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Te Taiao Tonga

Design of Stormwater Monitoring Programmes

Technical Report

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Design of Stormwater Monitoring Programmes

Prepared for Environment Southland

February 2014

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Executive summary

Stormwater monitoring is an essential task in understanding stormwater for catchment management and planning; however monitoring programmes are not always designed to deliver useful information to managers. This report provides guidance to Environment Southland on the design of stormwater monitoring programmes.

Part One outlines the major considerations in the design of a stormwater monitoring programme based on stormwater monitoring protocols and the experience of the authors. The rationale for various aspects of monitoring design are provided. Where relevant, the advantages and disadvantages of monitoring options are briefly discussed.

1. **Monitoring objectives** must clearly specify the aim of monitoring.
2. **Site selection.** To ensure samples accurately represent the area of interest, sites should be located at the bottom of the catchment, upstream of tidal influence, at a location where water is well-mixed and in a safe location for equipment and personnel.
3. **Storm events**. We recommend sampling events with a range rainfall depths (≥ 2.5 mm), guided by analysis of storm event rainfall distribution, with 5 days between events.
4. **Flow measurement.** For accurate measurement of stormwater flows, which can be very low with rapid changes, we recommend using water level control structures such as weirs and water level measurement using a float and counter-weight. Direct flow measurements or water level measurement can be used when accuracy is less important (when loads or flow-weighted measurements are not required).
5. **Water sampling methods.** We recommend using autosamplers in a volume-proportional mode as these collect more samples around peak flows and therefore better characterisation of events. Flow-proportional composites are recommended where event-based loads or concentrations are needed.
6. **Analytes and methods.** Primary measures of stormwater quality should include suspended solids concentration (SSC) or total suspended solids (TSS), total and dissolved copper and zinc, total nitrogen and either *E. coli* or enterococci. Additional analytes are recommended for industrial landuse. A secondary list of analytes should also be measured for initial storms.
7. **Data collection, management and manipulation.** Collection of additional metadata will assist in obtaining the maximum value from monitoring programmes. Stormwater flow and quality data should always be checked for errors on receipt.

Part Two of this report recommends stormwater monitoring programmes to meet four monitoring objectives. This part is presented in a way that will allow a stormwater manager to rapidly design a detailed stormwater monitoring programme for most purposes. For each objective, we have provided an outline of when this objective could be applied and the basic rationale for the programme design. The four objectives are:

1. Measuring maximum concentrations (in a discharge or receiving environment) for comparison to water quality standards or guidelines;
2. Measuring event-based mass loads or EMCs;
3. Identifying sources of poor stormwater quality;
4. Evaluating stormwater treatment device efficiency.

1 Introduction

1.1 The Need for Stormwater Monitoring

Environment Southland are responsible for managing water quality within the Southland Region. This includes regulating the discharge of urban stormwater, a function undertaken through rules in regional plans and through the conditions of resource consents. Stormwater is considered a non-point source of contaminants due to the large number of individual points of discharge over a wide area (and in some cases a diffuse area) and the origin in catchments whose characteristics and contaminant loadings vary through time (Burton & Pitt 2002). As a result, stormwater can be more challenging to manage and monitor than point source discharges of known and consistent quality and quantity. Adverse effects of stormwater include stream erosion, flooding, increased rates of sedimentation, toxic metal accumulation, reduced ecological health and the rendering of water bodies as unsuitable for recreation.

Stormwater management requires information on both the quality and quantity of stormwater discharges. Stormwater quality can be very challenging to measure compared to point sources because discharges are intermittent. Contaminant concentrations can vary by up to two orders of magnitude during a storm, often with highest concentrations at the start (the ‘first flush’). However, in other cases peak concentrations coincide with the peak flow. There is a wide range of contaminants that are found in stormwater and the concentrations of these can depend on the landuse and enterprise activities within each catchment. Analysis of contaminants such as persistent organic compounds can be very expensive and these compounds may only be intermittently present in stormwater discharges.

Storm flows are also challenging to monitor as catchments are relatively small, flows intermittent and peak flows and volumes low compared to natural streams and rivers. Runoff response to rainfall is rapid, resulting in high velocities and turbulent conditions at drainage outfalls. In other situations, flow is diffuse or follows multiple flow paths. Uncertainty over drainage networks can severely restrict the selection of sites. Equipment installation and operation is hampered by restrictive working environments.

Despite these challenges, accurate measurement of stormwater quality and quantity is essential for studies seeking to quantify contaminant loads discharged to receiving waterbodies since load is estimated as the product of contaminant concentration and volume of flow. Load-based limits are likely to become an important part of catchment management as the National Policy Statement for Freshwater Management is applied in each region.

1.2 Scope

This report provides Environment Southland with recommendations for the design of stormwater monitoring programmes, including site selection, sampling methods, parameters to monitor and data management practices. These guidelines are applicable for use in the preparation of resource consent applications, monitoring compliance with consent conditions and wider stormwater catchment management activities. The recommendations are targeted to provide guidance relevant to a number of different generic monitoring objectives, for example reflecting differences between situations in which contaminant concentrations are required and those in which contaminant loads are required.

This advice applies to monitoring in the reticulated stormwater network or in small streams that have a predominantly urban land use in the catchment. It does not apply to receiving environment monitoring, particularly in major rivers or estuaries.

1.3 Information Sources Used for this Advice

This report relies heavily on the expertise and experience of NIWA staff in the Urban Aquatic Environments Group, who regularly undertake stormwater monitoring. Some of that information is available within published reports on previous monitoring studies by the group (e.g., Moores et al. 2009; 2011; 2012); however much of it is not currently available in written format.

This report also makes reference to a number of manuals published in the United States, including guidance from the Center for Watershed Protection for developing local stormwater monitoring studies (Law et al. 2008); the “Stormwater Effects Handbook” by Burton & Pitt (2002) and the USGS field protocols for water sampling (USGS 2006).

There are several protocols available for monitoring of stormwater treatment devices (known as Best Management Practices or BMPs in the United States). These protocols (TARP 2003; USEPA 2002, WDOE 2008; Wong et al 2012) require more extensive monitoring than most of that outlined in this report, however much of the information contained in these protocols is also relevant to general stormwater monitoring.

1.4 Measures of Stormwater Quality

Stormwater quality is characterised by the concentration of contaminants in a collected sample. These samples may be collected at a single point in time, and as mentioned above, contaminant concentrations vary significantly during a storm event. Nonetheless, concentration data at individual time points is useful for contaminants that are acutely toxic, as the maximum concentration during a storm event may be of more significance than the average throughout the event.

Stormwater quality is commonly described in terms of an EMC, or event mean concentration (common units, mg/L or gm^{-3}). EMC is a statistical parameter used to represent the flow-proportional average concentration of a given parameter during a storm event (USEPA & ASCE 2002). It is defined as the total mass of a contaminant divided by the total runoff volume for a given storm event. EMCs are a useful measure of stormwater quality as this weighted-average statistic enables a better comparison between storm events and between sites than the quality at a single point in time.

Stormwater loads are the mass of contaminant discharged. These can be estimated from concentrations taken at individual points in time or from the EMC, but in either case, flow data must be available. Loads can be very useful for assessing the major sources of contaminants within a catchment. Loads are also a useful statistic for assessing downstream effects in estuaries or lakes where the total mass loading of contaminants over time can result in sedimentation or contaminant accumulation.

1.5 Structure of Report

This report is organised in two sections following this introduction.

Part One outlines the major considerations in the design of a stormwater monitoring programme based on stormwater monitoring protocols and the experience of the authors. These considerations include:

- **Monitoring objectives** that clearly specify the aim of monitoring.
- **Site selection considerations**, to ensure samples accurately represent the area of interest and to ensure safety of equipment and personnel.
- **Storm event considerations** such as the depth of rainfall required and the time between storms.
- **Flow measurement methods** including water level control structures, water level measurements and direct flow measurements; and the advantages and disadvantages of each.
- **Water sampling methods**, using grab sampling and autosamplers; time-proportional, flow-proportional and volume-proportional sampling; and discrete versus composite samples.
- **Analytes and methods** that will provide relevant and useable data for different monitoring programmes.
- **Data collection, management and manipulation** to obtain the maximum value from monitoring programmes through collection of additional metadata, error checking and calculation of stormwater measures such as EMC and loads.

Part Two of this report recommends stormwater monitoring programmes to meet four objectives including an outline of when this objective would apply and the basic rationale for the programme design. The four objectives are:

1. To measure maximum concentrations (in a discharge or receiving environment) for comparison to water quality standards or guidelines;
2. To measure event-based mass loads or EMCs;
3. To identify sources of poor stormwater quality;
4. To evaluate stormwater treatment device efficiency.

Part 1: Considerations in Designing Stormwater Monitoring Programmes

2 Monitoring Objectives

In order to obtain maximum value from a stormwater monitoring programme, it is important to clearly specify the objectives of monitoring. Some types of objectives include:

- To assess if the stormwater discharge from a site meets the consent conditions; for example, "*the discharge must not exceed a maximum limit of 50 mg/L of total suspended solids*";
- To determine if urban runoff is affecting the use of a stream for contact recreation; for example "*is the stormwater discharge increasing E. coli above 500 cfu/100mL?"*
- To identify sources of contaminants in a particular catchment; for example "*what is the source of elevated concentrations of copper in the western industrial catchment?*"
- To investigate whether stormwater treatment devices are performing as specified; for example "*is the eastern park wetland removing more than 75% of TSS?"*

The objectives of monitoring will be site-specific and are likely to depend on downstream receiving environments and the community's values of these environments, whether this be for recreation, amenity values or protection of aquatic life. NIWA recognises that these values and therefore the objectives of sampling are best assessed by Environment Southland or a consent applicant in collaboration and consultation with the community. This report therefore provides guidance on the design of stormwater monitoring programmes for a number of generic objectives (Part 2 of this report), but does not specify where or when these objectives should be applied.

In using these recommendations for resource consents conditions, Environment Southland or a consent applicant will therefore first need to decide on the relevant objectives and apply the relevant monitoring recommendations based on these.

3 Site Selection Considerations

In general, stormwater sampling sites should be located at the most downstream point possible for the catchment of interest. Ideally the entire catchment of interest will be captured, whether this is a single site (such as industrial site with one or more buildings) or a sub-catchment of a town or city. Stormwater may be sampled within the piped network, at pipe outlets or in small streams that have a predominantly urban land use in the catchment.

The contributing catchment area should be clearly defined. This can involve not only the use of maps of the piped network or overland flow paths but also walk-over assessments or more detailed investigations in the field. In our experience, on lifting a manhole cover to install equipment it is not uncommon to find pipes entering the manhole that are not represented on a network map.

Ideally the catchment will comprise only the land use or site of interest, rather than capturing additional upstream sources. This allows the runoff quality to be readily attributed to the activities in the catchment of interest. However, it can be necessary to install temporary piping to capture or bypass the runoff from source areas that are or are not, respectively, part of the target catchment area.

Sites should be located upstream of any tidal influence as the mixture of saline waters in urban streams (or stormwater pipes) will compromise the results of sampling. Tidal currents can affect stream flows further upstream than the saline water extends, reversing the flows in some places and causing backwater effects further upstream. Whilst this may not be a problem for water sampling, providing that stormwater is not mixed with the saline waters, flow measurement is likely to be severely affected and it may not be possible to calculate event-mean concentrations or loads.

The safety of personnel and equipment are also a critical consideration in site selection. Priority must be given to assuring the safety of technical staff given potential hazards associated with working near waterways, roads and/or in confined spaces such as manholes. Safe access to the site is essential. In many cases this is easiest through public land, however this may increase the potential for vandalism, and equipment will need to be housed within secure cabinets or sheds. There also must be space to house monitoring equipment at the site, although there are several options for this such as housing within a manhole (if deep enough to accommodate the equipment without flooding it), or at the side of the road adjacent to a manhole.

Water flow at the sampling location must be well mixed (not stagnant). Depositional zones such as river bends and mouths, pools, and impoundment structures should be avoided Wide shallow and fast flowing streams may be difficult to sample adequately. Sites downstream of discharge points should be located outside the “mixing zone”. This zone may already be specified by Environment Southland’s consents, agreed on by affected parties, or could be established on a site-specific basis using either tracer dye testing or rules of thumb (such as 5 or 10 times a river’s channel width).

There are a range of other site-specific challenges that may need to be addressed on-site. These include:

- The size of the pipe: there may not be sufficient flow in large, wide pipes during small storms to cover the flow monitoring equipment or sampler intake.
- The slope of the pipe: if a temporary weir is to be installed there will need to be adequate slope to ensure that stormwater is not backed up too far upstream. This could not only result in potential flooding issues but also compromise the representativeness of samples.
- Dry weather flow in pipes. Even clean dry weather flows in pipe will interfere with sampling of stormwater as this will dilute wet weather flows. However, if the monitoring study design objective is to characterize illicit discharges, sampling should include such sites in the study.

4 Storm Event Considerations

Contaminants in stormwater are derived from traffic sources (wear of brakes, tyres and roading materials), weathering of building surfaces (such as roofing) and dry deposition of pollutants emitted locally and in neighbouring areas. These contaminants accumulate over time during the dry periods between storms (antecedent periods). During storm events, the contaminants are washed off impervious surfaces, into the stormwater network and discharged into receiving environments.

Stormwater monitoring is therefore almost always undertaken during storm events when this wash-off of contaminants occurs. The exception to this is for urban streams where a comparison of the quality under baseflow and stormflow conditions may be desirable.

Most stormwater contaminants are considered to be ‘supply-limited’: this means the amount available for wash-off is a function of time since the last storm event. These contaminants are understood to accumulate in a non-linear way, with a reducing rate of increase, reaching an equilibrium or plateau. Studies suggest this plateau is reached within around 4-5 days (Ellis 1986). Based on this, an antecedent period of 5 days is recommended prior to sampling a storm event. Shorter antecedent periods may not allow for sufficient contaminant build-up and the concentrations can be expected to be lower than in storms with a 5 day antecedent dry period, all other things being equal.

Typically, sampling of storm events requires more than 2 mm of rainfall to fall, as less than this will not result in runoff due to evaporation and depression storage (Butler & Davies 2000). Therefore we recommend sampling storm event sizes from ≥ 2.5 mm per day.

An attempt should be made to sample events with a range of different rainfall depths. Ideally the storms sampled should reflect the typical annual rainfall distribution (see example in Figure 4-1). In this example ~75% of the time rainfall events are less than 10 mm, so it is important to ensure that these smaller storms are sampled as well as the larger events between 10 and 50 mm.

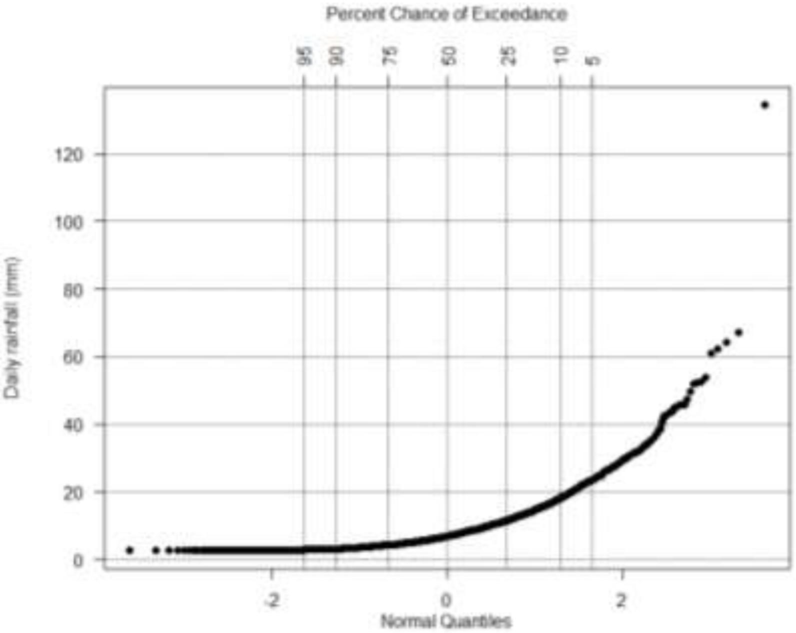

Figure 4-1: Example of rainfall frequency distribution.

Stormwater quality does vary considerably between storms even for a single site, as previously mentioned. For example, in our experience monitoring road runoff in a small, well-defined catchment with a single land use, over 15 storm events, the EMCs for suspended solids varied between storms by 100 times and the EMCs for copper and zinc varied by 3-20 times. Measurement of a single storm event is unlikely to provide sufficient information on which to base environmental assessments or to show compliance.

The number of storms to be monitored depends degree of confidence required in the results. Most protocols (TARP 2003; USEPA 2002, WDOE 2008; Wong et al 2012) recommend at least 12 events and up to 35, depending on data objectives. Of course, resourcing is a major consideration in the size of any monitoring programme. In our experience between 5 and 10 storm events are required to provide a reasonable characterisation of stormwater quality.

5 Flow Measurement Methods

The accurate measurement of stormwater flows is essential for studies seeking to quantify contaminant loads discharged to receiving waterbodies, because load is the product of concentration and volume. Flows are also required to collect flow-proportional composites (see Section 6.3 for more information) for measurement of EMCs. Flow data may also be used in the calculation of EMCs from analysis of multiple samples collected throughout a storm (see Section 8.3 for details of this).

In other situations it can be sufficient to measure water level alone. This is the case where information on the timing of different parts of a storm (for instance the onset, peak and recession) is required to help with the selection of samples for analysis. In such situations the measurement of water level acts as a surrogate for a flow hydrograph and allows the characterisation of variations in contaminant concentrations during different stages of the storm event. However, without an estimate of flow, contaminant loads cannot be calculated.

Another limitation is that when water level measurements are used to trigger automatic water samplers (see Section 6.3) it is not possible to collect flow- or volume-proportional water samples.

The characteristics of urban drainage systems present a number of challenges for flow measurement. Catchments are small, flows intermittent and peak flows and volumes low compared to natural streams and rivers. As shown in Figure 4-1, smaller storm events account for the majority of stormwater runoff so it is essential that any device used to measure stormwater flow is capable of accurately measuring at the lower range of the expected flows (USEPA & ASCE 2002). Then again, runoff response to rainfall is rapid, resulting in high velocities and turbulent conditions at drainage outfalls. This means that flow measurement devices must be able to measure throughout rapidly changing conditions (in contrast to many other applications such as water and wastewater flows where flows are less variable).

Several methods exist for monitoring flows. These include traditional hydrometric methods using a water level control (such as a weir) and measuring the change in stage (water level) height. Flows can also be monitored directly using area velocity flow meters. The calculation of flows from water level measurements requires water level control structures to be rated (i.e. having an equation allowing the estimation of flow from a given measurement of water level). For the control structures described below, theoretically-derived ratings are available, meaning that is it not necessary to develop site-specific ratings from flow gaugings and water level measurements in the field.

In NIWA’s experience, the measurement of stormwater flows is most reliably achieved by installing a temporary weir and using a float and counterweight recorder. Weirs can be constructed and installed even in relatively confined spaces such as manholes. Flumes are an alternative control structure which can be used, though we find that a sharp-crested weir is the easiest to build and also the most accurate. The use of weir boxes, baffles and stilling wells reduce the disturbance associated with high flow velocities.

Examples of temporary weirs are shown in Figure 5-1. In both cases the weir is a compound rectangular sharp-crested v-notch manufactured from marine plywood. In the left hand photograph a weir box has been constructed downstream of the outfall to provide the storage and control structure. Stage height is measured with a float and counterweight-driven logger (installed in the white stilling well at the right of the picture). In the right hand photograph, a weir is constructed within a manhole. The water enters the weir pond from the right, and the invert of the weir is above the top of the inflow pipe so that approach velocities do not affect the weir rating excessively. The stage is measured using a pressure transducer, which is contained in the small white plastic pipe to the right of the photo.

Figure 5-1: Examples of temporary sharp-crested weirs constructed for stormwater monitoring of an outfall pipe (using a weir box) and within a manhole.

A potential issue regarding the use of weirs in stormwater sampling is that the slower flows created by a weir may result in some settling of solids. However, in an assessment of this potential effect we found that the solids settled upstream of a weir were predominantly greater than 250 µm in size (i.e., medium sand, coarse sand, gravels and larger particles): these are particle sizes that are not representatively captured by automatic samplers (see Semadeni-Davies 2013; ASCE 2010 and Clark et al. 2009) and are not accurately measured in laboratories as part of the "Total Suspended Sediment" (TSS) measurement.

Stage height can be measured to the nearest millimetre by float and counter-weight recorder. Alternatively, a pressure transducer or bubbler tube may be used. These are not as accurate or reliable as a float and counter-weight recorder, but are easier to install and particularly useful when there are restrictions on space. In either case, stage height is then converted to discharge using the rating, which must be unchanging for any particular stage (e.g., tidal backwater effects would not be catered for).

Flows can be monitored directly using ultrasonic, submerged probe, bubbler, and area velocity flow meters. The most common of these for stormwater or stream flows are the acoustic doppler flow meters. This technique uses a single instrument to measure both stage and velocity concurrently. The stage is measured by either a pressure transducer or ultrasonic transducer, and the velocity is measured with an ultrasonic transducer that uses the Doppler principle. Prior to measurement, the cross-sectional area of the channel or the pipe diameter is entered into the logger. During measurement, stage or water level height is converted into a cross-sectional area. Flow rate is calculated by multiplying the mean velocity and the cross-sectional area of the pipe that is filled with stormwater.

While widely used for measuring pipe flow in sewers, in NIWA's experience they are often unreliable for situations where flow is intermittent and pipes are dry for most of the time, as is the case in stormwater pipes. The uncertainty in discharge measured by these instruments is mainly caused by the way velocity is measured. The ultrasonic beam that measures the velocity is aimed upstream, and at an angle to the horizontal so that it cuts a path from the transducer (which is normally mounted on the bed) to the water surface. It uses various methods to calculate the mean velocity in the water column between the transducer and the surface, but this mean velocity is then applied to the entire cross section, and so the discharge is a function of the mean velocity in the centre of the pipe (or channel), rather than the true mean velocity across the whole cross-section. The velocity that is measured is prone to over or under-reading if velocity drops to very low levels; in addition turbulence also contributes to the uncertainty. These factors limit the accuracy of the instrument and the measured discharge therefore has a larger range of uncertainty.

Selection of equipment for measurement of flows and automation of sample collection should therefore be approached with caution. Based on our experience, we recommend:

1. the use of a rated structure whenever possible, unless site conditions (e.g. tidal inundation, flood risk, drowning out of structure) preclude its use or where it is sufficient to measure water level alone; and

2. that where site conditions preclude selection of a rated structure, a Doppler instrument be used.

6 Water Sampling Methods

6.1 Grab Samples and Automatic Samplers

Water samples can be collected either manually (grab samples), or using automatic samplers (autosamplers). The transient nature and uncertainty of timing of storm events usually makes automatic samplers more practical than manual sampling. With grab sampling, it can be difficult to ensure the sample is collected during the first flush, or the peak storm. Furthermore, grab sampling relies on staff being available at the time of a storm event, which may occur at night or on the weekend. The advantages and disadvantages of grab and automatic sampling are outlined in Table 6-1.

Grab samples represent only a snapshot of the water quality at the time of collection and are not appropriate for calculating event mean concentrations unless a sufficient number are taken to represent the concentration changes over the period of runoff, and flow measurements are taken at the same time (Roesner et al. 2007). In the United States, autosamplers are the required method for sampling when assessing compliance with discharge permits (Burton & Pitt 2002).

However, grab sampling can be an appropriate method for an initial screening assessment of stormwater quality. We have used this approach to provide a first-cut comparison of variations in catchment stormwater quality in order to make decisions about the selection of locations for more intensive monitoring. Even in these circumstances, however, it is important to ensure that comparisons of water quality are based on grab samples collected under similar conditions at each site (i.e. that all samples represent the first flush or storm peak, for instance).

If grab sampling is to be used, we recommend the use of a sample bottle holder, such as a Mighty Gripper or similar, to enable samples to be collected within the middle of the flow and ensure sampler safety.

Table 6-1: Advantages and disadvantages of collecting samples manually and using autosamplers (adapted from Burton & Pitt 2002).

Grab sampling	Automatic sampling
Advantages	
Cheaper	Consistent samples: reduction in handling lowers possibility of sample variability
Recommended for analysis of bacteria, TPH, pH, temperature and others which are subject to rapid degradation, growth or adherence to sample bottles [1]	Less labour intensive, particularly for long term sampling
More practical to transport to remote locations	Ability to take multiple samples throughout a flow event, samples can be collected in single composite sample bottles or multiple bottles for discrete analysis of time or flow weighted compositing
Can collect additional samples in short time when necessary	Samples can be collected very close to commencement of runoff flow
Disadvantages	
Increased probability of missing first-flush as staff may not be on-site quickly enough	Require specialised equipment, power source (may be battery) and secure housing to prevent vandalism
Sampling technique inconsistent between events; difficult to sample without creating turbulence around sampler	Requires maintenance such cleaning, replacement of worn parts and unclogging suction tubing
Difficulty in obtaining representative samples throughout event	May require replacement sample bottles during extreme events
Difficulty in obtaining samples at multiple sites at the same time	Cannot sample large material (gross solids), bedload or floating solids
May be hazardous to be on-site at some locations or during some events (e.g., at night)	
Labour intensive for on-going monitoring programmes	

Note: [1] Although some protocols state that grab samples are **required** for these analytes, in our experience automatic samplers can be used in some cases, for example for TPH glass collection bottles can be used for analysis to mitigate contaminant adherence to the bottle. Samples for measurement of temperature can be collected by autosampler provided they are measured shortly after collection.

6.2 Automatic Samplers Installation and Operation

In general, we recommend a sampling strategy that involves use of an automatic sampler triggered by a water level measuring device (as described in Section 5). Water levels and flows are measured continuously and the automatic sampler is first triggered to collect a sample once a given stage height is exceeded. Subsequent samples are collected at intervals of a fixed volume. The cumulative volume passing the sampling point after each sample is collected is automatically calculated from the record of flows. Sample collection ends when all bottles are filled or the storm event ceases. Samplers can also be triggered manually by staff, either on-site or using telemetry; however if flow is to be measured anyway, this is the simplest way to do it.

Autosamplers need to be installed appropriately to ensure representative samples are collected. This includes:

- ensuring that the intake is positioned within a well-mixed section of flowing water;
- the nozzle intake should be orientated parallel to the flow stream pointing downstream (Roesner et al. 2007);
- the intake is slightly above the bed of the pipe to avoid being covered by bedload material (such as gravel and litter);
- the height of the sampler above the intake is not so great that the sampler cannot pump the sample from intake to the bottle;
- the length of the intake pipe is not so long that it takes an excessively long time (e.g., greater than 5 min) to pump up the sample and purge the pipe; and
- sampler tubing should be Teflon if organic contaminants are to be analysed.

Autosamplers can be configured in three ways (see ISO 1991):

1. **Time-proportional** sampling: samples of equal volume are taken at equal time increments (programmed prior to sampling).
2. **Flow-proportional** sampling: samples of variable volume, proportional to stormwater flow, are taken at equal time increments (programmed prior to sampling).
3. **Volume-proportional** sampling: samples of equal volume are taken at variable time intervals after a constant volume (programmed prior to sampling) has passed that sampling point.

These different modes are illustrated in Figure 6-1.

No matter what the mode of sampling, collection of a greater number of sub-samples will result in a better representation of the storm event and a more reliable EMC. Ma et al. (2009) found that collection of 10 flow-weighted samples resulted in 23% error in the EMC and 20 samples resulted in error of 17%. Fassman (2010) recommends that at least 8 samples be collected throughout the storm event. We recommend that at least 10 samples be collected per storm event.

Under most circumstances, flow- or volume-proportional sampling is our preferred method. However both modes require an understanding of how the flows will respond in relation to the rainfall. The catchment area and imperviousness can be used to calculate flow; however we find it is also valuable to monitor the storm flow for several events prior to sampling to gain an understanding of the site’s response to rainfall.

Time-proportional sampling can be used without the necessity to monitor flow and it can therefore be a less resource-demanding option, especially in relation to site installation. Where used in conjunction with water-level only monitoring, the construction and installation of a rated structure is avoided. We have used this approach when undertaking concurrent sampling at multiple sites in a catchment in order to maximise coverage under the available resources. Such an approach, however, is only applicable where contaminant loads and EMCs are not required. If flow is monitored, samples collected using time-proportional sampling **can** be used to create flow-weighted composites, although this requires more sample manipulation than other sampling modes (as described below in Section 6.3).

Grab

Take one (or a number of) samples

Time-proportional

Take an equal volume of sample at equal time increments

Flow-proportional

Take a variable sample volume (proportional to the stormwater flow) at equal time increments

Volume-proportional

Take an equal sample volume at variable time increments, after a constant volume has passed the sampling point

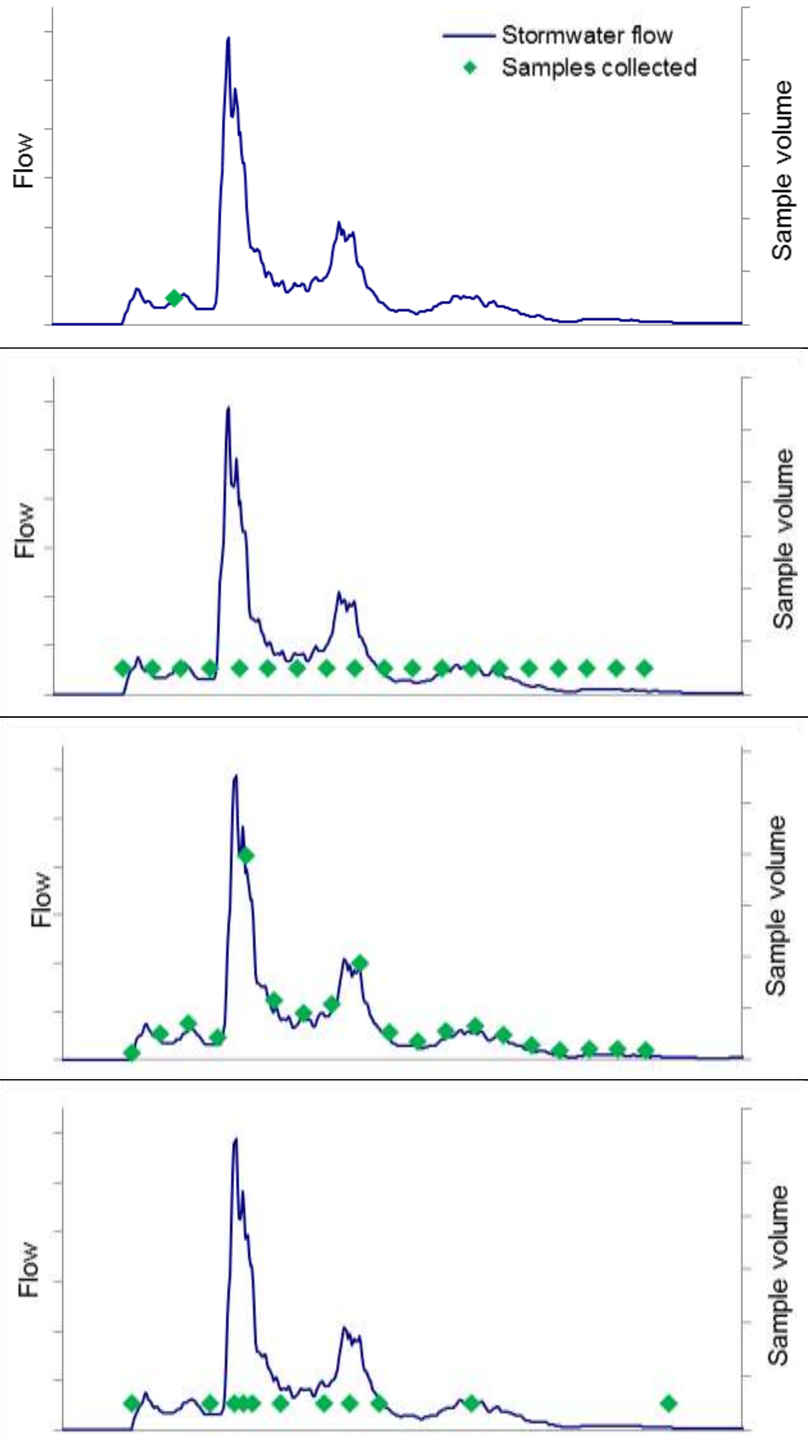

Figure 6-1: Sampling modes.

Although both flow-proportional and volume-proportional modes can be readily used to generate flow-weighted composites, volume-proportional sampling can be more useful when discrete samples are required. This is because the volume of sample collected is the same for each and can be programmed to be sufficient for analysis of all contaminants of interest. In contrast, some samples collected under flow-proportional mode may have insufficient volume for analyses such as TSS, which typically use > 500 mL.

6.3 Discrete and Composite Samples

Water samples can be in two forms: discrete samples and composite samples, and both can be made using either manual sampling or automatic samplers. These sample types are described below:

- **Discrete samples** are single samples made over a short period of time which give a snapshot of water quality at a given time and discharge. Discrete samples cannot be used to calculate event mean concentrations (EMC) unless flow is also monitored. Discrete samples are necessary to indicate maximum concentrations during a storm event.

- **Composite samples** are produced by combining samples to provide an estimate of average concentrations. Flow-weighted composite samples can be used to calculate event mean concentrations (EMC).

There are three methods which can be used to combine samples:

1. Time-weighted composites, samples are taken at equal time increments and are combined in equal measures. We do not recommend this combination method as it does not provide representative concentrations of the storm event, because equal volumes are used irrespective of differences in flow at the time of sampling.

2. Flow-weighted composites can be made using one of three methods:

    a) Samples taken after equal time intervals (from either time-proportional or flow-proportional sampling, see below) are combined with variable volumes proportional to the volume of flow between samples.

    b) Samples of equal volume are taken at variable time intervals after a constant volume has passed that sampling point (volume-proportional sampling) and are combined. This is the method recommended by the WERF protocol which states that it is the most commonly employed compositing method for stormwater sampling.

Composites can either be made directly by an autosampler when using a sampler with large volume collection bottles, or samples from either manual or automatic sampling can be collected into multiple bottles and composites prepared in the laboratory following retrieval of the samples.

If an autosampler is used to prepare the composites, samples must be collected in a flow-proportional or volume-proportional mode as described in the previous section.

If composites are to be prepared in the laboratory, samples can be collected on a time-proportional, flow-proportional or volume-proportional basis. When samples are collected on a time-proportional basis, the collected samples have equal volume and the proportional volume to prepare to composite must be manually calculated from the measured flow coinciding with the timing of sample collection. When samples are collected on a flow-proportional or volume-proportional basis, the collected samples can be simply combined as either their volume varies (flow-proportional) or the sampling time varies (volume-proportional) in a flow-weighted manner. Within the laboratory, it is therefore simplest to combine samples collected on a flow- or volume-proportional basis.

When the sample collection spans the entire storm event, a flow-weighted composite will represent the EMC. Measurement of the EMC allows for comparison between storm events and catchments.

6.4 Continuous Water Quality Measurements

For some water quality characteristics, it is best to measure *in situ*, rather than collect water samples for subsequent analysis. This includes water temperature and pH which may change rapidly following sample collection. Continuous monitoring probes or sondes can be relatively easily installed to measure these. In addition, *in situ* continuous monitoring probes are available for conductivity, turbidity, ammoniacal-N, nitrate-N, chloride and BOD. These are often measured in stormwater, either as indicators of contaminants (conductivity, chloride) or as contaminants themselves.

Continuous monitoring of water quality indicators or common contaminants can be particularly useful in catchments where there may be intermittent dry weather discharges, illegal discharges, spills or leaks. This is often more relevant to catchments with industrial activities.

6.5 Recommendations

Based on our experience in sampling for stormwater monitoring, we recommend:

1. Using autosamplers to collect water samples (although grab samples may be suitable for initial characterisation of sites prior to installing equipment for a more intensive monitoring programme);

2. Volume-proportional collection of samples if discrete samples are to be analysed, or either volume-proportional or flow-proportional collection if not;

3. Preparing flow-weighted composites for analysis, either using the auto-sampler or in the laboratory.

7 Analytes and Their Methods

7.1 Recommended Analytes for Monitoring

A wide range of contaminants may be present in stormwater, depending on the land use and specific activities being undertaken within the contributing catchment. A list of recommended analytes for the Southland Region is provided in Table 7-1. This list has been prepared by considering the land uses in the area; water quality issues specific to the Southland Region; the uses of receiving waters; the prevalence of the contaminants in typical urban stormwater at concentrations that may cause adverse effects downstream; and the ability of the contaminant to be sampled and analysed according to straight-forward and reliable methods.

Table 7-1: Recommended analytes for stormwater monitoring.

Analyte	Rationale
SSC (or TSS)	Sediment is a major contaminant in stormwater and carries other contaminants; sedimentation of estuaries is a primary issue of concern in Southland
Total & dissolved copper and zinc	Copper & zinc are prevalent in urban stormwater and regularly exceed water quality or sediment quality guidelines in downstream receiving environments
Total nitrogen	Little information on nitrogen in stormwater; nutrients are a primary issue of concern in Southland
E. coli or enterococci	Prevalent in urban stormwater, at times at very high levels; contact recreation & food gathering are primary issues of concern in Southland
Total & dissolved arsenic, cadmium, chromium, lead, nickel	Can be present at very high concentrations particularly from industrial areas, can exceed guidelines downstream
pH	Stormwater typically neutral in pH, but frequently outliers in industrial catchments; can indicate spills or illegal discharges and presence of other contaminants
Conductivity	Spikes in conductivity can indicate spills, illegal discharges and presence of other contaminants
Ammoniacal-N	Stormwater usually has low concentrations but can be present at high concentrations particularly from industrial areas, can exceed guidelines downstream
Nitrate-N	Nutrients are a primary issue of concern in Southland; sources of nitrate-N in stormwater are not well-characterised
DRP	Nutrients are a primary issue of concern in Southland; sources of DRP in stormwater are not well-characterised
Total phosphorus	Nutrients are a primary issue of concern in Southland; sources of TP in stormwater are not well-characterised
Mercury	Extremely ecotoxic and may be present in stormwater, particularly from industrial areas
BOD & COD	Oxygen demanding substances; outliers can indicate spills or illegal discharges and presence of other contaminants
TPH (Total petroleum hydrocarbons)	Ecotoxic, present in stormwater from fuel leaks and spills
PAHs (polycyclic aromatic hydrocarbons)	Ecotoxic and bioaccumulative; present in stormwater from fuel, combustion and coal tar based roading materials
SVOCs (semi-volatile organic compounds)	A suite of organic compounds that may be persistent and/or ecotoxic, present in stormwater from a variety of sources

The presence of solids in urban runoff is a major concern for stormwater management, due to the direct effects of sediments in receiving environments (e.g., reducing water clarity, smothering stream beds, increasing sedimentation in estuaries) and because they carry other contaminants, such as metals and polycyclic aromatic hydrocarbons. Their measurement is therefore one most frequently undertaken in stormwater monitoring.

Suspended solids in stormwater are most regularly referred to as TSS, or total suspended solids. TSS is a measurement developed for wastewater, whereby a pipette is used to take a sub-sample from a well-mixed water sample, which is filtered through a filter with pore size approximately 2 µm and the residual solids are measured after drying (see APHA 2540D). This method has limitations for stormwater monitoring as stormwater regularly contains larger sediment particles than wastewater, and these particles may not be sampled using the TSS method as they settle rapidly and may not fit within the orifice of the pipette.

In many stormwater studies, the measurement of SSC (suspended solids concentration) is becoming more common. SSC is measured in a similar way to TSS, with the primary difference being that the entire sample collected is filtered (i.e., all that in the sample container) rather than a sub-sample (see Roesner et al. (2007) for further information). This results in pronounced differences in the measured concentration when there are a lot of sand-sized particles present in the water (Gray et al. 2000). SSC is now the recommended method for Auckland Council for stormwater (see Semadeni-Davies 2013) and sediment in streams (see Hicks 2011) and is also recommended for monitoring stormwater in Southland.

We recommend analysis of both total and dissolved forms of metals. Dissolved metals are generally considered more toxic as they are more bioavailable to aquatic biota and water quality guidelines are often based on exposure to dissolved metals (ANZECC 2000). However, the partitioning between the dissolved and particulate (sediment-attached) metals can change within stormwater discharges and within receiving environments, so in many cases the total concentration discharged is also of interest. Further, for discharges to coastal areas, where accumulation of metals in sediments is an area of concern, the total concentration (dissolved + particulate) is of interest. Partitioning of metals is also useful information for selecting stormwater treatment devices, as devices that operate on settling or filtration will have lesser effect on stormwater with a high proportion of dissolved metals.

We recommend some differences in the analytes monitored for different catchment land uses (Table 7-2). The analytes have also been split into a primary suite and a secondary suite (Table 7-2). Ideally, both the primary and secondary suites should be analysed for the first storm. If analytes in the secondary suite are not detected, or are present at levels well below potential concern, then those analytes can be dropped from subsequent monitoring events. All analytes in the primary suite should be analysed in all subsequent monitoring events. US EPA (2002) suggest that initial screening samples should be collected from storms that occur after prolonged dry periods, to increase the probability of detecting the full range of pollutants.

Table 7-2: Recommended analytes for different catchment land uses.

Residential	Commercial	Industrial	Roading	Mixed Use
Primary suite				
SSC (or TSS)	SSC (or TSS)	SSC (or TSS)	SSC (or TSS)	SSC (or TSS)
Total & dissolved copper and zinc	Total & dissolved copper and zinc	Total & dissolved copper and zinc	Total & dissolved copper and zinc	Total & dissolved copper and zinc
Total nitrogen	Total nitrogen	Total nitrogen	Total nitrogen	Total nitrogen
E. coli or enterococci [1]	*E. coli* or enterococci [1]	*E. coli* or enterococci [1]		*E. coli* or enterococci [1]
		Total & dissolved arsenic, cadmium, chromium, lead, nickel		
		pH		
		Conductivity		
		Ammoniacal-N		
Secondary suite				
Nitrate-N	Nitrate-N	Nitrate-N	Nitrate-N	Nitrate-N
DRP	DRP	DRP	DRP	DRP
Total phosphorus	Total phosphorus	Total phosphorus	Total phosphorus	Total phosphorus
		BOD & COD		
TPH	TPH	TPH	TPH	TPH
		SVOCs		

Note: [1] The bacterial indicator of choice depends on the receiving environment. *E. coli* should be measured in discharges to freshwater, while Enterococci should be measured in discharges to estuarine or coastal areas. It would be prudent to measure both indicators for sites where the immediate receiving environment is freshwater, but near the mouth of the stream.

7.2 Analytical methods

The recommended analytical methods and references are presented in Table 7-3, based on information from commercial laboratories in New Zealand and guidelines from Burton & Pitt (2002) and USGS (2006). Analyses should be undertaken by suitably experienced laboratories. Where possible, IANZ accredited tests should be used, or appropriate QA/QC data should be requested from the analytical laboratory to ensure the accuracy and robustness of the results. Appropriate consideration should be paid to the detection limits of laboratory tests to ensure that samples generate useful data.

Currently fewer commercial laboratories offer measurement of SSC compared to measurement of TSS; however it is available at some laboratories. Furthermore, some laboratories use methods based on APHA 2540D and call it TSS but actually filter the entire sample by directly pouring in the sample rather than sub-sampling with a pipette, in which case, the method is more like SSC. Whatever the commercial laboratory call the analysis, the most important thing for the monitoring is to know how the sample has been analysed.

Table 7-3: Recommended bottles, preservation, holding times, methods and suitable detection limits for stormwater analytes.

Analyte	Bottle type	Preservation method	Recommended maximum holding time when preserved	Recommended Analytical Method	Method Reference	Suitable detection limit
Suspended solids concentration	PE	< 4°C	48 hours	Entire sample filtered, filter and residue dried and weighed	ASTM D3977-97-B	3 mg/L
TSS	PE	< 4°C	48 hours	Sub-sample filtered, filter and residue dried and weighed	APHA 2540D	3 mg/L
pH	PE or glass	None	Analyse immediately, or measure *in situ*	Electrochemically	APHA-4500-H^+	± 0.1
Temperature	PE or glass	None	Analyse immediately, or measure *in situ*	Electrochemically or thermometer		± 0.5°C
Turbidity	PE or glass	< 4°C	48 hours	Nephelometrically	APHA 2130	0.05 NTU
COD	PE or glass	< 4°C, H_2SO_4 to pH <2	28 days	Reflux, titimetry or colourimetrically	APHA 5220	1 mg/L
Ammoniacal-N	PE or glass	< 4°C or H_2SO_4 to pH <2	48 hours	Various possible	APHA 4500-NH3 or APHA-4110B	0.01 mg/L
Nitrate-N	PE or glass	< 4°C	48 hours	Various possible	APHA 4500-NO3 or APHA-4110B	0.001 mg/L
TKN	PE or glass	< 4°C, H_2SO_4 to pH <2	28 days	Various possible	APHA 4500-N	0.1 mg/L
Total nitrogen	PE or glass	< 4°C	48 hours	Various possible	APHA 4500-N	0.1 mg/L
Dissolved Reactive Phosphorus	PE or glass	< 4°C	48 hours	Various possible	APHA 4500-P	0.004 mg/L
Total phosphorus (TP)	PE or glass	< 4°C, H_2SO_4 to pH <2	28 days	Various possible	APHA 4500-P	0.04 mg/L
E. coli	Sterile PE	< 4°C	24 hours	MPN count or membrane filtration	APHA 9221E or APHA 9223B	1 / 100 mL
Enterococci	Sterile PE	< 4°C	24 hours	MPN count or membrane filtration	MIMM 12.4 or APHA 9230C	1 / 100 mL

Table 7-2 (contd.): **Recommended bottles, preservation, holding times, methods and suitable detection limits for stormwater analytes.**

Analyte	Bottle type	Preservation method	Recommended maximum holding time when preserved	Recommended Analytical Method	Method Reference	Suitable detection limit
Total metals (except mercury)	Acid-washed PE	Add HNO_3 to pH<2	6 months	Total recoverable digestion (HNO_3 / HCl) extraction, ICP-MS	USEPA 200.2	Cu 0.0005 mg/L Zn 0.001 mg/L As 0.001 mg/L Cd 0.0001 mg/L Cr 0.0005 mg/L Ni 0.005 mg/L Pb 0.0001 mg/L
Dissolved metals (except mercury)	Acid-washed PE	Filter immediately then add HNO3 to pH<2 If cannot be filtered, store at < 4°C	6 months	Filtration, ICP-MS	USEPA 200.2	Cu 0.0005 mg/L Zn 0.001 mg/L As 0.001 mg/L Cd 0.0001 mg/L Cr 0.0005 mg/L Ni 0.005 mg/L Pb 0.0001 mg/L
Total mercury	Acid-washed glass	Either HNO_3 to pH<2 or 0.5% H_2SO_4 + 0.025% $K_2Cr_2O_7$	28 days	Hydride/cold vapour AAS, or cold vapour AFS, or ICP-MS	APHA 3112B, USEPA 245.7, APHA 3125	0.0001 mg/L
Dissolved mercury	Acid-washed glass	Filter immediately then add HNO3 to pH<2 If cannot be filtered, store at < 4°C	28 days	Filtration then hydride/cold vapour AAS, or cold vapour AFS, or ICP-MS	APHA 3112B, USEPA 245.7, APHA 3125	0.0001 mg/L
TPH	Solvent-washed glass	< 4°C, H_2SO_4 to pH <2	7 days	Solvent extraction, GC-FID	OIEWG or USEPA 8015C	0.2 mg/L
VOCs	Solvent-washed amber glass	< 4°C	7 days	Purge and trap or headspace extraction, GC-MS	USEPA 5021	0.005 mg/L
SVOCs	Solvent-washed glass	< 4°C	14 days	Solid phase or liquid/liquid extraction (LLE), GC-MS selected ion monitoring (SIM) quantification	USEPA 8270	0.01 mg/L
PAHs	Solvent-washed glass	< 4°C	14 days	Solid phase or LLE, GC-MS SIM quantification	USEPA 8270	0.0001 mg/L
Phenols	Solvent-washed glass	< 4°C, H_2SO_4 to pH <2	28 days	Solid phase or LLE, GC-MS SIM quantification	USEPA 8270	0.01 mg/L

8 Data Collection, Management and Manipulation

8.1 Metadata Collection

In addition to collecting stormwater quantity and quality data, information about the sampling site and the storm events monitored should be collected. This type of information (called metadata) aids in the interpretation of results and the use of the data for more broader purposes, such as region-wide studies of stormwater quality.

The recommended metadata to be collected is outlined in Tables 8-1 to 8-3. This list will provide for Environment Southland's operational needs as well as being consistent with a national database for urban runoff (URQIS, see Gadd et al., 2013). Although the list looks extensive, items in Table 8-1 need only be collected once even when monitoring occurs on multiple occasions. Most of the items in these tables are readily available at the time of sampling, but is typically much more time consuming to collate at a later date.

Table 8-1: Metadata related to stormwater studies and monitoring site locations. Shaded lines are essential information, unshaded lines are useful data if available.

Metadata	Details
Main sponsoring agency	The funder of the stormwater monitoring (e.g., the territorial authority name)
Monitoring agency	The organisation undertaking the monitoring (e.g., consultancy name)
Publication details	Reference details for a published report, ie author, date, title, publisher, publication number.
Site name	Text entry – a unique name for every sampling site
Town	Text
Water type	Freshwater – stream; Stormwater – untreated; Stormwater – treated; Saline water - estuarine / coastal; Stormwater - treatment unknown; Combined stormwater / wastewater; Freshwater – lake; Stormwater - partially treated catchment
Stream name	Official name of the stream
Catchment name	Catchment the s/w discharges into, either a stream or coastal catchment
Presence of CSOs upstream	Present, Not present, Unknown
Primary, secondary & tertiary landuse	Low-density Residential, Medium-density Residential, High-density residential, LID residential, Commercial, CBD, Light industrial, Heavy industrial, Open-space, Mixed, Roads >20,000vpd, Roads 5000-20,000vpd, Roads <5,000vpd, Carparks, Pasture, Forest
Catchment area	The area of the catchment draining to the stormwater monitoring site (in m^2 or ha)
% imperviousness	The percentage of the drainage catchment covered with impervious surfaces
Stormwater treatment type	Essential if applicable: Dry detention pond, Wet detention pond, Wetland, Infiltration basin / trench, Raingarden, Swale / filter strip, Oil / water separator, Sand filter, Proprietary filter device, Proprietary hydrodynamic device, Green roof, Porous pavements, Treatment train, Street sweeping, Other (describe)

Table 8-2: Metadata related to monitoring details. Shaded lines are essential information, unshaded lines are useful data if available.

Metadata	Details
Sampling type	Storm event sampling, Baseflow sampling, or Continuous monitoring
Sampling mode	Grab, flow-proportional composite, time-proportional composite
Flow structure	Sharp-crested 60-degree v-notch weir, Sharp-crested 90-degree v-notch weir, Sharp-crested 120-degree v-notch weir, Sharp-crested trapezoid (Cipolletti) weir, Sharp-crested rectangular weir, Broad-crested - rectangular weir, Broad-crested, Crump / flat v weir, Flume, Orifice (round), Orifice (square), No control structure, Sharp-crested v-notch weir, angle unspecified; Artificial rock/concrete bed
Flow monitoring instruments	Essential if applicable: Bubble Gauge, Digital Recorder, Graphic Recorder, Crest Stage Indicator, Deflection Meter, Stilling Well (float and counterweight), CR Type Recorder, Acoustic Velocity Meter, Electromagnetic Flow Meter, Pressure Transducer
Event start date / time	Date / time value for the start of event monitoring
Event end date / time	Date / time value for the end of event monitoring
Sampling type	Grab, flow-proportional composite, time-proportional composite
Rainfall depth	The total rainfall that fell during the storm event (mm)
Rainfall duration	The length of time the rainfall fell during the storm event (hours and mins)
Rainfall site	Text describing the location of rainfall monitor or a site code for the monitor
Antecedent dry period	Number of dry days (<1 mm of rainfall) prior to sampling
Mean flow rate	Mean flow at the site during the storm event
Peak flow rate	Maximum flow at the site during the storm event
Total volume	Total volume of stormwater at the site during the storm event (essential if calculating loads)

Table 8-3: Metadata related to water samples collected. Shaded lines are essential information, unshaded lines are useful data if available.

Metadata	Details
Sample number	Numeric value (if more than one sample analysed per event)
Sampling scheme	Grab / manual probe (discrete sampling); Automatic, flow-proportional; Automatic, time-proportional; Automatic, volume-proportional
Sample type	Discrete sample, Flow-proportional composite, Time-proportional composite, First flush, Other (mixed) composite, Not clear/historic data set
No. of subsamples	Number of sub-samples comprising a composite sample

8.2 Data Storage, Checking and Analysis

Data collected from the field (e.g., flow measurements) and supplied by laboratories should be checked for errors. Standard QA/QC protocols developed for assuring the quality of flow data are relevant to purpose-collected stormwater flow data as much as any other flow records (such as river flows). Accordingly, we expect that Environment Southland and local councils in Southland will follow existing QA/QC protocols in collecting and checking flow data for stormwater monitoring purposes. This is likely to include checking logged water levels with measurements independently measured in the field, and cross-checking the correspondence of records between sites and with rainfall records.

In addition to these standard checks, stormwater flow monitoring and its use to trigger autosamplers can throw up some particular issues which, if missed, have the potential to lead to significant errors in the calculation of loads. Two recurring issues, based on our experience are as follows.

Firstly, stormwater catchments can be of variable size, increasing during extreme rainfall events where runoff exceeds the capacity of upstream catchpits. Evidence of this comes from events during which peak flows are markedly higher than during any other events. In such cases, the relationship between event runoff volumes and rainfall should be checked and compared with that during other events. Inclusion of additional runoff from outside the catchment of interest will result in an overestimate of event load.

Secondly, supposedly volume-proportional samples are not always collected after intervals of equal volume. This can be the case where a sample is collected near the end of a shower. Water level then drops below the initial autosampler trigger level. During the next shower a subsequent sample is collected as soon as the water level rises back above the trigger level, rather than after the specified flow volume has accumulated since the previous sample. In order to check for this, it is necessary to review the logged data on volumes between samples. Where a lower volume than that specified has accumulated at the time of sampling, the reduced volume should be used in calculating the load connected with that particular sample or in the calculating how much of that sample to include in a composite.

For some stormwater quality measurements, such as temperature and pH, there is a natural range which can be expected (i.e., 0-14 for pH) and values outside these will be errors. For indicator bacteria the range in values can be extremely variable and errors may not be as obvious. For most measurements, outlier analysis, or comparisons to expected stormwater quality (e.g., reviews or outputs from the Urban Runoff Quality Information System (URQIS)) can be useful to indicate errors in data entry.

Data reported by laboratories as less than the detection limit must be handled carefully. These data should not be reported as “zero” as this is inaccurate and will skew any data summaries. Data recorded without the limit of detection, such as “BDL” (below detection limit) or “ND” (not detected) conceals potentially valuable information. Data less than the detection limit will ideally be stored with the limit of detection recorded and a flag to indicate it was less than this value, such as “< 0.001”. In databases that will not allow the mixture of characters, a second column or field maybe required to store the flag. This type of system is used by other regional councils around New Zealand, for example Auckland Council’s Hydstra database.

8.3 Calculation of EMCs

As described in the introduction, the EMC is the flow-proportional average concentration of a given parameter during a storm event. EMCs can be either measured directly, if a flow-weighted composite is prepared over the entire storm event; or calculated from measurement of discrete samples, using the formula below:

$$EMC = \frac{Total\ pollutant\ loading\ per\ event}{Total\ runoff\ volume\ per\ event} = \frac{\sum V_i C_i}{V}$$

Where V_i is the runoff volume at the time of sampling; C_i is the concentration of that parameter in individual samples at time i and V is the total runoff volume for the event. More information on calculating EMCs can be found in Gulliver et al. (2010).

8.4 Calculation of Loads

Loads of contaminants can be calculated from either discrete samples or composite samples, to provide loads either at a certain point in time or event-based totals. Loads (g or kg) are calculated as the concentration of contaminant in a sample (g/m^3), multiplied by the volume of stormwater discharged (m^3).

For a discrete sample, the **load** is the concentration of contaminant in the discrete sample multiplied by the volume of stormwater represented by that sample concentration.

For a flow-weighted composite sample collected over the whole storm event, the **total event load** is the concentration of contaminant in the composite sample multiplied by the total volume of stormwater discharged over the storm event.

Event-based loads (or event-based concentrations) can be used to estimate **annual loads** using one of several methods.

1) Using the Simple Method (Schueler 1987), EMCs are calculated for each event monitored and the average EMC is used to estimate annual loads. The annual discharge from each sub-catchment can be calculated from annual rainfall, the catchment area and a runoff coefficient. Runoff coefficients should be based on accepted values (e.g., from Auckland Council's TP10 (ARC, 2003)), or where possible, based on the measured stormwater flow data.

   Annual load (kg/year) = EMC (g/m^3) × Annual rainfall (m/year) × catchment area (m^2) × runoff coefficient (unit-less) ÷ 1000

2) Using quantitative stormwater models such as SWMM, SLAMM, MUSIC (Model for Urban Stormwater Improvement Conceptualisation, CRCCH 2005), or NIWA's StormQual Model (see Timperley & Reed 2005).

9 Potential Problems in Stormwater Monitoring

There are a number of issues that may be expected to occur during a stormwater monitoring programme (adapted from Law et al. 2008). We have added comments on some ways to address these potential issues.

- Insufficient data to accurately characterize land use and land cover in catchments. Data could be obtained from GIS analysis of aerial photographs, along with on-ground reconnaissance surveys.
- Difficulty finding catchments that are representative of a particular land use type (e.g., 80 to 100% of catchment).
- Run-off from upstream properties or catchments may mix with the stormwater discharge of interest. In this case it may be possible to sample the upstream source as well as the downstream discharge and calculate the difference in stormwater contaminant loads or concentrations. Alternatively stormwater could be temporarily piped around the collection point.
- Variable size of stormwater catchments during extreme rainfall events where runoff exceeds the capacity of upstream catchpits. Flow data needs to be checked along with rainfall records to identify if this is an issue.
- Equipment repair or replacement due to vandalism, damage from high flow events, or malfunction. To reduce vandalism, all equipment should be housed in a lockable box and if possible locate this box within private premises.
- Insufficient samples collected due to lack of runoff-producing storm events, sampling errors, or storms occurring during “off” hours. Monitoring programmes need to be flexible and allow an adequate timeframe from the outset.
- Miscalculating storm size and filling too few bottles or running out of bottles before storm event finishes; or alternatively if using sampler to prepare composites, under or over-filling bottles. If storm size is under-estimated and it appears that the sampler will run out of bottles, it may be possible to visit site and re-stock bottles in sampler. Event size needs to be estimated as close as possible to the event based on most up-to-date weather forecasts.
- Samples not analyzed because criteria not met (e.g., sample contamination in field or lab, insufficient sample volume, holding time not met). In some cases (such as holding time not met for bacterial analysis) samples may still be able to be analysed for other analytes so that some use is made of samples.
- Errors or malfunctions during lab laboratory. If there is sufficient spare sample collected and stored (e.g.; in refrigerator), it may be possible to repeat the analysis.

Part 2: Recommended Design of Stormwater Monitoring Programmes

10 Overview

This section provides recommendations for the design of stormwater monitoring programmes in relation to four different objectives. These recommendations summarise the relevant components of each monitoring programme, drawing on the discussion provided in Part 1 of this report. The detailed information provided in Part 1 should be referred to for further explanation and justification.

11 Objective 1: Measure Maximum Concentrations for Comparison to Consent Limits or Water Quality Guidelines

11.1 When this objective may apply

Consent conditions may require contaminant concentrations to be measured in stormwater discharges or in the immediate receiving environments. When measured in the discharges, concentrations may be compared to particular consent conditions such as “maximum TSS of 100 mg/L”. If downstream receiving environment quality is of most interest, this should be monitored directly and compared to standards within Environment Southland’s regional plan or to relevant water quality guidelines (WQG) such as the ANZECC water quality guidelines (ANZECC 2000).

11.2 Important Considerations for Monitoring

For measurements of concentration to be compared directly to consent limits or water quality guidelines, the most important monitoring aspects are that the sample(s) measured accurately represent the poorest water quality discharged during a storm. Contaminant concentrations in stormwater are extremely variable, both within a particular storm, between different storm events and between different discharge locations. The peak concentration may occur at the beginning of a storm event (i.e., during the “first flush”), with the peak stormwater flow, or even at the end of the storm event. This generally cannot be predicted for a site prior to initial sampling, or even after sampling at a site multiple times, as it can be different for different storm events.

To ensure that samples collected do represent the poorest water quality of the storm event, we recommend collection of a larger number of samples throughout the event, and selection of a sub-set of these for analysis (see Figure 11-1). The recommended design of a monitoring programme for this objective is given in Table 11-1.

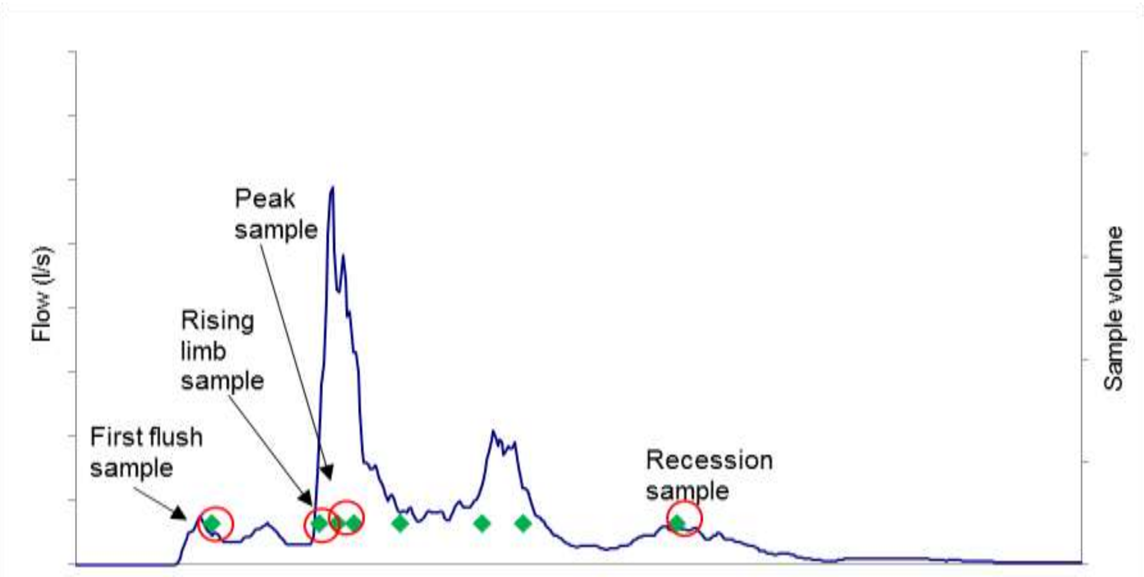

Figure 11-1:Illustration of samples to be analysed for an example storm.

Table 11-1: Recommended monitoring programme for Objective 1.

Aspect	Recommendations
Sites	At point of discharge into receiving environment; and/or downstream of discharge (in well-mixed area) to assess compliance with WQG
Storm size	Range of storm sizes, guided by analysis of storm event rainfall distribution
Number of storms	5 – 10 storms
Antecedent dry period	5 days between storm events
Flow measurement	Any method as accuracy of flow measurement less important – but measurement of at least water level is required as a surrogate for flow hydrograph
Sampling type	Automatic sampler is recommended to ensure first flush collected, but grab samples may be feasible in some circumstances (short distance to sampling site etc)
Sampling mode	Preference for samples collected on volume-proportional basis to increase chance of sampling peak flow as sample collection is more frequent during periods of higher flow; and sufficient volume of sample will be collected for analysis of discrete samples. If measuring water level as surrogate for flow then time-proportional is the only option.
Samples collected	At least 10 discrete samples per event to ensure capture of samples at desired stages of hydrograph
Samples analysed	4 discrete samples per storm: one from first flush; one on rising limb; one at peak and one on falling limb or recession.
Analytes	Primary & secondary suites appropriate to catchment land use, consent limits and water quality standards or guidelines.

12 Objective 2: Measure Event-based Mass Loads or EMCs

12.1 When this objective may apply

Contaminant loads are mass-based estimates of the total contaminants that are discharged from a catchment or specific location during a particular storm event. Loads are typically measured in kg or kg/event. There are many reasons why contaminant loads may be measured including:

- Where there are limits to the allowable mass to be discharged from a location;
- To compare between sites and/or catchments (ideally in this case the same storm event is monitored at each site);
- To estimate the total loads into an estuary from multiple sources (such as urban versus rural versus point discharges);
- To calibrate or validate catchment-scale models, on an event or annual time-scale;
- To use for modelling potential benefits of stormwater treatment.

EMCs are equally useful for many of the above reasons, such as comparing between sites and catchments and modelling benefits of stormwater treatment devices.

12.2 Important Considerations for Monitoring

When monitoring event-based loads, it is important to accurately measure the stormwater flows as well as the stormwater quality. As loads are the product of flow and concentration, the calculated loads will not be accurate if the flows are not accurate. Contaminant concentrations can range by 10-100 within a storm event, but flows can vary by 1000x.

For event-based loads, only one sample per storm event needs to be analysed if flow-weighted composites are prepared for analysis. Composite samples based on flow-proportional or volume-proportional sampling will only provide accurate estimates of the event load if the flows are accurately measured at the time of sample collection. The recommended design of a monitoring programme for this objective is given in Table 12-1.

Table 12-1: Recommended monitoring programme for Objective 2.

Aspect	Recommendations
Sites	At point of discharge from catchment or site of interest
Storm size	Range of storm sizes, guided by analysis of storm event rainfall distribution
Number of storms	5 – 10 storms
Antecedent dry period	5 days between storm events
Flow measurement	Weir with float & counterweight recommended as accuracy of measurement very important. Refer to Section 5 for circumstances when it may be necessary to use other methods.
Sampling type	Automatic sampler required
Sampling mode	Preference for samples collected on volume-proportional basis to increase chance of sampling peak flow as sample collection is more frequent during periods of higher flow; alternatively flow-proportional can be used with a short sample time increment.
Samples collected	At least 10 discrete samples per event to ensure capture of sub-samples throughout entire storm event
Samples analysed	One flow-weighted composite per storm
Analytes	Primary & secondary suites appropriate to catchment land use

13 Objective 3: Identify Sources of Poor Stormwater Quality

13.1 When this objective may apply

In some locations, there can be existing knowledge of poor stormwater quality or environmental degradation linked to stormwater. A more in-depth investigation may be warranted to determine the extent of contamination and trace the likely sources. An example of this type of investigation is an investigation undertaken in the Haytons Stream catchment of Christchurch, a predominantly urban catchment with areas of residential and industrial land use, to identify the sources of elevated sediment, nutrients, metals and bacteria (Moores et al. 2009).

13.2 Important Considerations for Monitoring

For this objective, multiple sites are required within the area of interest. These should include a site at the bottom of the catchment, at the downstream extent of different land uses and upstream and downstream of any suspected sources of contamination. Samples should be collected for the same event(s) in all locations to ensure that results are comparable between sites. However usually samples should not be collected at exactly the same time, but during the same part of the hydrograph (as illustrated in Figure 13-1), to allow for the transport of water (and associated contaminants) from upstream to downstream. Baseflow sampling can also be included if illegal discharges or cross-connections are suspected in the catchment.

The recommended design of a monitoring programme for this objective is given in Table 13-1.

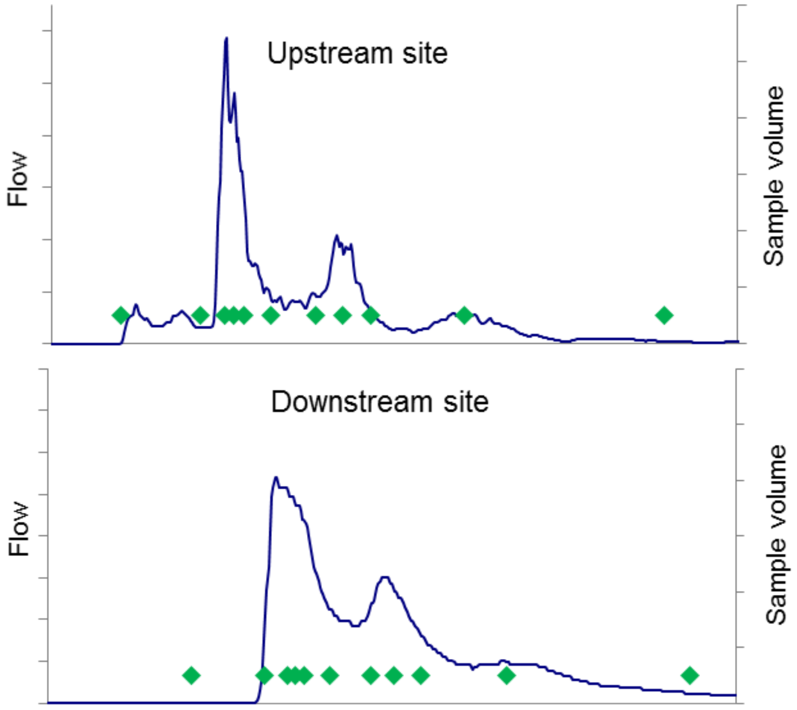

Figure 13-1:Illustration of sampling at same *part* of hydrograph, rather than same *time.*

Table 13-1: Recommended monitoring programme for Objective 3.

Aspect	Recommendations
Sites	At multiple locations in a catchment, including catchment outlet, subcatchment outlets and up- and downstream of potential significant contaminant sources
Storm size	Range of storm sizes, guided by analysis of storm event rainfall distribution, and baseflow sampling
Number of storms	2-3 storms and at least one at baseflow
Antecedent dry period	5 days between storm events
Flow measurement	Any method as accuracy of flow measurement less important – but measurement of at least water level is required as a surrogate for flow hydrograph
Sampling type	Automatic sampler is easiest to ensure samples collected at same time in different locations (otherwise require multiple staff on site) but manual sampling can be used for baseflow sampling.
Sampling mode	Preference for samples collected on volume-proportional basis to increase chance of sampling peak flow as sample collection is more frequent during periods of higher flow; and sufficient volume of sample will be collected for analysis of discrete samples. If measuring water level as surrogate for flow then time-proportional is the only option. Grab samples are suitable for baseflow sampling.
Samples collected	At least 10 discrete samples per event to ensure capture of sub-samples throughout entire storm event. One sample during baseflow.
Samples analysed	One flow-weighted composite per storm OR 4 discrete samples per storm: one from first flush (first 30 mins of event); one on rising limb; one at peak and one on falling limb or recession
Analytes	Primary & secondary suites appropriate to catchment land use

14 Objective 4: Evaluate Treatment Device Efficiency

14.1 When this objective may apply

In some cases, there is a desire to know whether a stormwater treatment device is performing as it was designed to, for example when a resource consent has been granted on the basis that a device will remove 75% of the incoming sediment load.

14.2 Important Considerations for Monitoring

There is a wealth of information related to monitoring stormwater devices to assess device efficiency. At least four protocols are in use in the United States (TARP 2003, USEPA 2002, USEPA & ASCE 2002, WDOE 2008) and one is proposed for Auckland (Wong et al 2012). These protocols are extensive and require sampling of at least 12 storms (up to 35 for some protocols) over a range of storm event sizes, collection of multiple samples to characterise each storm event, accurate measurement of flows and concentrations and strict quality control procedures. These protocols are designed for device manufacturers and suppliers to demonstrate device performance and achieve approval for their use from regulators and are therefore more robust than would be required for this objective. It is possible to get an indication of a particular device's performance (for example, if suspected of underperforming), from a less intensive monitoring exercise, although many of the principles in these protocols will be applicable.

There are a variety of approaches to evaluating the performance of a stormwater treatment device, such as percentage load reduction, percentage concentration reduction or statistical comparison tests. The different evaluation methods are described in USEPA and ASCE (2002) along with their limitations and more briefly in Moores et al. (2012). The most common methods compare either loads or EMCs and therefore the recommendations provided here are relevant to measurement of loads and EMCs.

To provide any estimate of the device performance, both stormwater quality and quantity must be measured accurately throughout the storm events monitored. Such assessments **cannot** be made on the basis of single (or even multiple) grab samples collected at the inlet and outlet of a device. Stormwater quality is too variable within an event for a single sample to accurately reflect the quality. In our experience multiple storms need to be monitored to assess the treatment efficiency as the performance of a stormwater treatment device can vary widely between storm events. Furthermore, any equipment failure at either the inlet or outlet will mean all the collected samples at the other location are of no or limited use, as a full set of samples must be collected at both sites for each storm event. The recommended design of a monitoring programme for this objective is given in Table 14-1.

Table 14-1: Recommended monitoring programme for Objective 4.

Aspect	Recommendations
Sites	At input to, and exit from, treatment device. These must reflect only the water entering

Aspect	Recommendations
	& exiting the device, with no addition of other stormwater sources.
Storm size	Range of storm sizes, guided by analysis of storm event rainfall distribution
Number of storms	> 10 storms including some large events that are at 75% of design storm and one that is larger than design storm
Antecedent dry period	5 days between storm events, guided by analysis of storm event rainfall distribution
Flow measurement	Weir with float & counterweight recommended as accuracy of measurement very important. Refer to Section 5 for circumstances when it may be necessary to use other methods.
Sampling type	Automatic sampler required
Sampling mode	Samples collected on flow- or volume-proportional basis
Samples collected	At least 10 discrete samples per event to ensure capture of sub-samples throughout entire storm event
Samples analysed	One flow-weighted composite from each site per storm
Analytes	Analytes appropriate to the design specifications of the treatment device (e.g., to remove solids or metals)

15 Multiple Objectives

When there are more than one objective, it is possible to amend the programmes to suit both. When designing a programme for multiple objectives, the recommendations for each objective should be reviewed and final programme should incorporate the more onerous of the two options. For example, if either time-proportional or volume-proportional sampling is suitable for one objective, but volume-proportional sampling is recommended for the other, then the final programme must use volume-proportional sampling.

In cases where both composites and discrete samples are required, both can be analysed from the same storm event if sufficient sample is collected (eg 800 mL or more). A flow-weighted composite can be prepared by taking an equal volume from each bottle; and the remaining sample could be analysed as a discrete sample. Alternatively all discrete samples could be analysed and the flows at each sampling period used to calculate a flow-weighted average for the entire event.

16 Summary

Stormwater monitoring is an essential task in understanding stormwater for catchment management and planning; however monitoring programmes are not always designed to deliver useful information to managers. There are many aspects to a stormwater monitoring programme and each need to be carefully considered, including monitoring objectives, site selection, storm events, flow measurement methods, water sampling methods, analytes and methods, data collection, management and manipulation.

This report has briefly reviewed the major considerations within each of these aspects for a monitoring programme, including advantages and disadvantages of different options. We have provided our recommendations and the conditions under which these are appropriate.

Part Two of this report uses the recommendations in Part One to recommend stormwater monitoring programmes to meet four monitoring objectives. This part is presented in a way that will allow a stormwater manager to rapidly design a detailed stormwater monitoring programme for most purposes. For each objective, we have provided an outline of when this objective would apply and the basic rationale for the programme design. The four objectives were as follows:

1. Measuring maximum concentrations (in a discharge or receiving environment) for comparison to water quality standards or guidelines;
2. Measuring event-based mass loads or EMCs;
3. Identifying sources of poor stormwater quality;
4. Evaluating stormwater treatment device efficiency.

17 Glossary of abbreviations and terms

ANZECC	Australian and New Zealand Environment and Conservation Council
APHA	American Public Health Association
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
Automatic (auto-) sample	Sample taken using an automatic water sampler.
Automatic (auto-) sampler	Device used to automatically take either discrete or composite water samples. Can refer to both passive and pumped auto samplers.
BMP	Best Management Practices – usually refers to drainage infrastructure intended for water quantity and quality control
Composite sample	Mixed sample whereby discrete water samples are composited proportionally either on the basis of time, flow or volume.
Discrete sample	Single water samples taken at one point in time and space using either an automatic or manual sampler
EMC	Event Mean Concentration
Manual sample	Discrete water sample taken using a manual water sampler. Often referred to as a grab-sample.
Manual sampler	Hand held sampler used to take manual samples consisting of a sample container which is lowered into the water stream to take samples.
PDEP	Auckland Council Proprietary Devices Evaluation Protocol
SSC	Suspended Sediment Concentration
Suspended solids	Solids held in a fluid suspension.
TSS	Total Suspended Solids
US EPA	US Environmental Protection Agency
USGS	United States Geological Survey
WERF	Water Environment Research Foundation

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