# North and West RUB marine receiving environments: review of existing information

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# Executive Summary

Auckland Council is currently considering options for future urban development outside of the current Rural Urban Boundary (RUB) to the south, west and north of the city. Future land development has the potential to introduce sediments and contaminants to marine receiving environments, affecting the habitats available and the plants and animals living there, as well as the recreational and aesthetic values of the receiving environment and the functional capacity of the environment.

The purpose of this report is to provide a review of the current environmental status of marine receiving environments that may be affected by run off from catchment development associated with shifting the current rural urban boundary. Such information may provide an initial assessment of the potential effects of urban development on the sediment quality and benthic ecology of marine receiving environments.

This report focuses on marine receiving environments (estuaries and harbours) potentially affected by the proposed Rural Urban Boundaries (RUBs) under consideration. It does not cover other environments such as land and soils (including land use capability), terrestrial biodiversity, air or freshwater environments. This report provides a summary of current environmental state (and any trends where a sufficient time series exists).

All of the receiving environments considered have been shown to have ecological value and sensitivities that would warrant consideration in land development decisions; however all show a degree of degradation already making it even more important to carefully consider the cumulative effects of increasing sediment and contaminant loads associated with urban development or rural intensification. Upper Waitemata Harbour and Mahurangi in particular are showing signs of degradation, with early signs for sites in Okura and Orewa estuaries. Kaipara ecology is generally ranked as good, however, sedimentation is still considered a prominent issue for the whole harbour. For all receiving environments, sedimentation currently appears to be the primary effect with contaminant levels generally low, although those in the Upper Waitemata Harbour are higher than might be expected from its predominantly rural catchment. It should be remembered that a degraded system may potentially be more sensitive to impacts as it is closer to a tipping point. A healthier system, may have a higher ecological value but also a higher degree of resilience to impact. All previous modelling for these areas suggest increased sedimentation and contaminant loads, with Okura in particular being identified as likely to have significant ecological effects.

As the majority of the current RUB areas being considered have been considered in various Environment Court decisions, as well as Metropolitan Urban Limit decisions, there is a wide range of modelling studies that already existing in most receiving environments. As further details of RUB scenarios become available, the applicability of these models can be further assessed and the potential of additional decision support systems (tools) explored. In addition, many, long term, ecological and physical quality monitoring programmes exist in these receiving environments which provide excellent baseline and trend information that can be used to inform initial decisions and as model input data.

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# 1.0 Introduction

## 1.1 Introduction

Auckland Council is currently considering options for future urban development outside of the current Rural Urban Boundary (RUB) to the south, west and north of the city.

At the intersection of land and ocean, estuarine and coastal ecosystems are of critical importance to the Region’s cultural, social, economic and environmental wellbeing. While Auckland’s marine environment is valuable for the range of habitats found that support a diverse range of species, it also provides a range of ecosystem services of great significance to the region. These can be broadly summarised to include: cultural values, recreational opportunities, quantity and quality of food resources, shoreline protection, climate change mitigation, nutrient cycling, contaminant processing, sediment stability, resilience and biodiversity, mitigation of harmful algal blooms, supporting science and education and underpinning natural aesthetic values and tourism. Therefore, when considering the environmental effects of a planning decision, it is not just a simple environmental consideration, but understanding that changes in environmental quality impact the human use and enjoyment of that environment and the liveability of Auckland. The marine ecosystems of Auckland already have high and often conflicting resource uses and their health is under increasing pressure from both direct use and activities which generate discharges to the marine environment.

Land based activities can generate discharges of sediment, chemical contaminants, nutrients and sewage which ultimately end up in the adjacent marine environment. While some of this catchment runoff is dispersed to the sea, part of the sediment load is trapped in the estuaries and harbours. Increased sediment to the marine environment can influence marine ecology, both through increased suspended sediment concentrations and sedimentation rates which can influence primary production and the organisms that feed by filtering the water. Increased sediment deposition can smother organisms and change the habitat (increasing muddiness) so that it is no longer suitable for some species. Toxic chemicals generated on land, such as heavy metals and organic pollutants can have negative effects on organisms living in the marine environment. Increased nutrients (particularly nitrates and phosphates) in the marine environment can lead to eutrophication which can result in algal blooms and ultimately in hypoxia (low oxygen). Sewage overflows can add nutrients to the marine environment, but also pathogens which may pose a human health risk. Note that specific effects of wastewater have not been considered in this report and will need to be considered as part of the infrastructure requirements for each proposed area.

## 1.2 Purpose

The purpose of this report is to provide a review of the current environmental status of marine receiving environments that may be affected by run off from catchment development associated with shifting the current rural urban boundary in the north and west of Auckland. Such information may provide an initial assessment of the potential effects of urban development on the sediment quality and benthic ecology of marine receiving environments.

## 1.3 Scope

This report focuses on marine receiving environments (estuaries and harbours) potentially affected by the proposed Rural Urban Boundaries (RUBs) under consideration. It does not cover other environments such as land and soils (including land use capability), terrestrial biodiversity, air or freshwater environments. As all of these areas have previously been considered in development decisions (e.g. Metropolitan Urban Limit considerations) there is a very large body of work available including predictive modelling. Rather than repeat detail here, this report attempts to provide a high level summary and further detail can be gained from the reports referenced. In addition, as much of the material is taken from existing Auckland Council (or Auckland Regional Council) publications, in many incidences the relevant summary material has been taken directly from the report. In these cases the reader is directed to those references for more detail and the original report should be cited rather than this report.

This report provides a summary of current environmental state (and any trends where a sufficient time series exists) for the following parameters:

- Benthic health (infaunal ecology)
- Contaminant levels
- Sedimentation
- Saline water quality
- Bathing beach quality

The following information has not been included.

- Wading birds
- Significant Ecological Areas and their provisions.
- Natural Character
- Human use, occupation, structures and values
- Economic values related to the receiving environment

A high level summary of any existing predictive modelling work (excluding any specific structure plan modelling) has also been provided where available but note that this information may or may not be relevant to the current RUB scenarios.

## 1.4 Receiving environments potentially affected

The following receiving environments have been identified as having catchments that will be affected by the proposed Rural Urban Boundaries under consideration.

- Upper Waitemata Harbour – parts of the Silverdale and Kumeu (Riverhead)/ Whenuapai proposed RUB areas drain to the UWH in particular to the Rangitopuni, Brighams Creek and Waiarohia subcatchments. The Dairy Flat part of Northern RUB area flows to the Rangitopuni catchment

- Southern Kaipara Harbour – parts of the Kumeu / Whenuapai proposed RUB areas drain to the Kaipara River via the Kumeu River
- Weiti, Okura and Orewa Estuaries – The catchment for the Wainui East RUB area flows into Orewa Estuary, while the Silverdale west business area flows in Weiti and potentially Okura
- Mahurangi Harbour (or Estuary) – the proposed Warkworth RUB area drains to this estuary

As parts of the different RUBs under consideration can flow to multiple receiving environments and likewise the receiving environments may receive runoff/catchment flow from two RUB areas, the main part of this report is structured by receiving environment rather than RUB area.

## 1.5 Potential effects of catchment development

Urban development increases catchment runoff of water and sediment during the earthworks phase, and contaminant loads as the urban area matures which alters the composition and quality of sediments in the estuaries. While some of this catchment runoff is dispersed to the sea, part of the sediment load is trapped in the estuaries and harbours. Estuaries are particularly vulnerable to the effects of catchment landuse changes because of their close proximity to the sediment source and physical and biological processes that promote sedimentation (Swales et al.2008).

A considerable amount of research by NIWA, both FRST and Auckland Regional Council (now Auckland Council) funded, has been undertaken on the effects of sedimentation on intertidal and subtidal soft sediment macrofauna communities. This research is synthesised in an ARC publication (Gibbs and Hewitt 2004, see also Thrush et al. 2004) and summarised below.

Land derived sediment can influence estuarine and coastal ecology, both through increased suspended sediment concentrations and sedimentation rates. Increased suspended sediment concentrations can influence primary production by reducing light and benthic organisms that feed by filtering the water, affecting feeding structures and reducing food quality.

Studies have shown that benthic communities on intertidal sand and mudflats are highly vulnerable to deposition of land derived sediment. Possible impacts of sedimentation range from lethal catastrophic events that smoother the benthic communities, to sublethal deposition events and increases in suspended sediment concentrations that alter the functional stability of the benthic community through subtle changes to food supply and physical structure of the sediments that form the habitat and cause shifts in the structure of benthic communities. The change in sediment structure due to accumulation of small deposits of land derived sediment over time may favour one species over another leading to changes in the types of species present.

While the magnitude of a sediment event may be an important factor in determining impact, the frequency of event may be more important in determining the risk to the benthic community. Catastrophic events may be rare but sublethal events may occur with every rainfall. While benthic communities may recover quickly from a single deposition event, a succession of deposition events at shorter intervals than the recovery time can result in cumulative effects that cause the habitat and the benthic community to change.

The recovery of a benthic community depends on many factors, including depth of deposition, the previous history of the community and the sediment structure of the habitat before the event (Thrush et al. 2004). For example, land derived sediment deposition on a diverse sandflat community is likely to have a far greater impact on that benthic community than the same deposition on a mudflat community where diversity is lower and the benthic community has already adapted to a silt/clay environment. Recovery from lethal catastrophic events may be driven by physical (e.g., wave action) and biological (e.g. bioturbation) parameters and considerable time can elapse before the original benthic community returns, if it ever does. Recovery of depopulated sediment may depend on the availability of appropriate macrofauna to recolonise the sediment. In the case of multiple smaller events at shorter intervals then the impact and recovery could depend on the ability of the community to recover between events.

Elevated sedimentation regimes tend to reduce the overall ecological heterogeneity with increasing muddiness (Thrush et al. 2004). In estuaries, multiple habitat types such as saltmarsh, seagrass and unvegetated intertidal flats promote diversity by enhancing recruitment and maintaining species with requirements for multiple resources. The modification or reduction of available habitats due to elevated sedimentation has been shown to lower diversity and abundance with functional differences including a reduction in the number of suspension feeders. More generally, the loss of large macrofuana could have important implications for ecosystem function in estuarine and marine ecosystems (Gibbs and Hewitt 2004, Thrush et al. 2004). Four guidelines were produced from the sedimentation work by NIWA for ARC (Gibbs and Hewitt 2004).

1. In general, the thicker the layer of mud, the more animals will be killed and the longer recovery will take. This will affect both the number of species and the number of animals within each species. Some species are more sensitive than others.
2. A mud layer greater than 20 mm thick, remaining for longer than five days, will result in all resident species in that area (with the exception of mobile crabs and shrimp) being killed by a lack of oxygen.
3. A mud thickness of 5 mm, persisting for longer than 10 days, will reduce the number of animals and the number of species, thereby changing the structure of the animal community.
4. Frequent deposition of mud, less than 5 mm, may still have long term impacts that can change the animal communities.

It is important to acknowledge the limitations of this work, in terms of information gaps, underlying assumptions and the effect of simplification. Four key points must be remembered when considering the above guidelines.

1. Community responses at the scale of an estuary or coastal area have been extrapolated from manipulative experiments. The underlying assumption is that the processes defined in the small scale experiments in one part of the system can be applied to the whole system.
2. There has been little work done on sublethal effects such as organism health, growth and reproductive output. Such sublethal effects may occur at sedimentation levels lower than those described above but may over time lead to changes in population and community

structure. All of these are likely to be important when making long term forecasts of population and community changes.

3. Interactions between the stress caused by increased sediment inputs and other facts, whether natural (e.g. predation) or anthropogenic (e.g. contaminants) are likely to multiplicative.
4. Little knowledge has yet been generated on the effect of duration and frequency of events over long-time scales or on large spatial scales, to the distribution of estuarine and coastal habitats.

## 1.6 Sources of information and indicators presented

In order to assess the current status of the marine receiving environments this report focuses on assessing indicators of estuarine sediment quality and the health of estuarine benthic invertebrate communities. Results are in the main derived from long term state of the environment monitoring programmes. Such monitoring programmes are important for assessing the efficacy of current policy and plans. However they also provide a vital baseline status and content for assessing the likely effects of new policy decisions. The indicators discussed in this report are described in the following sections.

### 1.6.1.1 Marine habitats, communities and benthic health

The state of the environment (SoE) marine ecology monitoring programme monitors temporal changes in specific benthic (bottom dwelling) ecological communities in harbours, estuaries and reefs across the region. The information is primarily used for determining trends of community change and therefore the monitoring is generally temporally intense (every two to three months). As well as detecting trends of community change that can be used to identify emerging issues and to track policy and plan effectiveness, the consistent SoE ecology monitoring provides a rich information base on the current status of receiving environments in order to inform and provide regional context to new policy decisions.

The benthic health programme is based on the Benthic Health Model (BHM) which provides a means to assess on a regional basis intertidal sites according to categories of relative ecosystem health, based on its community composition and predicted responses to storm-water contamination (BHMmetals) or muddiness (BHMmud) (Hewitt and Ellis 2010). Benthic health groupings are as follows: 1 = excellent, 2 = good, 3 = moderate, 4 = poor, 5 = unhealthy.

The Traits Based Indicator (TBI) was developed based on the richness of species in 7 functional groupings, with changes in index values reflecting potential shifts in ecological resilience (van Houte-Howes and Lohrer 2010, Lohrer and Rodil 2011). In conjunction with the Benthic Health Model, the TBI offers a useful way of assessing some of the elements of ecosystem health in our harbours and estuaries. The index ranges from 0 to 1, with values near 0 indicating highly degraded sites and values near 1 indicating the opposite. TBI functional scores can be separated into three categories to indicate benthic health; score greater than 0.4 are considered good, from 0.3-0.4 as intermediate and scores below 0.3 as poor health and low functional redundancy.

While sites in benthic health groups 1 or 2 can be considered healthy, changes in community structure can begin to be detected within these groups. Furthermore, recent work on the development and implementation of the TBI indicates that the resilience of an ecosystem becomes compromised around benthic health group 4 and that very little if any resilience to further stressors is left in the system once benthic health group 5 is reached (Lohrer and Rodil 2011). Therefore from the perspective of resilience, benthic health scores of 4 and 5 should be avoided, especially group 5. As an ecosystem becomes more degraded it is also likely to become more difficult to restore that environment, a phenomenon termed restoration hysteresis (Hewitt, et al. 2009). Therefore benthic health group 3 should be considered as an important group and with respect to protection and potential remedial management action.

The BHM (metals and mud) and TBI scores can be combined to provide a broad overall grading of a sites ecological health whereby; 1 = extremely good, 2 = good, 3 = moderate, 4 = poor and 5 = unhealthy with low resilience (Hewitt et al. in prep).

### 1.6.1 Contaminants in sediment

The level of heavy metal and organic contaminants in intertidal marine sediments is monitored across the Auckland region. The Environmental Response Criteria (ERC) were developed by Auckland Regional Council (now Auckland Council) to provide an Auckland relevant set of criteria by which to assess whether the concentrations of contaminants present in receiving-water sediments are likely to result in adverse environmental effects. The ERC are trigger values, in that breaches are meant to trigger further investigations. They are not pass–fail numbers, but benchmarks for action (ARC 2004a).

ERC Green conditions (<TEL) reflect a relatively low level of impact based on an individual contaminant. ERC Amber (>TEL but <ERL) conditions reflect contamination above a level at which adverse effects on benthic ecology may begin to show (the TEL). ERC Red conditions (>ERL) reflect conditions where significant degradation has probably already occurred.

While the guidelines outlined above are useful for assessing the effects of individual contaminants they do not take into account the cumulative effect of multiple contaminants or other stressors present at the same time (Thrush et al 2008), so it is still entirely possible for ecological health to be affected under ERC green conditions (Hewitt et al. 2009). Therefore contaminants in sediment provide a relative comparison of the levels of pollution among sites rather than a definitive measure of effect.

### 1.6.2 Sedimentation

Information of current sedimentation of the receiving environments of interest is available from a number of sources, including historical dating of sediment cores to determine the sediment accumulation rate (SAR). Based on results from multiple studies across the Auckland region, SARs in low energy estuarine receiving environments in pre-European times were likely in the range of 0.2 to 0.8 mm/yr (Oldman, et al. 2009, Swales, et al. 2002).

The ‘muddiness’ of the sediment can be determined as the proportion of bed-sediments in the clay and silt Wentworth particle size classes (<63 µm diameter). In many cases the effects of sediment can be seen in changes in the ecology (with decreases in sediment sensitive species and increases in sediment tolerant species) and changes in the benthic health (mud) grade. In section 2, information on current sedimentation conditions is collated for each receiving environment. Based on findings from the BHMmud and the new TBI, negative shift changes in ecological health and function can occur around 10%, 25% and 60% muddiness (Hewitt et al. in prep). However, these numbers should just be considered as a guide as different benthic communities can respond to the same level of muddiness in different ways. As these later thresholds are breached, ecosystem resilience is likely to become compromised and restoration potential more unlikely (Hewitt and Ellis 2010, Hewitt et al. in prep, Thrush et al. 2004).

### 1.6.3 Water Quality

Saline water quality is monitored monthly across the region. The water quality variables measured during each sampling run are a combination of physical observations, in situ meter readings, and chemical and biological analyses of collected samples in the laboratory. This programme monitors contaminants associated with erosion, nutrients and biological wastes (organic material and faecal contaminants) in the water column. Variables recorded include ambient weather and water conditions at the sample sites; water temperature; dissolved oxygen; dissolved oxygen saturation; salinity; conductivity; and water clarity.  The chosen variables principally describe water clarity and appearance, nutrient status, biological productivity (in response to nutrient inputs) and physical conditions important for supporting aquatic life. A water quality index is used to assign an overall water quality class using the following classifications: excellent, good, fair and poor.

# 2.0 Environmental quality

## 2.1 Upper Waitemata Harbour

### 2.1.1 Introduction

The Upper Waitemata Harbour (UWH) catchment encompasses 185 km$^2$ and drains to a relatively small sub-estuary with a restricted outlet emptying into the Central Waitemata Harbour. The UWH is a system of seven tidal creeks which receive runoff from a mixture of urban and rural sub-catchments. These tidal creeks are, from west to east: Rangitopuni; Brighams; Rawararu; Paremoremo; Waiarohia; Lucas and Hellyers Creeks. Lucas Creek is typical of the UWH creeks, with mangrove stands occupying most of the present-day tidal flat above MTL-2007 (Swales et al. 1999).

The UWH has been the focus of a number of studies which have attempted to predict the ecological impacts on this receiving environment of future development patterns. A study was initiated in 2001 to determine the sustainable carrying capacity for development in the UWH catchment, and identify the level of development and the controls necessary to secure long term protection of Upper Harbour environmental values. This study was completed in 2004.

It included a prediction of patterns and levels of contaminant accumulation in the Upper Harbour associated with urban development over the medium term (decades), and a comparison of predicted contaminant levels with relevant environmental guidelines (see Green et al. 2004 and references therein). A habitat/ecological discription of the UWH was also developed (Cummings et al. 2002).

These investigations lead to the establishment of a comprehensive monitoring programme in the UWH to test the predictions of the contaminant model and to provide data from early phase, during and after development through time to assess the effects of catchment development on contaminant accumulation rates, sediment deposition rates and estuarine biota.

### 2.1.2 Environmental quality

Parts of the Silverdale and Kumeu (Riverhead)/ Whenuapai proposed RUB areas drain to the UWH in particular to the Rangitopuni, Brighams Creek and Waiarohia sub catchments. The Dairy Flat part of Northern RUB area also flows to the UWH. While particular sub-catchments will be the immediate receivers of any catchment run-off, without specifically modelling it cannot be determined if effects will be contained within these sub-catchments or will be seen in the wider UWH catchment. Given the size of the sub-catchments and the hydrodynamics of this estuary, it is likely that effects will not be contained and also likely that discharges from the UWH will also affect the Central Waitemata Harbour to which it drains. Therefore, the following discussions are largely based on the whole Upper Waitemata Harbour.

#### 2.1.2.1 Marine habitats, communities and benthic health

In light of plans for increased urban development in the Upper Waitemata Harbour (UWH) catchment, the need to define the benthic ecological values of the UWH's intertidal and subtidal habitats was identified. In 2002 a survey of 74 sites was conducted to quantify the existing intertidal and subtidal benthic communities of UWH. It also included a qualitative assessment of the potential effect on these communities of long-term habitat change due to increased sediment muddiness (Cummings et al. 2002).

The survey showed that the intertidal and subtidal benthic communities and habitats of UWH were generally in good condition, and worthy of careful consideration when development occurred. In some areas of UWH, the sediment organic content was notably high in comparison to similar sites in other harbours. However, despite this the communities at these sites did not show characteristics of highly organically enriched areas (Cummings et al. 2002).

Information on the distribution and densities of these sensitive taxa identified some ecologically important areas of UWH, namely, the main body of outer UWH, Lucas Creek, Hellyers Creek; the northern side of UWH near the mouth of Paremoremo Creek; and the main body of inner UWH, in the vicinity of Herald Island (Cummings et al. 2002).

In November 2005, a long-term monitoring programme was established in the Upper Waitemata Harbour to monitor the ecological status of locations predicted to be affected by land-use changes in the surrounding catchments. Benthic macrofauna, sediment characteristics and contaminants are sampled to determine whether there are ecological changes associated with catchment development (Townsend et al 2012). A single site is located in each of the Rangitopuni, Brigham, Waiarohi, Lucas and Hellyers arms, and the upper section of the main harbour. Two sites are located in the central part of the harbour and outside the mouth. The Rangitopuni, Brigham and Waiarohi sites will be of particular interest to the north and western RUB considerations.

Sites form three distinct groupings based on location, sediment characteristics and macrofaunal communities: 1) very muddy upper harbour sites dominated by oligochaetes and corophid amphipods (Rangitopuni, Brighams, and the upper section of the main harbour); 2) muddy sites dominated by deposit feeding polychaetes (Central Main Channel, Lucas, Hellyers and one site outside of the mouth (Hobsonville)); and 3) outer harbour sandy sites dominated by bivalves (Waiarohia, Herald Island, and Outer Main Channel).

The 2012 report showed there were few significant changes for the sediment properties, which showed large variations over the monitoring period, although mud content and chlorophyll *a* have increased at Lucas (Townsend et al. 2012). Across the sites most species exhibited seasonal and multiyear patterns in abundance, with few trends over time being apparent. However, declines in the abundance of two amphipod families (*Corophidae* and *Phoxocephalidae*) and a small bivalve (*Arthritica bifurca*) were detected at the upper muddy sites. Declines in the abundances of bivalve species (e.g. *Nucula, Austrovenus* and *Macomona*) were observed at a number of other sites.

The functional Traits Based Indicator (TBI) and Benthic Health Model (BHM) scores show a general geographic trend; with lowest values found in the upper estuary and scores generally improving from middle to outer sandy sites (Figure 1).

Using the Benthic Health Models the Upper Waitemata Harbour sites spanned the range of health for intertidal sites relating to both mud and contaminants.  Increasing health was observed at Rangitopuni Creek, the upper Main Channel and Brigham Creek in relation to mud and at the upper Lucas Creek site and Brighams Creek in relation to contaminants. Decreasing health trends were seen at Herald Island in relation to mud and at upper Hellyers Creek in relation to contaminants (Hewitt et al. 2012). Despite some improvements, the Upper Waitemata remains an area in relatively reduced benthic health (Townsend et al. 2012).

The general characteristics of the Upper Waitemata Harbour sites are to have low functional scores (TBI) as a result of the combination of high levels of mud and the presence of contaminants. The upper muddy sites have the lowest overall TBI scores and are considered poor in health; with averages below 0.2. The sandy sites had the best overall health with Herald Island and Waiarohia Creek both rated ‘good’ (averaging over 0.4) since 2005; although both are below this threshold for 2011 (Townsend et al. 2012). Decreasing trends in TBI scores are evident for Upper Main Channel and Brighams Creek from 2005-2011 (Hewitt et al. in prep).

Overall health scores that combine BHM (metals), BHM mud and TBI groupings (Hewitt et al. in prep) found 7 sites to be ‘unhealthy with low resilience’ and 3 sites to be ‘poor’ in health (Figure 1). Thus all sites from this region fall within the bottom two out of five categories for intertidal site health (Townsend et al. 2012).

### 2.1.2.2 Contaminants

Modelling conducted prior to the establishment of the monitoring programmes suggested that stormwater contaminants would increase in multiple branches of the upper harbour; particularly with increased development over the next 100 years (Green et al. 2004). The majority of elevated zinc and copper concentrations stem from urban sources, with the exception of Rangitopuni and Paremoremo creeks (rural). Increases in metal concentrations can emerge from contaminants already locked in soils, eroded and entering the harbour during development. These contaminants are of concern as they affect the ecological functioning of the receiving estuarine environments (Cummings et al. 2002).

Fourteen sites in the Upper Waitemata Harbour (UWH) have been monitored annually for sediment contaminants from 2005-2009 ( 5 samplings) and again in 2012. This programme provides specific information on the effects of urban development on the UWH (Mills et al. 2012).

In 2012 all sites sampled for PAHs fell into the ERC green category. Of the 19 sites regularly sampled regularly for metals their ERC status was as follows (Figure 2);

- Copper: 42% are green, 58% are amber and none are red
- Lead: 84% are green, 16% are amber and none are red
- Zinc: 95% are green, 5% are amber and none are red

While these are mostly below ERC thresholds, they are higher than expected for the predominately rural surrounding land use, especially for copper (and possibly also for lead). The causes for elevated copper are, as yet, unknown (Mills et al. 2012).

#### 2.1.2.3 Water quality

There are eight sites in the Upper Waitemata Harbour (UWH), and five of these sites (Rangitopuni Creek, Confluence, Brighams Creek, Rarawaru Creek and Paremoremo Ski Club) will be of most interest to the north and west RUB investigation area. There are an additional three sites in the Central Waitemata Harbour.

Marine water quality of the UWH (using data from all eight sites) has been classed as fair (Figure 3). This fair rating is due to elevated concentrations of nutrients, suspended sediment, bacteria and phytoplankton. Of the five UWH sites mentioned above, only one site (Paremoremo Ski Club) has fair water quality while the remaining four sites (Rangitopuna Creek, Confluence, Brighams Creek and Rarawaru Creek) are all rated as poor. Long terms trends for the UWH indicate improvements in water quality have been observed with significant reductions in the concentrations of suspended sediment, phosphorous and bacteria at some sites.

#### 2.1.2.4 Bathing beach/safe swim

There are nine sites in the Central Waitemata Harbour and two sites in the Upper Waitemata Harbour that are monitored as part of the Safe swim program. In the upper Waitemata Harbour 46 tests were carried out over the 2012/13 summer and 96% of these passed the recreational bacteria guidelines. These current results have improved from last year as only one site was monitored and 22 tests were undertaken and 77% passed.

## 2.2 Kaipara Harbour

### 2.2.1 Introduction

Kaipara Harbour is the largest natural harbour in the Auckland region and the second largest in the southern hemisphere with a total surface area of 947 km$^2$ and a total intertidal area of 409 km$^2$ and more than 900 km of shoreline (Heath 1975). In general the harbour is very broad and shallow, although parts of the entrance channel are over 50 m deep (Haggitt et al. 2008). Formed from a system of drowned river valleys, the length and shape of the Kaipara means that current flows are generally high; and the width of the harbour and its wide mouth, bounded by two large sandspits, allow considerable wave activity. The area towards the mouth is a well-known great white shark habitat. The water in the harbour is frequently turbid. All these aspects contributed to the difficulty of sampling the area (Hewitt and Funnel 2005).

An extensive review of environmental information for the Kaipara Harbour was carried out by Haggitt et al. (2008) for the then Auckland Regional Council. The review confirmed that the Kaipara contains many high value species, communities and habitats and that the environmental values of the Kaipara have been, and are continuing to be, degraded. The review suggested that many activities threaten the environmental values of the Kaipara coastal marine area. Key issues included: landuse activities which generate sediment and other contaminants, fishing, sand extraction, tidal energy generation, aquaculture, and the spread of invasive species (marine and terrestrial). It was difficult to assess the scale of influence that these activities have had on the Kaipara Harbour, due a lack of detailed information on many of the activities (Haggitt el al. 2008).

Since this review, a number of long term monitoring programmes have been established in the Kaipara harbour to track changes in environmental quality as well as a large MBIE (previously FRST) funded research programme. Management of Cumulative Effects of Contaminants on Aquatic Ecosystems is a six year programme led by NIWA that began in 2010. It addresses six themes: (a) multiple stressor interactions, (b) ecosystem tipping points, (c) converting contaminant loads into ecologically relevant metrics (e.g., sediment loads into turbidity and light climate), (d) resource capacity as a vehicle for managing the cumulative effects of contaminants, (e) supporting Maori aspirations, (f) policy and planning opportunities and obstacles. A focus is on establishing a sediment capacity for the Kaipara Harbour.

This research would be of high relevance to RUB decisions, but timing unfortunately means it is currently not at a stage to provide answers, however there may be opportunities to utilise the work that has been done so far, when more detailed information is available on the RUB scenarios.

#### 2.2.1.1 Marine habitats, communities and benthic health

In 2004 and 2005, in response to requirements for information to inform decisions regarding aquaculture management areas in the harbour, an extensive survey of habitats and biological communities in the southern Kaipara was carried out (Hewitt and Funnell 2005), the findings of which are summarised in the following paragraphs.

The Southern Kaipara has a high diversity of habitats: extensive fringing mangroves and salt marshes; *Zostera* (seagrass) meadows and patches; non-vegetated mud and sand intertidal flats and shallow subtidal flats, as well as small areas of steep banks, deep high-flow channels and rocky reefs and cliffs. Despite the high flow and potential for wind and ocean swell generated waves, many areas of the Southern Kaipara displayed high taxonomic diversity at both a species and order level, and a number of organisms living in the harbour are large and long-lived. A number of species commonly associated with pristine environments (sponges, ascidians, bryozoans, hydroids, echinoderms and pipis) were found in the harbour.

While many of the taxa and habitats found in the Southern Kaipara occur elsewhere, some are unique. In particular, a subtidal association of tube-building worms was found in the shallow subtidal area of the main harbour comprised of high numbers of *Owenia*, *Macroclymenella*, *Euchone* and *Phoronids*. Subtidal *Zostera* (seagrass) is also comparatively rare in New Zealand and important for juvenile fish species. Strong differences were also recorded from different parts of the harbour; the Oruawharo Arm and Waionui Inlet both had distinctly different taxa than the main harbour. The *Atrina* (horse mussel) beds of the Kaipara while small are particularly important for juvenile snapper.

Mangrove habitat accounts for a substantial proportion (19%) of the ~407 km$^2$ intertidal area of the Kaipara Harbour (Swales et al. 2011). Analysis of aerial photography indicates that the total area of mangrove habitat has increased by 11% from an estimated 6845 ha in 1966/1977 to 7615 ha in 2002/2007. The estimated net increase includes the effects of large-scale reclamation works that reduced the area of mangrove habitat in the Southern Kaipara (Swales et al. 2011). Historical records show that in some locations major phases of mangrove-habitat expansion occurred prior to the 1940s.

The total area of salt-marsh habitat in the Kaipara Harbour has reduced by -3.6%, from 684 ha (1966/1977) to 660 ha in 2002/2007, with all of this net decrease occurring in the Auckland region (-31%) primarily due to reclamation. By contrast, the area of salt-marsh habitat in the Northland region has increased by 48% since the mid-1970s and now accounts for ~ 53% of the harbour total (Swales et al. 2011).

A soft sediment monitoring programme was established in October 2009, monitoring benthic ecology at six intertidal sites every two months to detect spatial and temporal patterns within and among sites. As this programme is still in its early phases, it is not possible to make robust statements on the changes in ecology over time. However, based on current results, benthic health was generally ranked as ‘good’, with two sites ranked as ‘moderately healthy’ (Hailes and Hewitt 2012) (Figure 1).

### 2.2.1.2 Contaminants

Contaminants in sediments were measured in 2010. The levels of copper, zinc, lead and PAH’s were generally very low across all six sites sampled and well within the ERC green category (Figure 2). Only one site near Shelly Beach exceeded the ERC amber threshold for copper.

### 2.2.1.3 Sedimentation

Sedimentation has been perceived as an increasing issue for the Kaipara Harbour, contributing to perceived degradation of water quality, biodiversity and decline in the fishery of the Kaipara Harbour. This perception has lead to a number of studies and research investigations into sediment input and dispersal in the harbour.

Swales et al (2011) found that most terrigenous (land derived) mud is delivered to the Kaipara Harbour by episodic flood events. Cores collected ~2km seaward of the Hoteo River mouth, contain the best examples of flood deposits, composed of pure mud layers up to 6-cm thick. Most of these flood deposits pre-date the 1950s. Elsewhere in the Kaipara Harbour, long-term accumulation of fine sediments is patchy.

The average sediment accumulation rate estimated for the Kaipara Harbour is 6.7 mm per year, although excluding data from two outlier core sites reduces this to 4 mm per year. This is high but not too different from the average sediment accumulation rates for Auckland’s east-coast estuaries (5.1 mm per year for estuaries and 3.3 mm per year for Central Waitemata Harbour).

Major fine-sediment accumulation zones include the southern Kaipara Harbour, Kakaraia Flats in the vicinity of the Hoteo River mouth and the Arapaoa River. Other long-term mud sinks in similar environments, such as the Otamatea and Oruwharo Rivers are inferred. By contrast, muds have not accumulated on large intertidal flats in the northern and southern arms of the harbour, such as the Omokoiti, Kaipara and Wairoa-River Flats, where waves and/or tidal currents deeply rework sediment deposits (Swales et al. 2011).

#### 2.2.1.4 Water quality

There are seven marine water quality sites in the Kaipara Harbour which were first sampled in 2009. Marine water quality of the Kaipara Harbour has been classed as fair due to elevated concentration of suspended sediment, nutrients (nitrogen and phosphorous) and consistently low water clarity (Figure 3).

Of these seven sites in the Kaipara the site of most interest to the western RUB investigation area will be the site at the mouth of the Kaipara River which is located to the southern end of the Kaipara Harbour. Using a three year average (2010, 2011, 2012) the marine water quality of the Kaipara River has been classified as having poor water quality. This is due to elevated concentration of suspended sediment, nutrients (nitrogen and phosphorous) and consistently low water clarity.

Long term trends are limited to only one site as we have a limited time series for the remaining sites (only 4 years of data). Shelly Beach in the Kaipara Harbour has been sampled since 1991 and long term trends (1991-2007) indicate significant improvements (from a lowered base line) in water quality with decreases in the concentrations of suspended sediment, phytoplankton, ammonia and total phosphorous which have provided for increases in water clarity.

#### 2.2.1.5 Bathing beach/safe swim

There are no safe swim sites in the Kaipara Harbour.

## 2.3 Orewa/Okura and Weiti Estuaries

### 2.3.1 Introduction

The Okura and Weiti estuaries are drowned-valley estuaries, with high-tide surface areas of 1.4 km$^2$ and 2.4 km$^2$ respectively. The estuaries are small in comparison to their catchment areas and the Okura and Weiti estuaries receive runoff from 22.7 km$^2$ and 33.3 km$^2$ catchments respectively. Mean annual suspended sediment loads have been estimated using the USGS SPARROW model calibrated for New Zealand catchments (Elliot et al. 2008). The estimated mean annual loads for the Okura and Weiti Catchments are 1100 tonnes and 2600 tonnes respectively (Swales et al. 2008).

Both estuaries are largely intertidal and exchange almost their entire high-tide volumes each tide. For example, the Okura Estuary is ~80% intertidal, with a single main tidal channel flanked by tidal flats that are submerged to an average depth of one metre at high tide (Swales et al. 2002). Okura estuary is funnel-shaped and its width, which is ~0.6 km at the mouth, rapidly diminishes towards the head of the estuary. In the middle estuary a shell spit, some 300-m long extends across the intertidal flats from the northern shore. Seaward of the spit, intertidal sediments are sandy whereas above the spit the intertidal flats become increasingly muddy. The upper estuary is also fringed by extensive stands of mangrove (Swales et al. 2008). Fine suspended sediments that do not settle during the mid–high tide period will be discharged to Karepiro Bay. The Bay has a high-tide surface area of ~4 km$^2$, of which ~70% is comprised of shallow subtidal flats with a maximum depth of 10 m at its mouth (Swales et al. 2008).

The Okura catchment and estuary was the subject of a comprehensive modelling program in the late 1990’s to predict the environmental risks associated with the development phase of the Okura catchment (see section 3.2.2). A number of reports were produced in association with an Environment Court ruling allowing development of the Okura and Long Bay catchments. The court decision placed the entirety of the Okura catchment outside the Metropolitan Urban Limit (MUL), and thus subjected it to relatively high restrictions on development, largely on the basis of the ecological and visual (aesthetic) quality of the Okura estuary, and the adverse effects which would likely result from urbanisation. A minimum lot size of 2 ha, and a maximum area of earthworks within any 12 month period lot of 1874 m$^2$, were specified. The marine reserve status and regionally significant amenity value of the Okura Estuary ‘raises the stakes’ in terms of the need to closely monitor the effects of catchment development and a comprehensive monitoring programme was established in 2000.

## 2.3.1 Environmental Quality

### 2.3.1.1 Marine habitats, communities and benthic health

Okura and Orewa

In 2000 the ARC began monitoring in Okura Estuary with the intention of capturing potential changes in the ecology of the estuary associated with periods of pre-development, development and post-development phases. Orewa (along with other east coast estuaries) was added in 2002.

A number of trends consistent with increased sedimentation have been detected through monitoring, including, increases in the very fine sediment fraction at five sites in depositional zones. All the trends detected for number of taxa, community composition, *Macomona, Aonides, Colurostylis* and *Waitangi* were consistent with increases in sedimentation. Sixty trends were detected, although a proportion of these are likely to turn out to be parts of multi-year cycles. More trends over time consistent with increased sedimentation were detected in Okura and fewest in Turanga and Waiwera, suggesting Okura is most likely to be exhibiting long-term changes related to increased terrestrial sedimentation (Hewitt and Simpson 2012).

Using the benthic health index (mud and contaminant) combined with the TBI, sites in Okura and Orewa are ranked as ‘good’ near the mouth of the estuary, declining to ‘moderate’ and ‘poor’ as you move up the estuary (Figure 1).

Weiti and Karepiro Bay

No ecological monitoring has been carried out in Weiti Estuary. However, in 2007, a quantitative benthic sampling of intertidal areas of Weiti Estuary and intertidal and subtidal areas of Karepiro Bay was carried out in order to provide more information on which to assess the state of this area and its sensitivity to sedimentation (Hewitt et al 2008). This survey revealed communities living in the outer estuary near the mouth that are sensitive to sedimentation events (both depositional events and increased levels of turbidity in the water column). In most cases these species are not only sensitive, but are large and slow growing. Their exclusion is likely to not only result in lower diversity but also in reduced ecological functioning. The habitat at the mouth of Weiti Estuary on the south western side is a complicated matrix of ridges and pools. The ridges are thick with *Boccardia* tube mats (an important structuring species), which is likely to be holding sediment and stabilizing the ridges. Currently the taxa observed are generally those that would be expected in a healthy estuary, with the exception that no large pipi beds were observed (Hewitt et al. 2008).

#### 2.3.1.2 Sedimentation

Okura and Weiti

Analysis of sediment accumulation rates was undertaken in 2007 for lower Okura and Weiti Estuaries and Karepiro Bay into which both estuaries drain (Swales et al. 2008). Upper Okura was sampled in an earlier study (Swales et al. 2002).

Today, the Okura and Weiti estuaries have reached advanced stages of infilling, with most of their surface area being intertidal. Dating of sediment cores shows that fine sediments are accumulating on intertidal flats in the upper Okura Estuary at 3 – 6 mm yr-1 (Swales et al. 2002). Long-term sediment accumulation in the upper estuary is favoured by: (1) proximity to the catchment outlet; (2) weak tidal currents on the tidal flats; and (3) limited potential for wave re-suspension due to the short fetch in most wind directions.

Seaward of the sand/shell bank, the intertidal flats are exposed to wave action, particularly from the northeasterly quarter (Green and Oldman 1999). The radioisotope data collected in more recent study indicate that there is a low potential for long-term fine-sediment accumulation on the intertidal flats of the lower Okura Estuary (Swales et al. 2008). Although slugs of fine sediment are likely to be deposited on the exposed intertidal flats, these deposits do not persist and are eventually re-mobilised by waves and transported from the flat by tidal currents (Green and Oldman, 1999). However, this type of temporary fine-sediment deposition still has sub-lethal and lethal effects on the benthic fauna, particularly on sand flats. These effects include long-term changes in species, communities and habitat, frequently resulting in low diversity systems dominated by a few species and one or two habitats. The general exclusion of slow-growing, large species frequently results in lower diversity and reduced ecological functioning of ecosystems (Thrush et al. 2004).

By comparison, the Weiti estuary is sheltered from wave action by its alignment perpendicular to the prevailing southwest/northeast winds and numerous sand and shell ridges, which break the intertidal flats up into smaller compartments with limited wave fetch. Sedimentation is occurring in the lower Weiti estuary at rates of 2.5 to 5.5 mm per year increasing from north to south, although SAR are likely to vary locally due to the complex morphology of the estuary (Swales et al. 2008).

Because the Okura and Weiti estuaries are largely intertidal and channelised, sediment-laden stormwater is likely to be discharged to Karepiro Bay as buoyant surface plumes. Sediment cores show that Karepiro Bay is a long-term sink for fine sediments. Radioisotope data show that sediments have been accumulating in the bay over the last 50 years or so at average rates similar to those measured in the upper Okura Estuary.  These data support the hypothesis that Karepiro Bay is a major sink for fine sediment eroded from land catchments and intertidal flats in the adjacent Okura and Weiti Estuaries (Swales et al. 2008).

Orewa and Weiti

Williamson et al. (2005a, 2005b) estimated the risk of depositional events in Orewa and Weiti estuaries associated with planned catchment development. Predictions were made of the likelihood of sediment deposits of a range of thicknesses (1-20mm) occurring in specific sub-estuaries under different development scenarios. A large number of different scenarios and sites were modelled and detailed results can be found in Williamson et al. (2005a, 2005b) and Cummings and Green (2007).  General findings were that Orewa already receives large sediment inputs and is likely to already be sediment stressed and under the development scenarios, 10 to 20mm thick deposits were predicted to occur in all but two of the sub-estuaries. These potential deposits were of concern to the ecology of parts of Orewa Estuary. The effect of sediment flushed from the estuary to the open coast was raised as a potentially important consideration that was not investigated in these reports.

#### 2.3.1.3 Contaminants

Contaminants in sediments are monitored at three sites in Orewa, three in Okura and one in Weiti. Currently, all sites fall into the ERC green category for lead, copper, zinc and PAHs (Figure 2).

The concentrations of zinc and copper in the Weiti Estuary were predicted from the USC-1 model (ARC 1998, 2004) from estimates of suspended sediment, zinc and copper loads from contributing catchments. Under the scenarios modelled, concentrations of zinc and copper are not expected to exceed the red ERC by the year 2051 largely due to low contaminant loads being diluted by inputs of sediment from rural sources (Williamson et al. 2005). However if land use were to change, these predictions would of course no longer be valid.

#### 2.3.1.4 Water quality

There is no water quality monitoring sites within the estuaries that would be direct receiving environments for the RUB areas. However there are four sites along the East Coast of Auckland from Leigh, in the North, to Browns Bay, in the South. Marine water quality on the East Coast is rated as good to excellent. Two marine water quality sites located at Orewa and Browns Bay may be of interest to the Northern RUB investigation area if sediments and contaminants discharged from the catchments flow through the estuaries to the open coast (Figure 3).

Marine water quality at Orewa (open coast not estuary) has been classed as excellent. Longer term trends show that water quality in this area is consistently of excellent quality. Marine water quality at Browns Bay has been classed as good. Longer term trends show that water quality in this area is consistently of high quality with observed reductions in the concentration of suspended sediment and phosphorous.

#### 2.3.1.5 Bathing beach/safe swim

During the 2012-13 summers period sampling was undertaken at Orewa beach. Twenty one tests were completed and 100% passed the Ministry for the Environment recreational bacteria guidelines. These current results are the same as last year's (2011-2012) results where 20 tests were carried out and 100% passed. Similar results were found at Browns Bay where 22 tests were undertaken in each year (2011-12 and 2012-13) and 100% of all tests passed Ministry for the Environment recreational bacteria guidelines.

## 2.4 Mahurangi Harbour

### 2.4.1 Introduction

The Mahurangi Harbour lies approximately 50 km north of Auckland on the east coast and is one of the largest drowned-valley systems on Auckland's east coast. The estuary has a high-tide surface area of 24.7 km$^2$ and a tidal volume of ~44.9 million m$^3$. At low tide, the main tidal channel is flanked by extensive intertidal flats composed of sands and muddy-sands, which are fringed by extensive mangrove stands (Swales et al. 1997). The estuary receives runoff from a 122-km$^2$ catchment of which 65% drains to the head of the estuary at Warkworth. The estuary is an important recreational resource, widely used for boating and fishing and is also the site of a pacific oyster aquaculture industry established in the early 1970's. Land-use in the catchment was primarily farming until 1975, at which time a *Pinus radiata* forest was planted in the upper reaches. There are two urban centres within the catchment, Warkworth and Snells Beach.

The terrain within the catchment is diverse. Steep hill country dominates, with pockets of rolling terrain typical of Northland. Of the land bordering the harbour, the western margins are somewhat higher (140-150 m asl) and steeper and more dissected than the eastern side (60-100 m asl) (Feeney, 1984). The southern eastern part of the catchment is moderately steep with areas of steep hill country.

The Mahurangi catchment has long been earmarked as a potential growth area. Even prior to the 1990's there were numerous investigations into potential environmental effects of potential increased pressure in the Mahurangi catchment (including a 1975 investigation in water quality).

During the 1990's the Auckland Regional Council (ARC) carried out investigations into the linkages between land-use within the catchment and possible effects within the marine receiving environment of the Mahurangi Harbour as there was the potential to experience significant future urban growth (e.g. Warkworth and Snells - Algies) in the catchment.

The work resulted in the compilation of a substantial body of information describing the Mahurangi catchment and receiving environment, its likely responses to a range of different land-uses, its susceptibility to soil erosion and vulnerability of the estuary to sedimentation. The investigation included development of a catchment and harbour model to help understand the relative sources, fate and possible impacts of sediment discharged from the catchment. Analysis of cores taken in the Mahurangi Harbour provided a record of changes in sedimentation rate since formation of the estuary near the end of the last ice age. Key investigations are listed below.

- Pesticide use and its risk of movement to waterways (Wilcock, 1994)
- Optical water quality in the estuary (Davies-Colley and Nagels, 1995)
- Sediment and nutrient loads to streams and the estuary (Stroud and Cooper, 1997)
- Sedimentation history in the estuary (Swales et al, 1997)
- Movement of water and contaminants within the estuary (Oldman, 1997), and
- Patterns and trends in the ecology of the estuary (Cummings et al, 1994).
- Sediment source tracking (Gibbs 2006)
- Sediment sources in streams within the catchment (Hicks and Hawcridge, 2004).

From these various investigations was found that the natural features of the Mahurangi catchment make it particularly susceptible to soil erosion and harbour infilling. This is primarily because the area experiences relatively high rainfall and more high-intensity storm events compared to other parts of the region. The combination of the steep slopes in parts of the catchment, together with soils that do not easily absorb rain, means sediment is more easily shifted during rainfall.

### 2.4.2 Environmental Quality

The Auckland Council (AC) operates a marine monitoring network within the Mahurangi Harbour as well as in rivers and streams throughout the catchment. NIWA also have a FRST programme of research embedded within the harbour and there are number of other studies around fish habitat being carried out by NIWA. Numerous studies and investigations of the marine environment in Mahurangi Harbour have been carried out by the University of Auckland.

#### 2.4.2.1 Marine habitats, communities and benthic health

In July 1994, the ARC began a long-term ecological monitoring programme of the intertidal and sub-tidal benthic (bottom dwelling) communities within the Mahurangi Harbour. Monitoring has been carried out at three-monthly intervals from 1994 at five intertidal sites (a 6th site was added in 2005) and three subtidal sites. Earlier monitoring provides strong evidence that the Mahurangi Harbour is already under sediment stress and monitoring today confirms this is still the case.

In 2001 and 2003 monitoring results showed declines in abundance of sediment intolerant species and increases in abundance of more sediment tolerant species at intertidal sites and a decline in the abundance and size of horse mussels (a habitat-forming species) at subtidal sites (Cummings et al. 2001 and Cummings et al. 2003). Ecological community structure at all intertidal sites was becoming increasingly similar despite being quite ecologically distinct when monitoring was initiated. This increased ecological homogeneity comes through a loss of the range of species present (diversity) as the more sediment intolerant species are lost. Such a broad-scale loss of diversity may be considered a sign of stress.

Surface sediments were also sampled during the monitoring programme. Results showed a step-wise shift in intertidal sediment grain size occurred between 1996 and 1997 where the percentage of fine-sand (63 – 250 µm) increased and medium sand (250 – 500 µm) decreased and then remained relatively constant. Subtidal sites also showed an increase in fine sand around 1996/97. Note that soils in the catchment are dominated by muds and fine sands and that Auckland's estuarine sediments are characterised by modal peaks of fine silts (~15-20µm) and fine sands (~130 –150µm). Much of what is perceived to be muddy actually has a large fine sand component. The 2003 monitoring report was independently peer reviewed by three international scientists and the findings found to be sound (ARC 2004b).

While we cannot be absolutely categorical about the cause of the ecological changes detected by the monitoring programme, there is strong empirical evidence to suggest that increased sedimentation and sediment flux are the primary drivers of change. In addition NIWA has carried out investigations for Auckland Council, into the historical sedimentation regime in the Mahurangi (see sections 2.4.1 and 2.4.2.3). In combination this information shows that, like most Auckland estuaries, the Mahurangi is vulnerable to infilling from sediment derived from the catchment, however, the soils and topography of the Mahurangi make it particularly susceptible to soil erosion. Modelling has shown that sediment discharges during storm events have the potential to distribute significant quantities of sediment across the Mahurangi including the areas where benthic marine ecology monitoring is being carried out.

Monitoring of the marine ecology of the Mahurangi Harbour has continued and while there have been changes in the types and numbers of patterns detected since those earlier trends in 2001/2003, the general pattern indicating sediment stress remains. Recommendations to investigate and implement improved sediment controls made following earlier ecological changes (2001/2003) still apply, as we have not yet detected increases (to previous levels) in abundances of taxa known to be sensitive to increased sediment loading. Of most concern is that five taxa considered sensitive to increased sediment loadings are exhibiting declines in abundance in Mahurangi Estuary (Halliday et al 2013). Four of these continue to decline in abundance at the muddiest site, Hamilton Landing. Decreasing trends for sediment intolerant species at Te Kapa Inlet are correlated with the continued expansion of the muddy portion of this site noted over the monitored period.

Analysis of the benthic health models for contaminants and mud suggests that the observed community assemblages are more influenced by mud content than by concentrations of copper, zinc and/or lead (Halliday et al. 2013). The BHM (Mud) ranks one site as good, three as moderate and one as poor with two sites worsening from the previous year (Halliday et al. 2013). Traits Based Indicator values for Mahurangi Estuary intertidal sites range from 0.40 at the muddy Dyers Creek site (indicative of moderate ecological functioning and, potentially, a moderately degraded site), to 1.11 at the sandier, more heterogeneous Jamieson Bay site in October 2012 (an extremely high value, greater than the theoretical maximum, indicating high ecological functioning). The remaining sites scored from 0.42 – 0.51 (Halliday et al. 2013). When the BHM and TBI results are combined all sites are ranked as moderately healthy (Figure 1).

### 2.4.2.2 Sedimentation

A detailed study of sedimentation history and present day sedimentation processes was undertaken by Swales et al (1997). The potential for estuarine sediments to be reworked by waves and tidal currents was also modelled (Swales et al, 1997).

The key findings from this research (Swales et al. 1997) are summarised below:

- At least 7300 years ago the Mahurangi Estuary was a deep subtidal basin, slowly infilling (0.3-0.8 mm/yr) with fine suspended sediment supplied by runoff from a native forest catchment. Rapid catchment deforestation following European settlement (1850-1900 AD) resulted in severe soil erosion and rapid deforestation of thick sequences of gravel, sand, mud and vegetation in the upper estuary.
- The overall pattern of increased sedimentation in the estuary following catchment deforestation is similar to that documented in other Auckland estuaries.
- Sedimentation in the Mahurangi Estuary is dominated by floods and infrequent large floods can deliver a large proportion of the annual sediment load to the estuary. For example, the May 1985 flood delivered 75% of the annual average sediment load (for the period 1975-1995) to the estuary.
- The largest sedimentation rates occurred in the upper Estuary (of the order of 15-20 mm/annum) with rates of the order of 2-5 mm/annum elsewhere in the harbour.
- The estuary is very susceptible to the impacts of catchment soil erosion as shown by rapid estuary infilling and a change to much coarser sediment deposition in the last 150 years. Despite the fact the future catchment sediment loads will never be as extreme as those which occurred during deforestation last century, sediment loads today are at least 5-6 times higher than prior to deforestation.

Swales et al. (1997) concludes that future catchment development that is likely to expose soils to erosion will have to be planned with particular care, if periods of potentially increased estuary sedimentation and the consequent adverse environmental effects are to be avoided or mitigated (Swales et al, 1997).

Sediment sources in the Mahurangi harbour have been mapped using sediment samples collected from the mudflats of the upper estuary and source samples collected from four land use types in the catchment (rural pasture, native forest, exotic pine forest and urban). The compound specific isotope (CSI) method analyses for a range of naturally occurring compounds, which act as natural tracers for the source of sediments (Gibbs 2006). The CSI sediment tracing method defines where the soil in the sediment came from but does not define how much. Interpretation of the results is based on the concept of proportional content in the sediment sampled rather than an estimate of the amount of soil from a source deposited at that location.

An overview of results shows that catchment soil entered Mahurangi Harbour via the Mahurangi River and from sub-catchments forming the side arms and local land drainage along both sides of the harbour to the sea. Based on the modelling data estimates, pine forest appears to contribute higher than expected sediment loads (for the proportion of the catchment it occupies) and also produces some locally high concentrations in the upper harbour (river delta). For the whole harbour, most of the sediment load comes from pasture and some native forest in the small sub-catchments along the sides of the harbour between the Mahurangi River and the harbour entrance. Under normal conditions (330 days per year) (not storm events) pine forest was estimated to produce 46.3 t (14%) and native plus pasture 283.8 t (86%) of sediment (Gibbs 2006).

#### 2.4.2.3 Contaminants

Sediment contaminant concentrations were measured at the intertidal marine ecology monitoring sites in November 2010. Levels of all metals and Polycyclic Aromatic Hydrocarbons (PAHs) were, with one exception, below threshold levels (Figure 2). Concentrations of arsenic at Te Kapa Inlet exceeded one guideline threshold and arsenic levels at all other intertidal sites except Dyers Creek were close to this threshold.

#### 2.4.2.4 Water Quality

Water quality monitoring in the Mahurangi Estuary first began in 1973, when the Auckland Regional Water Board carried out an initial bacteriological survey of the harbour (Feeney, 1984). Earlier results of the saline water quality monitoring programme have been reviewed by Feeney (1984) and Becker (1993) who summarised the overall pattern in water quality at that time from estuary to harbour as follows.

In summary, harbour water quality was affected by catchment land use, tidal movement and the time of discharge of contaminants. The harbour was susceptible to contaminants transported by catchment streams and from the estuary below the Warkworth township, as well as non-point source runoff from the surrounding pastoral lands and stormwater from coastal settlements (Becker 1993). Generally, the wider harbour water quality was high and the water more saline and less turbid with lower levels of contaminants than within the estuary, primarily due to dilution.

Currently there are two marine water quality sites in the Mahurangi Harbour, Mahurangi Heads and Dawsons Creek, first sampled in 1991 and 1993 respectively. Both sites are toward the entrance of the harbour so no statements regarding water quality of the upper reaches of the Mahurangi Harbour can be made. The marine water quality of the Mahurangi Harbour has been classed as good (Figure 3). Long term patterns in water quality for the Mahurangi Harbour indicate variable trends. Some water quality variables improved while others are deteriorating. At Dawsons Creek, significant declines in the concentrations of suspended sediment and phosphorus have been observed, while at Mahurangi Heads significant increases in turbidity (lower water clarity), phytoplankton and phosphorous have been observed.

#### 2.4.2.5 Bathing beach/safe swim

There are no safe swim sites in the Mahurangi Harbour.

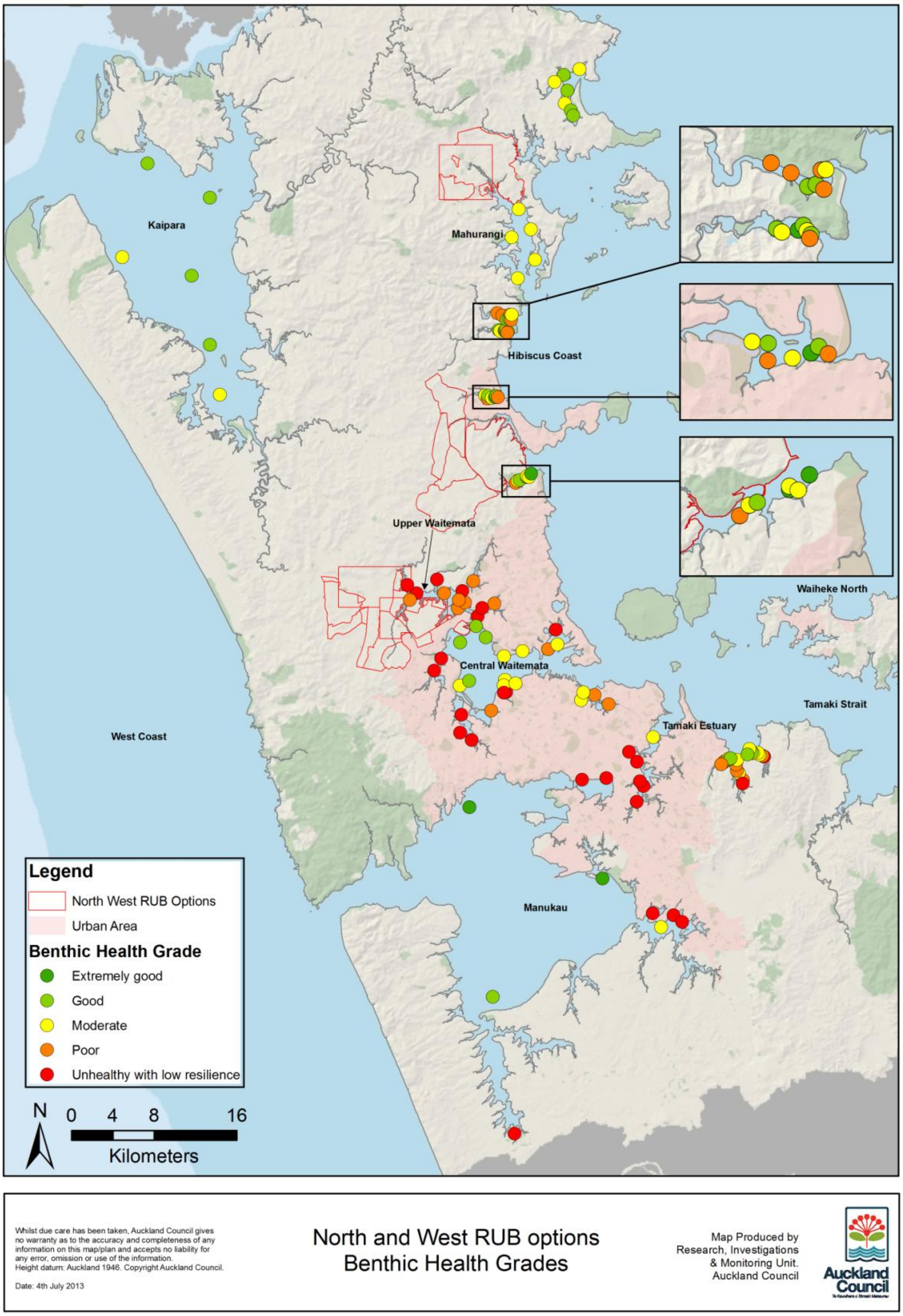


Figure 1: Benthic health monitoring sites and status for the Auckland region from State of the Environment monitoring

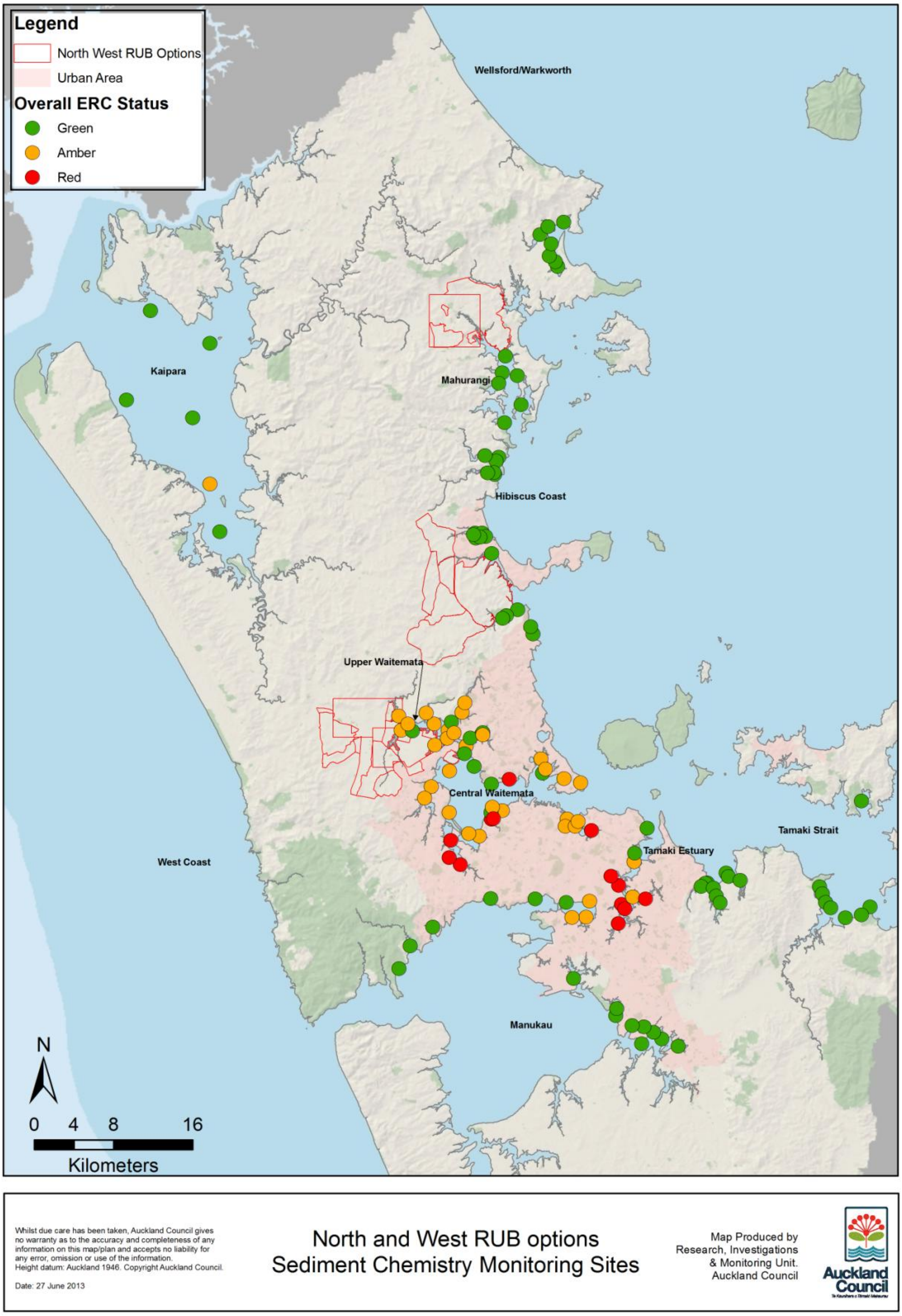
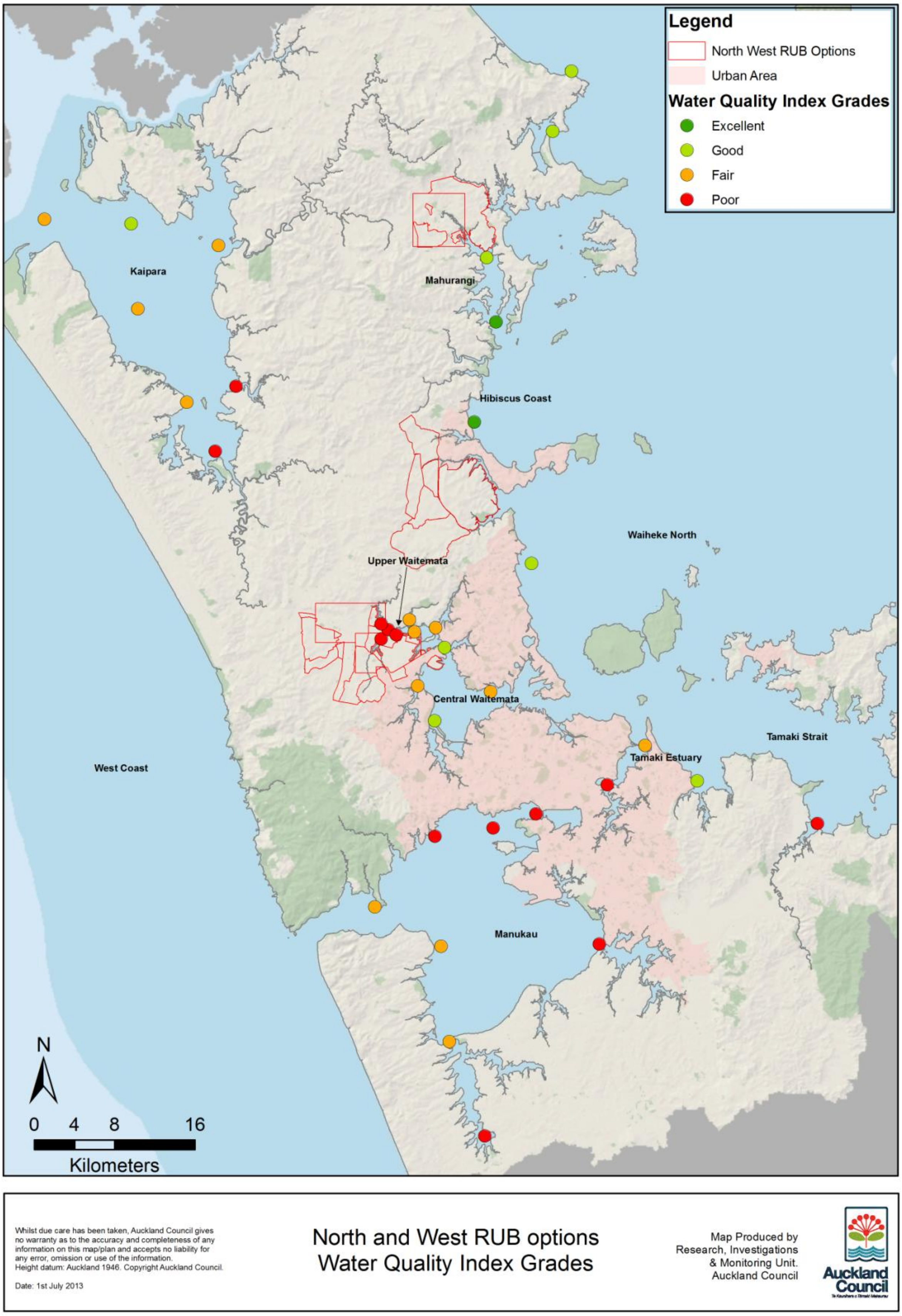


Figure 2: Sediment chemistry monitoring sites and status for the Auckland region from State of the Environment monitoring



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North and West RUB options
Water Quality Index Grades

Map Produced by
Research, Investigations
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Figure 3: Water Quality Index monitoring sites and grades for the Auckland region from State of the Environment monitoring

# 3.0 Predictive modelling and scenario testing

## 3.1 Introduction

Future land development has the potential to introduce sediments and contaminants to marine receiving environments, affecting the habitats available and the plants and animals living there, as well as the recreational and aesthetic values of the receiving environment and the functional capacity of the environment.

An understanding of the patterns and rates of sediment input, transport and accumulation or erosion in the harbour and resulting impact of these inputs on the harbours physical characteristics and the life it supports is required to enable and support management decisions.

Sediment transport models coupled with hydrodynamic models is one method of providing this information. Numerical models can be used to predict changes that might occur in the harbour due to changes in sediment inputs resulting from possible future land-use changes – modelled as different scenarios. Sediment transport modelling must be underpinned by accurate hydrodynamic modelling and the ability to predict different physical and ecological outcomes depends on the existing data and understanding for these components in the receiving environment being assessed.

The Urban Planning that Sustains Waterbodies (UPSW) research project has developed a pilot decision support system (DSS) for assessing the impacts of urban development on the values of receiving water bodies. Recently the UPSW pilot DSS has been applied to assess the potential effects of a range of future urban development scenarios in the Southern RUB area on parts of the Southeastern Manukau Harbour and adjoining tidal creeks. The study focused on assessing changes to estuarine sediment quality and the health of estuarine benthic invertebrate communities. The pilot DSS makes its predictions of these environmental indicators based on models (or versions of models) that have been previously developed and applied outside of the UPSW research project.

In another MBIE funded research project, NIWA are developing a tool to allow assessment of cumulative effects within a spatial planning/prioritisation framework is being developed. The tool is designed to assess the risk of cumulative effects causing a threshold-type response (as opposed to a gradual linear-type response) in several different system attributes (mainly related to biodiversity) both within the area that the activity(s) occur and within the larger management zone. It contains a decision support tree for reducing the risk of surprises and allowing trade-offs to occur between activities and is based on utility theory.

The extent of predictive modelling possible and the likely timing and cost, cannot be fully assessed until there is a clear indication of the numbers and types of scenarios that are under consideration and details of those scenarios.

In a broad overview, there are a number of options that could be explored further.

- Using existing data and models carried out for previous development and MUL decisions as well as previous Environment Court and hearing decisions.
- Re-running existing models with new scenarios – this will provide quantitative predicted outcomes for a range of variables, but can not be translated into changes in indicators
- Implement the UPSW as in the SE Manukau – in the Manukau this was underpinned by the existing SE Manukau modelling which included sediment and contaminant load modelling under a range of scenarios including a recent baseline. Models available for the north and north-western areas may be substituted but are less recent in their application and for most areas do not include contaminant loads.
- Trial NIWA's cumulative effects decision support tool.

External modelling advice will be sort on feasible potential options based one existing information, the details of scenarios that would need to be modelled and the timeframes in which outputs are required.

## 3.2 Existing modelling

As the majority of these areas have been considered in various Environment Court decisions, as well as Metropolitan Urban Limit decisions, there is a wide range of modelling studies already existing in most receiving environments. These are summarised below. External modelling advice will be sort as to whether any of the existing models could be re-run with new RUB scenarios, and the potential to use them as part of the UPSW decision support tool.

In addition, many, long term, ecological and physical quality monitoring programmes exist in these receiving environments which provide excellent baseline and trend information that can be used to inform initial decisions and as model input data (see section 2).

### 3.2.1 Upper Waitemata Harbour

The Upper Waitemata Harbour has been the focus of a number of studies which have attempted to predict the ecological impacts on this receiving environment of future development patterns. A study was initiated in 2001 to determine the sustainable carrying capacity for development in the Upper Harbour catchment, and identify the level of development and the controls necessary to secure long term protection of Upper Harbour environmental values. This study was completed in 2004.

Increased sediment runoff from the land into the harbour during development and ecological effects associated with that runoff were and are clearly of concern. However, full "sedimentation risk" modelling of the type carried out previously at Okura and Whitford was not undertaken due to the likely complexity and cost of modelling the relatively large, mixed-landuse Upper Waitemata catchment, and because the details of catchment development were not available at that time with sufficient precision to warrant that type of study. The management approach advocated in the absence of full sedimentation risk modelling was based on the adoption of high, precautionary-level controls (Green et al. 2004).

Prediction of patterns and levels of contaminant accumulation in the Upper Harbour associated with urban development over the medium term (decades) and a comparison of predicted contaminant levels with relevant environmental guidelines was made (see Green et al. 2004 and references therein). The study predicted spatial patterns 50 and 100 years out, of zinc, copper and PAH accumulation throughout the Upper Waitemata Harbour under a number of different scenarios, where each scenario was characterised by a particular landuse, sediment controls and stormwater treatment. A second study goal was to predict spatial patterns of organochlorine pesticide accumulation throughout the Upper Waitemata Harbour which is relevant as the disturbance of previously rural soils can release these pesticides in sediment runoff.

The 2004 Upper Waitemata Harbour (UWH) Contaminant Study (see Green et al. (2004)) utilised the USC-2 model suite which is the predecessor to the USC-3 model suite used in the south-eastern Manukau study. The study made predictions out for 108 years from 2001.

Modelling suggested that stormwater contaminants would increase in multiple branches of the upper harbour; particularly with increased development over the next 100 years (Green et al. 2004). The majority of elevated zinc and copper concentrations stemmed from urban sources, with the exception of Rangitopuni and Paremoremo creeks (rural). Increases in metal concentrations can emerge from contaminants already locked in soils, eroded and entering the harbour during development (Green et al. 2004).

It might be assumed that additional development over and above what was modelled in 2004, would increase the speed at this contaminants would increase and guidelines would be breached. This would however, require additional modelling to determine if this was the case and by how much and for what sub-catchments.

A further study has since evaluated the effect of uncertainties in the estimates of sediment yield from Rangitopuni sub-catchment (which is the largest sediment source in the Upper Waitemata catchment) on the predictions of contaminant accumulation that have been made in the Contaminant Study. In addition, the effect on contaminant predictions of possible landuse change programmed for the Rangitopuni sub-catchment was also evaluated (Green and Collins 2004).

In a follow up investigation, the environmental benefits in the UWH associated with a range of zinc source control options that might be implemented in the catchment were determined (Timperly and Green 2005). The results showed that the potential benefits in terms of zinc concentrations in estuarine sediments of source control (e.g. zinc roof run-off), would greatly exceed the benefits achievable by stormwater treatment only (Timperly and Green 2005).

### 3.2.1 Kaipara Harbour

Of all the catchments under consideration, the Kaipara Harbour probably has the least amount of existing modelling available, although it is the subject of a large MBIE (previously FRST) funded research programme which will provide a great deal of relevant information when completed. Management of Cumulative Effects of Contaminants on Aquatic Ecosystems is a six year programme led by NIWA in association with Auckland Council that began in 2010. It addresses six themes: (a) multiple stressor interactions, (b) ecosystem tipping points, (c) converting contaminant loads into ecologically relevant metrics (e.g., sediment loads into turbidity and light climate), (d) resource capacity as a vehicle for managing the cumulative effects of contaminants, (e) supporting Maori aspirations, (f) policy and planning opportunities and obstacles. A focus is on establishing a sediment capacity for the Kaipara Harbour.

To date, a 2D hydrodynamic model of the whole harbour has been set up, which includes all of the bathymetry, and calibrates and verifies the 2D hydro model against water-level and current data collected during the field deployments. Currently freshwater inputs are being sorted out and implementation of the 3D hydrodynamic model, which builds on the 2D model, is being started.

2012/13 this year (year 3 of the programme) will see implementation of the 3D hydro model completed. The implementation of the full sediment model, which will involve being able to inject sediments into the harbour with freshwater runoff from the land will be commenced.

Depending on the information available for the RUB scenarios, there is potential to trial the model with RUB sediment and contaminant loads.

2013/14 (year 4) will see the complete implementation of the full sediment model, which will include calibration and validation. The sediment model will allow us to inject sediments into the harbour with freshwater runoff from the land.

By years and 5 and 6 of the programme it will be possible to use the model to investigate a range of scientific questions and to look at dispersal pattern of sediments from freshwater sources This will culminate in development of a source-to-sink sedimentation model for the harbour and calculation of catchment sediment load limits to achieve sedimentation targets.

Note that some earlier modelling has been carried out by DHI Ltd for Rodney District Council. An assessment of water levels in Helensville has been carried out using a combination of a 2D model of Kaipara Harbour based on DHI’s MIKE 21 Flexible Mesh Model and the MIKE 11 model developed for the Kaipara River (Wo and van Kalken 2006). DHI Ltd has also prepared a number of reports for Rodney District Council as part of a catchment management plan for the Kaipara-Kumeu catchment (Wo and van Kalken 2007a and b).

### 3.2.2 Okura and Weiti (Karepiro Bay)

In the 1990’s a series of investigations was carried out for Okura to predict the risks of ecologically-damaging sediment events occurring in the estuary associated with various levels of urbanisation/rural intensification. Three key reports were completed which are synthesised in Cooper et al. (1999).

Norko et al. (1999) presents information on potential threats to Okura’s estuarine ecosystems that result from sediment deposition events, establishing critical depths and durations (limits) of event based sediment inputs, above which, impacts on the ecology of Okura might be expected. Deposition of flood-borne sediments in Okura was investigated (Green and Oldman 1999) in order to assess the likelihood that it will deposit in greater-than-critical thickness over significant areas (where critical and significant were defined from an ecological point of view). Stroud et al (1999) predict the risks of sediment input from the catchment exceeding these limit values for varying degrees of rural intensification. Beca (2000) provides a quantitative risk assessment for development in Okura based on the previous reports. Predictions were based on the risks of ecologically-damaging sedimentation events occurring in Okura estuary during the initial earthworks phase of development and not the effects of long-term change in land use (Cooper et al. 1999).

In summary, the biological communities of Okura are diverse and both polychaetes and bivalves were shown to be sensitive to sediment deposition events. In addition the biological communities of the estuary can take a considerable length of time to recover from a sediment deposition event (Cooper et al. 1999 from Norko et al. 1999). Conditions in the estuary generally favour the deposition of catchment derived sediments. Modelling predicted that the minimum sediment load delivered to the estuary in a single flood event would result – if conditions were favourable – in a 2cm thick deposition over an area of $100m^2$ in each sub-environment, with a 2cm thickness established as an ecologically critical depth posing significant threat to the biological communities of Okura (Cooper et al 1999 from Green and Oldman 1999). Conditions in the Okura catchment generally favour sediment runoff and delivery to the estuary. Modelling predicted that sediment loads would increase significantly as the degree of intensification increases (Cooper et al. 1999, from Stroud et al. 1999). The risk of threat to the ecological communities in Okura is outlined by scenario in Cooper et al (1999).

Stroud and Cooper (1999), conducts an analysis of the effects of possible catchment development on sediment loads to the Okura Estuary using the computer simulation model WAM (Watershed Assessment Model). Green and Oldman (1999) used the numerical model 3DD to simulate currents, the exchange of water between the estuary and the coast, inundation and tides. The transport and dispersal of particles was simulated using the POL3DD model and WGEN was used to simulate waves generated by winds blowing over the estuary.

More recently, Auckland Regional Council (ARC) commissioned NIWA to develop a monitoring plan to access the effects of harvesting the Weiti Forestry Block (WFB) at Okura in 2009. Deforestation through logging in the region has the potential of delivering elevated loads of fine sediments into local estuarine environments. The subsequent dispersal and deposition of fine sediments in the adjacent Okura and Weiti estuaries has a potential for detrimental ecological impacts on local benthic flora and fauna.

Measurements of localised stream/river sediment yields, stream/river freshwater discharge rates, tidal and weather data were used to develop a numerical modelling protocol for the Okura Estuary and immediate receiving waters in Karapiro Bay. The models used in the study were the DHI Water and Environment MIKE3 FM HD hydrodynamic model and the DHI MIKE3 FM MT (mud) sediment transport model (Pritchard et al 2009).

### 3.2.3 Orewa

Williamson et al. (2005a, 2005b) estimated the risk of depositional events in Orewa and Weiti estuaries associated with planned catchment development. Predictions were made of likelihood of sediment deposits of a range of thicknesses (1-20mm) occurring in specific sub-estuaries under different development scenarios. A large number of different scenarios and sites were modelled and detailed results can be found in Williamson et al. (2005a, 2005b) and Cummings and Green (2007). General findings were that Orewa already receives large sediment inputs and is likely to already be sediment stressed and under the development scenarios, 10 to 20mm thick deposits were predicted to occur in all but two of the sub-estuaries. Sediment run-off was predicted by extrapolating the results from applying the catchment model GLEAMS in Orewa.

### 3.2.4 Mahurangi Harbour

A series of studies were undertaken by NIWA, on behalf of the ARC, to investigate the impacts of land use activities within the Mahurangi catchment on water quality. A computer simulation model (Basin NZ catchment model) that is able to predict sediment and nutrient loadings to the estuary, using detailed information on the catchment and a long term climate record, was developed and validated for the Mahurangi catchment (Stroud and Cooper 1997).

The long term average sediment load delivered to the Mahurangi Estuary from the surrounding catchment was predicted by the model to be 52270 t year-1 (448 t km-2 year-1) and ranged from just over 13,000 tonnes year-1 to approximately 136,000 tonnes year-1. Many of the areas displaying high sediment losses were located in sub-catchments bordering the estuary, particularly Te Kapa Inlet, Pukapuka Inlet, Dyers Creek and Cowans Bay. These areas are dominated by pastoral land use, strongly rolling to steep slopes, and soil types that have low infiltration capacity (Stroud and Cooper 1997)

By comparing predicted sediment loads from the sub-catchments, the modelling indicated that despite forming approximately half of the entire catchment of the estuary, the Mahurangi River system only contributed 29% of the total sediment load to the estuary. The catchments draining the eastern and western shores were found to contribute approximately 71% of the sediment load entering the estuary. The model predicted that the combination of steep slope and pastoral land use was a dominant factor in the high sediment loss from these parts of the catchment (Stroud and Cooper 1997)

Models were then used as predictive tools to determine potential sediment loads from within the catchment, under a range of proposed land-use development scenarios. The land use changes examined included an increase in the area of urbanisation, harvesting of the existing Redwood forest, and conversion of the entire catchment to production forest (Oldman et al. 1998) The BNZ catchment model was used to predict sediment erosion rates within the catchment and sediment delivery rates to the estuary for each of these land uses. Sedimentation rates within the estuary were then predicted using hydrodynamic and transport/dispersion models.

The level of site disturbance during urban development was found to be important in determining the amount of sediment actually being delivered to the estuary. Developing relatively small blocks for urbanisation through earthworks that completely expose soils produced similar sedimentation within the estuary as harvesting of the forest (Oldman et al. 1998), suggesting that careful consideration of the location of earthworks and the level of sediment controls is required.

### 3.2.1 CLUES

Auckland Council has recently commissioned NIWA to demonstrate how the Catchment Land Use for Environmental Sustainability (CLUES) model can be used as part of the council's implementation programme for the National Policy Statement on Freshwater Management. CLUES is a modelling system for assessing the effects of land use change on water quality and socio-economic factors at a minimum scale of sub-catchments. It simulates annual catchment in-stream loads of total nitrogen, total phosphorus, sediments and E. coli, nutrient concentrations and generated yields of nutrients and sediment. The draft report provides simulation of annual sediment and nutrient annual yields, loads and concentrations from rural land uses across the Auckland region for the year 2002 (LCDB2), 2008 (LCDB3) and pre-european land use (1770) based on historical vegetation maps. Values for every stream reach in the region have been calculated but only selected estuaries have had all inputs consolidated into a single number (Includes Mahurangi River, Kaipara River, Rangitopuni River and Brighams Creek). Early indications are that for the Auckland region, this model needs further calibration at localised scales. Brad Scarfe in CLAW is the contact for this information which is currently in draft and being reviewed.

# 4.0 Summary

## 4.1 Upper Waitemata Harbour

The Upper Waitemata Harbour has been the focus of a number of studies which have attempted to predict the ecological impacts on this receiving environment of future development patterns. Modelling suggested that stormwater contaminants would increase in multiple branches of the upper harbour; particularly with increased development over the next 100 years (Green et al. 2004). The majority of elevated zinc and copper concentrations stemmed from urban sources, with the exception of Rangitopuni and Paremoremo creeks (rural). Increases in metal concentrations can emerge from contaminants already locked in soils, eroded and entering the harbour during development (Green et al. 2004).

It might be assumed that additional development over and above what was modelled in 2004, would increase the speed at which contaminants would increase and guidelines would be breached. This would however, require additional modelling to determine if this was the case and by how much and for what sub-catchments.

In a follow up investigation, the environmental benefits in the UWH associated with a range of zinc source control options that might be implemented in the catchment were determined (Timperly and Green 2005). The results showed that the potential benefits in terms of zinc concentrations in estuarine sediments of source control (e.g. zinc roof run-off), would greatly exceed the benefits achievable by stormwater treatment only (Timperly and Green 2005).

A 2002 survey showed that the intertidal and subtidal benthic communities and habitats of UWH were generally in good condition, and worthy of careful consideration when development occurred (Cummings et al. 2002). However ongoing monitoring has shown that the Upper Waitemata Harbour is an area of relatively reduced benthic health with functionally poor ecological communities. Overall health scores rank sites in the UWH as ‘unhealthy with low resilience’ or ‘poor’ (the bottom two out of five categories for intertidal site health) (Townsend et al. 2012). While contaminant levels in sediments in the UWH are mostly below ERC thresholds, they are higher than expected for the predominately rural surrounding land use, especially for copper (and possibly also for lead) (Mills et al. 2012). Water quality in the UWH has been ranked as fair and of those sites of most relevance to the RUB decisions, only one site is ranked is fair, while the remaining four sites are ranked as poor. Of those bathing beach tests carried out over summer 2012/13, 96% passed the recreational bacteria guidelines.

## 4.2 Kaipara

The Southern Kaipara has a high diversity of habitats including some unique or rare habitats (Hewitt and Funnell 2005). An extensive review confirmed that the Kaipara contains many high value species, communities and habitats and that the environmental values of the Kaipara have been, and are continuing to be, degraded (Haggitt et al. 2008). Benthic health was generally ranked as ‘good’, with two sites ranked as ‘moderately healthy’ (Hailes and Hewitt 2012). The levels of copper, zinc, lead and PAH’s were generally very low across all sites sampled and well within the ERC green category. Only one site near Shelly Beach exceeded the ERC amber threshold for copper. Average sediment accumulation rates in the Kaipara are similar to those from Auckland’s east coast estuaries. The marine water quality of the Kaipara River has been classified as poor due to the concentrations of suspended sediments, nutrients (nitrogen and phosphorous) and consistently low water clarity.

Of all the catchments under consideration, the Kaipara Harbour probably has the least amount of existing modelling available, although it is the subject of a large MBIE (previously FRST) funded research programme which will provide a great deal of relevant information when completed. Management of Cumulative Effects of Contaminants on Aquatic Ecosystems is a six year programme led by NIWA in association with Auckland Council that began in 2010. Depending on the information available for the RUB scenarios, there is potential to trial the model with RUB sediment and contaminant loads.

## 4.3 Orewa, Okura and Weiti

In the 1990’s a series of investigations were carried out for Okura estuary to predict the risks of ecologically-damaging sediment events occurring associated with various levels of urbanisation/rural intensification. Three key reports were completed which are synthesised in Cooper et al. (1999).

In summary, the biological communities of Okura are diverse and both polychaetes and bivalves were shown to be sensitive to sediment deposition events. In addition the biological communities of the estuary can take a considerable length of time to recover from a sediment deposition event (Cooper et al. 1999 from Norko et al. 1999). Conditions in the estuary generally favour the deposition of catchment derived sediments. Modelling predicted that the minimum sediment load delivered to the estuary in a single flood event would result – if conditions were favourable – in a 2cm thick deposition over an area of 100m$^2$ in each sub-environment, with a 2cm thickness established as an ecologically critical depth posing significant threat to the biological communities of Okura (Cooper et al 1999 from Green and Oldman 1999). Conditions in the Okura catchment generally favour sediment runoff and delivery to the estuary. Modelling predicted that sediment loads would increase significantly as the degree of intensification increases (Cooper et al. 1999, from Stroud et al. 1999). The risk of threat to the ecological communities in Okura is outlined by scenario in Cooper et al (1999).

A more recent study found there was a low potential for long-term fine-sediment accumulation on the wave-exposed intertidal flats of the lower Okura Estuary. By comparison, the Weiti estuary is sheltered from wave action by its alignment perpendicular to the prevailing southwest/northeast winds and numerous sand and shell ridges, which break the intertidal flats up into smaller compartments with limited wave fetch (Swales et al. 2008). Sedimentation is occurring in the lower Weiti estuary, although sediment accumulation rates are likely to vary locally due to the estuary’s complex morphology. Because the Okura and Weiti estuaries are largely intertidal and channelised, sediment-laden stormwater is likely to be discharged to Karepiro Bay as buoyant surface plumes thereby bypassing the estuaries (Swales et al. 2008).

Williamson et al. (2005a, 2005b) estimated the risk of depositional events in Orewa estuary associated with planned catchment development. General findings were that Orewa already receives large sediment inputs and is likely to already be sediment stressed and under the development scenarios, 10 to 20mm thick deposits were predicted to occur in all but two of the sub-estuaries and that these would be of concern to ecology in the Orewa estuary.

A combined health score ranks sites in Okura and Orewa as ‘good’ near the mouth of the estuary, declining to ‘moderate’ and ‘poor’ as you move up the estuary. A number of trends consistent with increased sedimentation have been detected through monitoring, with Okura most likely to be exhibiting long-term changes related to increased terrestrial sedimentation (Hewitt and Simpson 2012). A 2007 survey of Weiti Estuary revealed communities living in the outer estuary near the mouth that are sensitive to sedimentation events (both depositional events and increased levels of turbidity in the water column) and to contamination by copper, lead and zinc (Hewitt et al. 2008). All monitoring sites in Orewa, Okura and Weiti fall into the ERC green category for lead, copper, zinc and PAH’s. There is no water quality monitoring sites that would be direct receiving environments, however more coastal sites which may still be affected by discharges from these estuaries are ranked as excellent or good and of those bathing beach tests taken, 100% passed.

## 4.4 Mahurangi

The Mahurangi catchment has long been earmarked as a potential growth area. During the 1990’s the Auckland Regional Council (ARC) carried out investigations into the linkages between land-use within the catchment and possible effects within the marine receiving environment of the Mahurangi Harbour as there was the potential to experience significant future urban growth (e.g. Warkworth and Snells - Algies) in the catchment.

The work resulted in the compilation of a substantial body of information describing the Mahurangi catchment and receiving environment, its likely responses to a range of different land-uses, its susceptibility to soil erosion and vulnerability of the estuary to sedimentation. The investigation included development of a catchment and harbour model to help understand the relative sources, fate and possible impacts of sediment discharged from the catchment. Analysis of cores taken in the Mahurangi Harbour provided a record of changes in sedimentation rate since formation of the estuary near the end of the last ice age.

From these various investigations it was found that the natural features of the Mahurangi catchment make it particularly susceptible to soil erosion and harbour infilling. This is primarily because the area experiences relatively high rainfall and more high-intensity storm events compared to other parts of the region. The combination of the steep slopes in parts of the catchment, together with soils that do not easily absorb rain, means sediment is more easily shifted during rainfall.

Swales et al. (1997) cautions that future catchment development that is likely to expose soils to erosion will have to be planned with particular care, if periods of potentially increased estuary sedimentation and the consequent adverse environmental effects are to be avoided or mitigated.

The level of site disturbance during urban development was found to be important in determining the amount of sediment actually being delivered to the estuary. Developing relatively small blocks for urbanisation through earthworks that completely expose soils produced similar sedimentation within the estuary as harvesting of the forest (Oldman et al. 1998). This suggested that careful consideration of the location of earthworks and the level of sediment controls is required.

Earlier ecological monitoring provides strong evidence that the Mahurangi Harbour is already under sediment stress and monitoring today confirms this is still the case. Of most concern is that five taxa considered sensitive to increased sediment loadings are exhibiting declines in abundance in Mahurangi Estuary (Halliday et al 2013). The combined health score ranks all sites within the Mahurangi as moderately healthy (Figure 1). Levels of all metals and Polycyclic Aromatic Hydrocarbons (PAHs) were, with one exception, below threshold levels. Concentrations of arsenic at Te Kapa Inlet exceeded one guideline threshold and arsenic levels at all other intertidal sites except Dyers Creek were close to this threshold. Both water quality monitoring sites are toward the entrance of the harbour so no statements regarding water quality of the upper reaches of the Mahurangi Harbour can be made. Based on these two sites, marine water quality of the Mahurangi Harbour has been classed as good. Long term patterns in water quality for the Mahurangi Harbour indicate variable trends. Some water quality variables improved while others are deteriorating. At Dawsons Creek, significant declines in the concentrations of suspended sediment and phosphorus have been observed, while at Mahurangi Heads significant increases in turbidity (lower water clarity), phytoplankton and phosphorous have been observed.

## 4.5 Overall summary

Future land development has the potential to introduce sediments and contaminants to marine receiving environments, affecting the habitats available and the plants and animals living there, as well as the recreational and aesthetic values of the receiving environment and the functional capacity of the environment to deliver ecosystem services that benefit humans.

All of the receiving environments considered have been shown to have ecological value and sensitivities that would warrant consideration in land development decisions; however all show a degree of degradation already making it even more important to carefully consider the cumulative effects of increasing sediment and contaminant loads associated with urban development or rural intensification. Upper Waitemata Harbour and Mahurangi in particular are showing signs of degradation, with early signs for sites in Okura and Orewa estuaries. Kaipara ecology is generally ranked as good; however, sedimentation is still considered a prominent issue for the whole harbour. For all receiving environments, sedimentation currently appears to be the primary effect with contaminant levels generally low, although those in the Upper Waitemata Harbour are higher than might be expected from its predominantly rural catchment. It should be remembered that a degraded system may potentially be more sensitive to impacts as it is closer to a tipping point. A healthier system, may have a higher ecological value but also a higher degree of resilience to impact. All previous modelling for these areas suggest increased sedimentation and contaminant loads, with Okura in particular being identified as likely to have significant ecological effects.

As the majority of the current RUB areas being considered have been considered in various Environment Court decisions, as well as Metropolitan Urban Limit decisions, there is a wide range of modelling studies that already existing in most receiving environments. As further details of RUB scenarios become available, the applicability of these models can be further assessed and the potential of additional decision support systems (tools) explored. In addition, many, long term, ecological and physical quality monitoring programmes exist in these receiving environments which provide excellent baseline and trend information that can be used to inform initial decisions and as model input data

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