NIWA
Taihoro Nukurangi

Quantifying Contaminant Sources in the Upper Whangarei Harbour Catchment

Prepared for Whangarei District Council and Northland Regional Council

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Executive summary

A recent review of water quality monitoring data indicates that the middle and lower parts of Whangarei Harbour have good water quality, based on levels of nutrients and faecal bacteria. However, water quality in the upper harbour is often poor, with the lowest water and sediment quality in the northern Hatea River arm downstream of urban Whangarei. This report describes a review of existing information on contaminant sources in the catchment of the upper harbour, the estimation of contaminant loads from certain diffuse sources and the development of options to fill current gaps in knowledge. The contaminants of interest are sediment, nutrients (nitrogen and phosphorus), faecal pathogens and indicator bacteria, and metals (copper, lead and zinc).

The catchment of the upper harbour comprises nine sub-catchments and a mix of urban and rural land uses. Typical of a mixed land-use catchment, there are a range of potential sources of contaminants. Diffuse sources include stormwater runoff from urban land and major roads, pastoral farming and exotic and native forests. Point sources include discharges of treated and untreated wastewater and discharges from industrial activities. There are also background levels of the contaminants, for instance reflecting their natural occurrence in the catchment soils.

A number of previous studies have assessed stormwater contaminants in urban parts of Whangarei, and some of these provide estimates of contaminant loads. There have also been studies of water quality associated with pastoral farming in the Puwera sub-catchment and of the impacts of forestry on sediment generation in the Hatea sub-catchment. The data from these studies and from three long-term water quality monitoring sites in the Hatea and Waiarohia sub-catchments can be used to estimate loads of some contaminants. Water quality and sediment quality data from a range of other sites, including stormwater and industrial discharge monitoring sites, can be used to assess spatial variations in contaminant sources but contain too few data points for the calculation of loads. A current study into the sedimentation of Whangarei Harbour is expected to provide results which can be used to evaluate sources of sediment by sub-catchment and by rural land use type, as well as providing estimates of the sediment load delivered from the catchment as a whole.

There are a number of information sources relating to the operation of the Whangarei wastewater network and treatment plant (WWTP) and the health risks associated with discharges of faecal pathogens. System upgrades in recent years have resulted in a reduction in wet-weather overflows from the network and further measures are planned in order to reduce the discharge of partially-treated wastewater from the WWTP. Outputs from a model of the network, in combination with data on treated and untreated wastewater quality, can be used to calculate contaminant loads discharged from these sources.

Discharges from other point sources, including farm dairy effluent discharges, industrial activities and bulk construction earthworks, are reported to be well-controlled through compliance with the conditions of resource consents. The importance of other sources, including dry-weather wastewater discharges, domestic septic systems, lot-scale construction earthworks and quarries is uncertain. We are unaware of any information on loads from these sources in the catchment of the upper harbour.

Sub-catchment diffuse source loads of contaminants have been estimated using two models. The Catchment Land Use for Environmental Sustainability (CLUES) model was used to

estimate rural loads of nutrients (total nitrogen, TN and total phosphorus, TP), total suspended solids (TSS) and the faecal indicator bacteria *E. coli*. The Catchment Contaminant Annual Loads Model (C-CALM) was used to estimate urban loads of TSS and dissolved and particulate zinc and copper. The results of this exercise are indicative estimates showing the relative importance of each sub-catchment as a source of diffuse-source contaminants. However, the application of the models involved making certain assumptions and could be revisited to incorporate more precisely-defined input data.

Options have been developed for a programme of further work to generate additional estimates of contaminant loads and to assess the spatial variation in loads between and within sub-catchments. Different options reflect different objectives. Where the objective is to identify key source activities or sub-catchments in order to prioritise management responses, then knowledge on the relative importance of different sources is likely to be sufficient. Relevant methods to meet this objective involve further modelling and the use of existing locally collected or literature-based data.

In contrast, where the objective is to undertake a detailed evaluation of whether or not discharge limits imposed on individual activities are being exceeded, it becomes more important to attempt to quantify the absolute magnitude of loads with a high level of accuracy. Options associated with this objective involve new data collection to attempt to ground-truth modelled estimates. The level of effort associated with this set of options is much higher than that associated with options focusing on establishing the relative importance of sources. Indicative time scales and costs are provided to illustrate this distinction.

1 Introduction

1.1 Background

Northland Regional Council (NRC) is tasked with delivering against a number of statutory and non-statutory requirements in relation to managing water quality in Whangarei Harbour and its catchment. These include:

- meeting community aspirations relating to uses of the upper harbour for instance, for contact recreation and the harvesting of shellfish;
- achieving consistency with the New Zealand Coastal Policy Statement (NZCPS); and
- implementing the National Policy Statement (NPS) for Freshwater Management in relation to water bodies in the harbour catchment, which is likely to involve setting specific freshwater objectives and associated freshwater quality limits for the catchments draining to the upper harbour in order to meet objectives and water quality targets set for the harbour.

NRC and Whangarei District Council (WDC) are working collaboratively on a water quality action plan in order to set a strategic direction for management of water quality in the harbour and the upper harbour catchments, and to prioritise actions which will support the achievement of the community's aspirations.

As part of the development of the joint strategy, a review of water quality in Whangarei Harbour has been undertaken by the two councils (NRC & WDC, 2012). This has involved collating and reviewing existing sources of information on sediment and water quality, ecosystem health and sources of contaminants. The focus of the document is on the upper harbour, as it is the receiving environment for most catchment run-off. It is also the part of the harbour that is close to home for most of the district's population.

A recent review of water quality monitoring data (see Chapter 3 of this report for a summary) indicates that the middle and lower harbour has good water quality, based on levels of nutrients and faecal bacteria. However, water quality in the upper harbour is often poor, with the lowest water quality in the northern Hatea River arm downstream of urban Whangarei. The key contaminants of concern are sediments, the nutrients nitrogen (N) and phosphorus (P), and faecal pathogens. Levels of trace metals are elevated in benthic sediment in the Hatea River arm but appear to be below ANZECC Guideline low trigger values and are thought to be trending down (NRC & WDC, 2012).

At a meeting of 17 July 2012, staff from NRC, WDC and NIWA met to discuss options for progressing the development of the harbour action plan and which will support NRC meeting the statutory requirements set out above. Three groups of tasks emerged:

(1) Quantifying contaminant loads originating from direct and diffuse sources in the upper harbour catchments. The aim of this task is to define the historic and current (or baseline) states which are the starting point for the future management of the harbour and its catchment. This analysis will provide a more specific numeric estimate of loads from the various sources in the upper

harbour catchment. This will allow the regional council to evaluate the relative magnitude of sources and the locations of sources and inform the setting of objectives, limits and targets as part of the 2nd group of tasks (see below).

(2) Determining which of several possible environmental variables should be used as the basis for the setting of limits and targets, once (possibly narrative) objectives have been set for the harbour, and consequently determining the methods to be used in setting these limits and targets, and the limits and targets themselves.

(3) On the basis of the outcomes of tasks (1) and (2), the determining and prioritising the types, levels and locations of management interventions. This may involve making projections of future contaminant loads and the efficacy of various management interventions. The selection of management interventions is likely to be subject to future review, depending on the response of the harbour and/or the benefit of new information or knowledge.

This report describes the development of a programme to quantify contaminant sources in upper Whangarei Harbour catchment in order to progress the first group of tasks outlined above.

1.2 Scope

The scope of this project is to develop a programme for quantifying source loads of contaminants in upper Whangarei Harbour catchment. The area comprises the Onerahi, Hatea, Waiarohia, Kirikiri, Raumanga, Limeburners, Otaika, Puwera, and Whangarei South sub-catchments (see Chapter 2). The following contaminants are to be included in the programme: sediment; metals (copper, lead and zinc); nutrients (N and P); and faecal pathogens and indicator bacteria.

The project brief sets out the following steps:

1. Review NRC's recent report on current knowledge of the water quality of Whangarei Harbour (NRC & WDC, 2012). While not repeating the exercise of collating and undertaking a detailed review of the raw data on water quality in the harbour, in order to provide context, summarise relevant aspects of NRC's review as part of NIWA's report. As part of this summary, provide commentary on any aspects of the gaps analysis which are considered worth exploring further.

2. Establish existing knowledge and knowledge gaps on contaminant sources in upper Whangarei Harbour sub-catchments through reviewing and summarising existing data. Take account of information held by NRC and WDC along with other literature or data sources considered relevant.

3. Estimate sub-catchment, diffuse-source annual loads under the current land use of the following contaminants:

   - Sediment, copper and zinc in the urban areas of the catchments; and
   - Sediment, nitrogen, phosphorus and *E.Coli* in the rural areas of the catchments.

Estimate these urban and rural diffuse-source contaminant loads using the C-CALM and CLUES models, respectively.

4. Develop a programme to generate the additional information required to fill the knowledge gaps identified in step 2, taking into account the diffuse-source loads estimated in step 3. In developing the programme, evaluate the value of measures such as: additional model runs, continuation / modification of existing council monitoring programmes, and undertaking additional targeted sampling.

   The programme is to provide a basis for quantifying spatial variations in contaminants, including by sub-catchment and key sources within sub-catchments. Other important distinctions to be taken into account are the relative contributions of diffuse and point sources and of natural (background) and anthropogenic sources. Development of the programme is also to consider how variations over time can be quantified, including projections of future trends. Consideration is also to be given to temporal resolution (for instance annual versus event time scale), reflecting differences in the extent to which the effects of different contaminants are largely chronic or acute or a combination of both.

5. Deliver a report describing:

   - a summary of relevant aspects of NRC's review of harbour water quality including review/assessment of any gaps;
   - existing knowledge on contaminant sources in the upper harbour catchments from data held by NRC, WDC and NIWA (if available);
   - estimated annual urban diffuse-source loads of sediment, copper and zinc and rural diffuse-source loads of sediment, nitrogen, phosphorus and *E. Coli* under current land use; and
   - the recommended programme to further identify and quantify contaminant sources in the upper harbour catchment.

   The recommended programme is to be presented as a set of options. These options may, for instance, be presented as alternatives, complementary actions or a series of actions that could be implemented in sequence. Indicative timelines and costs for each option are to be provided along with the level of information that it is likely to yield.

1.3 Contents of this report

Chapter 2 of this report provides a description of the study area, while Chapter 3 summarises and comments on key points from NRC's recent review of harbour water quality (NRC & WDC, 2012)[1].

The next four chapters report on existing information, including work undertaken as part of this project and other research in progress, of relevance for quantifying contaminant sources in the catchment. Chapter 4 describes previous investigations into contaminant sources in the Upper Whangarei Harbour catchments while Chapter 5 reviews the potential for existing

[1] Where relevant and with NRC's permission, this report has adopted the approach of directly quoting relevant sections of the NRC & WDC (2012) background report rather than attempting to rewrite that material.

monitoring data held by NRC to be used for, or inform, the estimation of contaminant loads. Chapter 6 reports on the diffuse-source contaminant loads estimated using the CLUES and C-CALM models while Chapter 7 describes current research into sedimentation of the harbour and the potential application of the results of that study to inform the estimation of catchment sediment loads.

Chapter 8 provides a synthesis of the preceding four chapters by consolidating existing estimates of contaminant loads, identifying information gaps and summarising the ways in which existing information can be used to help address some of these gaps. Chapter 9 then builds on this synthesis to describe a range of further actions that can be undertaken to estimate contaminant loads. This includes consideration of the purpose for which the estimates may be required and consequent variations in the level of effort required to obtain them.

2 Description of Study Area

2.1 Whangarei Harbour

NRC's & WDC's (2012) background report provides the following description of Whangarei Harbour:

Whangarei Harbour is a drowned river valley/large estuarine ecosystem located on the east coast of Northland, which receives runoff from an approximately 300 km^2 catchment. At high tide the Harbour has an area of approximately 107 km^2, which decreases to approximately 54km^2 at low tide.

It is comprised of a diverse range of habitat types including saltmarsh, mangroves, seagrass, intertidal mudflats, subtidal beds, and sandy reefs, and has three distinct areas (see Figure 2-1)*:*

1. *The upper Harbour – the area west of Matakohe Island, and includes the northern Hatea River arm and the southern Mangapai arm.*
2. *The middle Harbour – the area that stretches east from Limestone Island and west from a line that stretches between Manganese Point and One Tree Point.*
3. *The lower Harbour – the area east of the line between Manganese Point and One Tree Point.*

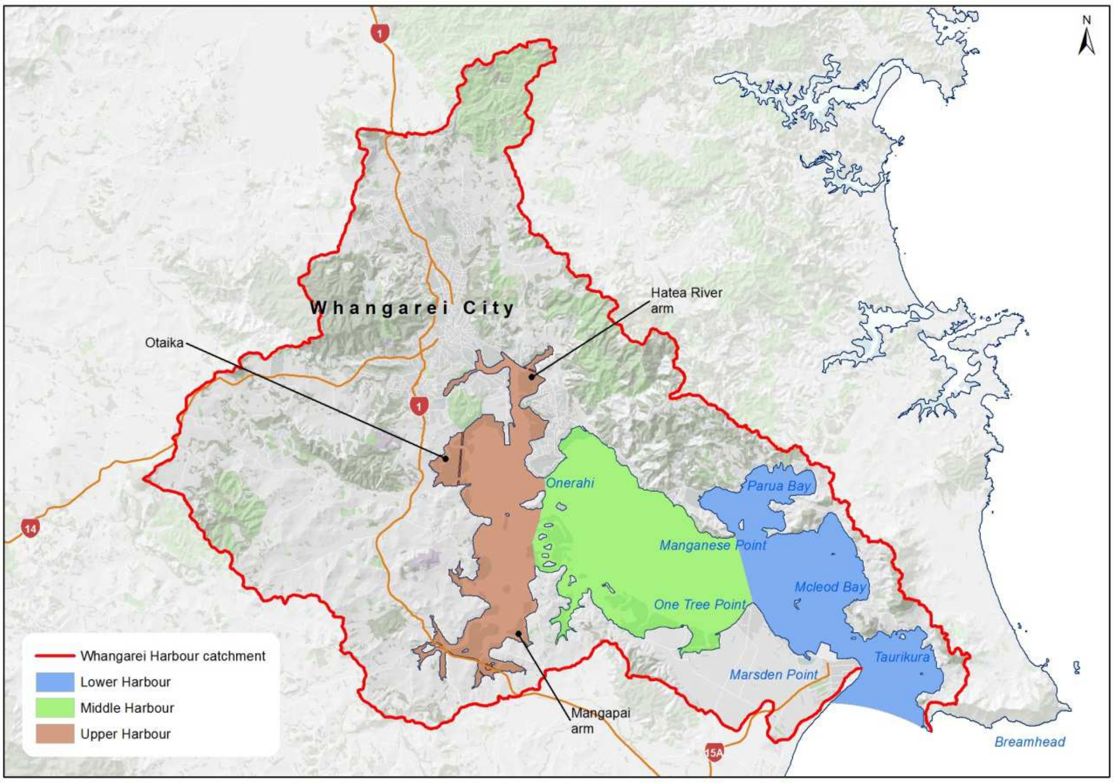

Figure 2-1: Whangarei Harbour and its catchment, showing delineation of the upper, middle and lower parts of the harbour. Source NRC & WDC (2012), copied with permission of NRC.

Freshwater inputs are highest in the upper Harbour – the receiving environment for run-off from 67% of the greater catchment – and progressively decline out to the lower Harbour. Water in the upper Harbour is subject to longer "flushing" periods than in the middle and lower Harbour areas. Flushing periods and patterns impact on the rate at which contaminants are diluted and dispersed. For example, hydrodynamic modelling shows contaminants flow down the Harbour during a falling tide before returning with the flood tide[2].

2.2 Upper Harbour Catchment

The catchment of the upper harbour has a total area of around 220 km^2 and comprises nine sub-catchments (Figure 2-2).

Figure 2-2: Sub-catchments of upper Whangarei Harbour.

[2] This refers to a model developed for NRC by NIWA (Reeve et al., 2010), described briefly in Chapter 4 of this report.

2.2.1 Physical characteristics

Geology, Soils and Topography

The area has a heterogeneous geology with northern parts of the catchment predominantly underlain by areas of greywacke (Waipapa terrane) and Kerikeri group volcanic rocks (Edbrooke and Brook, 2009). Rocks of the Northland Allochthon predominate in the central and southern parts of the catchment. These are primarily undifferentiated mudstones but also include areas of limestone, for instance in the Limeburners Creek catchment.

Brown earth and ultic soils predominate in the northern and southern parts of the catchment, respectively (Figure 2-3). Oxidic soils are found in areas of volcanic geology in the north and west of the catchment, while small areas of melanic soils are found in association with areas of limestone. River valleys are occupied by gleys and recent soils.

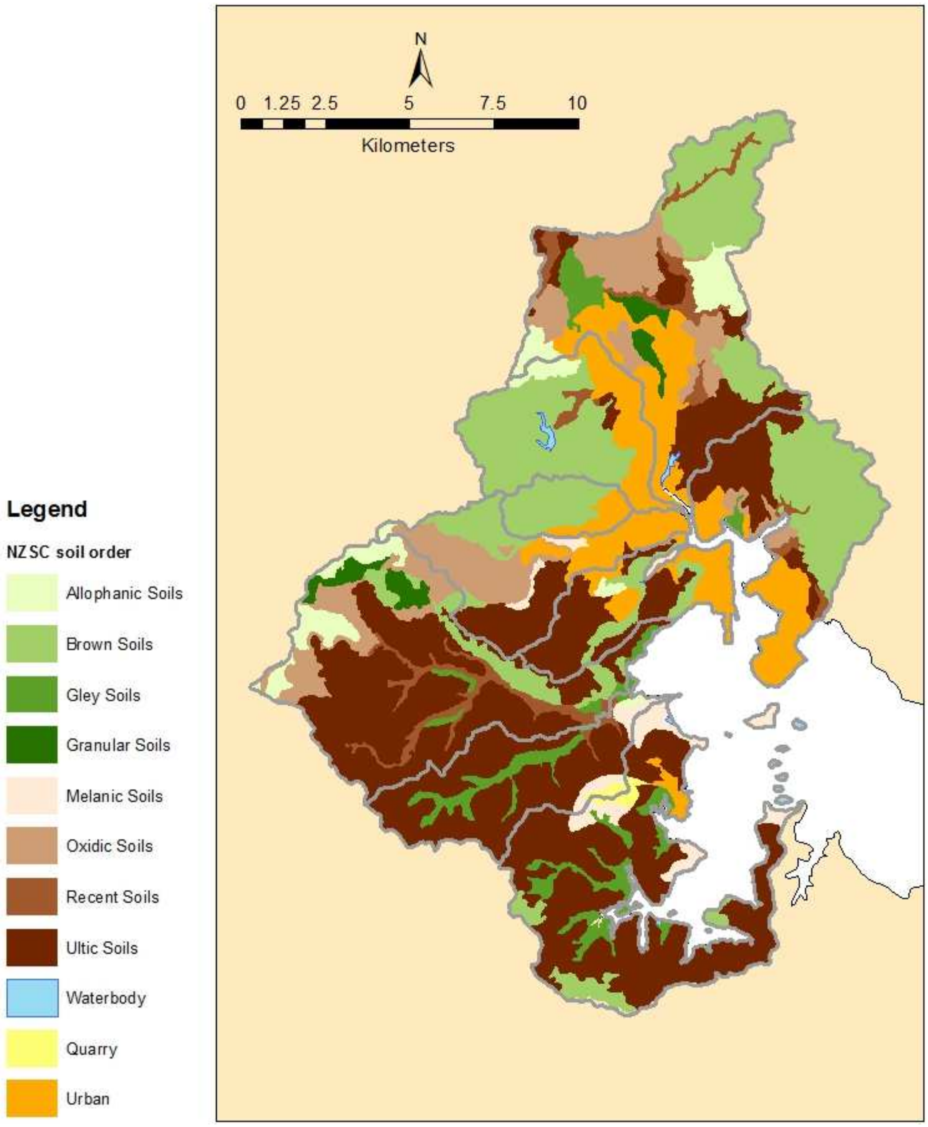

Figure 2-3: New Zealand Soil Classification, soil order, upper Whangarei Harbour catchment. Source, NZLRI Fundamental Soil Layer (Wilde et al., 2004).

The topography of the catchment is characterised by relative steep, elevated land in the north and undulating lower lying land in the south (see Figure 2-4). The catchment rises to a maximum elevation of 391m at Parakiore in the north-west of the Hatea sub-catchment. The hills in the north-eastern parts of the Hatea and Onerahi sub-catchments and the ridge dividing the Waiarohia and Kirikiri sub-catchments to the west of Whangarei are also elevated above 300m.

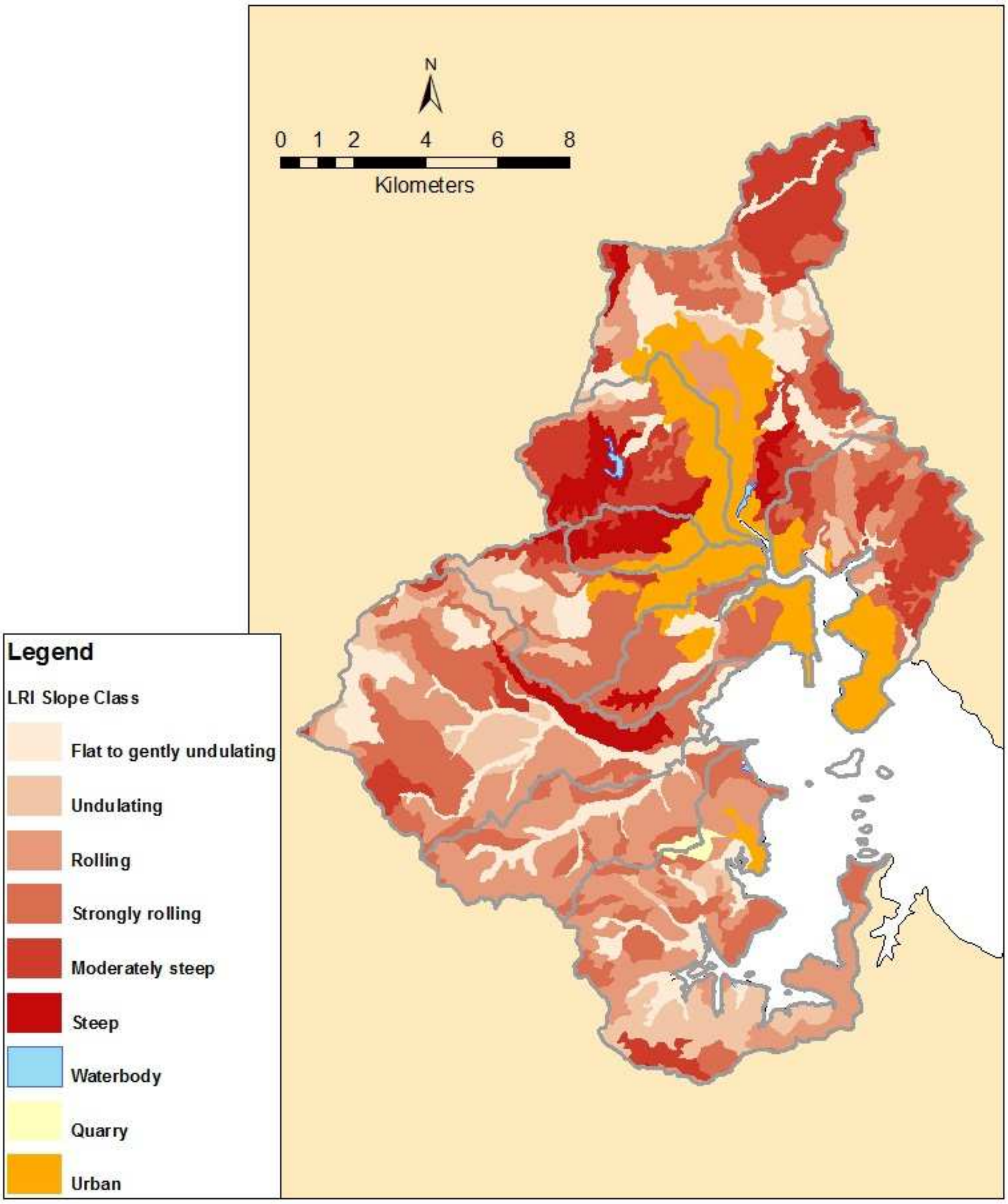

Figure 2-4: Slope, upper Whangarei Harbour catchment. Classified according to NZLRI slope classes (Newsome et al., 2008).

Erosion forms found in the study area are mapped in Figure 2-5. Gullies and tunnel gullies are found in the uplands to the south, particularly in areas with Ultic soils, which are prone to erosion. Sheet erosion is more common in the north. There is also stream bank erosion from recent soils along the Otaika Stream.

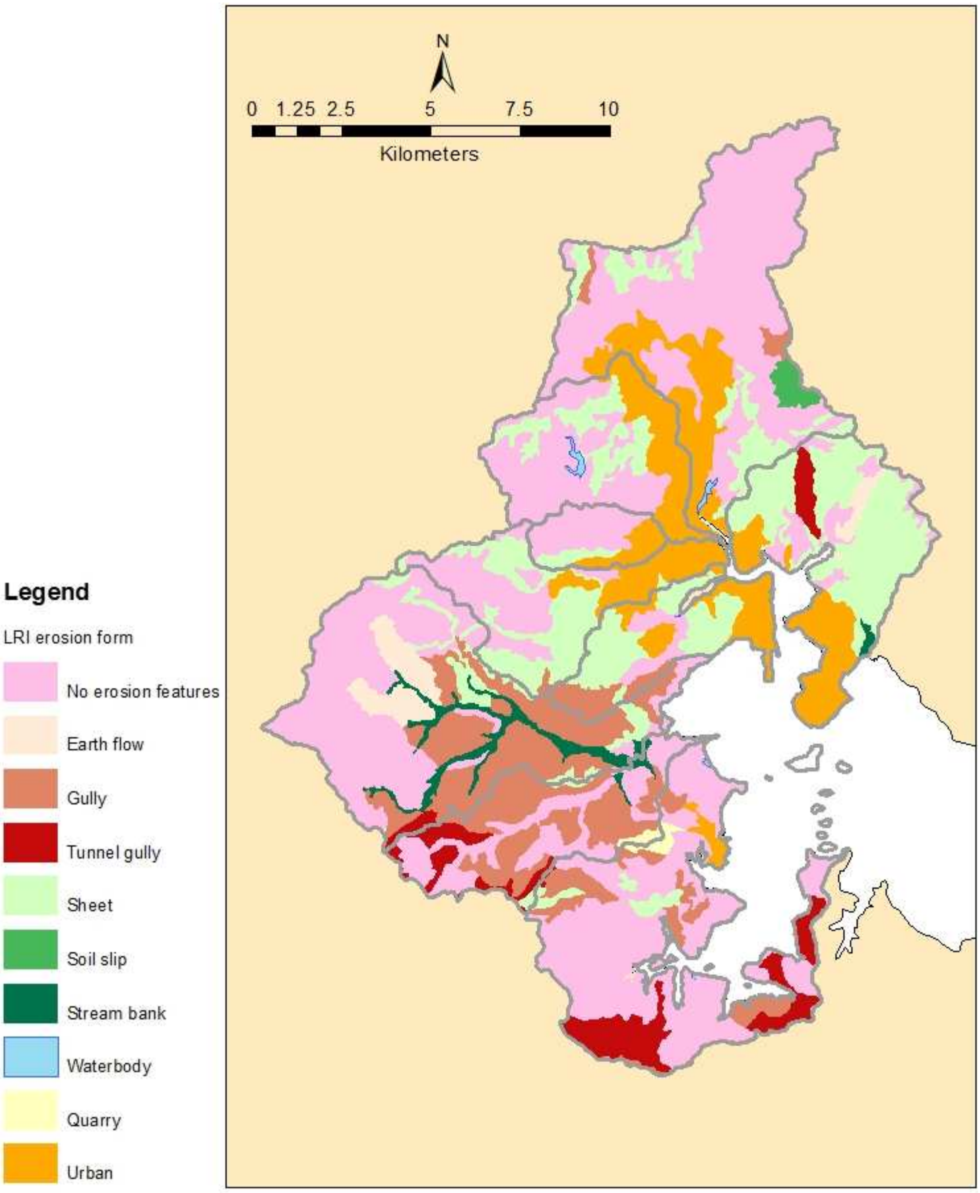

Figure 2-5: Erosion form, upper Whangarei Harbour catchment. Classified according to NZLRI erosion form classes (Newsome et al., 2008).

Rainfall and Hydrology

Mean annual rainfall is reported to be 1650mm in central Whangarei (NRC rain gauge site 547339) and somewhat higher in the most northerly part of the catchment, at 1867 mm in Glenbervie Forest in the upper Hatea River catchment (NRC rain gauge site 546301)[3]. NRC measures river flows at three sites in the catchment. Flows statistics for these sites are given in Table 2-1.

[3] Source: http://www.nrc.govt.nz/upload/4924/NRC_Automatic%20Rainfall%20site%20list%20(web).pdf

Table 2-1: River flow statistics, upper Whangarei Harbour catchment.

Site no.	Name	Date record began	Catchment area upstream of site (km^2)	Median Flow (l/s)	Mean Annual Low Flow (MALF) (l/s)
5538	Hatea @ Whareora Rd[1]	?	37.9	540	90
5527	Waiarohia @ Lovers Lane[2]	17-Oct-1979	18.6	152	60
5528	Raumanga @ Bernard St	30-Oct-1979	16.3	194	77

Notes

[1] This site is approximately 300m downstream of a consented river abstraction for public water supply. The flow record has not been naturalised (i.e. adjusted by adding the abstracted flow to the measured flow) and the MALF reported here is likely to be an underestimate (D.Hansen 2012, pers.comm., 26 November).

[2] This site is downstream of a public water supply dam. The flow record has not been naturalised (D.Hansen 2012, pers.comm., 29 November).

Estimates of mean river flows in each of the nine sub-catchments have been estimated using NIWA's Water Resources Explorer tool[4] (see Table 2-2) in order to provide an indication of the relative freshwater contribution of each to the upper harbour. These estimates indicate that approximately a quarter of the freshwater discharged to the upper harbour originates in the Hatea sub-catchment, with the Whangarei South, Otaika and Onerahi sub-catchments each contributing between 10-20% of total runoff.

Table 2-2: Estimated mean flows, upper Whangarei Harbour sub-catchments.

Sub-catchment	Sub-catchment area upstream of flow estimate (km^2)	Mean flow (l/s)
Onerahi[1]	24.0	570
Hatea[2]	42.9	1204
Waiarohia[2]	18.5	433
Kirikiri[2]	5.7	126
Raumanga[2]	15.9	328
Limeburners[2]	7.8	156
Otaika[2]	39.3	845
Puwera[2]	17.0	331
Whangarei South[1]	37.0	880
Whole catchment	208.1	4873

Notes

[1] catchment drains to multiple outlets, mean flow calculated from estimated mean annual runoff and total sub-catchment area.

[2] Mean flow calculated for principal catchment outlet, excludes parts of catchment draining to minor outlets.

2.2.2 Land use and population

The land use characteristics and population in each sub-catchment are given in Table 2-3 while land use is mapped in Figure 2-6. The harbour catchment as whole (including those

[4] http://wrenz.niwa.co.nz/webmodel/

parts draining to the middle and lower harbour) has a population of approximately 52,000 and is projected to increase to 71,000 by 2041 (NRC & WDC, 2012).

Table 2-3: Land use (% of area) in sub-catchments draining to the Upper Whangarei Harbour. Uses broad land use classes derived from LCDB3[5].

Land use (% of catchment area)	Onerahi	Hatea	Waiarohia	Kirikiri	Raumanga	Limeburners	Otaika	Puwera	Whangarei South
Coast (sand, gravel, mangroves)	1	0	0	0	0	2	0	0	1
Exotic forest and scrub	24	24	2	6	3	14	11	3	3
Native forest and scrub	27	21	53	58	22	23	23	3	12
Rural: crops, horticulture and viticulture	0	1	2	0	6	0	5	0	0
Rural: pasture	26	33	17	7	43	29	60	92	82
Surface Mines and Dumps	0	0	0	2	0	4	0	1	1
Urban	21	21	26	27	26	27	0	0	1
Water body	0	1	1	0	0	1	0	1	0
Total sub-catchment area[6] (ha)	2398	4491	1912	559	1733	1301	4240	1879	3702
Population (2006)[7]	Not available	18,600	7,700	3,600	5,600	2,400	800	180	1,200

NRC's & WDC's (2012) background report provides the following descriptions of the key features of land use and population in each of the sub-catchments[8]:

Onerahi sub-catchment

The Onerahi sub-catchment is comprised of several large streams that discharge directly to the eastern side of the Hatea River arm of the upper Harbour, including the Waimahanga, Awaroa, and Waioneone streams. The sub-catchment covers an area of approximately 8.2% of the greater Harbour catchment.

Land cover is a fairly even mixture of urban areas, pasture, indigenous vegetation, and forestry.

[5] We have reported land use proportions estimated from information held in the LCDB3 database, although the LCDB2 database was used in the modelling of contaminant loads described in Chapter 6 of this report. While there are some slight differences with land use proportions reported in NRC & WDC (2012), the two sources are in general agreement. The LCDB3 has a base year of 2008. Further information can be found at http://www.lcdb.scinfo.org.nz/home.
[6] We have reported sub-catchment areas taken from shapefiles provide by NRC, because these data were used in the modelling of contaminant loads described in Chapter 7 of this report. Again, while there are some slight differences with the areas reported in NRC & WDC (2012), these are insignificant with the two sources agreeing within 1%.
[7] Source: NRC & WDC (2012)
[8] We have removed land use percentages and sub-catchment areas quoted in the background report in order to avoid confusion with the values given in Table 2-3.

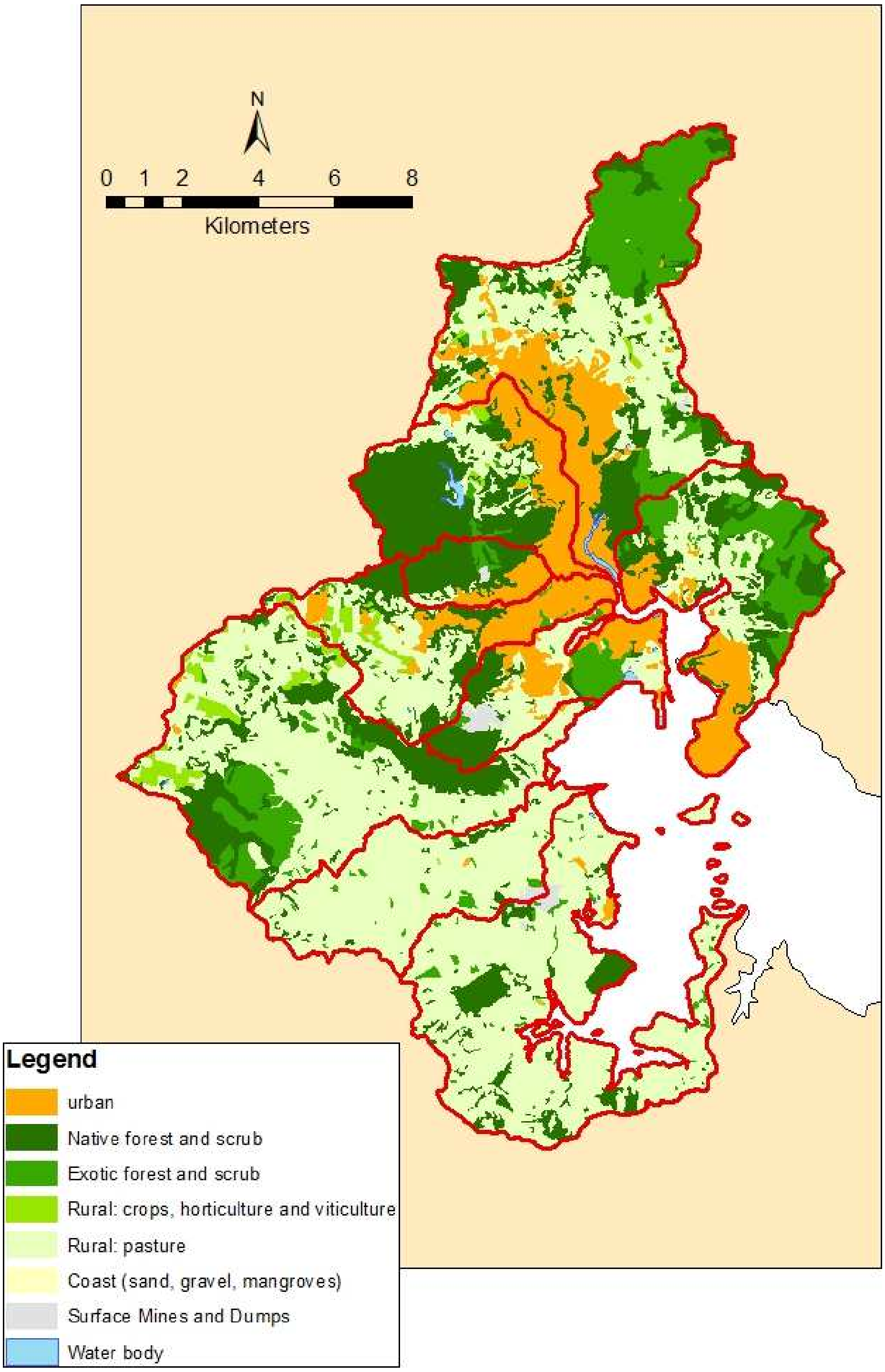

Figure 2-6: Land use in the upper Whangarei Harbour catchment. Shows broad land use classes derived from LCDB3.

Hatea sub-catchment

The Hatea sub-catchment drains to the Hatea River arm of the upper Harbour. It covers approximately 15% of the greater Harbour catchment. Land cover is a fairly even mix of urban land uses, exotic forest, indigenous vegetation, and pasture (including lifestyle blocks).

Its upper reaches are dominated by forestry (Glenbervie forest), lifestyle blocks (Vinegar Hill/Glenbervie/Whareora), and some remnant pastoral and horticulture land uses. Industrial *land can be found in the Waitaua area at Springs Flat and along the lowest reaches of the river near the estuarine mouth. Its middle reach is surrounded by developed urban area. The lowest reach is dominated by retail, commercial and light industrial land uses around the CBD, and much of the area has been developed on reclaimed land.*

The number of people living in the sub-catchment has steadily increased, with approximately 17,500 in 2001 to 18,600 in 2006. This is projected to reach approximately 26,000 by 2041. Most of the development is expected to occur in the Tikipunga area.

Waiarohia sub-catchment

The Waiarohia sub-catchment drains to the Hatea River arm of the upper Harbour. It covers approximately 6.4% of the greater Harbour catchment. Land cover is dominated by indigenous vegetation, pasture, and urban land uses.

The sub-catchment is heavily vegetated above the Whau valley reservoir, but shows increased levels of modification as it flows down through to Whangarei CBD.

The number of people living in the sub-catchment has increased, from approximately 7,100 in 2001 to 7,700 in 2006. This is projected to reach 10,200 by 2041. Most of this increase is likely to be the result of urbanisation below the Pukenui Hills, some lifestyle development in Whau Valley and some infill close to the central areas of Whangarei.

Kirikiri sub-catchment

The Kirikiri sub-catchment drains to the Hatea River arm of the upper Harbour via the lower reach of the Waiarohia Stream. It covers approximately 1.9% of the greater Harbour catchment. Land cover is dominated by indigenous vegetation and urban area.

The number of people living in the sub-catchment has remained relatively stable, with approximately 3,500 in 2001 to 3,600 in 2006. However, there have been a number of subdivisions in the sub-catchment in recent years, and the population is projected to reach 4,600 by 2041.

Raumanga sub-catchment

The Raumanga sub-catchment drains to the Hatea River arm of the upper Harbour via the lower reach of the Waiarohia Stream. It covers approximately 5.8% of the greater Harbour catchment. Land cover is dominated by pasture, urban areas, and indigenous vegetation.

Its three main tributaries, the Waiponamu, Te Hihi, and Nihotea, begin in the Otaika Valley Bush, Pukenui, and the hills above Austin Road respectively. These tributaries emerge within an area dominated by lifestyle blocks in its upper reaches, pass through riparian bush in the middle segment, before passing through a residential area and eventually joining the Waiarohia Stream.

The number of people living in the sub-catchment has also increased, with approximately 5,000 in 2001 to 5,600 in 2006. This is projected to reach 7,500 by 2041, with subdivision continuing to occur in the Raumanga and Maunu areas of the sub-catchment. It is likely that the sub-catchment will see increased residential land-uses over time, along with continued industrial activities in the lowest parts of the sub-catchment.

Limeburners Creek sub-catchment

The Limeburners Creek sub-catchment drains to the Hatea River arm of the upper Harbour. It covers approximately 4.3% of the greater Harbour catchment. Land cover is dominated by urban industrial and commercial areas, grassed areas, indigenous vegetation, forestry, and weeds. Increased commercial and industrial activity is likely within the catchment. In 2006, approximately 2,400 people lived in the catchment.

The lower estuarine reach of Limeburners Creek is the principal receiving environment for treated effluent from the Whangarei Wastewater Treatment Plant (WWTP) once it has passed through wetlands, and is classified as a mixing zone for this purpose in the Regional Coastal Plan.

Otaika sub-catchment

The Otaika sub-catchment drains to the eastern side upper Harbour. It covers approximately 14.3% of the greater Harbour catchment. Land cover is dominated by pasture, indigenous vegetation, and exotic forestry.

The number of people living in the catchment has increased, with approximately 700 in 2001 to 800 in 2006. This is projected to reach 1,300 by 2041. Much of the population increase has been in lifestyle blocks, especially in the lower reaches. Over the last decade, a large number of lifestyle blocks have been established near the river in the middle parts of the catchment, and it is this type of development that is expected to continue.

Puwera sub-catchment

The Puwera sub-catchment drains to the mid-point of the upper Harbour via the lower reach of the Otaika River. It covers approximately 6.3% of the greater Harbour catchment. Land cover is almost entirely pastoral, which is used for dairying and dry stock farming and lifestyle blocks. Very little indigenous vegetation remains in the catchment, and no significant indigenous riparian vegetation is evident.

The number of people living in the sub-catchment has remained relatively steady, with approximately 170 in 2001 and 180 in 2006. This is projected to increase to 300 by 2041.

Whangarei South sub-catchment

The Whangarei South sub-catchment is an unusual catchment in that it is comprised of a large number of short streams that individually discharge direct to the southern half of the upper Harbour (Mangapai arm). It covers approximately 12.6% of the greater Harbour catchment. Similar to the Puwera, its land cover is almost entirely pastoral for dairying and dry stock farming. In 2006, approximately 1,200 people lived in the sub-catchment.

2.3 Stormwater Management Catchments

WDC recognises twelve stormwater management catchments within the urban and peri-urban parts of the harbour catchment. While several of these catchments share names with the sub-catchments described above, they do not have the same boundaries (see Figure 2-7). In order to distinguish between the two sets of catchment, the WDC catchments are referred to as stormwater management catchments (SMCs) in the remainder of this report. The relationship between the SMCs and the upper Harbour catchments is shown in Table 2-4.

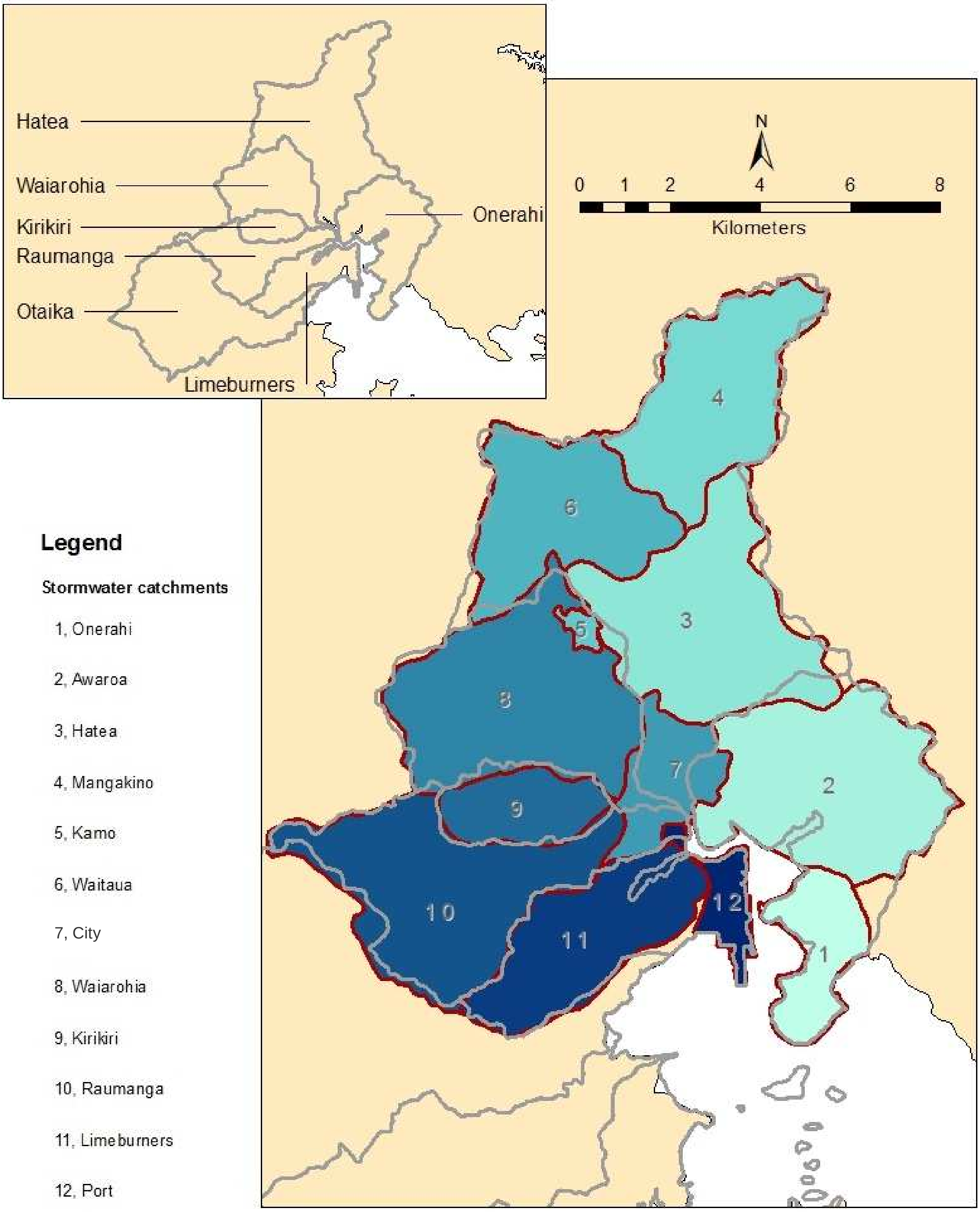

Figure 2-7: Map of WDC stormwater management catchments (SMCs). The insert and overlay on the main map show the boundaries of the harbour sub-catchments.

Table 2-4: Relationship between WDC stormwater management catchments (SMCs) and upper Harbour sub-catchments.

Stormwater Management Catchment	Upper Harbour Sub-Catchment
Onerahi	part Onerahi
Awaroa	part Onerahi
Hatea	part Hatea
Mangakino	part Hatea
Waitaua	part Hatea
Kamo	part Waiarohia
Waiarohia	most Waiarohia
City	part Onerahi, part Hatea, part Raumanga, part Waiarohia
Port	Part Limeburners
Kirikiri	Kirikiri
Raumanga	most Raumanga
Limeburners	most Limeburners

3 Contamination of Whangarei Harbour

3.1 Introduction

As noted in Chapter 1, NRC & WDC have undertaken a review of water quality in Whangarei Harbour to inform the development of the harbour water quality action plan (NRC & WDC, 2012). The purpose of the review is described as:

1. *To provide an up-to-date overview of Harbour water quality and the use and values associated with the Harbour;*

4. *To identify knowledge gaps that will be required to be addressed in order to better manage direct and diffuse discharges and better allocate resources;*

5. *To establish actions that will contribute to maintaining and improving water in order to meet agreed environmental outcomes for the Harbour and its catchment.*

The report focuses on the upper Harbour as it is the receiving environment for the majority of catchment runoff as well as being home to most of the district's population.

In order to provide context for the identification and quantification of contaminant sources in the upper Harbour catchment, this chapter summarises parts of NRC's background report which deal with the fate of sediment, nutrients, faecal contaminants and metals discharged to the harbour. It also summarises the information provided in the background report on the impacts of water and sediment quality degradation on the ecology and recreational values of the harbour.

As part of the review of the background report, we have also referred to NRC's web-based annual monitoring report 2010-11 (NRC, 2012a) to assess whether that contains any additional information of particular relevance.

Section 3.5 of this chapter provides our comments on the background report, with particular emphasis on making suggestions which could contribute to the development of the harbour water quality action plan.

3.2 Water Quality

3.2.1 Classification

NRC's & WDC's background report (2012) provides the following description of the classification of harbour water quality (see Figure 3-1):

Under the Regional Coastal Plan the Harbour water quality is classified for the following purposes:

- *General Quality Standard (CA) – provides for virtually all uses, including shellfish collection, and protection of marine ecosystems*
- *Contact Recreation Standard (CB) – provides for contact recreation*
- *Natural Quality Standard (CN) – provides for the protection of natural state*

- *Mixing Zone – provides mixing for major discharges.*

The background report noted that:

… the contact recreation classification (CB) for the extensive areas of the upper Harbour are concerned with public health, rather than effects on ecology.

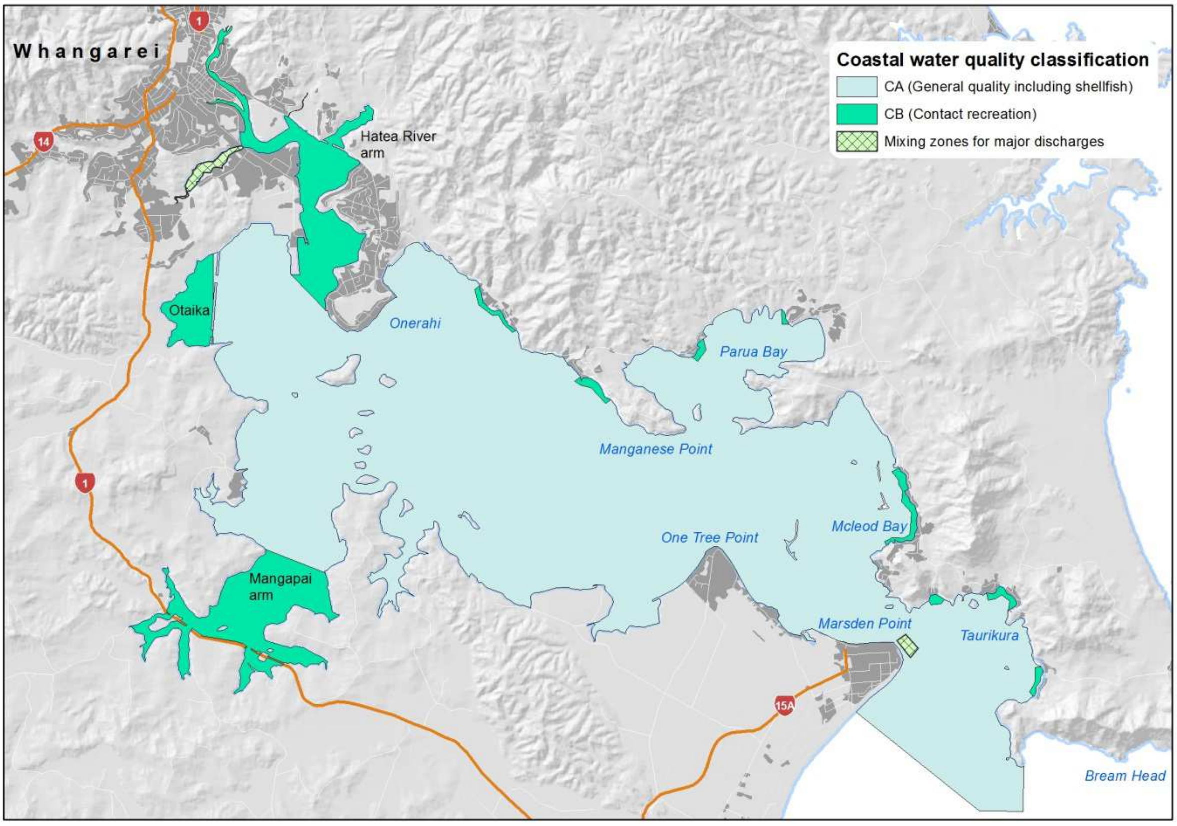

Figure 3-1: Water quality classification, Whangarei Harbour. Source: NRC & WDC (2012). Copied with the permission of NRC.

3.2.2 Turbidity

NRC's & WDC's (2012) background report provides the following description of turbidity in the harbour, based on sampling at 16 sites over the period 2008-12:

Monitoring information shows that water in the upper Harbour, particularly close to rivers and streams draining to it, has the highest turbidity (lowest clarity) in the Harbour during and soon after rain (see Figure 3-2).

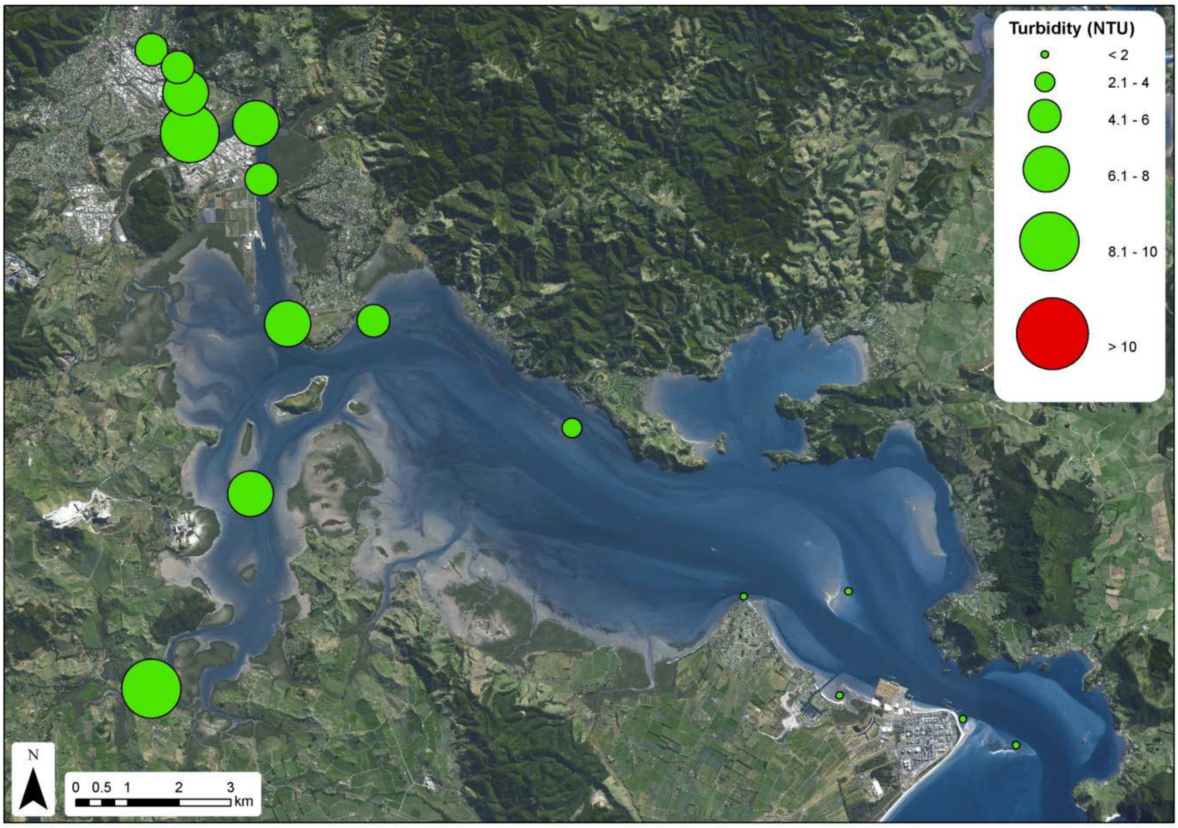

Figure 3-2: Median values of turbidity, Whangarei Harbour sampling sites 2008 – 2012.
Source: NRC & WDC (2012). Copied with the permission of NRC.

3.2.3 Nutrients

NRC's & WDC's (2012) background report provides the following description of nutrient concentrations in the harbour, based on analyses of samples collected at the 16 harbour monitoring sites for ammoniacal nitrogen (NH_4-N, see Figure 3-3), nitrate-nitrite nitrogen (NO_x-N or NNN, see Figure 3-4), dissolved reactive phosphorus (DRP, see Figure 3-5) and total phosphorus (TP, Figure 3-6):

Monitoring results show that median nutrient concentrations in the upper Harbour exceed the low guideline trigger values[9]*. Median nutrient concentrations significantly exceed the guideline low trigger values in the Hatea River arm.*

The Waiarohia Canal – the lower estuarine reach of the Waiarohia Stream that drains to the Hatea River arm – has the highest recorded concentrations of nutrients of all monitored sites including the downstream Limeburners Creek, the mixing zone for treated effluent from the Whangarei WWTP.

Nutrient levels in the middle and lower harbour are almost always low and fall below guideline low trigger values.

[9] The guidelines referred to are ANZECC/ARMCANZ (2000).

There appears to be no statistically meaningful improving or worsening trends in nutrient levels at any sites in the upper Harbour. However it is important to note that levels of nutrients have only been measured since 2008 and more data is needed to help identify any trends.

NRC's annual monitoring report 2010-11 noted that levels of nutrients were high and above the nutrient guideline values on all sampling occasions from five sites in the Hatea River.

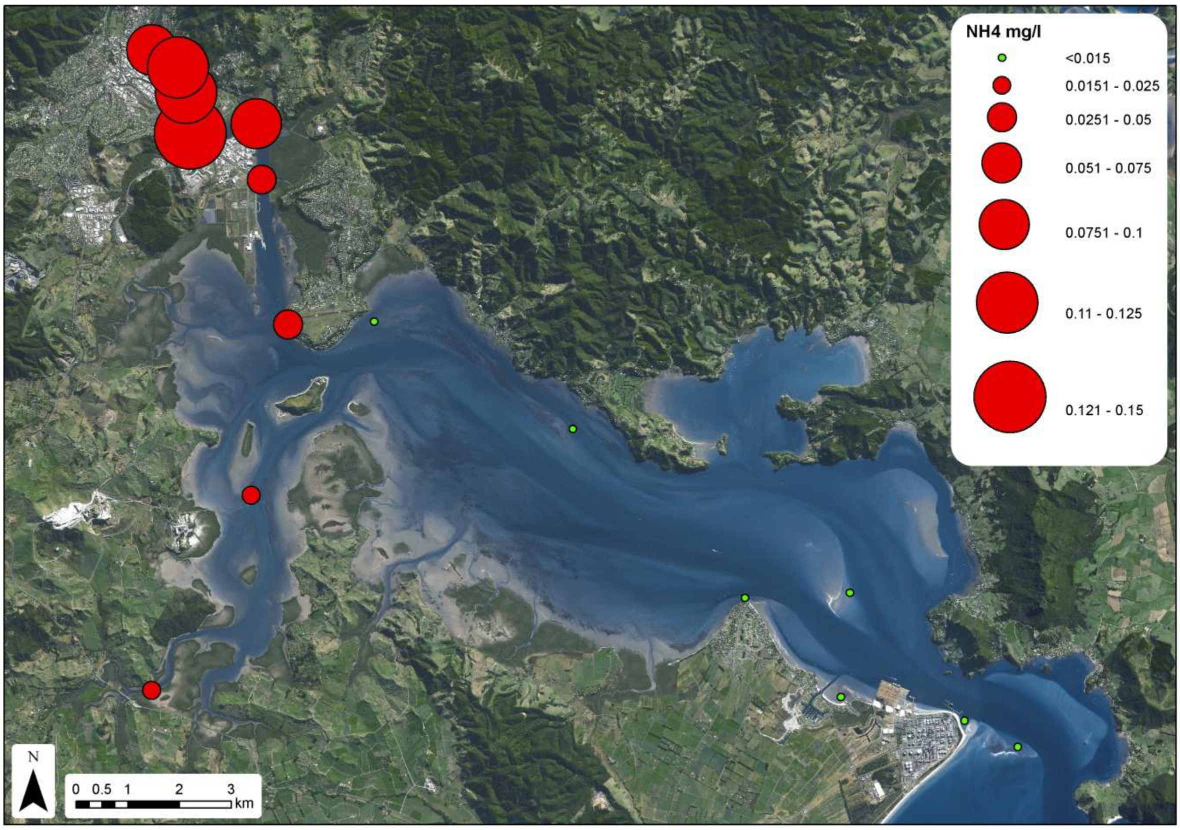

Figure 3-3: Median values of ammoniacal nitrogen, Whangarei Harbour sampling sites. Red circles indicate median values that exceed the ANZECC/ARMCANZ (2000) guideline low trigger value of 0.015 mg/l. Source: NRC & WDC (2012). Copied with the permission of NRC.

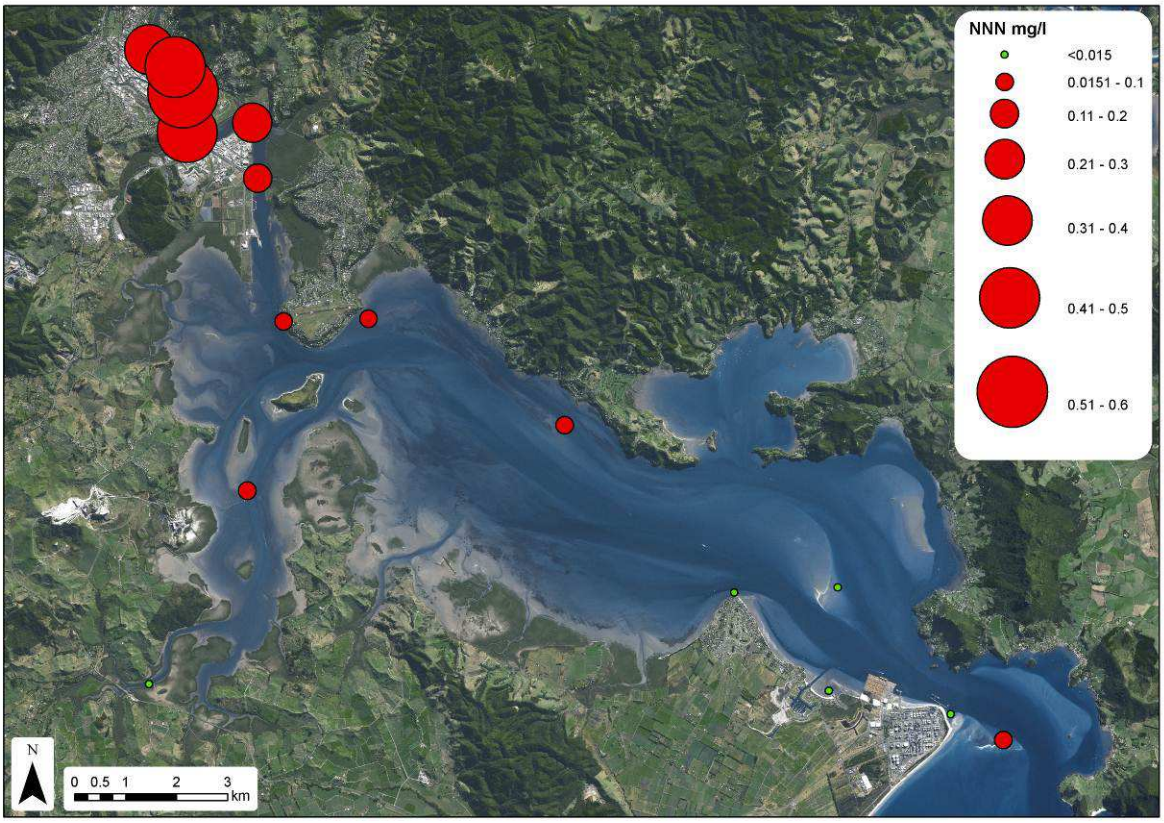

Figure 3-4: Median values of nitrate-nitrite nitrogen, Whangarei Harbour sampling sites. Red circles indicate median values that exceed the ANZECC/ARMCANZ (2000) guideline low trigger value of 0.015 mg/l. Source: NRC & WDC (2012). Copied with the permission of NRC.

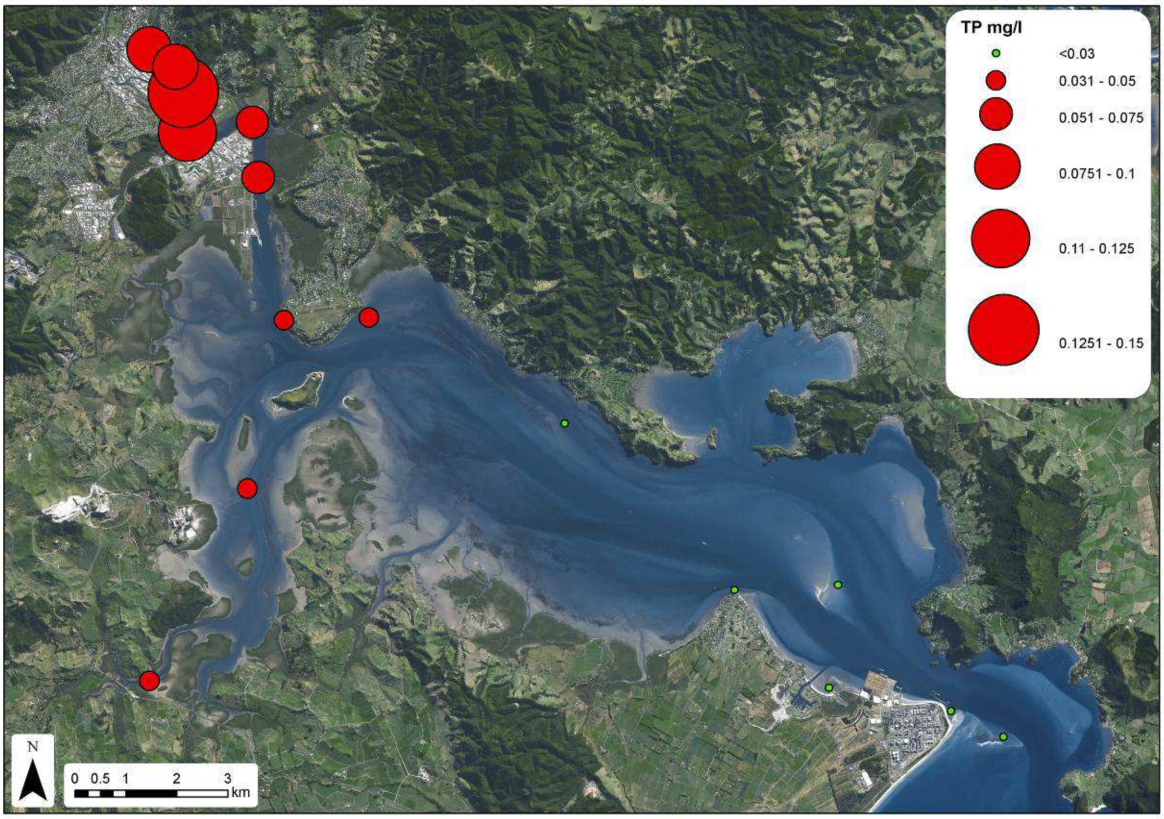

Figure 3-5: Median values of total phosphorus, Whangarei Harbour sampling sites. Red circles indicate median values that exceed the ANZECC/ARMCANZ (2000) guideline low trigger value of 0.03 mg/l. Source: NRC & WDC (2012). Copied with the permission of NRC.

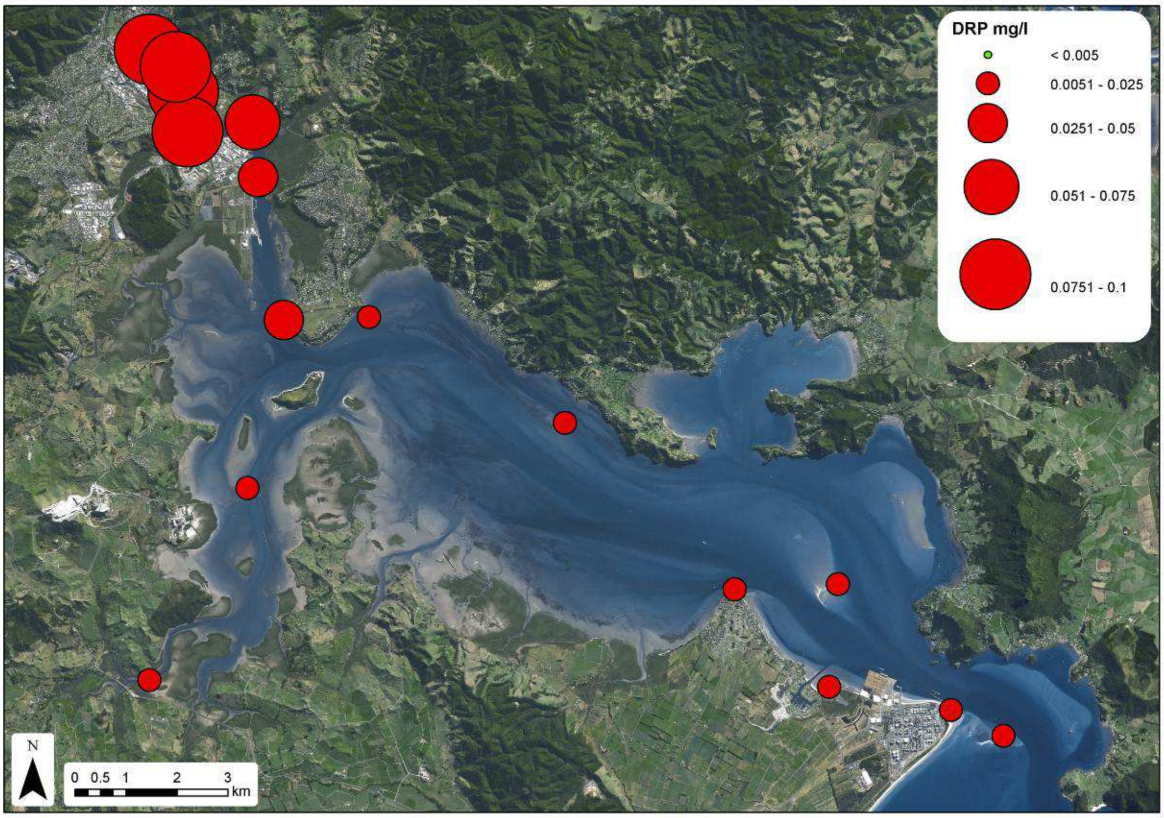

Figure 3-6: Median values of dissolved reactive phosphorus, Whangarei Harbour sampling sites. Red circles indicate median values that exceed the ANZECC/ARMCANZ (2000) guideline low trigger value of 0.025 mg/l. Source: NRC & WDC (2012). Copied with the permission of NRC.

3.2.4 Faecal pathogens and indicator bacteria

The discharge of human and animal waste to receiving water bodies can result in the presence of various faecal pathogens. The presence of pathogens can represent a significant public health risk, especially in relation to contact and partial-contact forms of water-based recreation and the consumption of harvested raw shellfish. The pathogens of most concern in relation to use of the harbour are likely to be:

- The viruses norovirus and rotavirus, particularly in parts of the harbour receiving discharges from urban parts of the catchment and in areas of shellfish harvesting; and
- The protozoan *cryptosporidium* oocysts in parts of the harbour receiving discharges from rural parts of the catchment.

As NRC's & WDC's (2012) background report notes:

It is difficult to measure the level of faecal pathogens in water. Instead, like other agencies, Northland Regional Council measures the levels of indicator micro-organisms in accordance with the national microbiological water quality guidelines published by the Ministry for the Environment and the Ministry of Health (the Recreational Guidelines, MfE/MoH (2003)*).*

The Recreational Guidelines use bacteriological indicators associated with the gut of warm-blooded animals to assess the risk of faecal contamination and therefore the potential presence of harmful pathogens. Compliance with the guidelines should ensure that people using water for contact recreation or gathering shellfish are not exposed to significant health risks. The bacteriological indicators used are:

- *Freshwater (including estuarine waters): Escherichia coli (E. coli)*
- *Marine waters: Enterococci*
- *Recreational shellfish-gathering waters: faecal coliforms.*

Northland Regional Council monitors levels of enterococci at five popular swimming sites in the harbour over the summer period (December-March) as part of the Recreational Swimming Water Quality Monitoring Programme. One of these is in the Upper Harbour - Onerahi,

The results for the past seven years show that water quality at these sites is almost always suitable for swimming. The seldom exceedances are typically associated with heavy rain.

Northland Regional Council also monitors (generally bi-monthly) levels of enterococci and faecal coliforms at a number of other sites in the harbour as part of the Harbour Water Quality Monitoring Programme – nine in Upper Harbour. Overall, the results indicate that most areas of the harbour are suitable for swimming most of the time. Or in other words, the potential risk of illness associated with contact recreation at most sites is 2% or less (≤19 per 1,000). However, levels of enterococci in the Hatea River arm above Kaiwaka Point exceeded 280 per 100 mL on a number of occasions (between 11% and 19% of the time).

As mentioned, in areas where water fluctuates in salinity due to mixing of fresh and coastal water, such as the Harbour, it is best to monitor multiple indicators. For this reason, the [report also reviews] the same 16 Harbour sites in terms of levels of faecal coliforms. While these are considered to be less specific than enterococci for assessing risk they do offer another insight on potential health risks.

Because [these] water quality monitoring results were not taken weekly or monthly (in accordance with the guideline) care should be taken in interpreting the percentage compliance results. However, for a number of the Hatea River arm sites their median values suggest that water quality does not meet the guideline value of 150 faecal coliform organisms per 100 mL most of the time.

The faecal coliform results paint a very different story to enterococci results in terms of potential health risks associated with swimming in the Hatea River arm. The compliance rates indicate that the potential risks are more often than not unacceptable. As with levels of enterococci, exceedances were strongly correlated to rainfall.

Northland Regional Council analysed water quality monitoring results (faecal coliform levels) for the period 1986-2012 and found a reduction in bacteria level at several sites in the Hatea River arm close to Limeburners Creek between 1989 and 1990. This improvement was linked to an upgrade of the Whangarei WWTP at that time. However, since then there has been no statistically significant reduction in bacteria levels, although on-going monitoring is *expected to show a reduction in loads from the Whangarei WWTP, and Okara Park and Hatea pump stations due to recent upgrades.*

NRC's annual monitoring report 2010-11 noted that levels of indicator bacteria in samples collected at five sites in the Hatea River exceeded guideline values more frequently than samples taken from sites in the outer harbour. It also noted that, as well as the downwards trends in faecal coliform levels at sites near Limeburners Creek described above, peak levels of enterococci also show a decrease over time. This trend was attributed to the improvements in the wastewater treatment plant.

3.3 Sediment Quality

3.3.1 Percentage mud

NRC's & WDC's (2012) background report provides the following description of the percentage mud in harbour sediments, based on analyses of samples collected at the 16 harbour monitoring sites in 2012 (see Figure 3-7).

The results are consistent with the size and uses of major sub-catchments, and also the upper Harbour being a flocculation zone.

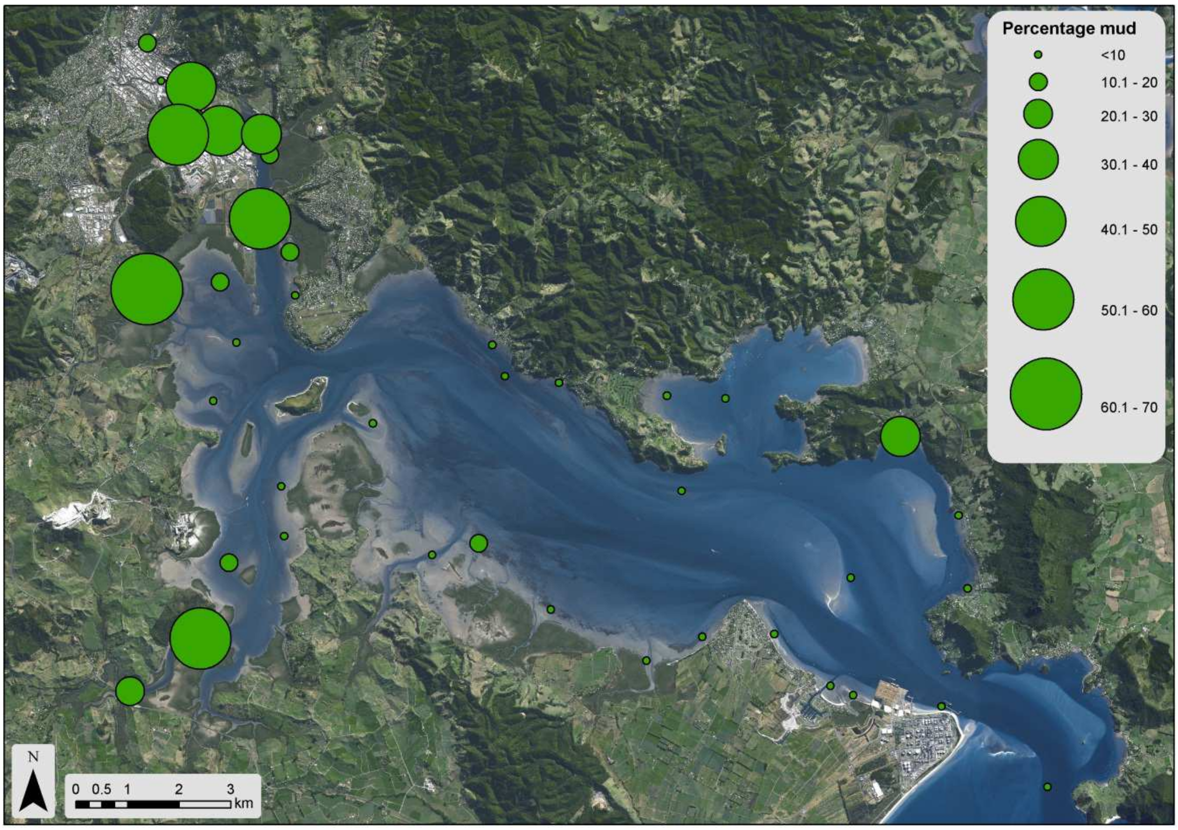

Figure 3-7: Percentage mud in 2012 harbour sediment samples, Whangarei Harbour sampling sites. Source: NRC & WDC (2012). Copied with the permission of NRC.

3.3.2 Nutrients

NRC's & WDC's (2012) background report provides the following description of nutrient concentrations in harbour sediments, based on analyses of samples collected at the 16 harbour monitoring sites (for example see results for total nitrogen, TN presented in see Figure 3-8)

Nitrogen and phosphorus levels are also elevated in benthic sediment in the upper Harbour, particularly the Hatea River arm, compared to levels in other parts of the Harbour. They are also high in comparison to concentrations recorded in similar monitoring programmes elsewhere in Northland and New Zealand, and are at levels that suggest the sites are enriched.

NRC's annual monitoring report 2010-11 noted that both phosphorus and nitrogen sediment concentrations were highest at sites in the Hatea River and Mangapai River.

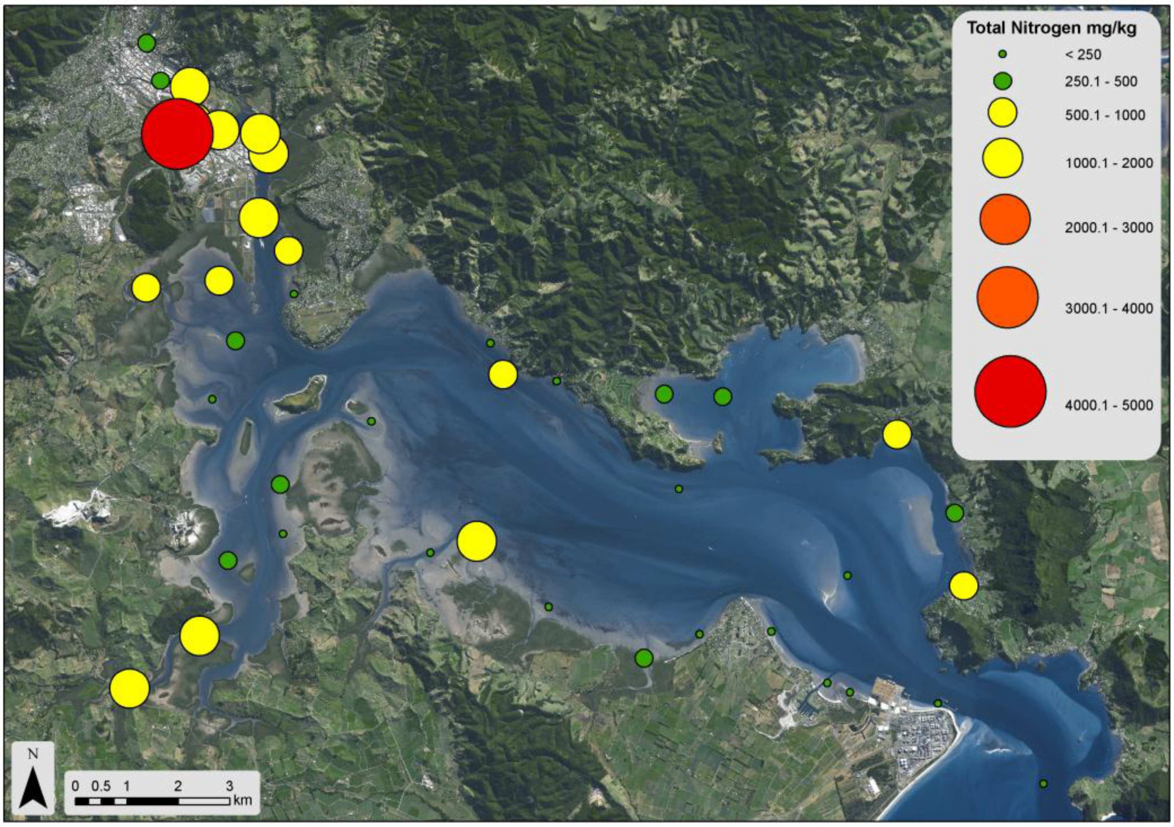

Figure 3-8: Concentrations of total nitrogen in 2012 harbour sediment samples, Whangarei Harbour sampling sites. Colour coding reflects levels of total nitrogen below 500 mg/kg as "very good" (green), levels between 500-2,000 as indicative of low to moderate enrichment (yellow), levels between 2,000 and 4,000 mg/kg as enriched (orange), and levels over 4,000 mg/kg as very enriched (red), after Robertson and Stevens (2007). Source: NRC & WDC (2012). Copied with the permission of NRC.

3.3.3 Metals

NRC's & WDC's (2012) background report provides the following description of concentrations of metals in harbour sediments, based on analyses of samples collected at the 16 harbour monitoring sites in 2012. Concentrations of copper (Cu), lead (Pb) and zinc (Zn) are shown in Figure 3-9, Figure 3-10 and Figure 3-11, respectively.

Results show slightly elevated levels at several sites across in Harbour. The highest recorded levels are in the Hatea River arm, although they are below ANZECC Guideline low trigger values. These findings indicate a low probability of some localised effects on aquatic species, and are consistent with the Hatea River arm being the receiving environment for discharges and runoff from Whangarei City area where the majority of urban and industrial development in the catchment is located.

Long term monitoring trends for heavy metals indicate that levels have not generally increased. In fact, concentrations of lead, zinc, copper, and chromium appear to be decreasing over time.

While sediment heavy metal concentrations in the Harbour appear to be within ANZECC Guideline low trigger values, recent research undertaken on four different sites in the upper Harbour (Hatea River arm, off Otaika, Mangapai arm, and Portland channel) has revealed that levels of nickel and copper are likely to be key factors for the composition of benthic invertebrate communities.

NRC's annual monitoring report 2010-11 noted that metal concentrations in sediments in the Whangarei Harbour were within guideline levels at all sites, except for zinc concentration measured in the Waiarohia Canal. It also comments that "sediments collected from tidal creeks in the upper Whangarei Harbour, Hatea River and Otaika Creek, generally had higher proportions of mud and metal concentrations. These patterns are as expected because tidal creek environments usually act as sediment traps and metal contaminants are attracted to mud."

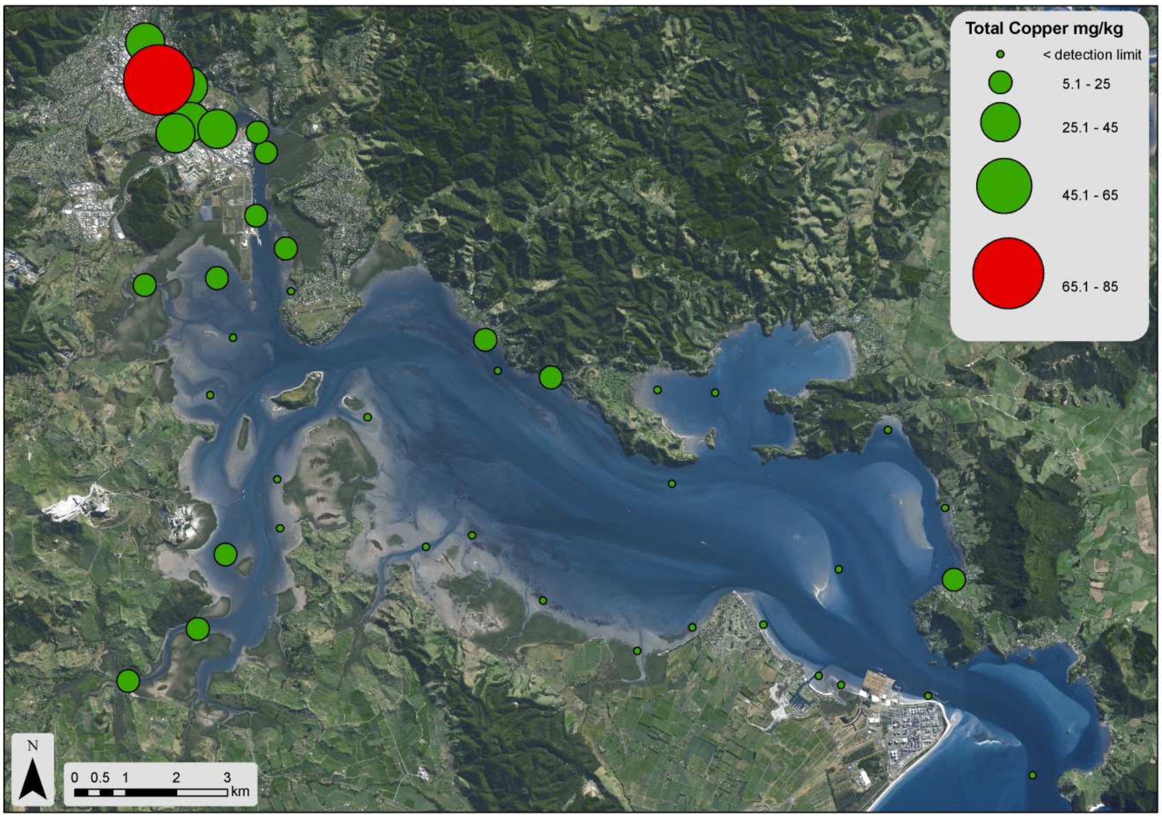

Figure 3-9: Concentrations of copper in 2012 harbour sediment samples, Whangarei Harbour sampling sites. Red circles indicate median values that exceed the ANZECC/ARMCANZ (2000) guideline low trigger value of 65 mg/kg. Source: NRC & WDC (2012). Copied with the permission of NRC.

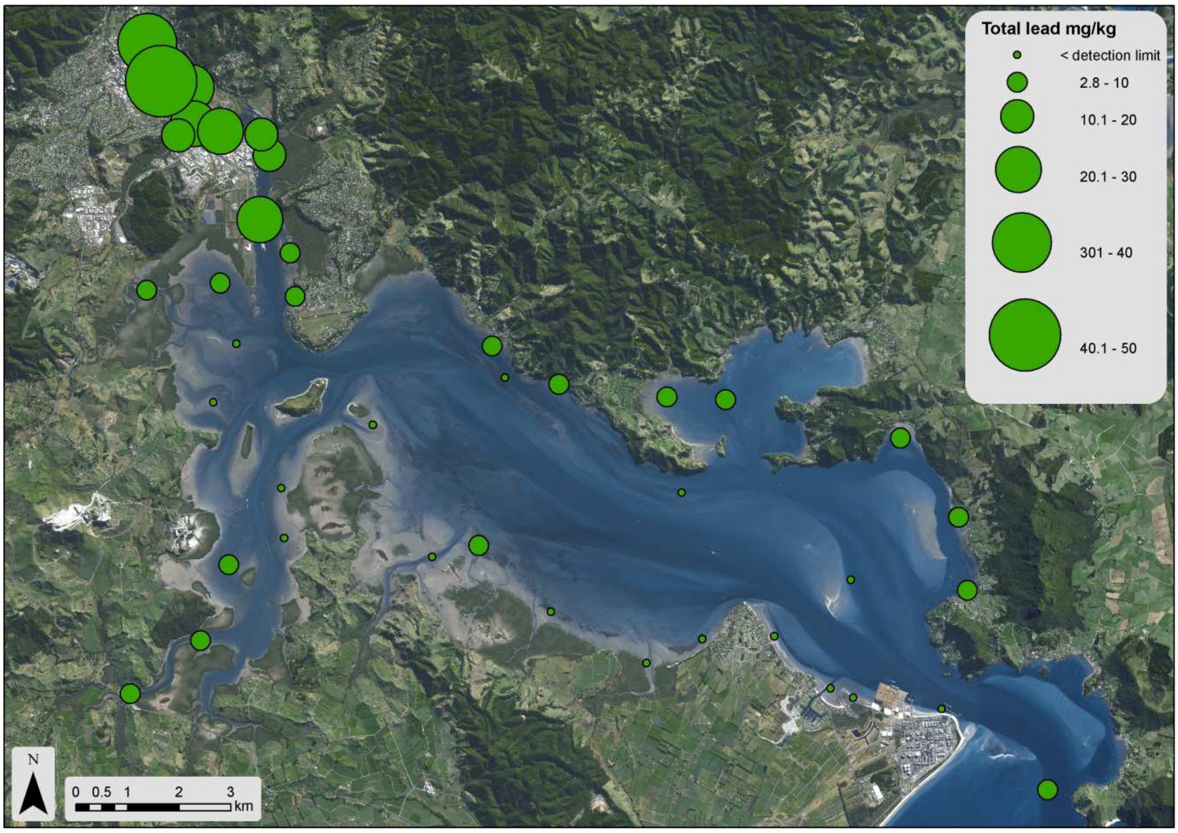

Figure 3-10:Concentrations of lead in 2012 harbour sediment samples, Whangarei Harbour sampling sites. Source: NRC & WDC (2012). Copied with the permission of NRC.

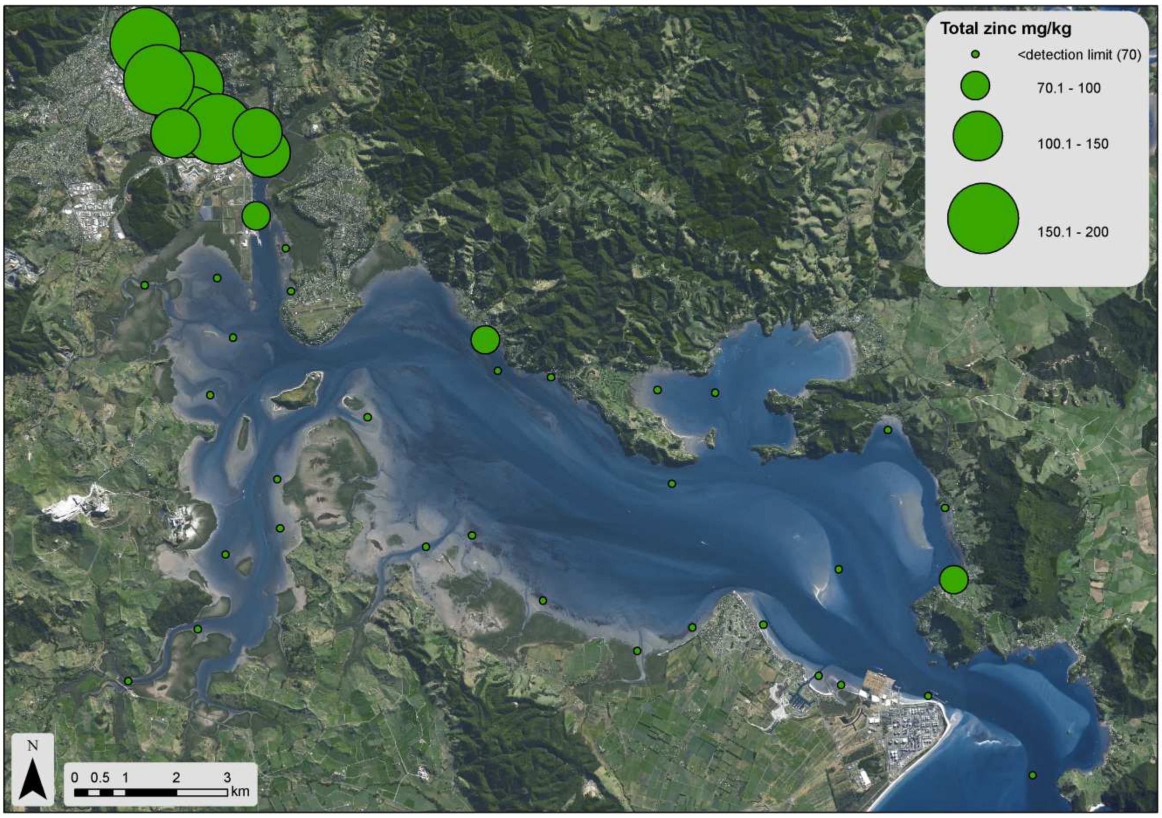

Figure 3-11:Concentrations of zinc in 2012 harbour sediment samples, Whangarei Harbour sampling sites. Source: NRC & WDC (2012). Copied with the permission of NRC.

Impacts on Ecological and Recreational Values

NRC's & WDC's (2012) background report indicates that there is a clearer link between water quality degradation in the harbour and impacts on recreational values than on ecological values, stating that:

Degraded water quality in the Harbour <u>may be impacting</u> on its ecological values, and <u>is impacting</u> on recreational, cultural and spiritual values of residents (underlining added for emphasis).

3.4.1 Ecological Impacts

Ecological degradation in the harbour is, in general, attributed more to the physical modification of particular parts of the harbour rather than to water quality changes, for instance:

The Harbour has a high diversity of estuarine vegetation types and extensive ecological sequences from intertidal flats to mangroves to saltmarsh to indigenous forest and shrubland. It also has small surrounding areas of freshwater wetlands and shell bank islands. While some areas have been highly modified by reclamation, sedimentation, and drainage (e.g. the Hatea River arm) much of the Harbour remains in relatively good ecological condition.

The report comments particularly on the loss of salt marsh habitats, but again attributes this to physical modification rather than to changes in water quality:

Significant areas of saltmarsh have been lost around the Harbour, mainly as a result of reclamations (e.g. roads around the Harbour margins). … Not much is known about the relationship between coastal water quality and saltmarsh growth. However, poor water quality is likely to be much less of factor for loss compared to reclamations and altered estuarine hydrology.

Similarly, in relation to mangroves:

… extensive areas around the CBD and the Old Port area were reclaimed, including by Northland Harbour Board. Reclamations were also carried out in some other parts of the harbour. As a consequence, much of the mangroves that once covered the shallow margins of the Upper Hatea River arm around the present day CBD are gone.

The report notes that while there has been some infilling of mangroves and expansion into areas of saltmarsh, coverage is approximately the same as in the 1940s.

The report also describes the significant reduction in seagrass meadows in Whangarei Harbour. In contrast to the modification of areas of saltmarsh and mangroves, the loss of seagrass meadows is largely attributed to the effects of reduced water clarity resulting from high levels of suspended sediments in the harbour:

The plant relies on clean clear water to grow. High levels of suspended sediments cause water to be murky and reduce the depth that sunlight can penetrate. If seagrass is unable to receive sufficient sunlight then it struggles to grow and may die.

Seagrass meadows were once a large component of the Harbour ecosystem (estimated to be at least 12-14 km^2). Areas around Takahiwai, One Tree Point, Snake Bank, Parua Bay and McDonald Bank are understood to be once covered with a thick layer of seagrass and were highly productive and rich habitats for shellfish and juvenile fish.

By the late 1960s most seagrass meadows had disappeared in the Harbour except for small remnant patches. It is thought that the main causes of the disappearance were fine sediments discharged from the cement works and dredged sediments being dumped back in the Harbour. It has been estimated that between 1.23 million tons of sediment were discharged to the harbour between 1957 and 1967, and a further 1.48 million tonnes between 1967 and 1981. The peak year for discharge was 1967, when 250,000 tonnes of sediment were discharged to the harbour.

Dredged material used to be dumped at places like Snake Bank, off Takahiwai, and at the entrance to Parua Bay. Combined with fine sediments this reduced water clarity. Dredging also altered channel depths, and in turn Harbour hydrology, which may have contributed to the die-back. Another possible factor was a marine fungus (Labyrinthula sp.).

While the report notes that sediments from the cement works and dredged materials are no longer dumped in the harbour and that seagrass beds are in places regenerating, it describes the impact of the widespread loss of seagrass beds:

The considerable loss of seagrass in the Harbour would have had a significant impact on other species such as benthic invertebrates and birds, and in turn resulted in a negative cascade effect on the productivity of the Harbour ecosystem.

Finally, the report also notes that while the upper Harbour has been most impacted in terms of habitat and water quality degradation, it:

… has the highest utilisation by fish, the highest abundance of commercially important fish species, and is used by more species. … This may be due to the high productivity of these estuarine areas and/or its potential to act as a fish nursery. High productivity may be a factor of elevated nutrient levels.

3.4.2 Recreational Impacts

NRC's & WDC's (2012) background report describes a wide range of recreational activities undertaken in Whangarei Harbour, noting that the water quality (and other aspects) of the upper Harbour makes it less well-suited for some activities than others:

Today, water based recreation in the Harbour includes fishing, seafood gathering, sailing, waka ama, windsurfing, kayaking, rowing, stand-up paddle boarding, snorkelling, diving, and swimming.

Most of these activities are undertaken in the middle and lower Harbour. Muddy intertidal flats, water quality issues (including poor water clarity), and limited public access (due to urban and industrial development and previous management decisions) limit the amount of primary contact recreation in the upper Harbour.

However, the Onerahi foreshore, located on the eastern side of the entrance to the Hatea arm of the harbour is a popular swimming spot and its water quality is monitored by NRC as part of the Recreational Swimming Water Quality Monitoring Programme. As noted in Section 3.2.4, monitoring of *enterococci* at this site (along with four others in the middle and outer harbour) indicates that it is almost always suitable for swimming.

The report goes on to note that:

However, secondary contact uses such as waka ama (outrigger canoes), rowing, kayaking, and stand-up paddle boarding are common [in the upper Harbour]*. Interestingly, the evidence suggesting that the upper Harbour has the highest utilisation by fish may also mean that the area is more important for activities such as fishing than many realise.*

Contact recreational activities have been regularly impacted by untreated wastewater overflows from the Whangarei wastewater network and untreated and partially treated discharges from the Whangarei WWTP during heavy rainfall. Recent upgrades to wastewater infrastructure and the on-going WDC wastewater management strategy are expected to reduce this issue over time.

In relation to the harvesting of shellfish the report notes that:

Kaiwaka Point (at Onerahi) is not monitored [to assess compliance against guidelines for recreational shellfish gathering] *as it is not known to be used for recreation shellfish gathering.*

However, monitoring is conducted at three sites in the middle and outer harbour where shellfish harvesting is known to occur. The lower Harbour also supports commercial pipi and cockle harvesting but there is no commercial fin-fishing in the Harbour.

The report also notes how changes in central Whangarei will provide for increased connectivity between the city and the harbour, something that has the potential to influence the way in which the water quality of the harbour is managed:

There is increasing public access and use in the Town Basin environment as a result of extended walkways, the development of the second Hatea crossing (to be completed in 2013), markets, and new public amenities (e.g. sculptures and playgrounds). The loop walkway (Heritage Trail), in particular, will allow for increased access to the Harbour environment. This revitalisation will allow the community to reconnect with the upper Harbour.

3.5 Comments on the Background Report

In our view, the background report provides a comprehensive summary of the available information on the water and sediment quality and ecological and recreational values of the harbour. Not only does it make good use of the results of various monitoring programmes implemented by NRC and WDC over the years, but it also draws on a significant body of reference material in order to portray how and where the harbour has been impacted as a result of water quality changes. The report also provides an excellent overview of the sources of contaminants, and we refer further to this in Chapter 4 of this report. The background report appears to be pitched at the right level to inform audiences of varying technical understanding and, as a result, we expect it will be a very valuable foundation document for the development of the harbour action plan.

We make the following suggestions as matters to consider as NRC and WDC continue to progress the development of the harbour action plan. Some of these matters are covered to some extent in the background report, in which case, we include them here to suggest additional emphasis be given. Others are areas that are not dealt with in the background report and which we consider to be gaps worth addressing.

1. The report describes historical activities which have influenced the water quality of the harbour, noting the cessation or improvement in the quality of certain discharges in recent years (for instance, discharges from the WWTP and cement works). It might be worth further emphasising further the temporal distinction between water quality and sediment quality impacts, i.e.:

   - To a large extent, today's water quality reflects present-day discharges of contaminants. It can vary at the time-scale of a rainfall event or tidal cycle (while noting that it may also be influenced by the re-suspension of, and exchanges with, harbour bed sediments and other contaminants).

   - In contrast, today's sediment quality reflects the cumulative impact of many years of contaminant discharges. Some of these may no longer occur, but may continue to have a 'legacy' effect.

   The importance of this distinction is that it provides the basis for establishing that catchment-based interventions may take different lengths of time to have a beneficial effect. Improvements in water quality, such as reductions in levels of faecal pathogens as a result of fewer wastewater overflows, can be expected to be more immediate than changes in sediment quality and consequential improvements in ecological health.

2. Section 3.3.1 of the background report provides a comprehensive summary of the results of monitoring harbour water quality to assess compliance with recreational guidelines. It would be helpful to map the results, or at least refer the reader to a map of sampling locations. We note that while key sampling locations are shown in the map on p.41, these are not named. However, perhaps local readers will be clear on where the sampling sites are.

3. Also with reference to Section 3.3.1, we note that MfE recommends reporting coastal recreational water quality using a beach grading approach, based on 95th percentiles of at least 5 years of data[10].

4. As far as is possible from the available information, the report examines the impacts of water quality degradation on the ecological values of the harbour, for instance relating the loss of seagrass meadows to historic sediment discharges to the harbour. It notes that some impacts are not well understood, for instance commenting that "While there is reasonable information on nutrient concentrations in the Harbour there is limited information about actual ecological effects in the Harbour, particularly the upper Harbour (p.55)". The report recommends further monitoring and research in this area. We suggest further emphasis be given to describing the likely links between water quality and ecological values, at least in a qualitative sense. This could take the form of a conceptual model (for instance, a diagram) showing the relationships between water quality and ecology. These would include, for instance, the influence of nutrient and metal concentrations in sediment and sediment particle size distribution on the composition and health of benthic invertebrate communities. Similarly, the diagram would show key water quality drivers influencing fish populations. The value in adding this kind of conceptual model is that it would establish a systematic way of linking objectives back to actions: what are the water quality attributes that need to be managed in order to meet specified ecological objectives?

5. The report briefly mentions that monitoring undertaken as part of the Whangarei Harbour Estuary Monitoring Programme suggests a link between sediment metal concentrations and the composition of benthic invertebrate communities in the Upper Harbour (p.38, based on findings reported in Griffiths, 2011). It would be worth providing a summary of the benthic invertebrate monitoring aspects of this programme in the background report to complement the already good coverage of the sediment monitoring aspects of the programme. This summary could be included as an additional sub-section in Section 3.2. The potential value of giving greater coverage to the benthic invertebrate monitoring programme would be to emphasise its role as a complimentary tool for tracking the ecological effects of changes in harbour water quality and responses to any management interventions that may arise from the Harbour Action Plan. It may

[10] See details at http://www.mfe.govt.nz/environmental-reporting/report-cards/water-quality/2012

be of interest to note that Cummings and Hatton (2003) reported previous limited sampling in the Mangapai Arm (including earlier sampling by another author) as part of investigations for a project to enhance shellfish beds in the Harbour.

6. The report describes the impacts of water quality degradation, specifically the impact of the discharge of faecal pathogens to the harbour, on contact recreation. While the report also describes other recreational uses of the harbour, it would be worth further emphasising the links between water quality and these values (in much the same way as we suggest for ecological values in (4) above). Again, the benefit of this would be to establish a systematic way of linking objectives back to actions: what are the water quality attributes that need to be managed in order to meet specified recreational objectives? This approach could also extend into other non-use values (i.e. ‘sense of place’) and cultural values.

7. The report establishes the connections between the harbour and its catchment, for instance through the discussion of contaminant sources. The influence of sub-catchment characteristics (such as land use) on the relative importance of sub-catchments as contaminant sources could be further developed by expanding on the narrative descriptions of stream water quality. For instance, by including plots to compare key stream water quality parameters at the key river water quality monitoring locations in the harbour (in the Hatea, Waiarohia, and Puwera sub-catchments, for instance).

8. The summary of potential contaminant sources in chapter 4 of the report identifies the likely major and minor sources and draws attention to the current lack of quantitative estimates of loads. In the discussion on roads, it might be worth mentioning State Highway 1 to illustrate that, although not necessarily a major source compared to the urban area, rural roads can be expected to contribute some of the total metal load. In the discussion on industrial discharges, it might be worth identifying key industrial areas (such as the Port area) to indicate where the risks of industrial discharges are greatest in the catchment. It might also be worth mentioning any major quarries within the catchment. We note, for instance, that specific water sampling for suspended solids has been undertaken upstream and downstream of a quarry in the Limeburners catchment, reflecting its potential to act as a source of sediment.

9. The report discusses boats as a possible source of metals arising from the use of antifouling biocides. While the report comments that discharges of these chemicals from boat-maintenance facilities have declined due to better management, it may be worth re-assessing the contribution of boats using or moored in the upper Harbour. A recent joint study by NIWA and Auckland Council estimated copper export from Auckland marinas to be double that in stormwater discharged from the entire catchment of the Waitemata Harbour (Gadd and Cameron, 2012).

4 Sources of Contaminants – Existing Knowledge

4.1 Introduction

This chapter describes the result of previous studies relating to the water quality of the harbour catchment and evaluates their relevance for the quantification of contaminant sources. The structure of the chapter follows that adopted in NRC's & WDC's (2012) background report, working through each of the key contaminant source types in sequence. Because the background report provides a comprehensive narrative overview of the key types of contaminant source in the catchment, we have again quoted relevant parts of that text in order to provide context for the evaluation of other studies. The reviews of previous studies are located within the relevant section on each type of contaminant source. Those aspects of each study which are of relevance for the estimation of contaminant loads are highlighted in a text boxes at the end of each review and this information is carried through into the synthesis found later in the report (Chapter8).

Table 4-1 summarises typical sources of sediment, nutrients, faecal pathogens and metals in a mixed land-use catchment.

Table 4-1: Typical sources of sediment, nutrients, faecal pathogens and metals in a mixed land-use catchment.

Contaminant Source	Sediment	Nutrients	Faecal pathogens	Metals
Diffuse sources				
Urban land use and major roads	✓	✓	✓	✓
Pastoral farming	✓	✓	✓	
Exotic forests	✓			
Native forests	✓			
Point sources				
Treated WWTP effluent		✓	✓	✓
Untreated wastewater overflows		✓	✓	✓
Dry weather wastewater overflows		✓	✓	✓
Septic systems effluent		✓	✓	✓
Farm dairy effluent		✓	✓	
Industrial discharges	✓	✓		✓
Landfills		✓		✓
Construction earthworks	✓			
Quarries	✓			
Background sources	✓	✓		✓

Diffuse sources are those which result in the discharge of contaminants to rivers and stream in response to rainfall-runoff over the land. These sources include urban areas and major roads from which contaminants are discharged in stormwater and road runoff[11], and rural

[11] Urban stormwater and road runoff can also be considered point source discharges where discharged from a reticulated pipe network, as noted in NRC & WDC (2012).

land uses such as pastoral farming and forestry. Point (or direct) sources are those from which contaminants are discharged at a point (i.e. a pipe outlet) and of which the origin is well-defined. These include wastewater discharges (treated and untreated) and discharges from industrial activities, construction earthworks and quarries[12]. In addition to these anthropogenic diffuse and point sources, there are also background sources of sediment, nutrients and metals in catchment runoff. Background metals, for instance, derive from the naturally occurrence of metals at trace concentrations in catchment soils.

4.2 Urban land use and major roads

4.2.1 Overview

NRC's & WDC's (2012) background report notes that:

Urban stormwater is mostly untreated in Whangarei District.

The most important networks are those that drain Whangarei City due to degraded water quality in the Hatea River arm of the upper Harbour. … All local networks discharge stormwater to freshwater bodies (including modified water courses). The CBD, Limeburners Creek, Port, and Onerahi networks[13] also discharge stormwater directly to the Harbour.

Stormwater quality monitoring has only been carried out on a sporadic basis at a limited number of mostly consented outfalls. Importantly, first flush events – the first part of a stormwater discharge which is thought to carry the bulk of contaminants – are poorly understood.

The report also notes that:

Stormwater quality monitoring has detected high levels of ammonia at a number of outfalls in the Whangarei City networks. Very high levels of ammonia and phosphorus were also detected by NIWA in an earlier (1994) study for Northland Regional Council. The study concluded that the high levels suggest a widespread diffuse source, which may include urban wastewater, decomposition of organic material in gully pots (catchpits), and/or high atmospheric decomposition. The diffuse source has not been identified, or subject to source tracking, although wastewater is potentially a key source. It is unknown whether this remains an issue. Although, high levels in the Hatea River arm highlights the need to understand sources and loads.

Limited data also suggests that heavy metal levels in Whangarei city stormwater are generally typical of urban stormwater elsewhere in New Zealand, i.e. are at average levels. However, sediment monitoring undertaken has revealed elevated levels of heavy metals in the upper Waitaua Stream (near the industrial area), a tributary of the Hatea River. At the Waitaua Bridge monitoring site in Kamo, levels of total nickel, total lead and total zinc are consistently well above guideline low trigger values. Elevated levels of heavy metals in sediments have also been found in the vicinity of a number of stormwater outfalls in the upper Hatea River arm close to the Town Basin.

[12] Again there is some blurring of the distinction between diffuse and point sources here, since runoff from earthworks and quarries is diffuse in origin but (if controlled) is discharged at a point. The distinction between these activities (as point sources) and urban land use (as a diffuse source) in Table 4-1 is really one of scale.
[13] Or, as defined in this report, SMCs (see Chapter 2).

The limited stormwater monitoring data also shows above average to high levels of suspended sediments at a number of outfalls across the networks.

It should be noted that lead is generally considered a 'legacy' stormwater contaminant, being present in catchment soils as a result of the historic use of lead-based paints and leaded-petrol. Loads can generally be expected to fall over time as the reservoir of lead originating from these sources is depleted. However, there may continue to be localised sources of lead associated with, for instance, specific industrial activities.

4.2.2 Relevance of Previous Studies for Quantifying Contaminant Sources

Whangarei Harbour Water Quality Management Plan: Working Report 3 (WHWQMP WR 3; NRC, undated-1)

This report describes the characteristics of sub-catchments of Whangarei Harbour and classifies rural land according to its erosion potential. It also proposed a field programme for the estimation of sediment loads delivered to the Harbour from the Hatea and Raumanga sub-catchments, including sampling of both storm flows and baseflows. While the report does not contain any data of relevance for the estimation of loads the methods proposed remain broadly relevant for any future monitoring programme.

Whangarei Harbour Water Quality Management Plan: Working Report 12 (WHWQMP WR12; NRC, undated-2)

This report describes the results of a two-part project to investigate diffuse-source contaminants entering the upper Harbour from Whangarei's stormwater network and four partially-urbanised sub-catchments. The first part involved collecting sediment samples around the mouths of 30 stormwater drain outlets and analysing these for a range of metals and total hydrocarbons. Average concentrations of copper, lead and zinc were found to be 15-35% higher than in sediment samples collected elsewhere in the Hatea River or Town Basin area, providing evidence that stormwater discharges were an important contributor of these metals. The report discusses water quality management considerations arising from these results.

The second part of the study involved collecting water samples from the Hatea, Raumanga, Waiarohia and Kirikiri Streams[14] during baseflow and storm event conditions, in accordance with the proposed programme set out in WHWQMP WR3 (NRC, undated-1). Samples were collected at water level recorder sites[15] using an automatic sampler in the Hatea and depth-integrated grab sampling at the other three streams. Eight baseflow samples were collected from each site. Stormflow sampling was conducted during five storms in the Hatea (including during Cyclone Bola, 6-9 March 1988) and during one storm at the other sites. Samples were analysed for concentrations of suspended solids (SS) and a range of nitrogen and phosphorus parameters. The results of the study included: a comparison of SS and nutrient concentrations in the four sub-catchments; investigation of relationships between concentrations and stream flow; and estimates of SS and nutrient loads under baseflow conditions, during specific storm events, and in the long term (see Table 4-2). Most emphasis

[14] Although we have included a description of this study under the heading 'Urban land use and major roads' because of the focus of the first part on stormwater discharges, the second part of the study characterised water quality from each of the four sub-catchments in their entirety, not just their urban areas.
[15] Except in the Kirikiri Stream where flows were estimated from those recorded at the other three sites.

was placed on the estimation of loads for the Hatea sub-catchment, given the more intensive sample collection from that stream.

Table 4-2: Estimated baseflow, storm event and annual loads of suspended solids and nutrients delivered from the Hatea, Raumanga, Waiarohia and Kirikiri sub-catchments (source NRC, undated-2).

	Baseflow (kg/day)					Stormflow (kg/day)	Annual (t/yr)	
	Total	Hatea	Raumanga	Waiarohia	Kirikiri	Hatea	Hatea	Others[a]
SS	166	77.2	49.5	29.2	10.1	26,500-107,000[b, c]	8,862 [c]	2,674 [c]
TKN	26.4	~ 13	~ 8	-	-	252, 755 [d]	-	-
NO_3-N	111.5	~ 56	~ 33	-	-	105, 189 [d]	-	-
NH_4-N	<5	-	-	-	-	6, 39 [d]	-	-
TP	<5	-	-	-	-	30, 44 [d]	-	-
DRP	<5	-	-	-	-	5.5, 8.5 [d]	-	-

Notes

[a] Sum of loads from Raumanga, Waiarohia and Kirikiri sub-catchments

[b] Range of peak daily load, four storm events. The report also estimates the load discharged during Cyclone Bola (6-9 March 1988) as being approximately 7,000 tonnes.

[c] Loads are originally reported in volumetric units (cubic metres). These have been converted to units of mass based on a reported density for mud of 1910 kg/m^3 (Tenzer et al., 2010).

[d] Peak daily loads from two storm events.

- not reported

The report found that the majority (85%) of sediment discharged to the upper Harbour is transported during large storm flow events, with around three quarters of the total load from the four streams sampled originating in the Hatea sub-catchment. The estimates of nutrient stormflow loads from the Hatea sub-catchment were compared with estimated daily loadings from Whangarei WWTP[16], indicating that stormflows can be an important contributor of TKN and NO_3-N (Table 4-3).

Table 4-3: Estimated daily loads (kg) of nutrients discharged in storm flows from the Hatea sub-catchment and from the Whangarei WWTP (source NRC, undated-2).

	Stormflow loads	WWTP loads
TKN	252, 755 [a]	245
NO_3-N	105, 189 [a]	168
NH_4-N	6, 39 [a]	153
TP	30, 44 [a]	90
DRP	5.5, 8.5 [da]	71

[a] Peak daily loads from two storm events.

[16] Based on the pre-1990 configuration of the WWTP.

The relevance of the findings of this study for quantifying contaminant loads discharged to the upper Harbour is:

- The estimated annual loads provide an independent estimate for comparison with loads calculated for the Hatea, Raumanga, Waiarohia and Kirikiri sub-catchments by other means, for instance modelled.
- The estimated daily loads discharged from the WWTP also provide an independent estimate for comparison with loads calculated by other methods.
- The method by which loads were estimated in this study could be adopted to estimate loads in other sub-catchments, subject to sufficient water quality (sampling results) and flow data. Where flow records are not available it may be possible to generate synthetic records, for instance, using gauging data and the flow records of nearby catchments.

Whangarei Harbour Water Quality Management Plan: Working Report 14 (WHWQMP WR12; NRC, undated-3)

This report describes the results of sediment sampling and analysis for heavy metals at six locations in the Hatea River arm of the upper Harbour. The survey was conducted in 1990 and is described as the first in a planned long-term programme[17]. The results showed a decreasing trend in metal concentration moving downstream in the estuary.

Whangarei Urban Runoff Quality (Williamson and Thomsen, 1994)

Williamson and Thomsen (1994) evaluated urban runoff quality in Whangarei based on a combination of grab and composite samples collected in a residential, mixed residential and industrial catchment. Runoff quality was compared with representative New Zealand stormwater concentrations of suspended solids, nutrients and metals. This is the 1994 NIWA study referred to above in the excerpt from NRC & WDC (2012).

The study found that:

- Suspended solids (SS) were as expected for a mature urban catchment, but higher in the industrial catchment than in residential (which the authors commented may have been due to sampling methods);
- Nitrate nitrogen (NO_3-N) concentrations were relatively low but, as noted above, total phosphorus (TP) and ammoniacal nitrogen (NH_4-N) were unusually high, the sources of which were unclear.
- Lead (Pb), zinc (Zn) and copper (Cu) concentrations were typical of urban catchments, although again copper was relatively high from the industrial catchment.

[17] Although data provided by NRC includes sediment metal concentrations for these same sites from 1985 and 1988.

The relevance of the findings of this study for quantifying contaminant loads in stormwater is:

- The general consistency of SS and metal concentrations with other urban areas in New Zealand supports the application of generic tools, such as the C-CALM model, which uses SS and metal yields derived from monitoring of residential, commercial and industrial stormwater elsewhere.
- An assessment is required of the extent to which the elevated concentrations of TP and NH_4-N in stormwater reported in this study remain an issue. If so, the assessment should evaluate whether high concentrations in stormwater translate into a significant proportion of the total catchment loads of these contaminants. That would then lead to consideration of potential sources: can some or all of these stormwater loads be accounted for as deriving from other quantifiable sources (e.g. from wastewater overflows) or do they originate from some other source(s) which requires quantification in their own right?

WDC Stormwater Catchment Management Plans (1994-2011)

WDC has stormwater catchment management plans (CMPs) for each of the SMCs. These have been prepared and updated at varying times, such that the most recent versions for each SMC date from between 1994 and 2011. A brief summary of the contents of each is given in Appendix A.

Much of focus in the CMPs is on management of flood risk. Generally, they do not attempt to quantify contaminant loads although they do identify where sampling has taken place and make recommendations for stormwater treatment. Based on advice from WDC staff, however, actual stormwater treatment is understood to be limited in its extent in all of the SMCs[18].

Two of the CMPs report on the results of sampling conducted during dry weather and at the onset of Cyclone Sosi in 2001. These are the CMPs for the Port Rd (Hydraulic Modelling Services, 2004) and Onerahi (Hydraulic Modelling Services, 2001) SMCs. Based on the results of that sampling, the Port Rd CMP estimated loads of various contaminants, including copper, lead, zinc, SS, TP and NH_4-N discharged during a 24-hour, 50-year storm (see Table 4-4).

Table 4-4: Estimated contaminant loads discharged from the Port Rd SMC during a 24-hour, 50-year storm (Hydraulic Modelling Services, 2004).

Contaminant	Load Discharged During a 24-hour, 50-year storm (kg)
Cu	90
Pb	6
Zn	55
SS	220,000
TP	300
NH_4-N	320

[18] (C. Summers 2012, pers. comm. , 30 October)

The relevance of the information contained in these CMPs for quantifying contaminant loads in stormwater is:

- The estimated loads during a 24-hour, 50-year storm are not especially helpful, as there are no other estimates of loads from other SMCs or other types of contaminant source that they can be compared against, nor do we suggest undertaking any additional estimates specifically for an event of this magnitude[19].
- However, the stormwater sampling results can be included in an assessment of the spatial variability in stormwater quality across Whangarei to guide the need (if any) for any location-specific programme of sampling.

Hatea River metals study (Webster et al., 2000)

Webster et al. (2000) evaluated the source and transport of metals based on the sampling of stream water and sediments at sites in the Hatea, Waiarohia, Raumanga, Kirikiri, and Limeburners sub-catchments. The Waiarohia Stream was found to contain the most contaminated sediments and Limeburners the least. Concentrations of lead and zinc were elevated in water samples from the Waiarohia stream, while concentrations of copper, lead and zinc were higher in stormwater samples than in freshwater (stream) samples. The study found that metals delivered to the harbour were predominantly in the particulate phase.

Samples were collected under four flow conditions, described as 'low', 'low-moderate', 'moderate' and 'high'. On the basis of measured SS concentrations associated with these different flows and analysis of record Hatea River flows[20], the authors estimated sediment loads delivered from the Hatea catchment to the harbour over the period. Loads were estimated for different flow ranges and then aggregated to give the total load (see Table 4-5). Measured sediment metal concentrations were then used to estimate metal loads, again by flow range and in total. The vast majority of the total load was estimated to be delivered during the 20% of highest flows.

Table 4-5: Estimated contaminant loads over the period 1986-95 discharged from the Hatea catchment (Webster et al., 2000).

Contaminant	Total load 1986-95
SS	2,643 t
Cu	117 kg
Pb	119 kg
Zn	1220 kg

[19] However, these event loads are compared with annual loads estimated by other methods in Chapter 8 of this report.
[20] Location not stated but assumed to be flows recorded at site 5538, Hatea @ Whareora Rd.

The relevance of the findings of this study for quantifying contaminant loads in stormwater is:

- The estimated loads for the Hatea catchment provide an independent estimate for comparison with loads calculated for the same sub-catchment by other means, for instance modelled.
- The method by which loads were estimated in this study could be adopted to estimate loads in other sub-catchments, subject to sufficient water quality (sampling results) and flow data. Where flow records are not available it may be possible to generate synthetic records, for instance, using gauging data and the flow records of nearby catchments.

C-CALM modelling of stormwater loads (Semadeni-Davies, 2009)

NIWA modelled annual loads of sediment, copper and zinc for three areas of Whangarei using the Catchment Contaminant Annual Loads Model (C-CALM; Semadeni-Davies, 2009). Estimated metal loads were highest for the Port Rd industrial area, followed by the mixed land use Raumanga catchment and the CBD (see Table 4-6). Sediment loads were estimated to be much higher for the Raumanga catchment than from the other two areas.

Table 4-6: Estimated annual loads of TSS, copper and zinc, C-CALM modelling study (Semadeni-Davies, 2009).

Catchment	Load (kg/year)						
	TSS	Total Copper	Particulate Copper	Dissolved Copper	Total Zinc	Particulate Zinc	Dissolved Zinc
CBD	14,599	12	9	3	138	21	117
Port Rd	63,471	81	61	20	915	249	665
Raumanga	2,876,073	40	34	6	402	160	242

The relevance of this study for quantifying contaminant loads in stormwater is:

- Much of the model input data assembled for the 2009 C-CALM study covers the entire urban extent of Whangarei, not just the three areas modelled here. The availability of this information has provided a valuable head start in repeating the study for Whangarei as a whole (see Chapter 6).
- While the estimated loads for these three areas are to some extent superseded by the catchment-wide modelling (described in Chapter 6), the loads and yields for the Port Rd and CBD can be compared against the new estimates for the larger sub-catchments within which these areas lie. This provides an indication of the relative importance of the Port Rd and CBD as contaminant sources, compared to other parts of the relevant sub-catchments.

Northland Macroinvertebrate Monitoring Programme (Pohe, 2012)

While this monitoring programme does not specifically focus on the effects of stormwater discharges, we have referred to it in this section of the report because it contains information of relevance for characterising urban land use impacts on streams.

The report presents the results of the 2012 round of the Northland macroinvertebrate monitoring programme and compares these results with those of previous monitoring undertaken since 1997. The programme involves sampling macroinvertebrates at 38 State of the Environment (SoE) stream sites and four resource consent monitoring sites. The results include assessments and rankings (based on the SQMCI[21]) of six sites located within the Upper Whangarei Harbour catchment (see Table 4-7).

The Waiarohia Stream @ Kamo Tributary culvert was the lowest ranked of all 38 SoE sites based on SQMCI. The report notes that this site "has had poor biological scores since monitoring began however the surrounding environment, in-stream habitat, as well as physical water parameters, all appear excellent. This site was highlighted as a particular concern in the 2010 and 2011 monitoring reports and a member of the public also reported concerns in 2010. Further investigation is strongly suggested."

Table 4-7: Assessment and rankings of macroinvertebrate monitoring sites in the upper Whangarei Harbour catchment (from Pohe, 2012).

Site no.	Site Name	Assessment	Ranking (out of 38 SoE sites)
110431	Otaika Stream @ Otaika Valley Rd	mild pollution	4
100194	Hatea River u/s Mair Park Bridge	moderate pollution	8
107773	Waiarohia Stream @ Whau Valley Road	severe pollution	18
105674	Waiarohia Stream @ Russell Road Bridge (Nth)	severe pollution	20
105672	Waiarohia Stream @ Rust Ave Bridge	severe pollution	30
105677	Waiarohia Stream @ Kamo tributary culvert	severe pollution	38

The relevance of this study for quantifying contaminant loads in stormwater is:

- The assessments and rankings for the Waiarohia Stream sites provide an indication of the relative importance of locations within this sub-catchment and of the sub-catchment as a whole as a contaminant source. Assessments of contaminant loads generated in the catchment upstream of the Kamo tributary culvert should have regard to the specific activities located in that area.

[21] Semi-Quantitative Macroinvertebrate Community Index (Stark, 1998)

4.3 Pastoral Farming

4.3.1 Overview

NRC's & WDC's (2012) background report provides the following description of pastoral farming as a source of contaminants:

Approximately 50 percent of the greater Harbour catchment is covered in pasture. …

… run-off from pastoral land can potentially contain nutrients, sediments, faecal pathogens, and also heavy metals. Nitrogen compounds and faecal pathogens can also leach through soil to water bodies, including groundwater. Diffuse sources include, but are not limited to, stream banks and other erosion prone land, stock access to the beds and riparian margins of waterways, general grazing of animals, and fertilisers.

Research undertaken in the Bay of Islands has revealed that pasture and production forestry are the main current source of sediment in its Harbour environments.

The report makes particular reference to the Puwera and Otaika sub-catchments:

The Puwera sub-catchment is typical of many Northland catchments in that it has high flow variability, it regularly dries up in summer, and it provides a typical and realistic picture of the relationship between water quality and dairying/dry stock land use in the region.

Waterways in the sub-catchment are generally small and not subject to the Dairy and Clean Streams Accord. A recent report by Northland Regional Council estimated that stock is excluded from less than 10 percent of waterways in the Puwera sub-catchment. The neighbouring Otaika sub-catchment also has a low proportion of fenced waterways.

Monitoring data reveals water is often turbid, which may be indicative of high levels of suspended sediments in waterways and/or colloidal sediment. …

Monitoring data [also] reveals high levels of nitrogen, phosphorus and faecal pathogen indicators in the Puwera Stream and Otaika Rivers.

The report also notes that water quality in the lower Hatea River and Waiarohia is also characterised by elevated concentrations of suspended sediments, nutrients and faecal pathogens. However, because there has not been routine monitoring upstream of the urban environment it is difficult to assess the extent to which pastoral land use contributes to these high contaminant concentrations, compared to urban stormwater discharges and wastewater overflows. An exception to this lack of specific monitoring is described:

An investigation into the bacterial water quality at Whangarei Falls (upstream of urban areas in the Hatea sub-catchment) found high levels of E.coli (a faecal pathogen indicator) in the four main tributaries flowing into the falls. Microbial source tracking indicated that bacterial contamination at the falls is not directly run-off related and more likely a result of stock and wildfowl in streams, although this is not to disregard run-off as an issue. Further monitoring is required to determine the relative impact of runoff on faecal indicator levels in the waterway.

4.3.2 Relevance of Previous Studies for Quantifying Contaminant Sources

Puwera Clean Streams Study (NRC, 2007; 2012b)

The study involved collection and analysis of water samples at two sites in the Puwera River catchment to investigate the impact of the 'Clean Streams Accord' on water quality in a catchment of predominantly dairy farm land use. Samples were collected at initially fortnightly and later monthly intervals between July 2006 and July 2012 and analysed for a range of contaminants including suspended solids, nutrients and indicator bacteria. Stream flow measurements and macroinvertebrate sampling were also undertaken.

Trend analysis of the sampling results was undertaken in order to establish whether any changes could be observed in water quality over the period of monitoring. The study found a meaningful decrease in concentrations of *E. coli* and faecal coliforms and a slight (but not significant) decrease in nutrient levels. These positive trends were considered to possibly reflect the upgrade of farm dairy effluent treatment systems prior to the study (see also Section 4.6). The study also found a negative trend in pH (i.e., a meaningful decrease), with possible explanations for the increased acidity of the stream water including an increase in soil erosion, releasing fragments of acidic soils washed down into the stream.

The relevance of this study for quantifying contaminant loads from pastoral farming is:

- The water quality data generated by this study is likely to be a sufficiently large dataset to allow their use for the estimation of contaminant loads, for instance for comparison with loads estimated by modelling for areas of dairy farming. However, in order to estimate loads it will be necessary to also produce a synthetic flow record for the sampling points, for instance based on the spot flow measurements and continuous flow records from a nearby catchment(s).

4.4 Forests

4.4.1 Overview

NRC's & WDC's (2012) background report comments that:

Approximately 10% of the greater catchment is covered in plantation forest. However, like pastoral cover, there is variation in amounts between its sub-catchments. The largest stand of plantation forest is in the upper Hatea sub-catchment. Smaller stands are found in the Otaika and Onerahi sub-catchments.

It is difficult to determine the influence of sediment runoff from production forestry on Harbour water quality because of limited water quality monitoring data for the upper Harbour catchments where forestry is a major land use.

Although the land cover of the Upper Harbour catchment has been extensively modified, in places there remain significant areas of native forest. More than half of the land cover in the Waiarohia and Kirikiri sub-catchments and more than 20% of that in the Onerahi, Hatea, Raumanga, Limeburners and Otaika catchments is classified as native forest and scrub (see Section 2.2.2). The sediment loads discharged in runoff from these parts of the catchment can be expected to be consistent with background (i.e. pre-human) loads.

4.4.2 Relevance of Previous Studies for Quantifying Contaminant Sources

Glenbervie Forest sediment study (Hicks and Harmsworth, 1989)

Hicks and Harmsworth (1989) reported on the monitoring of storm suspended sediment yields in a 63 ha experimental catchment at Glenbervie Forest in the northern part of the Hatea sub-catchment. The study ran from 1981 to 1988 and included monitoring of rainfall and stream flow and the collection of samples for analysis of suspended sediments during periods before, during and after the harvesting of Pinus radiate forest. The authors derived a sediment yield response factor (SYRF) which gives an estimate of the relative importance of increased erosion during the logging phase of forestry operations that is unbiased by the sequence of storms.

Monitoring between 1981 and early 1985 coincided with the forest in a mature and undisturbed state. In 1985, when landing-areas were constructed in preparation for harvesting, the SYRF increased up to 100-fold. The high sediment yields were derived mainly from earthfill bulldozed into the sub-basin headwaters. Over 1986 and 1987, the SYRF returned towards the undisturbed level as the sediment slug was either flushed from the sub-basin or was stabilised by vegetation and consolidation. The actual timber harvesting operation in 1986 caused no noticeable change in the SYRF, the authors suggesting that this may have been because it was swamped by the remnant impact of the preparatory works.

The authors estimated that the harvesting period contributed 70% of the total suspended sediment yield over the 32-year growing cycle.

The relevance of this study for quantifying contaminant loads from forestry operations is:

- It should be possible to access further results of this study (or the original data) to obtain estimates of sediment loads during the different phases of forestry operations. These estimates can be compared with loads estimated by modelling of areas of forestry in the catchment.

4.5 Reticulated Wastewater Discharges

4.5.1 Overview

Reticulated wastewater discharges include:

- treated effluent discharged from Whangarei Wastewater Treatment Plant (WWTP);
- wet weather discharges of untreated wastewater from overflow points and pump stations on the city’s wastewater network;
- wet weather discharges of partially treated wastewater from the WWTP extreme flow bypass;
- dry weather discharges and exfiltration of untreated wastewater from the network; and
- treated effluent from a community WWTP at Portland (WDC, 2010).

NRC's & WDC's (2012) background report describes Whangarei's wastewater network as follows:

The Whangarei WWTP treats wastewater from the Whangarei City wastewater network that extends to Springs Flat in the North, Maunu in the west, Raumanga in the south, and Onerahi through to Whangarei Heads in the east. The network services approximately 19,000 connections (households and businesses), has 343 km of gravity fed pipelines, 53 pumping stations, and 39 km of rising mains (pipes that go uphill). There are also constructed overflow pipes located in different parts of the network.

During periods of dry weather the Whangarei WWTP receives in the range of 10,000 to 20,000m^3 of wastewater per day. Treated wastewater is discharged through a series of wetlands to Limeburners Creek and ultimately the Hatea River arm of the upper Harbour. During wet weather the WWTP can receive much larger flows as a result of stormwater entering the wastewater network through illegal stormwater connections (inflow) and cracked and partly connected wastewater pipes (infiltration).

To accommodate increased flows resulting from recent upgrades to the Okara Park pump station [see below] *Whangarei District Council is undertaking further modifications to the WWTP that will result in increased treatment capacity. On completion of its upgrade in 2013 the WWTP will be able to treat extreme flows during wet weather.*

While these extreme flows currently receive screening and primary treatment, they bypass UV treatment. Extreme flows are considered to be the single largest discharge of wastewater pathogens into the Hatea River arm of the harbour (AWT, 2011). As part of the further upgrade of the WWTP, WDC is proposing that all extreme flow discharges also receive UV treatment (AWT, 2011).

NRC's & WDC's (2012) background report provides the following commentary on wet weather overflows from the network:

Inflow and infiltration to the network can cause capacity related (wet weather) overflows from manholes and pump stations at a number of sites across the network when volumes exceed the size of the pipe network.

In the last few years Whangarei District Council has undertaken a number of projects to reduce wastewater impacts on the Harbour. The most high-profile are upgrades to the Whangarei WWTP, Okara Park and Hatea pump stations, and the replacement of aging and low capacity pipes to improve network performance across urban Whangarei. It has also spent considerable effort investigating and addressing illegal stormwater connections.

Until recently, the major wet weather overflow point that discharged direct to the Harbour was from the Okara Park Pump Station. Overflows of up to 20,000m^3 of stormwater diluted untreated wastewater were recorded. In 2010/11 the pump station underwent a major upgrade in order to eliminate virtually all wet weather overflows of untreated wastewater. The Hatea pump station has also undergone a major upgrade. A large storage tank has been built to reduce the frequency of overflows and a treatment system has been put in place to reduce bacteria loads during any overflow. Any future overflows from the pump stations are authorised subject to stringent conditions in resource consents.

While considerable progress has been made in addressing large wet weather overflows from the Okara Park and Hatea pump stations and in improving treatment at the WWTP, the wastewater network still discharges untreated wastewater at a number of other wet weather overflow points and will still need to be the subject of future work.

Whangarei District Council developed a robust hydraulic computer model of the Whangarei wastewater network for the purposes of informing its asset management and upgrade decisions. The model identifies a large number of regular wet weather overflow points (manholes and pump stations) that discharge across Whangarei City. For example, during an annual rainfall event (1 in 1 year average return interval), the Whangarei urban network (not including Onerahi to Whangarei Heads) is predicted to overflow at close to 75 locations, of which the majority are less than 100 m^3, ten between 100 and 200 m^3, six between 1,000 and 2,000 m^3, and two greater than 2,000 m^3.

The background report also comments on dry weather exfiltration and overflows of untreated wastewater from the network:

While there is a lack of information on exfiltration as an issue it may be responsible in part some level of nutrients and faecal pathogens in the Hatea River arm during dry weather, however this is yet to be confirmed.

Overflows can also happen during dry weather as a consequence of blockages, which are managed by regular pipe inspections. There is also the possibility of exfiltration (leakage) from cracked or partially connected pipes in some areas however there is insufficient evidence to support whether exfiltration is a significant issue in terms of faecal pathogen and nutrient loads to the Hatea River arm of the upper Harbour.

4.5.2 Relevance of Previous Studies for Quantifying Contaminant Sources

Harbour hydrodynamic model and its use to model dispersion of indicator bacteria (Reeve et al. 2009; 2010)

Reeve et al. (2009) described the development of a 3-dimensional hydrodynamic model of Whangarei Harbour for modelling the dispersion of microbial contaminants (and which could be extended to other contaminants). Because the model was calibrated and validated with limited exiting field data, the authors noted that it was more suited to evaluating relative differences between discharge scenarios rather than absolute contaminant concentrations.

Reeve et al. (2010) described the application of the model to evaluate the dispersion of indicator bacteria discharged from the WWTP and Okara Park pump station. The report gives the assumed concentrations of indicator bacteria in river flows (guided by limited sampling data) and wastewater discharges that were used in the modelling[22].

[22] Sections 2.4 and 2.5 in (Reeve et al. 2010)

The relevance of these reports for quantifying contaminant loads from reticulated wastewater discharges is:

- The hydrodynamic model provides a basis for the modelling the dispersion of other contaminants and, in combination with catchment load models, could inform an assessment of the relationships between contaminant sources and sinks. The value of this approach, which has been applied in the Waitemata and Manukau harbours, for instance (Green et al., 2010), is that it allows the effectiveness of management interventions in key contributing catchments for achieving outcomes in specified parts of the harbour to be modelled.

Quantitative Microbial Risk Assessment (McBride and Reeve, 2011)

McBride and Reeve (2011) described a Quantitative Microbial Risk Assessment (QMRA) of human health effects associated with wet weather flows of untreated wastewater. The study assessed risk at the Hatea River / Limeburners Creek confluence (for swimming and secondary recreation) and at the Upper Harbour at Onerahi (for swimming, secondary recreation and shellfish gathering). The study compared 72 scenarios of discharges of treated wastewater from the WWTP, untreated wet weather overflows and stream 'non-monitored' sources (meaning catchment sources). These scenarios included both 'current' and 'improved' water quality. For each scenario, expert knowledge was used to derive representative concentrations of faecal pathogens and indicator bacteria in the river inputs and wastewater discharges. The QMRA then used a simple 1-D model (QUEST) rather than the full hydrodynamic model described in Reeve at al. (2009).

The relevance of this study for quantifying loads of faecal pathogens from reticulated wastewater discharges and other sources is:

- As part of this study, assumptions were made of the relative importance of treated wastewater, untreated overflows and background sources of faecal pathogens and indicator bacteria. Loads (for instance, background loads from other sub-catchments) can be estimated based on these assumptions, by using the representative concentrations adopted in the study.
- The QMRA described in this study could be extended to consider further scenarios. However extension to the wider catchment would require the use of the more sophisticated hydrodynamic models.

Whangarei Wastewater Treatment Plant: Application for Change to Consent (AWT, 2011)

This report was prepared in support of the application by WDC for a change to the conditions of the WWTP's discharge consent. It describes the current operation of the plant, including typical dry-weather inflow rates, and the proposed upgrades to deal with the increase influent flows resulting from the Okura Park pumping station upgrades.

The report provides some influent and extreme bypass effluent quality monitoring data collected in 2010[23] and gives some indicative concentrations of TSS, NH_4-N and *E. Coli* in the extreme bypass flows[24]. It also gives extreme flow volumes during events of 3 month to 5 year return period[25] as simulated by WDC's wastewater network model. The report states that the model has been run for a continuous time series of 14 years of rainfall data and predicts an average of approximately 5 spills a year from the extreme flow bypass.

The report also refers to the hydrodynamic modelling and QMRA described above in describing the evaluation of options to upgrade the plant.

The relevance of this report for quantifying contaminant loads from reticulated wastewater discharges is:

- The modelled flows and representative bypass concentrations of TSS, NH_4-N and *E. Coli* can be used to estimate loads of these contaminants discharged from the extreme flow bypass during events of the specified return periods.
- The dry-weather inflow rates can be used to estimate dry weather loads of contaminants discharged in treated effluent, in combination either with local effluent quality data or literature values.
- The results of the 14-year model run (or some shorter period of at least one representative rainfall year) could provide the basis for a more sophisticated approach to estimating average annual loads of contaminants discharged in treated effluent, bypassed partially-treated effluent and wet weather overflows. This approach would require modelled time series of flows of: influent to the WWTP, treated effluent, partially treated effluent from the extreme flow bypass and overflows (preferably all overflow points combined). Representative contaminant concentrations in treated and untreated effluent, either from local data or literature values, would be used.

With reference to the second bullet point above, WDC hold data on representative concentrations of TN, TP and TSS in dry weather treated effluent discharged from the WWTP. Table 4-8 presents WDC's estimates of the annual loads of TN, TP and TSS discharged in dry weather treated effluent from the WWTP, based on an average daily flow of 9.2 million litres.

Table 4-8: Representative concentrations and estimated loads of TN, TP and TSS in dry weather treated effluent discharges from Whangarei WWTP[26].

Contaminant	Concentration (mg/l)	Load (kg/d)	Load (T/yr)
TN	16	144	52
TP	9	91	30
TSS	10	90	33

[23] Figure 3-5 in AWT (2011)
[24] Table 4-4 in AWT (2011)
[25] Table 3-1 in AWT (2011)

[26] Source: Andrew Carvell , WDC (B. Tait 2013, pers.comm. 12 March).

For comparison, estimated daily loads of nutrients reported in WHWQMP WR12 (NRC, undated-2) based on the pre-1990 configuration of the WWTP are TN (approximated from TKN + NO_3-N) of 413 kg/day and TP of 90 kg/day.

4.6 Unreticulated Wastewater Discharges

Unreticulated wastewater discharges include:

- Community and household septic systems; and
- Farm dairy effluent discharges.

NRC's & WDC's (2012) background report provides the following description in relation to septic systems:

Septic, or onsite, systems refer to wastewater treatment that is not connected to a reticulated system. Septic systems fit into two main categories: community systems and single premise systems. Examples of community systems include schools, food premises, camping grounds and accommodation facilities, sports and recreation facilities, marae and community halls, and some residential communities such as retirement homes.

Until recently, failing and poorly performing septic systems were an issue in some areas, including the northern shore of the Harbour. Whangarei District Council now reticulates wastewater from Whangarei Heads to the WWTP and this has largely rectified the issue in this area. Northland Regional Council and Whangarei District Council continue to investigate evidence and reports of failing septic systems in other parts of the catchment.

In other parts of the greater Harbour catchment, and outside wastewater reticulated areas, households treat and dispose of their wastewater through septic systems. While there is always the potential for faecal pathogens and nutrients to enter streams via leaching from failing and poorly performing septic systems there is presently insufficient evidence to confirm whether it is a widespread or significant issue. For example, investigations have been undertaken in the upper Hatea catchment to determine the causes of regularly elevated levels of faecal bacteria indicators at Whangarei Falls, a popular freshwater swimming site. The investigation found that the sources of elevated levels were ruminants, dogs, and water fowl.

It is important to note that some of the soils in the greater Harbour catchment are poorly drained, particularly in the Otaika, Puwera, and Whangarei South sub-catchments, and are marginal for septic system disposal.

NRC's & WDC's (2012) background report provides the following description in relation to farm dairy effluent discharges:

The term farm dairy effluent refers to animal effluent from dairy farm facilities. There are approximately 4,000 dairy cows in the greater harbour catchment. Almost all of these are found in the Otaika, Puwera, Whangarei South, and Marsden Point sub-catchments. Sixteen of the 19 dairy farms discharge their effluent to land while the other three have consents to discharge effluent to water. There are no dairy farms in the sub-catchments that drain to the Hatea River arm of the upper Harbour.

Regionally and nationally, a lot of attention has been given to farm dairy effluent over the past two decades, and considerable improvement has been made in treating effluent and disposal. Farm dairy effluent is strongly regulated under the Regional Water and Soil Plan for Northland, and it is not considered by Northland Regional Council to be a major source of contamination in the upper Harbour.

We are not aware of any previous studies in the upper Harbour catchment which are relevant for estimating loads of contaminants discharged from septic systems or in farm dairy effluent.

4.7 Industrial discharges

NRC's & WDC's (2012) background report provides the following description in relation to discharges from industrial activities:

There are a small number of industrial sites and facilities in the greater catchment that discharge contaminants to the Harbour. The majority of the discharges from these sites are stormwater and cooling water, with the main contaminants being suspended sediments and other particulate matter, elevated temperature, and changes in pH. Levels of faecal pathogens, nutrients, and heavy metals are minor.

All discharges are authorised by conditions of resource consent, which are monitored regularly and reviewed. The sites have measures in place to prevent and control contaminants entering the Harbour, including management plans and procedures for any accidental spill, bunding and other detention structures, and other treatment systems.

Overall, the discharges have had good compliance with respective resource consents. Northland Regional Council considers that these discharges are generally well-managed. However there are some uncertainties regarding the actual composition of first flush stormwater and volumes discharged from some sites that may need to be assessed over time.

The report makes particular reference to improvements in the quality of discharges from the Portland cement works located on the Mangapai arm of the Upper Harbour:

Over the past several decades considerable effort has been spent on reducing discharges of contaminants to improve the quality of water in the Harbour. Major changes to the management of the Harbour include: … Ending the discharge of very fine textured sediment from the Portland cement factory – prior to 1982 huge quantities were discharged direct to the harbour.

We are not aware of any previous studies in the harbour catchment which are relevant for estimating loads of contaminants discharged from industrial activities, although the Port Rd CMP does estimate stormwater loads of certain contaminants discharged from this industrial area (see Section 4.2.2).

4.8 Other point source discharges

Other activities which have the potential to discharge contaminants at point sources include landfills, construction earthworks and quarries.

NRC's & WDC's (2012) background report provides the following description in relation to landfills:

Most water quality concerns involving landfills related to leachate, the water that passes through landfills and picks up waste-soluble compounds and particulate matter. If designed properly and managed well, landfills present very little risk to groundwater and surface waters that are hydrologically connected.

The Regional Water and Soil Plan regulates the operation of landfills to prevent and control any adverse effects on water quality.

The present landfill and the recent landfill for Whangarei District are both located within the greater Harbour catchment. The former landfill on Pohe Island sits at a prominent location beside the Hatea River quite close to central business areas, light industrial areas, and major council infrastructure such as the Whangarei Wastewater Treatment Plant. The Pohe Island landfill was closed in 2005 and is subject to a number of remedial works, including clay capping over the next few years. …

Any leachate from this site is currently piped to the Whangarei WWTP for disposal. Since 2006, six-monthly and annual monitoring has occurred on this site. Monitoring consists of site inspections, cap inspections, ground monitoring bores, and settlement inspections amongst other activities. Drainage on site is considered to be in good condition. Monitoring bores have noted some small amounts of leachate gas, while floodgate monitoring has not indicated any major issues. Overall the site is in good condition and is well maintained. The monitoring programme is on-going, and should help identify any leachate problems at an early stage.

In 2010 a new landfill was opened at Puwera. Compared with the former Pohe Island landfill, the new landfill is more distant from Harbour waters, and more technology has been made available to ensure little or no problems emerge from the site. An annual report is required as part of its resource consent. Monitoring to date has revealed a few small issues, with a small amount of odour, but more concerning, the presence of some leachate in monitoring bores, with elevated levels of ammoniacal nitrogen being recorded. However, this record may be due to the swampy nature of the monitoring site, and more baseline monitoring is required to confirm whether it is a seepage issue.

Prior to the use of Pohe Island, landfills were situated at the entrance to Limeburners Creek (at the present day cricket ground) and at Onerahi.

The main water quality concern relating to earthworks and quarries is the potential discharge of elevated concentrations of suspended solids in stormwater runoff. NRC's & WDC's (2012) background report provides the following description in relation to construction earthworks:

Land development for the purposes of building construction and subdivision activities, whether residential, commercial or industrial, can also be a source of sediment into local waterways and, ultimately, the Harbour. Subdivision and building construction activity across the district was very high during 2001-2008, with approximately 11300 lots created and approximately 6650 consents for new residential or commercial buildings being granted. Much of this activity occurred within the Harbour catchment.

Recent activity has slowed, with approximately 350 lots being created in 2010-2011, along with approximately 340 building consents being issued across the district. …most of the recent activity occurs within the Whangarei Harbour catchment. With 270 new households in *the Whangarei Harbour catchment per annum being projected in the Whangarei Growth Strategy, this trend is likely to continue.*

The Whangarei District Plan and associated Environmental Engineering Standards contain a number of provisions around subdivision activities that could generate environmental effects such as sediment, including the management of earthworks. The effectiveness of these provisions in reducing sediment from building or subdivision activity will continue to be monitored and amended as necessary.

Currently there are major construction earthworks at Pohe Island (in relation to the capping of the closed landfill) and associated with the construction of a new road bridge across the Hatea River. In both cases, extensive sediment control measures are in place and neither is considered a major sediment source to the harbour[27].

NRC staff advise that here are six operational quarries located in the harbour catchment. The two largest are the Portland quarry (operated by Golden Bay cement) in the Whangarei South sub-catchment and Otaika Quarry (operated by Winstone Aggregates) in the Limeburners sub-catchment. There is a second small boutique quarry at Portland (Paradise Quarry) and small quarries in the Kirikiri sub-catchment (Brocks Western Hills Quarry), Hatea sub-catchment (Dicksons Quarry) and Otaika sub-catchment (Kaigoose Lime). There is also one other quarry (H.E.B. Contractors Ltd) in the Otaika sub-catchment which is reported not to be currently operating.

We are not aware of any previous studies in the harbour catchment which are relevant for estimating loads of contaminants discharged from landfills, construction earthworks or quarries.

4.9 Background Sources

In addition to the generation of contaminants by anthropogenic activities it is important to recognise that there can be natural or ‘background’ sources of these substances. For the purpose of this discussion, we have defined what we mean by ‘background’ for the various contaminants of interest as follows.

Background sediment loads are those associated with the pre-human land cover. As noted in Section 4.4, sediment loads generated in the areas of remnant native forest in the catchment can be expected to be consistent with background loads.

For nutrients and metals we define background levels to mean the concentrations that these substances are found at in catchment soils in the absence of any anthropogenic activity that would increase their concentration (urban or rural). The background loads of nutrients and metals are then the present-day quantity of these substances discharged to the harbour that result solely from their presence at background concentrations in the catchment soils.

It is important to note that background sources can influence water quality. NRC (2012a) notes that, for Northland as a whole, the water quality of most river and stream monitoring sites “showed moderate performance in comparison to the total phosphorus guidelines for protection of aquatic ecosystems. This is partly due to Northland’s phosphorus-rich

[27] (B. Tait 2012, pers.comm. 23 November).

sandstone and mudstone catchment geology which provides a naturally high background level of phosphorus to streams."

For faecal pathogens, background concentrations are assumed to be zero, as the viruses of concern for human health cannot exist in the absence of humans and agricultural livestock. However, there are background levels of indicator bacteria and these are, again, defined as those that are present in the absence of any human activity. These background levels reflect the natural occurrence of indicator bacteria in the environment, but exclude those associated with livestock.

We are not aware of any previous studies in the upper Harbour catchment that have attempted to estimate background loads of contaminants.

5 Review of Monitoring Data

5.1 Introduction

NRC holds water and sediment quality data from around 150 monitoring sites within the Whangarei Harbour catchment. These sites range from long-term baseline water quality monitoring sites to locations at which one-off sampling has occurred.

This chapter reports on a review of relevant monitoring data provided by NRC and describes its utility for quantifying contaminant sources, principally for the estimation of contaminant loads but also for investigating the location of key sources within each sub-catchment.

The data reviewed includes:

- Monthly water quality data from long-term routine monitoring sites in the Hatea (1 site) and Waiarohia (2 sites) sub-catchments;
- Fortnightly to monthly water quality data from project-specific monitoring in the Puwera sub-catchment (2 sites);
- Monthly water quality data collected since July 2011 from a site in the Otaika sub-catchment;
- Urban water quality and sediment quality results from sporadic sampling for stormwater management purposes, including the results of both WDC sampling (2002-3, hardcopy) and more recent sampling data provided by NRC;
- Water quality data from sporadic sampling of effluent discharged from the WWTP;
- Water quality data from sporadic sampling of consented industrial discharges;
- Bacteriological data from project-specific sampling of four main tributaries of the Hatea River (faecal indicator bacteria);
- Sediment quality data from annual sampling at a number of sites in the Hatea River arm of the harbour; and
- Water quality data from miscellaneous sampling sites throughout the catchment.

Appendix B contains further details of the data provided by NRC.

The data was reviewed on a sub-catchment basis to identify:

- the locations of sites in relation to the sub-catchment outlet, land use and major activities having a potential influence on water quality;
- the number of samples and the frequency at which they were collected; and
- the range of water or sediment quality parameters analysed.

The review did not involve analysis of the data, other than the generation of simple plots to compare the number of data points and the distribution and median concentration of parameters at each site (see Figure 5-2 to Figure 5-15). The following sections describe the results of this review, stating the potential value and limitations of monitoring results from each sub-catchment for the estimation of loads or identification of key contaminants sources (using text box summaries, as in the previous chapter). Sites are listed and plotted working upstream of the catchment outlet. Sites that are not considered to be of particular value for either of the purposes described above, for instance those with very limited data, are not reported.

One general comment that applies to much of the nutrient data collected is that while samples have frequently been analysed for ammoniacal nitrogen (NH_4-N), their analysis for total nitrogen (TN) or nitrate-nitrite nitrogen (NO_x-N) has been much more limited. While NH_4-N is clearly an important parameter for water quality sampling programmes to include because of its toxicity at elevated concentrations, the absence of data on other forms of nitrogen or total nitrogen limits the value of much of the nutrient data for the estimation of loads. However, in some instances it may be possible to apply literature-based values to estimate TN from the observations of NH_4-N. Representative values of NH_4-N in untreated wastewater, for instance, suggest that it makes up about 60% of TN, with the remainder being present as organic forms of N (Ellis, 2004).

5.2 Onerahi sub-catchment

Table 5-1 lists the most data-rich water quality and sediment quality sampling sites in the Onerahi sub-catchment while their location is shown in Figure 5-1. Water quality and sediment quality data provided by NRC are plotted in Figure 5-2 and Figure 5-3, respectively. Note that the results of two WDC stormwater sampling runs undertaken in 2002 and 2003 include water and sediment quality data for sites corresponding with NRC numbers 100223 and 100224, but the data provided by NRC does not contains these results (other than the sediment quality data from 23/2/2002).

Table 5-1: Selected water quality and sediment quality sampling sites, Onerahi sub-catchment.

Site number	Site name
Water Quality	
100461	Riverside Creek @ Floodgate - landward side
102540	Riverside Creek @ Tanekaha Drive catchment
100223	Waioneone Creek e265 @ Onerahi Road
106103	Waioneone Creek @ Blw Drain from Flood Gate 10m
108017	Waioneone Creek @ upstream of tidal influence
106293	Hatea River @ Pohe Is. Tip face drain
Sediment Quality	
100224	Awaroa River @ Onerahi Rd
100223	Waioneone Creek e265 @ Onerahi Rd
106949	Parahaki Stream @ Rowing Club

The potential contribution that data from these sites can make is as follows:

- Sites 100461, 102540, 100223, 106293 are associated with monitoring of the closed Pohe Island landfill, hence the analysis of samples for acid soluble metals (As Cu, As Pb and As Zn). The data from these sites provide an indication of concentrations of SS, faecal coliforms, total Cu, total Pb, total Zn, and NH_4-N discharged from the landfill. Further information of leachate flow rates and the coverage of this monitoring relative to the landfill as whole would be required in order to determine whether they provide a basis for load estimation.
- The data from sites 106103, 108017 provide an indication of stream water concentrations of SS, NH_4-N, faecal coliforms and metals in a non-urban part of the Onerahi sub-catchment. The WDC data from sites 100223 and 100224 provide an indication of stream water concentrations of SS, NH_4-N and metals in an urban part of the Onerahi catchment. These data can be used in a catchment wide assessment (i.e. comparing water quality on a sub-catchment by sub-catchment basis) but do not allow an assessment of key source areas within the Onerahi sub-catchment and contain too few data points for the estimation of loads.
- Because the sediment quality sampling sites are all located in the harbour they are useful for characterising spatial variations in contamination of the harbour but not for attempting to identifying key sources within this sub-catchment.

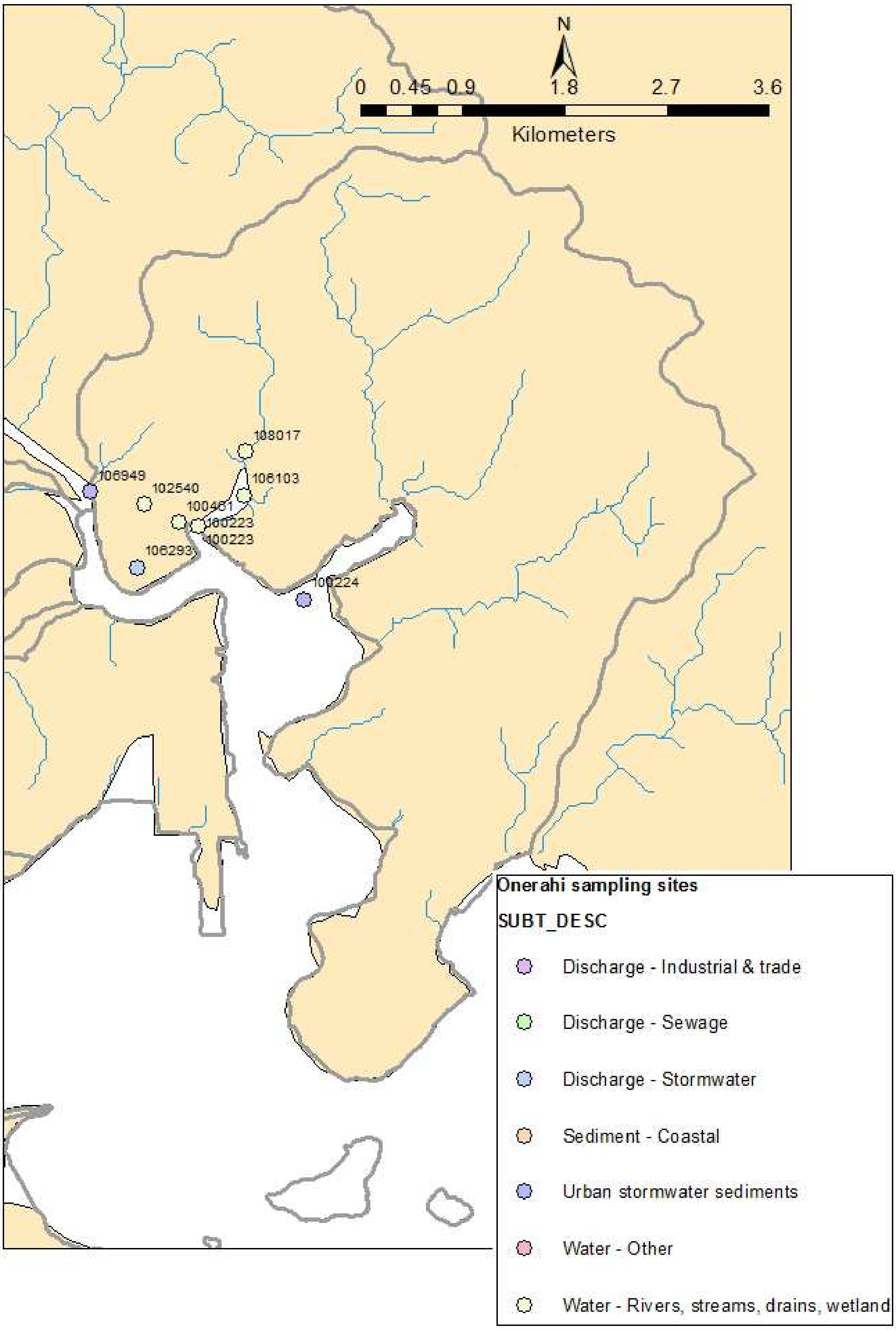

Figure 5-1: Location of selected water quality and sediment quality sampling sites, Onerahi sub-catchment.

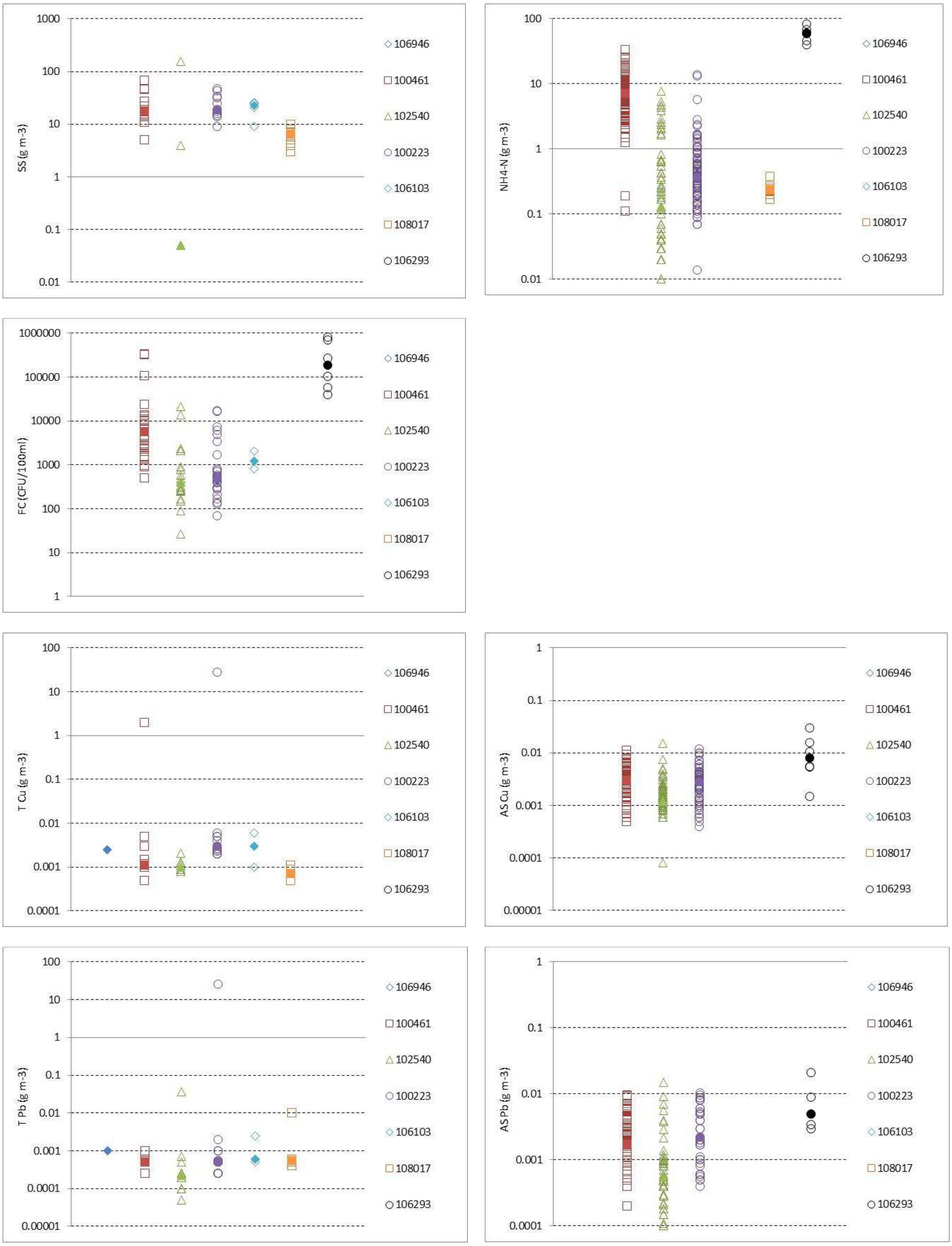

Figure 5-2 (see caption next page)

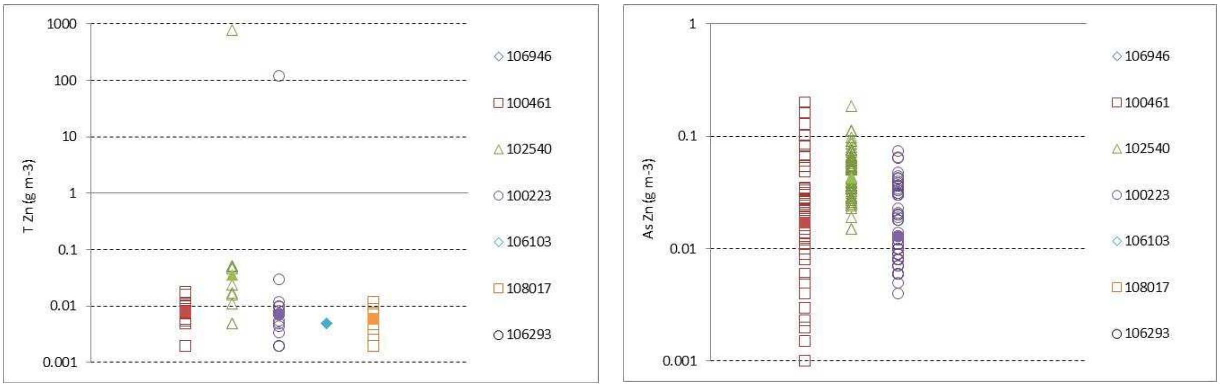

Figure 5-2: Summary plots of data from selected water quality sampling sites, Onerahi sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

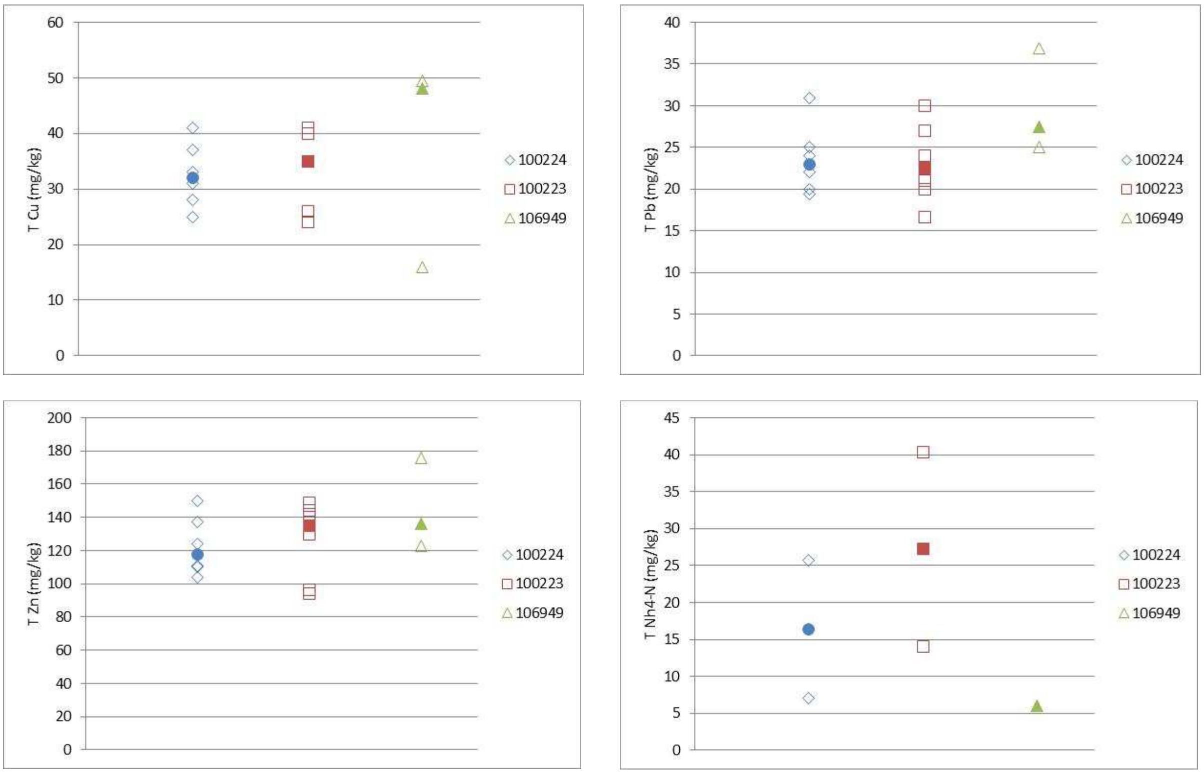

Figure 5-3: Summary plots of data from selected sediment quality sampling sites, Onerahi sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

5.3 Hatea sub-catchment

Table 5-2 lists the most data-rich water quality and sediment quality sampling sites in the Hatea sub-catchment while their location is shown in

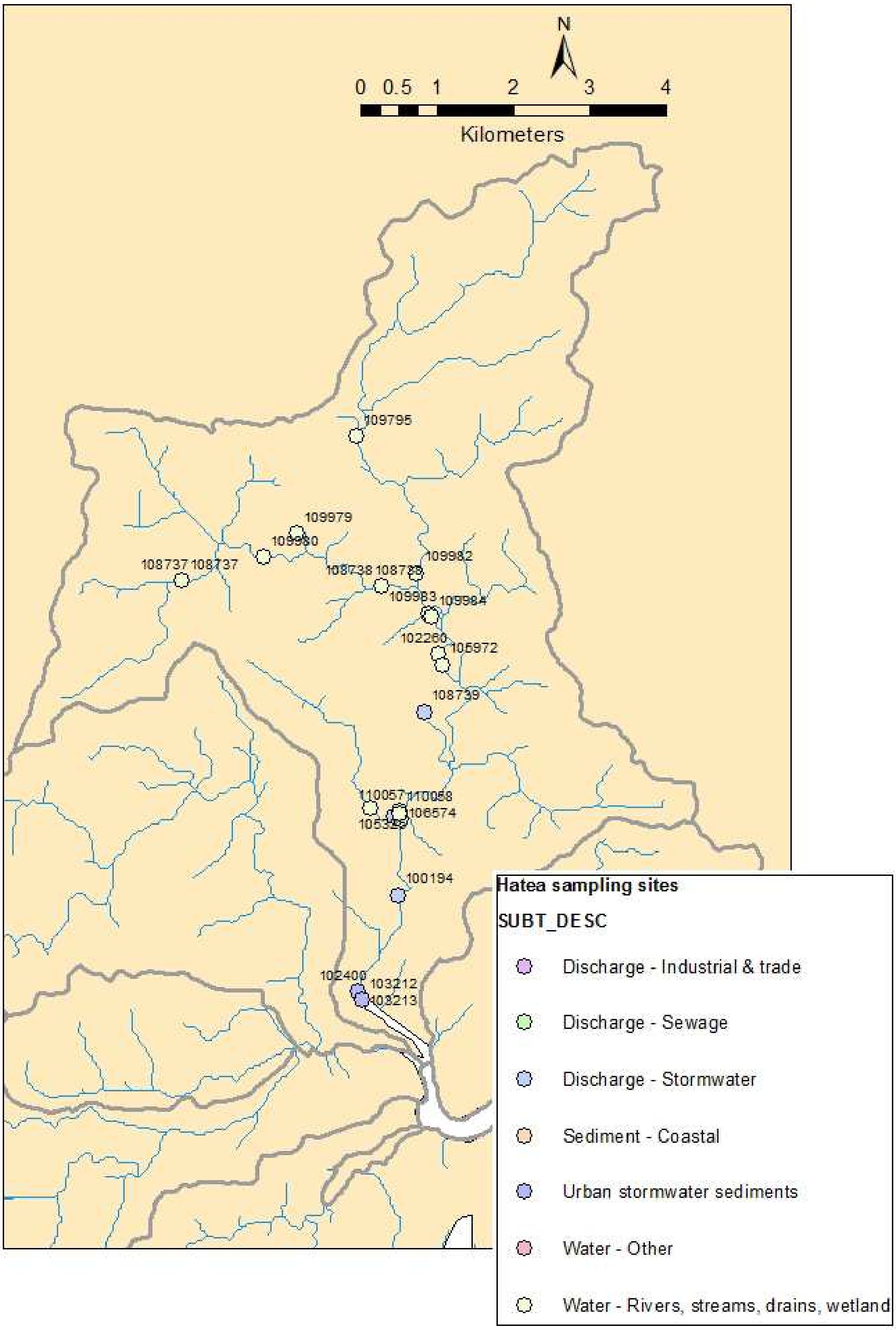

Figure 5-4. Water quality and sediment quality data provided by NRC are plotted in Figure 5-5 and Figure 5-6, respectively.

Note that the results of two WDC stormwater sampling runs undertaken in 2002 and 2003 include water and sediment quality data for sites corresponding with NRC numbers 108736, 108738 and 108737, but the data provided by NRC does not contains these results (other than the sediment quality data from 23/2/2002). The WDC data also include results for a site not listed in any of the data provided by NRC (WDC site 21 – City catchment, rowing club pontoon).

The potential contribution that the data from these sites can make is as follows:

- Site 100194 (Hatea River @ Mair Park Foot Bridge) is a long-term routine monitoring site located downstream of about 90% of the total sub-catchment area. This data may provide a basis for estimating sub-catchment loads of some contaminants, but not for SS and metals for which only limited are available. The data would need to be evaluated for its representativeness of a range of flow conditions, but this is facilitated by the fact that the sampling site is close to one of NRC's flow monitoring sites.
- The data from sites 108738, 108737 and 108736 provide an indication of stormwater and stream water concentrations of SS, NH_4-N and metals in the Waitaua SMC while sites 108740, 108739 and 103213 provide similar information for other parts of the sub-catchment (the CBD for instance). These data can be used in a comparative assessment of source areas within the Hatea sub-catchment but contain too few data points for the estimation of loads.
- Eleven sites provide data on faecal indicator concentrations upstream of the urban part of the catchment and can be used in a catchment-wide comparison.
- The sediment quality sampling sites are distributed from the sub-catchment outlet upstream as far as part of the upper catchment (in the Waitaua SMC). They can be used as part of a comparative assessment of source areas within the Hatea sub-catchment. An initial assessment suggests metal concentrations at site 108737 (near an industrial area at Kamo) are elevated above those at other sites, as reported elsewhere (for instance PDP, 2011a).

Table 5-2: Selected water quality and sediment quality sampling sites, Hatea sub-catchment.

Site number	Site name
Water Quality	
100194	Hatea River @ Mair Park Foot Bridge
106574*	Hatea River @ Below Whareroa Rd Bridge
110058*	Hatea River @ Point of Discharge Hatea Pump Station

Site number	Site name
102259	Hatea River @ Whareora Rd Br - recorder site
110057*	Hatea River @ 10m US of Hatea Pumpstation
105972	Whangarei Falls @ (Hatea River above falls)
102260*	Hatea River @ Above Whangarei Falls bridge
109984*	Hatea River @ Palms Retirement Village (45 Reed Street)
109983*	Hatea River @ US Tikipunga Sports Park
109982*	Mangakino Stream @ US Confluence with Waitaua Stream, Vinegar Hill Road
109795*	Mangakino stream @ the end of Mangakino Lane
108738	Waitaua Catchment @ Vinegar Hill Road, Waitaua Stream Bridge
109979*	Waitaua Stream UT @ The Rocks B&B, 58 Great North Road
109980*	Waitaua Stream @ Gillingham Road Bridge
108737	Waitaua Catchment @ Waitaua Stream Bridge, Kamo
108736	Waitaua Catchment @ Snake Hill
108740	Hatea Catchment, Otangarei Stream @ Whareora Road
105325*	Otangarei Stream @ Off end of Millers Lane
108739	Hatea Catchment @ Boundary Road Drain, Tikipunga
103213	Stormwater outlet (Hatea R) @ SW outlet D/S of bridge
Sediment Quality	
103212	Outlet (Hatea River)
102400	Hatea River @ Victoria Bridge s/w pipe
108738	Waitaua Catchment @ Vinegar Hil Road, Waitaua Stream Bridge
108737	Waitaua Catchment @ Waitaua Stream Bridge, Kamo
108736	Waitaua Catchment @ Snake Hill

* Faecal indicator bacteria data only, data not plotted in Figure 5-5

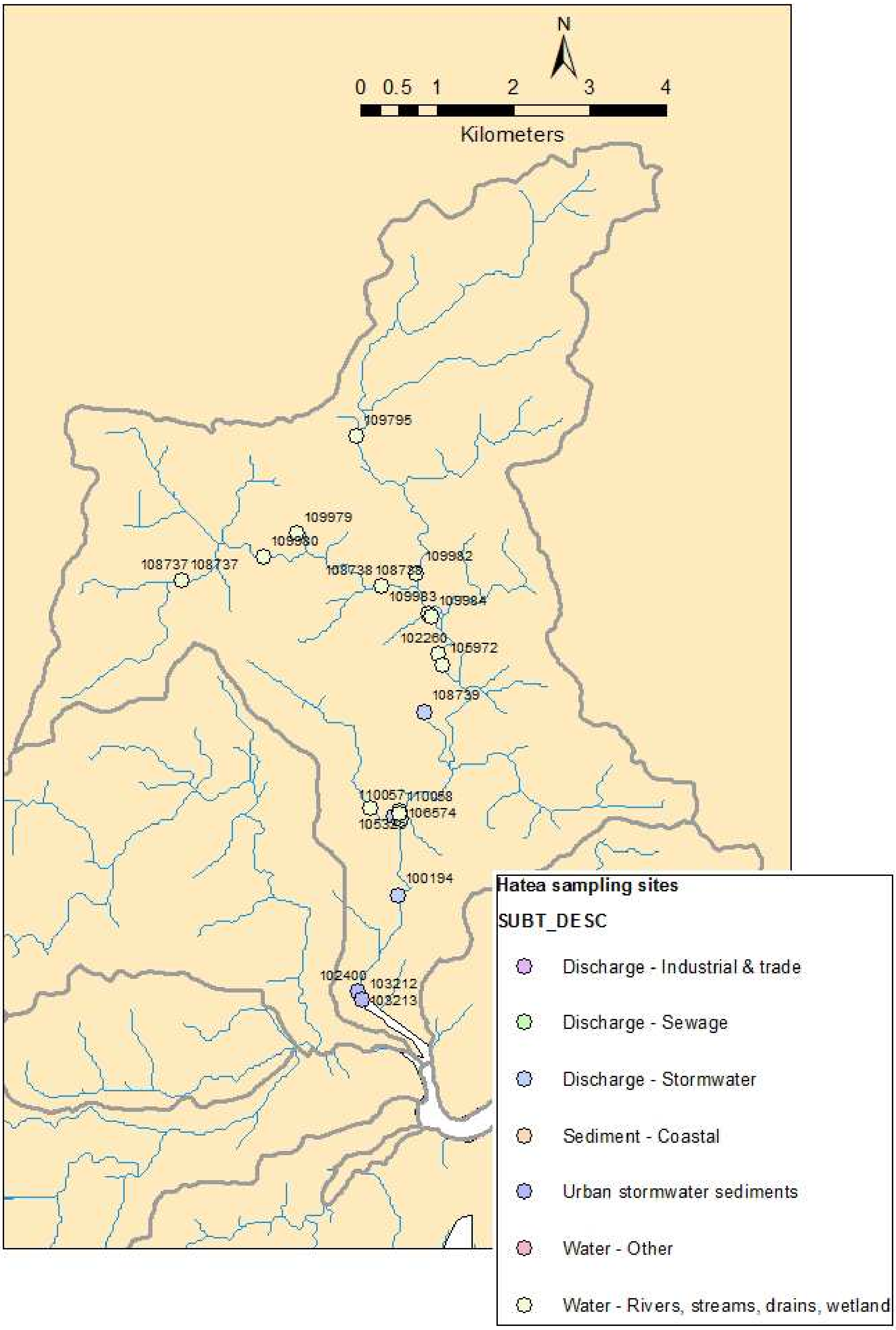

Figure 5-4: Location of selected water quality and sediment quality sampling sites, Hatea sub-catchment.

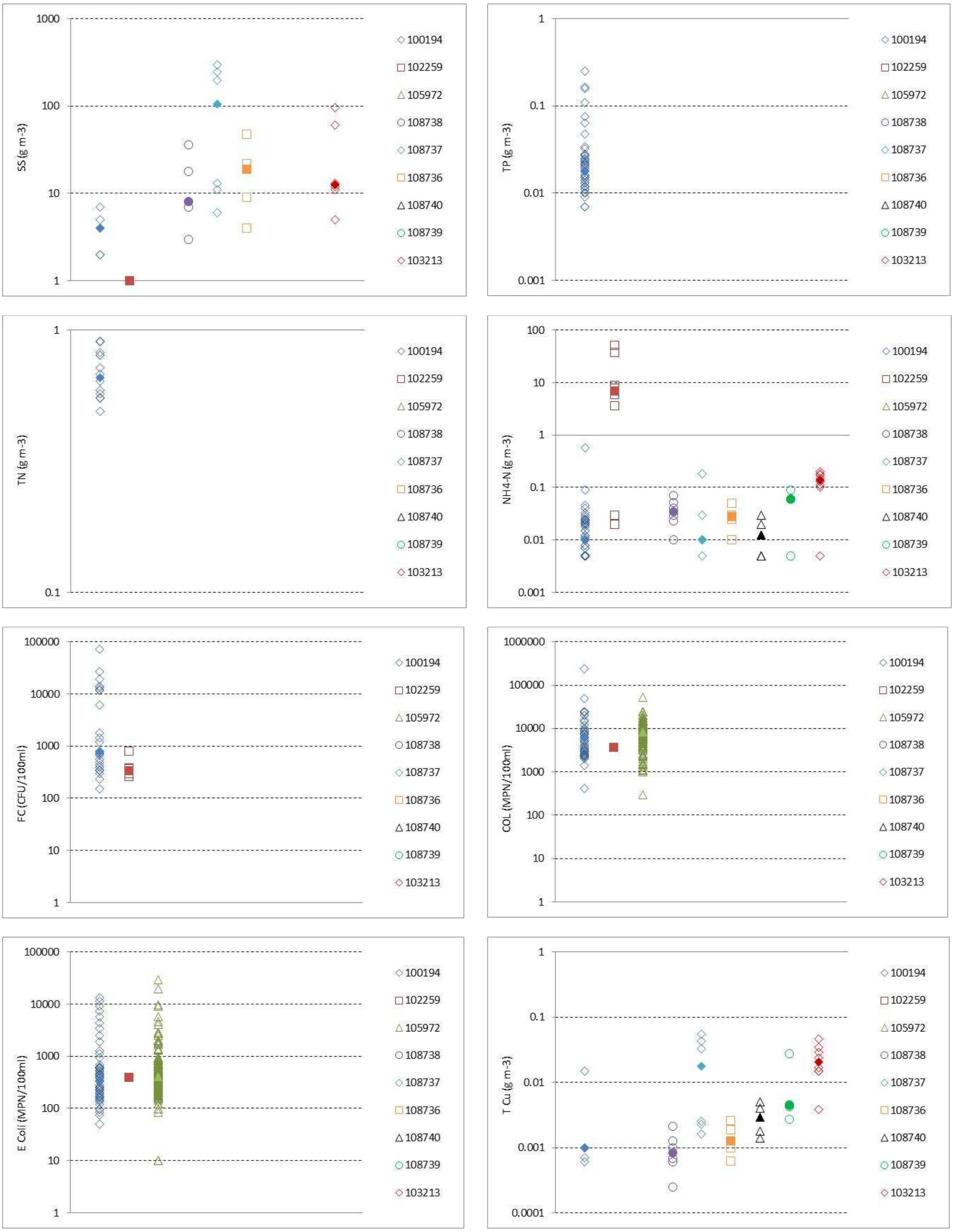

Figure 5-5 (see caption next page)

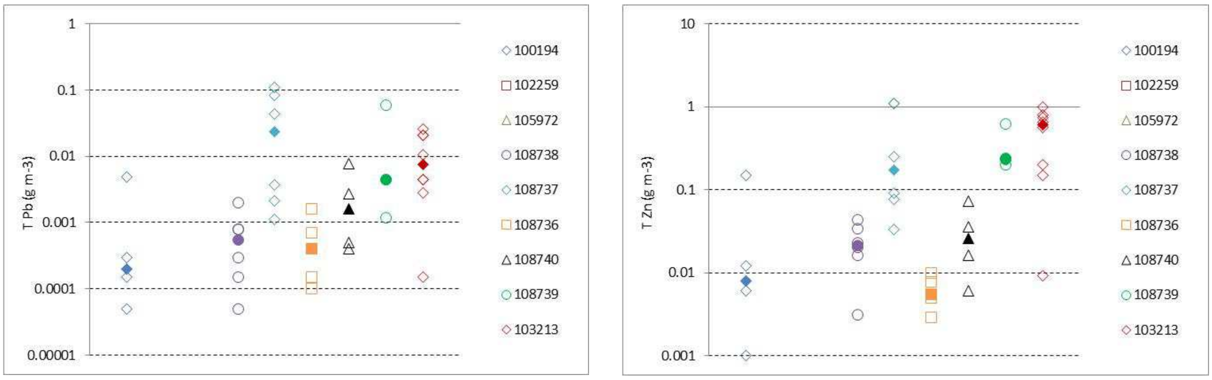

Figure 5-5: Summary plots of data from selected water quality sampling sites, Hatea sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

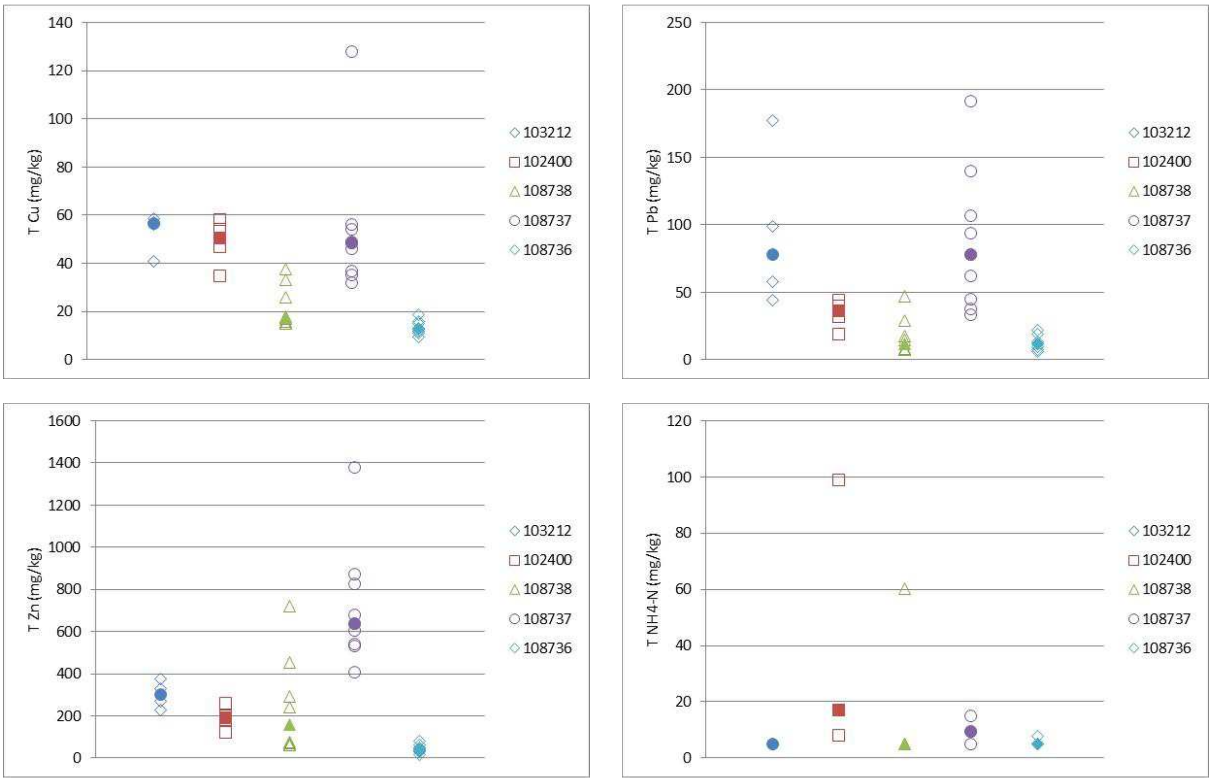

Figure 5-6: Summary plots of data from selected sediment quality sampling sites, Hatea sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

5.4 Waiarohia sub-catchment

Table 5-3 lists the most data-rich water quality and sediment quality sampling sites in the Waiarohia sub-catchment while their location is shown in Figure 5-7. Water quality and sediment quality data provided by NRC are plotted in Figure 5-8 and Figure 5-8: Summary plots of data from selected water quality sampling sites, Waiarohia sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

, respectively.

Note that the results of two WDC stormwater sampling runs undertaken in 2002 and 2003 include water and sediment quality data for sites corresponding with NRC numbers 107773, 108375 and 105672, but the data provided by NRC does not contains these results (other than the sediment quality data from 23/2/2002).

The potential contribution that the data from these sites can make is as follows:

- Site 108359 (Waiarohia @ Lovers Lane) is a long-term routine monitoring site located close to the catchment outlet. This data may provide a basis for estimating sub-catchment loads of some contaminants, but not for SS and metals for which only limited are available. The data would need to be evaluated for its representativeness of a range of flow conditions, but this is facilitated by the fact that the sampling site coincides with one of NRC's flow monitoring sites.
- Site 107773 (Waiarohia @ Whau Valley) is a long-term routine monitoring site located in the upper catchment. This data may provide a basis for estimating upper sub-catchment loads of some contaminants, but not for SS and metals for which only limited are available. It would be necessary to generate a synthetic flow record for the site, but this is feasible given the fact that there is flow monitoring site in the lower catchment.
- The data from sites 105672 and 108375 provide an indication of stormwater and stream water concentrations of SS, NH_4-N and metals at different locations in the sub-catchment. These data can be used in a comparative assessment of source areas within the Waiarohia sub-catchment but contain too few data points for the estimation of loads.
- The remaining three water quality sampling sites provide data on nutrient and faecal indicator concentrations upstream of the urban part of the catchment and can be used in a catchment-wide comparison.
- The sediment quality sampling sites are distributed from close to the sub-catchment outlet upstream as far as the confluence of the Waiarohia and Waikahitea Streams. They can be used as part of a comparative assessment of source areas within the Waiarohia sub-catchment.

Table 5-3: Selected water quality and sediment quality sampling sites, Waiarohia sub-catchment.

Site number	Site name
Water Quality	
108359	Waiarohia Stream @ Lovers Lane
105672	Waiarohia Stream @ Rust Avenue Bridge
105673	Waiarohia Stream @ Russell Road Bridge Sthern end
105674	Waiarohia Stream @ Russell Road Bridge Nthern end
105675	Waiarohia Stream @ Davidson property
108375	Waiarohia Stream @ Kamo confluence downstream
107773	Waiarohia @ Whau Valley
Sediment Quality	
104941	Waiarohia Stm @ U/S 30 m of Reyburn St road Bridge
105672	Waiarohia @ Rust Ave Bridge
108375	Waiarohia Stream @ Kamo confluence downstream
107773	Waiarohia Stream @ Waiarohia and Waikahitea stream.

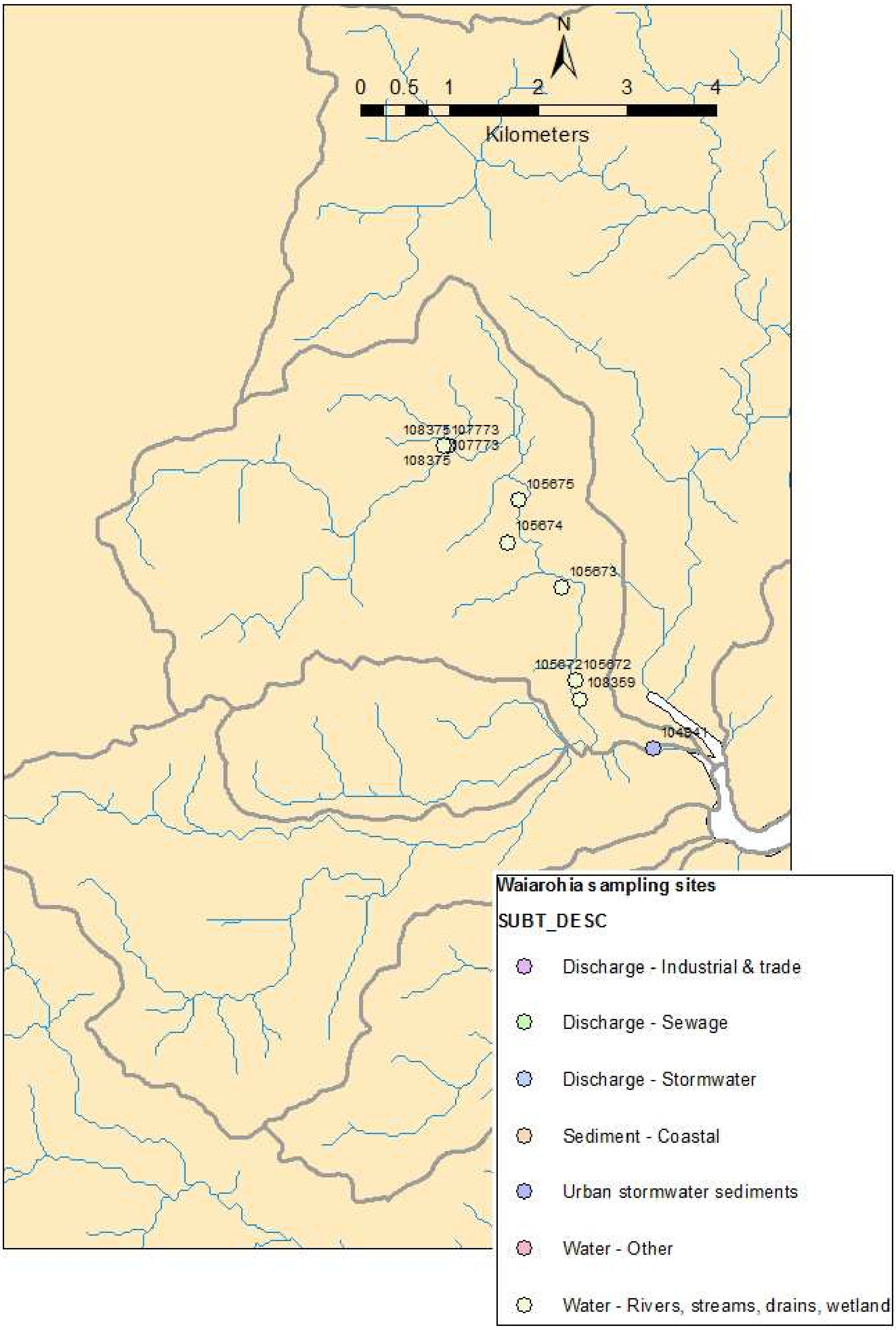

Figure 5-7: Location of selected water quality and sediment quality sampling sites, Waiarohia sub-catchment.

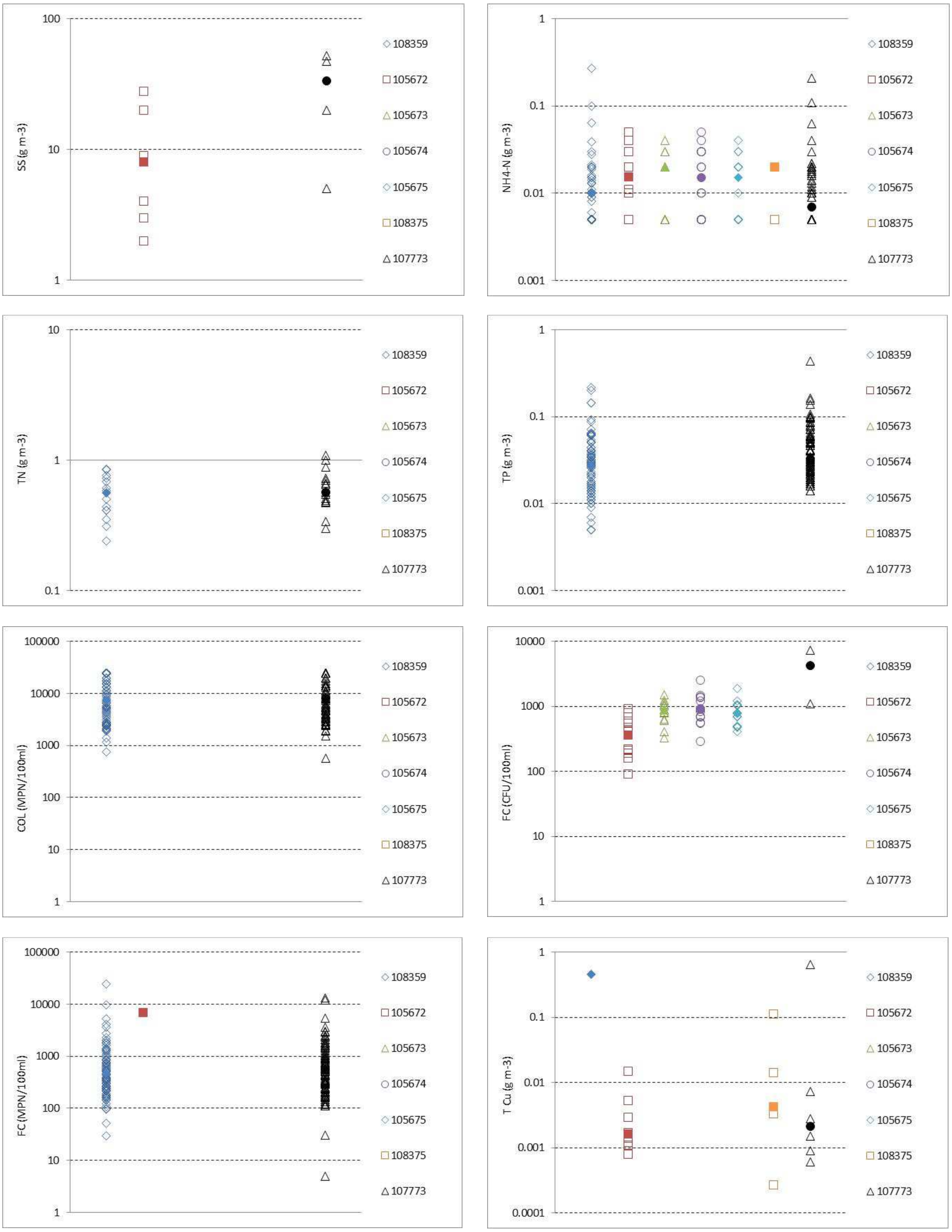

Figure 5-8: (see caption on next page)

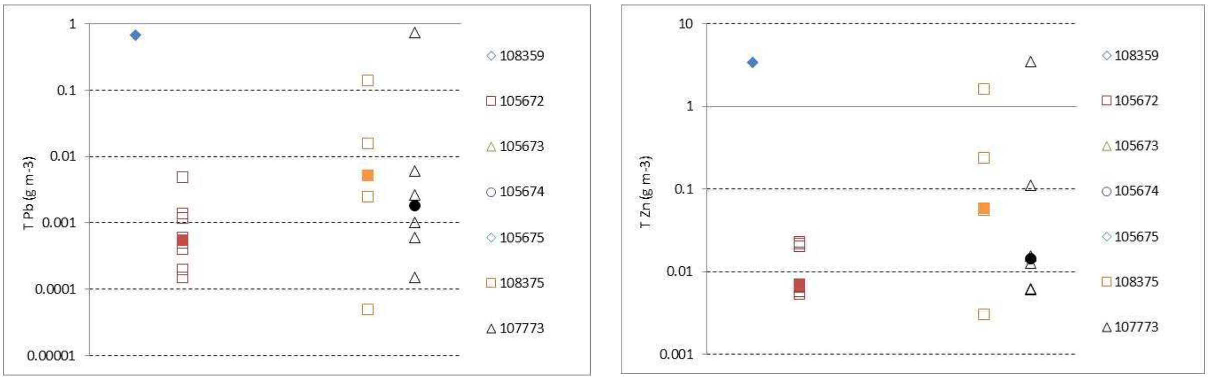

Figure 5-8: Summary plots of data from selected water quality sampling sites, Waiarohia sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

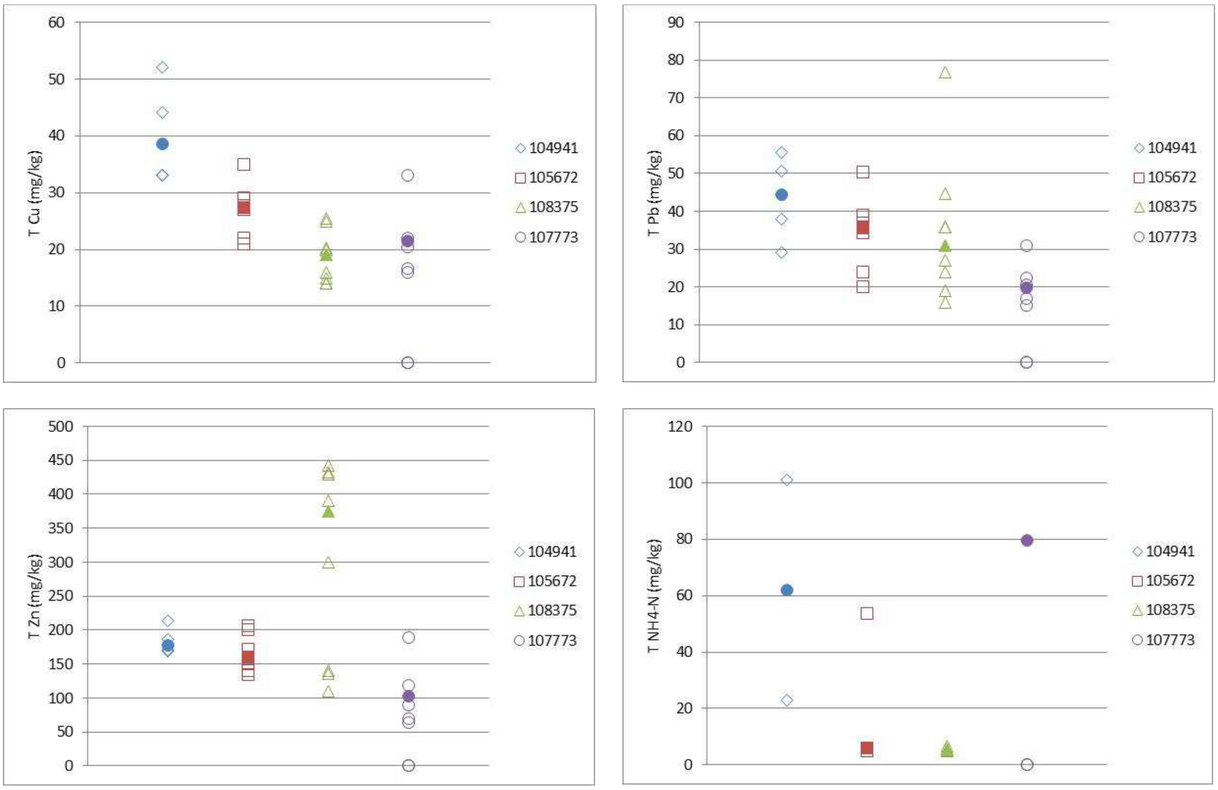

Figure 5-9: Summary plots of data from selected sediment quality sampling sites, Waiarohia sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

5.5 Kirikiri and Raumanga sub-catchments

Table 5-4 lists the most data-rich water quality sampling sites in the Kirikiri and Raumanga sub-catchments while their location is shown in

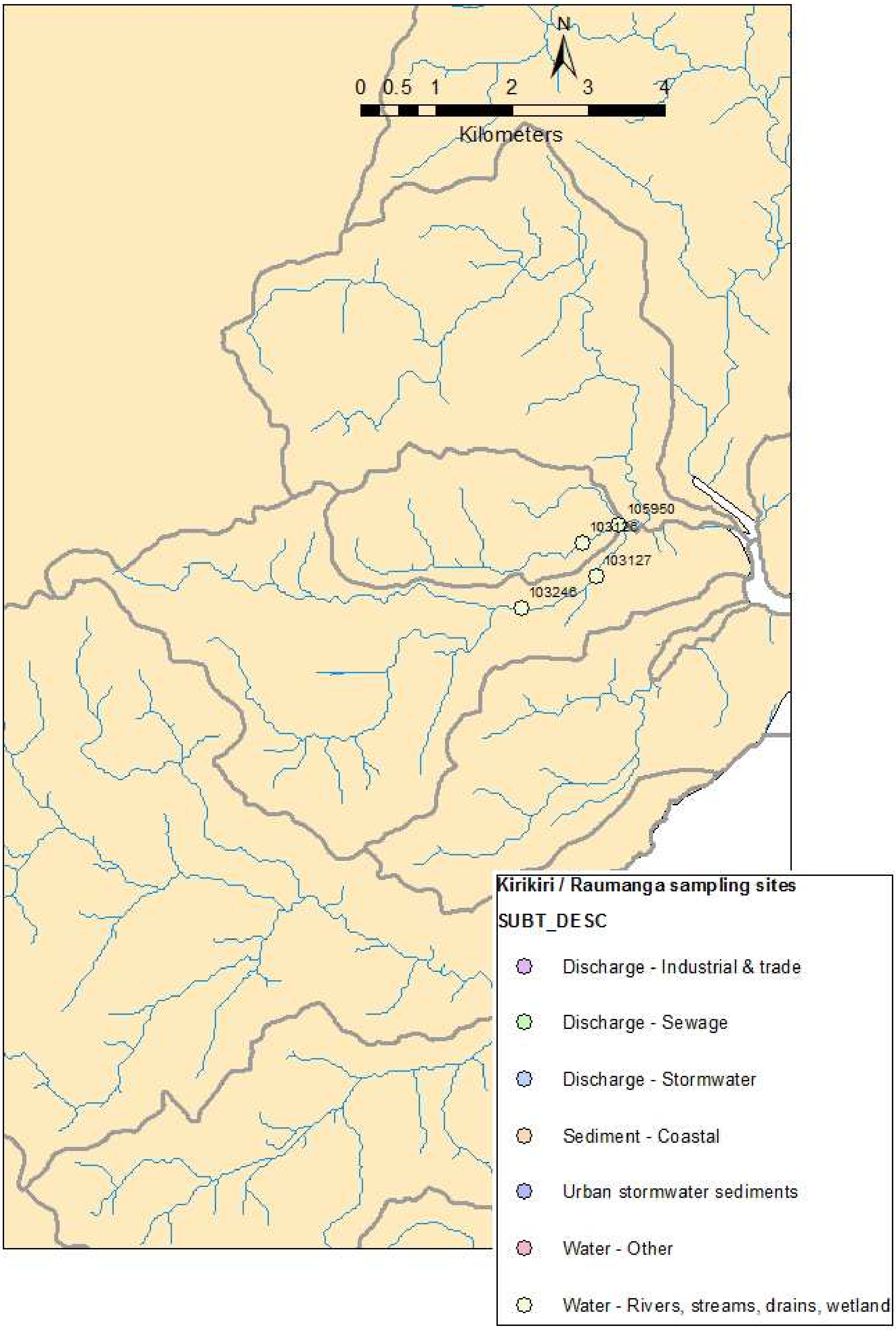

Figure 5-10. The data for these sites are limited to faecal indicator bacteria.

Note that the results of two WDC stormwater sampling runs undertaken in 2002 and 2003 include water and sediment quality data for sites corresponding with NRC numbers 110367, 104941 and 103213, but the data provided by NRC does not contains these results. The WDC data also include results for four sites not listed in any of the data provided by NRC (WDC sites 10 – Kirikiri Street Bridge; 11 – Porowini Bridge; 12 – Te Hihi Street; and 14 – Raumanga Reserve).

The potential contribution that the data from these sites can make is as follows:

- The four water quality sampling sites listed in Table 5-4 provide data on faecal indicator concentrations that can be used in a catchment-wide comparison.
- The WDC stormwater and sediment quality data can be used as part of a comparative assessment of urban water and sediment quality across the catchment, although it is limited to only two data points at each site.

Table 5-4: Selected water quality sampling sites, Kirikiri and Raumanga sub-catchments.

Site number	Site name
Water Quality	
105950	Kirikiri Stream @ Maunu Rd Bridge (above)
103126	Kirikiri Creek @ By pass culvert
103127	Raumanga Stream @ SH 1 bridge
103246	Raumanga Stream @ swimming pool below falls

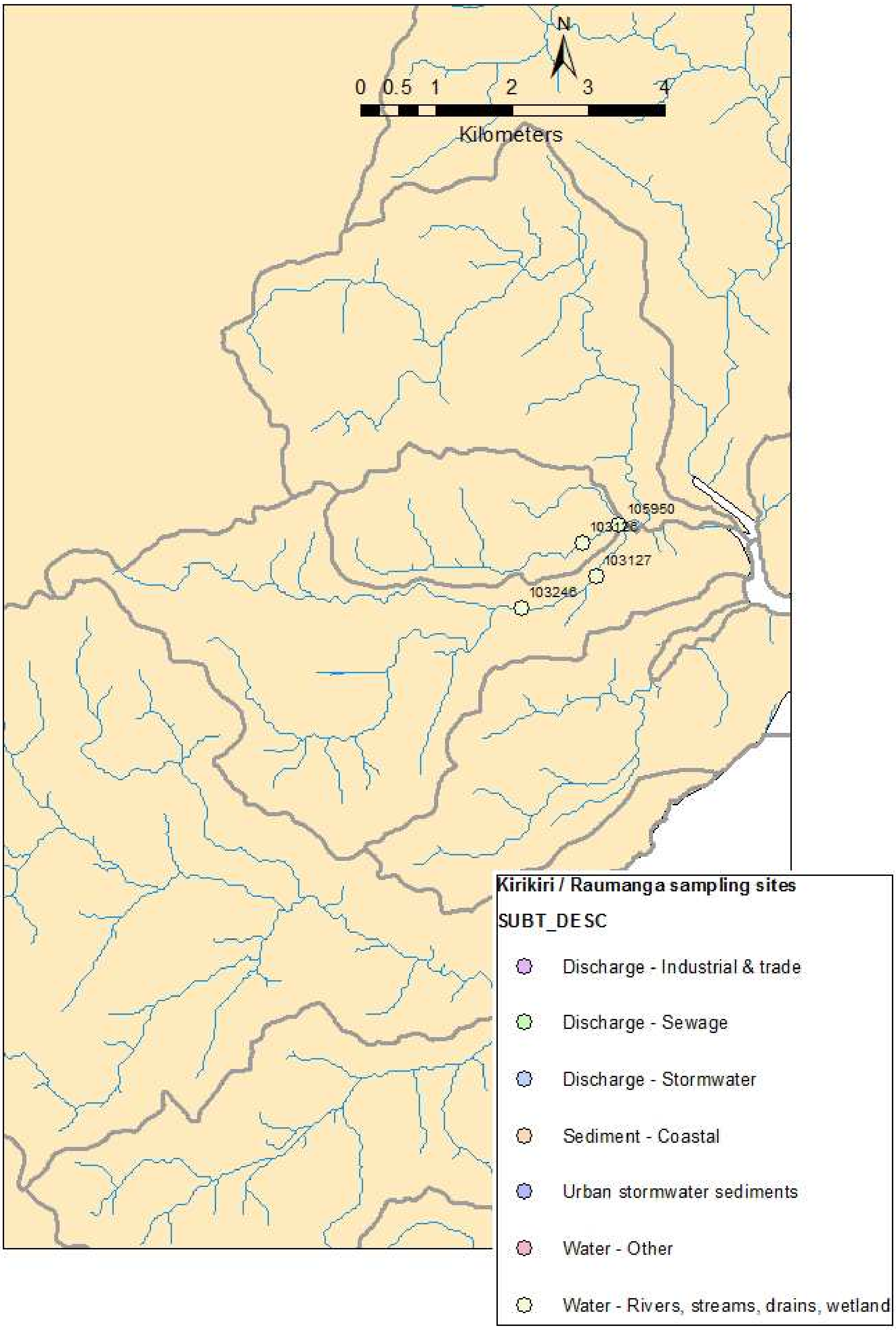

Figure 5-10:Location of selected water quality and sediment quality sampling sites, Kirikiri and Raumanga sub-catchments.

5.6 Limeburners sub-catchment

Table 5-5 lists the most data-rich water quality and sediment quality sampling sites in the Limeburners sub-catchment while their location is shown in

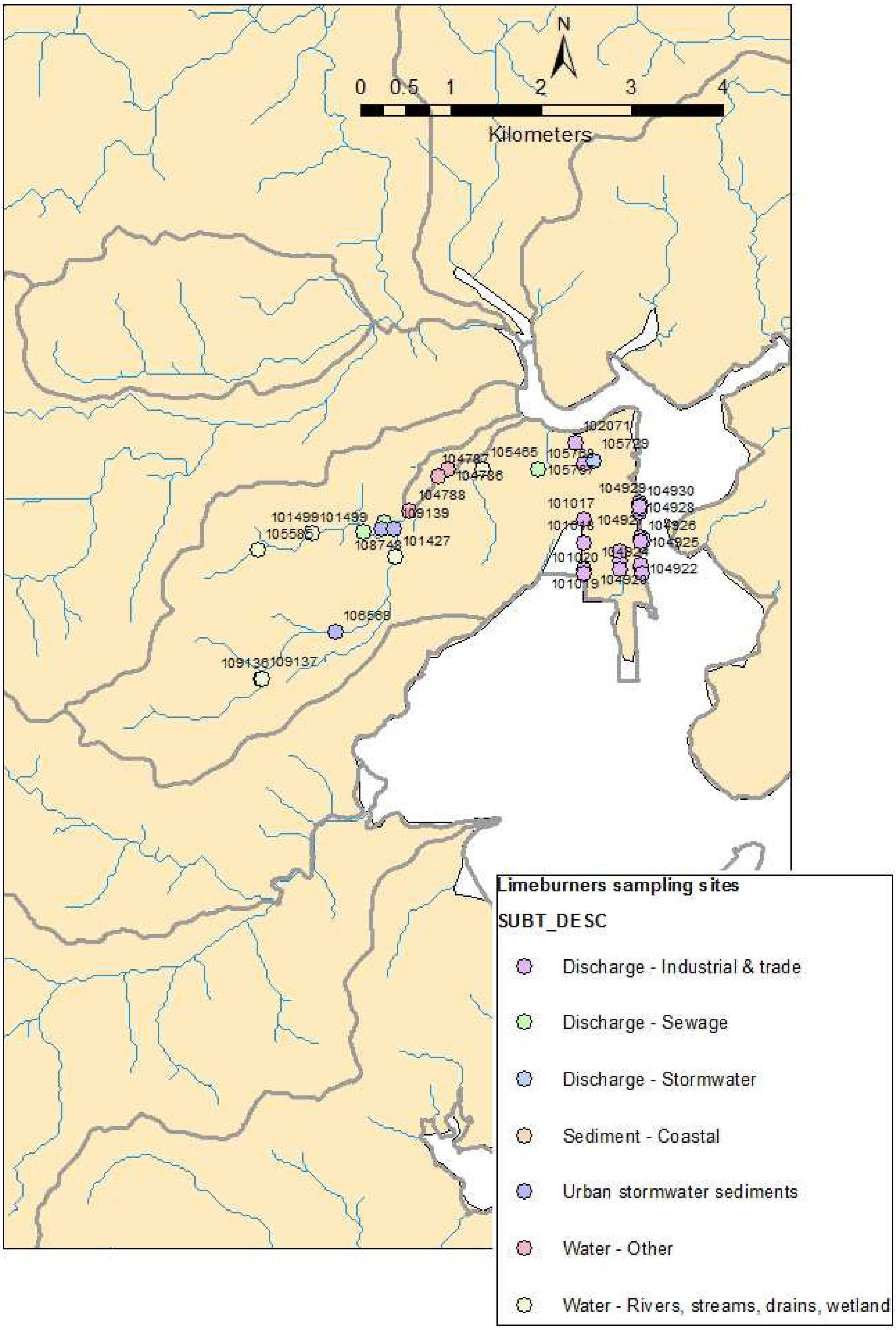

Figure 5-11. Water quality and sediment quality data provided by NRC are plotted in Figure 5-12 and

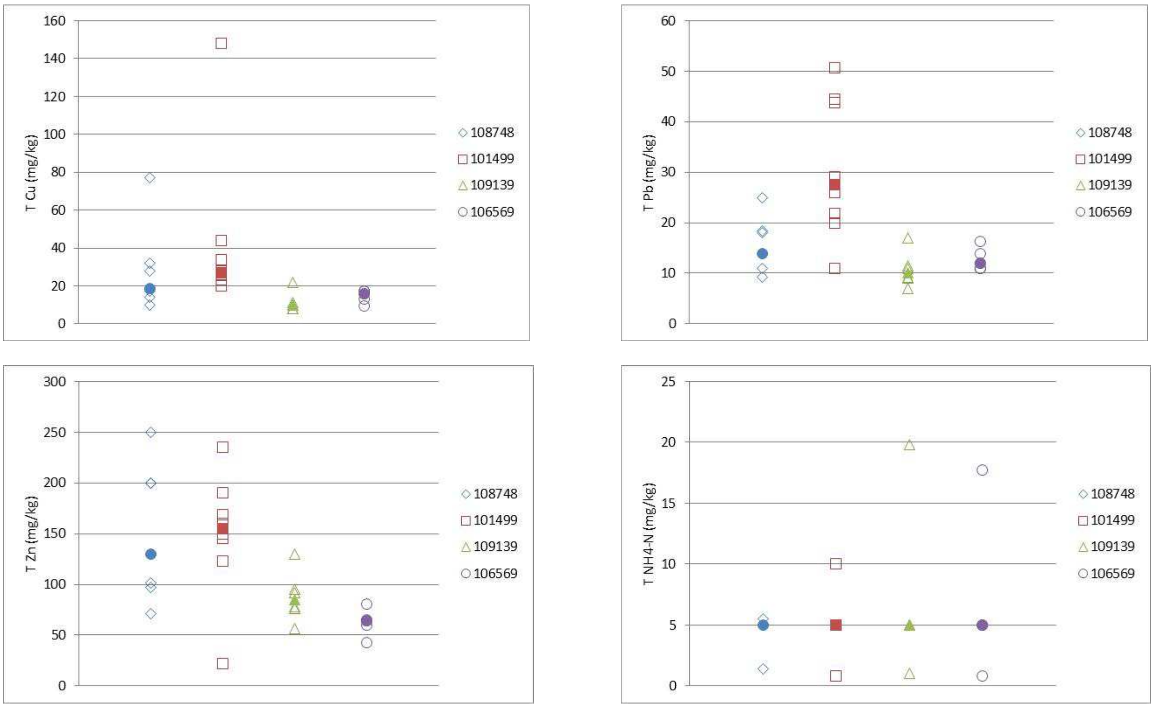

Figure 5-13:Summary plots of data from selected sediment quality sampling sites, Limeburners sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

, respectively.

Note that the results of two WDC stormwater sampling runs undertaken in 2002 and 2003 include water and sediment quality data for sites corresponding with NRC numbers 106569, 101499, 108748 and 109139, but the data provided by NRC does not contains these results (other than the sediment quality data from 23/2/2002).

The potential contribution that the data from these sites can make is as follows:

- Sites 108181 and 108182 are located upstream of discharge points from the WWTP. This data may provide a basis for estimating sub-catchment loads of SS, NH_4-N and faecal coliforms (excluding inputs from the WWTP). The data would need to be evaluated for its representativeness of a range of flow conditions, which would first require the development of a synthetic flow record based on analysis of flow records from neighbouring sub-catchments.
- The data from sites 101427, 105585 and 109137 provide an indication of stream water concentrations of SS and NH_4-N in the upper catchment. These data can be used in a comparative assessment of source areas within the Limeburners sub-catchment but contain too few data points for the estimation of loads.
- In combination with other information referred to elsewhere in this report, the data from four sites sampling treated wastewater effluent can be used to inform the estimation of loads of SS, NH_4-N and faecal indicator bacteria discharged from the WWTP.
- Data from 25+ additional sampling points can be used to provide an indication

of the water quality of discharges in the Port Rd industrial area and a quarry in the upper catchment but contain too few data points for the estimation of loads.

- Four sediment quality sampling sites are distributed through the catchment. The data from these sites can be used as part of a comparative assessment of source areas within the Limeburners sub-catchment and Upper Harbour catchment as a whole.

Table 5-5: Selected water quality and sediment quality sampling sites, Limeburners sub-catchment.

Site number	Site name
Stream Water Quality	
108182	Limeburners Creek @ 250m US wetland 2
108181	Limeburners Creek @ US Whangarei Sewage Treatment
101499	Upper Limeburners @ SH 1 Bridge
105585	Limeburners creek ut@ Tauroa Rd Culvert
101427	Limeburners Creek @ Rewarewa Rd bridge
109137	Winstone Aggregates @ 10m upstream
WWTP Discharges	
104788	Whangarei Sewage Treatment @ wetland 2 outlet
104787	Whangarei TP wetland no 1 @ Cascade - outlet B6
104786	Whangarei Sewage Treatment @ wetland 1 outlet
105465	Whangarei Sewage Treatment @ EQ basin bypass pipe
Other Point Source Discharges	
105768	Limeburners Creek UT @ Kiwi Downs Timber Treat. Yard
105729	Summit-Quinphos Port Road @ Settling pond outlet
101017	Farmers Fert Whangarei. @ Culvert - discharge
101018	Fert Factory Discharge @ First side drain,settling pond
101019	NPC Dredgings Ponds Drain @ Middle drain,above side stream
101020	Fert Factory Discharge @ Bend in drain
101399	Whangarei Harbour @ Drain CCA plant
101400	Whangarei Harbour @ Drain behind Office
101401	Whangarei Harbour @ Drain opposite main entrance
101402	Whangarei Harbour @ Drain by treatment plant
102071	Firth Certified Concrete @ East settling pond outlet
102112	Whangarei Harbour @ Fert works intake

Site number	Site name
104196	Works infrastructure Lower Port Road @ Final Settling Pond
104919	Whangarei Harbour (Log Store) @ A1 site Discharge from area
104920	Whangarei Harbour (Log Store) @ A2 site (10m north A1)
104922	Whangarei Harbour (Log Store) @ A4 site (10m south A1)
104923	Whangarei Harbour (log Store) @ B1 site Discharge from Area
104924	Whangarei Harbour (Log Store) @ B2 site 10m north B1
104925	Whangarei Harbour (Log Store) @ B3 site (10m east B1)
104926	Whangarei Harbour (Log Store) @ B4 site (10m south B1)
104927	Whangarei Harbour (Log Store) @ C1 site Discharge from Area
104928	Whangarei Harbour (Log Store) @ C2 site (10m north C1)
104929	Whnagrei Harbour (Log Store) @ C3 site (10n east C1)
104930	Whangarei Harbour (Log Store) @ C4 Site (10m south C1)
105767	Limeburners Creek UT @ Union East St Culvert
106086	Limeburners Creek UT @ U/S of Kiwi Timber
106087	Limeburners Creek UT @ Discharge from Kiwi Timber
109136	Winstone Aggregates @ Point of Discharge
Sediment Quality	
108748	Limeburners confluence@western stream
101499	Upper Limeburners @ SH 1 Bridge
109139	southern stream@Te Waiiti stream
106569	Limeburners UT @ Te Waiiti Stream

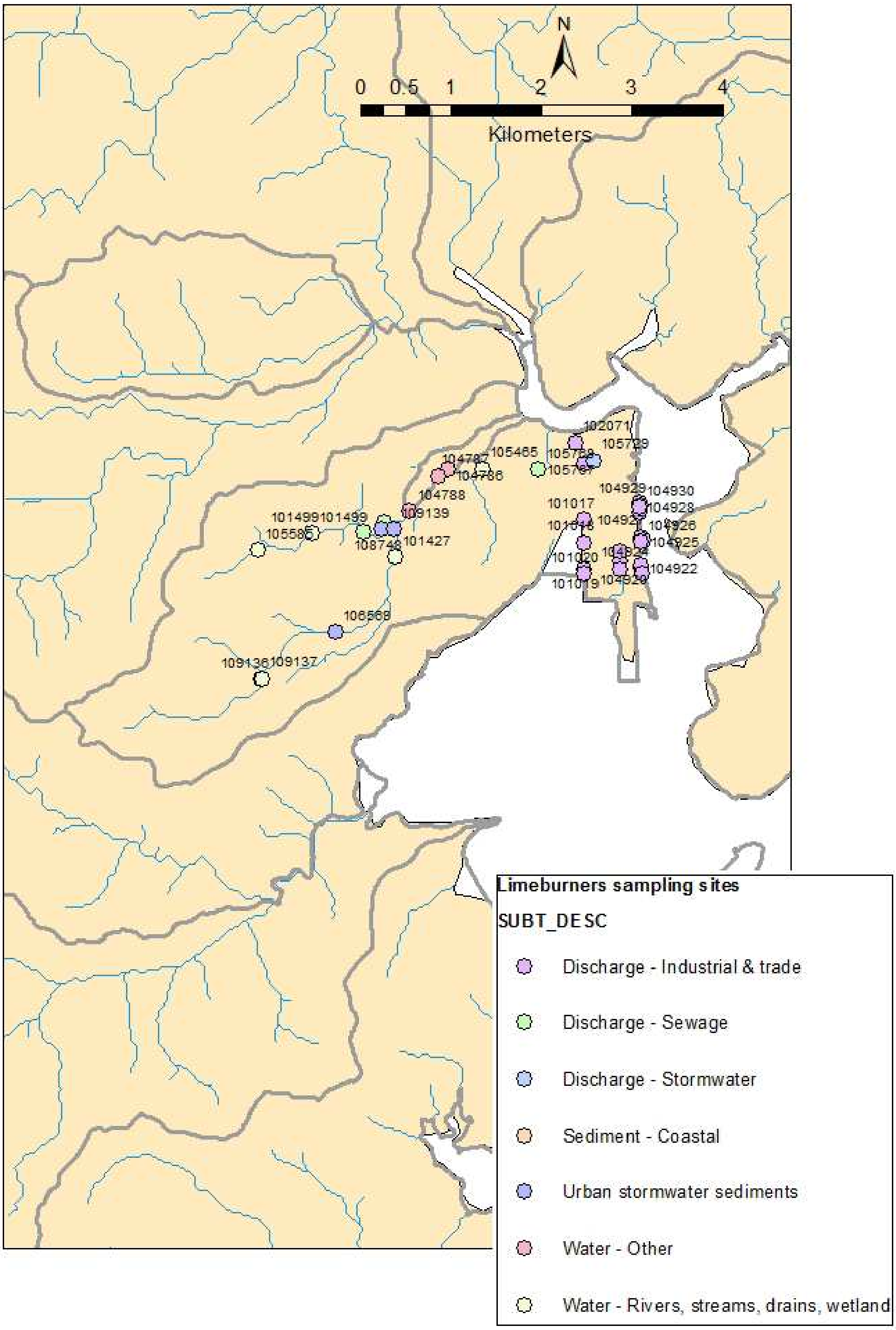

Figure 5-11:Location of selected water quality and sediment quality sampling sites, Limeburners sub-catchment.

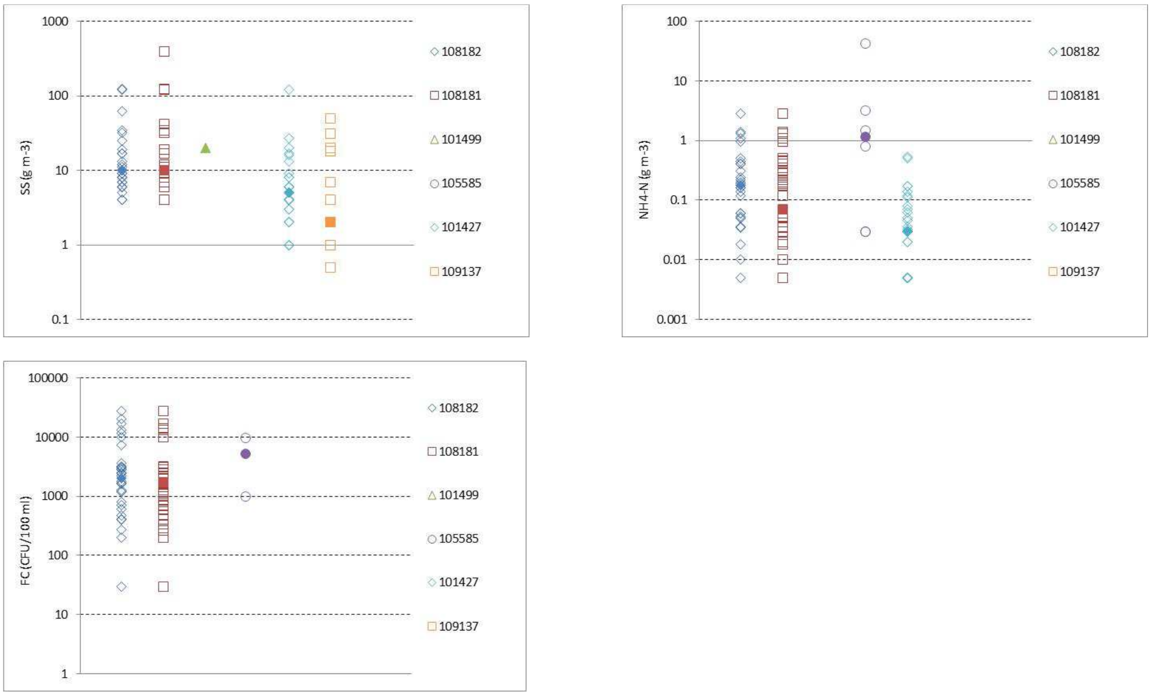

Figure 5-12:Summary plots of data from selected water quality sampling sites, Limeburners sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

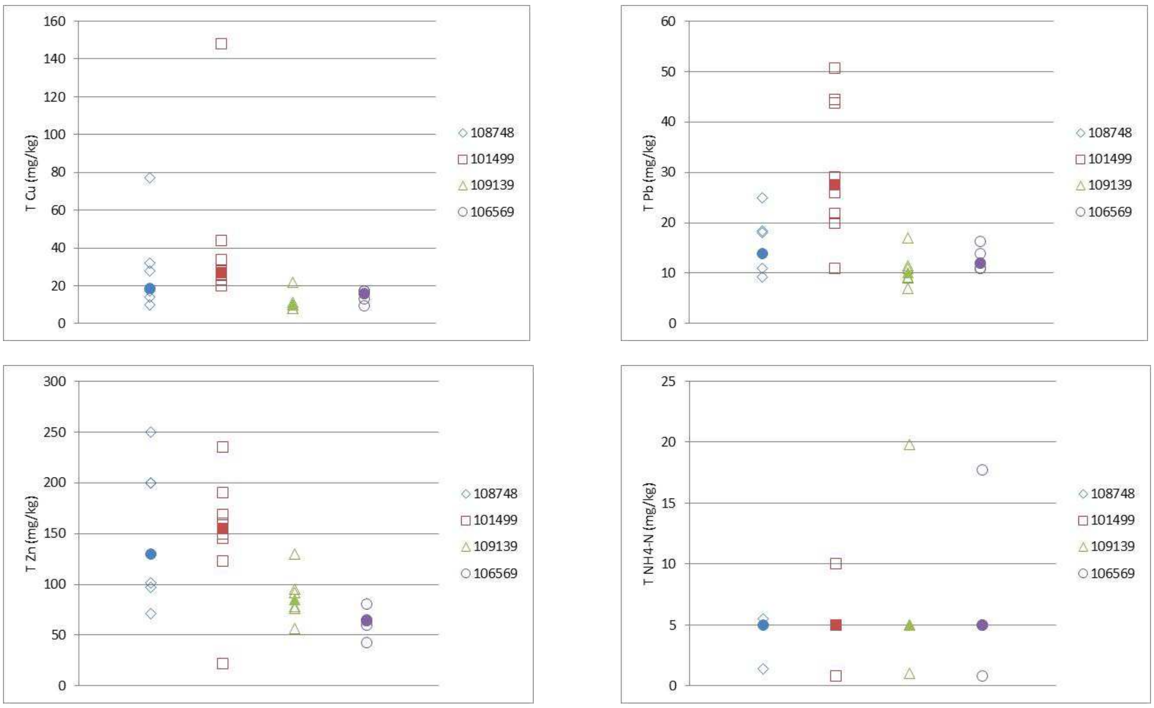

Figure 5-13:Summary plots of data from selected sediment quality sampling sites, Limeburners sub-catchment. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

5.7 Otaika and Puwera sub-catchments

Table 5-6 lists the most data-rich water quality sampling sites in the Otaika and Puwera sub-catchments while their location is shown in

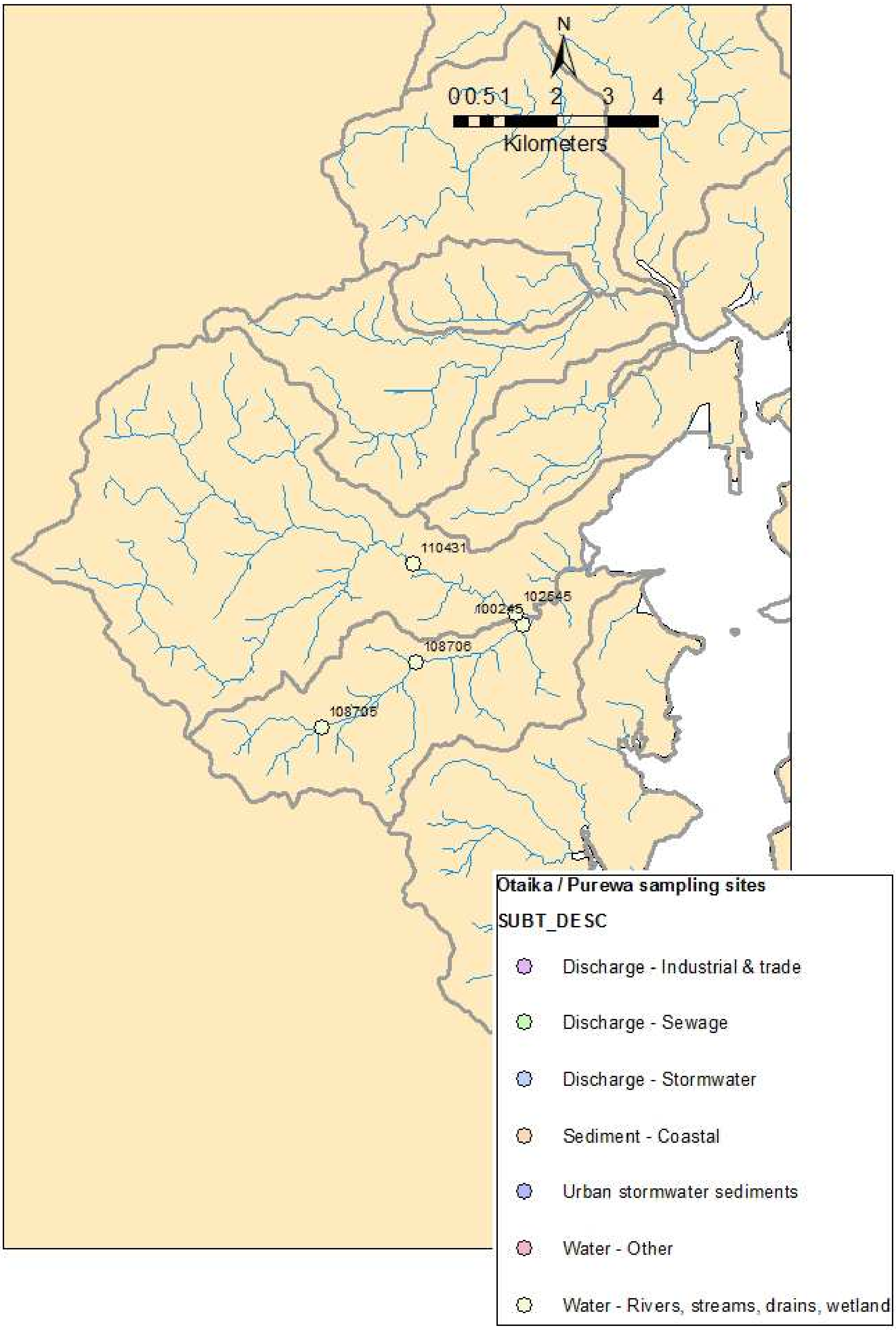

Figure 5-14. Water quality data provided by NRC are plotted in Figure 5-15.

The potential contribution that the data from these sites can make is as follows:

- Sites 108705 and 108706 in the Puwera sub-catchment are the monitoring sites established for the Clean Streams monitoring project described in Section 4.3.2. As noted in that section, the data from these sites may provide a basis for estimating sub-catchment loads of SS, nutrients and indicator bacteria. The data would need to be evaluated for its representativeness of a range of flow conditions and a synthetic flow record would need to be developed in order to calculate long term loads.
- The data from site 110431 in the Otaika sub-catchment provides an indication of nutrient and faecal indicator concentrations in a rural catchment that can be used in a catchment-wide comparison.
- The remaining two sites contain some a small amount of additional data on faecal indicator bacteria concentrations.

Table 5-6: Selected water quality and sediment quality sampling sites, Waiarohia sub-catchment.

Site number	Site name
Water Quality	
102545	Otaika St @ Portland weir
110431	Otaika Stream @ Otaika Valley Rd culvert
100245	Puwera Stream @ Bridge on Loop Rd
108706	Puwera Stream @ Bennett's farm race
108705	Puwera Stream @ Keays Access Road

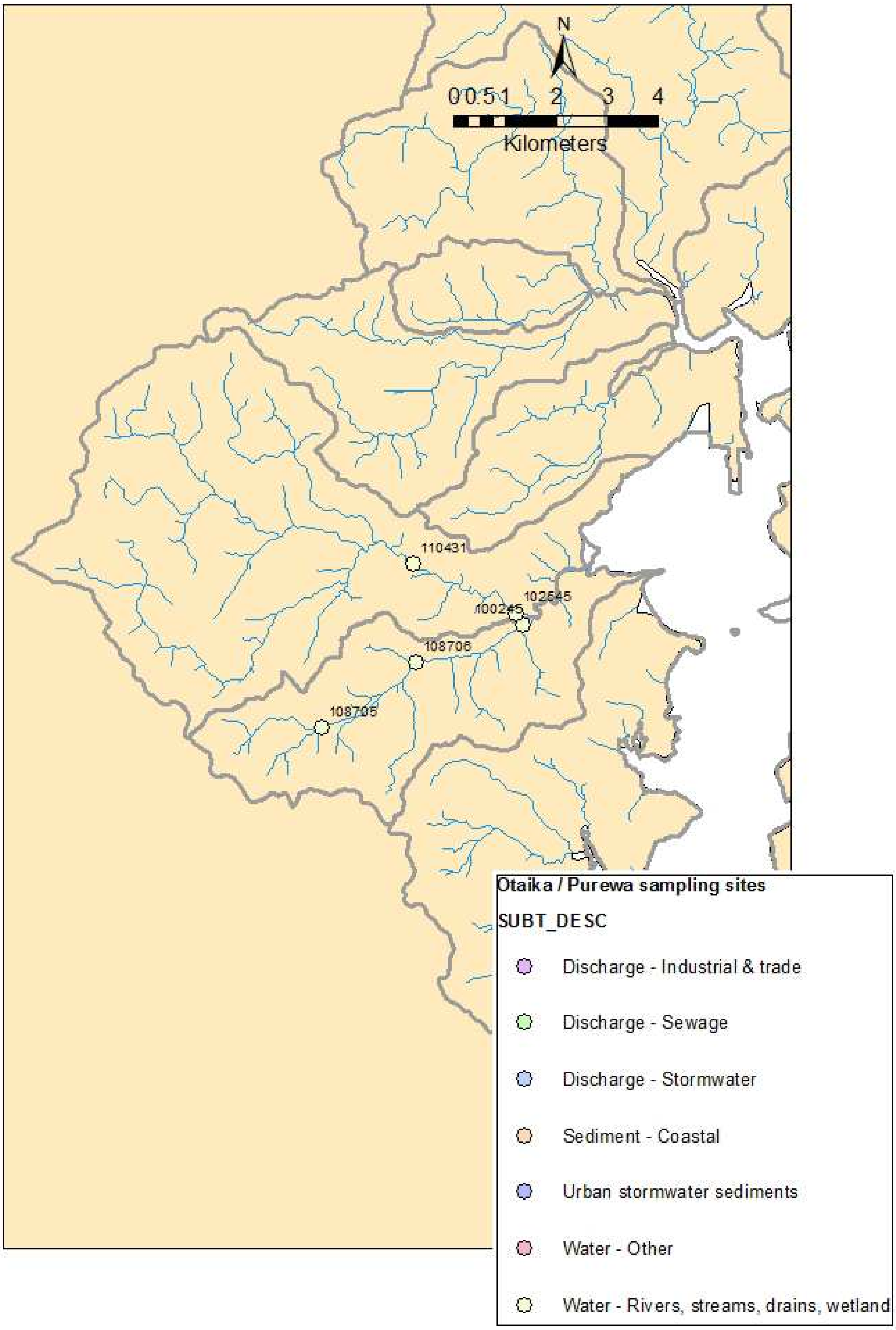

Figure 5-14:Location of selected water quality and sediment quality sampling sites, Puwera and Otaika sub-catchments.

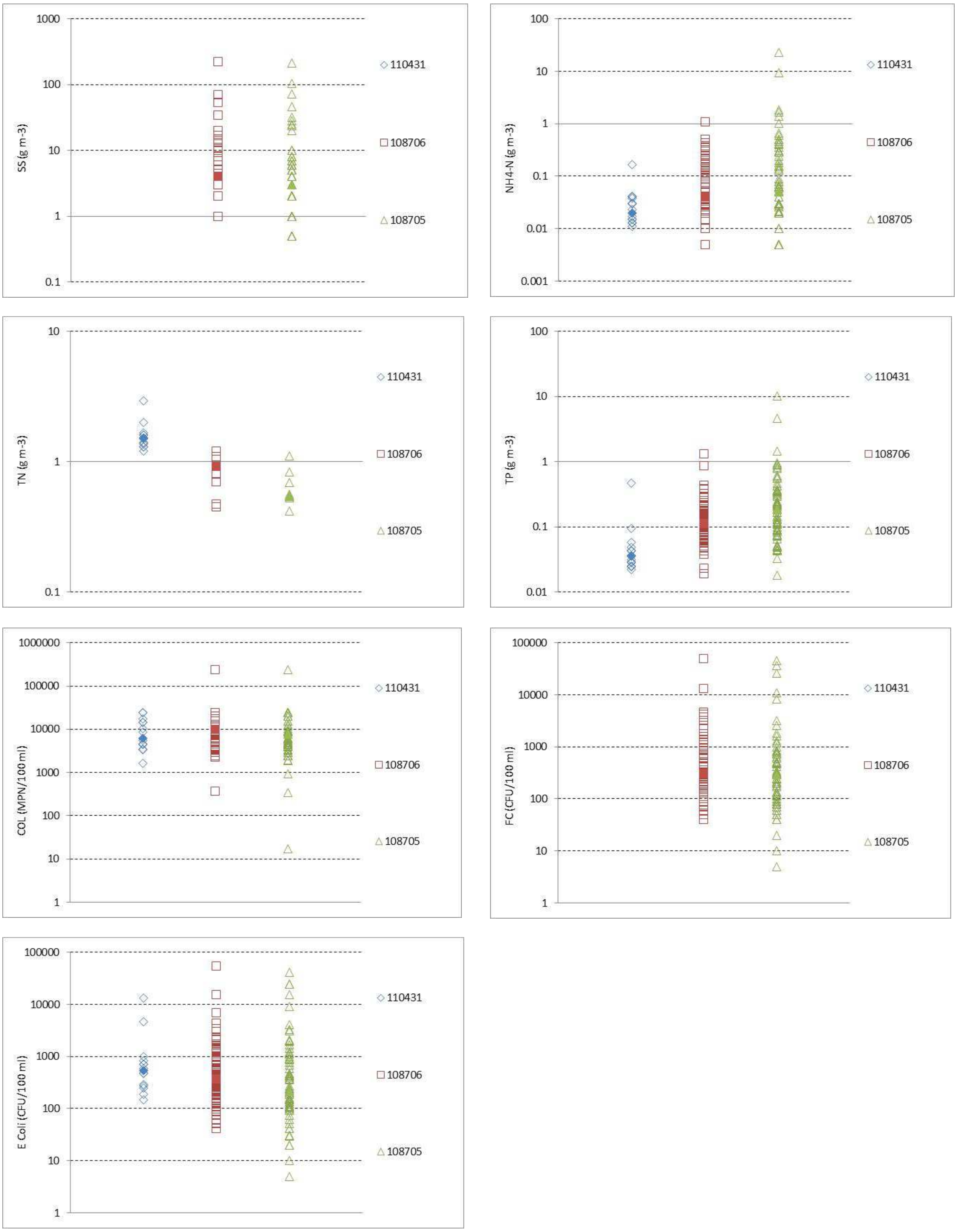

Figure 5-15:Summary plots of data from selected water quality sampling sites, Puwera and Otaika sub-catchments. Hollow symbols represent concentrations in individual samples while solid symbols represent median concentrations.

5.8 Whangarei South sub-catchment

Table 5-7 lists the most data-rich water quality sampling sites in the Whangarei South sub-catchment while their location is shown in

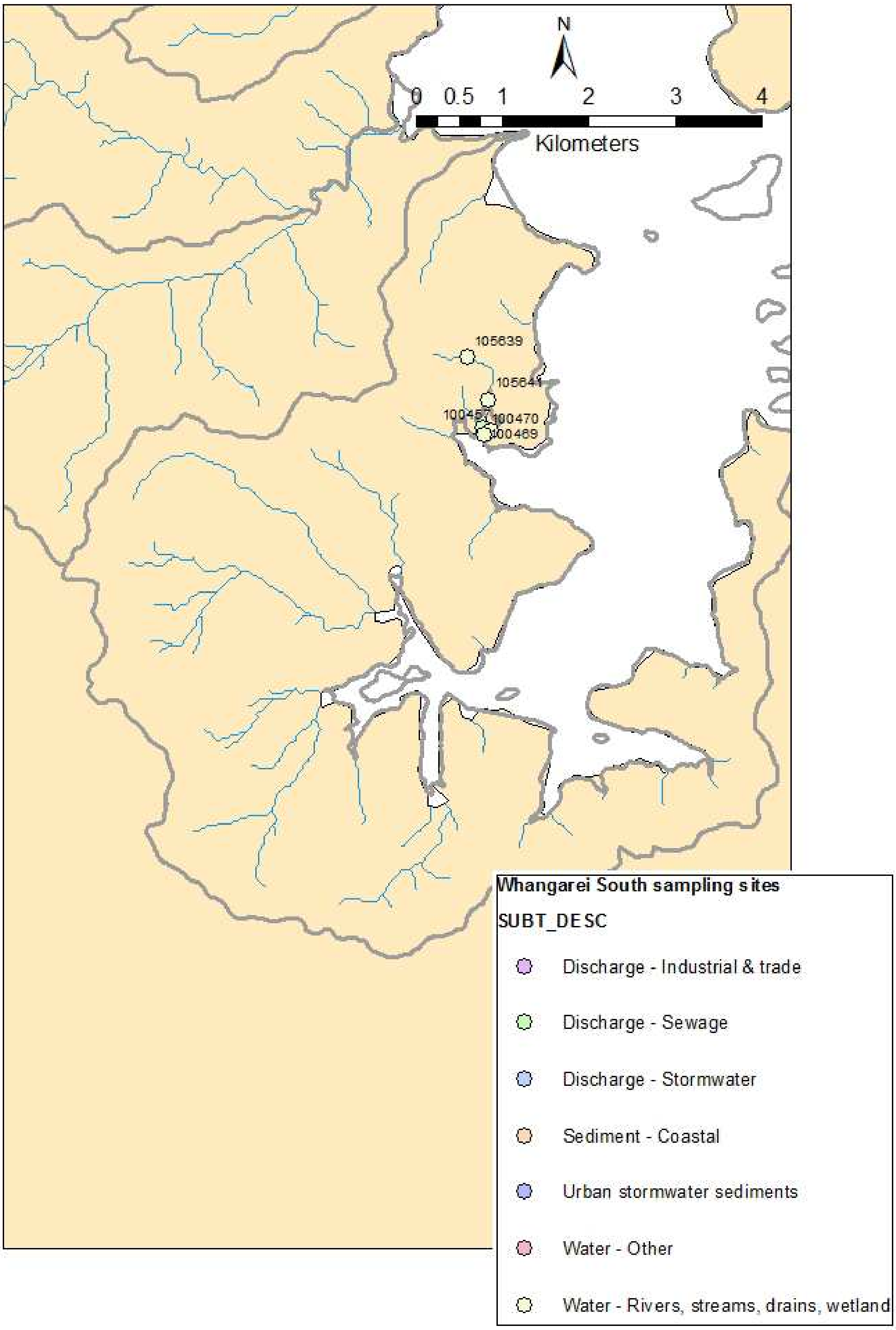
N
0 0.5 1 2 3 4
Kilometers
105639
105641
100457
100470
100469
Whangarei South sampling sites
SUBT_DESC
Discharge - Industrial & trade
Discharge - Sewage
Discharge - Stormwater
Sediment - Coastal
Urban stormwater sediments
Water - Other
Water - Rivers, streams, drains, wetland

Figure 5-16.

The potential contribution that the data from these sites can make is as follows:

- The sites are all associated with monitoring associated with either the Portland cement works or Portland WWTP. They provide an indication of concentrations of suspended solids, nutrients and indicator bacteria associated with these activities but contain too few data points for the estimation of loads.

Table 5-7: Selected water quality and sediment quality sampling sites, Waiarohia sub-catchment.

Site number	Site name
Water Quality	
100470	Tokitoki Creek @ D/S Portland sewage disch
100457	Tokitoki Creek @ Portland Sewage Discharge (Above)
100469	Portland Sewage Treatment Sys @ Marsh outlet
105641	Marusumi stormwater @ D/S of site
105639	Marusumi Stormwater @ U/S of site

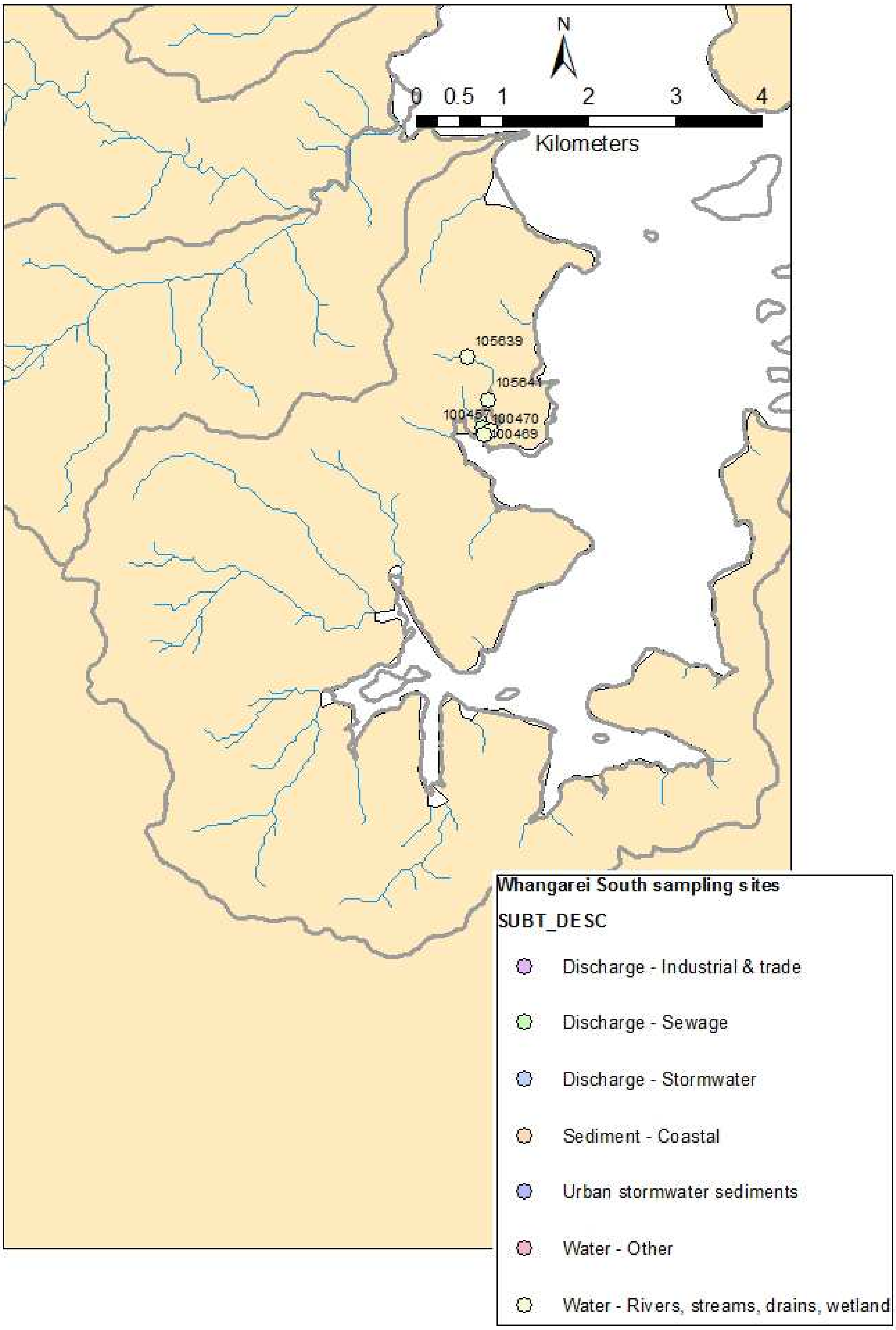

Figure 5-16:Location of selected water quality and sediment quality sampling sites, Whangarei South sub-catchment.

6 Estimates of Diffuse Source Contaminant Loads

6.1 Introduction

This chapter describes the use of two models that have been developed by NIWA to provide sub-catchment scale annual load estimates of diffuse-source contaminants. The Catchment Land Use for Environmental Sustainability (CLUES) model was used to estimate present-day rural loads of nutrients (total nitrogen, TN and total phosphorus, TP), TSS and the faecal indicator bacteria *E. coli*. Loads of TN, TP and TSS associated with assumed land cover in 1770 were also estimated to provide an indication of the influence of anthropogenic activities on the rural loads of these contaminants.

The Catchment Contaminant Annual Loads Model (C-CALM) was used to estimate urban loads of total suspended solids (TSS) and dissolved and particulate zinc and copper from urban sources.

Neither CLUES nor C-CALM explicitly model contaminant loads discharged during discrete storm events or under baseflow conditions. Instead, they estimate annual loads of contaminants based on long-term average yields of each contaminants that take into account variations in catchment characteristics. However, because they are based on long-term average yields, these estimates of annual contaminant loads do implicitly include loads discharged under different flow conditions.

The loads reported here should be considered indicative estimates showing the relative importance of each sub-catchment as a source of diffuse-source contaminants. As described in the following sections, the application of the models involved certain assumptions and could be revisited to incorporate more precisely-defined input data.

However, these estimates provide a basis from which to identify further actions to quantify key contaminant sources in the upper Harbour catchment. In addition, having run these models for the current land use, these results also provide a baseline against the results of further model runs to test (a) the effect of projected changes in land use and (b) the effectiveness of alternative future urban and rural mitigation measures.

6.2 Rural Sediment, Nutrients and *E. coli*

6.2.1 Model Description

CLUES was developed for the Ministry of Agriculture and Forestry (MAF, now Ministry for Primary Industries, MPI) in association with the Ministry for the Environment (MfE) by NIWA, in collaboration with Lincoln Ventures, Harris Consulting, AgResearch, HortResearch, Crop and Food Research, and Landcare Research. CLUES is a modelling system for assessing the effects of land use change on a range of water quality and socio-economic indicators at a minimum scale of sub-catchments (~10 km^2 and above). The basic spatial areal unit of CLUES is the REC sub-catchment which is defined as the drainage area surrounding an individual river reach from the NIWA River Environment Classification (REC, Snelder *et al.,* 2010). Predictions of the water quality and financial indicators can be made for any reach.

CLUES couples a number of existing models within a GIS-platform (Figure 6-1). These include:

- **OVERSEER**® (AgResearch, Wheeler et al. 2006) – a customised, pre-parameterised version of OVERSEER 6 is provided within CLUES which computes nutrient leaching for dairy, sheep and beef and deer farming. It provides annual average estimates of nutrient losses from these land uses, given information on rainfall, soil order, topography and fertiliser applications. For other variables, such as fertiliser application rates, typical values are used based on the region and land use.

- **SPARROW** (Spatially Referenced Regression on Watershed attributes) - predicts annual average stream loads of total nitrogen, total phosphorus, sediment and *E. coli*. It includes extensive provisions for stream routing and loss processes (storage and attenuation). This modelling procedure was originally developed by the USGS (Smith et al. 1997) and has since been applied and modified in the New Zealand context with extensive liaison with the developers. **SPARROW** has been applied to nitrogen and phosphorus in Waikato (Alexander et al. 2002) and subsequently to the whole New Zealand landscape (Elliott et al. 2005). The **SPARROW** sediment transport routines were assessed by Elliott et al. (2008) and simulations compared favourably with measured sediment load data.

- **SPASMO** (Soil Plant Atmosphere System Model, HortResearch) - calculates the nitrogen budget for a range of horticultural enterprise scenarios. Detailed simulations for many cases (combinations of crops, climate, fertiliser use) have been run (using a daily time step) to build look-up tables that CLUES queries. It has been validated against data from grazed pasture (Rosen et al. 2004) and pasture treated with herbicide (Close et al. 2003, Sarmah et al. 2004).

Further details on the CLUES modelling framework can be found in Semadeni-Davies et al. (2011) and Woods et al. (2006). CLUES has been applied in a number of regional and national studies into the effects of land use change and mitigation on water quality (e.g., farm practices such as stock exclusion, Olsen Phosphorus management, herd housing and conservation planting). Amongst others, recent examples include Monaghan et al. (2010), Semadeni-Davies and Elliott (2012) and on-going work for the MfE into determining the limits to rural land use expansion and intensification.

Geo-spatial data needed to run CLUES are provided with the software at a regional level. Terrain data is at 30 m resolution. In addition to the REC data on rivers, data provided are land use, runoff (derived from rainfall less evapotranspiration), slope, soil parameters (from the Land Resources Inventory, LRI, Fundamental Soils Layer[28] – Wilde et al., 2004), contaminant point sources[29] and lakes. The land use layer provided with CLUES was developed with extensive reference to the LCDB2, AgriBase (AssureQuality Ltd)[30], and Land Environments of New Zealand (LENZ)[31] land use geo-databases and refers to land use in

[28] http://soils.landcareresearch.co.nz/contents/index.aspx (date of last access 7 November 2012)
[29] Point sources include freezing works, pulp and paper mills, waste water treatment plants and piggeries. Currently, there are no point sources listed for the upper Whangarei Harbour.
[30] http://www.asurequality.com/capturing-information-technology-across-the-supply-chain/agribase-database-for-nz-rural-properties.cfm (date of last access 7 November 2012)
[31] http://www.landcareresearch.co.nz/resources/maps-satellites/lenz (date of last access 7 November 2012)

2002[32]. On the basis of the latter data bases, CLUES splits the LCDB2 land uses into finer classes. For instance, pastoral land in LCDB2 is separated into dairy, sheep and beef (three classes), deer and other animals. In all, there are 19 land use classes in CLUES.

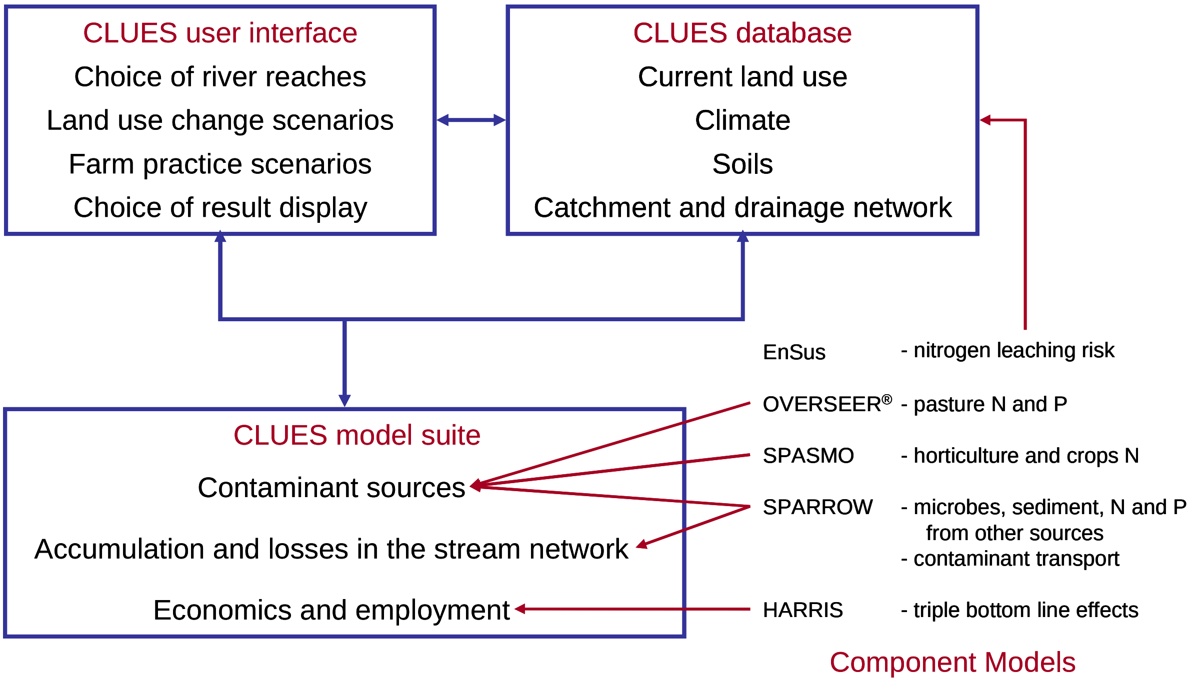

Figure 6-1: CLUES model framework. Source: Semadeni-Davies et al., 2011.

6.2.2 Application of CLUES to Whangarei Upper Harbour Catchments

The CLUES land uses classes present in the upper Harbour catchments are listed in Table 6-1 and are mapped in broad land use groups in Figure 6-2. Note that the dry stock areas shown in Figure 6-2 are dominated by lowland intensive sheep and beef farming. While CLUES does include urban as a land use class, the model is primarily designed for rural land use and in this study the contaminant loads from urban land were not simulated by CLUES. Instead, urban land was assigned to the "Other" land use class which sets contaminant yields to background levels.

In order to compare loads of TN, TP and TSS associated with pre-European land cover CLUES was also run using a national vegetation layer for the year 1770 supplied by Landcare Research (personal communication: Robbie Price). The layer breaks vegetation in the study area into forest, manuka/kanuka scrub, grass, swamp and fern. Forest was assigned to the CLUES land cover class Native Forest, and the other vegetation types were grouped into the CLUES Scrub land use class.

[32] There are plans to update CLUES to LCDB3 nationwide in the near future. Suffice to say, there are few differences between the two LCDB data sets in the upper harbour catchment study area. While it is possible to update CLUES for specific instances of land use change based on local knowledge, this was deemed outside the scope for this preliminary study.

Table 6-1: CLUES land use classes present in the upper Harbour study area showing percentage cover for each sub-catchment. Data obtained from the CLUES geo-database which relates to the base year of 2002.

CLUES land use class	Onerahi	Hatea	Raumanga	Waiarohia	Kirikiri	Limeburners	Otaika	Puwera	Whangarei South
Dairy	3	1	1	0	0	0	18	44	24
Dry stock: deer	0	1	0	0	0	0	1	0	0
Dry stock: sheep and beef (hill)	1	2	1	0	0	0	2	0	0
Dry stock: sheep and beef (intensive)	23	30	42	17	7	33	37	46	57
Other animals	1	1	0	0	0	0	2	1	0
Ungrazed pasture	1	2	1	1	1	0	2	1	0
Native forest	23	16	20	51	58	20	20	2	5
Scrub	5	3	3	3	1	6	3	2	6
Kiwifruit	0	0	1	0	0	0	1	0	0
Plantation forest	24	25	2	1	7	17	11	2	5
Tropical fruit	0	0	1	0	0	0	1	0	0
Urban	19	18	25	24	26	21	0	0	0
Other (e.g., bare soil)	1	1	3	3	2	4	2	2	2

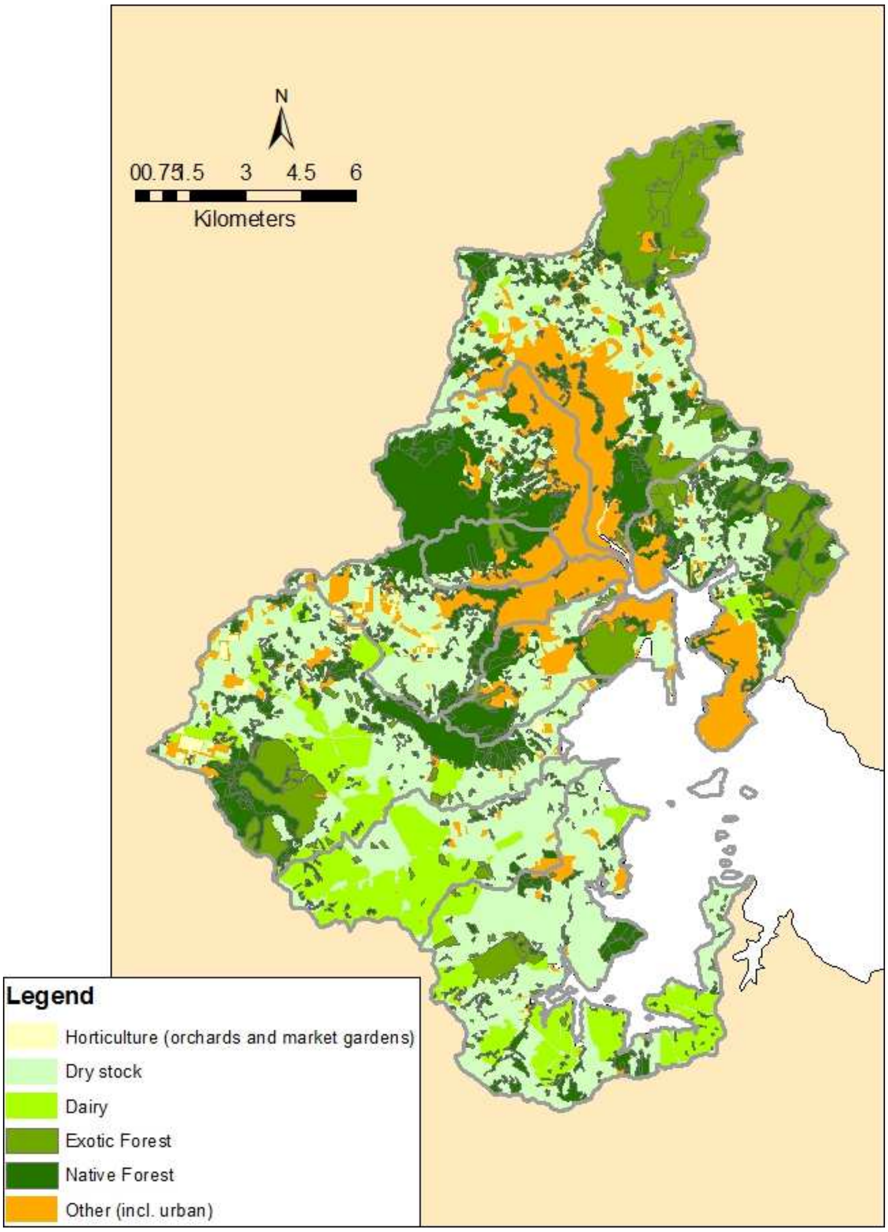

Figure 6-2: Broad land use classes within the CLUES geo-database. Sub-catchment boundaries marked in grey.

6.2.3 Results

Results generated by CLUES that are presented in this report are:

- Loads – these are in-stream cumulative loads for the lowest reach (i.e., outlet) of each sub-catchment. This indicator allows comparison of the absolute contribution of each sub-catchment to the harbour. For the Hatea, Waiarohia, and Otaika sub-catchments the lowest reach is the stream mouth. For the Raumanga, Kirikiri and Puwera sub-catchments the lowest reach is at their respective confluences with Waiarohia Stream and Otaika Stream. For the Onerahi, Limeburners and Whangarei South sub-catchments, which consist of multiple minor streams, the total cumulative load is the sum of the cumulative loads of the lowest reach for all streams in each sub-catchment.

- Cumulative yields – this is calculated from the loads as the cumulative load divided by the total sub-catchment area. This indicator allows comparison between sub-catchments of different sizes of their relative contribution to the harbour. For the Waiarohia and Otaika sub-catchments, the total area includes the areas of their respective tributary sub-catchments.
- Generated yields – this is the contaminant yield calculated for each REC sub-catchment which gives an indication of the spatial variability of contaminant sources within catchments.

Present Day

The simulated contaminant loads and yields for present-day land cover in each of the upper Harbour sub-catchments are presented in Table 6-2. Note that since the Raumanga and Kirikiri Streams are tributaries of the Waiarohia Stream, and the Puwera Stream is a tributary of Otaika Creek, the loads from these streams are not included in the calculation of the total load to the harbour (this avoids double counting), because these loads are included in the sub-totals for the Waiarohia and Otaika sub-catchments, respectively. The catchments with the highest nutrient and *E. coli* cumulative yields are Puwera, Otaika and Whangarei South. These are the catchments with the greatest proportion of dairy farming in the CLUES geo-database. The highest TSS yields are from the Otaika and Hatea sub-catchments, but these are considered to be overestimates for reasons given below.

Table 6-2: Present day CLUES simulated contaminant loads and yields by sub-catchments of the upper Harbour. Shaded rows indicate loads and yields that are included in the sub-catchment totals of which these streams are tributaries.

Catchment	TN		TP		TSS		*E. coli*	
	Load (t/y)	Yield (kg/ha/y)	Load (t/y)	Yield (kg/ha/y)	Load (kt/y)	Yield (t/ha/y)	Load (10^{15} /y)	Yield (10^{12}/ha/y)
Onerahi	9.7	4.1	1.6	0.7	1.6	0.7	1.2	0.5
Hatea	21.9	4.9	2.1	0.5	24.5	5.5	0.8	0.2
Waiarohia*	12.9	3.1	1.6	0.4	3.5	0.8	0.4	0.1
Raumanga**	7.0	4.4	1.0	0.6	1.7	1.1	0.4	0.2
Kirikiri**	1.3	2.4	0.3	0.5	0.6	1.1	0.05	0.1
Limeburners	4.8	3.8	0.8	0.7	0.7	0.6	0.4	0.3
Otaika*	56.9	9.3	6.6	1.1	209.8	34.4	3.4	0.6
Puwera**	22.6	12.1	2.9	1.6	2.3	1.2	2.1	1.1
Whangarei South	24.8	7.0	3.8	1.1	1.9	0.5	4.8	1.4
Total load to harbour	130.9		16.6		242.0		11.0	

*Yields calculated using the total catchment area (i.e., including tributaries).

**Loads are not included in the calculation of the total load to the harbour, because they are already included in the sub-totals for the Waiarohia and Otaika sub-catchments.

Generated yields (mapped in Figure 6-3) are calculated within CLUES for each REC reach sub-catchment as the load entering the river network from that sub-catchment over the sub-catchment area. Again, it can be seen that the highest nutrient and *E. coli* yields are associated with areas dominated by dairy farming followed by sheep and beef farming.

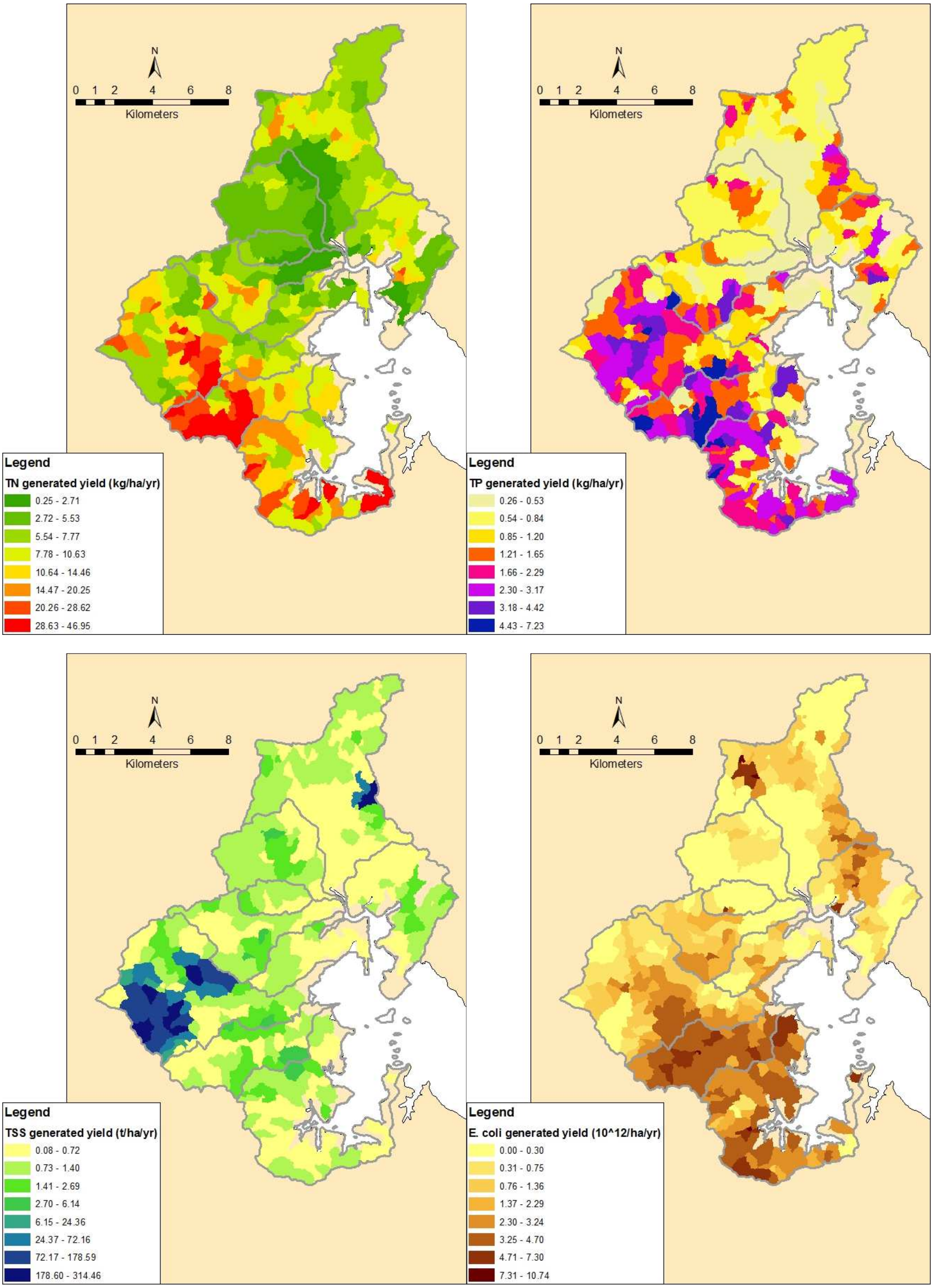

Figure 6-3: CLUES generated yields for present day land cover. Top left, TN; top right, TP; bottom left, TSS; bottom right, *E. coli*. Upper Harbour sub-catchment boundaries marked in grey.

The highest TSS yields are from the steep upper reaches of the Otaika catchment in an area dominated by a mixture of native and exotic forest, followed by those in areas of dairying and sheep and beef farming. There are also two REC sub-catchments in the Hatea sub-catchment in the Glenbervie area with high TSS yields. These contain mixed land use on steep land. While the moderately high yields in the Otaika catchment associated with stream bank erosion in the middle to lower reaches can be expected, the high yields from the forested headwaters and upper reaches are considered to be overestimates. While high sediment yields from the Glenbervie forest following earthworks associated with harvesting operations were reported by Hicks and Harmsworth (1989) it should be noted that CLUES does not take harvesting into account. Instead, the explanation of these high yield estimates lies in the representation of slope and underlying geology in CLUES which combine to give a high sediment yield coefficient in these areas. That is, the high sediment yield arises from an erodible geologic terrain within the LRI called 'intensely gullied crushed greywacke and argillite'. Indeed, gully erosion forms from largely ultic and recent soils are mapped in both areas in Figure 2-5. The area with the highest yields coincides with typic yellow and mottled albic ultic soils. The sediment yield coefficient for this terrain largely comes from East Cape where there is high erosion[33] . For this reason, we believe that the high yields, and therefore loads from the Otaika and Hatea catchments, are likely to be an artefact of the model calibration which requires further investigation to resolve.

Pre-European

The simulated contaminant loads and yields for pre-European land cover in each of the upper Harbour sub-catchments are presented in Table 6-3. Generated yields for TN, TP and TSS are mapped in Figure 6-4 using the same colour ramps as in Figure 6-3. While the results indicate markedly lower loads and yields in 1770, the TSS results for Hatea and Otaika sub-catchments are subject to the same uncertainty as described above.

Table 6-3: Pre-European CLUES simulated loads and yields of TN, TP and TSS for the upper Harbour catchments. Shaded rows indicate loads and yields that are included in the sub-catchment totals of which these streams are tributaries.

Catchment	TN		TP		TSS	
	Load (t/y)	Yield (kg/ha/y)	Load (t/y)	Yield (kg/ha/y)	Load (kt/y)	Yield (t/ha/y)
Onerahi	7.5	3.2	0.7	0.3	0.7	0.3
Hatea	16.7	3.7	1.2	0.3	7.0	1.6
Waiarohia*	13.0	3.1	1.0	0.2	1.5	0.4
Raumanga**	5.9	3.1	0.6	0.3	0.6	0.3
Kirikiri**	2.0	3.5	0.2	0.4	0.4	0.7
Limeburners	3.9	3.0	0.6	0.4	0.4	0.3
Otaika*	22.6	3.7	2.3	0.4	116.9	19.2
Puwera**	7.8	4.2	0.7	0.3	0.6	0.3
Whangarei South	11.0	3.1	0.8	0.2	0.5	0.1
Total	74.7		6.6		127.0	

*Yields calculated using the total catchment area (i.e., including tributaries).
**Loads are not included in the calculation of the total load to the harbour, because they are already included in the sub-totals for the Waiarohia and Otaika sub-catchments.

[33] (S.Elliott, NIWA, pers.comm., November 2012)

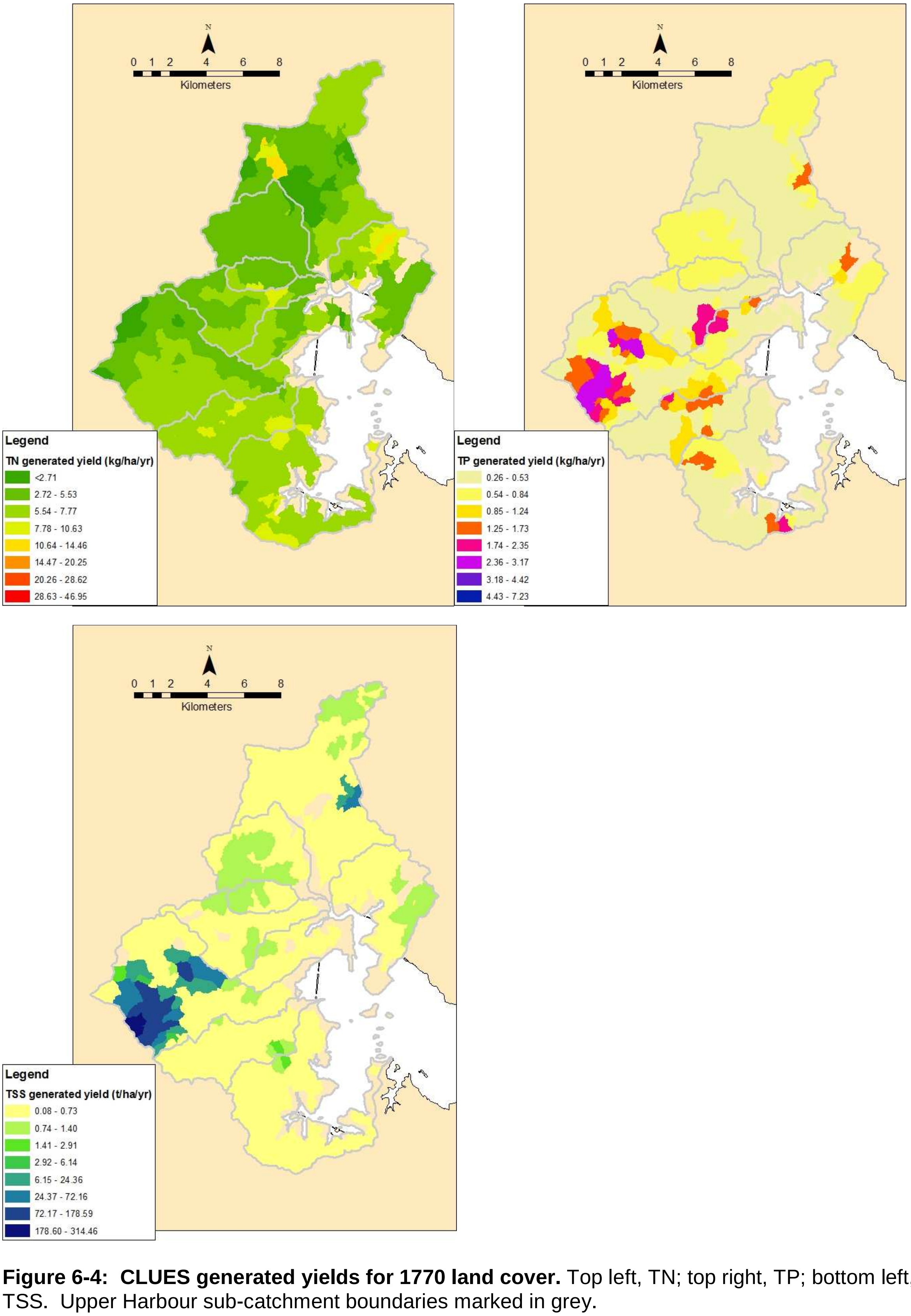

Figure 6-4: CLUES generated yields for 1770 land cover. Top left, TN; top right, TP; bottom left, TSS. Upper Harbour sub-catchment boundaries marked in grey.

6.3 Urban Sediment and Metals

6.3.1 Model Description

C-CALM was developed with funding from the Foundation for Research, Science and Technology (FRST) under subcontract to Landcare Research Ltd. as a planning tool at the sub-catchment (stormwater management unit) scale. The model has been documented in a number of papers (e.g., Semadeni-Davies et al., 2010, Semadeni-Davies and Altenberger, 2009). C-CALM embeds the Auckland Council's spreadsheet Catchment Loads Model (CLM; Timperley et al., 2010) into a GIS platform allowing more realistic representation of stormwater networks and geo-visualisation of model inputs and outputs. Both models estimate the annual contaminant load from a particular diffuse source (represented in C-CALM as a land cover type) from that source's annual contaminant yield and fractional coverage with respect to the catchment area. For each catchment, the annual load for each contaminant is calculated as:

$$Annual\ load = \left(\sum_{n=1}^{N} Area_n \ x \ Yield_n \right) x \ Treatment$$

Where N is the number of diffuse sources present, $Area_n$ is the total area of source type n, $Yield_n$ is the contaminant yield from source type n and 'Treatment' is a fraction by which the untreated contaminant load from all sources in the catchment is reduced. The annual yields and assumed fractionation for urban land use covers found in the upper Harbour are given in Table 6-4.

Table 6-4: C-CALM yields for urban surfaces found in the upper Whangarei Harbour catchment. Yields are the same as those in the Auckland Council Catchment Load Model (Timperley et al., 2010).

Land cover (diffuse contaminant source)	Annual Yields (g/m²/year)			Particulate Fraction	
	TSS	Zn	Cu	Zn	Cu
Roofs galvanised steel unpainted	5	2.240	0.0003	0.05	0.05
Roofs galvanised steel poor painted	5	1.340	0.0003	0.05	0.05
Roofs galvanised steel well painted	5	0.200	0.0003	0.05	0.05
Roofs galvanised steel coated	12	0.280	0.0017	0.05	0.05
Roofs zinc/aluminium unpainted	5	0.200	0.0009	0.05	0.05
Roofs zinc/aluminium coated	5	0.020	0.0016	0.05	0.05
Roofs other materials	10	0.020	0.0020	0.05	0.05
Low traffic (<1k)	21	0.004	0.0015	0.50	0.75
Roads 1k-5k vpd	28	0.027	0.0089	0.50	0.75
Roads 5k-20k vpd	53	0.111	0.0369	0.50	0.75
Main Road (20-50 k)	96	0.257	0.0858	0.50	0.75
Commercial paved	32	0.000	0.0294	0.50	0.75
Residential paved	32	0.195	0.0360	0.50	0.75
Industrial paved	22	0.590	0.1070	0.50	0.75
Urban grasslands and trees	64	0.002	0.0004	0.95	0.95

The contaminant yields used in C-CALM are identical to those used in Auckland Council's Contaminant Load Model (CLM) and are derived from a range of sampling programmes conducted in Auckland in recent years. These include: sampling of storm runoff from areas of residential, industrial and commercial land use; sampling of runoff from different roofing materials; and sampling of road runoff (see Timperley et al. (2010) for further details).

6.3.2 Application of C-CALM to Whangarei Upper Harbour Catchments

The simulation was restricted to the urban sections of Onerahi, Hatea, Waiarohia, Kirikiri, Raumanga and Limeburners sub-catchments which collectively contain the urban area of Whangarei and its sub-urban environs. Unlike CLUES, C-CALM is run independently for each stream catchment, that is, there is no downstream routing from the Raumanga and Kirikiri catchments through the Waiarohia catchment. It was decided to run C-CALM for stream catchments rather than WDC's SMCs (refer Section 2.3) to provide results in a consistent form with those generated from the CLUES modelling.

C-CALM has previously been used to estimate the zinc, copper and TSS loads from a mixed rural / residential section of Raumanga catchment, the CBD and Port Rd stormwater catchments (Semadeni-Davies, 2009, see Section 4.2.2) as examples of contaminant loads from residential, commercial and industrial land uses respectively. Reference was made to that study in order to estimate the proportions of land covers within each catchment on the basis of catchment land use.

The urban boundary within each catchment was derived from LCDB3[34]. The total urban area comes to just over 2700 ha. Note that there are some rural patches within the urban area (e.g., near Kamo in Hatea sub-catchment), which are not included in the simulation. The urban area of each catchment was split into residential, commercial and industrial land use classes according to the District Plan zones supplied as a shapefile by WDC using the ArcMap intersect tool. Land use zones were mapped using the broad classification in Table 6-5 on the basis of their descriptions in the District Plan. Since the land use zones do not include parks and open land, these areas were taken directly from the LCDB3 layer. The land use zones and roads, supplied as a shape file by NRC, within the urban areas are mapped along with catchment boundaries in Figure 6-5.

Table 6-5: Classification of District Plan land use zones for use in C-CALM.

District Plan land use type	C-CALM land use class
Airport	Industrial
Business 1-3	Commercial
Business 4	Industrial
Living 1-3	Residential
Port	Industrial
Town basin	Commercial

The urban land covers are summarised, along with imperviousness, for each sub-catchment in Table 6-6. The following sections describe how the proportions in the table were derived.

[34] The LCDB3 urban boundaries were used in preference to the District Plan land use zones in recognition that much of the urban zoned land has not yet been developed and remains under rural land covers.

Although there are a number of stormwater treatment facilities in Whangarei, based on advice from WDC staff that these only treat a small proportion of the total urban area[35], the impact of stormwater treatment on loads was not simulated in this study.

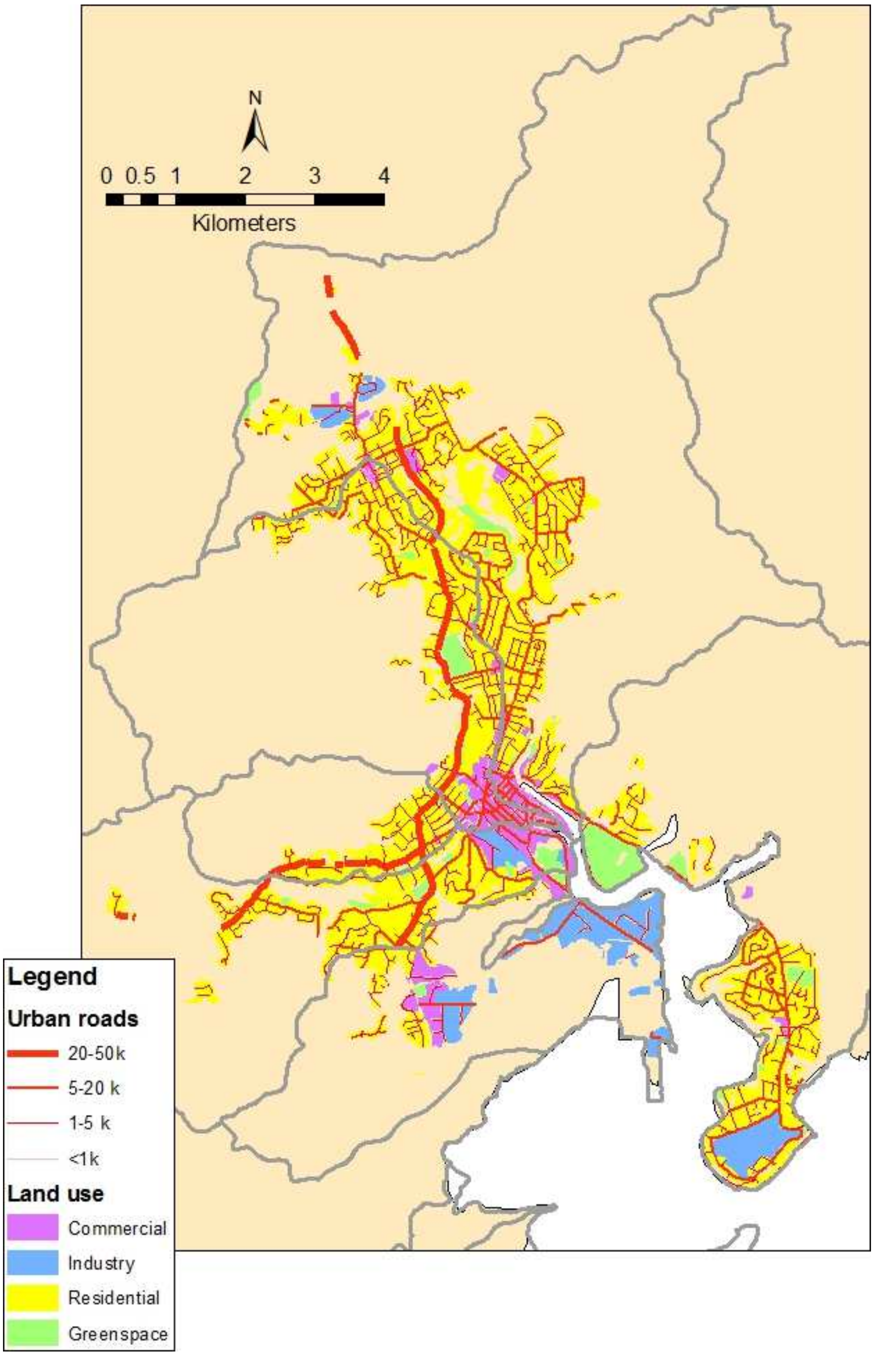

Figure 6-5: Urban land use zones and roads. Urban boundary and green-space determined from LCDB3, land use zone and road shape files supplied by NRC.

35 (C. Summers 2012, pers. comm. , 30 October)

Table 6-6: Urban contaminant diffuse source areas (ha) by sub-catchment. Percentage of total urban cover within each catchment in parentheses.

Land cover	Onerahi	Hatea	Waiarohia	Raumanga	Kirikiri	Limeburners
Commercial Roofs	2.7 (0.5)	26 (2.9)	29 (6)	14.8 (3.7)	0.6 (0.4)	20.7 (7.1)
Commercial Paving	2.4 (0.5)	23.4 (2.6)	26.1 (5.4)	13.4 (3.4)	0.5 (0.3)	18.6 (6.4)
Industrial Roofs	8.9 (1.8)	3.6 (0.4)	0 (0)	3.6 (0.9)	0 (0)	23.6 (8.1)
Industrial Paving	33.7 (6.9)	13.6 (1.5)	0 (0)	13.4 (3.4)	0 (0)	88.9 (30.5)
Residential Roofs	59 (12.1)	142.4 (15.7)	69 (14.2)	58.3 (14.7)	25.9 (17.6)	13.7 (4.7)
Residential Paving	5.2 (1.1)	12.6 (1.4)	6.1 (1.3)	5.1 (1.3)	2.3 (1.5)	1.2 (0.4)
Roads (<1 k v.p.d.)	1.6 (0.3)	3.2 (0.4)	4.2 (0.9)	2.5 (0.6)	0.6 (0.4)	1 (0.3)
Roads (1-5 k v.p.d.)	46.6 (9.6)	89.2 (9.9)	44 (9)	27.7 (7)	15.5 (10.5)	19 (6.5)
Roads (5-20 k v.p.d.)	26.6 (5.5)	51.8 (5.7)	26.6 (5.5)	18.4 (4.6)	1.2 (0.8)	12.5 (4.3)
Roads (20-50 k v.p.d.)	0 (0)	6.7 (0.7)	9.4 (1.9)	6.4 (1.6)	7.9 (5.4)	4.3 (1.5)
Green-space	298.8 (61.5)	532.2 (58.8)	271.2 (55.8)	233.3 (58.8)	92.8 (63)	87.5 (30.1)
Total urban area	485.6	904.8	485.7	397.1	147.3	290.9
Percentage Impervious	38.5	41.2	44.2	41.2	37.0	69.9

Note: v.p.d. = vehicles per day

Since the land use zone layer does not include roads or paved areas, the proportional areas of these land covers within the LCDB3 urban boundaries were calculated separately and then added to the urban area. The method followed is similar to that used for the previous application of C-CALM (Semadeni-Davies, 2009). The proportional area covered by roads within the urban area of each catchment was determined from the road shape-file provided by NRC by multiplying the road length by an assumed width. Traffic numbers from the NZ Transport Agency (NZTA, 2009) were used to classify road types into C-CALM classes, based on traffic density.

The earlier application of C-CALM to Whangarei (Semadeni-Davies, 2009) calculated roof area from a shape file of building foot prints supplied by NRC. Paved areas and green-space were mapped from aerial photos for the City (commercial) and Port (industrial) stormwater catchments and estimated for the simulated section of Raumanga (residential) catchment. The same relative proportions of roofs, green-space and paving were used in this study to estimate land covers within each catchments on the basis of land use zones in each catchment. The relative proportions are of roofs, roads and green-space are given in Table 6-7.

Table 6-7: Relative proportions (%) of land cover types by land use zone used to determine catchment diffuse source areas. Proportions are the same as those determined in Semadeni-Davies (2009).

Land cover (Diffuse source class)	Land use		
	Commercial	Industrial	Residential
Roofs	49	0.16	0.22
Green-space*	6	0.22	0.76
Paved surfaces	0.44	0.62	0.02

* Equivalent to gardens, courtyards and roadside verges

In addition to the green-space calculated above, which represents green-space within a land use zone such as residential gardens, grassed roadside verges and shopping centre courtyards, areas with a land use designated within the LCDB3 layer as *Urban Park-land / Open-space*[36], such as sports grounds (e.g., Sport Northland grounds in Kensington) and parks (e.g., Cafler Park and Denby Reserve) mapped in Figure 6-5, were added to the green-space land cover.

Within each catchment, roofs were further split into different roofing materials using the same generic breakdown according to land use as the earlier study (Table 6-8). In the absence of local information, this breakdown was derived from an investigation of Auckland roofing materials for different land use types (Timperley et al, 2005; Timperley et al., 2010).

Table 6-8: Generic proportions (%) of roof source materials by land use zone. (After Semadeni-Davies, 2009).

Landuse	Residential	Commercial	Industrial
Roofs galvanised steel unpainted	4	11	87
Roofs galvanised steel poor painted	17	24	4
Roofs galvanised steel well painted	8	6	2
Roofs galvanised steel coated	12	3	0
Roofs zinc/aluminium unpainted	1	4	0
Roofs zinc/aluminium coated	15	17	4
Roofs other materials	43	35	3

6.3.3 Results

The estimated sub-catchment loads and yields of contaminants from urban surfaces are mapped in Figure 6-6, Figure 6-7 and Figure 6-8 and collated in Table 6-9. Limeburners sub-catchment has the highest calculated total zinc and copper loads followed by Hatea which has the highest TSS loads. The high loads from the Limeburners sub-catchment reflect the high proportion of industrial land use. The high loads from Hatea sub-catchment are due to both the presence of commercial land use (e.g., the CBD) and the large urban area which is almost twice that of the Onerahi and Waiarohia sub-catchments and six times

[36] Parks and open space are not mapped in the NRC-supplied land use zone layer, that is, these areas appear blank in the layer.

that of the Kirikiri sub-catchment. This latter sub-catchment has the smallest urban area, and consequently, the lowest loads for all the contaminants. The Limeburners sub-catchment also has the highest zinc yields, again reflecting its industrial land use. The other sub-catchments have very similar zinc yields. Copper and TSS yields are very similar for all the sub- catchments with the Limeburners sub-catchment having the highest copper yield and Onerahi the highest TSS yield. Loads and yields from different land covers within each catchment are provided in

Table 6-10 to Table 6-15. It can be seen that the highest sediment loads and yields are from urban green-space followed by roads and paved areas. The highest zinc loads and yields are from roofs, which is due to the assumption that industrial and commercial areas, such as in Limeburners Catchment, have a high proportion of unpainted or poorly painted galvanised steel roofs. The highest copper loads and yields are from roads and paved areas which is not surprising as the primary source of copper in stormwater is wear and tear from brake linings.

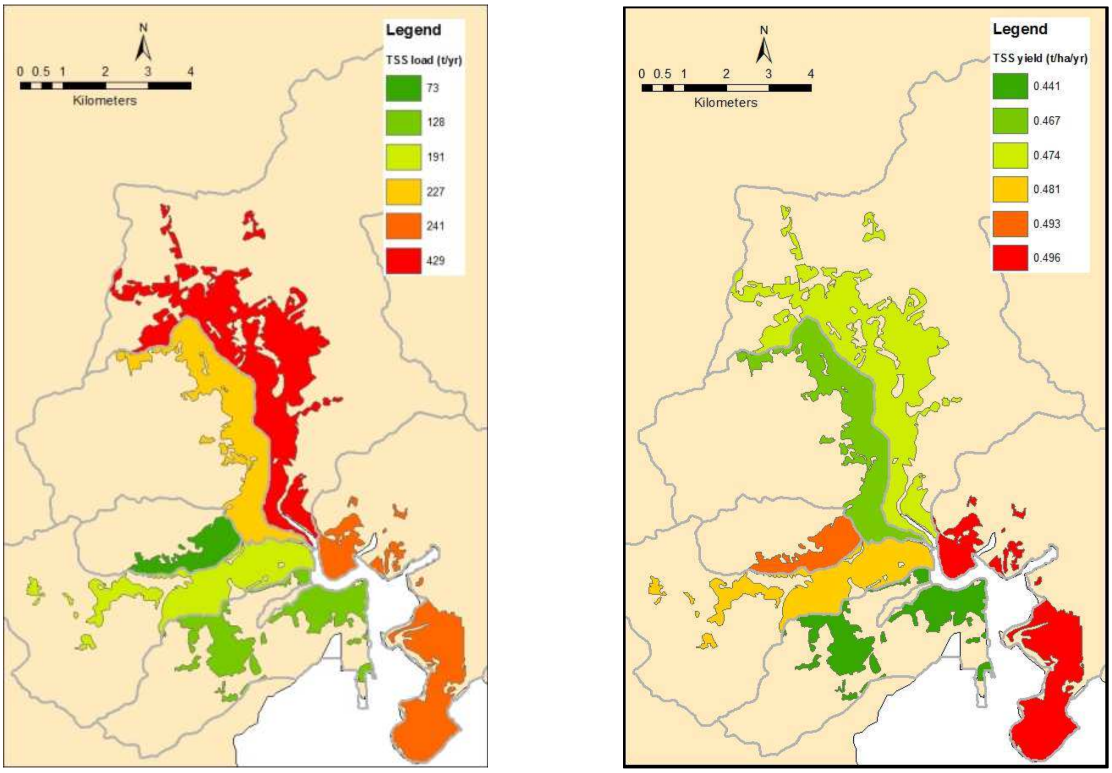

Figure 6-6: Ranked C-CALM loads and yields of TSS by sub-catchment, urban areas of the upper Whangarei Harbour.

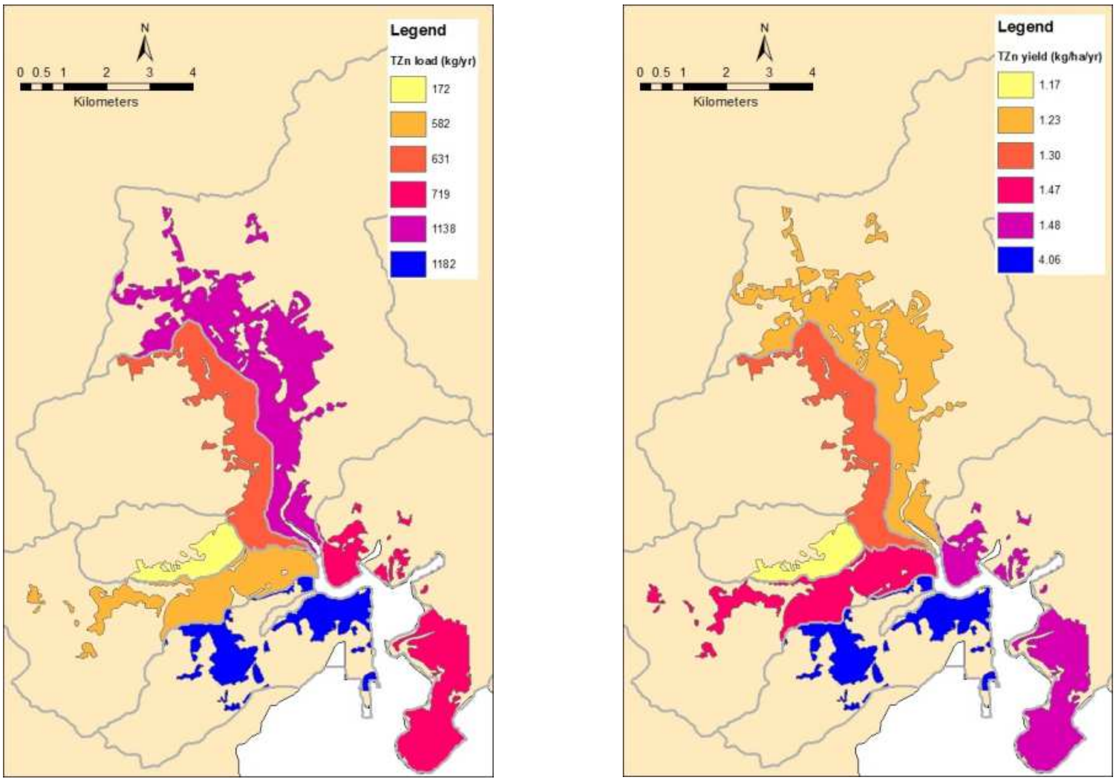

Figure 6-7: Ranked C-CALM loads and yields of total zinc by sub-catchment, urban areas of the upper Whangarei Harbour.

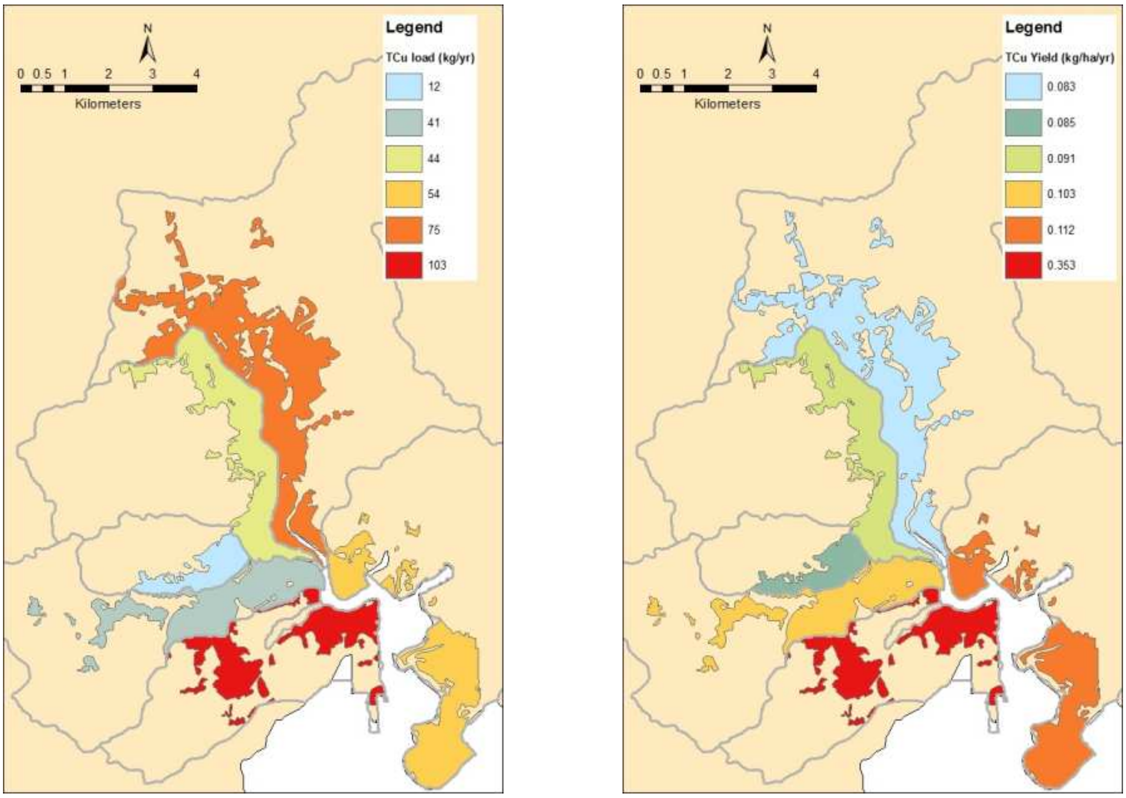

Figure 6-8: Ranked C-CALM loads and yields of total copper by sub-catchment, urban areas of the upper Whangarei Harbour.

Table 6-9: Urban contaminant yields and loads summarised by sub-catchment. Results relate only to urban parts of each sub-catchment.

Catchment	Area (ha)	TSS		TZn		PZn		DZn		TCu		PCu		DCu	
		Load (t)	Yield (t/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)
Onerahi	485.6	241.0	0.4964	719.1	1.5	173.3	0.4	545.8	1.1	54.47	0.11	40.46	0.08	14.00	0.03
Hatea	904.8	428.6	0.4737	1137.8	1.3	226.2	0.3	911.6	1.0	74.61	0.08	54.76	0.06	19.85	0.02
Waiarohia	485.7	226.7	0.4668	631.0	1.3	120.5	0.2	510.5	1.1	44.31	0.09	32.54	0.07	11.78	0.02
Raumanga	397.1	190.9	0.4808	582.2	1.5	120.6	0.3	461.6	1.2	40.80	0.10	30.08	0.08	10.72	0.03
Kirikiri	147.3	72.6	0.4928	172.1	1.2	41.0	0.3	131.1	0.9	12.47	0.08	9.17	0.06	3.30	0.02
Limeburners	290.9	128.2	0.4405	1182.0	4.1	299.1	1.0	882.9	3.0	102.62	0.35	76.67	0.26	25.96	0.09
Total	2711.5	1288.0		4424.1		980.7		3443.4		329.3		243.7		85.6	

Table 6-10: Contaminant loads and yields by land cover type for Onerahi sub-catchment.

Source type	Area ha (%)	TSS		TZn		PZn		DZn		TCu		PCu		DCu	
		Load (t)	Yield (t/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)
Roofs	70.6 (14.5)	5.4	0.08	419.9	5.95	21.0	0.30	398.9	5.65	0.9	0.01	0.0	0.00	0.8	0.01
Roads & paved	116.2 (23.9)	44.4	0.38	293.3	2.52	146.6	1.26	146.6	1.26	52.4	0.45	39.3	0.34	13.1	0.11
Green-space	298.8 (61.5)	191.3	0.64	6.0	0.02	5.7	0.02	0.3	0.00	1.2	0.00	1.1	0.00	0.1	0.00
Total	485.6	241.0		719.1		173.3		545.8		54.5		40.5		14.0	

Table 6-11: Contaminant loads and yields by land cover type for Hatea sub-catchment.

Source type	Area ha (%)	TSS		TZn		PZn		DZn		TCu		PCu		DCu	
		Load (t)	Yield (t/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)
Roofs	172 (19)	13.4	0.08	772.1	4.49	38.6	0.22	733.5	4.26	2.3	0.01	0.1	0.00	2.2	0.01
Roads & paved	200.5 (22.2)	74.6	0.37	355.0	1.77	177.5	0.89	177.5	0.89	70.2	0.35	52.6	0.26	17.5	0.09
Green-space	532.2 (58.8)	340.6	0.64	10.6	0.02	10.1	0.02	0.5	0.00	2.1	0.00	2.0	0.00	0.1	0.00
Total	904.8	428.6		1137.8		226.2		911.6		74.6		54.8		19.8	

Table 6-12: Contaminant loads and yields by land cover type for Waiarohia sub-catchment.

Source type	Area ha (%)	TSS		TZn		PZn		DZn		TCu		PCu		DCu	
		Load (t)	Yield (t/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)
Roofs	98.1 (20.2)	7.5	0.08	438.8	4.48	21.9	0.22	416.9	4.25	1.3	0.01	0.1	0.00	1.2	0.01
Roads & paved	116.5 (24.0)	45.6	0.39	186.7	1.60	93.4	0.80	93.4	0.80	41.9	0.36	31.4	0.27	10.5	0.09
Green-space	271.2 (55.8)	173.6	0.64	5.4	0.02	5.2	0.02	0.3	0.00	1.1	0.00	1.0	0.00	0.1	0.00
Total	485.7	226.7		631.0		120.5		510.5		44.3		32.5		11.8	

Table 6-13: Contaminant loads and yields by land cover type for Raumanga sub-catchment.

Source type	Area ha (%)	TSS		TZn		PZn		DZn		TCu		PCu		DCu	
		Load (t)	Yield (t/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)
Roofs	76.7 (19.3)	5.9	0.08	383.5	5.00	19.2	0.25	364.3	4.75	1.0	0.01	0.1	0.00	1.0	0.01
Roads & paved	87.1 (21.9)	35.7	0.41	194.0	2.23	97.0	1.11	97.0	1.11	38.9	0.45	29.1	0.33	9.7	0.11
Green-space	233.3 (58.8)	149.3	0.64	4.7	0.02	4.4	0.02	0.2	0.00	0.9	0.00	0.9	0.00	0.0	0.00
Total	397.1	190.9		582.2		120.6		461.6		40.8		30.1		10.7	

Table 6-14: Contaminant loads and yields by land cover type for Kirikiri sub-catchment.

Source type	Area ha (%)	TSS		TZn		PZn		DZn		TCu		PCu		DCu	
		Load (t)	Yield (t/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)
Roofs	26.4 (17.9)	2.1	0.08	101.9	3.85	5.1	0.19	96.8	3.66	0.4	0.01	0.0	0.00	0.4	0.01
Roads & paved	28.1 (19.1)	11.1	0.39	68.4	2.44	34.2	1.22	34.2	1.22	11.7	0.42	8.8	0.31	2.9	0.10
Green-space	92.8 (63)	59.4	0.64	1.9	0.02	1.8	0.02	0.1	0.00	0.4	0.00	0.4	0.00	0.0	0.00
Total	147.3	72.6		172.1		41.0		131.1		12.5		9.2		3.3	

Table 6-15: Contaminant loads and yields by land cover type for Limeburners sub-catchment.

Source type	Area ha (%)	TSS		TZn		PZn		DZn		TCu		PCu		DCu	
		Load (t)	Yield (t/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)	Load (kg)	Yield (kg/ha)
Roofs	57.9 (19.9)	3.7	0.06	650.4	11.23	32.5	0.56	617.8	10.67	0.5	0.01	0.0	0.00	0.5	0.01
Roads & paved	145.5 (50)	68.4	0.47	529.8	3.64	264.9	1.82	264.9	1.82	101.7	0.70	76.3	0.52	25.4	0.17
Green-space	87.5 (30.1)	56.0	0.64	1.8	0.02	1.7	0.02	0.1	0.00	0.4	0.00	0.3	0.00	0.0	0.00
Total	290.9	128.2		1182.0		299.1		882.9		102.6		76.7		26.0	

6.4 Comparison of Rural and Urban Sediment Loads

Table 6-16 compares rural and urban loads and yields of TSS estimated by CLUES and C-CALM, respectively. Urban loads are estimated to be around 10-15% of the total load in sub-catchments containing urban land, with the exception of the Hatea sub-catchment. As noted in Section 6.2.3, the estimate of the rural sediment load in the Hatea sub-catchment is likely to be an overestimate. If the true rural sediment yield in the Hatea sub-catchment is closer to those in neighbouring sub-catchments, then the urban derived sediment load would also be around 10% of the estimated total load from this sub-catchment. The probable overestimation of loads in the Otaika sub-catchment creates a similar issue when comparing rural and urban sediment loads at the catchment scale. Again, adopting a lower rural TSS yield for the Otaika sub-catchment (for instance, based on the yield in the Puwera sub-catchment) gives an estimate of around 6% of the total sediment load to the Upper Harbour being derived from urban sources.

Table 6-16: Estimated loads and yields of TSS from rural and urban parts of each sub-catchment.

Sub-catchment	Area (ha)		TSS Load (kt/y)		Yield (t/ha)	
	Rural	Urban	Rural	Urban	Rural	Urban
Onerahi	1912.4	485.6	1.6	0.2	0.7	0.5
Hatea	3556.2	904.8	24.5	0.4	5.5	0.5
Waiarohia	1426.3	485.7	1.2	0.2	0.8	0.5
Raumanga	1335.9	397.1	1.7	0.2	1.1	0.5
Kirikiri	411.7	147.3	0.6	0.07	1.1	0.5
Limeburners	1010.1	290.9	0.7	0.1	0.6	0.4
Otaika	4240	-	209.8	-	34.4	-
Puwera	1879	-	2.3	-	1.2	-
Whangarei South	3702	-	1.9	-	0.5	-
Total	19,473	452	242.0	1.3	-	-

6.5 Model Accuracy and Further Work

As noted in 6.1, the loads reported here should be considered indicative estimates showing the relative importance of each sub-catchment as a source of diffuse-source contaminants. Neither C-CALM nor CLUES estimate numeric confidence scores or other measures of the accuracy of model outputs.

However, as noted in Sections 6.2.1 and 6.3.1 the calculations made by both models involve the use of contaminant yields derived from data collected in the field, giving confidence in model estimates. In the case of CLUES, several recent studies have involved comparison of model estimates of median contaminant concentrations in streams with estimates derived from long-term monitoring, including at 12 sites in the Kaipara Harbour catchment (Semadeni-Davies, 2012). One of the comparisons made in that study found CLUES estimates of median TN and TP to be within 12% and 20% of the median concentrations calculated from the long-term monitoring data. Further details are given in Appendix C which contains an extract from the report on that study.

In the case of C-CALM, the contaminant yields used in the model (and Auckland Council's CLM on which it is based) are derived from extensive stormwater sampling programmes conducted over several years in Auckland. This gives confidence in the model predictions, providing that inputs (land use areas, for instance) are accurately specified. However, to date there have been no studies comparing contaminant load estimates produced by C-CALM with estimates from monitoring in catchments outside of those on which the model development is based. This is a recognised gap.

The application of both CLUES and C-CALM for this project involved making various assumptions, as described above, and could be revisited to incorporate more precisely-defined input data and to model alternative future and mitigation scenarios. This could include the following.

For CLUES:

- Update the CLUES rural land uses from 2002 to 2012 using NRC data (e.g. aerial photos) if significant land use change has occurred.
- Work with NRC to develop and apply farm mitigation practice scenarios (this would also benefit from input from AgResearch to determine what mitigations are possible, where they should be applied and what the expected decrease in yield would be).
- Work with NRC to include any known significant point sources (e.g. freezing works, piggeries).
- Local re-calibration of CLUES for areas of high sediment yield coefficients – this would require investigation of the data (if any) available to attempt a local calibration[37].

For C-CALM:

- Update the representation of urban land uses from local data (likely to involve digitisation of aerial photos with some ground-truthing to identify roof materials, for instance) rather than relying on default source type fractions and the other assumptions made here.
- Split urban sub-catchment areas up into industrial, commercial and residential zones and model these areas separately to help identify hot spots within sub-catchments.
- Work with NRC / WDC to develop and apply future land use and stormwater treatment scenarios.

[37] Noting also that the harbour sedimentation study described in Chapter 7 is expected to provide information which will help assess the relative contributions of sediment from each sub-catchment.

7 Harbour Sedimentation Study

7.1 Introduction

This Chapter provides a summary of a current study funded by NRC and Envirolink into the sources and fate of sediments delivered to Whangarei Harbour. The study is led by NIWA with the involvement of NRC staff and has as its main objectives:

- To quantify historical sedimentation rates within the harbour; and
- To identify the major contemporary sources of catchment sediments delivered to the harbour.

The following sections provide an overview of the methods being employed in the study, the nature of the information that it is anticipated it will yield, and ways in which this information has the potential to inform the estimation of sediment loads and identification of sediment source areas.

7.2 Modelling fine-sediment dispersion and deposition.

The first stage of the project during 2010/11 involved the use of the Whangarei Harbour hydrodynamic and sediment-transport model (Reeve et al., 2009) to investigate the dispersion and deposition of fine sediment discharged to the harbour from the Hatea, Otaika and Mangapai Rivers during flood events. The results of this modelling were subsequently used to identify areas within the harbour where fine-catchment sediments are likely to accumulate and thereby inform the selection of sediment-core sites.

Three different river-flow scenarios were used to investigate the dispersion and deposition of fine sediments in the harbour using NRC hydrometric data: (1) base-flow; (2) one-year and (3) ten-year return period flood events. This initial modelling suggests that a large proportion of river-borne fine sediments are deposited on intertidal flats in the upper Harbour, in close proximity to the river outlets. However the model also indicates that some of this fine sediment is more widely dispersed and deposited on intertidal flats along the northern shore of the harbour at sites which are relatively remote from any freshwater inputs. In particular, fine sediments are accumulating in Purua Bay and Munro Bay. These results are also supported by Millar (1980) who found that calcite-rich muds derived from the Portland cement works located in the upper Harbour are also accumulating in Parua Bay.

7.3 Sediment accumulation rates

The next stage of the project involved the collection of sediment cores at 12 sites (Figure 7-1). Duplicate 10cm diameter sediment cores up to 1.7m long were collected from intertidal and subtidal flats during 14–16 February 2012 using a gravity corer, as previously used in the Kaipara Harbour and Bay of Islands. An additional core was collected by NRC (WHG-14) on 5 October 2012, east of WHG-6 (Figure 7-1), from intertidal flats east of the Hatea channel near the airport. This was undertaken following radioisotope analysis of the first set of near-surface sediments, which indicated that fine-sediments are not accumulating in the middle reaches of the Hatea arm of the harbour. Data from WHG-6 and subsequent field observations suggest mud deposition is constrained to the more sheltered reaches of the Hatea arm.

Figure 7-1: Location of sediment cores collected in Whangarei Harbour, February 2012.

The sediment cores are being dated using the radioisotopes lead-210 and caesium-137. Sediment accumulation rates (SAR) over the last ≤ 150 years will be estimated from the activity profiles of these radioisotopes in the cores. Caesium-137 deposition, derived from atmospheric-nuclear weapons tests, was first detected in New Zealand in the early 1950s. The maximum depth of ^{137}Cs is the usual basis for dating sediments in New Zealand estuaries. Lead-210 (^{210}Pb) is a naturally occurring radioisotope and has been used extensively in North Island estuaries to quantify sedimentation. ^{210}Pb has the key advantage that major changes to sedimentation fluxes will be preserved in sediment cores. The short-lived radioisotope Berrylium-7 (^{7}Be) is also being used to estimate the depth of the surface-mixed layer (SML) resulting from the mixing of near-surface intertidal sediments by physical reworking (i.e., waves) or the activities of benthic fauna. A first order estimate of the residence time of sediments in the SML is derived from the maximum ^{7}Be depth and ^{210}Pb SAR.

With the exception of WHG-14, sediment cores from each site have also been x-ray imaged to provide fine detail of their sedimentary structure (i.e., layering, animal burrow traces etc.). This information will also be used to inform the interpretation of the radioisotope (i.e., dating) and stable-isotope (i.e., sediment sources) profiles. The first set of sediment samples from each core have also been submitted for radioisotope dating.

7.4 Sediment source determination

Samples of surficial harbour sediments and catchment top soils were collected at 93 sites by NIWA and NRC staff during February–March 2012 (Figure 7-2). These samples, along with the sediment cores, will provide the basis for quantifying present-day and historical sources of catchment soils that are depositing in the harbour.

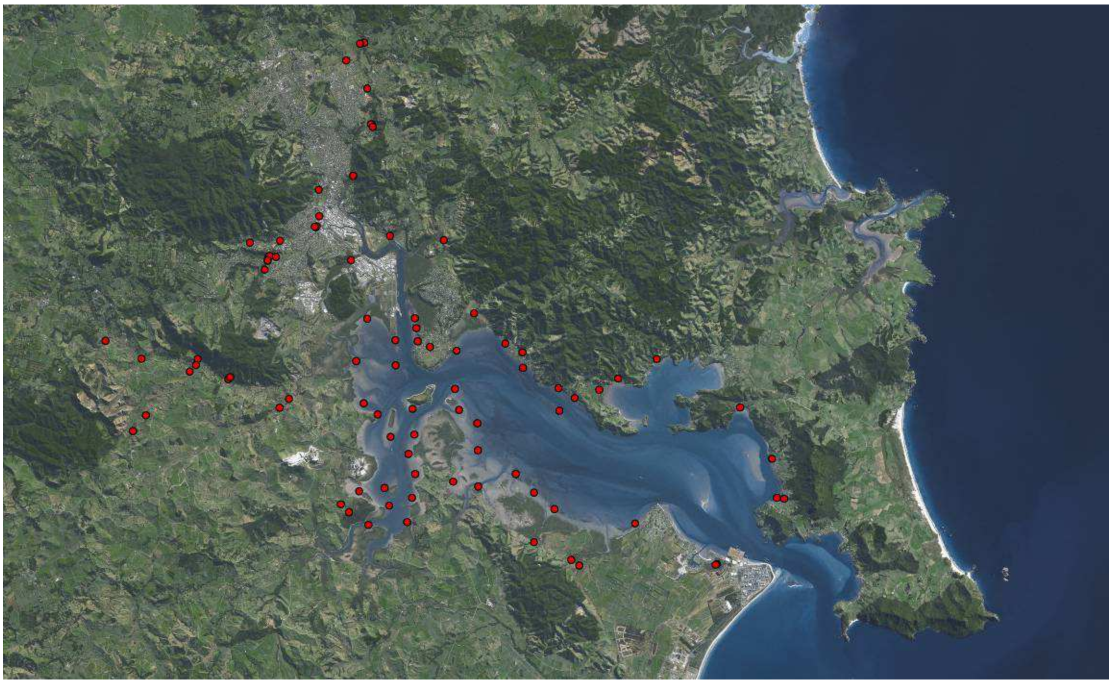

Figure 7-2: Location of surficial harbour sediment and soil-sampling sites in the Whangarei Harbour and catchment, Feb–March 2012.

The foundation of the Compound Specific Stable Isotope (CSSI) method is the fact that different vegetation types (e.g., native forest, pasture, pine, orchards, crops etc.) impart unique isotopic signatures to top soils. These isotopic signatures can be used to identify the proportion of the various soil sources in estuarine sediments. In this study, the CSSI signatures of fatty acids produced by plants are being used as sediment tracers. Harbour sediment and catchment soil samples were submitted for CSSI analysis and results were received in November 2012.

7.5 Potential contribution to quantification of sediment sources

The results generated by the harbour sedimentation study have the potential to contribute to the identification and quantification of contaminant sources in the following ways:

- Estimates of SAR from cores could be used to estimate long-term (i.e., decadal-scale) catchment sediment loads from the catchments discharging to the Mangapai and Hatea River arms in particular. This approach was used in the ARC-funded Mahurangi Harbour sedimentation study (Swales et al., 1997). This method assumes near complete trapping of fine sediments in an estuary. Confidence in these “sedimentation load” estimates increases with the number of cores and the similarity or otherwise of SAR estimates. This should be considered a first order estimate but does have the advantage that it is based on long-term data, whereas sediment-load measurements at hydrometric stations are typically short (i.e., several years at most) and/or do not sample the large infrequent events that dominate sediment delivery to estuaries;

- The CSSI sediment-source data will enable the relative importance of individual sub-catchments and/or land use types[38] as (present-day) sediment contributors to the harbour to be quantified. Initial analysis of the CSSI data indicates that deposition of catchment sediments is largely restricted to the Hatea and Mangapai Arms of the upper Harbour. Elsewhere, in the middle and lower reaches of the harbour, present-day sediments appear to be dominated by marine sources and/or sedimentation rates are so low that in situ production (e.g., seagrass) is isotopically labelling these sandy sediments.

Limitations on the potential of the sedimentation study to contribute to the contaminant study are:

- Most core sites are located in the upper Harbour (where catchment sediments appear to be mainly accumulating), so that we have limited data on sedimentation elsewhere in the harbour;
- The CSSI method is not being applied to dated sediment cores as was undertaken in the Bay of Islands study. Consequently, we cannot determine if major sediment sources have changed over time and therefore how long present-day catchment sources have dominated sediment delivery to the harbour.

Recommended actions that would result in further value being gained from the study results, in terms of the quantification of sediment sources are:

- The study would benefit from the application of the CSSI dating method to the cores to evaluate past changes in sediment sources.

[38] While the method is expected to distinguish between different rural land uses based on vegetation differences, it does not provide a basis for distinguishing the relative importance of urban land uses.

8 Synthesis

8.1 Introduction

This chapter brings together the results of:

- the review of existing knowledge on contaminant sources (Chapter 4);
- the review of monitoring data (Chapter 5);
- the new estimates of diffuse source contaminants (Chapter 6); and
- anticipated outputs of the harbour sedimentation study (Chapter 7),

in order to identify the key ‘knowns,’ and ‘unknowns’ in relation to the quantification of contaminant sources in the Upper Harbour catchment. It first consolidates and compares existing estimates of contaminant loads, before discussing the potential uses of other existing and anticipated information to add to the existing estimates and to guide assessments of catchment variations in contaminant sources.

8.2 Existing estimates of contaminant loads

Table 8-1 summarises the contaminant load estimates reported in the studies reviewed in Chapter 4 along with those resulting from the modelling undertaken as part of this project. Estimates of diffuse source contaminants are available for the whole catchment based on the C-CALM and CLUES modelling reported in Chapter 6. Previous studies have reported estimates of suspended solids, metals and nutrients for the Hatea, Raumanga, Waiarohia, Kirikiri and Limeburners sub-catchments.

Table 8-2 provides a comparison of the alternative estimates of diffuse-source loads of suspended solids, metals and nutrients. The C-CALM 2012 loads estimated for the Raumanga sub-catchment are compared with those estimated for the slightly smaller Raumanga SMC in the C-CALM 2009 study. The TSS load estimated in the present study is lower than that estimated in 2008, which reflects the fact that the present study has used CLUES for the rural parts of the catchment whereas the 2008 study used C-CALM for the entire catchment. The CLUES estimates for the rural area are based on a more sophisticated representation of catchment characteristics resulting in a spatially-varying TSS yield, while C-CALM applies a single yield for each broad rural land use class. This comparison suggests that the 2008 C-CALM TSS load for the Raumanga sub-catchment is probably an overestimate. The copper loads estimated by the two studies are very similar while zinc loads are more than 40% higher in the present study than as estimated in the 2008 study. Partly, this difference reflects the fact that the Raumanga SMC modelled in 2008 study excludes part of the CBD which is included in the Raumanga sub-catchment modelled in the present study. There are also differences in assumptions between the two studies, particularly in relation to the accuracy with which contaminant source areas have been defined (see Chapter 6).

Table 8-1: Summary of contaminant load estimates, upper Whangarei Harbour catchment.

Contaminant Source	Sediment	Nutrients	Faecal pathogens / indicator bacteria	Metals
Diffuse sources				
Whole sub-catchment	WHWQMP WR12	WHWQMP WR12		
Urban land use and major roads	C-CALM 2012 load estimates by sub-catchment C-CALM 2009 load estimates for 3 areas WDC CMP for Port Rd industrial area load estimates (1 in 50 yr storm) Part Hatea sub-catchment loads (Webster et al., 2000)	WDC CMP for Port Rd industrial area load estimates (TP, TN - 1 in 50 yr storm)	✓	C-CALM 2012 load estimates by sub-catchment (Cu & Zn) C-CALM 2009 load estimates for 3 areas (Cu & Zn) WDC CMP for Port Rd industrial area load estimates (1 in 50 yr storm) Part Hatea sub-catchment loads (Webster et al., 2000)
Major rural roads	✓			✓
Pastoral farming	CLUES load estimates by sub-catchment	CLUES load estimates by sub-catchment (TN & TP)	CLUES load estimates by sub-catchment (*E.Coli*)	
Exotic forests	CLUES load estimates by sub-catchment	CLUES load estimates by sub-catchment (TN & TP)	CLUES load estimates by sub-catchment (*E.Coli*)	
Native forests	CLUES load estimates by sub-catchment	CLUES load estimates by sub-catchment (TN & TP)	CLUES load estimates by sub-catchment (*E.Coli*)	
Point sources				
Treated WWTP effluent	WDC estimates from representative dry weather flow and concentration data	WDC estimates from representative dry weather flow and concentration data	Loads of faecal coliforms and viruses (McBride & Reeve, 2011)	✓
Untreated wastewater overflows		✓	Loads of faecal coliforms and viruses (McBride & Reeve, 2011)	✓
Dry weather wastewater overflows		✓	✓	✓
Septic systems effluent		✓	✓	✓
Farm dairy effluent		✓	✓	
Industrial discharges	✓	✓		✓
Landfills		✓		✓
Construction earthworks	✓			
Quarries	✓			
Background	✓	✓	✓	✓

✓ = potential source (see Chapter Four) but no known load estimates

Table 8-2: Comparison of alternative diffuse-source load estimates of suspended solids, copper and zinc. The text compares the underlined estimates in each sub-catchment.

Sub-catchment	Area for which loads estimated	Source	Time scale	Area (ha)	TSS (t)	Cu (kg)	Zn (kg)
Raumanga	Whole sub-catchment	CLUES 2012 (rural)	annual	1336	1700	-	-
		C-CALM 2012 (urban)	annual	397	191	41	582
		Total 2012	annual	1733	1891	-	-
	Raumanga SMC	C-CALM 2009	annual	1585	2876	40	402
Raumanga, Waiarohia and Kirikiri	All three sub-catchments combined	CLUES 2012 (rural)	annual	3175	3500	-	-
		C-CALM 2012 (urban)	annual	1029	490	-	-
		Total 2012	annual	4204	3990	-	-
		WHWQMP WR12	annual	4204	2674 [a]	-	-
Limeburners	Whole sub-catchment	CLUES 2012 (rural)	annual	1010	700	-	-
		C-CALM 2012 (urban)	annual	291	128	103	1182
		Total 2012	annual	1301	828	-	-
	Port Rd area	C-CALM 2009	annual	150	63	81	915
		Port Rd CMP	1-50 yr 24 hr storm		220	90	55
Hatea	Whole sub-catchment	CLUES 2012 (rural)	annual	3586	24500	-	-
		C-CALM 2012 (urban)	annual	905	429	75	1138
		Total 2012	annual	4491	24929	-	-
		WHWQMP WR12	annual	4491	8862[a]	-	-
	Upstream of flow recorder site	Webster et al. (2000)	annual (10 year mean)	3793	264	12	122

Notes

[a] Calculated from volumetric estimated reported in NRC (undated-2) – see Section 4.2.2.

Table 8-2 also compares summed diffuse-source load estimates for the Raumanga, Waiarohia and Kirikiri sub-catchments arising from the present study with those derived from WHWQMP WR12 (NRC, undated-2). The level of agreement between the two estimates is relatively close compared to that between other estimates shown in

Table 8-2 (described below), noting that the estimate reported in WHWQMP WR12 was based on very limited sampling and has been manipulated here to convert it from units of volume to units of mass.

Table 8-2 also compares diffuse-source load estimates for the Limeburners sub-catchment with those estimated for the Port Rd industrial area in the 2008 C-CALM study and in WDC's Port Rd CMP (Hydraulic Modelling Services, 2004). The Port Rd area makes up around 50%

of the total urban land use in the Limeburners sub-catchment. The 2008 C-CALM Port Rd load estimates of SS, copper and zinc are 49%, 79% and 77%, respectively of those estimated for the entire urban area in the sub-catchment in the present study. The apparently disproportionately high proportions of metals from the Port Rd area reflect its industrial land use, with large areas of galvanised roofs and heavy traffic leading to higher yields of zinc and copper than in other types of urban land use.

The load estimates of SS and copper reported in the Port Rd CMP for the 1-50 year 24 hour storm appear very high[39], exceeding the annual loads estimated in the 2008 C-CALM study. In contrast, the estimated Zn load during the 1-50 year 24 hour storm is only 6% of the estimated annual load. With the 1-50 year 24 hour storm depth estimated to be 312 mm (Hydraulic Modelling Services, 2004), or around 20% of the mean annual rainfall, this load estimate appears reasonable when compared with the annual load estimated by C-CALM. Something less than 20% of the mean annual load can be expected during a single storm of this magnitude because the quantity of zinc available for wash off will be limited by the length of the antecedent dry period preceding the storm. The key point arising from this comparison is the very different relationships which exist between the annual (C-CALM derived) and 1-50 year estimates for copper compared to zinc. Typically, zinc concentrations in urban runoff are around an order of magnitude higher than copper. The higher copper than zinc loads suggests additional sources of copper may be present in this catchment.

Table 8-2 also compares diffuse-source load estimated by the present study for the Hatea sub-catchment with those derived from WHWQMP WR12 (SS only; NRC, undated-2) and those estimated for most of the area of the same sub-catchment by Webster et al. (2000). The loads derived from WHWQMP WR12 are around a third of those estimated here while those reported by Webster et al. (2000) are much lower, even accounting for the slight difference in catchment area. The loads of SS and zinc estimated in the present study are two and one order of magnitude, respectively, higher than those estimated by Webster et al. (2000). While the estimates produced by the latter study were based on relatively limited water sample collection, the difference between the two sets of estimates means that it is important to review the assumptions upon which the estimates produced in the present study are based.

As noted in Section 6.2.3, we suspect that the CLUES-derived TSS load estimate for the Hatea sub-catchment is an overestimate. Adopting a TSS yield similar to neighbouring sub-catchments would result in a TSS load of around 5 kt/yr, closer to that derived from WHWQMP WR13 (8.8 kt/yr), but still an order of magnitude higher than that estimated by Webster et al. (2000), as is the case for the zinc estimates produced by the two studies. While the present study has estimated urban sediment and metal loads based on yields derived from Auckland data, we consider that these yields should be reasonably representative of yields in Whangarei. This assumption is consistent with the findings of Williamson and Thomsen (1994) that suspended solids and metal concentrations in Whangarei stormwater were generally consistent with other urban areas in New Zealand.

The only previous estimates of point source contaminant loads are those for faecal pathogens and indicator bacteria associated with the QMRA study of the discharge of treated and untreated wastewater (McBride and Reeve, 2011) and WDC's estimates of dry weather loads of TN, TP and TSS in treated effluent from the WWTP (see Section 4.5.2). Although the loads estimated in the QMRA study are not reported, the flow data and assumed

[39] The CMP notes that these estimates are based on catchment-wide mean concentrations multiplied by the total volume of the modelled 1-50 year 24 hour storm runoff and are to be treated with caution.

concentrations upon which they are based are readily available[40]. As a result of the CLUES modelling undertaken as part of the present study, loads of diffuse sources of *E.Coli* are now also available and these can be used as input to a further QMRA which takes account of catchment-wide sources. The previous study was confined to the sub-catchments draining to the Hatea River arm of the harbour.

Table 8-3 compares WDC's estimates of dry weather loads of TN, TP and TSS in treated effluent from the WWTP with estimates of diffuse-source loads for the Limeburners sub-catchment and the upper Harbour catchment as a whole. The estimated loads of TN and TP discharged in dry weather flows from the WWTP are an order of magnitude higher than those from diffuse sources in the Limeburners sub-catchment. The estimated loads of TN discharged in treated effluent from the WWTP are 40% of those from diffuse sources in the upper Harbour catchment as a whole, while the estimated loads of TP in treated effluent are nearly double those from the catchment. Estimated loads of TSS discharged in treated effluent from the WWTP are only 0.01% of those discharged from diffuse sources across the upper Harbour catchment as a whole.

Table 8-3: Estimated annual loads of TSS, TN and TP in dry weather discharges of treated effluent from the WWTP compared with diffuse-source loads in Limeburners sub-catchment and the upper Harbour catchment as a whole.

	TSS (kt)	TN (t)	TP (t)
WWTP dry weather treated effluent discharges	0.033[a]	52.0[a]	30.0[a]
Limeburners sub-catchment diffuse-sources	0.83[b]	4.8[c]	0.8[c]
Upper Harbour diffuse-sources	243.3[b]	130.9[c]	16.6[c]

Notes

[a] WDC estimates (see Section 4.5.2)

[b] sum of CLUES and C-CALM estimates reported in Chapter 6

[c] CLUES estimates reported in Chapter 6

8.3 Other potential uses of the existing information

While the information reviewed in Chapters 4 and 5 contains few estimates of contaminant loads, it does contain other information which can be of value in one of two ways:

- for the estimation of loads, subject to the availability (or estimation) of flow data; and
- to provide guidance on the spatial variability of contaminant sources within sub-catchments and the catchment as a whole, for instance to indicate likely contaminant 'hot spots'.

Table 8-4 summarises which of the existing information reviewed is of potential value for either or both of these purposes.

[40] Being included by way of numerous notes associated with many cells in the Excel Workbook used to perform the QMRA (using Monte Carlo simulation, with the @RISK Excel "plug-in" software).

Table 8-4: Existing information of potential value for the estimation of loads and/or assessment of spatial variability of contaminant sources. Information of potential use for estimating loads is shown in bold.

Contaminant Source	Sediment	Nutrients	Faecal pathogens / indicator bacteria	Metals
Diffuse sources				
Urban land use and major roads	WDC/NRC stormwater monitoring data	WDC/NRC stormwater monitoring data WDC CMPs for Port Rd, Onerahi	WDC/NRC stormwater monitoring data	WDC/NRC stormwater monitoring data WDC CMPs for Port Rd, Onerahi
Major rural roads	✓			✓
Pastoral farming	**Puwera Clean Streams monitoring data** NIWA/NRC harbour sediment study	**Puwera Clean Streams monitoring data**	**Puwera Clean Streams monitoring data**	
Exotic forests	**Yields or data from Glenbervie Forest study** NIWA/NRC harbour sediment study			
Native forests	NIWA/NRC harbour sediment study			
Point sources				
Treated WWTP effluent (including partially treated extreme bypass)	**Network model outputs and/or measured flows** **Representative untreated/treated concentrations (local or literature-based)**	**Network model outputs and/or measured flows** **Representative untreated/treated concentrations (local or literature-based)**	**Network model outputs and/or measured flows** **Representative untreated/treated concentrations (local or literature-based)**	**Network model outputs and/or measured flows** **Representative untreated/treated concentrations (local or literature-based)**
Untreated wastewater overflows	**Network model outputs** **Representative untreated/treated concentrations (local or literature-based)**	**Network model outputs** **Representative untreated/treated concentrations (local or literature-based)**	**Network model outputs** **Representative untreated/treated concentrations (local or literature-based)**	**Network model outputs** **Representative untreated/treated concentrations (local or literature-based)**
Dry weather wastewater overflows		✓	✓	✓
Septic systems effluent		✓	✓	✓
Farm dairy effluent		✓	✓	

Contaminant Source	Sediment	Nutrients	Faecal pathogens / indicator bacteria	Metals
Industrial discharges	Data from various industrial sites, mainly in Port Rd area	Data from various industrial sites, mainly in Port Rd area		Data from various industrial sites, mainly in Port Rd area
Landfills	**Pohe Island monitoring data**	**Pohe Island monitoring data**	**Pohe Island monitoring data**	**Pohe Island monitoring data**
Construction earthworks	✓			
Quarries	Data from one quarry			
Background	✓	✓	✓	✓
Mixed land use / multiple sources	**Data from sites in upper Limeburners (2) sub-catchment** **NIWA/NRC sediment study**	**Data from sites in Hatea (1), Waiarohia (2), Limeburners (2) sub-catchments** Data from various other sites (small datasets)	**Data from sites in Hatea (1), Waiarohia (2), Limeburners (2) sub-catchments** Data from various other sites (small datasets)	

✓ = potential source but no known load estimates (see Table 8-1) or catchment-specific existing information for load estimation / assessment of contaminant sources

8.3.1 Load estimation

The information from which it may be possible to calculate loads includes the data from the following NRC monitoring sites:

- The two sites in the Puwera sub-catchment established for the Clean Streams Accord monitoring project for the estimation of loads of SS, nutrients and indicator bacteria associated with pastoral farming;
- The long-term monitoring sites in the Hatea (1) and Waiarohia (2) sub-catchments, for the estimation of sub-catchment (or part sub-catchment) loads of nutrients and indicator bacteria;
- Two sites in the Limeburners sub-catchment (108181 and 108182) which are located upstream of discharge points from the WWTP for the estimation of sub-catchment loads of SS, NH_4-N and faecal coliforms (excluding inputs from the WWTP).

The data from each of these sites would need to be evaluated for its representativeness of a range of flow conditions and, in some cases, a synthetic flow record would need to be developed in order to calculate long term loads.

A range of information is available which can be used to calculate loads of contaminants discharged in wastewater, including both treated and partially treated wastewater discharged from the WWTP and untreated wastewater from wet-weather overflows. This includes:

- Outputs of the WDC network model. The results of the 14-year model run described in AWT (2011) (or some shorter period of at least one representative rainfall year) could provide the basis for estimating average annual loads of contaminants discharged in treated effluent, bypassed partially treated effluent and wet weather overflows, providing that the outputs from this model run include time series of flows of: influent to the WWTP, treated effluent, partially treated effluent from the extreme flow bypass and overflows (preferably all overflow points combined).

- Representative contaminant concentrations in treated and untreated effluent, either from locally-collected data as reported in AWT (2011) and in the monitoring data held by NRC or from assumed values reported in McBride and Reeve (2011) (for faecal pathogens and indicator bacteria only). Alternatively, it is also possible to use literature values of contaminant concentrations in treated and untreated wastewater derived from elsewhere (for instance, data from Auckland's Mangere WWTP or international literature reported in Ellis (2004)).

Other information which may be able to be used to estimate contaminant loads in relation to specific land uses is:

- Monitoring data from the closed Pohe Island landfill provides an indication of concentrations of SS, faecal coliforms, total Cu, total Pb, total Zn, and NH_4-N discharged from the landfill. Further information of leachate flow rates and the coverage of this monitoring relative to the landfill as whole would be required in order to determine whether they provide a basis for load estimation.

- Estimated sediment yields (or the original data) from the Glenbervie Forest study for the estimation of sediment loads during the different phases of forestry operations (Hicks and Harmsworth, 1989).

Finally, the NIWA/NRC harbour sediment study currently in progress will provide a basis for estimating the average annual sediment load discharged from the harbour catchment as a whole (see Section 7.5). This will provide a means of assessing the reliability of estimates for the individual sub-catchments produced by the other methods described above.

8.3.2 Identification of Contaminant Sources

The information which can be used to provide guidance on the spatial variability of contaminant sources within sub-catchments and the catchment as a whole includes:

- Sampling results from urban stormwater and sediment sampling (including in the CMPs for Port Rd and Onerahi SMCs), as part of an assessment of the spatial variability in stormwater quality across Whangarei. While the existing data from this monitoring is insufficient in itself for the estimation of loads, it can be used to investigate, for instance, the location of contaminant 'hot spots' and guide additional sampling specifically targeted at generating data for estimating loads.

- Other small data sets from various sampling locations, as part of an assessment of catchment wide variations in water quality, noting this data is mainly limited to nutrients (especially NH_4-N) and indicator bacteria (including the results of the targeted study in the upper Hatea sub-catchment) and that there are too few sites to investigate water quality variations within sub-catchments in any great detail. Analysis of variations in concentrations of indicator bacteria, for instance, could be undertaken to provide indications of faecal pathogen concentrations deriving from different sub-catchments (and within sub-catchments), with reference to relevant literature on the relationships between indicator bacteria and pathogens from diffuse rural sources (e.g. WHO, 2012).

- Data from 25+ industrial point source sampling locations, to provide an indication of the water quality of discharges in the Port Rd industrial area. Similarly, four sites in the Whangarei South catchment provide an indication of concentrations of suspended solids, nutrients and indicator bacteria associated with point source discharges in this sub-catchment.
- The macroinvertebrate monitoring assessments and rankings reported in Pohe (2012), as an indication of potentially contaminant 'hot-spots' that can be taken into account in further estimation of loads.
- The results of the NIWA/NRC harbour sedimentation study currently in progress, as an indicator of the relative importance of present day sediment loads by rural land use type and by sub-catchment.

Finally, the findings of elevated concentrations of TP and NH_4-N in urban stormwater reported in Williamson and Thomsen (1994) suggest that an assessment of more recently collected data should be undertaken to see whether or not this remains an issue. If so, the assessment should evaluate whether high concentrations in stormwater translate into a significant proportion of the total catchment loads of these contaminants. That would then lead to consideration of potential sources: i.e. whether or not some or all of these stormwater loads can be accounted for as deriving from other quantifiable sources (e.g. from wastewater overflows) or originate from some other source(s) which requires quantification in its own right.

9 Programme of Further Work - Options

9.1 Introduction

This chapter describes options for a programme of further work to generate additional estimates of contaminant loads and to assess the spatial variation in loads between and within sub-catchments. It begins by establishing the importance of setting the programme objectives in order to determine the most appropriate methods for generating further load estimates. It then describes the methods will deliver on these objectives, taking account of the synthesis of existing information and the anticipated results of work in progress described in Chapter 8. The various methods are presented as a series of options aimed at delivering increasing levels of information, but which would require a corresponding increasing level of effort. Indicative time scales and costs are given to illustrate the relative level of effort likely to be associated with each option. In general, the options adopt a guiding principle of, first, trying to get the most out of existing information wherever possible.

9.2 Setting the Programme Objectives

A first consideration when setting objectives for the programme of further actions is to identify how much (or how little) additional information is required in order to inform the management decisions of the future. There are two main aspects involved in this consideration:

1. Firstly, based on the information available, what is likely to be the relative importance of each of the contaminant sources identified in Chapter 4?
2. Secondly, given the purposes for which the load estimates are likely to be used, what level of accuracy is required?

9.2.1 Relative Importance of Sources

Guidance for answering the first of these questions is available from some of the estimates of diffuse source contaminant loads presented in Chapter 6, the commentary provide in NRC's & WDC's (2012) background report (summarised in Chapter 4) and the findings of previous studies (also presented in Chapter 4). The relatively more important contaminants are likely to be:

- Sediment: diffuse catchment runoff from the rural parts of the catchment[41], including from forestry during harvesting operations;
- Nutrients: diffuse catchment runoff from the rural parts of the catchment; discharges of treated wastewater; discharges of untreated wastewater during wet weather; possibly diffuse urban sources of some nutrients[42] and possibly dry-weather wastewater overflows / exfiltration;
- Faecal pathogens: diffuse catchment runoff from the rural parts of the catchment (including stock access to streams); discharges of untreated wastewater during wet weather; and possibly dry-weather wastewater overflows / exfiltration;

[41] Refer to Chapter 6: the total rural load estimated by CLUES is about an order of magnitude higher than the urban load estimated by C-CALM (excluding the loads for the Otaika and Hatea sub-catchments which are considered to be overestimates).
[42] Refer to the findings of Williamson and Thomsen (1994) reported in Chapter 4.

- Metals: stormwater discharges from the urban part of the catchment.

While there are several other potential sources of each of these four groups of contaminant, the commentary provided in NRC & WDC (2012) suggests that these are generally well-controlled through various management interventions that have already taken place and through on-going compliance with the conditions of resource consents. Measures which have resulted in some of these other sources becoming relatively less important include:

- Improved management of farm dairy effluent disposal;
- Ending the discharge of fine sediments from the Portland cement factory;
- The consenting and compliance monitoring of industrial discharges;
- Closure of the Pohe Island landfill and reticulation of its leachate to the WWTP; and
- The consenting and compliance monitoring of large-scale construction earthworks.

It is also the case that untreated wastewater overflows, while still considered to be one of the more relatively important sources of nutrients and faecal pathogens, are also greatly reduced as a result of the upgrades to the network and WWTP described in Chapter 4. Future upgrades, including the proposed increase in storage to reduce extreme flow bypasses (AWT, 2011) are expected to reduce discharges of untreated and partially-treated wastewater further.

Sources which are considered to be more uncertain in terms of their importance, for instance based on the commentary given in NRC & WDC (2012) include:

- Community and household septic systems outside the areas of wastewater reticulation;
- Subdivision and construction earthworks at the lot scale;
- Quarries; and
- Background sources, for instance reflecting the phosphorus rich geology of parts of the catchment.

9.2.2 Level of Accuracy Required

The level of accuracy required depends on the purpose for which the load estimates will be used. A distinction can be drawn between:

(1) Purposes for which it is sufficient to establishing the relative importance of different sources and source areas (i.e. sub-catchments and locations within sub-catchments); and

(2) Purposes for which is it necessary to attempt to quantify the absolute magnitude of sources.

Where the aim of the exercise is to identify key source activities or sub-catchments in order to prioritise management responses, then knowledge on the relative importance of different sources is likely to be sufficient. In contrast, where other information is indicating a decline in the state of a receiving water body it may become necessary to undertake a detailed evaluation of whether or not discharge limits imposed on individual activities are being exceeded. In that case, it would be more important to attempt to quantify the absolute magnitude of loads with a high level of accuracy.

This two-fold distinction between purposes which require only the relative importance of loads and those which require absolute estimates can be thought of as representing two ends of a spectrum, with the level of effort required to generate the estimates increasing from the former to the latter. Table 9-1 shows this spectrum in terms of five levels of effort.

Table 9-1: Varying levels of effort associated with estimating loads.

Objective	Level of effort	Diffuse sources	Point sources	Comments
Interested in relative importance of sources ↑	1 (Lowest)	Model loads based on generic inputs (e.g. default land use proportions).	Attempt load calculation from representative local or literature values of contaminant concentrations and representative flow data, focusing on likely key discharges (e.g. WWTP and overflows).	Uncertainty over relativity of loads estimated by different methods. However, relative importance of loads from different sources estimated by any single method should be reliable.
	2	Model loads with more accurately defined land use input data.	Still focusing on likely key discharges (e.g. WWTP and overflows), attempt more sophisticated load calculation using network model time series of discharges.	Model estimates more accurate, but uncertainty over relativity of estimates produced by different methods remains.
	3	Model loads as above, attempt limited ground-truthing by estimating loads at sites with sufficient existing WQ data.	As above.	A low effort approach to addressing relativity between methods, but only limited existing data to go on.
	4	Model loads as above, ground-truthing at representative sites with targeted new WQ data (event based sampling). Use results of sampling to attempt local calibration of models or to identify hot spots.	Refine load calculation based on new data collection, still focusing on likely key discharges (e.g. event-based sampling at WWTP and overflows).	A more resource-hungry approach to addressing the relativity between methods, but could reveal contaminant 'hot spots' that are masked by the sub-catchment scale modelling.
↓ Need absolute loads	5 (Highest)	Model loads as above, ground-truthing and hot spot identification at sites in all sub-catchments with targeted new WQ data (event based sampling).	Refine load calculation based on new data collection, comprehensive set of point discharges (e.g. event-based sampling at WWTP, overflows and major industrial discharges).	Likely to be a very-resource hungry approach compared to addressing the relativity between methods.

The lowest level of effort is associated with estimates required only to establish the relative importance of diffuse and key point sources. Diffuse sources are modelled with generic inputs, for instance by representing contaminant source areas with model default values. Point source loads from key discharges are estimated using, for instance, information on representative (such as mean) flow rates and representative local or literature-based contaminant concentrations. The main limitation of this combination of methods is that there is uncertainty over the relativity of load estimates estimated by different models or methods. So while the estimates of, say, modelled stormwater loads give a good indication of the relative importance of each sub-catchment, we might have less confidence when comparing these loads with those estimated by other methods for other sources, for instance rural or key point source discharges.

With increased effort (level 2), the accuracy of estimates generated by the different methods improves. Model inputs can be more accurately defined, for instance involving analysis of catchment land use data rather than the use of default values. More sophisticated approaches can be used for the estimation of point source loads, for instance using flow time series (such as the outputs from the wastewater network model) and time-dependent concentration data. However, unless each of these methods has been previously validated, there remains uncertainty over the relativity of the estimates generated by the different methods.

Further increased effort (level 3) involves analysis of existing monitoring data in order to attempt to ground-truth[43] modelled estimates and resolve the issue of uncertainty in the relativity of estimates generated by the different methods. There are a number of alternative methods by which loads can be estimated from concentration and flow data and these can produce widely diverging estimates (see, for instance, Littlewood, 1998; Letcher et al., 2002; Li et al., 2003). Suffice to say that the more data points the better: the ground-truthing of model estimates is likely to be limited to sites with long–term routine sampling and continuous flow records (either actual or reliable synthetic records). Estimates produced from small data sets are unlikely to resolve any questions over the reliability of model estimates. The relevance of existing monitoring data for ground-truthing will therefore depend on the location of long-term monitoring sites. Where sites are downstream of multiple contaminant sources (i.e. close to the outlet of a mixed land use catchment) then they can only be used in attempting to ground-truth the modelled estimates for all upstream sources, not of any one source in particular.

Additional effort (levels 4 and 5) involves undertaking new data collection, with significant cost and time implications in order to collect enough new data for it to make a meaningful improvement in the estimation of loads. This additional monitoring could focus on both diffuse and point sources and would need to include (probably give priority to) intensive wet-weather sampling to allow characterisation of contaminant loads discharged during storm events, including capturing the ‘first flush’. This involves taking multiple samples and measuring flow during storm events in order to estimate event loads. Sampling during multiple events (again the more the better) allows the estimation of annual loads, again by a range of methods. The difference in the effort between levels 4 and 5 reflects the objectives and, hence, number of sites that new data is collected at. At level 4, the focus is on attempting to ground truth model estimates at representative locations. This ground-truthing can then be used to attempt a local calibration of the model: for instance if modelled

[43] By ground-truthing we mean attempting to validate the modelled loads through comparison with loads estimated from observations of water quality and flow.

industrial stormwater loads were found to be significantly more than those estimated by sampling at the outlet of an industrial stormwater catchment, then the decision could be made to reduce contaminant yields for industrial areas in the model and refine the model estimates based on this adjustment. Alternatively, selective additional sampling could be used to investigate suspected contaminant 'hot-spots' that are masked by the model estimates because of the scale at which it is applied. Level 5 represents an extension of the monitoring effort whereby loads from all sub-catchments and different diffuse and point sources within sub-catchments are ground-truthed.

9.3 Temporal scale

A further consideration for the estimation of loads is determining the relevant temporal scale for each type of contaminant.

The models employed in the present study provide annual average estimates of sediments, nutrients, metals and faecal indicator bacteria. This annual timescale is appropriate for sediments, nutrients and metals because the primary effects of these contaminants on the values of the upper Harbour results from their long-term accumulation; i.e. changes in the physical and chemical characteristics of harbour bed sediments that result in chronic effects on harbour biota and changes to habitat. While these contaminants can also have acute effects (for instance, where NH4-N and metal concentrations are elevated to toxic levels and suspended sediment concentrations result in degraded water clarity), those acute effects are generally of more consequence for smaller water bodies, i.e. the rivers and streams draining to the harbour.

Where a given source can be expected to generate significant, and predictable, variations from the annual mean then it is also relevant to estimate loads for these circumstances. This is most notably the case for sediment generation associated with forestry operations. As noted in Section 4.4.2, the study in Glenbervie Forest indicated that around 70% of the total suspended sediment yield over the 32-year growing cycle was generated during harvesting operations (Hicks and Harmsworth, 1989).

While the annual loads of *E. coli* estimated by CLUES are informative in terms of identifying likely spatial variations in diffuse sources of faecal pathogens, in order to facilitate a QMRA, loads of pathogens and indicator bacteria are also required at a much shorter time scale. In order to be consistent with the surveillance / grading modes of the MfE/MoH (2003) guidelines, loads of faecal pathogens and indicator bacteria should be calculated from time-varying concentrations over a single tidal cycle based on discharges and catchment sources that reflect conditions during the summer bathing season.

9.4 Methods by Source Type

The following sections translate the generic framework presented in Table 9-1 into a series of options for each of the relatively more important sources identified in Section 9.2.1, taking account of the synthesis of existing information and the anticipated results of work in progress described in Chapter 8. Indicative time scales are given which represent the expected approximate duration of work required to complete each option based on our experience with similar projects. Indicative cost ranges are also provided. Again, these costs are based on our experience with delivering similar projects and are indicative of the level of resourcing required if each option was to be undertaken as a commercial project. There are, of course, other ways in which each project could be delivered, for instance with the involvement of internal council staff time. The point of these indicative cost estimates is therefore to provide an indication of the relative level of effort likely to be associated with each option. It should be noted that the indicative cost ranges are not based on any precisely-defined programme of work nor should they be taken as an offer by NIWA to provide any of services for these costs.

9.4.1 Urban diffuse sources and major roads

Table 9-2 summarises methods for estimating loads of sediments, metals, nutrients and faecal pathogens and indicator bacteria from urban land use and major roads. These methods are designed to estimate annual average loads, except for faecal indicator bacteria, for which loads are required at the timescale of a tidal cycle, as noted above.

Table 9-2: Methods for estimating contaminant loads from urban diffuse sources and major roads.

Level of effort	Methods	Indicative duration	Indicative cost range
1 (Lowest)	C-CALM modelling of TSS, Cu and Zn loads based on generic inputs – completed (see Chapter 6, this report).	-	-
2	C-CALM modelling of TSS, Cu and Zn loads with more accurately defined land use input data, including future land use / stormwater management scenarios (see Section 6.4). Estimation of Cu, Zn loads from major rural roads based on published vehicle emission factors (Moores et al. 2010). Estimation of urban Pb loads based on analysis of stormwater monitoring data for Cu:Pb and/or Zn:Pb relationships. Estimation of urban nutrient loads and faecal pathogens and indicator bacteria based on literature data and analysis of long-term monitoring data from Waiarohia sub-catchment (comparison of upper and lower catchment sites). Attempt to assess whether elevated nutrient concentrations identified by Williamson and Thomsen (1994) are present.	1-2 months	$25-50k
3	Estimation of loads as level 2. Insufficient existing data to attempt ground-truthing of loads from monitoring data, but undertake comparison of NRC/WDC stormwater monitoring data to assess spatial variation in contaminant sources to help prioritise management responses.	1-2 months	$30-50k (includes level 2)
4	Initial estimation of loads as level 2. Ground-truthing at, say, five sites (combination of representative land use sites and/or suspected hot spots) with targeted event-based sampling programme. Involves flow measurement and auto-sampling at each site, aiming for 5-10 events distributed over at least a 12 month period. Samples analysed for TSS, metals, nutrients. Use results of sampling to undertake local calibration of model and/or to identify hot spots.	≥ 2 years	$200-300k
5 (Highest)	As level 4 but increase the number of sites (to say, ten) and/or sampling events (to say, 15 at each site). It's unlikely that all sites could be monitored concurrently, so a programme on this scale can be expected to at least double the duration of the monitoring programme.	≥ 4 years	$600k+

While level 1 methods have been implemented, we have noted limitations relating to model inputs and assumptions (see Section 6) and some questions over results based on the comparison with other estimates (see Section 8.2). Progressing to level 2 and trying to more accurately define inputs would aim to deal with this uncertainty and also provide estimates for lead, nutrients and faecal pathogens and indicator bacteria. Although none of the existing monitoring data is considered suitable for the estimation of loads to ground-truth the model results, an evaluation of stormwater monitoring data (level 3) could be undertaken for much the same level of overall effort.

The additional effort required to implement a programme of event-based monitoring (level 4 or level 5) is considered significant.

9.4.2 Rural diffuse sources

Table 9-3 summarises methods for estimating loads of sediment, nutrients and faecal pathogens and indicator bacteria from rural diffuse sources, including areas of pastoral farming and exotic and native forests.

Table 9-3: Methods for estimating contaminant loads from rural diffuse sources.

Level of effort	Methods	Indicative duration	Indicative cost range
1 (Lowest)	CLUES modelling of TSS, TN, TP and *E.Coli* loads based on generic inputs – completed (see Chapter 6, this report).	-	-
2	CLUES modelling with more accurately defined input data, for instance better representing local sediment yields in some parts of the catchment (see (see Section 6.4). Estimation of rural diffuse loads of faecal pathogens and indicator bacteria based on literature data (e.g. WHO, 2012).	1-2 months	$30-50k
3	Estimation of loads as level 2. Attempt ground-truthing of loads of sediments, nutrients and faecal indicator bacteria from pastoral farming from analysis of Puwera Stream monitoring data and possibly sites upstream of urban land use in the Waiarohia and Limeburners catchments. Attempt ground-truthing of sediment loads from exotic forestry from results of Glenbervie Forest study, including loads during different phases of forestry operations. Ground-truthing also to take account of results of harbour sedimentation study on relative importance of sub-catchments and land uses.	1-2 months	$40-60k (includes level 2)
4	Initial estimation of loads as level 2. Ground-truthing at, say, five sites (combination of representative land use sites and/or locations where model estimates are considered most uncertain) with targeted baseflow and event-based sampling programme. Involves flow measurement and auto-sampling at each site, aiming for 5-10 events distributed over at least a 12 month period. Samples analysed for TSS, nutrients, faecal indicator bacteria. Use results of sampling to undertake local calibration of model and/or to identify hot spots.	≥ 2 years	$200-300k

Level of effort	Methods	Indicative duration	Indicative cost range
5 (Highest)	As level 4 but increase the number of sites (to say, ten) and/or sampling events (to say, 15 at each site). It's unlikely that all sites could be monitored concurrently, so a programme on this scale can be expected to at least double the duration of the monitoring programme.	≥ 4 years	$600k+

9.4.3 Discharges from the wastewater network

Table 9-4 summarises methods for estimating loads of sediment, nutrients, faecal pathogens and indicator bacteria and metals from point source discharges of treated, partially-treated and untreated wastewater. These methods are designed to estimate annual average loads, except for faecal indicator bacteria, for which loads are required at the timescale of a tidal cycle.

Table 9-4: Methods for estimating contaminant loads in discharges from the wastewater network.

Level of effort	Methods	Indicative duration	Indicative cost range
1 (Lowest)	Estimate loads from treated discharges (WWTP), partially-treated discharges (extreme flow bypass) and untreated discharges (overflows) from representative local or literature values of contaminant concentrations and representative flow data.	1-2 weeks	$5-10k
2	Estimate loads from treated discharges (WWTP), partially-treated discharges (extreme flow bypass) and untreated discharges (overflows) from representative local or literature values of contaminant concentrations and network model time series of discharges. Include alternative discharge scenarios (including future population growth).	<1 month	$10-20k
3		-	-
4	Refine load calculation based on new data collection, for instance time series of monitored (rather than modelled) flows and results of event-based sampling of treated and untreated effluent discharges. Sample analyses to include norovirus in influent and effluent[44].	≥ 2 years	>$100k
5 (Highest)			

Level 1 involves estimation of loads based on representative flow rates and contaminant concentrations. This has been done for faecal pathogens (viruses) and indicator bacteria (faecal coliforms) as part of the previous QMRA study (McBride and Reeve, 2011), but not for any other contaminants. While there is some local data available on concentrations of these other contaminants in treated and untreated wastewater, the level 1 assessment would also consider literature values of contaminant concentrations (for instance, data from Auckland's Mangere WWTP or international literature reported in Ellis (2004)).

A more sophisticated approach (level 2/3[45]) would use the same or similar concentration data alongside the time series outputs of the wastewater network model. NIWA has previously employed this type of method in assessing the effects of wastewater overflows from part of Auckland's combined sewer system (Moores et al., 2012a). The approach would allow loads

[44] Analyses for norovirus could be limited to a relatively small number of samples, as has been done for recent and on-going QMRA exercises for Napier, New Plymouth and Hawera.

under alternative current and future discharge scenarios to be estimated as follows, for each time step (t) and in total (i.e. for an average year):

During dry weather:

$$L_{TW(t)} = (V_{DW} \times C_{TW}) \quad \ldots(1)$$

During wet weather:

$$L_{TW(t)} = (V_{DW} \times C_{TW}) \times [V_{TW(t)} / (V_{TW(t)} + V_{NO(t)} + V_{EB(t)})] \quad \ldots(2)$$

$$L_{NO(t)} = (V_{DW} \times C_{UW}) \times [V_{NO(t)} / (V_{TW(t)} + V_{NO(t)} + V_{EB(t)})] \quad \ldots(3)$$

$$L_{EB(t)} = (V_{DW} \times C_{UW}) \times [V_{EB(t)} / (V_{TW(t)} + V_{NO(t)} + V_{EB(t)})] \quad \ldots(4)$$

Where:

L_{TW} = Loads in treated wastewater

L_{NO} = Loads in network overflows

L_{EB} = Loads in extreme bypass

V_{DW} = Representative (constant) dry weather volume of treated wastewater

V_{TW} = Volume of treated wastewater

V_{NO} = Volume of network overflows (all overflows combined)

V_{EB} = Volume of extreme bypass flows

C_{TW} = Representative (constant) dry-weather concentration in treated wastewater

C_{UW} = Representative (constant) dry-weather concentration in untreated wastewater

And L, V and C are in units of g, m^3 and g m^{-3}, respectively.

Essentially, this approach would involve:

- Calculating a dry weather load from the discharge of treated wastewater (equation 1) and assuming that this load is constant under all dry weather conditions.
- During wet weather events, calculating the proportion of total network flow which is treated, discharged through the extreme bypass and discharged at overflow points, respectively.
- The treated load during wet weather events is equal to the treated dry weather load multiplied by the proportion of total flow that is treated in that time step (equation 2).
- The untreated load discharged from network overflows during wet weather events is equal to the untreated dry weather load multiplied by the proportion of

[45] No distinction is made between level 2 and 3. Relevant existing local sampling data would be used in the estimation of loads by this method rather than as an independent ground-truthing exercise.

total flow that is discharged from overflows in that time step (equation 3). Similarly to the treated dry weather load, the untreated dry weather load is assumed to be constant, based on representative dry weather flow rates and concentrations.

- The untreated load discharged from extreme bypass during wet weather events is equal to the untreated dry weather load multiplied by the proportion of total flow that is discharged from the extreme flow bypass in that time step (equation 4). It is recognised that these flows are in fact partially treated so some adjustment of the untreated wastewater concentrations should be attempted here.

Note that the loads of contaminants originating in stormwater entering the network during wet-weather events are not accounted for by this method. The role of stormwater in these calculations is limited to influencing volumes, i.e. the proportion of wet weather flows that are treated or untreated. The contaminant loads originating in stormwater would be, however, accounted for by other methods as described in Section 9.4.1[46].

The level of effort required to implement a programme of monitoring (level 4/5) to attempt to ground-truth model-based estimates is likely to be significant, although limited sampling to provide indicative concentrations of norovirus is considered worthwhile[47]. However, given the improvements to reduced overflows from the wastewater network in recent years and the proposed further measures to reduce discharges of partially-treated wastewater from the extreme flow bypass, it may be difficult to justify any more intensive monitoring effort for the purposes of this exercise (as opposed to, for example, monitoring for consent compliance purposes).

None of the options described above provide a basis for estimating loads from dry-weather overflows and exfiltration of wastewater from the network. As noted in Chapter 4, NRC & WDC (2012) report that there is currently insufficient information to assess whether or not these sources contribute significantly to the total load of contaminants discharged to the upper Harbour. Both dry-weather overflows and exfiltration result from localised failures of the network (pipe blockages and cracking), the extent and locations of which cannot be predicted. Unlike wet-weather overflows, which can be simulated based on the known capacity of the network, this means that dry-weather overflows and exfiltration cannot easily be modelled. In an assessment of wastewater overflows in the Auckland region, no attempt was made to assess the effects of dry-weather overflows (Moores et al., 2012b). Instead, the network operator chose to emphasise a robust management regime to avoid and/or respond to such discharges.

[46] Alternatively, the contaminant loads in the stormwater component of wet weather discharges could be modelled as part of this exercise based on representative concentrations of each contaminant in stormwater.
[47] This could include investigating residence times of pathogens by analysing dry weather water samples and sediment samples downstream of overflows for norovirus, as was done in an assessment of the effects of wastewater overflows in the Auckland region (Moores et al., 2012a).

9.4.4 Other sources

Based on the commentary provided in NRC & WDC (2012) that the following point sources are considered to be well controlled, we have not suggested any methods to attempt to estimate loads originating from them:

- farm dairy effluent disposal;
- industrial activities, including Portland cement factory;
- landfills; or
- large-scale construction earthworks.

Sources which are considered to be more uncertain in terms of their importance, for instance based on the commentary given in NRC & WDC (2012) include:

- Community and household septic systems outside the areas of wastewater reticulation;
- Subdivision and construction earthworks at the lot scale;
- Quarries; and
- Background sources.

At this stage, it is probably worth attempting to estimate contaminant loads from these sources based on representative literature data, where that exists, and only considering a more detailed assessment if those initial estimates suggest that these are relatively important sources compared to the diffuse sources and WWTP discharge estimates generated by the methods set out above. One method for estimating background loads of nutrients and metals, for instance, is to multiply modelled sediment loads (from CLUES, for instance) by measured concentrations of nutrients and metals in catchment soils and/or harbour sediments deposited prior to human modification of the catchment (for instance from dated sediment cores).

9.5 Chapter Summary

The methods described in the previous sections are distinguished by a marked difference in effort between levels 1-3 and level 4-5. The level of effort associated with levels 4 and 5 is much higher, because these methods involve significant new data collection in an effort to ground truth model estimates.

In deciding whether or not this additional effort is worth it, we suggest returning to a consideration of the objectives of the programme. As noted in Section 9.2.2, where the aim of the exercise is to identify key source activities or sub-catchments in order to prioritise management responses, then knowledge on the relative importance of different sources is likely to be sufficient. In contrast, where other information is indicating a decline in the state of a receiving water body it may become necessary to undertake a detailed evaluation of whether or not discharge limits imposed on individual activities are being exceeded. In that case, it would be more important to attempt to quantify the absolute magnitude of loads with a high level of accuracy.

10 Summary

A recent review of water quality monitoring data indicates that the middle and lower parts of Whangarei Harbour have good water quality, based on levels of nutrients and faecal bacteria. However, water quality in the upper Harbour is often poor, with the lowest water and sediment quality in the northern Hatea River arm downstream of urban Whangarei. This report describes a review of existing information on contaminant sources in the catchment of the upper Harbour, the estimation of contaminant loads from certain diffuse sources and the development of options to fill current gaps in knowledge. The contaminants of interest are sediment, nutrients (nitrogen and phosphorus), faecal pathogens and indicator bacteria, and metals (copper, lead and zinc).

The catchment of the upper Harbour comprises nine sub-catchments and a mix of urban and rural land uses. Typical of a mixed land-use catchment, there are a range of potential sources of contaminants. Diffuse sources include stormwater runoff from urban land and major roads, pastoral farming and exotic and native forests. Point sources include discharges of treated and untreated wastewater and discharges from industrial activities. There are also background levels of the contaminants, for instance reflecting their natural occurrence in the catchment soils.

A number of previous studies have assessed stormwater contaminants in urban parts of Whangarei, and some of these provide estimates of contaminant loads. There have also been studies of water quality associated with pastoral farming in the Puwera sub-catchment and of the impacts of forestry on sediment generation in the Hatea sub-catchment. The data from these studies and from three long-term water quality monitoring sites in the Hatea and Waiarohia sub-catchments can be used to estimate loads of some contaminants. Water quality and sediment quality data from a range of other sites, including stormwater and industrial discharge monitoring sites, can be used to assess spatial variations in contaminant sources but contain too few data points for the calculation of loads. A current study into the sedimentation of Whangarei Harbour is expected to provide results which can be used to evaluate sources of sediment by sub-catchment and by rural land use type, as well as providing estimates of the sediment load delivered from the catchment as a whole.

There are a number of information sources relating to the operation of the Whangarei wastewater network and treatment plant (WWTP) and the health risks associated with discharges of faecal pathogens. System upgrades in recent years have resulted in a reduction in wet-weather overflows from the network and further measures are planned in order to reduce the discharge of partially-treated wastewater from the WWTP. Outputs from a model of the network, in combination with data on treated and untreated wastewater quality, can be used to calculate contaminant loads discharged from these sources.

Discharges from other point sources, including farm dairy effluent discharges, industrial activities and bulk construction earthworks, are reported to be well-controlled through compliance with the conditions of resource consents. The importance of other sources, including dry-weather wastewater discharges, domestic septic systems, lot-scale construction earthworks and quarries is uncertain. We are unaware of any information on loads from these sources in the catchment of the upper Harbour.

Sub-catchment diffuse source loads of contaminants have been estimated using two models. The Catchment Land Use for Environmental Sustainability (CLUES) model was used to estimate rural loads of nutrients (total nitrogen, TN and total phosphorus, TP), total suspended solids (TSS) and the faecal indicator bacteria *E. coli*. The Catchment Contaminant Annual Loads Model (C-CALM) was used to estimate urban loads of TSS and dissolved and particulate zinc and copper. The results of this exercise are indicative estimates showing the relative importance of each sub-catchment as a source of diffuse-source contaminants. However, the application of the models involved making certain assumptions and could be revisited to incorporate more precisely-defined input data.

Options have been developed for a programme of further work to generate additional estimates of contaminant loads and to assess the spatial variation in loads between and within sub-catchments. Different options reflect different objectives. Where the objective is to identify key source activities or sub-catchments in order to prioritise management responses, then knowledge on the relative importance of different sources is likely to be sufficient. Relevant methods to meet this objective involve further modelling and the use of existing locally collected or literature-based data.

In contrast, where the objective is to undertake a detailed evaluation of whether or not discharge limits imposed on individual activities are being exceeded, it becomes more important to attempt to quantify the absolute magnitude of loads with a high level of accuracy. Options associated with this objective involve new data collection to attempt to ground-truth modelled estimates. The level of effort associated with this set of options is much higher than that associated with options focusing on establishing the relative importance of sources. Indicative time scales and costs are provided to illustrate this distinction.

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Appendix A Summary of Stormwater CMPs

Onerahi (Hydraulic Modelling Services, 2001)

This CMP covers only part of the Onerahi sub-catchment (see Section 2.3). It covers the area on the eastern side of the city north of the harbour which includes the airport and residential land. The northern part of the Onerahi sub-catchment has its own CMP (Awaroa, see below). There is a section on water quality which gives the results of sampling before and during an extreme rainfall event in 2001 (Cyclone Sosi, 24-hour 2% AEP). It is noted that the level of treatment during this event was very low. The CMP recommends construction of devices ranging from on-site detention (similar to swales and raingardens) to vegetated ponds (i.e., wetlands).

Awaroa (City Design, 1998a)

This CMP covers the northern, mainly rural, part of the Onerahi sub-catchment. The urbanised section of the catchment to the south has its own CMP (Onerahi, see above). This report is a status update for a CMP produced in 1985. It reports whether or not earlier recommendations have been implemented and gives new recommendations where needed. The CMP area was around 2% urbanised with a plan to develop up to 9%. The main issues are flooding and erosion. No stormwater treatment is listed, but options discussed include swales, infiltration, ponds and filters.

Hatea (Harrison Grierson, 1997)

This CMP covers the whole Hatea sub-catchment, including the Hatea, Waitaua and Mangakino SMCs (see Section 2.3). This is a status update for a CMP done in 1983 that reports whether or not earlier recommendations have been implemented and gives new recommendations where needed. No treatment devices are listed, but there is a section on SW quality that states a need for treatment using a combination of devices such as filter strips and ponds designed to TP 10 (ARC, 1992) standard.

Waitaua (PDP, 2011a)

This is a mainly rural SMC within the Hatea River sub-catchment that is 22% urbanised. The CMP focuses on water quantity control to manage flood risk. Water quality, including stormwater, has been monitored at three sites with elevated metal concentrations noted. The SMC is serviced by reticulated pipe network, no treatment devices are listed. Future development is planned with mention of riparian planting, Low Impact Design (LID) and stormwater treatment (devices unspecified) to TP10 standard.

Waiarohia (City Design, 1998b)

This is a largely rural catchment with urban land use bordering the north western edge of Whangarei. No stormwater treatment listed, but the CMP recommends source control and range of treatment devices including swales, infiltration, filters and ponds.

City Catchment (Beca Steven, 1999a)

This CMP covers the CBD and urban surrounds (mostly residential with some industrial). The stormwater network is described as reticulated with inadequate capacity for water quantity control. The CMP recommends a variety of treatment options including source control for new developments and retrofitted to existing areas where possible (e.g., filters), catch-pit inserts, riparian planting. This CMP also cites the original TP 10 guidelines. Ponds are also discussed, with several options for possible locations proposed.

Kirikiri (Beca Steven, 2001)

The Kirikiri SMC is largely rural with urban development in the mid to lower reaches. The catchment is a tributary of the Raumanga catchment and does not drain directly to the harbour. This report is a status update for a CMP done in 1984. Unlike the earlier report, it does include a section on stormwater management. With the exception of a quarry treatment pond there is stormwater treatment listed. The CMP recommends source control for new developments, installation of devices such as filters and catchpit inserts, riparian planting and construction of a treatment pond in the lower part of the catchment.

Raumanga (Beca Steven, 1999b)

The Raumanga SMC is largely rural with urban development in the mid to lower reaches. This report is a status update for a CMP done in 1985. Unlike the earlier report, it includes a section on stormwater management. No stormwater treatment is listed. The CMP recommends source control for new developments, installation of devices such as filters and catchpit inserts, riparian planting and construction of a treatment pond in the lower part of the catchment.

Limeburners (PDP, 2011b)

This is a mainly rural catchment with 16 % urbanised land. The CMP focuses on flood risk management. No water quality monitoring is mentioned (although sampling of estuary bed sediments is noted). No stormwater treatment devices are listed. Future stormwater treatment options include riparian planting, construction of a downstream detention pond and upstream LID site control devices (not specified).

Port Road (Hydraulic Modelling Services, 2004)

The Port Road CMP covers an industrial park that is largely fully developed. The report has sections on both water quantity and quality control. The existence of water treatment devices is noted, but no details are given. There is a section on water quality which gives the results of sampling before and during an extreme rainfall event in 2001 (Cyclone Sosi, 24-hour 2% AEP). It is noted that the level of treatment during this event was very low. The CMP recommends construction of devices ranging from on-site detention (similar to swales and raingardens) to vegetated ponds (i.e., wetlands).

Appendix B List of Water and Sediment Quality Monitoring Data Provided by NRC

Summary of Data	Files Provided
Register of sampling sites in the Whangarei Harbour and its catchment.	"Copy of All_Whangarei_sampling_sites.xlsx"
Stream water quality monitoring data for the following rivers: Lower reach of the Hatea River (1993-present) Lower and mid reaches of the Waiarohia Stream (2004-present) Mid to lower reach of the Otaika River (2011-present) Two sites on the Puwera Stream (2006-2011) Additional water quality monitoring data (faecal indicators only) for four main tributaries of the Hatea River and for the mid reach of the Raumanga Stream Other miscellaneous sites.	"River Water Quality Network Monitoring Data - Whangarei Harbour catchment.xls" "Water quality data for the Waiarohia Stream and the Hatea River.xls" "Puwera Water Qlty + Flow Data 2006-11.xls" "Rivers streams drains wetland 1.xls" "Rivers streams drains wetland 2.xls" *"H*atea Catchment Water Quality Investigation - Bacteria Results.xls" "Monitoring in vicinity of wastewater discharges.xls"
Effluent quality data from the Whangarei Wastewater Treatment Plant.	"Water Other.xls"
Effluent quality data from consented industrial discharges that discharge directly to the upper Harbour. List of discharge consents, compliance monitoring records, summary of compliance of major industrial discharges.	"Industrial and Trade Discharges.xls" "Industrial and Trade Discharges Notes.xls"
Stormwater quality monitoring data for a number of sites around Whangarei (2002 to present).	Whangarei Urban Stormwater Quality Monitoring Results.pdf and Whangarei Urban Drainage Area Stormwater Monitoring Plan.pdf "Stormwater discharge monitoring.xls" "WDC STW water results.xls"
Sediment quality data for urban streams, estuaries and stormwater outfalls (2002-present).	"Whangarei Urban Stormwater Sediment Monitoring Results.xls" "Harbour Sediment.xls"

Summary of Data	**Files Provided**
Sediment quality data for a number of sites in the Hatea River arm of the upper Harbour, including at the confluence of a number of other streams, e.g. Limeburners Creek, Waimahanga (1985 – present)	"Copy of Whangarei Harbour sediment metals 2010.xls" "Copy of Whangarei EMP subtidal sediment results 2012" "Copy of Whangarei EMP 2012 sediment results.xls" "Copy of Whangarei EMP intertidal sediment results 2012" "Harbour sediment contamination.xls"
Marine water quality monitoring data for a number of sites in the upper Harbour.	"Coastal Water 1.xls" "Coastal Water 2.xls"

Appendix C Evaluation of CLUES Estimates of Nutrient Concentrations, Kaipara Harbour Catchment.

The following is an extract from the report "CLUES for Kaipara Harbour Drainage Area Land use comparison 1770-2002" (Semadeni-Davies, 2012):

CLUES calculates the annual median concentration for sediment and nutrients for each river reach using a statistical relationship between the mean annual load and mean average annual river flow, the methodology is summarised in the CLUES user manual (Semadeni-Davies et al, 2011).

CLUES nutrient concentrations were compared to long-term observations from 12 sites in the Kaipara Harbour drainage area. These data were collated into a database by Unwin et al. (2010)[48] as part of a national survey of water quality. Observations are made at monthly intervals at a number of sites by NIWA (National River Water Quality Network, NRWQN), the Auckland Council (formally Auckland Regional Council, ARC) and the Northland Regional Council (NRC). Site locations are shown in Figure C-1, and site names and catchments are listed in Table C-1.

Unwin et al. (2010) summarised the data into five-, ten- and twenty-year median concentrations covering the periods 2003–2007, 1998–2007 and 1988–2007, respectively. The five- and ten-year medians are given in Table C-1 along with the number of months for which samples were available (i.e., out of a possible 60 or 120 months, respectively). The corresponding CLUES simulated median annual TN and TP concentrations for each river reach where an observation site is located are also shown. The twenty-year medians are not included in the analysis as they were considered to be unrepresentative of the default land use (i.e. 2002). Moreover, only three sites had data records longer than 15 years.

Regression analysis was carried out between the observed and modelled nutrient concentrations. Figure C-2 plots the observed TN and TP 5- and 10-year median concentrations respectively against the CLUES concentrations. The plots show reasonable agreement with the exception of three sites (NAT-WH03, NRC-101625 and NRC-100281) located to the north in the Wairoa River and its Wairua tributary, and site ARC-45313 located to the south in the Kumeu River catchment. The points for these outliers are marked on the plots. The outliers could be due to incorrect land use in the default scenarios or localised discrepancies in the global parameters used by CLUES, for example, nutrient loss rates which govern yields, in-stream decay rates, and flow-weightings used to convert annual mean to median concentrations. The agreement was better for TN than for TP concentrations, which could reflect the different methods used to simulate these nutrients within CLUES. For TN, the coefficient of determination (R^2) was 0.94 for the 5-year medians and 0.56 for the 10-year medians. For TP, the corresponding values are 0.61 and 0.50 respectively. The CLUES concentrations are within 12% of the observed five-year median concentrations for TN and within 20% for TP.

[48] Data were stored in a database queried for this study

The comparison supports the use of CLUES as an indicative tool that can be used to evaluate the impacts of land use change on water quality in the Kaipara Harbour catchment.

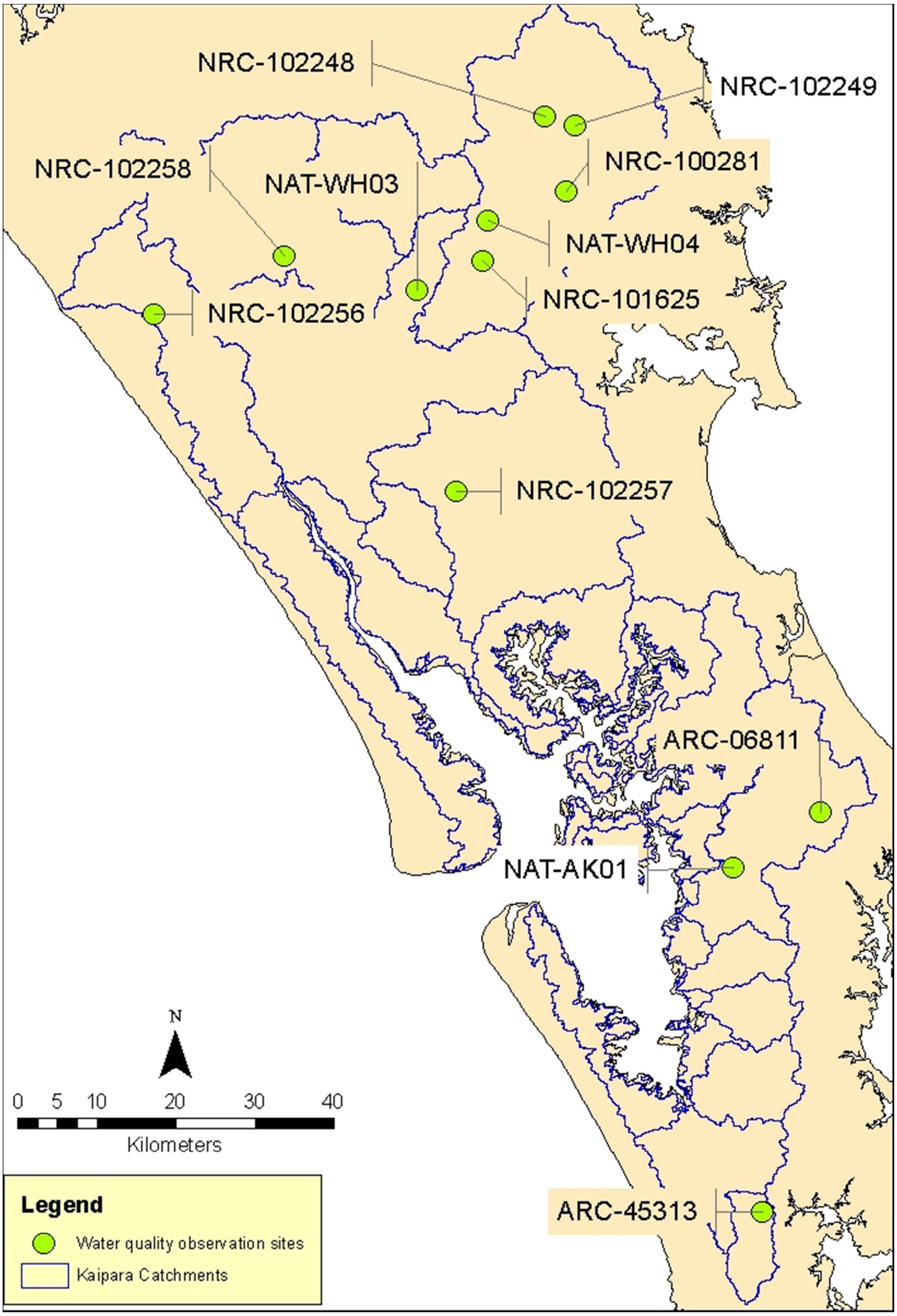

Figure C-1: Location of water quality observation sites evaluated against CLUES default (2002) simulations.

Table C-1: Water quality observation sites and long term median nutrient concentrations against median annual concentrations simulated by CLUES for the default (2002) land use scenario. (Observations taken from the national database collated by Unwin et al. 2010).

Water quality monitoring site				Five-year (60 months) median concentrations 2003-2007				Ten-year (120 months) median concentrations 1998-2007				CLUES median annual concentration (mg/l)	
ID and agency	Name	Catchment		Total Nitrogen		Total Phosphorus		Total Nitrogen		Total Phosphorus		Total Nitrogen	Total Phosphorus
				Months sampled	Conc. (mg/l)	Months sampled	Conc. (mg/l)	Months sampled	Conc. (mg/l)	Months sampled	Conc. (mg/l)		
NAT-WH03	Mangakahia @ Titoki Bridge	Wairoa River	1	60	0.30	60	0.029	120	0.32	120	0.028	1.32	0.178
NRC-102258	Opouteke River @ suspension bridge	Mangakahia River	2	55	0.21	54	0.039	113	0.24	113	0.058	0.25	0.045
NAT-WH04	Wairua @ Purua	Wairua River	4	60	0.71	60	0.072	119	0.81	120	0.073	0.70	0.062
NRC-100281	Mangahahuru Stream @ Apotu Rd bridge	Wairua River	4	56	0.66	56	0.082	116	0.74	116	0.090	0.34	0.031
NRC-101625	Mangere Stream @ Knight Rd	Wairua River	4	57	1.17	57	0.161	117	1.28	117	0.162	0.83	0.067
NRC-102248	Waiotu River @ SH1	Wairua River	4	56	0.59	56	0.067	89	0.65	89	0.068	0.67	0.067
NRC-102249	Whakapara River @ cableway	Wairua River	4	57	0.46	57	0.052	116	0.50	117	0.052	0.49	0.062
NRC-102257	Manganui River @ Mitaitai Rd	Tauaroa River	5	57	0.69	57	0.094	74	0.70	74	0.093	0.92	0.084
NRC-102256	Kaihu River @ gorge	Kaihu River	7	57	0.41	57	0.020	63	0.42	63	0.020	0.44	0.057
ARC-06811	Mahurangi @ Forestry HQ	Hoteo River	17	50	0.26	50	0.030	74	0.29	106	0.030	0.31	0.027
NAT-AK01*	Hoteo @ Gubbs	Hoteo River	17	60	0.62	60	0.058	120	0.67	120	0.055	0.69	0.064
ARC-45313	Kumeu River @ No. 1 Bridge	Kumeu River	23	48	0.89	48	0.070	71	0.89	102	0.070	1.07	0.028

* site duplicated by ARC 45703

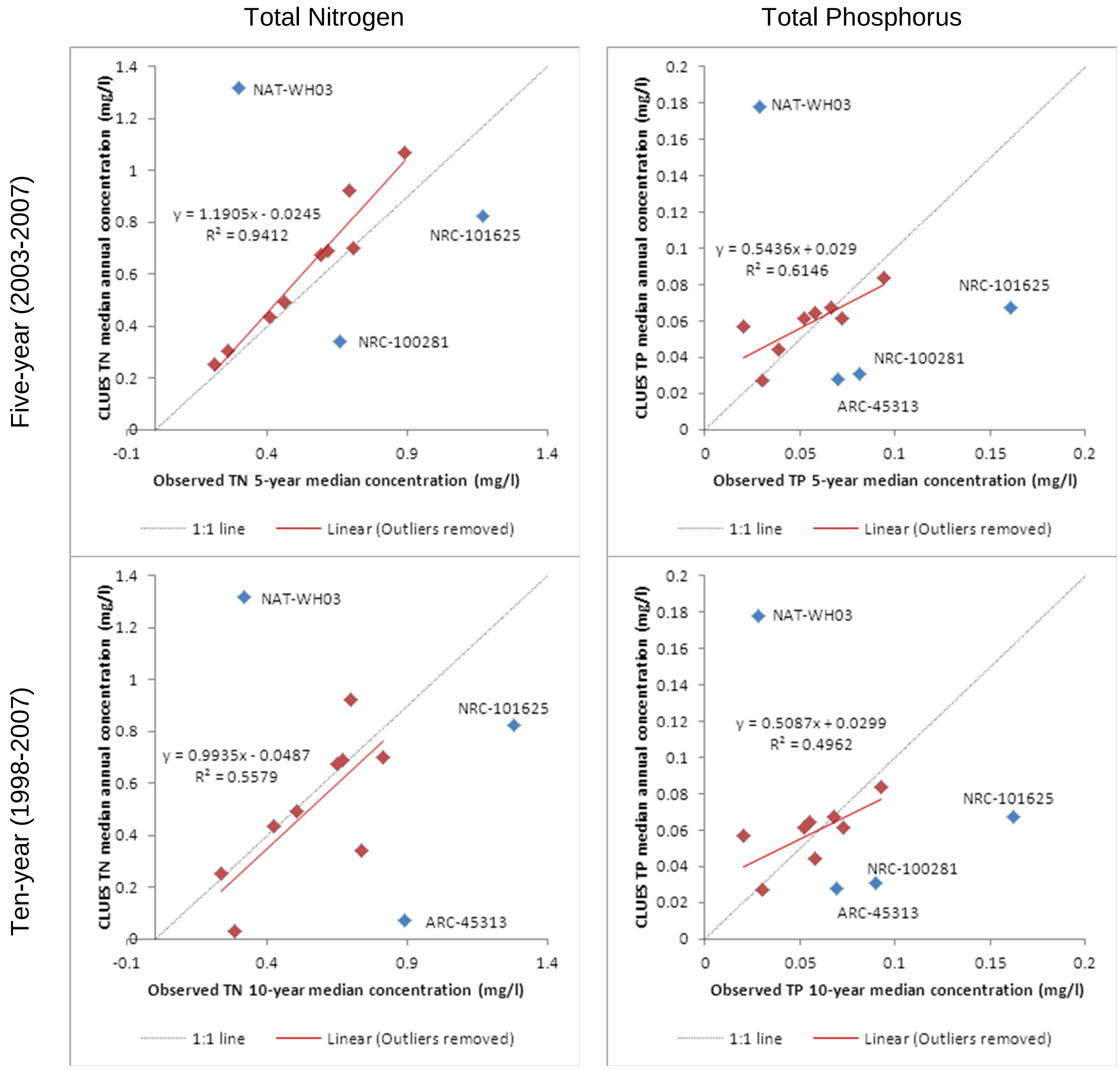

Figure C-2: Regression plots of observed vs. CLUES long-term median nutrient concentrations. Outliers (blue) are labelled by observation site.