**Permanent.**
Climate change	**Not relevant.**	**Needs to be considered.**