Auckland Regional Council
TE RAUHITANGA TAIAO

Blueprint for monitoring urban receiving environments

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2 Introduction

Contaminants such as heavy metals, hydrocarbons and toxic exhaust emissions are washed off industrial sites, roads, roofs, and other surfaces whenever it rains. Blocked, leaking, and illegally connected wastewater (sewage) pipes, together with inadequate sewer capacity and pump failures add wastewater contaminants to the mix. Polluted stormwater running off the land enters the drainage system and is eventually discharged into the sea or, in some cases, to groundwater. Toxic contaminants discharged into the marine environment may be dispersed widely, either in solution or bound to very fine particles that remain suspended in the water column. Conversely, contaminants bound to coarse sediments and large organic particles tend to settle out relatively quickly, and accumulate in sheltered near-shore zones. Auckland's sheltered harbours and estuaries are particularly vulnerable to contamination because waves and currents are not strong enough to keep particles in suspension, so they rapidly sink and become incorporated in sand and mudflat sediments.

Because of the potential impact of stormwater and wastewater on aquatic receiving environments, network operators and territorial authorities throughout the Auckland Region are required to obtain resource consents for their discharges. Network consent applications are being processed under the umbrella of the Regional Discharges Project (RDP). The overall strategic aim of the project is to ensure that discharges from stormwater and wastewater networks are managed under a best practical options (BPO) framework which prevents or minimises adverse effects on the environment, taking into account the sensitivity of the environment, financial implications, technical knowledge, and the likelihood of success (Resource Management Act, 1991).

Upgrading and maintaining stormwater and wastewater infrastructure is expensive, and environmental benefits may only be realised after a considerable periods of time. Consequently, the development and implementation of BPOs must be underpinned by reliable information on environmental quality. It is therefore very important to have robust and regionally consistent methods of assessing the severity of impacts on receiving environments, and the effectiveness of BPOs.

The RDP methodology involves three important steps:

Investigate:	Use sediment quality, benthic ecology, human health risk and, where necessary, water quality to determine the severity of impact.
Assess:	Determine the necessity and level of stormwater and wastewater infrastructure upgrades, and the time frame for works based on: ❑ investigation results ❑ practicality ❑ affordability ❑ community expectations
Monitor:	Monitor for environmental responses to management actions

As part of the RDP, the ARC has developed environmental response criteria (ERC) for the coastal marine area that provide thresholds for assessing environmental quality in relation to stormwater and wastewater discharges. These ERC will assist in the assessment of stormwater and wastewater consent applications and in the development of management responses under a BPO framework. The ARC has deliberately taken a conservative approach in the development of regional ERC, and is using them to provide early warning signals which allow action to be taken before substantial impacts occur. This approach was adopted because:

- urban intensification, which is occurring at a rapid rate, accelerates contaminant accumulation;
- monitoring shows that contaminants are accumulating quickly in receiving environments and concentrations in some areas are rapidly approaching levels where substantial changes in ecological health are likely to be seen (Auckland Regional Council 2002e);
- preventing or slowing degradation is likely to be easier than reversing it.

The Proposed Auckland Regional Plan: Coastal defines environmental targets and policies for the coastal marine area. These provisions have been subjected to a wide range of public input and scrutiny and provide general policy guidance to both the ARC and resource users. However, the ARC considers that additional guidance is required to provide stormwater and wastewater network operators with greater certainty regarding acceptable effects of their discharges on the quality of the coastal marine receiving environment.

This blueprint for monitoring urban receiving environments was developed to provide regionally consistent methods for collecting and analysing monitoring data. There are a number of supporting documents for this report, they are:

- Larcombe (2001). "Stormwater disposal to the Auckland urban coastal marine area". This is a very broad-based and comprehensive description of actual and potential impacts of stormwater and wastewater on the receiving environment. It forms the basis for:
- Auckland Regional Council TP 169 (2002a). "Environmental targets for urban coastal marine environment" gives an overview of the monitoring process, environmental targets and the criteria used in the RDP, and defines two areas within the receiving environment: settling zones and outer zones.
- Williamson and Mills (2002). "Sediment quality guidelines for the Regional Discharge Project" provides scientific information to support the environmental response criteria for sediment quality.
- Auckland Regional Council TP 170 (2002b). "Regional maps of settling and outer zones" provides maps of settling and outer zones, and the location of indicative sampling sites. It also delineates areas for special investigation – where environmental impact and monitoring strategies are yet to be defined.

- Williamson and Green (2002). "Regional identification of settling zones" develops and describes the methodology used to locate settling zones, and applies these methods to two case studies; the Tamaki Estuary and the Upper Waitemata Harbour.
- Auckland Regional Council TP 203 (2003). "Regional Discharges Project. Marine receiving environment status report 2003". This document summarises the sediment quality and benthic ecology data from the Regional Discharges Project and is the basis for the 2004 revisions to the blueprint.

The assessment and monitoring of receiving environments uses sediment quality, benthic ecology, and human health risk as the primary tools for assessing the impact of stormwater and wastewater discharges. Where appropriate, water quality may also be assessed. Sediment and water quality are graded according to the level of impact with green, amber and red environmental response criteria (ERC).

- Green sites are low impact sites. Additional investigations are not required unless significant changes in catchment land use occur. Green sites should be reassessed every 5 years.
- Amber sites are showing signs of degradation. Management actions taken as early as possible are likely to be most effective at limiting further degradation. These sites present the best opportunity to make a difference to the future quality of the receiving environment.
- Red sites are higher impact sites where significant degradation has already occurred, and remedial opportunities are often more limited. Restoration of the site may not be feasible in the short term, but actions should be taken to slow the rate of decline and limit the spread of contaminants.

ERC numerical values for sediment, water, and bathing beach quality are incorporated into the Regional Plan: Coastal. Sites with amber or red sediment quality are also required to be investigated for ecological impacts, with the results assessed against the ARC's ecological community health index. Eventually, the ARC aims to rank benthic health as green, amber or red, however, additional data is required to validate the model used for this purpose. A variation to the Regional Plan: Coastal may be sought to include ecological ERC once the model has been verified.

Methods for carrying out each type of assessment are described in the following sections. The overall assessment process is a priority setting exercise that provides information on the state of the receiving environment. It is not a pass/fail test. Rather, it provides a scientific basis for determining appropriate management responses. If sites are classified as amber or red then further investigations are recommended to provide scientific guidance to the agencies responsible for addressing the management of the stormwater and wastewater discharges. The purpose of the investigations is to direct the evaluation of the management options. These options are likely to include source identification and control, and the assessment and application of appropriate BPO's. Following this, a monitoring programme would be implemented to measure the response of the marine receiving environment to management initiatives.

3 Sediment quality

A significant proportion of stormwater contaminants bind to particulate material, settle out of the water column, and become incorporated into marine sediments. However, some contaminants remain available for uptake by marine organisms. Sediments ingested by, or in close contact with, benthic biota may release loosely-bound “bioavailable” contaminants which are taken up by marine organisms. Many organisms accumulate these contaminants within their tissues and may suffer toxic effects, even at relatively low sediment concentrations. High levels of contaminants in marine sediments therefore pose a significant risk to the biological functioning of marine receiving environments. Accordingly, this chapter provides details on how to collect and analyse sediment samples for urban stormwater contaminants. Information is provided on:

- the primary and secondary contaminants of concern;
- environmental response criteria used to grade contaminant levels according to the level of biological risk;
- selecting sediment sampling sites;
- collecting and processing sediment samples, and reporting the results of analyses;

3.1 Contaminants of interest

The most significant medium-to-long term implication of stormwater discharges on marine receiving environments is the accumulation of stormwater contaminants in the sediments, and their impact on benthic organisms.

The primary contaminants of concern are:

- heavy metals: copper (Cu), lead (Pb), and zinc (Zn)
- polynuclear aromatic hydrocarbons (PAHs): (a sub-set of which, the High Molecular Weight or HMW-PAH or HPAH for short, are recommended for monitoring)

Of secondary importance are the organochlorines:

- chlordane;
- dieldrin;
- the DDT suite (p,p’-DDD, p,p'-DDE, p,p'-DDT, total DDT);
- lindane;
- polychlorinated biphenyls (PCB’s).

In addition to these, there are some important sediment characteristics that determine contaminant bioavailability:

- acid volatile sulphide (AVS) which precipitates and binds heavy metals;
- total organic carbon (TOC) which controls the bioavailability of toxic organics.

The initial assessment of the receiving environment is conducted by measuring the concentrations of the primary contaminants zinc, copper, lead, and HMW-PAH. Assessments of ecosystem health (e.g. benthic ecology) may follow depending on the results of this initial assessment, but secondary toxic organics are only measured in particular circumstances (see Chapter 7).

3.2 Environmental response criteria (ERC) for sediment contaminants

Sediment quality ERC are used to assess whether the measured contaminant concentrations are likely to be causing adverse environmental effects. The ERC were derived from ANZECC (2000) Sediment Quality Guideline ISQG-Low values and other internationally recognised guidelines presented in ANZECC (2000) and are used to grade contaminant concentrations as green, amber or red (Table 3.1) where:

- Concentrations in the green zone present a low risk to the biology so the site is unlikely to be impacted.
- Concentrations in the amber zone indicate contaminant levels are elevated and the biology of the site is possibly impacted.
- Concentrations in the red zone indicate that contaminant levels are high and the biology of the site is probably impacted.

The rationale for using values other than the interim ANZECC (2000) trigger values are outlined in Appendix A and explained more fully in "Sediment Quality Guidelines for the Regional Discharges Project" (Diffuse Sources Ltd 2002).

The ERC are conservative thresholds that provide an early warning of environmental degradation. They were intentionally set at relatively low levels to allow management responses to be properly assessed and implemented before serious degradation occurred. Initial RDP sediment quality assessments compare measured contaminant concentrations against ERC and rank them as green, amber or red. However, ERC are not pass-fail numbers, rather they are prompts for further investigations. These may include ecological evaluations, toxicity testing, source identification, prediction of future sediment quality and an evaluation of management options. Ongoing monitoring is then used to detect subsequent changes in environmental quality and evaluate the efficacy of management actions.

Table 3.1 Environmental response criteria for sediment contaminants.

A. Primary contaminants (mg/kg)

Parameter	Red[1,2]	Amber[1,2]	Green[1,2]	Source of Red – Amber Threshold	Source of Amber-Green Threshold[3]
Zinc	>150	124-150	<124	ER-L	ISQG (CCME)
Copper	>34	19-34	<19	ER-L	ISQG (CCME)
Lead	>50	30-50	<30	ISQG-Low (ANZECC)	ISQG (CCME)
HMW-PAH[4]	>1.7	0.66-1.7	<0.66	ISQG-Low (ANZECC)	TEL

B. Secondary toxic organics (µg/kg)

Parameter	Red[1,2,4]	Amber[5]	Green[1,2,4]	Source of Green - Red Threshold
Chlordane	>2.3	n/a	<2.3	ISQG (CCME)
p,p'-DDD	>1.2	n/a	<1.2	ISQG (CCME)
p,p'-DDE	>2.1	n/a	<2.1	ISQG (CCME)
p,p'-DDT	>3.2	n/a	<3.2	ISQG (CCME)
DDT, total	>3.9	n/a	<3.9	TEL
Dieldrin	>0.72	n/a	<0.72	ISQG (CCME)
Lindane	>0.3	n/a	<0.3	ISQG (CCME)
Total PCB	>22	n/a	<22	ISQG (CCME)

[1] Values rounded to two significant figures.

[2] Values are for the total sediment in the settling zone and for the mud fraction within the outer zone.

[3] Source:

- ER-L = Effects Range Low (Long et al. 1995)
- TEL = Threshold Effects Level for Florida Department of Environmental Protection (MacDonald 1996)
- ISQG-Low = Interim Sediment Quality Guideline-Low (ANZECC 2000)
- ISQG (CCME) = Interim Sediment Quality Guideline for Canadian Council of Ministers for the Environment (CCME 1999).

[4.] After normalisation to 1% total organic carbon (TOC), as recommended in the ANZECC (2000) guidelines. This involves dividing the measured concentrations (mg/kg or µg/kg) by TOC concentration (%).

[5.] Amber values for organochlorines are not specified because of uncertainties about the sources of these contaminants and trends in their concentrations. Any exceedance of the green values will therefore require an investigation into trends and effects. In contrast, the major sources of heavy metal and PAH contamination are relatively well known. Concentrations are expected to increase into the foreseeable future because their sources will persist in urban catchments.

3.2.1 Levels of protection for settling and outer zones

The Regional Discharges Project has divided Auckland's urban marine area into two types of receiving environments for the purposes of monitoring the impact of stormwater and wastewater discharges:

- Settling zones
- Outer zones

The rationale for this subdivison is explained in Auckland Regional Council (2002a) "Environmental Targets for the Urban Coastal Marine Area". Maps for the urban coastal marine area are reproduced in the report "Regional maps of settling zones and outer zones" (Auckland Regional Council 2002b).

Briefly, settling zones are areas were most (~75%) contaminants settle out of suspension and become incorporated into benthic sediments. Consequently, settling zones are prone to contaminant accumulation and some level of degradation is expected. Outer zones are wider estuarine areas downstream of the settling zone or located in higher energy environments were contaminants are less likely to settle permanently. The rate of contaminant accumulation in outer zones is therefore expected to be slower than in settling zones.

Copper, lead and zinc ERC are applied slightly differently in settling and outer zones , reflecting the distinct characteristics of these two areas. In settling zones, the metals ERC are applied to the < 500 μm sediment fraction (which is often referred to as the total sediment fraction). In outer zones, a more protective approach is adopted and the ERC for heavy metals are compared against the greater concentration obtained from:

- weak acid digestion of the mud fraction (<63 μm); or
- strong acid digestion of the total sediment fraction (<500 μm).

The precautionary approach for outer zones reflects their sandier nature and the greater sensitivity of organisms living in them. The aim is to prevent any significant ecological degradation in outer zones. The justification for analysing both the mud and total sediment fractions is based on the following:

- sandy outer zone areas are likely to contain more pollution-sensitive organisms than muddy settling zones;
- the fine sediment fraction is the most ecologically relevant component of sediments in terms of contaminants, since it is more likely that benthic animals will ingest, or be in intimate contact with, fine rather than coarse materials;
- weak acid digestion of the mud fraction (<63 μm) is more conservative (protective) than strong acid digestion of the total sediment fraction (<500 μm) in sandy outer zone sediments;
- strong acid digestion of the total sediment fraction (<500 μm) is more conservative than weak acid digestion of the mud fraction (<63 μm) in muddy outer zone sediments;
- sandy sediments have a lower capacity to bind heavy metals and organic contaminants, because of smaller specific surface areas, and lower concentrations of the adsorbing phases of iron oxide (FeOOH), acid volatile sulphides (AVS), and organic matter, so heavy metals are potentially more bioavailable in outer zones (Williamson and Mills);
- it moves toward the approach recommended by the ANZECC (2000) guidelines of using a better measure of bioavailable (rather than total) metals. The weak acid extractable fraction is associated with phases actively involved in early diagenesis, i.e. adsorbed on $FeCO_3$, $CaCO_3$, amorphous iron and manganese oxides and organic matter, or coprecipitated with

acid volatile sulphides (mostly FeS). It includes the bioavailable fraction, either that which is available at the time of sampling or after diagenetic mobilisation, and probably most of the anthropogenic input (Auckland Regional Council 1994).

- using the mud fraction in areas with large changes in sediment texture, as occurs in the outer zone, simplifies sample collection, improves analytical standardisation and reduces variability.

This approach is not recommended for very sandy sediments with low mud content (<5%) due to uncertainties about the nature of fine materials in such sediments, and how chemical contaminants interact with them. It is therefore recommended that an interim cut-off point of 5% mud be applied when assessing heavy metals. Sediments with a mud content below this threshold should not be sampled.

For organics, separate analyses of the mud and total sediment fractions are unnecessary because trigger values are standardised against the proportion of total organic carbon (TOC) present in the sample. The lower organic content in sandy sediments effectively lowers the trigger value for organic contaminants in outer zones. Conversely, the higher organic content in muddy sediment increases the trigger value. Organic analysis are therefore required only on the total sediment sample. ARC recommend an interim lower cut-off point of 0.2% TOC in the application of these guidelines.

3.3 Sampling protocols

3.3.1 Overview

RDP sampling protocols were taken from the ARC's Sediment Contaminant State of the Environment (SoE) Monitoring Programme (Auckland Regional Council 1998a), and modified slightly to meet the requirements of the RDP programme. The ARC SoE protocols were primarily designed to detect changes in sediment contaminant levels over time, whereas the RDP monitoring programme is primarily interested in comparing measured concentrations with ERC, and secondarily with detecting temporal trends. The advantages of adopting the SoE protocols were:

- they were developed from extensive research on contaminant accumulation in the Auckland estuaries and are known to provide consistent, reliable results;
- they produce small sample variances and therefore provide good statistical power for trend detection;
- changes in contaminant levels that result from catchment management initiatives can be rapidly measured. This provides an efficient feedback mechanism on the efficacy of management initiatives.
- RDP data can be directly compared with SoE data;
- SoE data can be utilised for RDP purposes, thereby minimising unnecessary duplication.

The protocols were specifically designed to minimise spatial variation in contaminant concentrations and maximise the potential for detecting trends through time.

3.3.2 Depth of sampling

Sampling is targeted toward recently deposited, surficial sediments in order to detect changes in contaminants that can be linked, as closely as possibly, to existing stormwater quality. Surface sediments also encompass the most biologically active zone of the benthic habitat and most water/sediment interactions occur within this zone.

For most settling zones the top 2 cm contains sediments deposited over a 0.2 - 7 year period. In terms of detecting trends, 2 cm is a compromise between shallower depths that might be biased by 1 or 2 large recent events and greater depths where recent changes in concentration are diluted by levels laid down over long periods. Sampling the whole bioturbated layer (~ 15 cm) is not desirable because it equates to a timeframe of 5-30 years. This period is considered to be too long to be useful in underpinning stormwater management decisions.

3.3.3 Time (season) of sampling

The intention of the RDP sediment assessment programme is to look at long-term contaminant accumulation. As outlined above, surface sediments provide an integrated picture of recent contaminant inputs. The season of sampling is therefore unimportant.

3.3.4 Settling zones

3.3.4.1 Choosing sampling sites

Settling zone sites should be located on intertidal flats toward the centre of the settling zone. Low-tide channels, channel banks, side channels, mangrove forests and pneumatophore zones should be avoided. Similarly the site should not be located near settling zone/outer zone boundaries (Fig. 3.1).

Figure 3.1: Intertidal mud flats. A. Marking out a suitable site between channel and mangroves, sampling can be difficult. B. Mudflat to the left of the mangroves is suitable for sampling. Avoid mangroves or surrounding pneumatophores if possible. C. The low tide channel banks may not give a representative samples because both deposition and scour can occur here.

(a)

(b)

(c)

Sampling sites should be well defined patches within an estuary, whose locations are permanently recorded with GPS and marker pegs. Each site must be large enough to enable the requisite number of samples to be obtained. A rectangular site, running 50 m parallel and 20 m perpendicular to the estuary channel is used in the ARC SoE programme, and should be appropriate for RDP sites. The outer edge of a site should be located no less than 0.5 m, and preferably 1-2 m or more, from the top of the low-tide channel bank (Appendix B).

Sites need to be remote from obvious point sources of contamination. This can be checked by inspecting the estuarine riparian area. Pipes, incised channels exposed at low tide, and discoloration (e.g., iron staining) are obvious signs of point source discharges.

3.3.4.2 Replication

Three replicates are collected from each site using a suitable plastic scoop, with each replicate consisting of a composite of ten sub-samples (see Appendix B). The ARC SoE programme uses a scoop made from a square unused polyethylene bottle, with the 2 cm sampling depth clearly marked.

Replication and compositing are achieved by collecting sub-samples and assigning them to the 3 replicates in a sequential manner (i.e., sub-sample 1 is placed in replicate 1, sub-sample 2 is placed in replicate 2, sub-sample 3 is placed in replicate 3, sub-sample 4 in placed in replicate 1, etc.) as follows:

Sub-sample within replicate	1	2	3	4	5	6	.	.	.	.	.	.	25	26	27	28	29	30
Replicate	1	2	3	1	2	3	.	.	.	.	.	.	1	2	3	1	2	3

This method is similar to that used in the ARC SoE sediment quality survey (Auckland Regional Council 1998a, Appendix B). The rationale for this design is the need to obtain a good estimate of the concentrations within the site, while minimising the sampling variance for trend detection. Intermingling sub-samples within composites, rather than collecting each sub-sample from a different part of the site, reduces the overall variance between replicates. Spatial variance within the site is of little, or no, interest in the RDP programme.

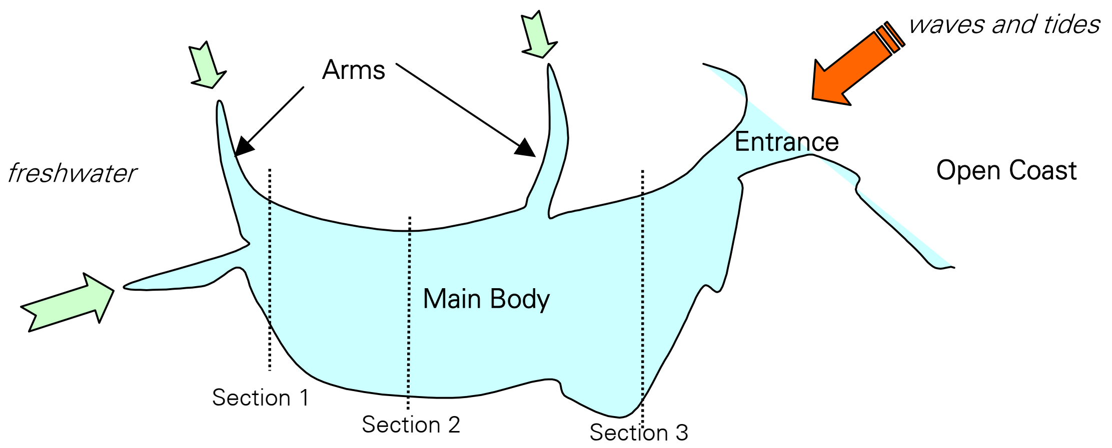
3.3.5 Outer zones

Outer zones contain a variety of sediment textures from coarse shell material to fine mud. In order to ensure that the results of individual samples and sites are comparable, metals analyses are carried out on both the mud and total sediment fractions. Nevertheless, sites with a significant proportion of mud should be selected in preference to sites with very sandy sediments. Often the best locations are near the low tide channel, where a higher proportion of muddy sediments are found (Auckland Regional Council 2001). It is difficult to specify exactly where sampling sites should be located, because sediment texture often varies widely within outer zones, both spatially and temporally. For example, changes in prevailing winds may result in a bay becoming muddy or vice versa, and the muddy deposits can vary in size shape and depth (see Figure 3.2). However, most RDP sites have moderately sandy sediments with sufficient mud content.

The methods used to sample intertidal outer zones are the same as those used in settling zones except the sampling site can larger on broad sandy areas. In smaller, muddy, outer zones such as those in the Upper Tamaki, Middle Tamaki Lower Whau, Waiarohia, and Hellyers (see Regional maps for settling and outer zones (Auckland Regional Council 2002b), the settling zone protocols can be directly applied.

Figure 3.2 (a)   Characteristics of estuarine main body (Summarised from Auckland Regional Council 2001).

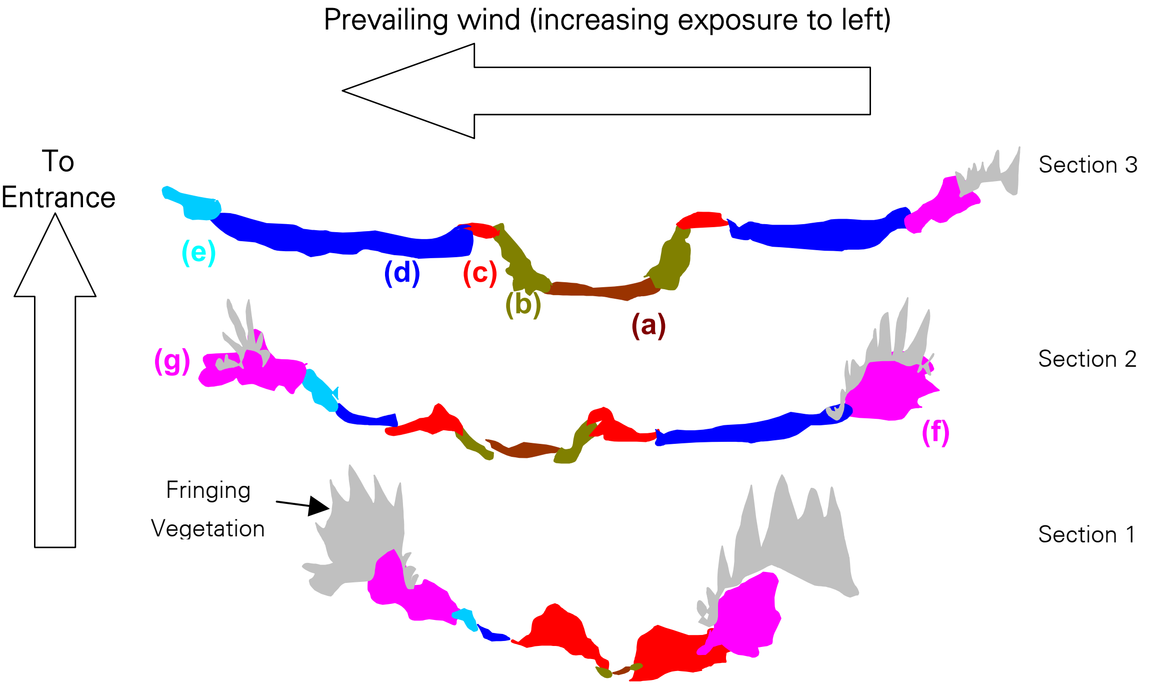
An estuary classification scheme has been developed for Auckland estuaries that combines our understanding of estuarine geomorphology and the processes that disperse sediments/contaminants. The Auckland estuary archetype is shown below:



The main body is muddy in the upper reaches, where it connects with the arms associated with source streams. The lower reaches, which are connected to the coastal ocean via the entrance (throat), tend to be sandy. The main process is secondary redistribution of muds injected from arms during floods and of sands that are pushed through the entrance by waves and tides. Secondary redistribution is achieved mainly by tides, internally generated waves, and gravitational flows. The main body is characterised by mixed sediments (mud and sand) and, in places, encroachment of muds on sands and vice versa.

Figure 3.2 (b): Characteristics of estuarine main body. Refer to Fig. 3.2 (a) for the position of cross sections.

In addition to the characteristic longitudinal gradient in sediments, there is also a typical cross-sectional gradient: sandy intertidal flats lie between areas of mud along the channel margins and mud or sand/shell on upper intertidal-flat margins.



(a) Lagged channel bottom. Typically, a larger area of the channel bottom is lagged in the lower reaches of the estuary, where tidal currents are stronger.

(b) Mud accumulations along the subtidal margins of channels.

(c) Mud accumulations along the intertidal fringe of the channel. These typically become thinner in the lower reaches where tidal currents are stronger, exposure to wind is greater, and distance from the source of mud is greater.

(d) Sandy intertidal flat, typically covered by wave-induced ripples and littered with shells and shell fragments. Broadest in the lower reaches, which are closer to source of marine sands. May be exposed to swells that penetrate through the estuary mouth.

(e) Wave-built accumulations of sand/shell on the fringes of the upper intertidal flats. These may be thicker and more numerous in the lower reaches, but they occur throughout an estuary and will vary greatly with local exposure and sediment supply.

(f) Mud accumulations on the fringes of upper intertidal flats. These are typically stabilised and promoted by fringing vegetation. Typically more extensive in the upper reaches, but, again, occurrence throughout estuary will vary greatly with local exposure and sediment supply.

(g) Mud impoundment behind a wave-built barrier.

3.3.5.1 Procedures for subtidal outer zones

Open coast zones such as the East Coast Bays may require subtidal sampling. The ARC State of the Environment monitoring protocols have been applied to the low tide surf, but the proportion of mud obtained from samples taken in this area is often too low for the analysis of metals. Samples should therefore be taken beyond the surf zone, using divers or a suitable surface sediment sampler deployed from a boat. Note that the high energy of the coastal zone will dilute and disperse discharges, slowing contaminant accumulation and any ecological effects, so assessing these areas is not as high a priority as for sheltered outer zones.

At the present time, the procedure recommended is to collect 3 replicates with a sampling device such as a stainless steel Eckman Dredge. The surface 2 cm should then be carefully removed from the sample and retained for analysis. The rest of the sample can be discarded. The 3 replicates are analysed separately to determine the variability between samples. More definitive recommendations will be made on sampling open coastal sites once sufficient sites have been sampled and better information is available on contamination levels, and spatial and temporal variability.

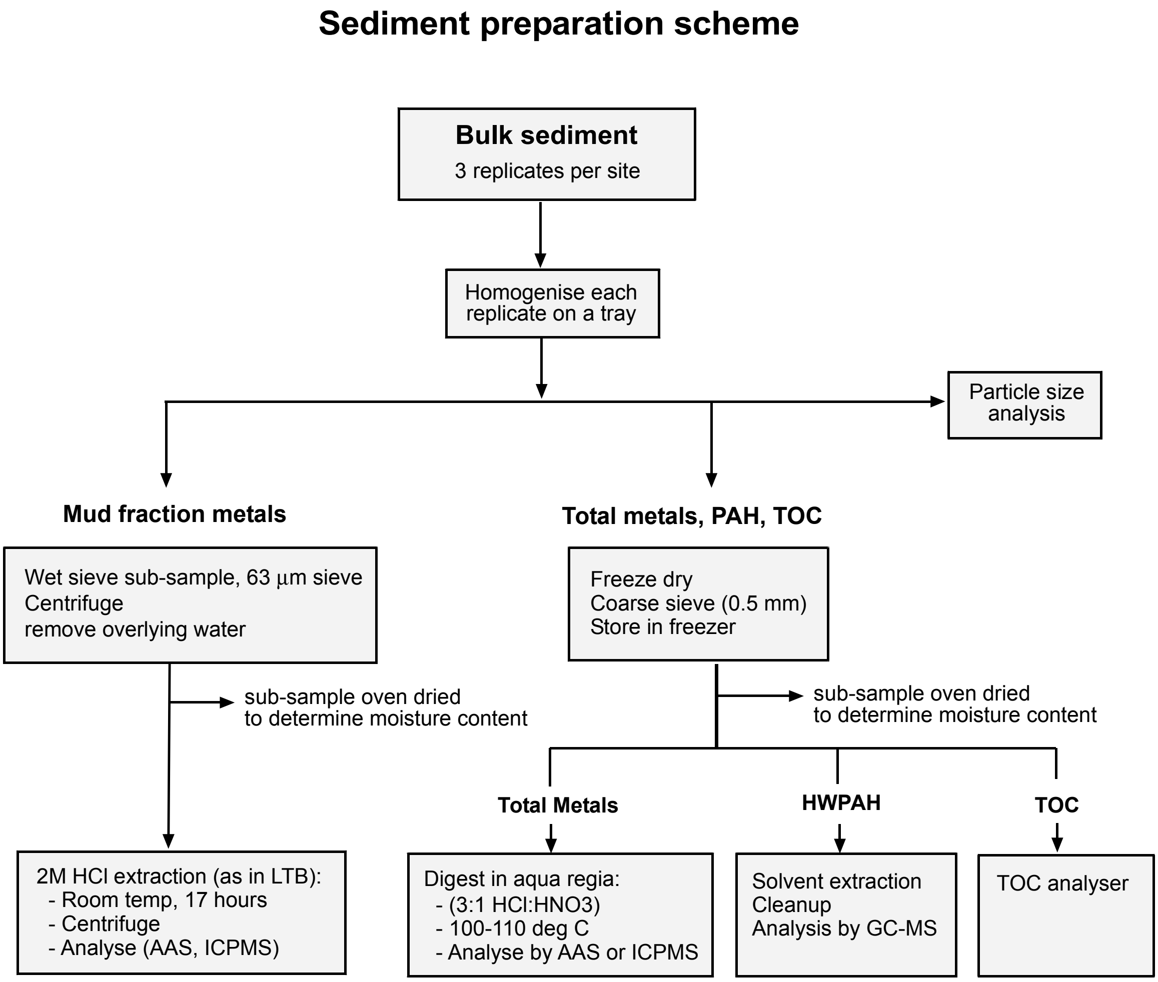
3.4 Sample analysis

3.4.1 Sample processing

The samples are dispatched in chilly bins, unfrozen if on the day of collection, or frozen if dispatched later. On receipt, or on thawing, each composite is placed in a shallow plastic tray and thoroughly homogenised (Fig. 3.3). A sub- sample is wet-sieved through a nylon mesh to obtain a representative <63 µm fraction. These two steps must be carried out very thoroughly and with care to maintain low variability among replicates.

The remainder of the sample is freeze dried for total lead, copper, zinc, high molecular weight PAH and (if necessary) organochlorine analysis. The freeze-dried sample is sieved through a 0.5 mm sieve to remove any large particles e.g., shell, before analysis. This reduces variability associated with the presence of large debris (e.g. wood, rock, shell) that can be significant in some samples, while retaining a sufficient amount of the original sample to allow an analysis of organic contaminants (which usually require more material than the heavy metal analyses). It is acknowledged that freeze-drying will result in the loss of some volatile organic compounds during sample preparation. This is partly why the high molecular weight PAH (which are not susceptible to these losses) are used. Freeze-drying and sieving produces a sediment sample that is fairly homogeneous, and which is much more easily and reproducibly analysed than a wet sample. These advantages outweigh the potential for losses outlined above. Freeze-drying would not be recommended if volatile compounds (e.g. low molecular weight PAH) are of interest. This is not generally the case for the SoE or RDP programmes.

Figure 3.3 The flow sheet for analysis of RDP sediment samples for contaminants.



3.4.1.1 Quality assurance and control

The methods must be reproducible. Analytical variability hampers detection of trends over time, which is an important component of the programme. Reproducibility must be demonstrated by the analysis and reporting of duplicates from a single replicate within a batch, and by the re-analysis of archived replicates from previous batches. Consequently, samples have to be archived from every batch processed to enable future analysis and quality control. The number of duplicates analysed must be sufficient to clearly demonstrate the reproducibility of the data. As a rule of thumb at least 10% of the samples should be analysed as duplicates.

The methods must be accurate. This is best demonstrated by analysis of estuarine sediment Standard Reference Materials (SRMs), for which internationally accepted concentrations have been determined. Reporting of SRM sample results for each batch of samples is recommended to verify the accuracy of the data. Suitable SRMs are available from several agencies, one of the most appropriate for NZ estuarine sediments being the US National Institute of Standards and Technology (NIST) SRM1941a.

If the site is going to be assessed through time, (e.g., for trend analysis following management action) then samples need to be archived for future analysis and quality control.

3.4.2 Metals

3.4.2.1 Settling zones

In settling zones ERC are compared against the value of metals extracted after strong acid digestion of the freeze dried <500 µm (total) sediment fraction in aqua regia (HCl/HNO3) at 100-110°C.

3.4.2.2 Outer zones

In outer zones ERC are compared against the higher value of metals extracted after:

1. Overnight weak acid digestion in 2 M HCl of the <63 µm (mud) sediment fraction at room temperature;
2. Strong acid digestion of the freeze dried <500 µm (total) sediment fraction in aqua regia (HCl/HNO3) at 100-110°C.

3.4.3 Organic contaminants

Recommended methods for the analysis of organic contaminants are based on gas chromotography-mass spectrography (GC-MS). Guidance on appropriate procedures can be obtained from international agencies such as USEPA, NOAA, and Environment Canada.

The chosen method must meet the following performance criteria:

1. The method must be sensitive enough to reliably determine the levels of the targeted contaminants at the low concentrations often found in New Zealand estuarine sediments. Detection limits must be well below the relevant ERC. This can be problematic for organochlorine pesticides, some of which are difficult to reliably quantify at low levels, and for which ERC are also low (e.g. dieldrin, DDTs, lindane, chlordane). A suitable detection limit for organochlorine pesticides would be approximately 0.05 - 0.1 ng/g (ppb) dry weight sediment. This is a compromise between what is currently achievable by most labs, and what is required to reach ERC. Detection limits for PAHs of approximately 0.1 – 0.5 ng/g per compound should be adequate to allow accurate determination of PAH levels in both muddy and sandy sediments. Data for blanks analysed with each batch should be reported to verify that any low level contaminants found in the samples are not spurious laboratory artefacts.
2. The method must be reproducible (see section 3.4.1.1).
3. The method must be accurate (see section 3.4.1.1).
4. Analytical surrogate recoveries must be measured and reported for each sample, or a recovery statistical summary included in the analytical report, to demonstrate the integrity of the analyses. It must be clearly stated whether (or not) results have been

corrected for surrogate recovery. Analytical surrogates must be appropriate for the contaminants being measured (e.g. deuterated or ^{13}C-labelled compounds are best) and the concentrations used in the analysis must be similar to those encountered in the samples (e.g. within a factor of approximately 10 of the sample concentration).

5. If the site is going to be monitored through time, (e.g., for trend analysis following management action) then samples need to be archived for future analysis and quality control.

Samples are initially analysed for HMW-PAH and TOC. After processing, the freeze-dried sieved fraction is also archived (freezing) for possible analysis of organochlorines, depending on the requirements of the receiving water assessment (see Chapter 7).

3.4.4 Total organic carbon (TOC)

Toxic organics are normalised to 1% TOC before comparing to ERC, so TOC is always analysed with organic contaminants. TOC is analysed on the same fraction as HMW-PAH analysis (freeze-dried, 500 µm sieved). Suitable methods are summarised in ANZECC (2000), Volume 7, "Guidelines For Water Quality Monitoring And Reporting", Table 5.2, p 5.4 and the accompanying text.

3.4.5 Acid volatile sulphide (AVS)

Samples are only analysed for AVS if required by the assessment procedure (see Chapter 7). Samples for AVS analysis are therefore collected and frozen for later analysis if needed. Suitable methods for analysis are given in ANZECC (2000).

AVS is unstable due to atmospheric oxidation. However, whole sediment samples are usually stable for at least 24 hours, provided they are compacted, because oxygen penetration is slow. Nevertheless, problems can be experienced with sandy samples, because their high permeability means interstitial water can drain. Sandy samples should therefore be packed in small, rigid plastic containers and kept upright. Note that such containers are ideal for collection, but not for long term storage, because they are permeable to oxygen.

Samples can also be homogenised without undue loss of AVS, provided this is done quickly. After homogenisation of the sample, sub-samples should be frozen immediately in small glass vials, preferably after flushing with oxygen-free nitrogen.

3.4.6 Particle size

One composite of the three replicates is dispersed by peroxide oxidation dispersing agent and agitation. It is then wet sieved to obtain the >500 µm, 500-250 µm, 250-125 µm, 125-63 µm, and <63 µm fractions. Alternatively, methods that analyse particle size spectra could be used.

3.5 Reporting requirements

3.5.1 Compilation of data into a freely-available database

The ARC has prepared a Coastal Environment Database for storing data on sediment quality, water quality, biological quality and benthic ecology. This database is available to interested parties, and will be regularly updated with ARC SoE data, RDP data, and data provided by other parties. Data may be included by submitting it to ARC, preferably in the electronic form provided by the analytical laboratory.

3.5.2 Site assessment

Site assessment involves comparing observed concentrations in sediment samples with ERC values.

3.5.2.1 Metals

For settling zones the total (digests) metals in the total (<500 µm) sediment are compared against ERC.

For outer zones, the higher of the two sets of analyses:

1. the total (digests) metals in the total (<500 µm) sediment;
2. the 2 M HCl extractable metals from the mud (<63 µm) fraction

are compared against ERC.

3.5.2.2 Toxic organics

Concentrations in both settling zones and outer zones are measured against ERC after normalizing to 1% TOC (multiply total concentrations by the factor 1/[TOC]).

4 Ecology

4.1 Why do we monitor ecological communities?

As described in Chapter 1 the primary components of the Regional Discharges Assessment Programme are sediment quality, benthic ecology and human health risk. Measuring the abundance of animals in sediments (benthic ecology) is the most appropriate measure of the affect of contaminants on ecological communities because:

1. Contaminants in stormwater runoff accumulate in sediments within marine receiving environments.
2. A diverse range of organisms live in marine sediments and are continuously exposed to stormwater contaminants.
3. Sediment dwelling organisms are a major component of broader estuarine, harbour and coastal ecosystems, providing food for birds, fish and humans, and affecting water quality, nutrient cycling and productivity.
4. Contaminant levels can reach concentrations that are toxic to sediment dwelling organisms.
5. Contaminants can accumulate to toxic levels in sediment dwelling organisms even at relatively low concentrations in water and sediment.

A large number of animal species inhabit the soft sediment intertidal areas of the Auckland region. In a recent survey of six sites in the Manukau, 99 species were found on a single occasion (Auckland Regional Council unpublished data). The response of individual species to pollution depends upon their tolerance to contaminants, as well as associated changes that may occur to the chemical, physical and/or biological characteristics of their habitat. For instance, tolerant species may benefit from the loss of sensitive species, and actually increase in abundance in moderately polluted habitats. Consequently, in systems with relatively high diversity it can be difficult to disentangle community changes due to pollution from those caused by other factors.

Several methods are commonly used to monitor biological responses to pollution. Diversity indices and indicator species provide very coarse measures of ecological response, because they do not take into account the types of taxa present at a site, or only consider the response of few species. Consequently, there is a risk that biologically important changes may be missed by these techniques. Multivariate techniques, which take into account variations in all of the species, offer a more sensitive alternative for detecting ecological responses.

Auckland Regional Council commissioned NIWA and University of Auckland to investigate methods for assessing the health of benthic communities in relation to pollution levels, specifically for Auckland's harbours and estuaries. Details of the protocols for site selection, sample collection and analysis, and multivariate analysis developed during this process are provided in the following sections.

4.2 Monitoring protocols

4.2.1 Rationale behind selecting sites for benthic ecology

Many of the principles used in the selection of sediment quality sites are also applicable to benthic ecology sites. Moreover, it is desirable to have sediment quality and benthic ecology sites located as close as possible to each other, even though the rationale used to select them is slightly different. The steps involved in selecting benthic ecology sites are described below and applied to the Pakuranga estuary as a case study:

1. Long-term experience of monitoring benthic ecology in the Auckland region, and the dictates of pragmatism indicate that the maximum area that can be reasonably represented by a ecological sampling site is 1 km^2. It is therefore recommended that the number of potential sites in an area of interest be calculated by overlaying blocks of 1 km^2 upon the intertidal habitat. Note that the irregular shape of the coastline means that individual blocks commonly include some land within their boundaries.
2. Drainage channels, industrial (point source), stormwater, and wastewater discharges should be identified and where possible the relative size and type of discharge determined for each block.
3. Catchment boundaries should be defined and landuse categories determined (i.e. residential, commercial, industrial or open space) for each block.
4. A table should be prepared summarising the attributes of each block. At a minimum, this should include details of:
   (a) Available information on sediment texture;
   (b) Available information on community structure;
   (c) The level of contaminant input (high, medium, low) using information on landuse, the location, type and size of discharges, and concentrations of sediment contaminants;
   (d) Suitability, based on a pragmatic assessment of the location in terms of habitat type (e.g. presence of mangroves), sediment dynamics, and/or other physical characteristics that may affect the ecological community independently of contaminant inputs.
5. Blocks with similar attributes and those deemed to be unsuitable (see above) should be identified.
6. The number of blocks should be rationalised by eliminating unsuitable ones, selecting representative samples from sets of similar blocks, and in some cases by removing

blocks for pragmatic reasons. The latter option should only be used if the remaining coverage is sufficient to allow a robust assessment of stormwater and wastewater impacts.

Six potential sites were initially identified when the above steps were applied to Pakuranga Estuary (Fig. 4.1). Information from each potential site was collated and summarised (Table 4.1). As a result of this analysis, sites 4, 5 & 6 were identified as being unsuitable for monitoring because:

- they were in the upper reaches of the settling zone where the freshwater influence is likely to be quite strong,
- they were subject to high channel velocities which lead to scour and deposition, and
- they were dominated by mangroves.

Sites 1, 2 & 3 were considered suitable. The summary information indicated that each block had different characteristics (Table 4.1). However, given the close proximity of the sites to one another, it seemed reasonable from a pragmatic perspective to monitor only sites 1 and 3. These sites cover the range of communities and contaminant inputs and should characterise the impacts within the settling zone adequately. While this method of site selection does not provide a complete description of the entire area, it does fulfil the major objective, which is to provide a robust assessment of the impact of stormwater and wastewater in the receiving environment.

Figure 4.1. Potential monitoring sites in the Pakuranga.

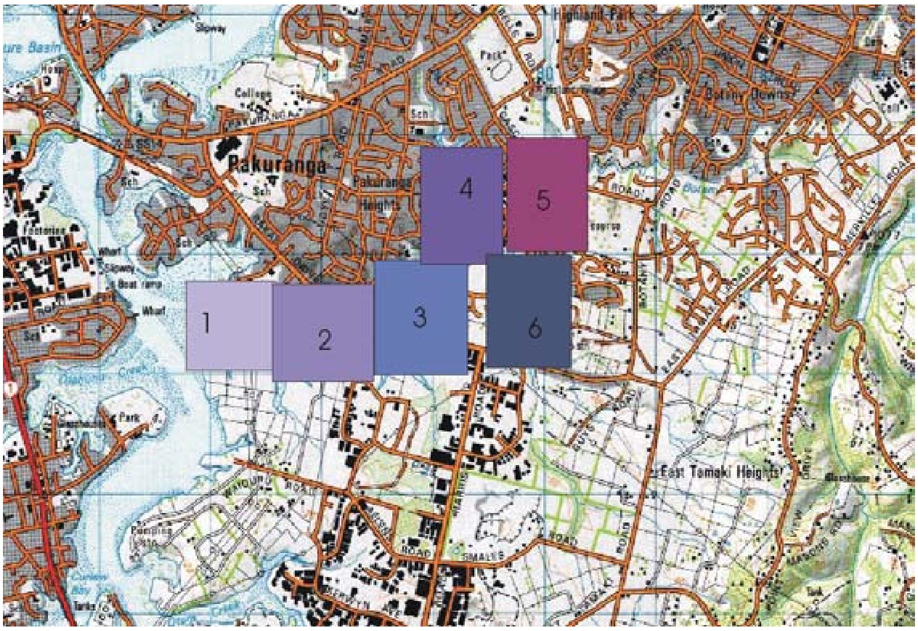


Table 4.1 Determination of potential ecological monitoring site characteristics in Pakuranga Estuary.

	Block					
Character	1	2	3	4	5	6
%mud	20-30	>60	>60	>60	Unknown	Unknown
Communities	A	B	B	B	B (estimated)	B (estimated)
Contaminant Inputs	Low	Medium	High	High	High	High
Categories	A	B	C	Unsuitable	Unsuitable	Unsuitable

4.2.2 Monitoring site size and location

Prior to undertaking sampling, the suitability of each site should be confirmed with a field visit, in particular checking the location of discharge pipes. Sites need to be remote from obvious point sources of contamination. This can be checked by inspecting the estuarine riparian area. Pipes, incised channels exposed at low tide and discoloration (e.g., iron staining) are obvious signs of point sources. Areas of vegetation, excessive shell, and large wave-forms should also be avoided. Ideally, ecological sites should be situated between mid tide and low water on relatively flat areas. During the site visit, the coordinates of each corner of the site should be recorded using GPS.

In settling zones, the size of the sampling site should be 2500 m^2 (for example, 50m x 50m). However, in some settling zones, rocks, mangroves or other features may constrain the area available. In this case a smaller area may need to be sampled, such as the 20m x 50m area recommended for sediment quality. Intertidal flats in outer zones are generally more extensive, and therefore a 1 ha site should be sampled (for example, 100m x 100m).

4.2.3 Sampling protocols

The sampling protocols used for settling and outer zones are the same. Samples should be collected in October to reduce or eliminate the confounding influence of seasonal variability. A stratified random approach is used, where the sampling site is divided into 10 separate sub-areas. A single, circular, core sample (13 cm diameter x 15 cm deep) is taken from a random position within each sub-area. After collection, all samples are sieved using a 500 µm mesh sieve, preserved in 70% isopropanol, and stained with 2% rose bengal. Animals are sorted from the remaining material before microscopic identification is carried out. Identification must be to the same, or a lower, taxonomic level as that given in the species lists provided in Appendix C. The sizes of larger, frequently occurring, bivalve species should also be recorded.

It is highly recommended that the site is initially assessed twice to confirm its ecological health status.

4.3 Multivariate analysis

Advances in computing power mean that multivariate techniques are now the favoured method of assessing and comparing the composition of ecological communities. Without these techniques community data must be reduced to indices, which do not maintain important information on taxa composition, or data on individual species must be considered independently using univariate techniques This quickly becomes unwieldy as the number of species increases, making it difficult to detect relationships between biological variables and physico-chemical processes, such as ecological responses to pollution.

In multivariate analyses each species (or taxon) within a community is regarded as a dimension in multivariate space. Changes in the abundance of a species from one site to the next can be thought of as a difference between the sites in that particular dimension. Multivariate ordination methods are generally used to reduce the number of dimensions to allow graphical representation of the sites in 2 dimensions, where the relative distances between sample points (sites) in the diagram correspond to the relative differences between communities (e.g. MDS plots, Clarke 1993). Canonical, or constrained, ordination techniques have been developed which, instead, reduce dimensionality by projecting communities onto a particular variable or gradient of interest, such as a pollution gradient (e.g. canonical correlation analysis, Gittins 1985). These canonical methods can be used to: (a) test for significant relationships between community structure and a pollution gradient, (b) construct a model of community structure by reference to a gradient and (c) place new observations (sites) along the model canonical axis for classification.

Recently, Anderson and Robinson (2003) and Anderson and Willis (2003) have generalised canonical analysis to allow any measure of community similarity to be used as the basis of the analysis. Their canonical analysis of principle coordinates (CAP) method was adapted by ARC to rank the community structure of new or re-surveyed sites against the community structure of existing sites with known levels of pollution (Auckland Regional Council 2002c). Separate CAP models were required for settling and outer zones because of differences in the biology and sediment dynamics of these areas. Community structure (species counts) and pollution rank data from 22 settling zone and 34 outer zone sites are presently used in the analyses. The settling zone model includes 117 species while the outer zone model 144 species (Appendix C). A summary of the development history of these models is provided in Appendix D.

The results of the analyses are presented as an index of ecological health based on the value of the site on the first canonical axis (the y axis in the model output, Fig. 4.2). This is used to:

1. Provide a measure of the current community health of a site relative to other sites;
2. Track changes in the community health of a site over time;
3. Track the recovery of polluted sites following active management decisions.
4. Detect ecological impacts related to measured contaminants and/or unmeasured secondary contaminants such as organochlorines;

5. Provide reference values for future comparisons (i.e. protect against the shifting baseline).

The benthic health index currently ranges from:

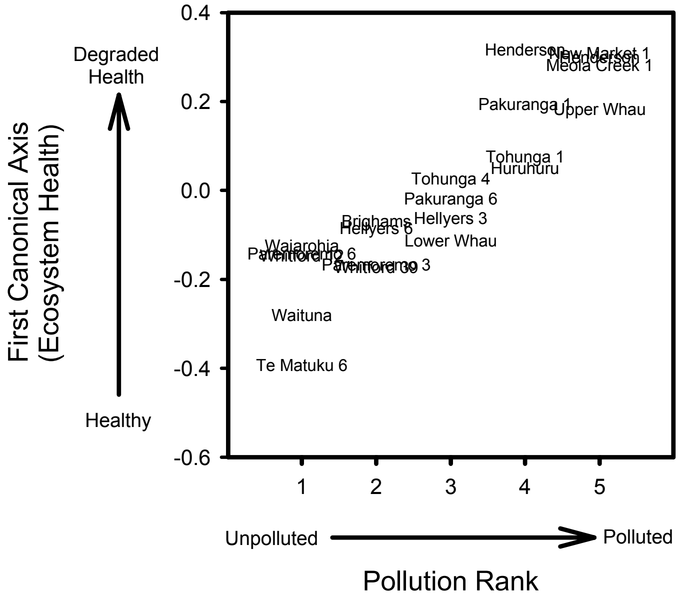
	Healthy		Degraded Health
Settling Zones	-0.4	→	0.35
Outer Zones	0.3	→	-0.35

These values may change as additional data are added to the models. Eventually, the ARC aim to rank benthic ecology according to green, amber and red ERC. However, further testing of the models used to carry out these rankings is required.

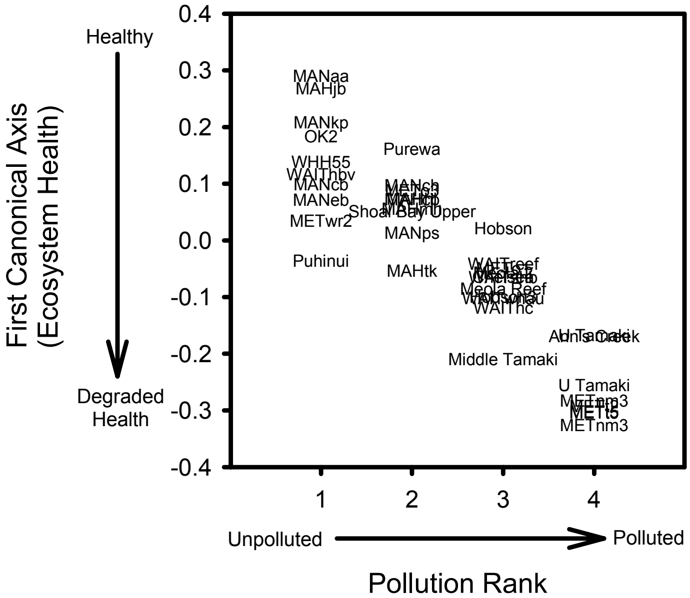
Where appropriate other analytical techniques such as redundancy analysis (RDA) (Legendre, 2001), or canonical correspondence analysis (CCA) (after Braak, 1986), may also be used to provide a better understanding of community health and/or causes of change.

Figure 4.2: Results of the gradient canonical analysis of principle coordinates (CAP) analyses on (a) settling zone and (b) outer zone sites. The benthic health index is derived from the value of a new or resurveyed site on the first canonical axis. Note that the ordination axis represents a constrained axis that does not have a fixed orientation in multivariate space. Consequently, the relationship between pollution rank and the ordination axis (which represents community health) varies between settling and outer zones. This is not unexpected and does not alter the validity of either model.

(a)



(b)



4.4 Analysis of new or re-sampled sites

When assessing benthic health, CAP analysis compares benthic community data from the new or re-sampled sites with data already contained in the settling and outer zone models. The reliability of results is critically dependent on the correct identification and enumeration of taxa from sediment cores. Consequently, it is essential that biota are identified to the same, or a lower, taxonomic level than data used in the comparisons. Full species lists for the models are provided in Appendix C.

Statistical analyses should only be carried out by people skilled in the analysis and interpretation of multivariate data. Data can either be submitted to ARC, or research providers such as NIWA or University of Auckland. Analyses are carried out using programmes developed by Dr. Marti Anderson, University of Auckland, which require data for individual sites to be entered as text files, with a single column of species counts. Species counts are entered in the same order as the species listed in Appendix C for settling and outer zones. Any new species not listed in Appendix C should be entered beneath the existing species. Zeros should be entered in the relevant rows where species are not present at a site.

5 Water Quality – Ecosystem Protection

5.1 Outline

Water Quality (WQ) monitoring, excluding human health-related monitoring, is conducted at a secondary level because:

1. Defining targets and guidelines for some major water quality parameters such as suspended solids and turbidity is not possible at present;
2. It is difficult to obtain representative water quality samples due to concentration gradients, mixing, dispersion, and tidal currents.

Nevertheless, ARC recommend targeted monitoring of some parameters. These include:

1. Dissolved oxygen, to ensure that organic-rich discharges do not lead to excessive oxygen depletion. Dissolved oxygen is a critical parameter that is relatively easy to measure and could reflect excessive inputs of wastewater from overflows or spills to stormwater. ARC recommend monitoring under special circumstances (see below) when there is reason to suspect that wastewater overflows or cross-connections are occurring.
2. The toxicants dissolved copper, zinc (from stormwater and wastewater) and ammonia (from wastewater) to ensure these do not exceed Water Quality Guidelines for significant periods of time. Routine monitoring of these parameters is not recommended. Rather, the ARC propose that monitoring only be carried out under special circumstances, where relatively large stormwater or wastewater inflows occur. A thorough assessment of where and when to monitor should be carried out prior to the initiation of such as programme (e.g. using hydrodynamic harbour modelling) to ensure that samples are collected from an appropriate place and time in the dispersion field.

5.2 Dissolved oxygen

Low levels of dissolved oxygen can stress and/or kill aquatic organisms and increase the anaerobic character of sediments, which may in turn stress other benthic organisms.

There is unlikely to be widespread dissolved oxygen depletion in Auckland's harbours and estuaries, except after a prolonged discharge of wastewater. No guidelines have been developed specifically for New Zealand estuaries. As an interim measure the ANZEEC (2000) water quality guidelines recommend that consideration should be given to using South-East Australian trigger values (Table 5.1). The ARC support the use of these values for the green - amber thresholds until appropriate dissolved oxygen levels have been determined for New

Zealand. The dissolved oxygen threshold for amber - red ERC was derived using the best professional judgement of an independent scientist (M. Larcombe).

Table 5.1: Trigger values for dissolve oxygen values estuaries adopted from ANZEEC (2000) guidelines for South-East Australia (green-amber thresholds) and best professional judgement (amber – red thresholds).

ERC	Lower Threshold	Upper Threshold
Green	>80%	<110%
Amber	65-80	>110
Red	<65	

There are a number of suitable methods for measuring dissolved oxygen (APHA 1998), such as the ARC SoE protocols for saline sites, which are outlined in Appendix E. Dissolved oxygen (DO) should be measured as depth-averaged percentage saturation. Samples should be taken within 2 hours of dawn, to coincide with lowest, diurnal, percentage saturation levels. Water temperature and salinity are required to calculate DO % saturation, and readings of these parameters must also be taken at the same time as DO is measured.

5.3 Dissolved copper and zinc

Concentrations of dissolved copper and zinc in stormwater can exceed Water Quality Guidelines (WQG) for urban freshwaters (Timperley 2000). Potentially, concentrations could also exceed WQG in marine receiving waters, but there is very little data to assess the frequency, magnitude, or extent of exceedances in Auckland. However, exceedances of WQG for dissolved metals are not expected to be widespread and/or persistent in the marine environment. They are only likely to occur during storm events, and for a short time afterwards, depending on flushing times and whether the metals desorb from the suspended or freshly-deposited sediments. ARC therefore consider that the dissolved metals, copper and zinc should be included only as secondary assessment parameters.

The concentrations experienced in the marine receiving waters will depend on:

- The degree of mixing of fresh and salt waters, and, conversely, the persistence of freshwater lenses or salinity gradients;
- Dilution and dispersion through the mixing of incoming stormwater with marine water;
- Reactions between dissolved metals and particulate matter – especially adsorption onto particulate matter[1].

The complexity of hydrological processes such as the persistence of salinity gradients, mixing, dispersion, storm flows, and tidal currents, makes it very difficult to predetermine suitable

1 Freshwater-derived dissolved metals can exhibit many different behaviours in different estuaries. Concentrations can remain conservative, i.e., only changed by dilution; concentrations can be non-conservative i.e., they can increase as dissolved metals are released from particulate matter, or they can decrease through adsorption mechanisms.

sampling locations, depths and times. The most expedient method of identifying when and where to sample is to model estuary concentrations of dissolved copper and zinc assuming conservative behaviour[1]. If conservative behaviour is assumed, an initial assessment can be done using salinity data as a proxy, i.e., the hydrodynamic model does not need to be calibrated with dissolved copper and zinc concentrations. However, concentrations still need to be measured directly to validate model predictions. The results from actual measurements can then be used to upgrade the model to allow for non-conservative behaviour. This is not a trivial exercise and would only be undertaken at new sites if investigative studies indicate that there may be serious dissolved copper and zinc contamination.

Once developed such models can be used to examine a range of scenarios (land use, storm size etc.) to see how often, and under what conditions, water quality ERC (Table 5.2) are exceeded in Auckland estuaries and coastal areas.

Sampling, analysis and quality assurance for dissolved copper and zinc should follow recommendations and procedures in ANZECC (2000) procedures (see Volume 7, Monitoring and Reporting, Chapters 3-6).

Table 5.2: Water quality environmental response criteria (ERC) for copper and zinc.

	Environmental Response Criteria (µg/l)			
Parameter	Green	Amber	Red	Source of ERC
Copper	<1.3	1.3-3.0	>3.0	ANZECC (2000)
Zinc	<15	15-23	>23	ANZECC (2000)

5.4 Ammonia

The term 'ammonia' refers to two chemical species of ammonia that are in equilibrium in water: the un-ionised ammonia, NH_3, and the ionised ammonium ion, NH_4^+. Ammonia is a non-persistent and non-cumulative toxin. Toxic effects of ammonia are mainly attributed to un-ionised NH_3 (ANZECC 2000). Being a neutral molecule, it is able to cross epithelial membranes of aquatic organisms more readily than the ammonium ion. The proportion of the two chemical forms varies with the physico-chemical properties of the water, particularly pH and temperature. In general, more un-ionised NH_3 exists at higher pH. Accordingly, toxicity also tends to increase with pH.

ANZECC (2000) water quality guidelines provide marine, moderate reliability trigger values of 910 µg/L and 1200 µg/L **total** ammonia-N (i.e. un-ionised ammonia (NH3) plus the ionised ammonium ions (NH4+)) for pH 8.0 with 95% protection and 90% protection respectively. The pH of seawater is approximately 8.2, but it tends to decrease as salinity is reduced. In Auckland, the pH of marine and estuarine water rarely exceeds 8.2, but it is often less than 8.0 depending on the location, tide and level of freshwater input. Table 5.3 indicates how the figures for the total ammonia-N guideline change in relation to pH (ANZECC 2000). Note that trigger values increase at low pH due to a reduction in un-ionised NH3, and hence lower toxicity. Given that the toxicity of ammonia is likely to be less in estuaries than on the open coast, the ARC consider it appropriate to adopt the ANZECC (2000) marine water quality guidelines for total ammonia-N.

Table 5.3. Marine trigger values as total ammonia-N in µg/L at different pH (from ANZECC 2000)

(Temperature is not taken into consideration)

pH	Marine Trigger value (µg/L as total ammonia-N)
7.7	1560
7.8	1320
7.9	1100
8.0	910
8.1	750
8.2	620
8.3	510

Ammonia samples should be taken at the same stations and depths and at the same times as dissolved oxygen samples. Note that temperature, salinity and pH data must also be collected to allow a more rigorous assessment of total ammonia toxicity if required. Sampling precautions, methods of preservation, analysis, and quality assurance are described in ANZECC (2000), Volume 7: Monitoring, Chapters 3-6, Table 5.2.

6 Water Quality - Human Health Risk

The Microbiological Water Quality Guidelines for Marine and Freshwater Areas (Ministry for the Environment and Ministry of Health 2002) recommend a framework for grading and monitoring bathing beach quality. The framework couples a risk-based catchment assessment, which is used to inform the public of the general condition of a site, with a bathing beach monitoring programme used to alert the public to immediate health risks.

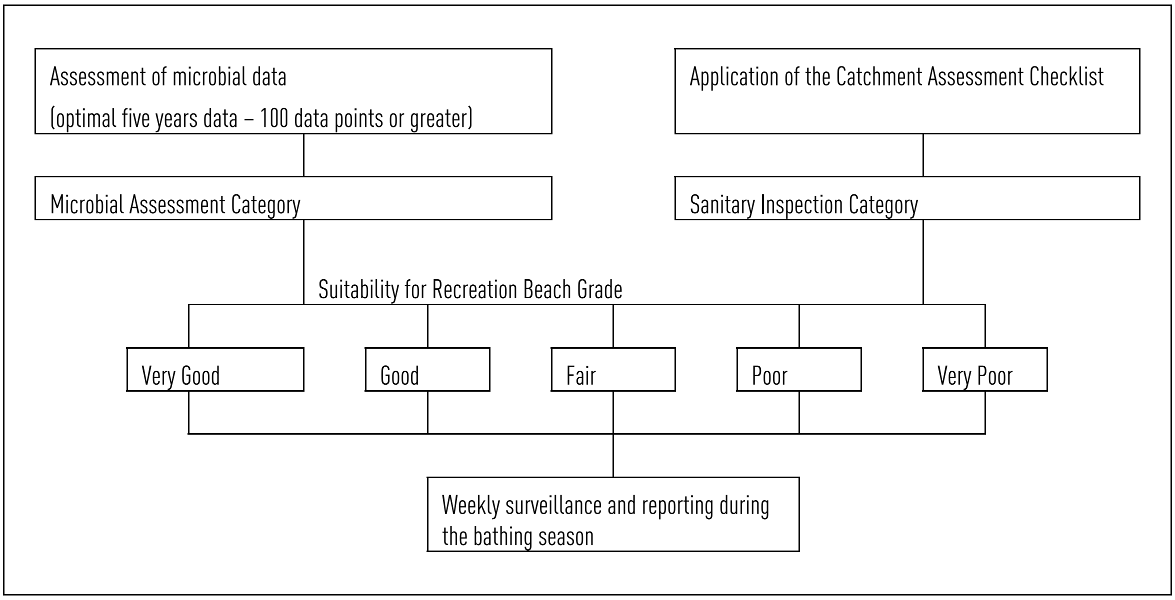
The risk-based assessment process uses catchment landuse information to derive a sanitary inspection category, and long-term historical data on beach enterococci levels to derive a microbial assessment category. These two indices are combined to establish the suitability of a beach for recreational activities (Suitability for Recreation Beach Grade), which is ranked as: very poor; poor; fair; good; or very good (Fig. 6.1).

The ARC and Medical Officer of Health (Auckland District Health Board) accept that ongoing land use activities occurring within urban catchments are such that it may be difficult to achieve a suitability for recreation beach grade better than *Poor* or *Fair*. Consequently, within the Auckland Metropolitan Urban Limits (as established in the Auckland Regional Policy Statement) the territorial authorities, the Medical Officer of Health and the ARC jointly consider that it is more important that:

- a robust monitoring programme is in place for recreational water areas (high recreational use beaches) so that risks to public health can be avoided when the microbiological action mode guideline is exceeded (Ministry for the Environment and Ministry of Health 2002);
- works are undertaken by stormwater and wastewater network operators within a best practicable option framework to remove significant risks to public health in the medium term;
- network resource consent application processes are used to identify those overflows that may lead to an exceedance of the alert/amber and action/red modes given in the guidelines (Ministry for the Environment and Ministry of Health 2002), and to determine the key climatic or network failure events that will cause those overflows to occur.

Outside of the Auckland Metropolitan Urban Limits, the land uses occurring within predominantly rural catchments are such that Suitability for Recreation Grades of *Good* or *Very Good* are realistically achievable. Consequently, the territorial authorities, the Medical Officer of Health and the ARC jointly agree that there would be benefit in undertaking Suitability for Recreation Gradings for water recreation areas located in these areas.

Figure 6.1: Process outlined in the Microbial Water Quality Guidelines for Marine and Freshwater Areas (Ministry for the Environment and Ministry of Health 2002) to grade the suitability of a beach for contact recreation.



6.1 Microbiological water quality guidelines and the RDP process

According to the guidelines (Ministry for the Environment and Ministry of Health 2002), water recreational areas should be defined and surveillance monitoring should be undertaken in those areas. Surveillance monitoring involves routine (e.g. weekly) sampling of bacteriological levels. Where microbiological thresholds are exceeded alert or action modes are initiated. Alert mode requires investigation of the causes of elevated microbiological levels and increased sampling to enable the risks to bathers to be more accurately assessed. Action mode requires the local authority and health authorities to warn the public that the beach is considered unsuitable for recreation.

The territorial authorities and the ARC will define water recreational areas in the Auckland Region. Note that the term "water recreational areas" used in the guidelines (Ministry for the Environment and Ministry of Health 2002) is analogous to the term "high recreational use beach" used in the Auckland Regional Plan: Coastal.

6.1.1 Within the metropolitan urban limits

High recreational use beaches subject to urban stormwater and wastewater discharges pose a relatively high risk to human health (Ministry for the Environment and Ministry of Health 2002). The RDP aims to minimise that risk by ensuring that:

- Regular monitoring and/or hydrodynamic modeling is carried out to detect or predict periods when microbiological contaminants pose an immediate threat to human health;

- The public are notified of immediate health threats through appropriate signage and media releases;
- The number of wet weather events triggering the action mode (Table 6.1) and leading to a public notification of immediate health risks at defined water recreational areas is limited to a maximum of 2 per annum.
- Dry weather wastewater overflows which trigger the action mode (Table 6.1) are not permitted.

Monitoring and sample analysis will be carried out in accordance with the protocols provided in the Microbiological Water Quality Guidelines for Marine and Freshwater Areas (Ministry for the Environment and Ministry of Health 2002). Enterococci trigger values and actions given in the guidelines are summarised in (Table 6.1). If enterococci levels exceed 136 enterococci/100 ml^{-1}, the rate of sampling is increased to daily. The public must be informed if samples, or model predictions, from two consecutive days indicate enterococci levels exceed 277 enterococci/100 ml.

Table 6.1: Marine bathing beach monitoring guidelines outlined in the Microbial Water Quality Guidelines (Ministry for the Environment and Ministry of Health 2002).

Mode	ERC Equivalent	Indicator	Action
Surveillance Mode	Green	No single sample greater than 136 enterococci/100 mL.	Continue routine (e.g. weekly) monitoring.
Alert Mode	Amber	Single sample greater than 136 enterococci/100 mL.	Increase sampling to daily. (Initial samples will be used to confirm if a problem exists.) Consult Catchment Assessment Checklist (Ministry for the Environment and Ministry of Health 2002), or similar checklist to assist in identifying possible sources. Undertake a sanitary survey to identify sources of contamination.
Action Mode	Red	Two consecutive single samples (resample within 24 hours of receiving the first sample results, or as soon as is practicable,) greater than 277 enterococci/100 mL.	Increase sampling to daily. (Initial samples will be used to confirm if a problem exists.) Consult Catchment Assessment Checklist (Ministry for the Environment and Ministry of Health 2002) or similar checklist to assist in identifying possible sources. Undertake a sanitary survey, identify sources of contamination. Erect warning signs. Inform public through the media that a public health problem exists.

6.1.2 Outside the metropolitan urban limits

Beaches outside the metropolitan urban limits should be graded to ascertain their suitability for recreation, and monitored, in accordance with the Microbial Water Quality Guidelines for Marine and Freshwater Areas (Ministry for the Environment and Ministry of Health 2002).

7 Synthesis and Assessment

7.1 Introduction

Previous chapters provide technical details on monitoring urban coastal receiving environments for the effects of stormwater and wastewater overflows. The aim of this synthesis is to provide a framework for site assessment leading to decision making.

The process was designed to:

- maximise the use of existing information by using sediment quality of key metals and PAH as triggers for further investigation;
- minimise the analysis of secondary contaminants unless warranted;
- maximise the use of information collected during ongoing monitoring;
- ensure the decision making process is underpinned by scientifically robust information.

Two types of monitoring will be required to assess the impacts of stormwater and wastewater discharges: monitoring for environmental quality and monitoring for human health risk.

For environmental quality, a receiving environment is initially assessed for sediment quality (Fig. 7.1) and categorised as green, amber or red according to contaminant levels. If the site is green, no immediate action is required. Further monitoring should be carried out in 5 years, unless there is a major change in catchment land use. If the site is amber or red, ecological community health is assessed (Fig. 7.2 & 7.3).

The amber condition represents the region's best opportunity to maintain current status or delay further degradation. Priorities for action are determined by applying a predictive model to see how rapidly the site will become red. The rate of predicted increase in concentration to a red sediment quality condition determines the priority for evaluating remedial options.

Red indicates that contaminant concentrations are probably having an effect on the biology of the site. Investigations should therefore be carried out to establish the cause of the impact and provide a decision-making framework for evaluating management actions (such as infrastructure upgrades).

For human health risk, the assessment follows the procedures outlined in Chapter 6. Local network operators and the ARC will first decide which beaches need to be monitored for human health risks associated with swimming or other contact recreation. Each beach will be assessed by predictive modelling of enterococci numbers and/or by routine monitoring of enterococci as specified in the Ministry for the Environment and Ministry of Health (2002) guidelines. No environmental response criteria are provided for human health. Rather, the number of wet weather events leading to a public notification of immediate health risk at defined water recreational areas is limited to a maximum of 2 per annum. Dry weather wastewater overflows capable of triggering the need for public notification (Ministry for the Environment and Ministry of Health 2002) are prohibited.

7.2 Assessment of environmental and human health risk

7.2.1 Sediment quality assessment

Initial screening of existing sediment quality information should be carried out using the primary contaminants zinc, copper, lead and HMW-PAH. Many sites have been surveyed for sediment contamination in the Auckland region, so a relatively large pool of data is available (Auckland Regional Council 2003). If data does not exist for the area of interest, contaminant levels will need to be measured and used to rank the site according to green, amber and red ERC (see Chapter 3).

Although sediments in settling zones are expected to be reasonably homogeneous, there is inevitably going to be some variability in contaminant concentrations. The costs of detailed investigations into the source of contaminants and appropriate management responses, means it is very important to confirm the rank of a site prior to undertaking such studies. For sites that have not been previously monitored, this would mean following up an initial sample with a subsequent sample one year later, or comparing the results with data from adjacent sites.

If the site is ranked green, no further action is required and the site is reassessed in 5 years unless there is a major change in catchment land use. Ecological community health, the source of contaminants, and temporal trends in contaminant concentration, should be assessed if: the site is confirmed as amber or red and; contaminant levels are increasing. Information from this assessment should be used to evaluate options for remediation and to prioritise management options. In respect to accumulation rates, lead concentrations are likely to decrease with time, whereas zinc, copper and PAH concentrations are likely to increase with time. If lead is the only contaminant to have amber or red status with respect to ERC, then it may be more sensible to repeat the sediment quality sampling in 2 years time, rather than immediately carry out the additional assessments. If zinc, copper and/or PAH levels are amber or red, then an ecological community health assessment must be carried out.

7.2.2 Ecological community health

Ecological community health will be assessed if a site is ranked amber or red according to sediment quality. Methods for assessing ecological community health are described in Chapter 4. It was initially envisaged that ecological community health would be ranked in a similar fashion to sediment quality using green, amber and red categories. However, the adoption of this approach has been delayed until further testing has been carried out. In the interim the value of a site on the first canonical axis will instead be used to:

1. Provide a measure of the current community health of a site relative to other sites;
2. Track changes in the community health of a site over time;

3. Track the recovery of polluted sites following active management decisions;
4. Detect ecological impacts related to measured contaminants and/or unmeasured secondary contaminants such as organochlorines;
5. Provide reference values for future comparisons (i.e. protect against the shifting baseline).

The present state of ecological community health and changes through time will also be used to direct further investigations into the causes and effects of contamination.

7.3 Prediction of future sediment quality

7.3.1 Settling zones

Future sediment quality can be predicted for settling zones with simple models, such as the Urban Stormwater Contaminant Model (Auckland Regional Council 1998b, Green et al. 2001). These are described briefly in the report "Environmental Targets for Urban Coastal Marine Area" (Auckland Regional Council 2002a (TP169)). Future sediment quality can also be predicted from empirical data, as is done in the ARC SoE marine sediment monitoring programme (Auckland Regional Council 2002e).

For amber sites, the predicted time to reach red contaminant levels determines the priority for evaluating remedial options.

- < 5 years – very high priority
- 5-10 years – high priority
- 10-20 years – moderate priority
- >20 years – low priority

Predictions of future sediment quality should also be undertaken for red sites, to see how rapidly a site is deteriorating and to evaluate remedial options.

7.3.2 Outer zones

For outer zones, prediction of sediment quality can currently only be achieved through monitoring. However, models to predict future sediment quality in outer zones are under development. If the outer zone is associated with an upstream settling zone, then these should be considered together and predictions can be made based on future concentrations in the settling zone.

7.4 Detailed investigations

For a site that has scored amber or red for sediment quality and contaminant levels are increasing, a detailed investigation should be carried out to establish cause and to ensure that any remedial action is appropriate. Site assessments need to be detailed enough to provide the local network operator with sufficient information to evaluate management actions that are capable of addressing environmental effects.

Sediment **organochlorine** concentrations would be checked if ecological monitoring indicated that the benthic community was responding in a way that could not be explained solely by elevated concentrations of the primary contaminants. These persistent chemicals are widely sourced from past agricultural, household and industrial use and their concentrations can exceed ERC at sites around Auckland (Diffuse Sources 2002). Methods for analysis are described in Chapter 3.

Dissolved zinc and copper would be monitored if it were suspected that these were exceeding their ERC in the receiving water. At this stage, only general guidance can be provided on where such excedences are likely to occur. The site would need to have large stormwater inputs and be poorly flushed. Hydrodynamic modelling of the Waitemata harbours will give much better guidance in the future.

Water quality **dissolved oxygen** and **total ammonia** would be checked if significant wastewater overflows occur (See Chapter 5). Indications of such occurrences would be obtained from the human health assessments of bathing beaches (Chapter 6). However, this should not be the only source of information used as discharges into areas that are not monitored for bathing beach quality may be missed. Methods for measuring dissolved oxygen and NH_3 are given in Chapter 5.

Acid volatile sulphide (AVS) would be measured to assess the bioavailability of metals, and determine their role as toxic agents, if the concentration of primary contaminants (copper, lead, zinc and HMW-PAH) could not explain a degraded score for ecological community health. Methods for determining AVS are referenced in Chapter 3.

Total organic carbon (TOC) is routinely monitored to normalise toxic organics concentrations. It is also required to assess the bioavailability of toxic organics (Chapter 3).

Laboratory toxicity testing could also be undertaken if ecological monitoring indicated that the ecological community was responding in a way that could not be explained solely by elevated concentrations of primary or secondary contaminants. Toxicity testing would be useful in:

1. testing for phototoxicity by PAH. If phototoxicity is found, then PAH is probably a causative agent, and could then receive special consideration in assessing remedial options;
2. examining the possibility that sediment pore water NH_3 concentrations are sufficiently high to cause toxicity and downgrade the benthic community health index. In this case, the sediments are likely to be enriched with organic matter, which could be sourced from wastewater overflows or other catchment-related sources;

3. determining the degree of toxicity of the sediment (i.e. how far into the red zone the site is in terms of actual impact). This "degree of redness" may help with decision making, especially in setting priorities. For example, if the sediment is toxic to amphipods or worms, then the site would be considered highly contaminated and management responses should reflect this.

Note that toxicity testing is recommended by ANZECC (2000) as the final step in assessing sediment contamination.

7.5 Human health status

Monitoring for human health risk is effectively carried out independently of environmental quality assessment and monitoring. Territorial authorities have primary responsibility for implementing and carrying out bathing beach monitoring in accordance with recommendations made in the Microbiological Water Quality Guidelines for Marine and Freshwater Areas (Ministry for the Environment and Ministry of Health 2002), subject to the changes recommended by the ARC and Medical Officer of Health regarding bathing beach grading within the metropolitan urban limits (Chapter 6). Impacts on bathing beach quality would be evaluated using monitoring data, together with the results of network and hydrodynamic models.

7.6 Evaluation of remedial options

An evaluation of remedial options should include, but is not limited to:

- Confirm the source of contamination by catchment based investigations;
- Assess the values of the receiving environment;
- Identify targets for the receiving environment;
- Examine the potential mix of source control, network improvement and treatment options that will achieve the proposed targets;
- Consider the costs of options;
- Canvas public expectations;
- If necessary refine options analysis;
- Identify priorities for action;
- Set time frames for implementation.

These are not discussed in this document. They would be considered under a formal review of discharge consent conditions initiated by ARC under Section 128 of the Resource Management Act (1991).

7.7 Additional notes for outer zones

ARC recommend a slightly different approach depending on whether the source of contaminations is:

1. Directly from the catchment
2. Mainly from upstream settling zone(s)

In the first case, monitoring the outer zone forms the basis for decision-making, and in this situation the procedures outlined for settling zones may be directly applied to the outer zone. In the second case, assessing the outer zone occurs in parallel with the assessment of the upstream settling zone. Remedial options may be evaluated on the basis of the settling zone, the outer zone or both. For example, in Motions Creek, an initial appraisal assigned a red status to the settling zone and the outer zone. The settling zone is highly contaminated, in fact it is one of the most contaminated receiving environments identified in Auckland to date. The catchment is also fully developed, and an evaluation of remedial options may discover that only limited reductions in contaminant export can be achieved, which would not result in a significant shift in the settling zone status, apart from slowing its rate of deterioration. However, because degradation of the outer zone is partially driven by 'leakage' from the settling zone, it may be possible to reverse it's deterioration and return it to an amber status.

Figure 7.1: Flow diagram summarising procedures for assessing monitoring requirements for a site.

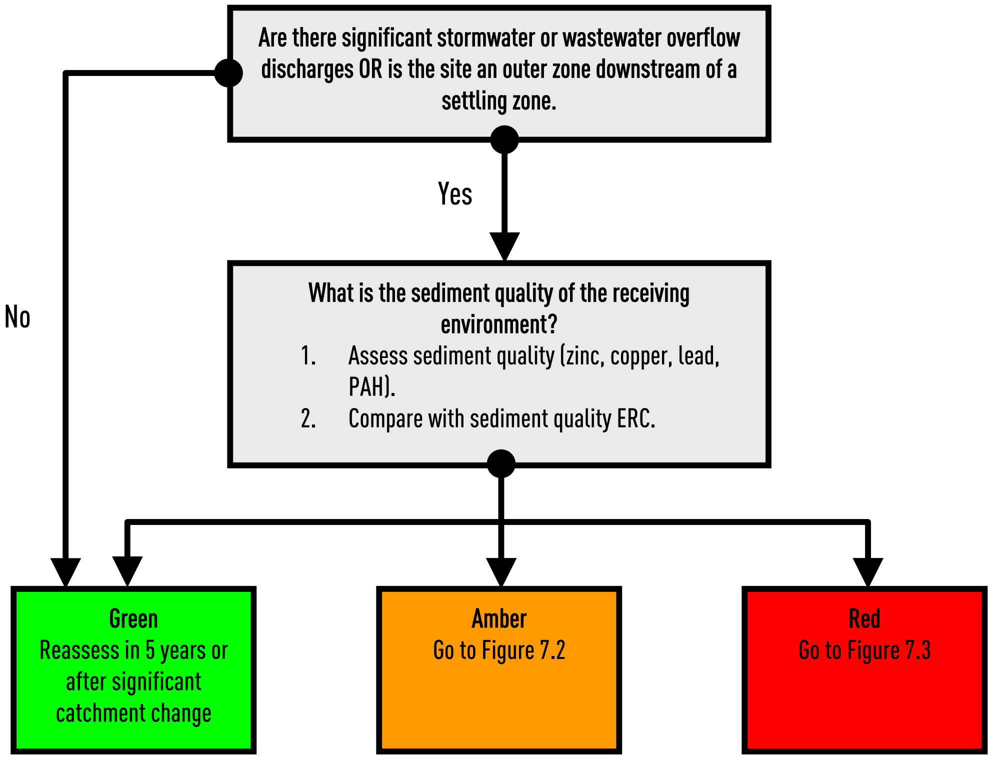


Figure 7.2: Flow diagram summarising procedures for monitoring and assessing settling (SZ) and outer zones (OZ) with amber sediment quality.

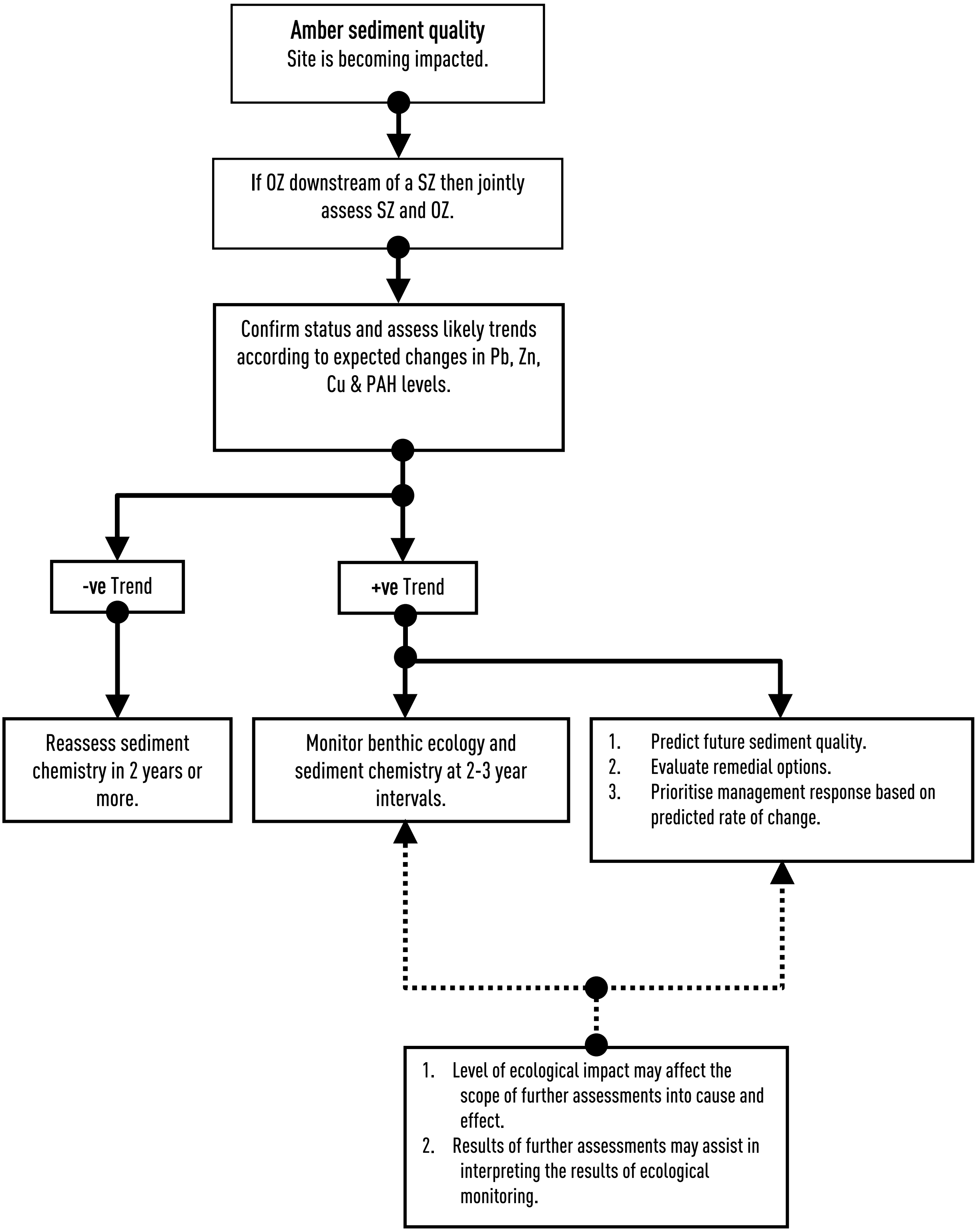
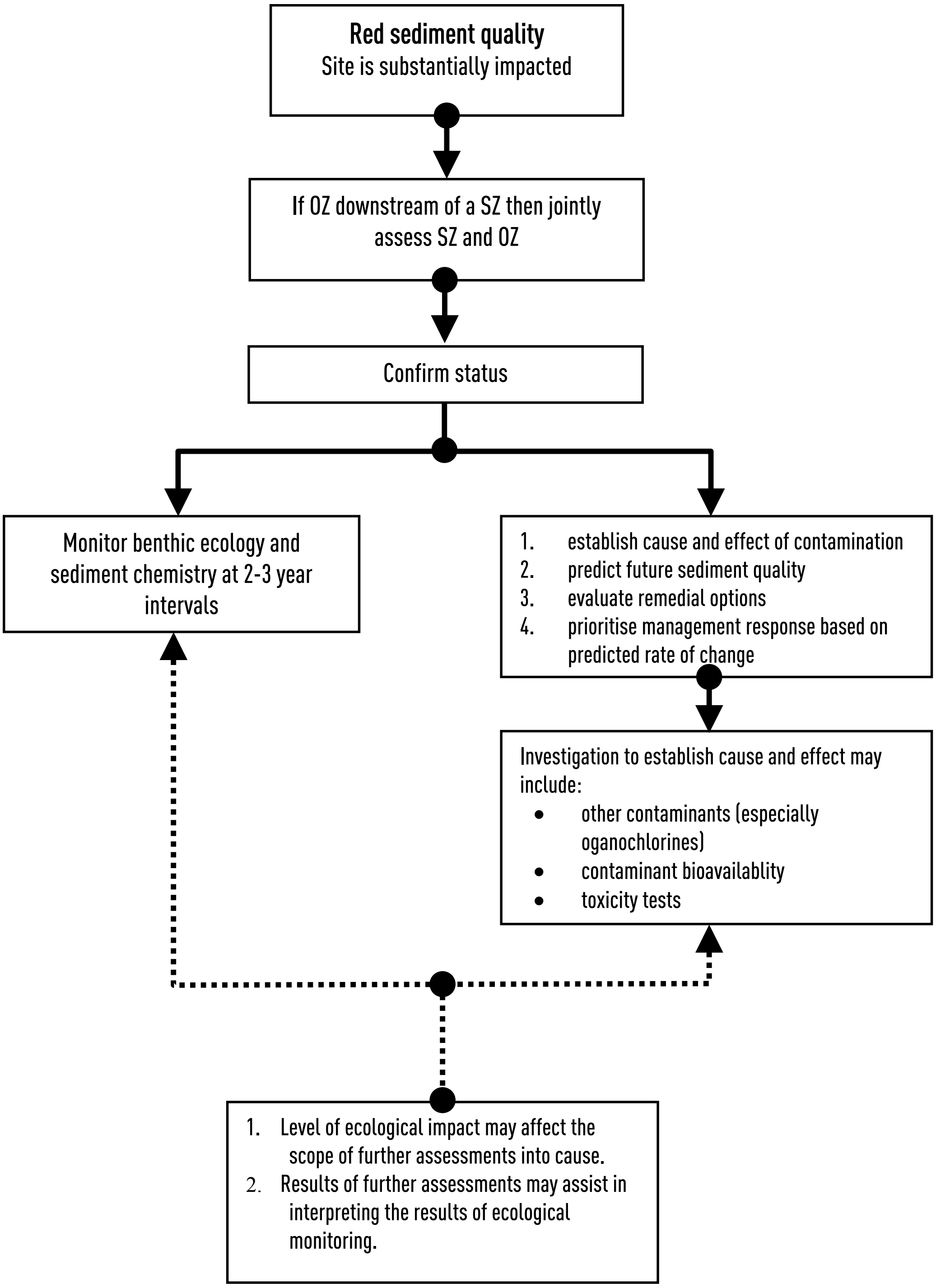


Figure 7.3: Flow diagram summarising procedures for monitoring and assessing settling (SZ) and outer zones (OZ) with red sediment quality.



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9 Glossary

Acid Volatile Sulphide (AVS). The AVS concentration in sediments is the solid state sulphide associated with FeS, CdS, ZnS, PbS, NiS, CoS. In uncontaminated sediments, AVS is dominantly FeS.

Best Practicable Option (BPO). The BPO is defined in the Resource Management Act (1991) as: "in relation to a discharge of a contaminant or an emission of noise, means the best method of preventing or minimising the adverse effects on the environment having regard, among other things, to:

1. The nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects; and
2. The financial implications, and the effects on the environment, of that option when compared with other options; and
3. The current state of technical knowledge and the likelihood that the option can be successfully applied:"

ERC. Environmental Response Criteria used by the Auckland Regional Council.

ER-L. Effects Range Low (Long et al. 1995). Concentration at which 10% of toxicity studies show no effect. Developed by the National Oceanic and Atmospheric Administration (NOAA) from an extensive North American database of sediment chemistry and toxicity studies (Long et al. 1995, http://response.restoration.noaa.gov/cpr/glossary.html).

ER-M. Effects Range Medium. Concentration at which 50% of toxicity studies show an effect. See ER-L.

ISQG ANZECC. Interim Sediment Quality Guideline for Australia and New Zealand (Australia and New Zealand Environment and Conservation Council (2000))

ISQG CCME. Interim Sediment Quality Guideline for Canada (Canadian Council of Ministers for the Environment (CCME) 1999).

ISQG-Low. Interim Sediment Quality Guideline-Low (ANZECC 2000).

PAH. Polynuclear Aromatic Hydrocarbons – in this report specifically the high molecular weight fraction.

PEL. See TEL.

Phototoxicity. Some PAHs are more toxic in the presence of ultraviolet (UV) light than in tests conducted under standard laboratory light. This increased sensitivity is termed phototoxicity. When PAH, sunlight, and organism are present simultaneously, photo-enhanced toxicity can occur if the organism is transparent/translucent to sunlight.

SQG. Sediment Quality Guideline.

TEL. Threshold Effects Level for Florida Department of Environmental Protection (MacDonald et al.1996). The Florida and earlier Canadian SQG (Smith et al. 1996) define the Threshold Effects Level (TEL) below which adverse effects are predicted to rarely occur, and the Probable Effects Level (PEL) above which adverse effects are predicted to occur frequently. SQGs were based on a compilation by the National Oceanic and Atmospheric Administration (NOAA) from an extensive North American database of sediment chemistry and toxicity studies (Long et al. 1995). These were subsequently modified for application in Florida (McDonald et al. 1996), and in Canada (Smith et al. 1996, CCME 1999).

TOC. Total Organic carbon

10 Appendix A: Summary of the rationale for selecting ERC

10.1 Differences between red ERC and ANZECC guidelines

The red thresholds for the ERC used to assess sediment contaminants are summarised in Table 10.1 and 10.2. As described above, they are based on the ANZECC ISQG-Low Guidelines (ANZECC 2000), but other currently available guidelines were also adopted when the values provided were considered inappropriate to the Auckland region. This is consistent with the ANZECC (2000) philosophy of developing trigger values appropriate to local conditions. Note that as the Auckland Region is assessed for effects from stormwater and wastewater discharges, better information will accrue, allowing re-evaluation of the appropriateness of the ERC values and the assessment procedures. Table 10.1 shows the original ANZECC (2000) trigger values and ARC's amendments.

10.1.1 Zinc and copper.

The ANZECC (2000) ISQG-Low values for copper and zinc are the same as the Hong Kong interim sediment quality values for dredge spoil disposal "ISQV" (Chapman et al. 1999). The Hong Kong data are based on local unpublished studies, which did not find toxic effects below these concentrations. The text accompanying the ANZECC (2000) guidelines asserts a high level of confidence in ER-L (Long et al. 1995) values for copper and zinc and the guidelines have used ER-L for other toxicants. There seems to be no justification for the substitution of ER-L values with ISQV values in the ANZECC (2000) guidelines, so the ER-L values for copper and zinc were adopted by ARC.

10.1.2 Organochlorines.

The ANZECC (2000) guideline values for organochlorines were not used because:

1. An unrealistically low ANZECC (2000) dieldrin value that is below commonly quoted analytical detection limits and would be exceeded at most Auckland settling zones.
2. ARC believes that no-effects data[2] as well as effects data should be included in derivation of guidelines for contaminants that are present at low concentrations because there is a low reliability in derived values from effects data alone (Diffuse Sources Ltd 2002). The ANZECC (2000) values for organochlorines are based on the ER-L values of Long et al (1995) that were derived from effects data alone.

The ERC adopted by ARC will probably reduce the number of toxicity/ecological investigations that could unnecessarily be triggered by the low ANZECC guideline values of some organochlorine compounds.

[2] No-effects data are studies that show no relationship between the specific contaminant level and a measured specific biological effect. Effects data are studies that have established a link between the contaminant and a measured specific biological effect. Either effects data alone or both databases can be used in developing guidelines (MacDonald et al 1996).

Table 10.1 ANZECC (2000) trigger values for contaminants and ARC amendments.

A. Primary contaminants (mg/kg dry weight)

Parameter	ISQG- low[1,2] (ANZECC 2000)	Red ERC Thresholds[1,2]	Source of Amended Value[3]
Zinc	200	150	ER-L
Copper	65	34	ER-L
Lead	50	50	
HMW-PAH	1.74	1.74	

B. Secondary toxic organics[1,2] (μg/kg dry weight)

Parameter	ISQG-low (ANZECC 2000)	ERC[4]	Source of Amended Value[3]
Chlordane	0.5	2.3	ISQG (CCME)
p,p'-DDD5	2	1.2	ISQG (CCME)
p,p'-DDE	2.2	2.1	ISQG (CCME)
p,p'-DDT	No value	3.2	ISQG (CCME)
DDT, total	1.6	3.9	TEL
Dieldrin	0.02	0.72	ISQG (CCME)
Lindane	0.32	0.3	ISQG (CCME)
Total PCB	23	22	ISQG (CCME)

[1] Values rounded to two significant figures.

[2] Values are for the total sediment in the settling zone and for the mud fraction within the outer zone.

[3] Source:

- ER-L = Effects Range Low (Long et al. 1995)
- TEL = Threshold Effects Level for Florida Department of Environmental Protection (MacDonald 1996)
- ISQG-Low = Interim Sediment Quality Guideline-Low (ANZECC 2000)
- ISQG CCME = Interim Sediment Quality Guideline for Canadian Council of Ministers for the Environment (CCME 1999).

[4] ANZECC (2000) has specified this for an organic carbon content of 1% (see text).

[5]ANZECC guideline is for o,p'- + p,p'-DDD. This is slightly (c.a. 20%) higher than for p,p'-DDD alone.

10.1.3 Polycyclic aromatic hydrocarbons.

The use of ANZECC (2000) guideline values for high molecular weight PAH were adopted for use as ERC because:

- This group of compounds is better defined than Total PAH, which can be somewhat arbitrarily defined by the analytical method used;
- The higher molecular weight PAH compounds are more reliably analysed, since they are less susceptible to volatilisation or biodegradation losses, and;
- They are more relevant for evaluating stormwater contamination, as combustion-derived PAH (which are mainly high molecular weight compounds) represent the most significant fraction of PAHs found accumulating in estuarine sediments.

High molecular weight PAH are defined in the ANZECC (2000) guidelines as "the sum of concentrations of benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene"(ANZECC 2000, Volume 1, pg. 3.5-4). PAH's are normalised to 1% total organic carbon before comparing to ERC.

The possibility that other measures of PAH may be required in particular circumstances is not ruled out. For example, low molecular weight PAH, which are less persistent, less accumulative, but more acutely toxic than the high molecular weight compounds, are more relevant for short-term fuel spill issues.

10.1.4 Other contaminants

There are other contaminants in urban coastal marine areas that presently exceed, or may exceed, guideline values in the future – such as mercury (Hg) (P. Kennedy, pers. comm.) and dioxins. Their sources and relationship with stormwater and wastewater discharges need further research and investigation before ARC would consider their inclusion as ERC in the RDP. While these other contaminants may exist, their impacts are likely to be addressed by managing the receiving environment on the basis of the major contaminants.

10.1.5 Amber ERC

Amber levels for the major contaminants: zinc, copper, lead and high molecular weight PAH; were chosen using sediment quality guidelines derived from both effects and no-effects data. These guidelines are more conservative and hence protective than those derived solely from no-effects data. Guidelines developed using effects and no-effects data are available from the Florida Department of Environmental Protection (MacDonald et al 1966) and from the Canadian Council of Ministry for the Environment (CCME 1999). These two guidelines are very similar (see ANZECC 2000 for more details). The relevant Florida SQG is called the Threshold Effects Level, or TEL, while the relevant Canadian SQG is called the Interim Sediment Quality Guideline, or ISQG. The latter source was selected for the amber ERC thresholds of zinc, copper and lead, however, no ISQG values were provided for high molecular weight PAH, so the Florida TEL values were adopted for this contaminant.

For other contaminants of concern in Auckland estuaries, specifically organochlorines, the SQG database is not robust enough to establish amber levels. Also, there is no clear evidence that their concentrations are building-up, as they are for the major contaminants, so an amber warning level is not as critical.

11 Appendix B: ARC sediment sampling protocols

Sampling procedure for collecting 5 replicates in the ARC state of the environment (SoE) survey of sediment quality (Auckland Regional Council 1998a).

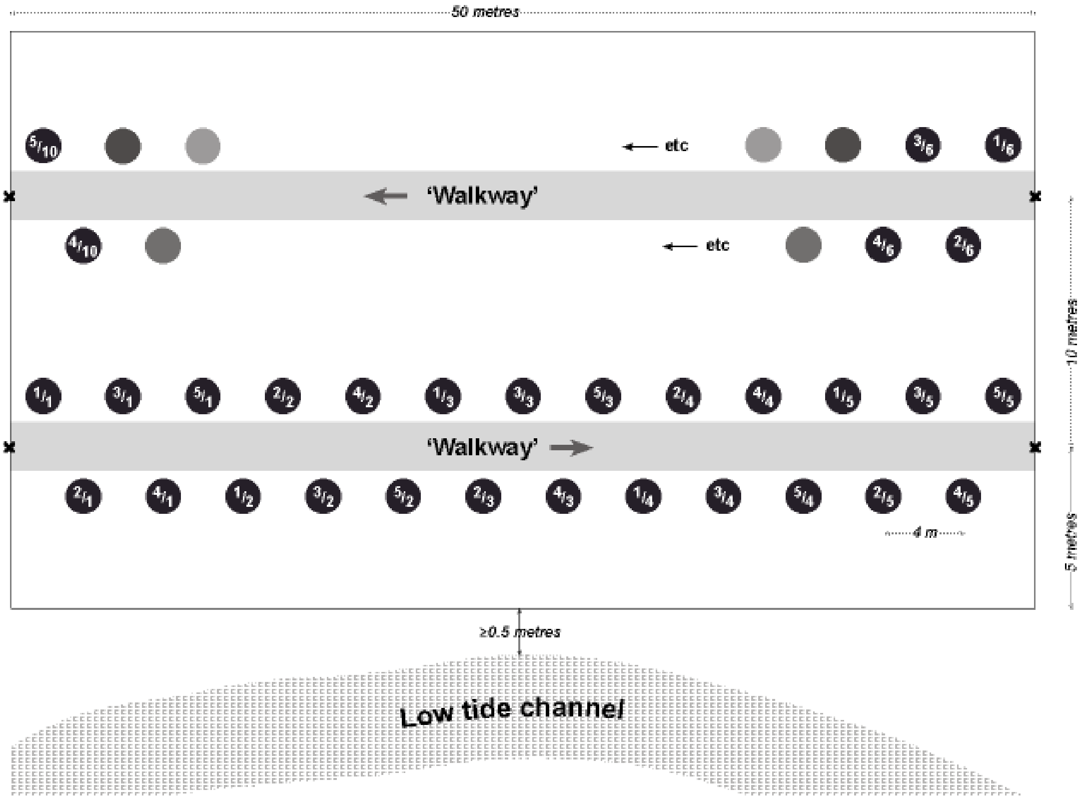
Samples are collected using a scoop made from a square unused polyethylene bottle, with the 2 cm sampling depth clearly marked. A 1 litre square "milk bottle" style container is recommended, with no more than about 5 cm^2 of sediment being collected per sub-sample.

Five wide-mouthed containers (replicates 1-5) are lined with plastic bags and placed on a sled, which is pushed or pulled by the sampling person who follows the sampling pattern described below. A minimum of 2 people are needed for safety reasons.

Pegs are placed on the sides of the rectangular sampling site to help orientate the sampling person. From experience, ARC staff recommend that the pegs are placed at opposite ends of the sampling 'walkway' (Fig. A.1). This is located 5 m from 'channel side' of the rectangle. The sampling person walks upstream parallel to the 'channel side' sampling alternative sides of the walkway every 2 meters (using the sled as a length guide). In the SoE programme 5 replicates are collected (c.f. 3 recommended for RDP sediment sampling). Sub-sample 1 is placed in replicate 1, sub-sample 2 to replicate 2, sub-sample 3 to replicate 3, sub-sample 4 in replicate 4, sub-sample 5 in replicate 5, sub-sample 6 in replicate 1, sub-sample 7 in replicate 2 etc. By the end of the first walkway the sampling person should have five sub-samples in each replicate. This is illustrated in Fig. A.1, where sub-sample 1/1 refers to replicate 1, sub-sample 1. This process is repeated along the second walkway, 10 m toward the shore. On completion, there should be ten sub-samples in each replicate. There is no need to clean the scoop between each sub-sample. The scoop should be washed (e.g., in low tide channel) to remove sediment before using it at another site. The scoop itself needs no special cleaning before the exercise as long as it was a new, unused, polyethylene container.

The samplers should use mudders (special footwear to prevent sinking) to improve mobility in the soft mud, protect their legs and feet and minimize "stirring" of surface and sub-surface sediments. In addition, the samplers must avoid stepping outside the walkway to ensure that the collection area remains as undisturbed as possible.

Fig. A1: Sediment quality sample collection strategy. Sampling begins from the end of the walkway closest to the channel. Sub-samples are collected from alternate sides of the walkway with sub-samples being fed sequentially into composited replicates. Circles indicate replicate Nº./sub-sample within replicate Nº..



For depositional areas, which may not meet the criteria for settling zones (e.g., Otahuhu Creek), a similar number of sub-samples could be collected (and composited) from a wider area to provide an integrated sample covering any concentration gradient. Because of the difficulty of access in these muddy environments, high tide sampling may be preferable.

12 Appendix C: Species included in the ecological health models

Species included in the settling and outer zone ecological health models. Note that species counts must be presented in the species order provided.

Settling Zone Species

1 Agalophamus macroura
2 Alpheus sp.
3 Amalda spp.
4 Amphibola crenata
5 Anthopleura aureoradiata
6 Anthozoa
7 Anthuridae
8 Aonides oxycephala (trifides)
9 Aquilaspio (Prionospio) aucklandica
10 Arabellidae
11 Aricidea
12 Armandia maculata
13 Arthritica bifurca
14 Ascidiians
15 Austrovenus stutchburyi
16 Barnacles
17 Bocardia srytis
18 Calliopidae
19 Capitella spp.
20 Caprellidae
21 Chironomidae
22 Cirolanidae
23 Cirratulidae
24 Colurostylis lemurum
25 Cominella adspera
26 Cominella glandiformis
27 Corophidae
28 Cossura sp.
29 Crab larvae
30 Crassostrea gigas
31 Cyclomactra combine these with Mactra
32 Diloma
33 Diptera
34 Edwardsia
35 Elimnus modestus
36 Euchone sp.
37 Eunicidae
38 Exogoninae
39 Exosphaeroma ?falcatum
40 Exosphaeroma chilensis
41 Fellaster
42 Gammarid
43 Glycera sp.(ovigera/americana)
44 Goniada emerita (Gylcinde)
45 Halcarcinus sp.
46 Halicarcinus whitei
47 Haminoea zelandiae
48 Haustoridae
49 Helice crassa
50 Hemigrapsus crenulatus
51 Hessionidae
52 Heteromastus filiformis
53 Hiatula siliqua
54 Hyboscolex longiseta
55 Ischnochiton maorianus
56 Limpet- not Notoacmea
57 Llijiborgidae
58 Lyssinassidae
59 Macomona liliana
60 Macroclymenella stewartensis
61 Macrophthalmus hirtipes
62 Magelona sp.
63 Maldanidae (not Asychis or Macrocylmenella)
64 Melitidae
65 Micrelenchus
66 Microspio
67 Minuspio
68 Modiolarca impacta
69 Mysidacea
70 Nebalacea
71 Nemertina
72 Neriedae
73 Notoacmea helmsi
74 Notomastus sp.
75 Nucula hartvigiana
76 Oedicerotidae
77 Oligochaeta
78 Ophellidae (not Travisia)
79 Orbinia papillosa
80 Paphies australis
81 Paracalliope novizealandiae
82 Paraonidae (not Aricidea)
83 Pectinaria australis
84 Perinereis
85 Perna canaliculus
86 Phoronidae
87 Phoxocephalidae
88 Platyheminthes
89 Polydorid (not Boccardia)
90 Polynoid
91 Potamopyrgus antipodarum
92 Potamopyrgus estuarinus
93 Prionospio spp.
94 Pseudopolydora sp.
95 Pycnogonid
96 Sabellaridae
97 Scolecolepides ?benhami
98 Scolepis
99 Scoloplos spp.
100 Sipunculid
101 Solemya parkinson
102 Sphaeroma quoyanum
103 Sylliniae
104 Talitridae
105 Tanaidacea
106 Tawera spissa
107 Theora lubrica
108 Torridoharpinia hurleyi
109 Trochodota dendyi
110 Unidentified juvenile bivalve
111 Unidentified spionid
112 Unidentifies juvenile gastropods (clear)
113 Veneridae
114 Waitangi brevirostris
115 Wildus wapiro
116 Xymene
117 Zeacumantus lutulensis

Outer Zone Species

1 Agalophamus macroura
2 Alpheus sp.
3 Amalda spp.
4 Aminotrypan
5 Ampelisca
6 Amphibola crenata
7 Amphiura rosea rename Ophiuroid
8 Anthopleura aureoradiata
9 Anthuridae
10 Aonides oxycephala (trifides)
11 Aquilaspio (Prionospio) aucklandica
12 Aricidea
13 Armandia maculata
14 Arthritica bifurca
15 Asychis
16 Atrina zelandica
17 Austrovenus stutchburyi
18 Barnacles
19 Bocardia srytis
20 Bulla quoyi
21 Calliopidae
22 Capitella spp.
23 Caprellidae
24 Cassidinopsis admirabilis
25 Ceratonereis
26 Cirolanidae
27 Cirratulidae
28 Colurostylis lemurum
29 Cominella adspera
30 Cominella glandiformis
31 Corbula zelandica
32 Corophidae
33 Cossura sp.
34 Cyclapsis thomsoni
35 Cyclomactra combine these with Mactra
36 Dexaminidae
37 Diloma
38 Diptera
39 Dosina zelandica
40 Echinocardium australe (cordatum)
41 Edwardsia
42 Eteone sp.
43 Euchlymene
44 Euchone sp.
45 Eusiridae
46 Exogoninae
47 Exosphaeroma ?falcatum
48 Exosphaeroma chilensis
49 Fellaster
50 Fenella zelandica
51 Gammarid
52 Glycera sp.(ovigera/americana)
53 Goniada emerita (Gylcinde)
54 Halcarcinus sp.
55 Halicarcinus whitei
56 Haminoea zelandiae
57 Helice crassa
58 Hemigrapsus crenulatus
59 Hemileucon ?uniplicatus
60 Hessionidae
61 Heteromastus filiformis
62 Hiatula siliqua
63 Ischnochiton maorianus
64 Isocladus sp.
65 Lepitinotidae
66 Limaria orientalis
67 Limpet- not Notoacmea
68 Llijiborgidae
69 Lumbrineridae
70 Lyssinassidae
71 Macomona liliana
72 Macroclymenella stewartensis
73 Macrophthalmus hirtipes
74 Magelona sp.
75 Maoriculpus
76 Melitidae
77 Methlimedon
78 Micrelenchus
79 Microspio
80 Minuspio
81 Musculista senhousia
82 Myadora
83 Mylitella vivens
84 Mysidacea
85 Nebalacea
86 Nemertina
87 Neoguraleus
88 Nepthyd (not Algaophamus)
89 Neriedae
90 Notoacmea helmsi
91 Notomastus sp.
92 Nucula hartvigiana
93 Oedicerotidae
94 Oligochaeta
95 Onuphis sp.
96 Ophellidae (not Travisia)
97 Opistobrancha
98 Orbinia papillosa
99 Ovalipes
100 Owenia fusiformis
101 Paguristes ?papillosa
102 Paphies australis
103 Paracalliope novizealandiae
104 Paraonidae (not Aricidea)
105 Paraprionospiro
106 Pectinaria australis
107 Petrolisthes novaezelandiae
108 Phoronidae
109 Phoxocephalidae
110 Phyllodicidae (not Eteone)
111 Pinnotheres
112 Polydorid (not Boccardia)
113 Pontophilus australis
114 Prionospio spp.
115 Pseudopolydora sp.
116 Rhytida
117 Ruditapes largillierti
118 Scintillona
119 Scolecolepides ?benhami
120 Scolepis
121 Scoloplos spp.
122 Sigalonidae
123 Solemya parkinson
124 Sphaeroma quoyanum
125 Struthiolaria papulosa
126 Sylliniae
127 Tanaidacea
128 Tawera spissa
129 Terebellidae
130 Theora lubrica
131 Torridoharpinia hurleyi
132 Travisia olens
133 Trochodota dendyi
134 Turbo smaragus
135 Turbonilla
136 Unidentified juvenile bivalve
137 Unidentifies juvenile gastropods (clear)
138 Venericardia juveniles
139 Waitangi brevirostris
140 Xenostrobus
141 Xymene
142 Zeacumantus lutulensis
143 Zegalerus
144 Zenatia acinacea

13 Appendix D: Development history of the ARC benthic ecology models

The ARC benthic ecology models allow the benthic community structure of new sites to be ranked against the community structure expected for a given level of pollution. Pollution ranks were primarily derived from information on sediment contaminants (Auckland Regional Council 2002d). Details of how the models were developed are provided in Auckland Regional Council (2002c) and Auckland Regional Council (2002d). Each model has been tested and refined since their initial development (Auckland Regional Council 2003, Anderson 2004), and further refinement will occur as new data is added. It was initially proposed that sites be categorised based on the mean value of two related CAP analyses (Auckland Regional Council 2002c):

- Gradient analysis using the scale of pollution as a continuous variable ranging from 1 to 5.
- Group analysis using 5 pollution categories.

The advantage of the gradient analysis is that information on the degree of pollution is used in the model. The analysis provides an index of community health according to the value of the new site along the first canonical axis, which is then used to categorise a new site relative to the pollution gradient (see Auckland Regional Council 2002c for full details). The group analysis does not take into account the actual level of pollution, i.e. pollution ranks 1 - 5 are treated as categories. New sites are categorised according to the group they are closest to in multivariate space. The advantage of using this method, and the reason it was initially used in conjunction with the gradient model, is that it provides an estimate of the probability of allocation error using a "leave one out" technique. However, the analysis is dependent on clear separation between groups. As the degree of overlap between groups increases, the probability that sites are mis-allocated also increases.

The initial dataset used in the development of the models included multiple sites of the same rank from a single location. This had the potential to bias the results because locations with many sites could exert a greater influence on the analysis than sites with one or a few sites. Duplicate sites were therefore dropped from the models (Auckland Regional Council 2003, Anderson 2004). Since then, data from extra sites have been added to the outer zone model, and the rankings of some outer zone sites were revised in light of new information on contaminant concentrations. As a result of these changes, only 1 outer zone site was given a pollution rank of 5. Unfortunately, this site had to be included with the rank 4 sites because CAP analysis requires at least 2 sites within each rank. This meant the revised outer zone community health model was based on only 4 pollution ranks (Auckland Regional Council 2003).

More recently, an error was found, and corrected, in the software used to calculate allocation success. As a consequence of these changes, group analyses for both settling and outer zones were unable to successfully allocate sites to a particular pollution category based on community structure. However, further testing of the gradient analyses confirmed that the fit using the pollution gradient was significantly better than expected by chance i.e. the gradient model provides a statistically robust method of measuring community health ($P = 0.0429$ for the settling zone model and $P = 0.0204$ for the outer zone model) (see Fig. 4.2).

Community health assessment should therefore include CAP gradient analysis using the settling and outer zone benthic health models. However, use of the CAP group analysis has been discontinued for the time being. Further refinements to the models are likely to occur as new data comes to hand, and it is possible that the group model will be reinstated as an analytical tool at some stage. In the interim the use of green, amber, red ecological environmental response criteria has been discontinued.

14 Appendix E Summary of ARC water quality SoE protocols

14.1 Dissolved oxygen / salinity profiles

The following protocol assumes that suitable dissolved oxygen and salinity field instruments and probes are available and calibrated.

1. Once established on site, lower probes into water until probe heads are submerged just below the surface of the water.
2. Read salinity. Once reading is stable, record reading for surface.
3. Dissolved oxygen meter: Adjust salinity scale on the DO meter to the reading obtained from the salinity meter. Then read DO from appropriate scale.
4. Set both meters to temperature setting. Read both, to check they are in agreement. Record temperature.
5. Lower both probes through water column, monitoring readings all way to bottom. If there is *no change*, record that the profile is well mixed. If there *is a change* of more than 2 salinity units, or one full DO unit, the column is considered to be stratified, and parameters need to be recorded at 1 m intervals from 0.5m below the surface to the bottom.

Alternatively:

1. Lower DO and salinity probes to bottom.
2. Raise slowly, monitoring meters.
3. If meter readings constant, water column is mixed; record salinity, DO, and temperature.
4. If meter readings change as probes are raised, water column is stratified; record parameters at 1 m intervals from 0.5m below the surface to the bottom.

14.2 Ammonia and pH measurement

1. Lower bulk sample bottle and collect surface sample.
2. Decant into prepared sample bottles through funnel – completely fill PE bottle for pH measurement, after rinsing. Fill 100 ml PE bottle for ammonia measurement, do not rinse out concentrated sulphuric acid preservative (the ammonia bottle is taken to the site with the conc. sulphuric acid preservative already added).
3. If water column found to be stratified at any site, surface and bottom samples to be collected.

4. Bottom sample to be collected with Van Dorn bottle, using following procedure:

    a. Use Van Dorn bottle with weight 0.5 meters below base of bottle.

    b. Load van Dorn bottle and lower.

    c. When weight felt to touch bottom, raise slightly, so that bottle just over 0.5 meters above bottom.

    d. Deploy messenger, wait until bottle felt to close.

    e. Retrieve bottle, and use funnel to decant sample into appropriate bottles for pH and for NH_3 measurements.