
30 STORMWATER QUALITY MONITORING

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30.1 GENERAL

The main objective of this Chapter is to highlight the essential procedures and requirements for stormwater quality monitoring. Monitoring plays an important role in the design and operation of stormwater management facilities. Parts of this Chapter are adapted from NSW EPA (1997) and Dodson (1999).

30.1.1 Purpose of Monitoring

The chemical and biological monitoring of stormwater systems can provide valuable information on the existing characteristics of a system and the performance of stormwater management practices. It is important that monitoring programs be carefully designed and have a specific aim, as poorly designed programs can often yield results with limited relevance at significant cost. It is important that monitoring programs are carefully designed to:

- have a specific aim;
- relate the monitoring to both the characteristics of the catchment and water body being monitored and the prevailing climatic conditions; and
- select the parameters for water quality testing to ensure that the results can be used to satisfy the aim of the program.

Details of monitoring program design can be obtained from Ward et al. (1990) and EPA (1995). The following discussion on monitoring relates to rivers and streams, with different monitoring techniques required for lakes and estuaries.

30.1.2 Types of Monitoring

(a) Baseline Monitoring

The primary goal of baseline monitoring is to determine the prevailing water quality and/or ecological conditions in a stormwater system or receiving water body. This might be done to determine conditions prior to an urban development, or following a development to assess the extent of any impacts on the receiving water bodies, perhaps with a view to design and prioritise remedial measures within the catchment. This long-term monitoring is primarily done at regular time intervals and therefore, mainly in dry weather conditions (which occur for the majority of the time) and is similar to local monitoring practices. The results of this form of monitoring can be related to the ambient water quality objectives.

Flow measurement for this monitoring is desirable but not necessary, although flow velocity should be noted during sampling. A combination of chemical and biological monitoring is an advantage for this form of monitoring. The macroinvertebrates commonly used in biological monitoring respond to long-term water quality conditions,

while chemical monitoring represents instantaneous conditions only. Continuous monitoring using water quality probes may also provide useful data.

If a baseline water quality study has been done in the catchment prior to a land use change, post development monitoring can utilise the same sites and monitoring techniques. In these circumstances, two levels of investigation may be appropriate:

- screening level studies on a regular basis; and
- more comprehensive monitoring if the conditions are found to be unsatisfactory and the causes of degradation need to be determined.

(b) Event Monitoring

Event monitoring refers to the investigation of water quality (or some related factor) resulting from a specific runoff-producing storm event. The aim of event monitoring is to provide details on the hydrological and water quality conditions of a catchment during, or following, storm events. The data collected may be used to calibrate water quality models.

Pollution concentrations during storms are generally higher than those occurring under dry weather conditions, especially, in the rising limb of the respond hydrograph. Sufficient samples (usually collected by an automatic sampler) should be collected to assess variations in concentration during passage of the event to ensure that samples are adequately representative.

Flow measurements should be taken at the same time as instantaneous water quality sampling during the passage of a storm. If the purpose of monitoring is to derive an estimate of Event Mean Concentration (EMC), sufficient events should be monitored to derive a reliable estimate of the EMC from the catchment for each pollutant of interest. The EMC value is flow-weighted (see Chapter 15) and its calculation requires data on flow. Collection of flow-weighted composite samples can also be undertaken (US EPA, 1993) to estimate the EMC.

(c) Stormwater Treatment Measure Performance Monitoring

The goal of this form of monitoring is to assess the actual performance of a stormwater treatment measure relative to its expected performance. This form of monitoring will be dependent on the type of management practice, with the most common practice expected to be monitored being wet basins and artificial wetlands.

Monitoring of these practices should be undertaken during both dry weather (base flow) and storm event conditions. The dry weather monitoring aims to detect whether the basin has a negative impact on dry weather pollutant concentrations and requires simultaneous monitoring of

inflow and outflow concentrations. Monitoring of flow is not necessary, although flow velocity should be monitored on a continuous basis throughout the passage of the storm event (as for event monitoring). The resulting reduction in inflow load for the event using the calculated hydraulic residence time can be related to the expected performance. Continuous monitoring of these practices using water quality probes will also provide useful information.

Two levels of investigation may again be appropriate. A screening level study could be undertaken to assess the indicative performance of the management practice. Comprehensive monitoring could be undertaken if the indicative performance is found to be unsatisfactory and the cause of this poor performance needs to be determined.

(d) Paired Catchment Monitoring

Paired catchment monitoring is a method of investigating the impacts of catchment change, such as urbanisation, or of changes in stormwater management practices. In this method two adjacent catchments with similar characteristics are selected. One catchment is then modified and the other is kept unchanged to provide reference data. An overseas example is described in National Capital Development Commission (1980).

In a study of paired catchments, data is analysed from the same rainfall events from the modified and reference catchments. Note that over a given period, the number of runoff events in the non-urban catchment will generally be lower than the number from an urban catchment, due to the higher runoff rates in urban catchments.

30.1.3 Monitoring Requirements

A number of facilities are required to perform analytical monitoring of their discharge. Analytical monitoring is required for the sectors or subsectors, which are determined to have a high potential to discharge a pollutant at concentrations of concern. To identify these dischargers, the sampling data were divided by sector or subsector and statistically analysed. The median concentration value and other statistics should be calculated for each pollutant within each subsector. The median value should be compared to pollutant benchmark value (can be derived from the water quality criteria).

A benchmark is the concentration at which a storm water discharge could potentially impair, or contribute to impairing, water quality or affect human health from ingestion of water or fish. If a facility is discharging pollutants at levels below the established benchmarks, then the facility represents little potential for water quality concern, and would not warrant further analytical monitoring. Therefore, the benchmarks help to determine whether a facility's storm water pollution prevention

measures are being successfully implemented. The benchmark concentrations are not effluent limitations and should not be interpreted or adopted as such. These values are merely levels which the DOE has used to determine whether a storm water discharge from any given facility requires further monitoring to ensure that the facility has been successful in implementing a storm water pollution prevention plan. As such, these levels represent a target concentration for a facility to achieve through implementation of pollution prevention measures at the facility.

Benchmark concentrations can be determined based upon a number of existing standards or other sources. The DOE must also develop values, which can realistically be measured and achieved by dischargers. Monitoring must be conducted for the same storm water discharge outfall in each sampling period. Where a given storm water discharge is addressed by more than one sector's or subsector's monitoring requirements, the monitoring requirements for the applicable sector's or subsector's activities are cumulative. Therefore, if a particular discharge fits under more than one set of monitoring requirements, the facility must comply with all sets of sampling requirements. Monitoring requirements must be evaluated on an outfall-by-outfall basis. Analytical monitoring is designed to provide some feedback for a facility operator to assess the effectiveness of the pollution prevention plan. An incentive is also built in to stimulate the implementation of more effective pollution prevention measures, the average concentration for each required monitoring parameter must be computed, using all samples collected. If the average concentration for a pollutant parameter is less than or equal to the benchmark value, then analytical monitoring is not required for that pollutant. If, however, the average concentration for a pollutant is greater than the analytical monitoring is conditional on the facility's maintaining operations and BMPs that will ensure a quality of storm water discharges consistent with average concentrations recorded.

30.2 DESIGN OF STORMWATER QUALITY MONITORING PROGRAMS

30.2.1 Site Selection

There are a number of potential considerations when selecting a monitoring site including:

- purpose of the monitoring program;
- safe access to the sites;
- location of past monitoring (if applicable);
- avoiding upstream point sources of pollution (or the ability to simultaneously monitor this source);
- well mixed flow conditions, so that the water quality sample is representative of the conditions at the monitoring site;

- the presence of physical structures that may influence water quality, such as weirs or dams;
- uniform catchment landuse if undertaking event monitoring for the purpose of calibrating a water quality model;
- a flow control structure at the site or the ability to define a rating curve for flow measurement (particularly for event monitoring);
- a power supply for some event monitoring equipment; and
- compatibility with monitoring activities undertaken under the auspices of the Department of Environment.

For baseline monitoring relating to the impact of a specific (existing or proposed) development, the sampling sites can be located upstream and downstream of the (proposed) development site. For event monitoring, a discrete catchment should be defined by the monitoring site. Section 30.2.4 discusses the influence on equipment for water quality sampling of catchment size.

30.2.2 Monitoring Period and Frequency

(a) Baseline Monitoring

For baseline monitoring, the monitoring period should be sufficiently long to investigate potential seasonal effects on water quality and represent reasonably 'average' flow conditions (i.e. not a drought period). Monitoring over a twelve month period is likely to be appropriate, although the total rainfall over this period should be within $\pm 25\%$ of the average annual rainfall in the vicinity of the site and the rainfall for each month of the monitoring period should generally be $\pm 50\%$ of the long term average monthly rainfall. If this is not achieved, consider extending the monitoring period.

To achieve a degree of certainty regarding the monitoring results, the number of samples taken during the monitoring period should account for both any seasonal influences and variability in concentrations. The sampling frequency should also ensure that the samples are statistically independent. To account for seasonal variability, one sample per month can be collected (Ward et al., 1990). EPA (1995) contains a technique for determining the minimum number of samples for a desired statistical confidence level.

(b) Event Monitoring

There is no general rule for determining the number of monitoring events required to confidently estimate an EMC. As a guide, at least six to ten events may need to be monitored. These events should range in size from high frequency (e.g. less than one month ARI rainfall) to moderately frequent (e.g. greater than three months ARI rainfall). Low frequency events are also beneficial (e.g. greater than six months ARI).

To define pollutant loads or EMCs from urban catchments with reasonable degree of accuracy, Bedient et al. (1980) suggested collecting a minimum of four samples during the period of increasing flow from the storm, and six samples during the fall of the storm. Kachka et al. (1994) also described an approach for reducing the number of sample analysis without significantly affecting the accuracy of the load estimate.

(c) Stormwater Treatment Measure Performance Monitoring

The period and frequency of monitoring of stormwater treatment measure performance monitoring can be similar to that for event monitoring.

30.2.3 Monitoring Parameters

Table 30.1 provides some guidance as to the water quality parameters that can be monitored during baseline and event monitoring programs.

The detection limits used in the laboratory undertaking the analysis should be specified at the start of the monitoring program. This particularly applies to phosphorus and nitrogen, for which stormwater concentrations are typically considerably lower than those found in sewage. It is important to discuss with the laboratory undertaking the sample analyses the minimum volume of each sample required for each test, as this may vary with detection limit. A guide to the minimum sample volume can be found in APHA (1995).

It should be noted that conventional water quality monitoring does not involve the measurement of bed load. This may represent a significant proportion of the total sediment load from a catchment.

30.2.4 Monitoring Techniques

Grab sampling techniques for baseline water quality studies are reasonably well known. The use of automatic samplers is described in Section 30.2.4, with additional information provided in Angus et al (1993) and US EPA (1993).

Biological monitoring is a comparatively new technique in Malaysia and monitoring techniques are currently evolving. References to biological monitoring techniques are included in EPA (1995), Davies (1994), Chessman (1995), Rosenberg (1993), EPA (1994), Kramer (1993) and APHA (1995).

For event-based monitoring, flow can be monitored by a meter integral with the automatic sampler or by a separate flow meter. A more sophisticated flow meter can accommodate irregular channel geometries (where a conventional rating curve cannot be readily defined). Rainfall can be monitored using a pluviometer or

pluviograph (tipping bucket rain gauge) connected to a data logger. As event rainfall is of interest, a daily rain gauge is generally unsuitable, although a daily gauge can be installed to check the results from a pluviograph.

(a) Automatic Water Quality Sampling

Automatic samplers are powered devices that collect samples according to programmed criteria. They generally contain the following features (US EPA 1993):

- a programming unit, where instructions on the operation of the sampler are entered;
- a sample intake tube from the sampling point to the sampler;
- flow sensor (some types of units only);
- rain gauge (some types of units only);

- pump to draw water through the tube to the sampler;
- distribution arm which distributes water from the pump to the sample bottles;
- sample bottles, located in the base of the unit (commonly 24, 1 litre bottles); and
- pre-purging mechanism that purge/clean existing stored water in the inlet tube.

Automatic samplers can generally be programmed to collect samples on two bases:

- time:- samples are collected at specified time intervals from an initial trigger; and
- volume (sometimes termed “flow”):- samples are collected whenever a specified volume of water has passed the sampler from an initial trigger.

Table 30.1 Typical Water Quality Monitoring Parameters

Parameter	Baseline Monitoring	Event Monitoring
Suspended solids (SS)	Y	Y
Total phosphorus (TP)	Y	Y
Filterable reactive phosphorus (FRP) ¹	?	?
Total nitrogen (TN)	Y	Y
Total kjeldahl nitrogen (TKN)	?	?
Oxidised nitrogen (NO _x) ²	?	?
Faecal coliforms (FC) ³	?	?
Dissolved oxygen (DO) ⁴	Y	Y
Temperature ⁴	Y	N
Turbidity ⁴	Y	N
pH ⁴	Y	N
Conductivity ⁴	Y	N
Biological	?	N
Heavy Metal	Y	N

Notes:

Y Generally appropriate parameter to monitor.

? Possibly appropriate parameter to monitor.

N Generally inappropriate parameter to monitor.

¹ Testing for FRP can provide an indication of the biological availability of phosphorus, but samples should be filtered within of sample collection.

² Total nitrogen is commonly calculated as the sum of TKN and NO_x, and the reporting of these parameters separately can be useful.

³ Faecal coliforms can be monitored when there is concern regarding bacterial pollution (e.g. recreational areas).

⁴ These parameters can be measured in the field using a portable water quality probe.

For samples with integral flow sensors, sampling is usually triggered by the flow exceeding a specified depth. Automatic samplers without integral flow meters can be connected electronically to separate flow meters. These meters can be programmed to send a signal to the sampler to trigger sampling.

Stormwater samplers are usually programmed on a time basis as programming for collection of samples at specified flow (not volumes) is generally not available. This is not an ideal situation, as hydrograph shapes can vary considerably between storms leading to potentially unrepresentative samples.

Samplers are usually programmed to operate at time intervals based on the expected average duration of storm events at the monitoring site. This recognises that some storm events will be shorter than the 'average' and sampling frequency may be inadequate to define the water quality variation during the storm event. Conversely, events longer than the average may have insufficient samples to define water quality during the latter part of the event.

The time intervals for urban sites will generally be shorter than those for rural sites, due to the more rapid runoff response from impervious surfaces. The sampling period could be defined so that the estimated time of concentration from the catchment occurred approximately one-third of the way through the monitoring period. As the hydrographs rise more rapidly than they fall, the sampling interval will generally decrease with increasing time.

The use of automatic samplers can be difficult in small catchment, particularly urban catchments. This is due to:

- the flow sensor head interfering with flow patterns in the stormwater system when flow depths are low. For example, a sensor head may be 20 mm high with flows less than approximately 30 mm being potentially affected by the sensor.
- time of between 30 and 60 seconds taken to fill the sample bottle, depending on factors such as the length of the intake tube and the difference in elevation between the sampling point and the sampler. This time can be longer if the tube is purged by a sample before commencing filling of a bottle. In small urban catchments, where hydrograph shapes can change rapidly, this can result in insufficient time being available to fill bottles. Alternatively, the filling time sets the minimum time between samples, which may result in insufficient samples being collected for intense storm events.
- complete or partial blocking of the flow sensor head or intake tube by sediment or litter. This can result in inaccurate measurement of flow, inappropriate triggering the sampling and the pumping of air rather than water into the sampler. As the sample volume

distributed to the sampler bottles is based on the pumping time, rather than the depth of water in the bottle, this can result in the partial filling of the sampler bottle.

- relatively high flow velocities in small urban catchments, as the gradients of stormwater systems can be relatively steep. This can reduce the accuracy of the flow meter and the potentially turbulent conditions can result in pumping an air-water mixture by the unit.

There are a number of other potential problems with automatic samplers, including:

- partial filling of bottles;
- events occurring in quick succession, with insufficient time available to collect the samples. This can result in insufficient empty bottles being available for the second or subsequent events;
- event duration exceeding the set monitoring duration;
- power failure;
- blockage of the intake tube;
- damage to the sensor head (e.g. due to sediment); and
- vandalism/theft (need a secured site).

Before samples from an automatic sampler are forwarded to the laboratory for testing, it is useful to assess the sample collection times against the recorded hydrograph. It is important that samples cover the peak and the majority of the rising and falling limbs of the hydrograph. If the early portion of the rising limb and the tail of the falling arm have not been sampled, this is not likely to result in a significant error in estimating the load from the event as the flow at these times is generally comparatively low.

Automatic samplers are generally unsuitable for bacteriological analysis because of the difficulties in maintaining sterility of the apparatus, and in maintaining bacteriostatic conditions in the sample bottles after sampling. Attempts have been made to reduce these problems with the use of refrigeration and comprehensive purging of the uptake tubes, together with sterilisation or disinfection of the tubing following every event.

(b) *In-line Sensing*

Recent improvements in technology have made it possible to continuously monitor many water quality parameters in-line, using electronic sensors. The data can then be stored on data loggers, transmitted to a central supervisory station or even used to trigger indicators or alarms. The fact that data are captured in electronic form eliminates much of the cost and delays associated with sampling and laboratory analysis.

Parameters, which are able to be measured in-line using existing technology include:

- dissolved oxygen (DO);
- BOD;
- TOC;
- Conductivity;
- Temperature;
- pH;
- TDS; and
- Turbidity.

The main limitations with in-line monitoring are:

- Limited range of parameters that can be measured;
- Sensors require periodic re-calibration;
- Sensors typically have higher detection limits (i.e. they are less sensitive) and less accuracy than laboratory analysis methods; and
- The sensors are vulnerable to fouling or damage.

Technological advances in this field are ongoing, and users should consult scientific equipment manufacturers for advice on potential applications.

(c) Biological Monitoring

Biological monitoring is a useful technique in water quality studies of receiving waters. However it unlikely to have much application in urban stormwater systems in Malaysia in the short to medium term. The specialised methods required are outside the scope of this Manual.

Other common features related to sampling for stormwater quality monitoring are given below (Dodson, 1999).

(i) First-flush Grab Samples

A *first-flush grab sample* is obtained within the first 30 minutes (min) of discharge. This is generally the most polluted portion of the discharge, because it may contain pollutants that lie on the surface of the drainage area. The grab sample should be taken from a well-mixed portion of flow stream, so that it is representative of the majority of discharge.

The first 30 min. of discharge may not coincide with the first 30 min. of rainfall. In fact, facilities equipped with detention or retention facilities may experience a considerable delay before the first discharge occurs as a result of a particular rainfall event.

If it is not possible to obtain a grab sample within the first 30 min of discharge, then the grab sample may be obtained within the first 1 h of discharge. However, the monitoring report should note this condition and explain why it was necessary.

Grab samples must be tested in the field for both pH and temperature. Testing for pH provides an indication of the potential availability of metals within the discharge. In some cases it will provide information regarding material management.

Grab samples should be tested in the laboratory for the following "conventional" pollutants:

- Oil and grease (mg/L);
- Total suspended solids, TSS (mg/L);
- The 5-day biochemical oxygen demand, BOD₅ (mg/L);
- Chemical oxygen demand, COD (mg/L);
- Total Kjeldhal nitrogen, TKN (mg/L);
- Nitrate plus nitrite nitrogen (mg/L); and
- Total phosphorus, TP (mg/L).

In addition to these conventional pollutants, discharge should be analysed for several other types of pollutants as applicable; and standards set by DOE.

- Pollutants listed in a storm water effluent concentration guideline for the facility.
- All components, chemicals, and pollutants limited by any existing discharge permits for the facility.
- Any other pollutant which may be present as a result of existing or previous operations at the facility.

Laboratory testing may be done in-house or by an accredited contract laboratory.

(ii) Flow-weighted composite samples

In addition to a grab sample, the second type of sample required is a flow-weighted composite sample, which is a combination of individual "aliquots" (samples) at least 15 min apart, or a minimum of 3 aliquots per hour for the entire discharge or for first 3 h of discharge. Ideally, the aliquots are obtained at constant time intervals 20 min apart. The flow rate is measured at the time each aliquot is obtained.

The samples are combined in proportion to the flow rate at the time each sample was obtained. Along with the total volume of discharge, this provides a method of estimating the average pollutant concentration and total pollutant loading in the discharge. After the storm event ends, the maximum flow rate is identified, and the full volume [generally 1000 millilitres (ml)] of the corresponding aliquot is added to the composite sample container. For aliquots obtained at other flow rates, a lesser volume is added to the composite sample container. The volume in each case is determined by the following equation:

$$V = V_{\max} \left(\frac{Q}{Q_{\max}} \right) \quad (30.1)$$

where

V = volume of individual aliquot added to composite sample container

Q = flow rate measured at time individual aliquot was obtained

Q_{\max} = maximum flow rate observed during storm event

V_{\max} = volume of aliquot obtained at time of maximum flow rate

Table 30.2 illustrates such a computation for a set of 9 aliquots. Note that the peak flow rate is 2.5 cubic metre per minute (m^3/min), which occurred at the time the third aliquot was obtained. Therefore, the full volume of this aliquot (1000 ml) is added to the composite sample. The volume of each of the other aliquots added to the composite sample is proportional to the flow rate measured at the time aliquot was obtained. The Adjusted Volume column is the volume required to produce a total sample of 1000 ml. Figure 30.1 illustrates the relationship between the measured flow rate and computed sample volume for a flow-weighted composite sample.

Table 30.2 Example of Flow-weighted Composite Sample

Sample	Time (min)	Flow Rate (m^3/min)	Weighted Ratio	Volume (ml)	Adjusted Volume (ml)
1	20	1.0	1.0/2.5	400	80
2	40	2.0	2.0/2.5	800	160
3	60	2.5	2.5/2.5	1000	200
4	80	2.0	2.0/2.5	800	160
5	100	1.0	1.0/2.5	400	80
6	120	1.5	1.5/2.5	600	120
7	140	1.0	1.0/2.5	400	80
8	160	0.5	0.5/2.5	200	40
9	180	1.0	1.0/2.5	400	80
Total Volume (ml)				5000	1000

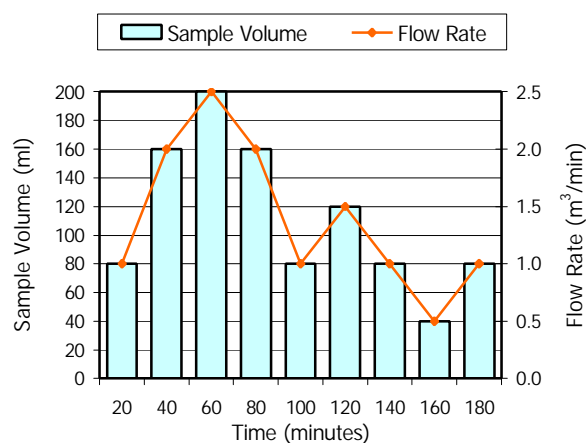


Figure 30.1 Flow-weighted Composite Sample

(iii) Sampling Equipment and Laboratories

It is advisable to coordinate the sampling effort in advance with the laboratory, which will perform the analyses. The laboratory will generally be able to provide decontaminated sample containers with a shipping container and other necessary supplies. The following equipment is recommended:

- *Sample containers.* Plastic sample containers are safer and more convenient, but glass containers may be required for grab samples, because they must be tested for oil and grease. Sample containers should be relabelled and numbered, so as to avoid confusion during or after the storm event.
- *Sample scoop.* A wide, flat plastic scoop is used to obtain storm water samples when the depth of flow is not sufficient to fill sample containers directly.
- *Sample logbook with waterproof markers.* This book is used to record sample times, container numbers, and flow rates occurring at each sample time. A survey field book (available at survey supply stores and most engineering reprographics suppliers) serves as a good sample logbook.
- *Ice chest with ice (or refrigerator).* This is used to lower the temperature of samples to 4°C until they reach the laboratory. All storm water samples must be stabilised so that the chemical composition does not change before the laboratory tests can be performed. Generally, thermal stabilisation (refrigeration) is best. However, in some circumstances, when the sample will not reach the testing laboratory within 24 h, chemical stabilisation may have to be used. If this may be the case, check with the laboratory for instructions.
- *Thermometer.* It is used to perform field tests on grab samples. A good-quality digital electronic thermometer is recommended.

- *A pH meter.* This is also used for field test on grab samples. A good-quality electronic meter with glass electrodes of accuracy to within ± 0.1 pH unit is required. For best results, however, a self-calibrating digital pH meter is recommended. A pH "strip kit" (pH paper) is not acceptable for pH measurements because of the lack of precision.
- *Container of distilled water.* This is used to clean the pH meter, temperature probe, and sample scoop after each use.
- *Watch or stopwatch.* This is needed to record sample time and/or sample intervals.
- *Rain gear.* This is used to protect employees during field work. Flashlights and other equipment may also be necessary.

The chain of custody from the person obtaining the samples to the laboratory should be clearly recorded in writing.

(iv) Manual and Automatic Sampling Methods

An automatic continuous sampler can be used as an alternative to a series of manually collected samples. Manual and automatic sampling methods each have advantages and disadvantages. Manual methods have the advantage of being appropriate for all types of pollutants and requiring equipment. However, manual grab samples are labour-intensive, may involve exposing personnel to hazardous situations, and are subject to human error. Manual flow weighted composites require that flow measurements be taken during sampling. In addition, it may not be possible to get the sampling personnel and equipment to the outfall location(s) within the requirement 30 min.

Automatic sampling methods can be triggered remotely or initiated according to present conditions. The equipment may be battery-operated or remote operation and may include refrigeration systems to stabilise storm water samples. However, the methods may not be representative for oil and grease parameters, and cannot be used for analysis of volatile organic carbons. The samples may not be appropriate for pH and temperature tests or for other parameters with short holding times (such as faecal streptococcus, faecal coliform, and chlorine). There is also the potential for cross-contamination of the aliquot if the tubing and sample containers are not properly washed. This is especially true for certain pollutants such as pH, temperature, cyanide, total phenols, residual chlorine, oil and grease, faecal coliform, and faecal streptococcus. The automated equipment requires installation, maintenance, and operator training, and accurate flow measurement must be linked to the automatic sampler.

30.2.5 Sample Analysis

Details on appropriate sample analysis techniques are contained in EPA (1995). This document also discusses quality assurance/quality control (QA/QC) procedures, which are also discussed in EPAV (1995) and APHA (1995). EPAV (1995) contains a series of minimum recommended QC procedures.

30.2.6 Monitoring Results and Documentation

(a) *Baseline Studies*

As a baseline water quality study is intended to characterise existing water quality conditions, a comprehensive statistical analysis of the data is generally unnecessary, unless a comparison with previous data sets is proposed. For each of the monitored parameters the 10th, 25th, 75th, 90th percentiles can be calculated.

(b) *Event Monitoring*

The water quality and flow data collected during a storm event can be used to determine the pollutant load and runoff volume from the event, possibly using the technique described by Kachka et al. (1994). The EMC can then be determined as the event load divided by the event runoff volume. The EMCs for most parameters (excluding faecal coliforms) can generally be described by a log-normal distribution.

(c) *Reporting*

The following information should be included in any type of water quality monitoring report, as a minimum requirement:

- objectives of the monitoring program;
- limitations of the program;
- map indicating the location of the monitoring sites;
- Narrative description of pollutant sources;
- Significant leaks or spills;
- Outfall locations;
- Date, duration and pattern of storm event;
- Time since last measurable event (hours);
- Flow measurements or estimates;
- Total runoff volume for event;
- Amount of precipitation;
- description of the monitoring site's catchment, including catchment area, land use and estimated impervious fraction;
- summary of the sampling techniques;
- summary of the analytical techniques, including detection limits;
- QA/QC procedures;
- any factors which may have affected the results; and

- the laboratory test certificates (can be included in an Appendix).

For a baseline study report, the following additional information should be included:

- 'whisker' plots indicating the concentration percentiles for each site;
- a table containing the percentiles;
- a discussion (including graphs) on the influence of season and flow conditions on the monitoring results; and
- a comparison between the observed pollutant concentrations and the applicable water quality objectives (e.g. ANZECC 1992)

For an event study, the report should include the following additional information:

- a table containing the event data, runoff volume (or depth), EMC and load. The event rainfall depth, peak flow and peak concentration rate can also be included;
- calculated log-mean EMC; and
- graphs showing flow and concentration for each event can be useful to indicate the variation in water quality with flow and time (i.e., indicate the presence of any 'first flush' effect).

A stormwater treatment measure performance monitoring report could contain the same information as an event study, in addition to:

- comparison of inflow and outflow concentrations under base flow conditions; and
- calculated pollutant retention and a comparison against predicted performance.

30.3 DATA ARCHIVAL

The planning and design of a stormwater quality monitoring system should include planning of a systematic method for recording, storing, analysing and archiving the data.

Manual data collection and archiving may be acceptable for small projects of limited scope. For larger projects, consideration should be given to computerisation. Computer methods also assist in the statistical and other analyses of the data.

An example of a computer data archive system is HYDSYS/WQ. Other equivalent software is also available.

HYDSYS/WQ is a system for managing and analysing discrete water quality data generated when water samples are sent to a laboratory for the analysis of various chemical, physical and biological properties.

Conceptually, water quality data is stored in two database tables, one containing information about the samples, and one containing information about the results of analyses performed on those samples. If you think of the sample as a bottle of water, which it often is, then the attributes of that bottle include information such as where and when it was collected, by whom, and to whom was it sent for analysis.

When water is analysed at a laboratory, a number of analyses may be performed on portions of the sample. Each analysis returns a single result, which has attributes including the variable being analysed for, and the analysis value of that variable. Each analysis must return a numeric value for the result.

Once a sample and its corresponding results have been stored in the system, a variety of graphical outputs and printed reports are available to analyse the data. Available outputs include:

- Plots of data against time;
- Plots of one variable against another;
- Plots of data against the depth at which the sample was collected;
- Frequency distribution plots for a variable; and
- Statistical summary reports.

30.4 PROBLEMS AND SAFETY ISSUES

Storm water sampling is considerably more difficult than the sampling of process water discharges, because of the lack of control over sampling times and conditions. Rainfall events do not follow a predetermined schedule. They often occur at night, on weekends and holidays and with little advance notice.

There may be an "adverse climatic conditions" provision allowing a discharger to temporarily waive sampling and to submit a description of why samples could not be collected. *Adverse climatic conditions* include insurmountable weather condition that create dangerous conditions for personnel (such as local flooding, flash floods, high winds, hurricane, tornadoes, and electrical storms) or otherwise make the collection of a sample impracticable (drought). These events tend to be isolated incidents and should not be used as an excuse for not conducting sampling under more favourable conditions associated with other storm events.

The sampling waiver is not intended to apply to difficult logistical conditions, such as remove facilities with few employees, or discharge locations, which are difficult to access. "Ordinary" difficulties of the following sorts do not relieve the discharger from the responsibility to collect storm water samples:

- *Lack of rainfall* : In arid regions or regions experiencing a period of unusually low rainfall, it is advisable to submit whatever samples are available, even if fewer than 9 aliquots have been obtained. Document the conditions under which the available samples have been obtained. In the case of difficult climatic conditions, the authority may accept sampling data from any storm event of at least 5 mm total rainfall.
- *Too much rainfall* : Some regions may experience such frequent rainfall events that there is never a period of 72 h or more between storms. Again, it is advisable to submit the best samples available, even if the 72-h criterion cannot be met. Document the conditions under which the samples were obtained.
- *Short rainfall events* : If rainfall begins and then ends before at least 3 h of rainfall has occurred, then it is advisable to go ahead and perform the laboratory tests in whatever samples were obtained, provided that at least 3 aliquots are available. Be sure to document the conditions under which the samples were obtained when you submit the test results.
- *Start-and-stop rainfall* : If rainfall ends before the 3-h duration and then begins again later, it is advisable to continue sampling, provided that no more than a "reasonable" period has passed before the rainfall resumes. What constitutes a reasonable period is left to the judgement of the person obtaining the samples. However, it should not be more than a few hours. As with the other conditions noted above, this condition should be documented when the test results are submitted.
- *Inaccessible outfalls* : Some outfalls are inaccessible, especially during storm events. For example, a storm sewer outfall may be submerged during storm conditions. In such cases, it may be necessary to obtain samples at an upstream location, such as the next manhole or inspection point upstream. (Note : Before you sample within manholes, read the safety warnings later in this chapter). If another manhole or inspection point is not available, tap into the pipe or sample at several locations to best represent the total site runoff.
- *Multiple outfalls* : If one person is responsible for sampling at multiple outfall points or multiple sites, it may not be possible to obtain a first-flush grab sample for each outfall for a single storm event. In such cases, it may be necessary to obtain the first-flush sample for different storm events at each outfall or site. For most parameters, automatic samplers may be used to collect samples within the first 30 min, triggered by the amount of rainfall, depth of flow, flow volume, or time.
- *Numerous small point discharges* : If it is not feasible to sample all discharges, then impound the discharge channel or combine the discharges by building a weir or digging a ditch to collect discharges at a low point

for sampling. This artificial collection point should be lined with plastic to prevent infiltration and/or high levels of sediment.

- *Sampling in manholes* : Sample in manholes only when necessary. Any sampling performed in confined spaces should meet the "SET" test: Supported, Equipped, and Trained. Anyone sampling in a confined space should have a support person monitoring performance and safety. The person doing the sampling should be properly equipped for the task and should be trained in confined-space entry.
- *Run-on from other property* : If possible, estimate the volume of off-site run-on contribution and off-site run-on sources of pollutants to perform a mass-balance calculation. The mass-balance calculation simply provides an estimate of the total volume of run-on times the concentration of various pollutants in the run-on, compared with the total volume and pollutant concentrations of site discharges. Include this information in the permit application. If this estimation is not possible, provide a narrative discussion of the upstream site (e.g., the type of facilities located on the upstream site and the types of pollutants that may be present in discharges).
- *Commingled discharges* : If process water is known to be mixed with the storm water at a particular outfall, attempt to sample the storm water discharge before it mixes with the non-storm water discharge. If this is impossible, perform dry-weather sampling of the process water discharge and provide both sets of data to the permitting authority. This will give an indication of the contribution of pollutants from each source.

By definition, storm water sampling is performed under adverse conditions. These conditions can be merely uncomfortable, or they may be hazardous. Sampling in confined spaces, such as in storm sewer manholes, can be hazardous because of vapours, which may collect in such locations. Physical hazards such as lightning and slick surfaces can create significant danger. In addition, there are biological hazards (sometimes known as the "three R's"-roaches, rodents and reptiles). As noted above, the authority may have a temporary sampling waiver for unusually dangerous conditions.

Occupational Safety and Health safety rules should be followed, along with any applicable state and local regulations.

In addition to personal safety and health issues, there are property hazards that must be considered when designing a storm water sampling program. Expensive equipment such as automatic samplers may be subject to theft and vandalism. Appropriate measures should be taken to safeguard such equipment.