Sampling design and preparation

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Sampling scope and design

1 Purpose and scope

This document outlines the key elements that need to be taken into account when developing a sampling program. This document is adapted from the ANZECC and ARMCANZ (2000) *Australian Guidelines for Water Quality Monitoring and Reporting*. It should be read in conjunction with *Sampling design and preparation—Preparation for sampling* as logistical issues may influence sampling design (e.g. holding times).

2 Associated documents

Sampling design and preparation:

- *Permits and approvals*
- *Preparation for sampling*
- *Choosing a laboratory and analytical method, holding times and preservation.*
- *Quality control for water and sediment sampling*
- *Control and reference sites*

Physical and chemical assessment: Background to event monitoring

3 Introduction

Some of the primary reasons for monitoring and assessment covered by this manual are:

- *Investigating pollution incidents*. In such cases, the aim of sampling should be to obtain evidence that will:
    - discover and prove the source, nature, extent of impact and the effects of the contaminants
    - be performed in such a way as to be legally admissible in court
- *Confirming compliance to licence conditions of an environmental authority or development approval or other statutory provision*. Key points are:
    - To test for compliance with the licence conditions, samples must be collected in a manner that will ensure valid analysis results for those particular contaminants. Reference should be made to the current conditions of any relevant licence or permits. The conditions may include specific sampling locations, times of release and water quality characteristics that will assist with designing the sampling strategy.
    - Where the aim of the sampling is to measure compliance with conditions of an environmental authority or development approval, and the conditions include a statistically robust sampling regime, this should be followed. However, if there is reason to believe variability is a confounding factor, additional samples may be necessary for further investigation.
    - Where the statutory provision is not explicit, the sample should fairly represent the body of material from which it is taken during the period of the sampling.
- *Undertaking a receiving environment monitoring program.*
- *Undertaking an environmental evaluation of an activity*.
    - The *Environmental Protection Act 1994* and its subordinate legislation, including the *Environmental Protection Regulation 2008* and the Environmental Protection (Water) Policy 2009, must be taken

into account when deciding where and when to sample for a pollution investigation, checking compliance with an environmental authority or development approval, or undertaking a receiving environment monitoring program.

Before any sampling is carried out, the objectives aim of the sampling exercise, and how the results will be used should be established (scope of sampling). That information will help identify where and when sampling should take place, and the parameters that need to be determined for those samples (sampling design). Tasks associated with implementing the sampling design are presented in *Sampling design and preparation—Preparation for sampling.*

Essential features of a sampling strategy include ensuring that:

- samples collected are representative of the source material (i.e. waters, sediments and biota in a creek, river or lake) at the location of interest
- variation is taken into account – both in space (spatially) and over time (temporally)
- *in situ* measurements are reliable
- the integrity of materials sent for laboratory analysis has not been compromised by contamination, degradation or transformation
- sufficient sample volume is meet required detection limits for a particular analytical method and appropriate collection methods are used
- reference or control sample data are collected
- consideration of flow conditions (whether event or ambient) (See *Physical and chemical assessment—Background to event monitoring*).

Sampling designs should ultimately be defined by program objectives that can include the required statistical power required for discriminating between hypotheses or be based on the levels of acceptable sampling variability.

4 Importance of understanding the system being sampled

An understanding of the ecosystem is important to achieve a good sampling design. This understanding is best formalised in a conceptual model (or process model) of the system being examined. The model can be a simple box diagram that illustrates the components and linkages in the system, or a graphical representation of the system. Whatever model is used, it should present the factors that are influencing the system and the linkages of these factors.

During the formulation of a model, several decisions must be made or the model will be too complex. For example:

- What are the major issues of concern (e.g. nutrients, metal loads, bioavailable metals)?
- What ecosystem (including subsystem type) should the model describe (e.g. freshwater, marine waters, estuarine waters, wetland, seagrass bed, mangroves)?
- Which state of flow should the model describe (e.g. base flow, flood event)?

Once formulated, the process model can be used to help define:

- important components of the system and the important linkages
- key processes
- cause–effect relationships
- important questions to be addressed
- spatial boundaries
- valid measurement parameters for the processes of concern; what to measure, and with what precision

- site selection
- time and seasonal considerations.

An example of graphical conceptual model that may assist sampling design is presented in Figure 1.

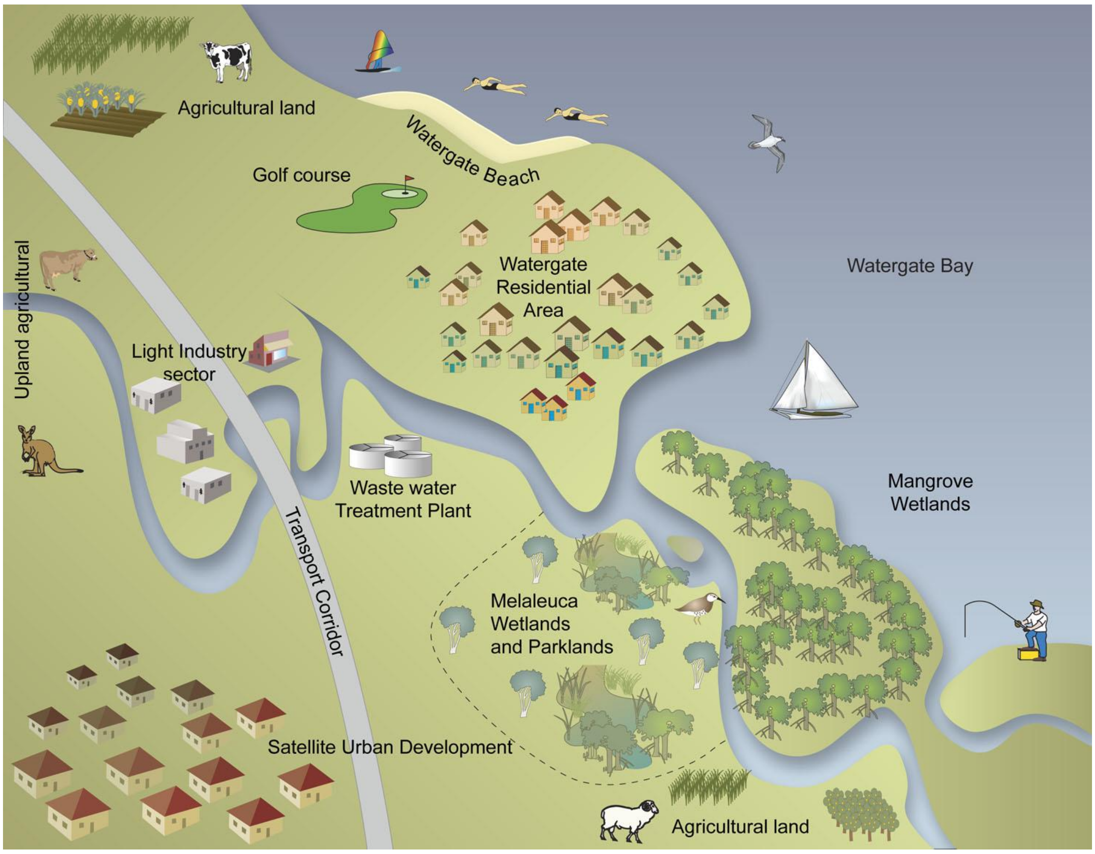

Figure 1: Conceptual diagram of a coastal system including anthropogenic activities, inputs to waterways and areas of value

5 Why Sample?

The objectives of the sampling program should be determined and documented. These should be as specific as possible. Common sampling objectives include:

- determining if one or more contaminants found in the environment have originated from one or more sources
- determining whether one or more contaminants in a release are in sufficient quantity to cause adverse environmental effects consistent with those observed at the time of the incident
- determining whether the contaminants in a waste release are having a measurable impact on the receiving environment water quality and whether environmental values are being affected
- determining whether the quality of waters have changed significantly, consistent with the definition of the term ‘environmental harm’ in the *Environmental Protection Act 1994* as a result of a release.

When sampling the receiving environment your assessment should take into account:

- potential sources of contamination/releases

- likely contaminants
- type of waterway and flow rates, whether:
  - freshwater, estuarine or marine
  - a flowing stream, lake, or ephemeral/temporary waters (in which case it may be wet or dry, or evaporating and concentrating contaminants at the time of sampling)
- licensed releases into the waters
- recent weather such as heavy rain, showers or drought conditions
- historical occurrences of similar incidents.

6 Spatial boundaries of sampling

The geographic boundaries of the sampling event should be based on the issue of concern and the ecosystem type rather than on convenience and/or budgets. For example, some important considerations would include:

- the likely spatial uniformity of the parameter/s of interest at a location (e.g. at depth, cross section of a river)
- the extent of the potential impacts downstream.

It is important to ensure that the sampling regime is representative of the system and parameter/s of interest. For example, where a water body is well mixed and a parameter of interest is evenly distributed in the water column, a grab sample may be appropriate. However, if water quality changes with depth, a number of samples at different depths may be required.

7 What to sample

Environmental authority or development approval conditions typically specify the contaminants and the permitted ranges of concentrations allowed in the release. However, in cases of suspected environmental pollution incidents, the pollutants present may be unknown and an assessment should be made on potential sources of contaminants in the area.

When sampling the receiving environment, there may be a range of related indicators that will be measured across different media such as surface water, sediments or biota. Indicators are physical, chemical or biological measures that best represent the key elements of an ecosystem. When choosing indicators, it is important to know whether there are defined benchmarks such as water quality objectives, guidelines, limits or other standards to compare measured data to. Indicators may be chosen because they have such benchmarks and may best indicate water condition or potential environmental harm. Sources of guidelines and benchmarks for Queensland are:

- Water Quality Objectives and Environmental Values prescribed under the Environmental Protection Policy (Water). Available from: http://www.des.qld.gov.au/water/policy/index.html
- DEHP (Department of Environment and Heritage Protection) 2009, *Queensland Water Quality Guidelines*, Version 3, ISBN 978-0-9806986-0-2. Queensland. Available from: https://www.des.qld.gov.au/water/pdf/water-quality-guidelines.pdf
- ANZECC and ARMCANZ (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand) 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, National Water Quality Management Strategy, Paper 4. ANZECC and ARMCANZ, Canberra. Available from: http://www.environment.gov.au/system/files/resources/53cda9ea-7ec2-49d4-af29-d1dde09e96ef/files/nwqms-guidelines-4-vol1.pdf
- NHMRC (National Resource Management Ministerial Council) 2008, *Guidelines for managing risks in recreational water*. Australian Government, Canberra, 216p. Available from: http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/eh38.pdf
- NHMRC and NRMMC (National Health and Medical Research Council and National Resource Management

Ministerial Council) 2011, *Australian Drinking Water Guidelines*, National Water Quality Management Strategy, Paper 6. NHMRC and NRMMC, Commonwealth of Australia, Canberra. Available from: www.nhmrc.gov.au/guidelines/publications/eh52

Under the National Water Quality Management Strategy (ANZECC & ARMCANZ 2000) water quality framework and the Environmental Protection Policy (Water), properly developed and approved local guidelines hold higher precedence over state or national guidelines. State (or national) guidelines apply when local guidelines do not exist, and are used for any parameters that are not included in the most locally relevant guidelines.

Although environmental authority or development approval conditions typically specify contaminants and the permitted ranges of concentrations allowed, additional characteristics may provide greater information about the potential environmental harm that might be caused. For example, although only biochemical oxygen demand (BOD) might be specified in the environmental authority or development approval, chemical oxygen demand (COD) and total organic carbon (TOC) often provide more information, and may be worth assessing. It may also be important to measure other characteristics due to a change in an operating condition or a specific incident.

In addition to measuring water quality characteristics, flow measurement of wastes/wastewater is often required for point source releases. This allows regulation and quantification of flow and loads of contaminants. Flow measurements of water bodies can be important for regulation as they can be used to assess initial mixing of point source discharges or as triggers that permit the release of licensed discharges, particularly for event-based releases. Flow measurements of waterways may also be required for pollution incidents to assess or predict the extent of impact. Any monitoring for these purposes should be in accordance with National Industry Guidelines for hydrometric monitoring (http://www.bom.gov.au/water/standards/niGuidelinesHyd.shtml).

8 Where to sample

Many environmental authorities have conditions that specify where samples are to be taken. Some have more than one sample point (two or more outlets, or an intake as well as an outlet). Where no sampling location is specified, samples should be collected from a site representative of the release material (and the receiving waters, where relevant).

When investigating environmental pollution incidents, consider all possible sources of the pollutant (including licensed and unlicensed sources of release). Samples should be collected:

- at the site of the reported pollution
- at the point of any contributing or suspected sources
- in an area upstream from the suspected source/s (control site)
- at points downstream of the suspected source (to measure extent). Samples should be collected as far downstream from the source as suspected of being polluted.

Reference or control sites must be sampled (if water is present) in order to understand the background conditions at the time of sampling, and in order to fully understand the potential impact from the pollution event under investigation. If assessing sediment, reference or control sites must be sampled. See *Sampling design and preparation—Control and Reference sites.*

It is important to identify with sufficient accuracy the location from which a sample has been collected to avoid raising a doubt about ‘what the sample represents’, particularly in cases where a location a few metres away might have given significantly different results. This is done by using a GPS and making a mud map in notes about exactly where a sample was collected from. See *Sampling Design and Preparation— Operating a basic handheld Global Positioning System unit for an investigation or compliance inspection.*

Water bodies are not homogeneous within a cross sectional area or depth profile and can be stratified (layered). This means that the composition of the different layers is substantially different in respect of at least one characteristic. For example, in estuaries, water quality characteristics can vary because of ingress/egress of saline waters. Estuaries are commonly stratified when freshwater flow is much larger than tidal flow–the fresh flows seawards over the saline waters and a ‘salt wedge’ develops. Stratification can also result from temperature effects in waters with low current velocities (such as lake, dams and pools). Such stratification is usually most pronounced in summer months when surface waters are much warmer than bottom waters. After separation, the water layers often develop markedly different chemistry. Such layers also tend to prevent mixing of discharged contaminants. The reverse process (de-stratification) can occur when the seasons change. The resulting inversion (‘turnover’) of the water can result in low oxygen water rising to the surface and causing adverse effects (such as odours from anaerobic decomposition at depth, and/or nutrient/metal enrichment). Other examples include the distribution of suspended solids within the water column from physical processes of re-suspension, deposition and flocculation.

When sampling environmental waters (typically, when investigating a pollution incident), it is important to remember that stratification might have occurred. *In situ* measurements taken at different depths can be used to detect stratification and sampling can be adjusted accordingly.

9 When to sample

Virtually all waters show both temporal and spatial variations in quality and so the timing and choice of location/s for taking water samples must be chosen with care. The quality of sediments and biota will also vary over time and space, although these changes may occur over a longer period than those detectable in water samples.

If the variation within a water body is not understood, it may be necessary to establish a pilot sampling program to determine the variability and determine the optimum sampling program. In circumstances where undertaking an assessment of variability is not practical or possible, it is recommended that information from relevant peer reviewed literature on the likely variability is used to provide guidance on an appropriate sampling strategy. A similar approach (for dealing with inherent variability) is recommended when designing sampling programs involving the collection of other materials such as sediments and biota.

The schedule for the sampling program should take account of the expected temporal resolution of changes in the environment. For example, in programs for monitoring wastewater treatment effluents, sampling around the clock may be required to determine whether control variables have been met or exceeded.

In terms of frequency, sampling may be required every hour, day, week, fortnight, month or possibly only once a year. The frequency of sampling (level of resolution) should be sufficient to meet the requirements of the program objective but not cost more than necessary. Composite sampling and passive samplers can be used to integrate variations in water quality over an extended period of time.

Some conditions on environmental authorities specify that release is to take place only at certain times of the day (for example, on an outgoing tide) or under certain weather conditions. This should be considered in your sampling design where applicable.

For impact assessments, sampling before and after is important (but not always possible), preferably with multiple before and after reference sites. In situations where there is no ‘before’ information available at the impact location, data collected by sampling from reference or control sites may be indicative of conditions at the impact location prior to the incident. For example, a chemical spill may have contaminated the receiving environment, and caused impacts on local biota, but there are no pre-spill data available. However, concentrations of contaminants or biological community indices measured at unimpacted reference or control sites after a chemical spill can be indicative of what those parameters could have been at the incident location prior to the spill.

Water quality varies with stream flow conditions, so when considering the timing of sampling, it is important to establish whether sampling during baseflow or during flood event conditions (or both) is appropriate. See *Physical and chemical assessment—Background to event monitoring* for more information.

9.1 How many samples should be collected?

Unless the material being sampled is known to be well mixed (well mixed water body or end-of-pipe discharge), it is unlikely that a single measure will be representative of the source body of material. Multiple measurements are needed to allow the calculation of descriptive statistics (i.e. a mean and confidence interval, or percentile statistics) for the characteristic of interest, or to allow statistical testing for significant differences between locations or non-compliance with statutory provisions. This requires multiple readings for *in situ* measurements and multiple samples where laboratory analysis is involved. A minimum is three data points per site for basic statistical tests, but more may be required depending on the inherent variability in the measurement data. The number of data points needed may not be known until after chemical analysis of some samples. It is good practice to take additional samples and to store these for subsequent analysis if required, although short maximum holding times for some contaminants may mean this is impractical.

9.2 Is grab sampling adequate or should composite samples be taken?

Most samples taken will be grab samples—taken by filling sample containers over a 'short' period (seconds or minutes). A single grab sample may be used where:

- a hazardous situation has arisen or is suspected and the sample is taken to confirm the presence of the hazardous substance
- where the body of water being tested is well mixed and its quality can be adequately described by a single sample.

Note: A single grab sample can be of limited use if it takes no account of variations in quality with time or space. In such a situation, the taking of a composite sample is a useful strategy. A composite sample may be:

- **temporal** by combining contributions of material collected over a longer period (minutes, hours or days).
- **spatial**, for example, comprising a series of equal contributions of material taken along a transect (e.g. across a channel). This gives a spatially 'more representative' sample than a single grab sample at a single point.

However, composite sampling will not provide information on the maximum concentration in a series of samples, and will provide an average. Depending upon the situation, the maximum concentrations can be important when dealing with toxicants[1].

9.3 Quality Control

Quality control is an essential component of any sampling exercise. The purpose of a quality control scheme is to check whether bias, sample contamination, or analyte loss could affect the results, and so invalidate the process. Quality control is discussed in more detail in *Sampling Design and Preparation: Quality control for water and sediment sampling.*

9.4 Cost effectiveness

It is preferable for the cost of sampling programs to be as small as possible while still meeting the stated objectives of the monitoring study. Cost-effectiveness considerations involve trade-offs between loss of statistical 'power' (i.e. the capacity of a program to discriminate between various hypotheses) and the cost of data acquisition. Costs of data acquisition taken into account for cost effectiveness include:

- the number of sampling stations, sampling occasions and replicates
- the cost of collecting samples (staff, transport, consumables)
- the cost of analysis
- the cost of data handling and interpretation (cost of reporting).

Cost-savings can result from collaborative monitoring, for example, when local councils pool resources with other water managers to comprehensively monitor a particular water body.

10 References and additional reading

ANZECC and ARMCANZ (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand) 2000, *Australian Guidelines for Water*

[1] A toxicant is a chemical capable of producing an adverse response (effect) in a biological system, seriously injuring structure or function or producing death. Examples include pesticides, heavy metals and biotoxins (i.e. domoic acid, ciguatoxin) (ANZECC and ARMCANZ 2000)

Quality Monitoring and Reporting. National Water Quality Management Strategy. No. 7. Available from: http://www.agriculture.gov.au/SiteCollectionDocuments/water/nwqms-monitoring-reporting.pdf

DEHP (Department of Environment and Heritage Protection) 2009, *Queensland Water Quality Guidelines*, Version 3, ISBN 978-0-9806986-0-2. Queensland. Available from: https://www.des.qld.gov.au/water/pdf/water-quality-guidelines.pdf

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