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coastalmanagement

Waimea Inlet 2010

Vulnerability Assessment & Monitoring Recommendations

Prepared
for

Tasman
District
Council

March 2010

Cover Photo: Measuring sedimentation rate in the western arm of Waimea Inlet.

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By

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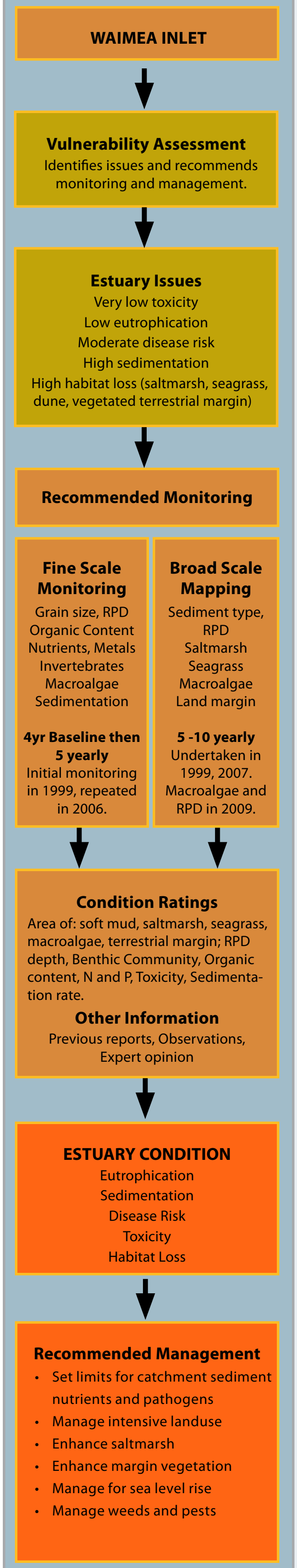
Abbreviations

ASSETS	Assessment of Estuarine Eutrophication Status
DO	Dissolved Oxygen
DP	Dilution Potential
FC	Faecal Coliforms
FCC	Fruitgrowers Chemical Company
FP	Flushing Potential
LIDAR	Light Detection And Ranging
N	Nitrogen
NCC	Nelson City Council
NEMP	National Estuary Monitoring Protocol
P	Phosphorus
RPD	Redox Potential Discontinuity
SLR	Sea Level Rise
SOE	State of the Environment
SVOC	Semi Volatile Organic Compounds
TDC	Tasman District Council
TOC	Total Organic Carbon
WRENZ	Water Resources Explorer New Zealand
WTP	Wastewater Treatment Plant

All photos by Wriggle except where noted otherwise.

EXECUTIVE SUMMARY

Overview of Waimea Inlet monitoring.



To help define ecological monitoring and management priorities for Waimea Inlet, Tasman District Council (TDC) recently contracted Wriggle Coastal Management to undertake an Ecological Vulnerability Assessment of the estuary. The approach involved application of a tool (adapted from a UNESCO (2000) methodology) used by experts to represent how an estuary ecosystem is likely to react to the effects of potential "stressors" (the causes of estuary issues).

The ecological vulnerability assessment reviews current uses and values, physical susceptibility, and existing condition (based on existing data, local knowledge, field observations and expert judgement) before considering how stressors may affect uses and values in relation to the five main problems affecting most New Zealand estuaries; excessive sedimentation, excessive nutrients, disease risk, toxic contamination, and habitat loss.

The assessment showed that the Waimea Inlet has high ecological values and is widely used and appreciated by humans. The major human uses are natural character, walking, fishing (e.g. for whitebait, flounder, kahawai), boating, swimming, duckshooting, shellfish collection, bird watching and waste assimilation. Ecologically it is valued for its remaining saltmarsh and seagrass habitat, extensive shellfish beds, and particularly its nationally significant birdlife, and fish.

In terms of physical susceptibility to problems, the estuary has limited dilution capacity, but its relatively large size and high rate of flushing (it almost completely empties on each tide) means that overall it is only moderately susceptible to water and sediment quality problems, poorly flushed areas being most susceptible.

In terms of existing condition, past monitoring has shown the bulk of the estuary to be in relatively good condition, although it is muddier than it should be, and has lost much of its saltmarsh, seagrass and terrestrial vegetated margin. Some localised areas of enrichment are present but the estuary is generally able to assimilate current nutrient inputs. The estuary is generally safe for bathing, although disease risk indicators are elevated following rainfall, and shellfish consumption is not recommended.

The major stressors identified were:

- Catchment runoff from intensive land use (primarily sediment and, to a lesser extent, faecal coliforms and nutrients),
- Climate change - sea level rise and changes to temperature and rainfall,
- Drainage and reclamation (mostly historical).
- Other stressors included; causeways and flapgates (restricting tidal flows and fish passage), seawalls (limiting saltmarsh habitat and potential retreat in response to sea level rise), increased population pressure and margin encroachment (wildlife disturbance, predator introductions, habitat loss, depletion of living resources), invasive species (e.g. Pacific oysters and iceplant), spills, vehicle damage, and point source discharges (e.g. stormwater, treated sewage, contaminated sites).

The widest range of stressors occurred in the saltmarsh and terrestrial margins of the estuary, with habitat loss the issue affected by the most stressors (see matrix pp X-XII).

The overall estuary condition and rating of vulnerability to the five key issues affecting estuaries is summarised below and presented on the following pages:

CONDITION OF WAIMEA INLET	
Human Use	HIGH
Ecological Value	HIGH
Existing Condition	GOOD
Physical Susceptibility	MODERATE
Presence of Stressors	MOD-HIGH

VULNERABILITY RATING	
Sedimentation	HIGH
Habitat Loss	HIGH
Disease Risk	MOD-HIGH
Eutrophication	MODERATE
Toxins	LOW

EXECUTIVE SUMMARY (CONTINUED)

VULNERABILITY TO SEDIMENTATION	HIGH	HIGH expression of symptoms, MODERATE flushing and dilution potential, HIGH sediment influence. Symptoms expected to remain similar or increase based on current inputs and predicted catchment development.

Waimea Inlet is dominated by poorly oxygenated, soft mud/sand sediments (55%) spread throughout the middle and upper estuary. The fine muds present mean that the waters within the estuary are relatively turbid and the sediment life is dominated by organisms able to tolerate muddy conditions. The presence of mud, exacerbated by the presence of fine glacial silts, constrains human use of the estuary by making it difficult to walk in, and by reducing water clarity. It also reduces the range of different habitats present (one of the key reasons the Waimea Inlet is rated of national significance), and by displacing high value species e.g. shellfish, seagrass.

The main source of mud is catchment runoff of sediment (estimated at 120,700t/yr, with 91% discharging via the Waimea River). The highest sediment runoff is predicted from pasture and rotational cropping (mostly in the lower catchment), and plantation forestry (mostly in the middle catchment). The most significant inputs are expected during periodic land disturbance (e.g. subdivision, roadworks, horticultural development, forest harvesting, flooding) and are likely to enter the estuary in pulses. Sediment release from poisoned *Spartina* roots was estimated at 5,000t/yr over 10 years, ~5% of the annual load. There is a negligible input from the Bells Island Wastewater Treatment Plant (WTP) (151t/yr, ~0.1%). Predicted sedimentation rates are high (~8mm/yr based on all catchment sediment runoff depositing in intertidal soft mud areas), but are mitigated by tidal export to Tasman Bay (evident in turbid plumes seen at the estuary mouth). Vertical profiles in the middle estuary indicate net sedimentation rates in the order of 6-8mm/year for the past 150 years. An increase in the area of soft mud (445ha from 1999-2006) indicates that current inputs are having a direct and adverse impact on the estuary.

Sediment inputs are likely to increase in the future if catchment development increases or intensifies, and as a result of increased coastal erosion and runoff associated with climate change and sea level rise.

VULNERABILITY TO HABITAT LOSS	HIGH	HIGH expression of symptoms and HIGH habitat loss influence. Symptoms expected to remain similar or increase based on current catchment pressures (sediment inputs), and predicted margin development.

Waimea Inlet has lost almost all of the terrestrial forest and freshwater wetland that once covered the Waimea plains and surrounding hillsides, as well as large areas (~90%) of estuary saltmarsh. There has also been a steady decline in seagrass. These largely historical changes have resulted in the direct loss of highly valued habitat, particularly whitebait spawning sites, loss of biodiversity, a reduced capacity to buffer against weed and pest incursions, and reduced sediment and nutrient filtering and assimilation. Increased sediment inputs have resulted in some sand, cobble, and gravel habitats becoming buried by soft mud, while development and drainage of margin areas has seen significant impacts from vegetation clearance, roading, causeways, and seawalls. Remaining saltmarsh and seagrass is generally in good condition, although recent losses (e.g. Ruby Bay bypass) and the presence of introduced pests (e.g. iceplant) show degradation is continuing. Extensive margin replanting initiatives have been undertaken by TDC, NCC, and estuary care groups.

The main cause of habitat loss has been historical margin development (dominated by drainage and reclamation) and to a lesser extent, catchment runoff of sediment.

The estuary was rated as being highly susceptible to further loss of saltmarsh and seagrass from predicted sea level rise, particularly where margin development (e.g. roading, housing, industry) restricts the capacity of estuary saltmarsh to retreat inland. Displacement of bird roosts and increased shoreline erosion is also predicted with sea level rise, while margin development will increase pressure on birds which are vulnerable to disturbance, as well as predation by domestic animals (cats and dogs) and pests.

VULNERABILITY TO DISEASE RISK	MODERATE -HIGH	HIGH expression of symptoms, MODERATE flushing and dilution potential, MODERATE-HIGH disease risk influence. Symptoms expected to remain similar or increase based on current inputs and predicted catchment development.

Excessive inputs of faecal material can cause high disease risk associated with bathing and shellfish consumption. Although the estuary was found to be generally safe for swimming, indicator bacteria are elevated during rainfall events, and faecal concentrations in shellfish have been found unsuitable for human consumption at sites throughout the estuary. The estuary is rated as having a moderate vulnerability to disease risk for bathing, and a high risk for shellfish collection, driven by high flushing of the estuary. Any increases are likely to push the rating further towards high.

Landuse estimates indicate most of faecal disease risk comes from catchment runoff (predominantly sheep/beef (81%) and dairy farming (12%). Monitoring data from 9 tributary streams and the Waimea River, while limited by a lack of flood data when most catchment inputs are expected, indicates 47% of the total faecal coliform load enters the estuary from the Waimea River with 17% from small tributary streams located throughout the estuary. Because the tributary streams do not get as much dilution with clean water from the forested upper catchment as the Waimea River, they contribute a disproportional load based on flow - 17% of the total faecal coliform inputs to the estuary from just 5.6% of the freshwater flow. As such, localised problems are likely in the smaller streams.

The contribution from the Bells Island WTP is estimated at 36% of total inputs. Monitoring data show swimming is safe beyond the 500m mixing zone, although localised shellfish impacts are expected directly downstream of the outfall.

EXECUTIVE SUMMARY (CONTINUED)

VULNERABILITY TO EUTROPHICATION	MODERATE	LOW-MODERATE expression of symptoms, MODERATE flushing and dilution potential, MODERATE nutrient influence. Nutrient enrichment and nuisance algal growth symptoms predicted to increase with future inputs.

The vast bulk of Waimea Inlet exhibits few symptoms of excessive nutrients (e.g. algal blooms, excessive plant growth, low sediment oxygen, toxic sulphides) consistent with it being in an unenriched (oligiotrophic) state. It does not experience problems with phytoplankton blooms, and there are no known instances of algal blooms from the sea causing problems in the estuary. However, in a few localised patches nuisance macroalgal growths, particularly *Gracilaria,* trap sediment (increasing muddiness), and rotting algae causes nuisance smells, depletes sediment oxygen, and releases nutrients to further fuel growths. Heaviest growths were near the mouth of the Waimea River (e.g. between Best and Bells Islands), and in the upper eastern arm (e.g. adjacent to the Bark Processors site).

Because Waimea Inlet is large and well flushed it has a large capacity to assimilate and flush nutrient inputs. Currently the nitrogen (N) loading to the estuary (30mg.m^{-2}.d^{-1}) is below the range where nuisance macroalgal conditions in tidally dominated NZ estuaries generally begin to appear. The key stressor is catchment runoff. Climate change (increased rainfall) will increase inputs, as will intensification of land use and will push the rating from moderate towards high. Most nutrients currently come from native and plantation forests (32%) - the relatively high contribution because they cover 3/4 of the catchment. Sheep and beef farm runoff (25%), Bells Island WTP and biosolids runoff (16%), horticulture (15%), and dairy farming (9%) are the main human derived sources. Dairy farm runoff is high relative to the small area it occupies. The relatively high N input from the Bells Island WTP discharge is reflected in an abundant growth of macroalgae downstream of the outfall, but this isn't causing nuisance conditions due to rapid flushing on the outgoing tide.

Although the greatest loads of nutrients enter the estuary from the Waimea River, elevated nutrient concentrations in the smaller streams highlight these as a priority.

VULNERABILITY TO TOXINS	LOW	LOW expression of symptoms, MODERATE flushing and dilution potential, LOW toxicant influence. Symptoms expected to remain similar or increase based on predicted catchment development.

The vast bulk of Waimea Inlet has very low concentrations of heavy metals in sediment and shellfish, indicating toxins are unlikely to place stress on existing plant and animal communities or pose a risk to people using the estuary. Nickel, chromium and iron are naturally elevated due to erosion of ultramafic rock in the catchment.

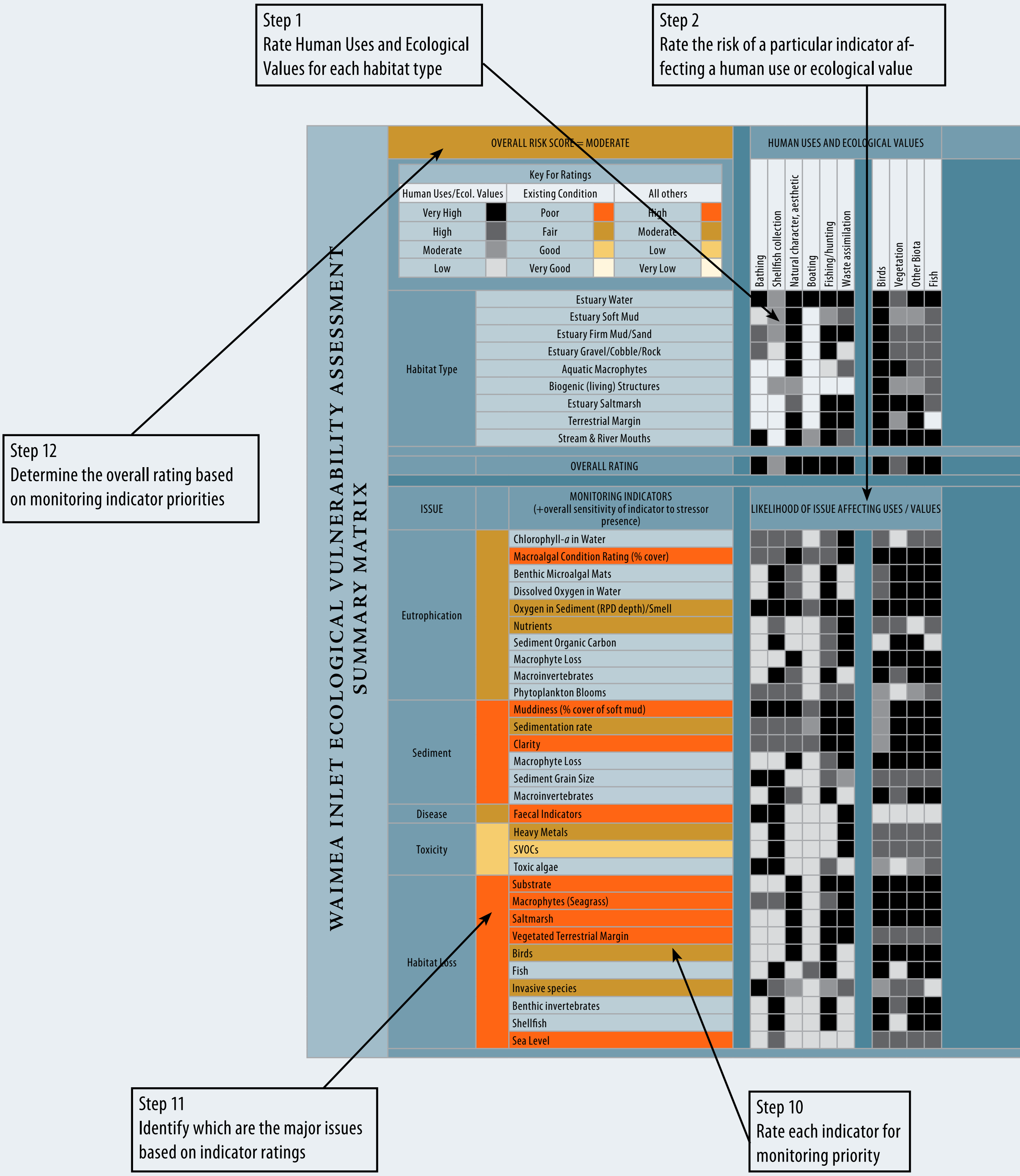
In a few localised areas (primarily close to urban and industrial stormwater outfalls or historical sources such as old landfills) moderately elevated concentrations of toxins are present. These only extend a few to 10s of metres from outfalls/sources and pose a low risk. Organochlorine pesticides at the Fruitgrowers Chemical Company (FCC) site in Mapua have been successfully remediated, with only very low concentrations detected in sediments and shellfish immediately adjacent to the site.

The major stressor was catchment runoff with inputs derived from human activities. Key sources are the developed urban and industrial areas of Tahunanui, Stoke and Richmond via stormwater (predominantly road runoff), air discharges, or spills. The Bells Island WTP outfall and biosolids disposal areas are not significant toxin sources to the estuary.

Future catchment development is predicted to increase symptoms but these are expected to remain localised and are unlikely to change the current low rating.

EXECUTIVE SUMMARY (CONTINUED)

STEPS IN FILLING OUT THE VULNERABILITY MATRIX



Step 1
Rate Human Uses and Ecological Values for each habitat type

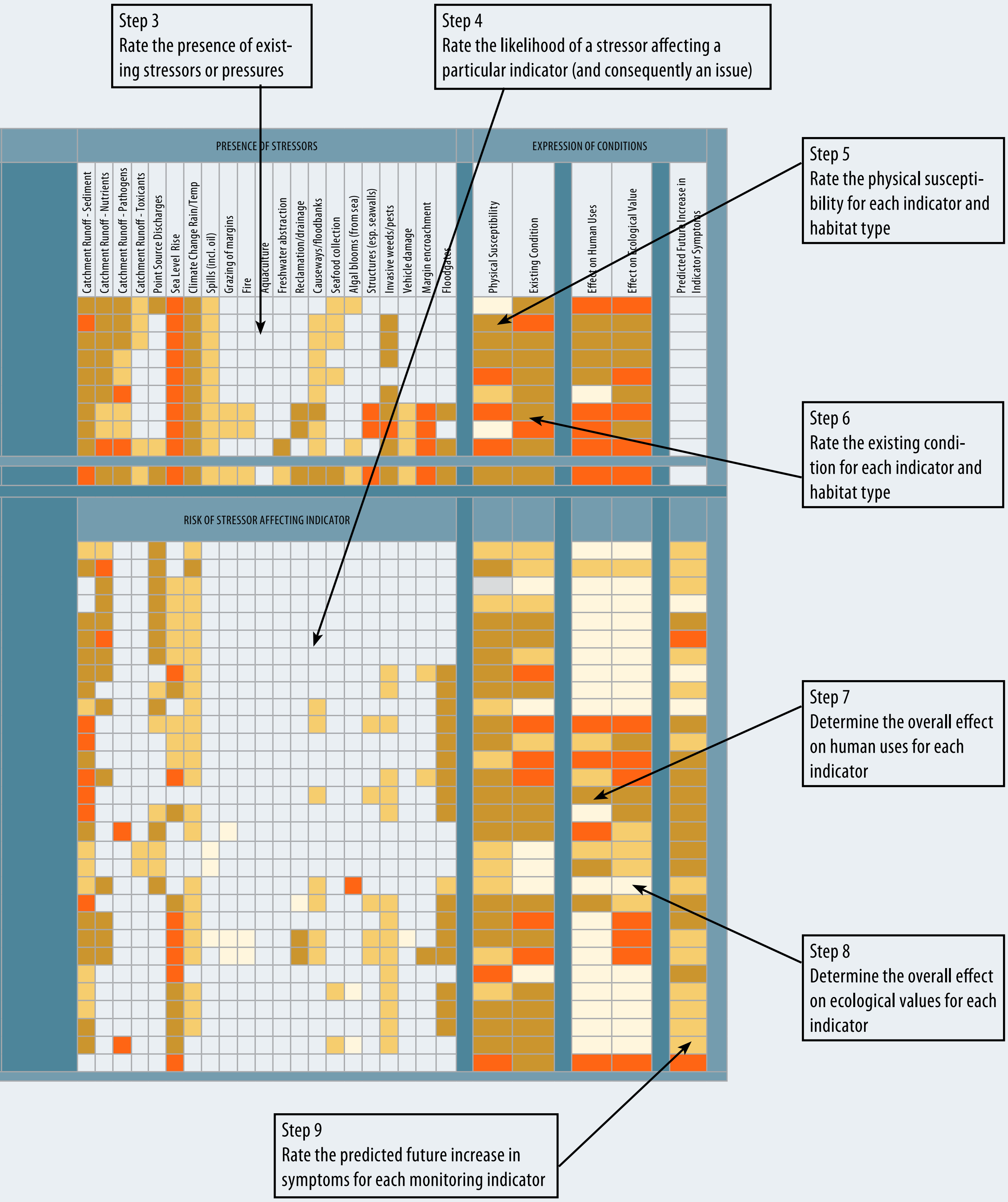
Step 2
Rate the risk of a particular indicator affecting a human use or ecological value

Step 12
Determine the overall rating based on monitoring indicator priorities

Step 11
Identify which are the major issues based on indicator ratings

Step 10
Rate each indicator for monitoring priority

Human Uses/Ecol. Values		Existing Condition		All others	
Very High	■	Poor	🟧	High	🟧
High	■	Fair	🟫	Moderate	🟫
Moderate	■	Good	🟨	Low	🟨
Low	□	Very Good	□	Very Low	□



Step 3
Rate the presence of existing stressors or pressures

Step 4
Rate the likelihood of a stressor affecting a particular indicator (and consequently an issue)

Step 5
Rate the physical susceptibility for each indicator and habitat type

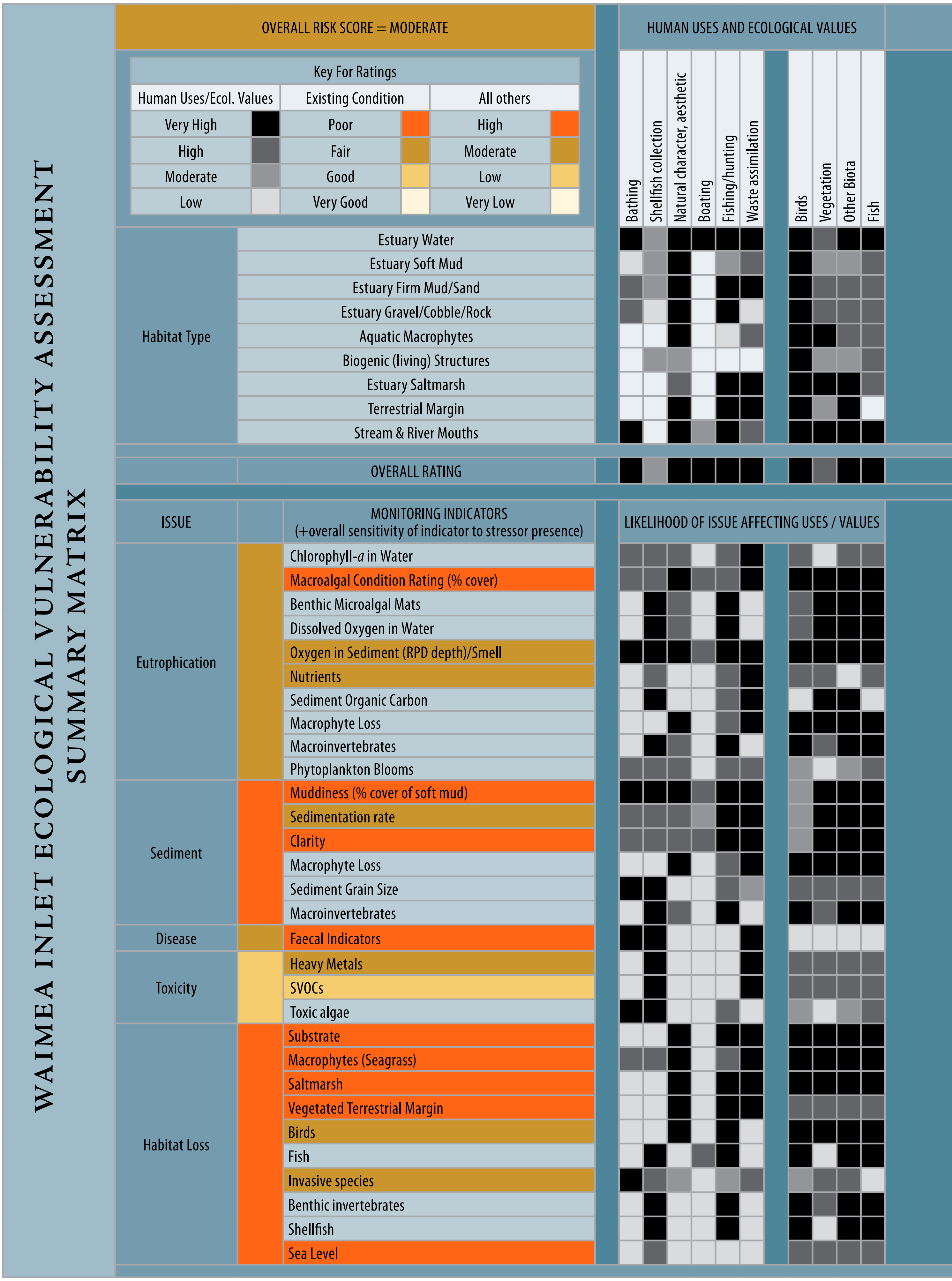
Step 6
Rate the existing condition for each indicator and habitat type

Step 7
Determine the overall effect on human uses for each indicator

Step 8
Determine the overall effect on ecological values for each indicator

Step 9
Rate the predicted future increase in symptoms for each monitoring indicator

WAIMEA INLET ECOLOGICAL VULNERABILITY ASSESSMENT
SUMMARY MATRIX



OVERALL RISK SCORE = MODERATE

Key For Ratings

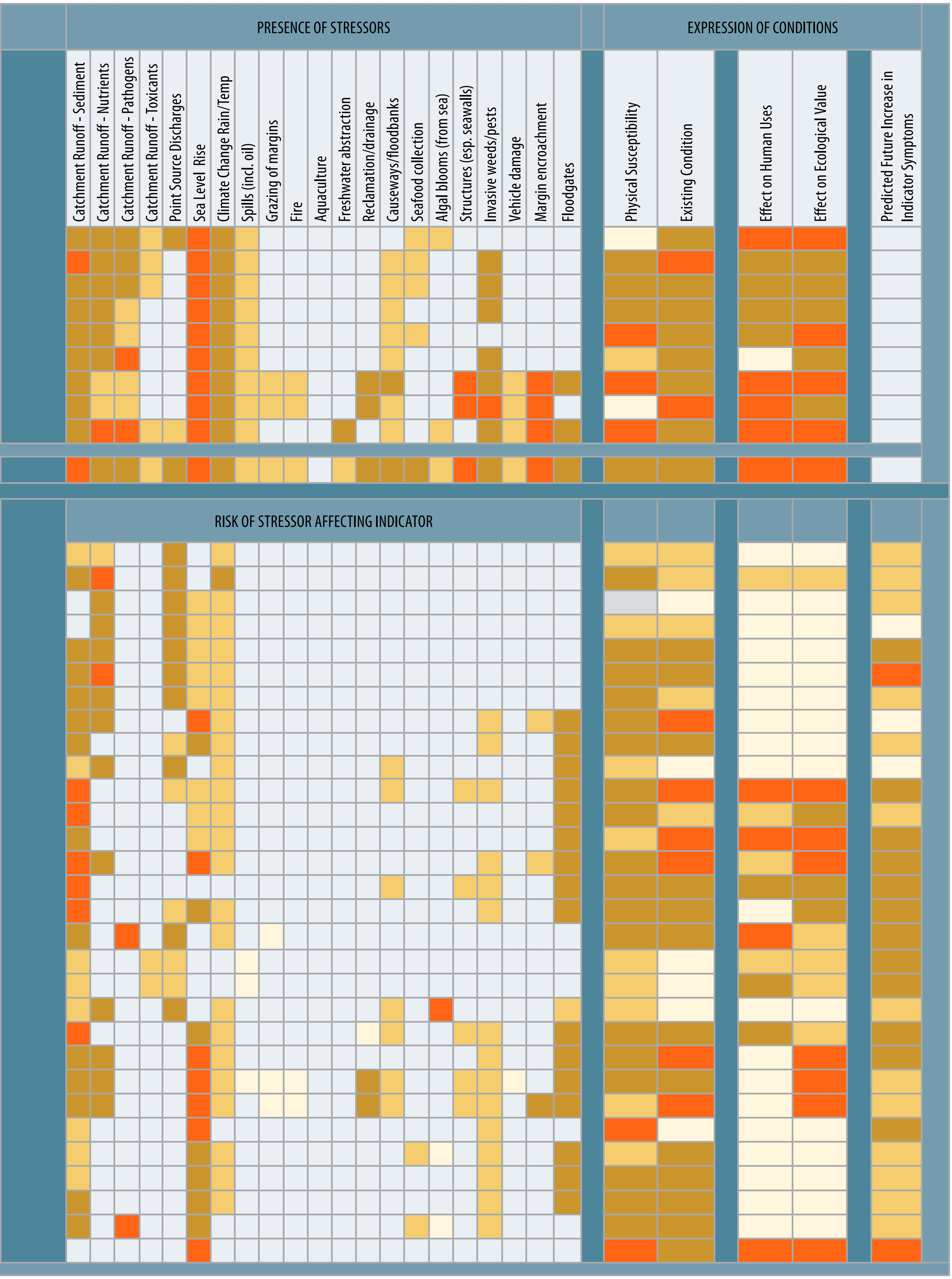
Human Uses/Ecol. Values		Existing Condition		All others	
Very High	■	Poor	🟧	High	🟧
High	▓	Fair	🟫	Moderate	🟫
Moderate	▒	Good	🟨	Low	🟨
Low	░	Very Good	⬜	Very Low	⬜

HUMAN USES AND ECOLOGICAL VALUES

		Bathing	Shellfish collection	Natural character, aesthetic	Boating	Fishing/hunting	Waste assimilation	Birds	Vegetation	Other Biota	Fish
Habitat Type	Estuary Water	■	▒	■	■	■	■	■	▓	■	■
	Estuary Soft Mud	░	▒	■		▒	▓	■	▒	▒	▓
	Estuary Firm Mud/Sand	▓	▒	■		■	■	■	▓	▓	▓
	Estuary Gravel/Cobble/Rock	▓	░	■		■	░	■	▓	▓	▓
	Aquatic Macrophytes			■		░	▓	■	■	▓	▓
	Biogenic (living) Structures		▒	▒				■	▒	▒	▓
	Estuary Saltmarsh			▓		■	■	■	■	■	▓
	Terrestrial Margin			■		■	■	■	▒	■	
	Stream & River Mouths	■		■	▒	■	▓	■	■	■	■
	OVERALL RATING	■	▒	■	■	■	■	■	▓	■	■

LIKELIHOOD OF ISSUE AFFECTING USES / VALUES

ISSUE		MONITORING INDICATORS (+overall sensitivity of indicator to stressor presence)		Bathing	Shellfish collection	Natural character, aesthetic	Boating	Fishing/hunting	Waste assimilation	Birds	Vegetation	Other Biota	Fish
Eutrophication	🟫	Chlorophyll-*a* in Water		▓	▓	▓	░	▓	■	▓	░	▓	▓
		Macroalgal Condition Rating (% cover)	🟧	▓	▓	■	▓	▓	■	■	■	■	■
		Benthic Microalgal Mats		░	■	▓	░	■	░	▓	■	■	■
		Dissolved Oxygen in Water		░	■	▓	░	■	░	▓	■	■	■
		Oxygen in Sediment (RPD depth)/Smell	🟫	■	■	■	▓	■	■	■	■	■	■
		Nutrients	🟫	░	▓	░	░	▓	■	▓	▓	░	▓
		Sediment Organic Carbon		░	■	░	░	▓	■	░	■	■	░
		Macrophyte Loss		░	░	■	░	▓	■	■	■	■	■
		Macroinvertebrates		░	■	▓	░	■	░	■	▓	■	■
		Phytoplankton Blooms		▓	▓	▓	░	▓	▓	▒	░	▒	▓
Sediment	🟧	Muddiness (% cover of soft mud)	🟧	■	■	■	▓	■	■	▒	■	■	■
		Sedimentation rate	🟫	▓	▓	▓	▒	■	■	▒	■	■	■
		Clarity	🟧	▓	▓	▓	▓	■	■	▒	■	■	■
		Macrophyte Loss		░	░	■	░	▓	■	■	■	■	■
		Sediment Grain Size		■	■	░	░	▓	▒	▓	▓	▓	▓
		Macroinvertebrates		░	■	▓	░	■	░	■	▓	■	■
Disease	🟫	Faecal Indicators	🟧	■	■	░	░	░	■	░	░	░	░
Toxicity	🟨	Heavy Metals	🟫	░	■	░	░	░	■	▓	▓	▓	▓
		SVOCs	🟨	░	■	░	░	░	■	▓	▓	▓	▓
		Toxic algae		■	■	░	░	▓	░	▒	░	▒	▓
Habitat Loss	🟧	Substrate	🟧	░	░	■	░	■	■	■	■	■	■
		Macrophytes (Seagrass)	🟧	▓	▓	■	░	▓	■	■	■	■	■
		Saltmarsh	🟧	░	░	■	░	■	■	■	■	■	■
		Vegetated Terrestrial Margin	🟧	░	░	■	░	■	■	▓	▓	▓	▓
		Birds	🟫	░	░	■	░	■	░	■	■	■	■
		Fish		░	■	░	▓	■	░	■	░	■	■
		Invasive species	🟫	■	▓	▒	░	▒	▓	▒	▓	▓	░
		Benthic invertebrates		░	■	░	░	■	░	■	▓	■	■
		Shellfish		░	■	░	░	■	░	■	░	■	■
		Sea Level	🟧	░	▓	░	░	░	░	▓	▓	▓	▓



PRESENCE OF STRESSORS

EXPRESSION OF CONDITIONS

Catchment Runoff - Sediment

Catchment Runoff - Nutrients

Catchment Runoff - Pathogens

Catchment Runoff - Toxicants

Point Source Discharges

Sea Level Rise

Climate Change Rain/Temp

Spills (incl. oil)

Grazing of margins

Fire

Aquaculture

Freshwater abstraction

Reclamation/drainage

Causeways/floodbanks

Seafood collection

Algal blooms (from sea)

Structures (esp. seawalls)

Invasive weeds/pests

Vehicle damage

Margin encroachment

Floodgates

Physical Susceptibility

Existing Condition

Effect on Human Uses

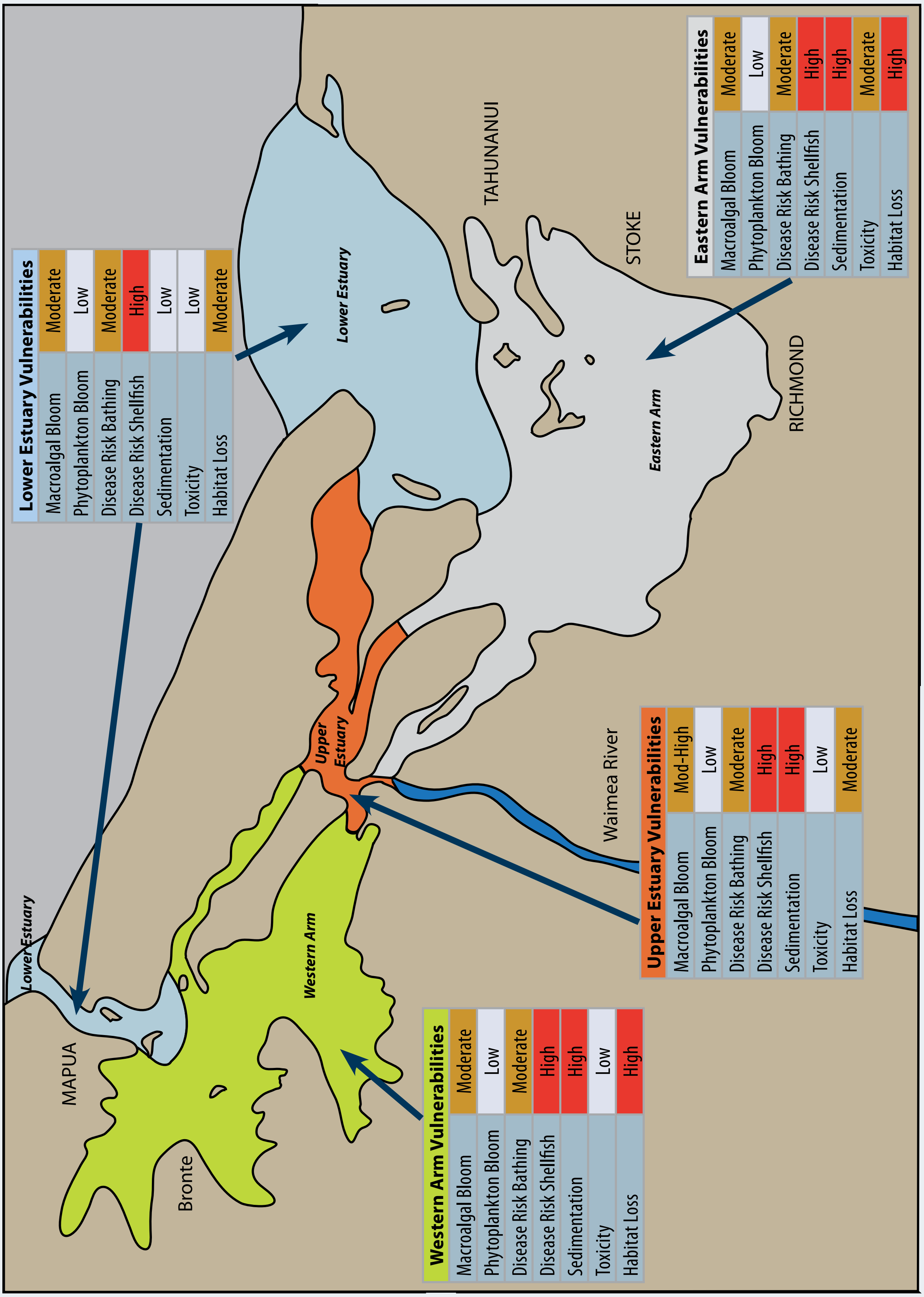
Effect on Ecological Value

Predicted Future Increase in Indicator Symptoms

RISK OF STRESSOR AFFECTING INDICATOR

EXECUTIVE SUMMARY (CONTINUED)

Summary of vulnerability ratings for key estuary issues different parts of Waimea Inlet.



Lower Estuary Vulnerabilities	
Macroalgal Bloom	Moderate
Phytoplankton Bloom	Low
Disease Risk Bathing	Moderate
Disease Risk Shellfish	High
Sedimentation	Low
Toxicity	Low
Habitat Loss	Moderate

Eastern Arm Vulnerabilities	
Macroalgal Bloom	Moderate
Phytoplankton Bloom	Low
Disease Risk Bathing	Moderate
Disease Risk Shellfish	High
Sedimentation	High
Toxicity	Moderate
Habitat Loss	High

Upper Estuary Vulnerabilities	
Macroalgal Bloom	Mod-High
Phytoplankton Bloom	Low
Disease Risk Bathing	Moderate
Disease Risk Shellfish	High
Sedimentation	High
Toxicity	Low
Habitat Loss	Moderate

Western Arm Vulnerabilities	
Macroalgal Bloom	Moderate
Phytoplankton Bloom	Low
Disease Risk Bathing	Moderate
Disease Risk Shellfish	High
Sedimentation	High
Toxicity	Low
Habitat Loss	High

EXECUTIVE SUMMARY (CONTINUED)

Issues, Causes, and Recommended Management and Monitoring

Sedimentation

Condition ratings indicate the estuary is too muddy and is infilling rapidly. If sediment inputs are not reduced, the estuary will become a saline swamp in the next few hundred years.

The main cause is runoff from land disturbance in the catchment and shoreline erosion. This load is likely to increase with predicted increased storm runoff associated with climate change and predicted accelerated sea level rise.

To address this issue it is recommended that **catchment sediment inputs be reduced to a level that maintains the estuary sedimentation rate below 2.0mm/year**. This process should involve the production of a long-term catchment sediment budget that identifies areas of high sediment release in the catchment, i.e. sediment "hot spot" areas. Meeting the target sedimentation rate of 2mm/yr will involve the reduction of "hot spot" sediment yields to appropriate levels.

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Continue to map the extent and condition of the major estuary habitats at 5 yearly intervals (i.e. Broad Scale Habitat Mapping).
- Continue to monitor the sedimentation rate in the estuary annually using plates buried in representative areas.
- Continue to monitor the condition of the dominant habitat type in the estuary at 5 year intervals following the completion of a 3-4 year baseline survey (i.e. Fine Scale Monitoring).
- Monitor the major sediment inputs to the estuary, including high and low flow periods, in sufficient detail to determine annual sediment budgets.

Habitat Loss/Degradation

Extensive areas of valuable estuary habitat, important for the health of the estuary, have been lost. These should be restored where possible or the estuary will continue to function well below its full potential.

The main causes are reclamation of saltmarsh, and terrestrial margin modification for urban and agricultural development (primarily historical), excessive sedimentation, and human/animal presence disturbing wildlife. In the future, this loss is likely to be further exacerbated by predicted accelerated sea level rise associated with climate change as many structures along the margins restrict the movement of these habitats inland.

To address this issue it is recommended that **important degraded areas be restored and existing high value saltmarsh habitat be allowed to migrate inland as sea level rises** as follows:

- Identify those areas of degraded habitat which, if restored, would lead to a significant increase in estuary functioning ability (particularly the terrestrial margin, saltmarsh, seagrass, raised sand banks, shellfish beds, and muddy tidal flats).
- Develop restoration plans and undertake restoration of these priority areas in a staged manner.
- Protect and enhance important bird roosting and nesting areas through initiatives such as predator control and managed access.
- Identify low lying land areas likely to be inundated by sea level rise and plan for changing human use, vegetation and wildlife needs.
- Develop long term plans to maintain or improve estuary function by ensuring inland habitat migration as a result of sea level rise. Remove artificial barriers in key locations.

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Continue to map the extent and condition of the major estuary habitats at 5 yearly intervals (i.e. Broad Scale Habitat Mapping).
- Continue to monitor the sedimentation rate in the estuary annually using plates buried in representative areas.

Disease Risk (Shellfish Consumption and Bathing)

Shellfish in the estuary are currently unfit for human consumption due to their excessive faecal bacterial content and high disease risk. Disease risk also restricts bathing in the estuary during high river flow periods. Such degradation seriously diminishes human use values and consequently needs to be reversed.

The main causes are the Bells Island wastewater treatment plant discharge, runoff from urban areas (particularly dog and duck faeces as well as imperfections in the sewerage network) and runoff from sheep, beef and dairy farms. Runoff is likely to be exacerbated by predicted increased storm runoff associated with climate change.

To address this issue it is recommended that **catchment faecal coliform inputs be reduced to a level that allows shellfish consumption and bathing in the estuary**. This process should involve the production of a long-term catchment faecal bacterial budget that identifies areas of high faecal bacterial release in the catchment, i.e. faecal bacterial "hot spot" areas. Meeting the target level should involve reduction in "hot spot" yields to appropriate levels. Because the Bells Island WTP discharge is the largest and most regular source of faecal bacteria to the estuary, ensure discharge limits meet shellfish criteria prior to impacting major shellfish beds in the estuary (e.g. within 100m-500m from the outfall).

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Monitor the major faecal bacterial inputs to the estuary, including high and low flow periods, in sufficient detail to determine annual faecal bacterial budgets.
- Monitor shellfish and bathing disease risk at key estuary locations during both high and low river flow periods.

EXECUTIVE SUMMARY (CONTINUED)

Issues, Causes, and Recommended Management and Monitoring

Eutrophication (Excessive Nutrients)

Waimea Estuary shows little sign of excessive nutrients (i.e. nuisance macroalgal or phytoplankton blooms) except for around the mouths of the Waimea River and the various small streams that enter the estuary. Such localised eutrophication needs to be minimised as it reduces estuary values in such areas and serves as a warning of the potential for more widespread problems if nutrient loads were to increase.

The likely main cause is runoff from urban areas and sheep, beef and dairy farms and is likely to be exacerbated by predicted increased storm runoff associated with climate change.

To address this issue it is recommended that **catchment nitrogen inputs be maintained at a level below that which causes nuisance conditions in the estuary** (i.e. areal N loading less than 50 $mg.m^2.d^{-1}$). This process should involve the production of a long-term catchment nutrient budget that identifies areas of high nutrient release in the catchment, i.e. nutrient "hot spot" areas. Meeting the target level should involve the reduction of "hot spot" nutrient yields to appropriate levels.

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Monitor the major nutrient inputs to the estuary, including high and low flow periods, in sufficient detail to determine annual nutrient budgets.
- Map the presence of nuisance macroalgal conditions and sediment oxygenation (RPD depth) at 5 yearly intervals (i.e. Broad Scale Macroalgal Mapping).
- Monitor the condition of the dominant habitat type in the estuary at 5 year intervals following the completion of a 3-4 year baseline survey (i.e. Fine Scale Monitoring).

Toxicity

Waimea Estuary shows little sign of excessive toxicants except for around of small urban streams and discharges that enter the estuary. Such localised toxicity needs to be minimised as it reduces estuary values in such areas and serves as a warning of the potential for more widespread problems if toxicant loads were to increase.

The main cause is stormwater runoff from urban and industrial areas and is likely to be exacerbated by predicted increased storm runoff associated with climate change.

To address this issue it is recommended that the cumulative effects from **all urban and industrial stormwater and effluent discharges to streams in the catchment meet ANZECC (2000) ISQG-low sediment toxicity criteria within 50m of the discharge outfall**. If there are problems in meeting these criteria then the process should involve the production of a long-term catchment toxicant budget that identifies areas of high toxicant release in the catchment, i.e. toxicant "hot spot" areas. Meeting the target level should involve the reduction of "hot spot" toxicant yields to appropriate levels.

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Monitor the major toxicant inputs to the estuary, including high and low flow periods, in sufficient detail to determine annual toxicant budgets.
- Continue to monitor sediment toxicant quality within 50m of all problem outfalls.
- Monitor the toxicant condition of the dominant habitat type in the estuary at 5 year intervals following the completion of a 3-4 year baseline survey (i.e. Fine Scale Monitoring).

1. INTRODUCTION

1.1 OUTLINE

Being able to identify and assess the vulnerability of estuarine and coastal areas to specific problems is vital to effectively managing these high value and iconic treasures. Since 2001, Tasman District Council (TDC) has monitored the condition of the five largest estuaries in its region (Ruataniwha, Motupipi, Motueka, Moutere, and Waimea) using the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002). The results are summarised in Robertson and Stevens (2009), along with condition ratings developed to help Councils interpret the monitoring results.

The Waimea Inlet is the largest estuary in the region. This vulnerability assessment uses the current and future risk to identified uses and values to help define ecological monitoring and management priorities. A region-wide coastal vulnerability assessment is scheduled for 2010/12 to prioritise monitoring and management for the remaining estuaries and the coastline of Tasman District.

The Ecological Vulnerability Assessment uses a tool adapted from a UNESCO methodology (UNESCO 2000). It is designed to be used by experts to assess the vulnerability of estuaries to the five major issues affecting most New Zealand estuaries; excessive sedimentation, excessive nutrients, disease risk, toxic contamination, and habitat loss (Table 1).

The approach, summarised in Figure 1 and described in Sections 2-6, involves:

1. Assessment of the human and ecological uses and values of an estuary,
2. Assessment of the physical susceptibility of the estuary,
3. Assessment of existing condition,
4. Identification of key "stressors" (the causes of estuary issues - often farming and other landuse activities) potentially affecting the estuary,
5. Integration of the above to identify vulnerability to key issues, and the indicators best suited to monitor change in specific stressors.

The output is a transparent assessment of estuary vulnerability, from which management and monitoring priorities can be set.

Figure 1. Summary of the steps used in completing an estuary ecological vulnerability assessment.

1. INTRODUCTION (CONTINUED)

Because the first four components (human and ecological uses and values, physical susceptibility, existing condition, and identification of key "stressors") contain generic items common to all five issues described in Table 1, they are addressed separately in the following sections. For each, a description is provided of the method used to assess and rate the relevant components, the rating given, and the rationale for the overall rating assigned.

Following this, relevant information from each section is drawn together and applied to each of the five key issues in detail. Finally, the detail from all issues is combined in a summary matrix and used to identify monitoring and management priorities.

The report is structured as follows:

- Section 1. Introduction.
- Section 2. Human Uses and Ecological Values.
- Section 3. Physical Susceptibility.
- Section 4. Existing Condition.
- Section 5. Identification of Stressors.
- Section 6. Ecological Vulnerability Assessment, and the ratings assigned to the key estuary issues (eutrophication, sedimentation, disease risk, toxicants, habitat loss).
- Sections 7 and 8. Summary and monitoring and management recommendations.

Table 1. Summary of the major issues affecting most New Zealand estuaries.

Sedimentation	Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived.
Eutrophication (Nutrients)	Increased nutrient richness of estuarine ecosystems stimulates the production and abundance of fast-growing algae, such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce). Fortunately, because most New Zealand estuaries are well flushed, phytoplankton blooms are generally not a major problem. Of greater concern is the mass blooms of green and red macroalgae, mainly of the genera *Enteromorpha, Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose producing sulphurous odours. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there.
Disease Risk	Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoa) that, once discharged into the estuarine environment, can survive for some time. Every time people come into contact with seawater that has been contaminated with human and animal faeces, they are exposed to these organisms and risk getting sick. Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds. Diseases linked to pathogens include gastroenteritis, salmonellosis, hepatitis A, and noroviruses.
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to estuaries through urban and agricultural stormwater runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to people and marine life.
Habitat Change	Estuaries have many different types of habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of habitat negatively affects fisheries, diverse animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes cited as sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff and wastewater discharges.

OVERVIEW OF ESTUARY CONDITION

Estuaries are coastal transitional waters that are formed when freshwater from rivers flows into, and mixes with, saltwater from the ocean. Many are highly valued by humans and contain a wide variety of plant and animal life. In good condition, they provide more life per square metre than the richest New Zealand farmland. Their high value lies in two main characteristics;

- The wide diversity of habitats they offer, and
- Their natural ability to collect and assimilate sediment and nutrients from the surrounding catchment and inflowing tidal waters.

If either of these features are degraded, then the estuary condition deteriorates and the value to humans and estuary plants and animals is lessened.

Well flushed tidal lagoon estuaries like Waimea Inlet (see Table 2 for a description of physical characteristics) are typically in one of three contrasting states (PRISTINE, MODERATE, OR DEGRADED), and the state of the estuary is commonly related directly to the extent and intensity of development in the surrounding catchment.

PRISTINE: In a pristine state, estuaries have high water clarity, low nutrient and sediment inputs, high sediment quality (very little mud), and high biodiversity. They retain an intact saltmarsh and terrestrial margin that buffers against weed and pest invasions, assimilate sediment and nutrients, and provide key habitat for birds and fish. Disease risk and toxicity are low, and there are no extensive growths of nuisance macroalgae (e.g. sea lettuce, *Enteromorpha* and *Gracilaria*), microalgae or phytoplankton.

MODERATE: Following initial catchment development, sediment, nutrient, and faecal bacteria inputs typically increase, and modification of the estuary margin (primarily by drainage and reclamation) is common. Increased nutrients cause a shift to increased eutrophication, evident in low-moderate nuisance macroalgal growth, and increased phytoplankton production. This, along with increased fine sediment deposition, starts to reduce sediment oxygenation and water clarity. The increasing inputs of fine sediment may also lead to a reduction in seagrass populations and a shift in the macroinvertebrate community to one more tolerant of fine muds.

DEGRADED: With more intensive catchment development, soft muds commonly accumulate in the upper estuary and on sheltered tidal flats, and water clarity decreases further. The combined effects of sediment smothering and reduced light levels may contribute to the loss of seagrass and shellfish beds. Aggressive macrophyte growth is encouraged by high sediment and nutrient inputs. Farm runoff, human wastewater, and inputs from urban and agricultural stormwater increase disease risk and toxicity, and as a result can constrain bathing and shellfish gathering, particularly after rainfall events. Further habitat loss, particularly remaining upper intertidal saltmarsh and terrestrial buffer vegetation, increasingly degrades bird habitat and whitebait spawning areas, facilitates the encroachment of weeds and pests into saltmarsh areas, reduces natural assimilation and filtering of sediment and nutrients, and reduces the important role saltmarsh plays in flood attenuation. Protection of developed margins from erosion and inundation becomes an increasing issue.

Waimea Inlet is in currently in a MODERATE state due to high sediment inputs, habitat loss, and to a lesser extent disease risk and eutrophication. Section 4 summarises condition monitoring of the estuary.

Descriptions of the most common habitats found in estuaries, their importance, and the major threats to their health are appended in Appendix 5. These include the subtidal, soft mud, sand, gravel/cobble/rock, saltmarsh, seagrass (aquatic macrophytes), shellfish beds (biogenic structures), and water column (subtidal) habitats.

Figure 2. Waimea Inlet, including location of islands and major freshwater streams.

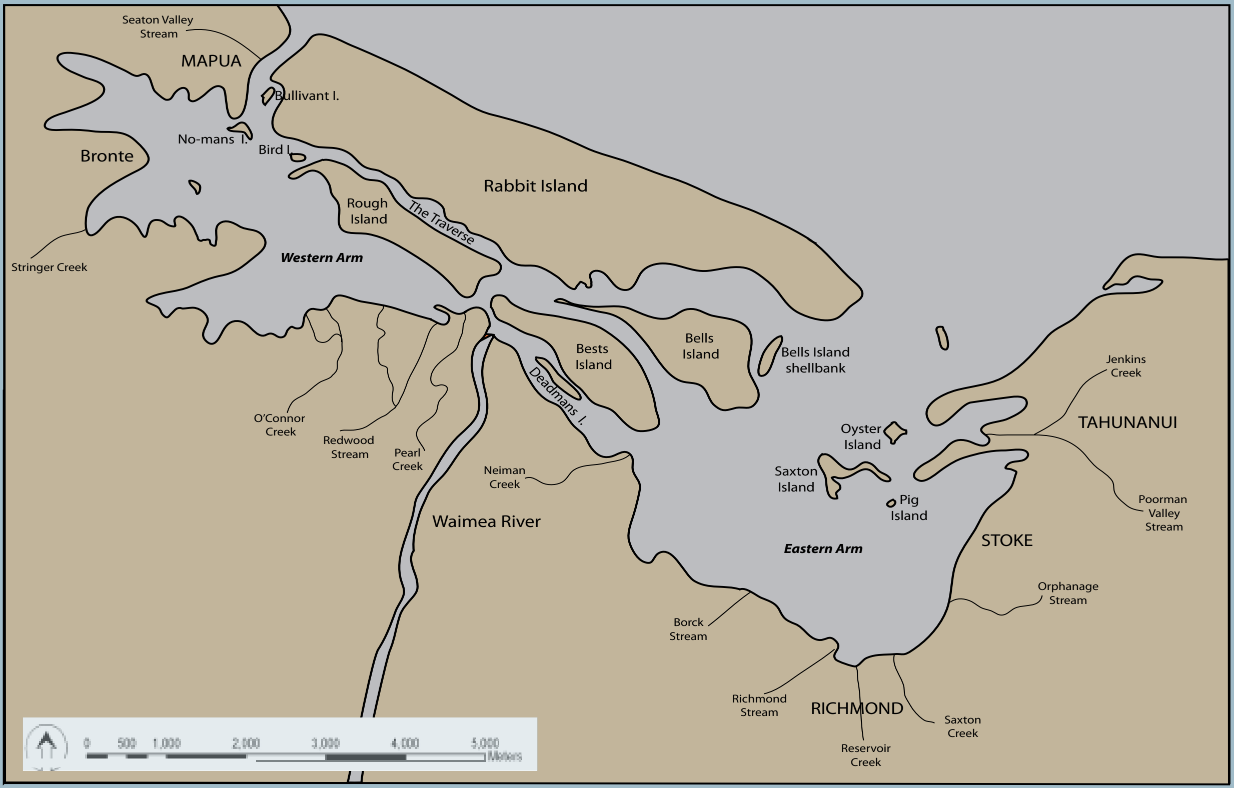


Table 2. Characteristics of tidal lagoon estuaries.

Waimea Inlet (Figures 2 and 3) is an example of a "tidal lagoon" type estuary. Such estuaries have the following general characteristics (McLay 1976, Kirk & Lauder 2000, Hume et al. 2007):

- Broad shallow circular to slightly elongate basins, narrow mouths, usually enclosed by a sand spit (hence sometimes called "barrier enclosed lagoons").
- Simple or complex shorelines - some have more than one arm (Waimea Inlet has a complex shoreline with two main arms, numerous smaller ones (drowned valleys) and numerous islands).
- An entrance to the sea which is always open.
- Funnel-shaped entrance (if alongshore movement of sand due to waves breaking at a angle to the shoreline is small - as is the case for the Waimea).
- Extensive intertidal areas which are cut by channels draining the arms.
- A large tidal prism (i.e. a large difference in the volume of water in the estuary between low and high tides).
- The volume of river water inflow is generally small in comparison to marine inputs, and most of the estuary drains on each tidal cycle. Hence they have low water residence times (often <3 days), and good flushing, particularly in the lower estuary. Most of the Waimea Inlet drains at low tide and residence time is <1 day.
- Salinities tend to be high and close to that of seawater.
- Resuspension of sediment by waves at high tide can be high if arms are broad and exposure to wind fetch is elevated. Waimea Inlet has moderate-high wind exposure and there is a lot of sediment resuspension.
- Mainwater bodies are well flushed and dominated by sandy sediments with a shift to muds in the sheltered arms and upper reaches where flushing and resuspension is less active, as well as where freshwater inputs, often with elevated sediment loads, enter the estuary. The upper reaches, margins of drainage channels, and sheltered arms, are commonly the muddiest parts of Waimea Inlet.
- A well-mixed water column due to strong tidal flushing, wind mixing and shallow depths. In the Waimea Inlet, the only area unlikely to always be well-mixed is where the Waimea River channel enters the estuary. Here more buoyant freshwater is expected to float on top of tidal salt water.
- The coastal plumes from tidal lagoon estuaries are generally much cleaner than from tidal river lagoons and estuaries, although ocean swell can resuspend sediment in the entrance of estuaries.
- High habitat diversity and ecological richness (in their natural state).

2. HUMAN USES AND ECOLOGICAL VALUES

HUMAN USES AND VALUES
HIGH
ECOLOGICAL VALUES
HIGH

Defining and rating the human uses and ecological value of an estuary is the first step in the vulnerability assessment as it identifies what parts of the estuary are highly valued and used. This information then sets the basis for determining how stressors (pressures and activities) present in the estuary may affect the different values and uses identified.

Human uses and ecological values have been assessed using four broad rating categories (Very Low, Low, Moderate, High) based on the UNESCO (2000) methodology. Table 2 summarises the uses and values assessed, and the rating applied to each of the habitat types present in and around Waimea Inlet. A summary of the information used to decide on the rating is provided in support of each decision. Expert judgement is then used to provide a combined rating for each habitat type and value, and an overall rating. The assessment criteria used to set ratings are as follows:

1. Human Uses and Values

The information used to rate human uses and values of estuary habitat and its margins is based on local knowledge and available information. The estimated number of people involved are used to guide the rating:

Very Low:	<10 per year.
Low:	10 to 50 per year (<30 per day in summer).
Moderate:	>30 per day (may be only in summer) but <200 per day.
High:	>200 per day (any time during year).

Overall the estuary has a HIGH human use rating. It is particularly valued for its aesthetic appeal, despite the natural character being degraded by habitat loss and industrial and residential development of the margins. It provides for a wide range of recreational uses including, duck shooting, bathing, whitebaiting, fishing, boating, walking, birdwatching, and scientific appeal. Human use of shellfish is rated as "low" because of the potential disease risk associated with faecal contaminants in the estuary. An indirect but highly valued use of the estuary is waste assimilation of urban stormwater, treated sewage, and terrestrial runoff, particularly nutrients and sediment.

2. Ecological Values (Richness)

Ecological value defines an ecosystem's natural riches (generally interpreted as habitat diversity and biodiversity). It can be supposed that the more rich and diversified an ecosystem is, the greater the losses will be in the event of a disruption. The ecological richness component is divided into four subcategories; birds, vegetation, fish and other biota.

Overall the estuary has a HIGH ecological value rating. Habitat diversity is high with a variety of substrate types present (e.g. cobble, gravel, sand, mud, rock). Intertidal habitats are largely unmodified, there are moderate areas of saltmarsh (10% of the estuary), some large seagrass beds, and a small area of highly diverse, subtidal sponge-dominated community. The estuary is rated as being of outstanding value to birdlife (recognised as nationally significant), in part due to the broad range of habitats supporting many different associated biota (e.g. marine worms, crabs, shellfish, fish, aquatic vegetation).

However, values are degraded by a large proportion of the estuary comprising relatively unproductive soft muds (55%), and most of the natural vegetated margin surrounding the estuary having been cleared, drained or developed. Significant modification has also occurred within the estuary. For example, since 1946 at least 83 ha of saltmarsh has been reclaimed. Despite the muddy nature of the estuary sediments, the inlet is recognised as an important nursery and feeding area for a diverse assemblage of marine and freshwater fish and shellfish.

Table 3. Estuary Uses and Ecological Values

Key for Use and Value Rating	
Very High	■
High	▓
Moderate	▒
Low	░

WAIMEA INLET	HUMAN USE							ECOLOGICAL VALUES				
HABITAT TYPE	Bathing	Shellfish collection	Natural character, aesthetic	Boating (waterskiing, sailing, canoeing)	Fishing, white-baiting, duckshooting	Waste assimilation	Habitat Rating Summary for Human Use	Birds	Vegetation (dune, salt-marsh, macrophytes)	Other Biota (macroinvertebrates, insects)	Fish	Habitat Rating Summary for Ecological Values
Estuary Water	■	▒	■	■	■	■	High	■	▓	■	■	High
Estuary Soft Mud	░	▒	■		▒	▓	Low-Mod	■	▒	▒	▓	Mod-High
Estuary Firm Mud/Sand	▓	▒	■		■	■	Mod-High	■	▓	▓	▓	High
Estuary Gravel/Cobble/Rock	▓	░	■		■	░	Mod	■	▓	▓	▓	Mod
Aquatic Macrophytes			■		░	▓	Low	■	■	▓	▓	High
Biogenic (living) Structures		▒	▒				Very Low	■	▒	▒	▓	Mod
Estuary Saltmarsh			▓		■	■	Mod-High	■	■	■	▓	High
Terrestrial Margin			■		■	■	Mod-High	■	▒	■		Mod-High
Stream & River Mouths	■		■	▒	■	▓	High	■	■	■	■	High
OVERALL USE OR VALUE RATING	High	Low	High	High	High	High	HIGH	High	Mod	High	High	HIGH

HUMAN USES AND VALUES - RATIONALE

NATURAL CHARACTER AND AESTHETICS	Aesthetic values high. Water and surrounds important, pleasant odour, but extensive areas of mud and poor water clarity. Reduced natural character from loss of most margin vegetation and extensive past drainage, reclamation, and human development including roading (e.g. Richmond deviation, Moutere highway realignment), Lower Queen Street industrial area, sewage treatment and disposal at Bells and Rabbit Islands, forestry, and residential housing. Extensive loss of saltmarsh beginning to be addressed through several replanting initiatives (e.g. Borck Creek, Stoke bypass), some removal of previously reclaimed land (e.g. Bark Processors, Showgrounds), and rehabilitation of contaminated sites (FCC site at Mapua).
FISHING, WHITEBAITING DUCKSHOOTING	Fishing (especially with nets) is undertaken in the estuary mainly near the mouth and in tidal creeks for a variety of fish including, whitebait, mullet, kahawai, and flounder. The estuary is popular for shooting ducks and other waterfowl.
BATHING	Use predominantly in the lower estuary in summer, particularly near Mapua, Rabbit Island, and Monaco.
WASTE ASSIMILATION	Discharges of urban stormwater and treated sewage discharge. Estuary saltmarsh and margin play a key role in uptake and assimilation of terrestrial nutrient and sediment inputs, and important in flood mitigation and coastal erosion protection.
BOATING	Range of recreational boating activities particularly in the lower estuary. Larger boats are moored near Monaco and Mapua, and many properties along the estuary edge have small boats or kayaks. Sailing and kayaking popular, particularly at high tide within the estuary, as is water skiing and jet skiing (especially between Rabbit Island and Rough and Bells Islands).
SHELLFISH COLLECTION	Large numbers of edible shellfish present in the middle and lower estuary, but likely to be unsafe to eat.

ECOLOGICAL VALUE (RICHNESS) - RATIONALE

BIRDLIFE	Rated as of outstanding value, with a wide variety of birdlife (~50 species). Shallow margins valued as feeding habitat for waders (including arctic migrants - godwits, red knot, turnstones), with specific areas preferred in both the eastern and western arms. Regionally significant high tide roosting, breeding and feeding areas. Nationally important for some species (e.g. wrybill, pied oystercatchers). Saltmarsh and margin habitat used by birds including banded rail, bittern, fernbird, marsh crake.
VEGETATION	**Saltmarsh:** Extensively modified and cover now relatively low (10%) compared to historical extent (Stevens & Robertson 2009) but of high ecological value. Some rare species present e.g. peppercress, a DOC priority for protection. Many introduced weeds present at the estuary margin, and pest plants in the estuary including *Spartina* (now largely eradicated) and ice plant. **Aquatic Macrophytes**: Restricted cover of seagrass (1% cover of *Zostera muelleri*), reported as diminishing in area from 1999-2005 (Clark et al. 2007). Otherwise most intertidal vegetation intact. **Phytoplankton**: Likely to be low based on visual assessment and high flushing. **Macroalgae**: Few widespread nuisance growths but localised areas of growth near the Waimea River mouth (Appendix 2).
BIOTA	Extensive, given broad range of habitats. Polychaetes, crabs, shellfish all common. Pacific oyster present as a pest species.
FISH	Wide range of marine (31) and freshwater (11) fish species recorded (Davidson and Moffat 1990). Estuary known as an important feeding area, while diverse habitat provides areas of refuge from predation (particularly for juveniles). Spawning in estuary, saltmarsh and tributary streams.

3. PHYSICAL SUSCEPTIBILITY

PHYSICAL SUSCEPTIBILITY

MODERATE

"Physical Susceptibility" is assessed to estimate how likely an estuary is to become degraded based primarily on its ability to dilute and/or flush inputs. This is in turn governed primarily by the physical characteristics of the estuary (described in Table 2).

The physical susceptibility of an estuary to nutrient inputs is estimated by calculating dilution and flushing based on the "Assessment of Estuarine Eutrophication Status" (ASSETS) methodology described in Bricker et al. (1999):

Dilution: Dilution potential (DP) measures the potential for the estuary to dilute incoming freshwater flows based purely on the estuary volume. The Waimea Inlet (Figures 2 and 3) is relatively large by New Zealand standards (2932 ha in area), has a mean depth of ~3.4m, and a spring tide estuary volume of ~99.8 million m^3 (NIWA Coastal Explorer data). The estuary is vertically homogenous (well mixed), although localised stratification (e.g. where freshwater flows on top of seawater) is expected in the low tide drainage channels of rivers and streams. The calculation of DP = 1/volume of estuary = 1/99,818,432 =1 x 10^{-8}. This equates to a "LOW" rating for dilution using Bricker's criteria, (i.e. the potential for the estuary to dilute incoming nutrients is considered low).

Flushing: Flushing potential (FP) measures the ability of an estuary to flush contaminants and is based on the assumption that flushing increases with tidal range and/or freshwater flow. FP is given by the ratio of freshwater inflow (m^3/day)/estuary volume (m^3). In the Waimea, the mean freshwater inflow is approximately 21 m^3/s. The daily freshwater inflow volume is therefore calculated as: 21 x 86400 = 1,814,400 m^3/d. Therefore FP = 1,814,400/99,818,432 = 0.018. The vast majority of freshwater (~90%) enters the estuary from the Waimea River, although numerous other small streams also enter the estuary (Figure 3).

For the macrotidal Waimea Inlet, the high tidal range, and ratio of freshwater inflow to estuary volume, puts it in the "HIGH" Flushing Potential category (i.e. a high potential to physically flush contaminants e.g. nutrients or sediment from the estuary). This is reflected in its short residence time (0.6 days - Robertson et al. 2002).

The combination of low dilution and high flushing potential gives a MODERATE rating overall. This means the Waimea Inlet has a good capacity to flush water borne contaminants from the estuary, but limited ability to dilute them within the estuary. This is consistent with the estuary's physical characteristics, being a relatively large, shallow estuary that remains open at all times, has salinities >30 ppt throughout most of the estuary, extensive intertidal areas, is well mixed, fast draining, and empties almost completely at low tide (Figure 3).

Physical susceptibility to sedimentation is ideally assessed using models that account for various interrelated site-specific factors (e.g. estuary shape and size, depth, freshwater input, tidal prism, grain size, wave fetch, etc.) which influence sediment settlement within an estuary. Because modelling approaches are generally expensive and require detailed underlying data, for this assessment susceptibility to sedimentation is based on expert judgement of physical characteristics and existing condition. Waimea Inlet is given a MODERATE rating to sedimentation based on the presence of extensive muddy areas in both arms despite high flushing.

Figure 3. Waimea Inlet, showing estuary almost completely drained at low tide.

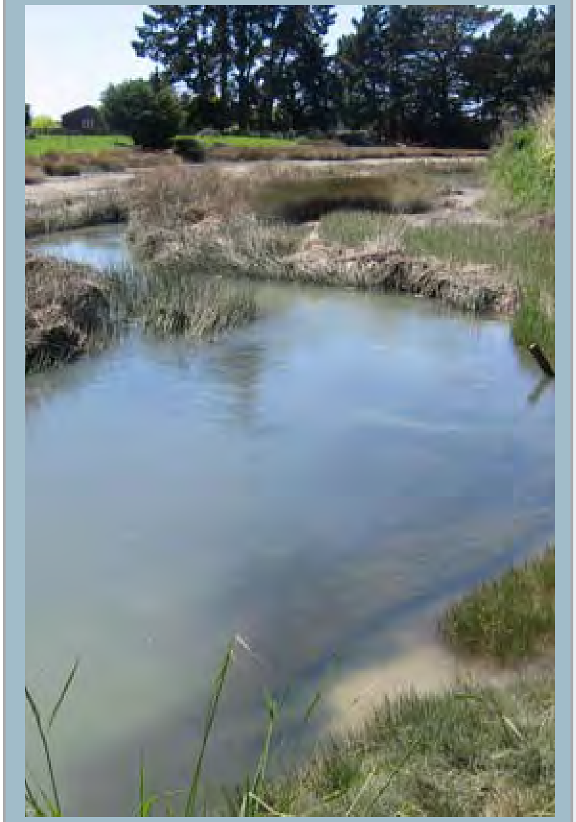
4. EXISTING CONDITION

SUMMARY OF THE CURRENT STATE OF WAIMEA INLET (Source - Robertson and Stevens 2009).

Recent evaluation of Waimea Inlet, based on monitoring signs of eutrophication, sedimentation, disease risk, habitat loss, and toxicants, indicates the estuary is in a MODERATE condition overall (Robertson and Stevens 2009). A synopsis of each issue is given below. The vulnerability assessment in Section 6 applies a range of additional monitoring indicators relevant to each issue to further assess existing condition. This detail is used to rate the different habitats present in the estuary based on the key stressors present (described in Section 5), and determine the indicators most likely to detect a change in condition.

SEDIMENT POOR	**1. Sedimentation.** Waimea Inlet is dominated by poorly oxygenated, soft mud/sand sediments (55%) and is rated in a "POOR" state for this issue. The muddy conditions mean that the waters within the estuary are relatively turbid and the sediment life is dominated by organisms able to tolerate fine muds. The presence of mud constrains human use of the estuary by making it difficult to walk in and by reducing the water clarity. It also reduces the biodiversity of the intertidal area by reducing the range of different habitats present (one of the key reasons the Waimea Inlet is rated of national significance), and by displacing key species such as pipi, cockles and seagrass.
HABITAT LOSS POOR	**2. Habitat Loss**. Overall, the estuary has lost most of the natural filtering and assimilation provided by the margin vegetation and is rated "POOR". There has been extensive loss of saltmarsh due to drainage and reclamation, and an almost complete loss of the terrestrial forest and freshwater wetland that once covered the Waimea plains and surrounding hillsides. A consistent decline in seagrass has been reported. There has also been extensive development in margin areas (e.g. light industry, residential housing, lifestyle blocks, dairy farming, horticulture, forestry, sewage treatment works), resulting in a range of impacts from roading, causeways, seawalls, stormwater runoff, and point source discharges. The increased residential development has had a mixed impact on birdlife with increased habitat loss, physical disturbance, and predation offset in some instances by restoration, pest control and increased awareness.
DISEASE MODERATE	**3. Disease Risk**. Monitoring of disease risk to humans from faecal organisms shows the estuary is generally safe for swimming although indicator bacteria are elevated during rainfall events, and consumption of shellfish is not recommended. Overall the estuary is rated as "MODERATE". The main sources of the faecal disease risk are runoff and drainage from the catchment, in particular the smaller tributaries entering the estuary, and the discharge of treated wastewater from the Bells Island WTP.
EUTROPHICATION GOOD	**4. Eutrophication: Nutrient Enrichment and Nuisance Algal Growths**. At present the Waimea Inlet has relatively few symptoms of eutrophication. However, there are localised areas of nuisance macroalgal growth (Appendix 2), poor sediment oxygenation (Appendix 3), and an associated imbalanced community of sediment dwelling organisms. Overall a rating of "GOOD". The localised areas of macroalgal growth are commonly associated with areas of soft mud or obvious sources of elevated nutrients coming from many of the small streams entering the estuary. There is poor sediment oxygenation where growths occur. The capacity of large and well flushed tidal lagoon estuaries like Waimea Inlet to assimilate and flush catchment nutrient inputs has prevented more widespread problems.
TOXICITY VERY GOOD	**5. Toxins**. Past monitoring has shown that away from localised point source inputs (e.g. stormwater outfalls, old landfills), estuary sediments are not contaminated (e.g. low concentrations of heavy metals and pesticides). The estuary state is rated as "VERY GOOD".
	6. Other Issues. Other issues present in the estuary include the presence of invasive species (e.g. *Spartina* (largely eradicated), Pacific oysters, iceplant), restoration of the natural vegetated terrestrial margin, development and planting of an estuary walkway near Richmond, declamation adjacent to Bark Processors in Lower Queen Street, and the successful remediation of the former FCC site at Mapua.

5. IDENTIFICATION OF KEY STRESSORS



Stressors (or pressures) are activities that affect the ecological condition of coastal and estuarine habitat. The main stressors or threats to estuaries commonly include runoff from developed catchments, drainage and reclamation, climate change (sea level rise, changes to temperature and rainfall), depletion of living resources (e.g. shellfish, fish), artificial structures, and invasive species introductions.

Because their harmful effects cause a variety of environmental deteriorations they are identified so that their risk can be characterised according to their estimated effect on relevant condition indicators (e.g. loss of saltmarsh, increased macroalgal growth). The identification of stressors is based on existing data, observation, and expert opinion. Because many potential stressors may be either absent or unlikely to have a significant impact, expert judgement is commonly used to quickly and cost effectively review existing knowledge and identify what issues are most likely to affect a particular habitat. This then provides a basis for deciding what level of effort should be put into addressing different issues.

An introduction to the major stressors is presented below. This is followed by a summary of the stressors identified as present in Waimea Inlet. Expert judgement has been used to rate the level of expression expected for each stressor in key estuary habitat types in Table 4, along with a prediction of future change. The rationale for selection is described in Table 5.

OVERVIEW OF MAJOR ESTUARY STRESSORS

Catchment Runoff
Runoff from developed catchments can carry excessive loads of sediment, nutrients, toxins and disease-causing organisms into estuaries. Excessive sediment leads to muddier estuaries which reduces human use and ecological values. Excessive nutrients stimulate algal blooms (e.g. sea lettuce) and nuisance conditions. Excessive toxins collect in sediments and bio-accumulate in fish and shellfish, causing health risks to people and marine life. Excessive disease-causing organisms can cause serious health risks to recreational users and human consumers, and economic loss due to closed shellfishing areas.

Point Source Discharges
The discharge of inadequately treated wastewater from municipal and heavy industrial plants into estuaries has the potential to cause significant adverse affects on the estuarine environment, aquatic organisms and human health. Discharges can lead to poor water quality, stained shorelines, unpleasant odours and colourations, health risks to humans, mutations and mortality in aquatic organisms, loss of recreational value, and the accumulation of toxins in the food chain. Currently the Waimea Inlet receives much of Nelson and Richmond 's treated wastewater, while the Richmond and Tahunanui Industrial zones are located on the estuary margin.

Blooms of green and red algae (*Enteromorpha* and *Gracilaria*) between Bests and Bells Island caused by nutrients in the Waimea River becoming concentrated in the poorly flushed region upstream of the Bells Island causeway.

Bells Island Regional Sewage Authority point source discharge of treated wastewater to Waimea Inlet.

5. IDENTIFICATION OF KEY STRESSORS (CONT.)

Drainage and Reclamation

Drainage and reclamation, including construction of causeways and floodbanks, displaces or degrades estuary saltmarsh and the terrestrial vegetated buffer and constricts tidal flows. This greatly reduces the natural assimilative capacity of the estuary, leading to elevated sedimentation rates and low habitat quality. Development and reclamation of the margins around Waimea Inlet has resulted in the loss of most of the historical saltmarsh and terrestrial margin vegetation, and significantly reduced the extent of the estuary. On the positive side, Nelson City Council have planted 55,000 native trees adjacent to the motorway bypass; and a partial removal of previously reclaimed land has recently been undertaken near Richmond, along with the planting of 21,000 native trees by TDC.

Climate Change - Sea level Rise

Estuaries are extremely sensitive to changes in sea level as this can drastically alter the dynamic ecological balance. As sea level rises estuaries will widen, deepen and tidal penetration upstream will be extended. If sea level rise is not too rapid, saltmarsh and tidal flat vegetation and organisms will likely re-establish to favourable habitat if the estuary is allowed to retreat inland. Certainly landowners will try to prevent shoreline retreat, but care will be needed as such actions can cause more harm than good (e.g. loss of saltmarsh, increased wave reflection from seawalls).

Climate Change - Rainfall and Temperature

MFE (2008) currently predict a 2°C change in annual average air temperature and a 4% increase in the annual average rainfall for Nelson by 2090. The wetter climate may contribute to increased runoff and greater nutrient, sediment, and pathogen loads to at-risk coastal waterbodies. In combination with increased temperatures, the increased loads will mean much greater vulnerability of Nelson estuaries to eutrophication and its associated nuisance conditions (e.g. low oxygen, algal blooms), disease risk, and sedimentation.

Artificial Structures (seawalls, marinas, marine farms)

Pressure to protect developed estuary margins by artificial structures is expected to increase to defend existing development and infrastructure against sea-level rise and the greater frequency of storms. Such artificial shoreline hardening will affect the ecological services of shoreline habitats, particularly where coastal squeeze occurs and marginal vegetation is displaced. These habitats provide physical and biogeochemical buffers in estuaries, and are essential to sustainable fishery production.

Other structures such as wharfs, marine farms and marinas can have a wide range of localised impacts but are commonly subjected to full assessment as part of the resource consent process.

Other commonly present stressors:

Invasive Species (e.g. *Spartina*, ice plant, Pacific oyster), Over-collection of living resources, Recreation, Human disturbance of wildlife, Stock grazing in stream channels and saltmarsh, Vehicle damage, Freshwater abstraction, Algal blooms (marine), Spills, Floodgates.

Measuring sedimentation rate in soft muds in Waimea Inlet.

Saltmarsh habitat will be lost with sea level rise if it cannot migrate inland.

Sulphide rich muds in estuaries are likely to become more widespread with climate change.

Small seawall constructed to protect residential land from erosion.

Invasive cord grass *Spartina* (left) and Pacific oyster (right) - two pest species in Waimea Inlet.

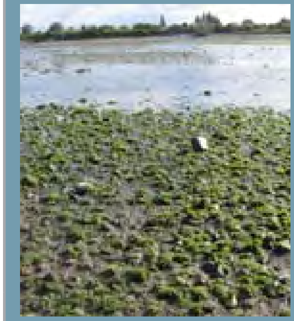
5. IDENTIFICATION OF KEY STRESSORS (CONT.)

PRESENCE OF STRESSORS

MODERATE-HIGH

Table 4 summarises the existing influence predicted for each stressor included in the assessment for each of the habitat types present in and around Waimea Inlet. Ratings are based on existing data, local knowledge, field observations and expert judgement, with the rationale for the rating provided in Table 5.

Overall, the presence of stressors in Waimea Inlet is rated as MODERATE-HIGH. The stressors influencing the widest range of habitats are sea level rise, climate change, and catchment runoff of sediment, nutrients, and disease causing organisms (pathogens). The habitats affected by the widest range of stressors are the terrestrial margin, estuary saltmarsh, and stream and river mouths. In many cases the influence of stressors is predicted to increase in response to increasing population pressure and intensification of landuse.



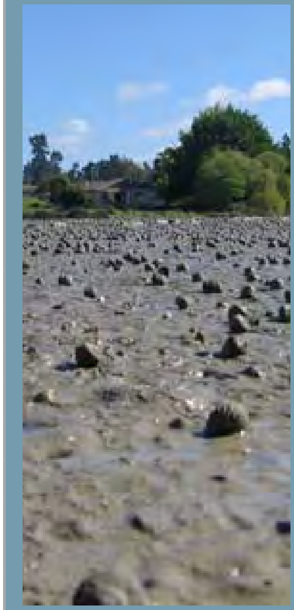


Table 4. Presence and Rating of Stressors in Waimea Inlet.

Key For Rating	
Stressors	
High	🟥
Moderate	🟧
Low	🟨

WAIMEA INLET	HABITAT TYPE									
	Estuary Water	Estuary Soft Mud	Estuary Firm Mud/Sand	Estuary Gravel/Cobble	Aquatic Macrophytes	Biogenic Structures	Estuary Saltmarsh	Terrestrial Margin	Stream & River Mouths	Mean Bulk of Estuary
STRESSORS	EXISTING STRESSOR INFLUENCE									
Catchment Runoff - Sediment	🟧	🟥	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟥
Catchment Runoff - Nutrients	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟥	🟧
Catchment Runoff - Pathogens	🟧	🟧	🟧	🟨	🟨	🟥	🟨	🟨	🟥	🟧
Catchment Runoff - Toxicants	🟨	🟨	🟨						🟨	🟨
Point Source Discharges	🟧								🟨	🟧
Sea Level Rise	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
Climate Change Rain/Temp	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
Spills (incl. oil)	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Grazing							🟨	🟨		🟨
Fire							🟨	🟨		🟨
Aquaculture										
Freshwater abstraction									🟧	🟨
Reclamation/drainage							🟧	🟧		🟧
Causeways/floodbanks		🟨	🟨	🟨	🟨	🟨	🟧	🟨	🟨	🟧
Seafood collection	🟨	🟨	🟨			🟨				🟧
Algal blooms (from sea)	🟨									🟨
Structures (esp. seawalls)							🟥	🟥		🟥
Invasive weeds/pests		🟧	🟧	🟧		🟧	🟧	🟥	🟧	🟧
Vehicle damage							🟨	🟨	🟨	🟨
Margin encroachment							🟥	🟥	🟥	🟥
Floodgates							🟧		🟧	🟧
OVERALL RATING ACROSS HABITAT TYPES	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥	🟥	🟥

Table 5. Selection, Rationale and Rating of Stressors in Waimea Inlet.

A combination of existing information, local knowledge, field observations and expert judgement were used to identify and rate stressors present in Waimea Inlet. Further detail for each of the five key issues is included in Section 6.

Stressor	**Level of Expression** 🟨 Low 🟫 Moderate 🟧 High	Eutrophication	Sediment	Disease	Toxins	Habitat Loss
Terrestrial Runoff - Sediment	MODERATE catchment runoff of nutrients, sediment and pathogens is expected based on the following: Water quality in the Waimea River is generally high with low nutrient concentrations (80% terrestrial runoff, 20% point source inputs), low concentrations of disease-causing organisms, and moderate concentrations of sediment. Main sources of non-point source runoff from terrestrial areas, including the land disposal of sewage sludge from the Bells Island oxidation ponds on Rabbit and Bell Islands. Guideline values for clarity, faecal coliforms, and dissolved nutrients generally not exceeded in the Waimea River. Summary base flow water quality data for the Waimea River (median, max, min) are provided as follows (source Trevor James TDC, period 2000-2009): DIN g/m3 (0.345, 0.43, 1.1); DRP g/m3 (0.005, 0.001, 0.014); *E. coli* c.f.u. (10, <5, 145), Clarity m (8.5, 1.7, 16.8). NIWA (see maps on website) predict a low annual catchment N yield (3 kg/ha/yr) and a moderate sediment yield (134 t/km^2/yr). However, values for smaller streams throughout the estuary indicate elevated localised inputs to the estuary for nutrients and pathogens under both dry and rainfall affected flows (e.g. Gillespie et al. 2001). Mass catchment sediment load estimates: 120,700 tonnes SS/yr from 902km^2 catchment = 134 t/km^2/yr (WRENZ). 91% of the estimated SS loads are discharged via the Waimea River (data in Table 11).		🟫			🟫
Terrestrial Runoff - Nutrients		🟫				
Terrestrial Runoff - Pathogens				🟫		
Terrestrial Runoff - Toxicants	LOW. Non-point sources of heavy metals and Semi Volatile Organic Compounds (SVOC's) in catchment e.g. stormwater from roads and industrial areas in Richmond, Tahunanui and Stoke. Possible historical sources at old landfills (e.g. Beach Road Richmond, Waimea River mouth, Mapua). Major historical organochlorine pesticides at the Mapua FCC site now cleaned up. Risk of point-source discharges reduced through a TDC monitoring programme for sites using hazardous chemicals.				🟨	
Point Source Discharges	MODERATE. Bells Island regional sewage outfall (LOADS: Faecal coliforms = 1.3 x 10^{14} FC/yr, Nutrients: N=224 kgN/day (81.8 tN/yr), P=64 kgP/day (23.4 tP/yr), Suspended Sediment: Median 30gSS/m^3 and 13,767 m^3/d discharge = 30 x 13,767 x 365 = 151 T SS/yr - calculations in Section 6. Stormwater from industrial, agricultural (horticulture, drystock farming, dairying) and urban (Stoke and Richmond) sources. Very occasional sewer overflows.	🟫	🟫	🟫	🟫	
Sea Level Rise	Barrier beach, estuary lagoon, saltmarsh, tidal flats and low lying islands are all critical habitats that have HIGH or VERY HIGH vulnerability to sea level rise (SLR) (Pendleton et al. 2004). Because all are present in the Waimea Inlet and the spring tidal range is 3.6m, a VERY HIGH risk is assumed. If saltmarsh retreat to SLR is restricted, sediment trapping capacity is reduced by saltmarsh loss. SLR also likely to expose fresh earth for exposure to erosion.		🟫			🟧
Climate Change	MODERATE. Predicted wetter climate (MfE 2008, Wratt et al. 2008) will likely contribute to increased runoff and greater nutrient, sediment, and pathogen loads. In combination with increased temperatures, the increased loads will mean much greater vulnerability of Nelson estuaries to eutrophication and its associated nuisance conditions (e.g. low DO, algal blooms).	🟫	🟫	🟫		
Spills	LOW risk of spills. Terrestrial sources most likely, with highest risk in dilution limited streams and upper estuary.				🟨	🟨
Grazing in margins	LOW. Farming to edge of estuary so some potential for uncontrolled grazing of terrestrial margin and saltmarsh.			🟨		🟨
Fire	LOW. Low and localised risk to saltmarsh and terrestrial margin.					🟨
Aquaculture	VERY LOW. No aquaculture in estuary.					
Freshwater Abstraction	LOW. Negligible impact on estuary. Greatest potential impact in freshwater streams (e.g. reduced flows, flow related temperature changes, limited flushing and dilution, ponding). Reduction in freshwater plant and fish habitat.	🟨				🟨
Reclamation, Drainage	MODERATE reclamation and drainage of saltmarsh undertaken in the past (see Stevens and Robertson 2009). The major effects of these stressors are expected to be direct and indirect habitat loss, including increased risk of pest animals and weeds getting in to the estuary, and increased human disturbance/displacement of wildlife. Reduced capacity for assimilating sediment and nutrient inputs through reduced estuary area and saltmarsh loss.	🟫	🟫			🟫
Causeways/Floodbanks	MODERATE. Major issue direct and indirect habitat loss by reduced tidal flows. Some localised sediment and nutrient problems due to restricted flushing. Reduction in freshwater plant and fish habitat.	🟫	🟫			🟫
Seafood Collection	Lots of shellfish and fish in estuary. Assume MODERATE as extent of human collection and consumption uncertain.					🟫
Algal Blooms (sea)	VERY LOW.	🟨			🟨	
Structures	Presence of seawalls and erosion protection works is HIGH, particularly road margins and some shorelines. Few other significant structures present. A small historically significant wharf at Mapua. No marine farms or marinas.					🟧
Invasive weeds/pests	MODERATE - but large uncertainty - some weeds growing in wetland areas, particularly gorse. Pacific oysters widespread, ice plant well established. Tamarisk and creeping bent becoming established. Sediment trapping *Spartina* largely eradicated but still occasionally found. Wildlife predation and disturbance from pest animals (including cats and dogs).		🟫			🟫
Vehicle Damage	LOW. Some localised access of vehicles to estuary (e.g. around Borck Creek).					🟨
Margin Encroachment	HIGH - most margins are developed e.g. housing, industrial areas, roading, orchards, grazing, forestry.					🟧
Floodgates	MODERATE. Flapgates are present on some culverts in tributaries entering the estuary e.g. Pearl Creek, Tahi St Mapua resulting in direct and indirect habitat loss, particularly for fish and saltmarsh plants. May limit flushing of sediment.		🟫			🟫
OVERALL STRESSOR RATING		🟫	🟫	🟫	🟨	🟧

6. ECOLOGICAL VULNERABILITY ASSESSMENT

Caspian tern chick and egg. Bells Island shellbank.

Table 6. Indicators for Monitoring Condition of Key Estuary Issues.

	MONITORING INDICATORS FOR KEY ISSUES
Eutrophication	Chlorophyll-*a* in Water
	Macroalgal Condition Rating (% cover)
	Benthic Microalgal Mats
	Dissolved Oxygen in Water
	Oxygen in Sediment (RPD depth)
	Nutrient Loadings
	Sediment Organic Carbon
	Macrophyte Loss
	Macroinvertebrates
	Phytoplankton Blooms
Sediment	Area of Soft Mud
	Sedimentation Rate
	Clarity
	Sediment Grain Size
	Macroinvertebrates
Disease	Faecal Indicators - Bathing water
	Faecal Indicators - Shellfish
	Faecal Indicators - Stock drinking water
Toxicity	Heavy Metals
	SVOCs
	Toxic Algae
	Macroinvertebrates
Habitat Loss	Substrate
	Macrophytes (Seagrass)
	Saltmarsh
	Vegetated Terrestrial Margin
	Birds
	Fish
	Invasive species
	Benthic invertebrates
	Shellfish
	Sea Level

The Ecological Vulnerability Assessment is the process where key stressors are related to each of the key issues facing the estuary (eutrophication, sedimentation, disease risk, toxicants and habitat loss) to characterise and rate the vulnerability of an estuary to problems.

This is done by combining information on human uses and values, ecological richness and physical susceptibility, and relating it to the presence and significance of key stressors. The influence of key stressors on existing condition is further assessed using the monitoring indicators listed in Table 6.

The level of expression for each indicator and the overall vulnerability is determined based on:

- Primary and Secondary Symptoms relevant to each Issue (existing condition symptoms, e.g. macroalgal growth, chlorophyll-a concentrations)
- Physical Susceptibility to Stressors (e.g. potential to dilute and flush nutrients)
- Influence of the Key Stressor (e.g. nutrients in the case of the eutrophication issue)
- Likely Future Outlook
- Likely Impact on Human Uses and Ecological Values

Information upon which the expert judgements have been based, and the reason for each decision, are included to provide a transparent process, to enable additional information to be added as it becomes available, and to allow other experts to contribute to the assessment process. In order to simplify the presentation of the detailed information, summary tables are used throughout with underlying detail referenced or appended as appropriate (e.g. calculations of sediment, nutrient, and pathogen mass loads, mapping of macroalgal growth, mapping of sediment RPD depth, landuse summaries).

A synopsis of the key findings for each issue is provided in the following sections, and an Estuary Vulnerability Matrix (Section 7, p.42) is used to summarise the ratings, the key issues, and priority monitoring indicators for the estuary overall. Ratings are based on a combination of condition ratings (e.g. those developed for NZ estuaries (see Robertson and Stevens 2009), ASSETS eutrophication assessment criteria (see Bricker et al. 1999), guidelines (ANZECC 1992, 2000, MFE/MOH 2003), and expert judgement.

Finally, the vulnerability ratings are used to guide the design of a monitoring programme by assessing which monitoring indicators are most likely respond to the stressors and indicate a change in the condition of the estuary. Those indicators most likely to show change are the ones where all of the following are rated in the moderate or high category:

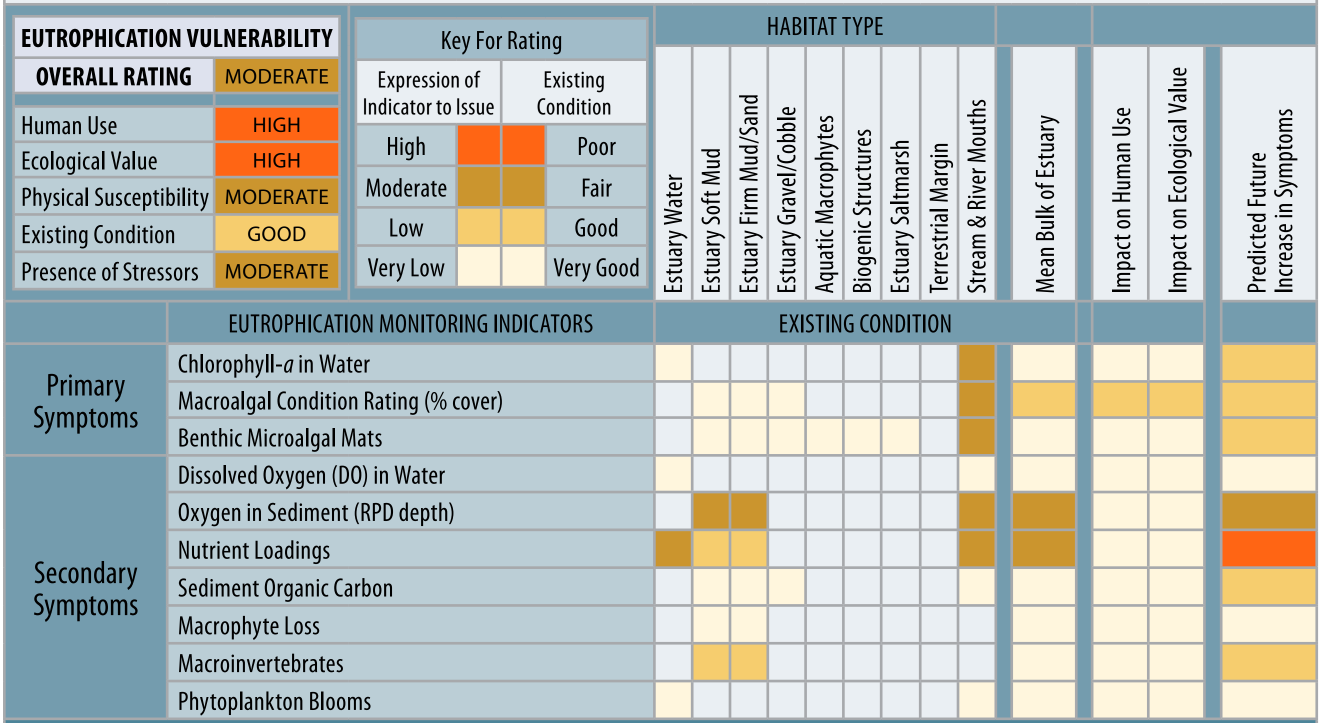
- risk of an indicator affecting a particular use/value.
- risk of an indicator being impacted by a particular stressor.
- risk of an indicator of existing condition already being impacted.
- risk of an indicator being impacted by the physical susceptibility of the habitat.

These are indicated in the summary tables for each issue and linked to recommended monitoring and management in Section 8.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.1 EUTROPHICATION

The approach used to assess the existing condition and susceptibility to eutrophication is based on the “Assessment of Estuarine Eutrophication Status” (ASSETS) methodology (Bricker et al. 1999), but with a strong emphasis on the use of primarily qualitative data and expert opinion.



EUTROPHICATION VULNERABILITY	
OVERALL RATING	MODERATE
Human Use	HIGH
Ecological Value	HIGH
Physical Susceptibility	MODERATE
Existing Condition	GOOD
Presence of Stressors	MODERATE

Key For Rating			
Expression of Indicator to Issue			Existing Condition
High	🟧	🟧	Poor
Moderate	🟫	🟫	Fair
Low	🟨	🟨	Good
Very Low	⬜	⬜	Very Good

	EUTROPHICATION MONITORING INDICATORS	Estuary Water	Estuary Soft Mud	Estuary Firm Mud/Sand	Estuary Gravel/Cobble	Aquatic Macrophytes	Biogenic Structures	Estuary Saltmarsh	Terrestrial Margin	Stream & River Mouths	Mean Bulk of Estuary	Impact on Human Use	Impact on Ecological Value	Predicted Future Increase in Symptoms
		HABITAT TYPE												
		EXISTING CONDITION												
Primary Symptoms	Chlorophyll-*a* in Water	⬜								🟫	⬜	⬜	⬜	🟨
	Macroalgal Condition Rating (% cover)		⬜	⬜	⬜					🟫	🟨	🟨	🟨	🟨
	Benthic Microalgal Mats		⬜	⬜	⬜	⬜	⬜	⬜		🟫	⬜	⬜	⬜	🟨
Secondary Symptoms	Dissolved Oxygen (DO) in Water	⬜								⬜	⬜	⬜	⬜	⬜
	Oxygen in Sediment (RPD depth)		🟫	🟫						🟫	🟫	⬜	⬜	🟫
	Nutrient Loadings	🟫	🟨	🟨						🟫	🟫	⬜	⬜	🟧
	Sediment Organic Carbon		⬜	⬜	⬜					⬜	⬜	⬜	⬜	🟨
	Macrophyte Loss		⬜	⬜							⬜	⬜	⬜	⬜
	Macroinvertebrates		🟨	🟨							⬜	⬜	⬜	🟨
	Phytoplankton Blooms	⬜								⬜	⬜	⬜	⬜	⬜

EXPRESSION OF EUTROPHICATION CONDITIONS

Chlorophyll-*a* in water	Chlorophyll-a concentration in estuary water not measured but likely to be LOW (≤5 µg chl-a/l) based on expert opinion. Higher concentrations expected at stream and river mouths, but low spatial coverage. A LOW level of expression is assumed.
Macroalgae	Nuisance macroalgal growth is known to be present at a relatively low spatial coverage (2009 Macroalgal coefficient = 0.2 - Appendix 2). Growth was concentrated near main channels in the lower estuary, and in parts of the upper reaches of sheltered arms and embayments. Frequency is periodic. This gives a LOW level of expression.
Benthic Microalgal Mats	Chlorophyll-a concentration in estuary sediment is LOW (1-50 mg chl-a.m^2) based on sediment values reported in Robertson et al. (2002) and Gillespie et al. (2007). Benthic microalgal mats not conspicuous. A LOW level of expression is assumed.
DO in Water	Water column DO has not been measured in the estuary but it is expected to be high. A LOW level of expression is assumed.
Oxygen in Sediment	The 2009 RPD rating for the vast majority (68%) of the estuary was “fair” with the RPD depth in the 1-3cm depth range (Appendix 3). This was most common in the fine and often soft muds that dominate the upper tidal reaches of both the eastern and western arms. This gives a MODERATE level of expression.
Nutrient Loadings	Nitrogen is generally the nutrient controlling the growth of nuisance algae in coastal and estuarine waters and as such, nutrient loadings are a key stressor. The nutrient influence for Waimea Inlet was calculated using the ASSETS approach (Bricker et al. 1999) with calculation details provided in Table 7. Overall, nutrient loadings present a MODERATE level of expression.
Sediment Organic Carbon	The 2001 and 2006 monitoring data Robertson et al. (2002) and Gillespie et al. (2007) showed a mean total organic carbon (TOC) of around 1%. This gives a LOW level of expression.
Macrophyte Loss	Reported seagrass losses (Clarke et al. 2008) are unlikely to be caused by overgrowth of algae or as a result of epiphyte growth on leaves. Therefore a LOW level of expression is assumed.
Macroinvertebrates	Macroinvertebrates were rated as representing “slightly polluted” conditions with shift towards a community more tolerant of muddy or enriched conditions from 2001 and 2006 (Robertson and Stevens 2009). However, the absence of a multi-year baseline mean the changes cannot reliably be distinguished from natural variation. A LOW level of expression is assumed.
Phytoplankton Blooms	No known toxic blooms or blooms of phytoplankton species causing nuisance conditions. The 0.6 day residence time of Waimea Inlet is <3 days, which means phytoplankton blooms are unlikely. This gives a LOW level of expression.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.1 EUTROPHICATION (CONT.)

EXPRESSION OF EUTROPHICATION CONDITIONS

OVERALL EXPRESSION OF EUTROPHICATION CONDITIONS

An overall rating is derived by combining the average rating of the three primary symptoms (taking the localised areas showing primary symptoms into account) - LOW, and the highest rating of the secondary symptoms - MODERATE. The overall rating is LOW-MODERATE. Eutrophication conditions are not an issue across the majority of the estuary but primary symptoms of macroalgal growth are present in localised areas.

PHYSICAL SUSCEPTIBILITY (DILUTION AND FLUSHING POTENTIAL)

The combination of low dilution and high flushing (Section 2) gives a MODERATE overall susceptibility to nutrients. In the Waimea Inlet strong flushing means that phytoplankton are unlikely to spend enough time in the estuary to grow to bloom proportions (phytoplankton require >3 days to double in size but nearly all of the estuary water leaves the estuary each tide). In areas where flushing is poor, a salt wedge or temperature thermocline could develop (e.g. high salinity bottom water trapped under freshwater), and small localised parts of the estuary may experience direct symptoms of eutrophication from phytoplankton blooms, nuisance macroalgae, and excessive benthic microalgae.

INFLUENCE OF STRESSORS

Table 5 identified the following stressors contributing to eutrophication symptoms: nutrient inputs from catchment run off, point source discharges, climate change, freshwater abstraction, and causeways. Of these, the key stressor is catchment nutrient inputs. The combined influence of nutrients from both catchment runoff and the Bells Island WTP point source discharge is calculated using a modified ASSETS approach (Bricker et al. 1999) as described in Table 7. This rates the current nutrient influence on the estuary as MODERATE. Climate change is expected to increase runoff and therefore nutrient inputs, while the other stressors serve to exacerbate eutrophication symptoms primarily by localised concentration of nutrient inputs. Any increase in nutrient inputs is likely to shift the influence to a HIGH.

Table 7. Calculations for the influence of nutrients on the estuary.

The influence of nutrients, a key estuary stressor, are calculated using a modified ASSETS approach (Bricker et al. 1999) as follows:

- Assume: Salinity of estuary (Se); Salinity of ocean (So).
- Nitrogen concentration in inflow to the estuary (Nin)
- Nitrogen concentration of the ocean (Nsea)
- Background nitrogen concentration (Nb) = Nsea(Se/So)
- Human derived nitrogen concentration (Nh) = Nin
- Expected total N concentration (Nc) = Nh + Nb
- Influence of Nutrients = Nh/(Nb + Nh)

RATING	Thresholds and Categories for Influence of Nutrients
1	Low: 0-0.2
2	Moderate-Low: 0.2-0.4
3	Moderate: 0.4-0.7
4	High: >0.7

Waimea Inlet Nutrient Influence

- (Se) = 30 ‰; (So) = 32 ‰, (Nsea) = 0.02 mg/L assumed, (Nb) = Nsea(Se/So) = 0.02x30/32 = 0.02.
- (Nin) = (Rivers annual load + Point Discharges annual load)/Annual Water Input Load
  $=\{1\text{x}10^6(250+80+40)\}/664.3\text{x}10^6 = 390/664 = 0.587\ \text{g/m}^3$
- (Nh) = Nin (So-Se)/So = 0.587 (32-30)/32 =0.037.
- Influence of Nutrients = Nh/(Nb + Nh) = 0.037/0.057 = 0.65 which corresponds to a “Moderate” nutrient input score.
- Sources: Terrestrial Runoff 80%, Point Discharges 20% (See Tables 8 and 9 for source and load calculations).

EFFECT ON HUMAN USES

The existing impact on human uses of the estuary from eutrophication symptoms overall is minor. Macroalgal growth creates localised nuisance conditions in small areas of the estuary. Impacts in these areas are significant, reducing aesthetic values and contributing to increased muddiness (particularly amongst dense *Gracilaria* beds), decreased sediment oxygenation, and nuisance smells.

EFFECT ON ECOLOGICAL VALUES

Macroalgal growth, concentrated in the main channels and around the banks of the main estuary, alters sediment chemistry primarily through sediment nutrient enrichment and oxygen depletion. This consequently changes macrofaunal communities. Such symptoms would be most severe in the summer periods when water temperatures are at their peak and growth is greatest, but currently present only a localised problem in small parts of the estuary.

FUTURE INFLUENCE

Future nutrient loads are likely to increase. The main source of nutrients to the estuary is currently from non-point catchment runoff discharged via the Waimea River and small tributaries, and local point sources from the Bells Island and Rabbit Island sewage outfall and biosolids disposal (see detail on the following pages). Pressure to reduce catchment nutrient yields from intensive landuse is a national priority at present. However, given past inaction in this area, and ongoing population expansion, a conservative approach of assuming that the future nutrient load remains the same or increases is recommended.

Influence of climate change will likely increase intensity of storm events; therefore increase nutrient runoff as most inputs are from terrestrial runoff from developed land. Increased inputs are likely to increase growths of macroalgae, and reduce sediment oxygenation.

SUPPORTING INFORMATION: ESTIMATION DETAILS - EUTROPHICATION: NUTRIENT SOURCES AND LOADS

Waimea Inlet: Nutrient Sources and Loads

Figure 4 and Table 8 show the contribution and loads of nitrogen and phosphorus from major catchment land uses. The nitrogen and phosphorus loads to Waimea Inlet are estimated at 630 and 96 tonnes per year respectively (calculations in Table 9). Native bush and plantation forests contribute the most nitrogen (32%) to the estuary despite a low export rate (~3 kgN/ha/yr) because they cover large areas of the catchment (see Appendix 5). Sheep and beef farm runoff (25%, ~9 kg/ha/yr) is the largest of the farming inputs.

Dairy farm runoff contributes a disproportionately large amount (10% of the total from 2% of the catchment) because it has the highest estimated export per hectare (~30 kgN/ha/yr). Estimates of export from horticultural sources are generally high, but inputs will relate strongly to the amount and timing of fertilizer applications. The estimated export rate used (25 kgN/ha/yr) assumes moderate fertiliser application and moderate runoff.

The nitrogen load from the Bells Island Wastewater Treatment Plant (WTP) discharge is also a significant contributor to the estuary (~20% of the total). Additional inputs to the estuary are also expected from biosolids disposal on Rabbit Island. Biosolids disposal is estimated to contribute a maximum of 80 tN/yr if there is no uptake (an unlikely worst case scenario). A more likely estimate is a 20% loss to the estuary (80% uptake) which would add 16tN/yr, ~3% of the total catchment load. Phosphorus inputs to the estuary follow a similar trend to nitrogen (Figure 4, Table 8).

Table 8. Estimated nitrogen and phosphorus loads from the Waimea catchment and Bells Island WTP.

Sources	Sheep/beef	Native Forest	Horticulture	Exotic Forest	Bells I. WTP	Dairy	Urban areas	Biosolids	Scrub	TOTAL
Tonnes N/yr (%)	160 (25%)	103 (16%)	95 (15%)	88 (14%)	82 (13%)	55 (9%)	20 (3%)	16 (3%)	11 (2%)	630
Tonnes P/yr	36	13	10	10	23	2	2	5	2	103

Figure 4. Estimated nitrogen and phosphorus loads from the Waimea catchment and Bells Island WTP.

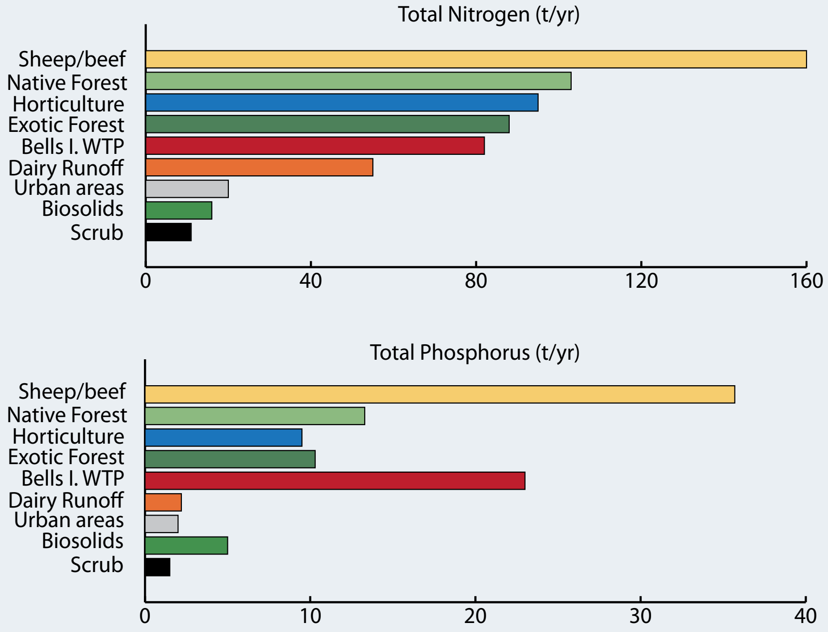


Table 9. Calculations of nutrient inputs (N and P) to Waimea Inlet.

Method 1: NIWA's WRENZ Model: http://wrenz.niwa.co.nz/webmodel/		
NIWA's WRENZ Model Output:	**Waimea Inlet Catchment N**	**tN/yr**
	3 kgN/ha/yr	266.9

Method 2: Landuse Estimates				
Sources	**Waimea Inlet Catchment N**	**tN/yr**	**Waimea Inlet Catchment P**	**tP/yr**
Native Forest	3 kgN/ha/yr* x 34,211ha =	102.6	0.39 kgP/ha/yr* x 34,211ha =	13.3
Scrub	3 kgN/ha/yr* x 3,718ha =	11.2	0.39 kgP/ha/yr* x 3,718ha =	1.5
Exotic Forest	3 kgN/ha/yr* x 29,478 ha =	88.4	0.35 kgP/ha/yr* x 29,478 ha =	10.3
Dairy (runoff, leachate)	30 kgN/ha/yr** x 1,766ha =	53.0	1.0 kgP/ha/yr** x 1,766ha =	1.8
Dairy Oxidation pond discharges (assuming all dairy shed effluent to ponds)	5.4 kgN/cow/yr x 1,645cows = 8.9 tN/yr. Assume 75% removal in dual ponds =	2.2	0.66 kgP/cow/yr x1,645cows = 1.1 tP/yr. Assume 60% removal in dual ponds =	0.4
Other Improved Pasture (e.g. sheep/beef)	9 kgN/ha/yr* x 17,823ha =	160.4	2.0 kgP/ha/yr* x 17,823ha =	35.7
Horticulture	Assume 25 kgN/ha/yr x 3,801***ha =	95.0	Assume 2.5kgP/ha/yr x 3,801****ha =	9.5
Urban Areas	8 kgN/ha/yr* x 2,507ha =	20.1	0.8 kgP/ha/yr* x 2,507ha =	2.0
TOTAL	5.7 kgN/ha/yr	533	0.8 kgP/ha/yr	75

* Based on estimates in Elliot and Sorrell (2002)

** based on estimates in Elliot and Sorrell (2002) and Environment Waikato Equation for Nitrogen Load (kgN/ha/yr) = 10.28 x cows/ha + 2.241 (based on data from Waikato dairy farms) see; http://www.ew.govt.nz/environmental-information/Environmental-indicators/Inland-water/River-and-streams/riv7a-techinfo/

*** Available estimates indicate high loadings, but dependent on fertiliser use.
**** Assume 10% of estimated N load.

Additional Inputs	**N**	**tN/yr**	**P**	**tP/yr**
Bells Island Oxidation Ponds	NRSBU 2008 median = 224 kgN/day	81.8	NRSBU 2008 median = 64 kgP/day	23.4
Bells and Rabbit Island Biosolids Disposal	Assume equivalent load to oxid. ponds (NRSBU annual report) and 20% loss from land	16.4	Assume equivalent load to oxid. ponds (NRSBU annual report) and 20% loss from land	4.7
TOTAL	27% of total N input (Method 1): 16% of total N input (Method 2):	98.2	27% of total P input (Method 2):	28.1

SUPPORTING INFORMATION: ESTIMATION DETAILS - EUTROPHICATION: PREDICTED MACROALGAL GROWTH

Waimea Inlet: Predicted Macroalgal Growth

Nitrogen is generally the nutrient controlling the growth of nuisance algae in coastal and estuarine waters. The current estimated nitrogen load to the Waimea Inlet (533 tonnes N/yr - Table 9) results in an areal N loading to the estuary of 30mg.m^{-2}.d^{-1} which is below the range where nuisance macroalgal conditions in NZ tidally dominated estuaries generally begin to appear (Figure 5). Consequently, widespread growths of nuisance macroalgae are not expected within the estuary, and were not found during a recent monitoring survey (Appendix 2) .

Although widespread nuisance growths are not found in the estuary itself, the Waimea River and smaller streams entering the estuary have the potential to cause localised problems of nuisance algal and plant growths on the river bed before they are diluted by tidal flows if nitrogen and phosphorus concentrations are sufficiently elevated.

Figures 6 and 7, and Table 10, summarise monitoring data collected by TDC for many of the small tributaries entering the Waimea Inlet, as well as the dominant input to the estuary from the Waimea River. Results show both nitrogen and phosphorus at mean concentrations which exceed nuisance algal growth guidelines, although data are limited for all but the Waimea River. Nitrogen exceeds periphyton guidelines for all waterways (often by a substantial margin), while phosphorus is elevated to problem levels in many locations. As a consequence, nuisance algal growth is likely to be a localised problem within, and around the mouths of, most freshwater flows that discharge into Waimea Inlet.

A notable feature of the results is that the Waimea River concentrations are low relative to the other smaller streams. This reflects extensive dilution of nutrients in the Waimea River with clean water from the upper catchment (dominated by native and plantation forest). Consequently, while the total loads from the smaller waterways are substantially lower than the Waimea, because they are more concentrated (less diluted), they may cause more significant localised problems in the estuary.

Figure 5. Areal N loads and presence of nuisance macroalgal conditions, NZ estuaries.

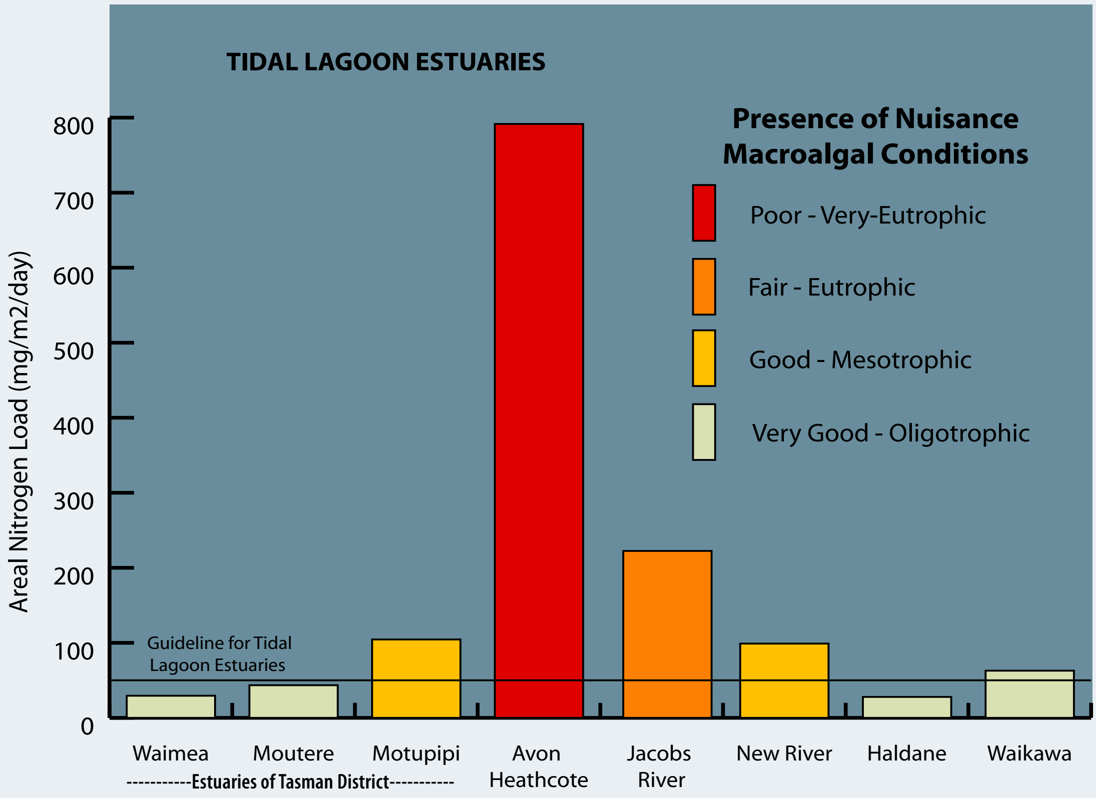


Figure 6. River and stream nitrate concentrations and guideline criteria.

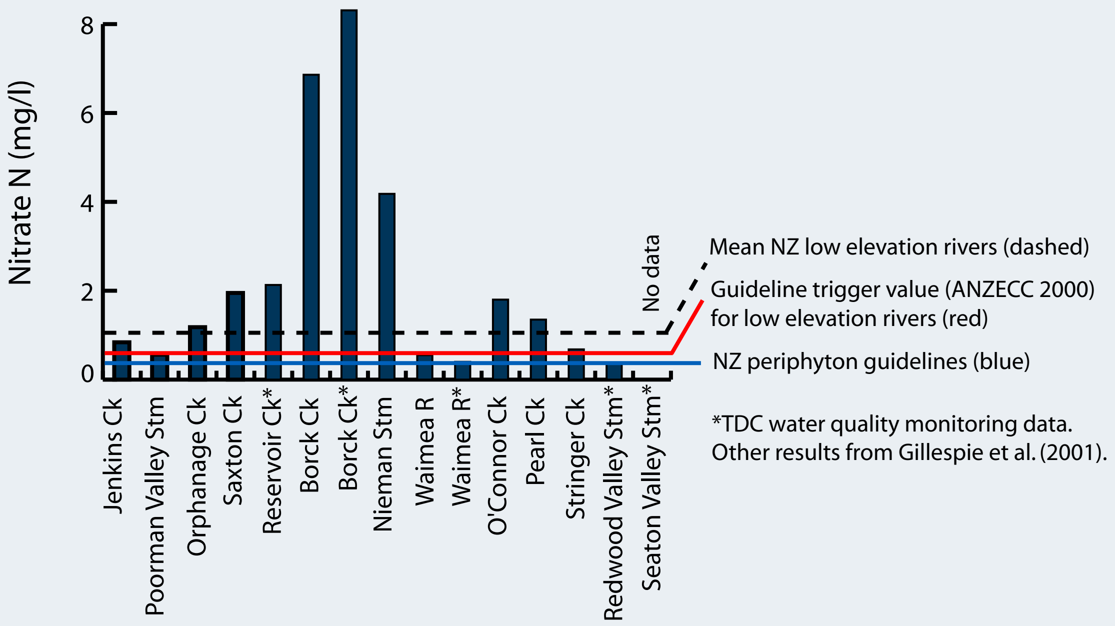
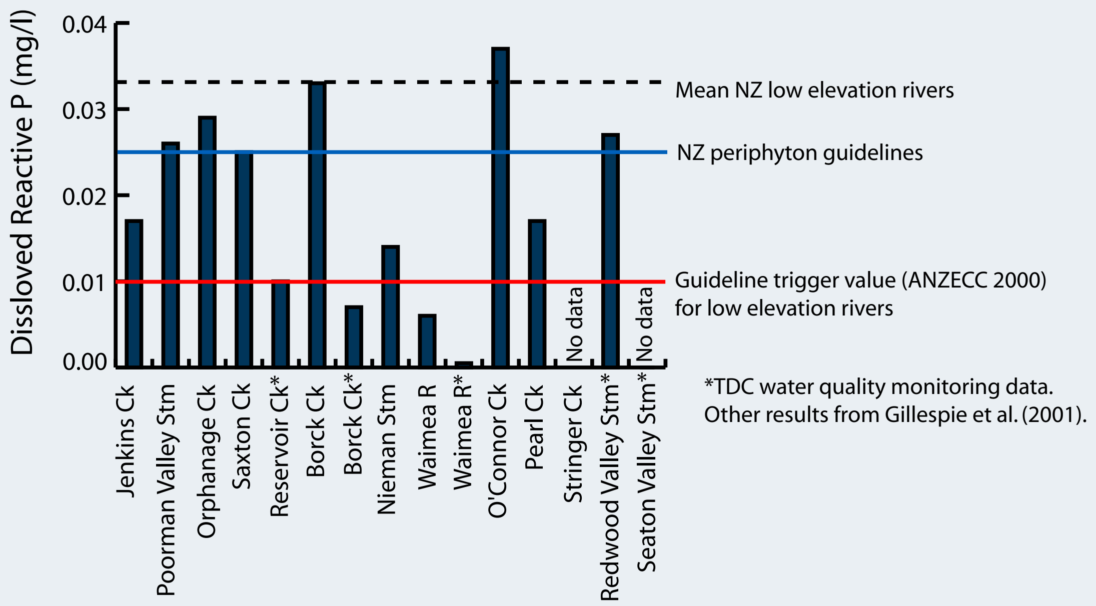


Figure 7. River and stream dissolved reactive phosphorus concentrations and guideline criteria.



SUPPORTING INFORMATION: ESTIMATION DETAILS - EUTROPHICATION: WATER QUALITY DATA

Table 10. Summary of available water quality data (means) from the Waimea River and smaller streams discharging to Waimea Inlet.

See Figure 3 for site locations.	Mean Flow	Suspended Solids	Black Disk Clarity	Total Nitrogen (N)	Total Phosphorus (P)	Dissolved Reactive P	Dissolved Inorganic N	*E. coli*
	m^3/s	g/m^3	m	g/m^3	g/m^3	g/m^3	g/m^3	median/100ml
Jenkins Creek	0.05	7		1.41	0.04	0.017	0.84	440**
Poorman Valley Stream	0.12	4		0.79	0.04	0.026	0.56	362**
Orphanage Creek	0.09	12		1.86	0.07	0.029	1.18	171**
Saxton Creek	0.05	12		2.51	0.08	0.025	1.95	246**
Reservoir Creek*	0.01		1.9	2.99	0.06	0.01	2.13	90
Borck Stream	0.07	7		7.89	0.12	0.033	6.86	132**
Borck Stream*	0.10		2.6	8.30	0.012	0.007	8.31	140
Nieman Creek	0.11	3		4.80	0.03	0.014	4.18	296**
Waimea River	20.37	5		0.70	0.02	0.006	0.55	28**
Waimea River*			7.7	0.51	0.02	0.0005	0.4	30
Pearl Creek	0.21	2		2.63	0.06	0.037	1.8	84**
O'Connor Creek	0.26	6		1.88	0.06	0.017	1.35	567**
Redwood Valley Stream*			2.1	1.01			0.68	125
Stringer Creek	0.01	17		1.33	0.1	0.027	0.36	278**
Seaton Valley Stream*			0.7					218
NZ Low Elevation Rivers (summarised data)[1]			1.3 mean	1.71 mean	0.07 mean	0.033 mean	1.08 mean	664 median/100ml
Guideline trigger levels (ANZECC 2000) for low elevation rivers.				0.614	0.033	0.01	0.444	<126 median/100ml
Freshwater Recreational Guidelines[2]								Alert 260 Action 550
NZ Periphyton Guidelines[3]						0.026	0.295 SIN	

Data from Gillespie et al. 2001. Includes 2 low flow and 3 rain affected monitoring events collected June 1997-November 1998.
*TDC monitoring data supplied by Trevor James. Covers variable periods of low flow sampling. (Borck, 2009, n=3; Reservoir, 2000-09, n=26; Redwood, 2006-09, n=10; Seaton Valley, 2006-09, n=16, Waimea, 2000-09, n=26)
** Indicates value converted from *Enterococci* data. Conversions are based on approximate conversion of *Enterococci* to faecal coliforms using the power expression in MfE/MoH(2003:H12) and assuming that 90% of the faecal coliform group are *E. coli*

[1] Results from NZ Low Elevation Rivers (Larned et al. 2004). Low-elevation rivers are considered to be those draining catchment areas where ≥50% of the rainfall occurs at elevations less than 400m above sea level (Snelder & Biggs 2002).

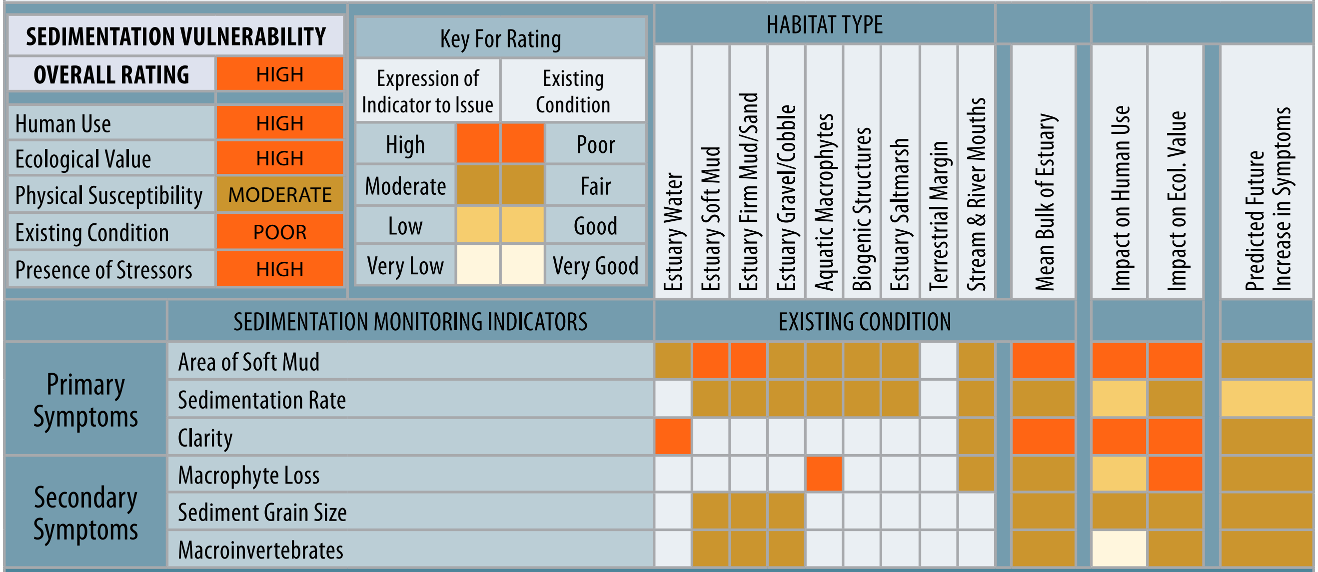
[2] 260 *E. coli* = Alert threshold for single sample. 550 *E. coli* per 100 mL = Action threshold for single sample.
Source; Microbiological Guidelines for Recreational Water Quality (Ministry for the Environment and Ministry of Health, 2003)

[3] DRP< 0.026 mg/L (NZ Periphyton Guidelines (Biggs, 2000)) for 20-day accrual period.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.2 SEDIMENTATION

The approach used to assess the existing condition and susceptibility to sedimentation is similar to that used for "eutrophication" but lacks the more rigorous foundation used to determine overall ratings of eutrophication. Instead, expert opinion and available information are used to provide likely ratings.



SEDIMENTATION VULNERABILITY	
OVERALL RATING	HIGH
Human Use	HIGH
Ecological Value	HIGH
Physical Susceptibility	MODERATE
Existing Condition	POOR
Presence of Stressors	HIGH

Key For Rating			
Expression of Indicator to Issue			Existing Condition
High	🟧	🟧	Poor
Moderate	🟫	🟫	Fair
Low	🟨	🟨	Good
Very Low	⬜	⬜	Very Good

	SEDIMENTATION MONITORING INDICATORS	Estuary Water	Estuary Soft Mud	Estuary Firm Mud/Sand	Estuary Gravel/Cobble	Aquatic Macrophytes	Biogenic Structures	Estuary Saltmarsh	Terrestrial Margin	Stream & River Mouths	Mean Bulk of Estuary	Impact on Human Use	Impact on Ecol. Value	Predicted Future Increase in Symptoms
		HABITAT TYPE												
		EXISTING CONDITION												
Primary Symptoms	Area of Soft Mud	🟫	🟧	🟧	🟫	🟫	🟫	🟫		🟫	🟧	🟧	🟧	🟫
	Sedimentation Rate		🟫	🟫	🟫	🟫	🟫	🟫		🟫	🟫	🟨	🟫	🟨
	Clarity	🟧								🟫	🟧	🟧	🟧	🟫
Secondary Symptoms	Macrophyte Loss					🟧				🟫	🟫	🟨	🟧	🟫
	Sediment Grain Size		🟫	🟫	🟫						🟫	🟫	🟫	🟫
	Macroinvertebrates		🟫	🟫	🟫						🟫	⬜	🟫	🟫

EXPRESSION OF SEDIMENTATION CONDITIONS

Area of Soft Mud	Sediment inputs to the estuary are estimated in Table 10. Soft muds occupy 55% of the estuary intertidal area, particularly in the upper reaches and sheltered arms of the estuary where it overlies sand, gravel and cobble, along the banks of low tide channels, and where inputs are trapped, for example upstream of the Bells Island causeway. The estuary has a Condition Rating of POOR (>15% of the estuary is soft mud) - Robertson and Stevens (2009). A reported increase in soft mud (445ha) from 1999 to 2006 (Clarke et al. 2008) suggest the soft sediment area is increasing, although recent field observations indicate increases may be smaller than reported. Soft mud area gives a HIGH level of expression.
Sedimentation Rate	Sedimentation rates over buried plates measured from 2008-2009 show little recent deposition (0-1mm) however monitoring has only just commenced and more time is needed to establish a meaningful record. Vertical profiles in the middle estuary indicate net sedimentation rates in the order of 6-8mm/year for the past 150 years, a POOR condition rating (sedimentation rate 5-10mm/yr). Overall a MODERATE level of expression is applied.
Clarity	Estuary water clarity has not been regularly measured but field observations suggest that it is likely to be in the low category (0-1m) most of the time. During high flows clarity is reduced, and fine sediments are quickly mobilised from intertidal sediments during rain events. Wind generated waves are common in the estuary and these resuspend sediment. Overall a HIGH level of expression is attributed to sediment associated clarity symptoms. Sediment related light reduction to macrophytes in stream mouths (e.g. *Ruppia*) is considered unlikely to be a significant issue as clarity, based on field observations and TDC stream monitoring data (Table 9), generally exceeds stream depth.
Macrophyte Loss	Macrophytes may be lost from the estuary due to sediment related physical smothering or light limitation. For example, poor clarity will limit seagrass to areas where light penetration is sufficient to support growth, sediment deposition on leaves will reduce photosynthetic efficiency, and high sediment deposition may bury plants. The condition rating for seagrass area in the estuary is POOR (Robertson and Stevens 2009), and reported seagrass losses coincide with an increase in the area of soft mud (Clarke et al. 2008). Therefore a HIGH level of expression is assumed although recent observations indicate that actual seagrass losses may be less than reported. Stream mouth macrophyte loss is unknown so is rated MODERATE.
Sediment Grain Size	Fine scale monitoring (results in Robertson and Stevens 2009) indicates an increase in mud content in lower intertidal firm muddy sand sites representative of the dominant intertidal habitat in the estuary. The presence of very fine grained glacial silt in the catchment exacerbates issues of muddiness and clarity. Overall a MODERATE level of expression is applied.
Macroinvertebrates	Increased muddiness changes the types of animals found in the estuary sediments. Macro-invertebrate monitoring has shown a slight change in community composition from unpolluted in 1988 (Davidson and Moffat 1990) to slightly polluted in 2001 and 2006 (Robertson and Stevens 2009). This is thought to reflect measured increases in muddiness and to a lesser extent, enrichment. The absence of a baseline of natural variation means the cause is tentative. A MODERATE level of expression is assumed.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.2 SEDIMENTATION (CONT.)

EXPRESSION OF SEDIMENTATION CONDITIONS

OVERALL EXPRESSION OF SEDIMENT CONDITIONS	Combining the MODERATE-HIGH of the three primary symptoms (taking area of cover into account), and MODERATE, the highest rating of the secondary symptoms, gives an overall rating of HIGH. There is substantial evidence of existing sedimentation symptoms in the estuary.
PHYSICAL SUSCEPTIBILITY (DILUTION AND FLUSHING POTENTIAL)	The capacity of an estuary to either flush or dilute and spread incoming sediment determines its physical susceptibility. Generally, well flushed estuaries with a large area have the greatest potential for assimilation. Based on the relatively large intertidal area of the estuary (2793ha) a MODERATE capacity to spread sediment inputs is applied. Combined with HIGH flushing within the estuary (Section 2) a MODERATE overall susceptibility to sediment is assumed.
INFLUENCE OF STRESSORS	Table 5 identified the following stressors contributing to sedimentation symptoms: sediment inputs from catchment run off and point source discharges, climate change, causeways and floodbanks, reclamation, invasive weeds, and flapgates. Of these, the key stressor is sediment inputs from catchment runoff, with the Bells Island WTP point source discharge a relatively minor contributor (see estimation details on following page). Because of the very fine collidial nature of the sediment (sourced from glacial silts), the impact of sediment is strongly expressed. For example, tightly packed sediments restrict re-oxygenation from tidal flows (evident in sediment oxygen levels close to the surface - see Appendix 3) and fine silts are readily suspended and contribute to poor water clarity in the estuary. Symptoms of excessive sedimentation are moderated by the vast bulk of inputs (estimated at 91%) being sourced from the Waimea River (Table 10). As a consequence of the relatively direct flow path to the eastern entrance of the Inlet, much of the river-borne sediment is expected to be carried into the lower estuary where rapid tidal flushing will see sediment transported and discharged to Tasman Bay. However, in the middle estuary of both the western and particularly the eastern arms, sedimentation is likely to be encouraged in areas where flushing is less elevated. In addition, causeways, Pacific oyster beds, and macroalgal growths all contribute to the trapping of sediment within the estuary. Field observations show widespread fine sediment present in estuary low tide channels. The streams that discharge into the Waimea Inlet generally do not appear muddy, have good clarity, and are dominated by gravels and cobbles. However, the available suspended solids data (Table 7), and field observations (Figure 8) indicate concentrations from these sources can be elevated at times. The current sediment influence on the estuary is rated as HIGH based on area of soft mud, and estimated sedimentation rate. Climate change is expected to increase runoff and therefore sediment inputs. Causeways, floodbanks, and flapgates exacerbate sedimentation symptoms primarily by creating sediment traps, or reducing flushing flows, with natural assimilation reduced by the reclamation, particularly of estuarine saltmarsh. Flood banks limit estuary area but concentrate flushing flows in streams and rivers. The invasive weed *Spartina*, previously planted in the estuary to trap sediment, has now been eradicated with the decaying root systems releasing trapped sediment to the estuary. Any increase in sediment inputs is likely to add to the existing poor condition for this issue. Climate change effects - sea level rise and increased rainfall, while difficult to predict with any certainty, are expected to further reduce saltmarsh (and sediment trapping capacity), increase runoff, and increase shoreline erosion.
EFFECT ON HUMAN USES	The existing impact on human uses of the estuary from sedimentation symptoms is significant. Large areas of soft mud create a physical deterrent to people walking in the estuary, and lowered water clarity impacts on swimming, fishing and aesthetic values. Fine muds decrease sediment oxygenation and contribute to sediment enrichment, although enriched black and smelly sediments are not currently widespread.
EFFECT ON ECOLOGICAL VALUES	The presence of large and increasing areas of muddy sediments are likely to lead to major and detrimental ecological changes (e.g. loss of seagrass, shift in macroinvertebrate community, decreased biodiversity), and a reduction in habitat diversity. For example, soft muds now cover many areas of cobble and gravel in the upper tidal reaches, while sandy intertidal flats, a key bird foraging habitat, have been overlain by soft muds in many parts of the estuary. Soft mud dominated areas are likely to have direct adverse impacts on filter feeding bivalve shellfish (e.g. cockles and pipis), seagrass beds, and sediment dwelling animals, which all provide important food resources to the many birds using the estuary.
FUTURE INFLUENCE	Future sediment loads are likely to increase. The main source of sediment to the estuary is currently from non-point catchment runoff during rain events. Influence of climate change will likely increase intensity of storm events; therefore increase sediment runoff. Pressure to reduce catchment sediment yields from agricultural and urban landuse is a national priority at present. Given the past inaction in this area, and ongoing population expansion, a conservative approach is recommended of assuming that the future sediment load remains the same or increases. The response to the estuary to further inputs is likely to be moderate because of its already very muddy state.

SUPPORTING INFORMATION: ESTIMATION DETAILS - SEDIMENTATION: SOURCES AND LOADS

Waimea Inlet: Sediment Sources and Loads

Catchment sediment mass load estimates are: 120,700 tonnes SS/yr from 902km^2 catchment = 134 t/km^2/yr (WRENZ, data in Table 11). Bells Island Wastewater Discharge: Median 30gSS/m^3 and 13,767 m^3/d discharge = 30 x 13,767 x 365 = 151 T SS/yr.

If all the predicted 120,700 tonnes of catchment sediment runoff deposited in intertidal soft mud areas, sediment levels would increase at a rate of ~8mm/yr. However a lower rate is expected because the Waimea River (estimated source of 91% of sediment inputs) carries most of the sediment directly into the lower eastern arm of the estuary where tidal flows will flush a large proportion to Tasman Bay. This flushing is evident in the turbid plumes seen at the estuary mouth following floods or freshes in the streams and rivers, or on the outgoing tide following wind generated wave re-suspension of sediment. The fine glacial silts present in the catchment runoff (easily suspended and slow to settle) mean clarity within the estuary waters is low, and pore spaces within the intertidal sediments are tightly packed, limiting water exchange and sediment oxygenation.

Sediment rate monitoring was established by TDC in the estuary in 2008 to measure future inputs. Past sedimentation has been estimated in intertidal soft mud areas by digging vertical profiles down to underlying sands. Based on the presence of coarse sands at 1.0-1.2m depth, and assuming that the estuary was sandy prior to European settlement, net sedimentation rates are estimated in the order of 6-8mm/year for the past 150 years. Allowing for sediment export from the estuary, this estimated deposition rate indicates net annual sediment inputs may be higher than estimated by WRENZ.

The source of most sediment is expected to be from exotic forestry (32% of the catchment), earthworks for subdivisions and land development, and intensively developed high productivity grassland, horticulture (including vineyards) and rotational cropping (~20% of the catchment). This is based on existing landuse loadings derived from the Motueka catchment (Young et al. 2005) which indicate the lowest loadings are from native bush catchments, slightly greater for plantation forest, and much greater for pasture. The highest inputs are likely to come during periodic disturbance (e.g. subdivision, roadworks, horticultural development, forest harvesting), sediment either directly washing into the estuary or accumulating in river and stream beds where it is released following floods. For example, studies of forest removal impacts (see following text box) have shown that major problems with water quality in plantation forest streams usually only become evident after logging, where increased run-off of sediment and nutrients may occur, and/or associated with erosion from unsealed roads (Harding et al. 2000, Coker et al. 1993). High losses are also known from historical horticultural land development around the Research Orchard Road area - Trevor James TDC). Another key input is expected from river bed erosion during floods. Both will result in pulses of sediment entering the estuary.

Clark et al. (2008) suggested the release of sediments from the decaying root systems of poisoned *Spartina* as another potentially significant source. Calculations based on the total area of *Spartina* (~100ha), and the likely average sediment depth around root systems (0.5m), give ~50,000T of sediment available for release. Observations show a gradual eroding of this sediment over ~10 years (=5,000T/yr, ~5% of the annual load), resulting in a potential annual soft mud increase of 3.2mm for 10 years on top of other catchment inputs. Therefore, while this source is likely to have contributed to localised muddiness, it accounts for only a small portion of the sediment inputs to the estuary.

Forest Removal Impacts The most serious consequences of forest removal on water quality in New Zealand are related to increased supply of sediment to streams after logging and road building. Clearfelling and burning of small catchments near Reefton during a relatively dry period, raised the total sediment yields (t/km2/yr) from an estimated 33 for undisturbed forest, to 47 in a cable logged catchment with no tracks and 264 in a skidder-logged catchment over the first two years after treatment. Streams flowing from undisturbed indigenous forest were clear (<20 mg/L suspended sediment) about 97 per cent of the total time. Over the first two years after clearfelling and burning, streams draining the treated catchments were clear only 88 per cent of the time (O'Loughlin et al. 1980).

Figure 8. Fine colloidal suspended sediment in a small stream flowing to the western arm of Waimea Inlet.

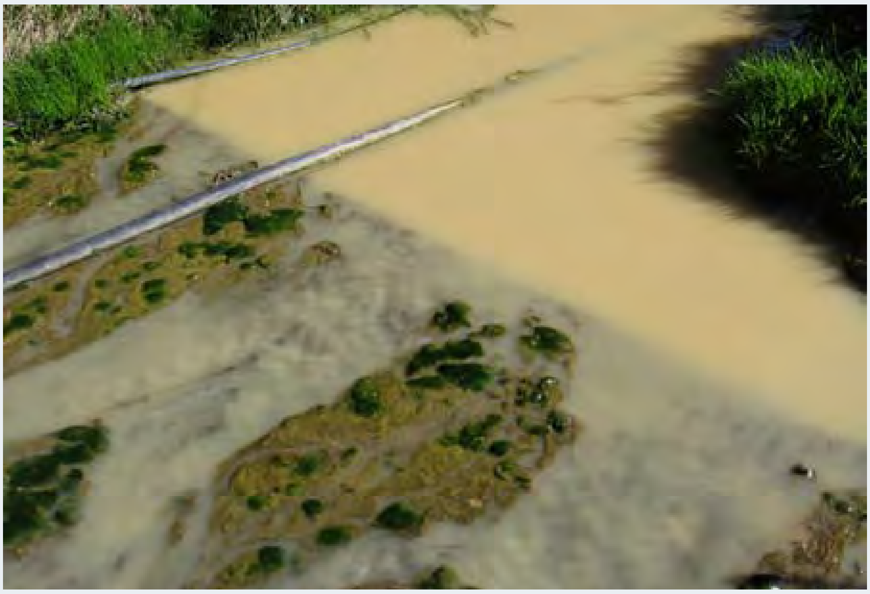


Table 11. Estimation of Total Sediment Loads from specified Waimea Inlet Stream and River Catchments.

Waimea Inlet Catchment Area: 902.4 km^2 | WRENZ Estimated Sediment Yield: 120.7 KT/y

Data source: WRENZ model (NIWA) : http://wrenz.niwa.co.nz/webmodel/

Inputs to Waimea Inlet - Eastern Arm	Catchment Area (km^2)	Estimated Sediment Yield (KT/y)	% of total	Inputs to Waimea Inlet - Western Arm	Catchment Area (km^2)	Estimated Sediment Yield (KT/y)	% of total
Back Beach Stream	0.6	0	0.0	O'Connor Creek	44.4	4.2	3.5
Parkers Road Stream	2.1	0.2	0.2	Research Orchard Road	0.4	0	0.0
Jenkins Creek	7.5	0.8	0.7	Maisey's Road	0.6	0.1	0.1
Poorman Valley Stream	6.9	0.6	0.5	Maisey's Road East	0.6	0	0.0
Nayland Stream	2.3	0.2	0.2	Westdale Road	1.1	0.1	0.1
Orphanage Creek	9.4	0.8	0.7	Hoddy Road	0.5	0	0.0
Saxton Creek	6.6	0.5	0.4	Stringer Creek East	3.6	0.3	0.2
Reservior Creek	3.5	0.2	0.2	Stringer Creek	4.0	0.3	0.2
Jimmy-Lee Creek (Beach Rd)	3.4	0.2	0.2	Bronte Road	0.8	0	0.0
Borck Stream	18.7	1.2	1.0	Apple Valley Stream	3.3	0.3	0.2
Neiman Creek	1.7	0.1	0.1	Dominion Road	4.6	0.4	0.3
Waimea River	770.2	109.7	90.9	Seaton Valley Road	4.5	0.4	0.3
Pearl Creek	1.7	0.1	0.1				
Total	835.2	114.6	94.9%	Total	68.4	6.1	5.1

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.3 DISEASE RISK

The approach adopted to assess the existing condition and susceptibility to disease risk symptoms uses a combination of expert opinion and available information to provide likely ratings.

DISEASE RISK VULNERABILITY	
OVERALL RATING	MOD-HIGH
Human Use	HIGH
Ecological Value	HIGH
Physical Susceptibility	MODERATE
Existing Condition	MODERATE
Presence of Stressors	MODERATE

Key For Rating			
Expression of Indicator to Issue			Existing Condition
High	🟥	🟥	Poor
Moderate	🟧	🟧	Fair
Low	🟨	🟨	Good
Very Low	⬜	⬜	Very Good

		HABITAT TYPE												
		Estuary Water	Estuary Soft Mud	Estuary Firm Mud/Sand	Estuary Gravel/Cobble	Aquatic Macrophytes	Biogenic Structures	Estuary Saltmarsh	Terrestrial Margin	Stream & River Mouths	Mean Bulk of Estuary	Impact on Human Use	Impact on Ecol. Value	Predicted Future Increase in Symptoms
	DISEASE MONITORING INDICATORS	EXISTING CONDITION												
Primary Symptoms	Faecal Indicators - Bathing water	🟧								🟧	🟧	🟨	🟨	🟧
	Faecal Indicators - Shellfish	🟥								🟧	🟥	🟥	🟨	🟧
	Faecal Indicators - Stock drinking water									🟧	🟨	🟨	🟨	🟧

EXPRESSION OF DISEASE RISK CONDITIONS

Faecal Indicators - Bathing water	Bathing water quality, monitored regularly in the estuary by TDC since 2002, indicates the estuary is generally safe for swimming at the monitored bathing sites under base flows (Table 12). Risk conditions are present following rainfall events with elevated faecal indicators in the Waimea River correlating with elevated levels at bathing water sites. Evaluation of the magnitude of the risk is limited by very few samples being collected during rain or flood events. Several freshwater streams entering the estuary (e.g. Waimea, Reservoir, Redwood Valley, Jenkins, Poormans) have been monitored quarterly for several years. Coordinated sampling of 9 streams and the Waimea River under base flow and rain influenced conditions (Gillespie et al. 2001) identified a localised disease risk existed in many of the smaller tributary streams entering the estuary under both base flow and rain influenced conditions (Figure 9). Waimea River water quality was consistently better than tributary streams, likely to be reflecting greater dilution with clean water from the forested upper catchment. Regular low flow river monitoring of the Waimea River by TDC shows a low disease risk from the river outside of rainfall events. Gillespie and Asher (1999) concluded that the Bells Island WTP effluent, discharged to the lower estuary on the outgoing tide, did not pose a risk for bathing outside of the 500m effluent mixing zone. Overall a MODERATE level of expression is attributed to symptoms of exceedance of bathing guidelines.
Faecal Indicators - Shellfish	Edible shellfish (pipis, cockles, mussels, oysters) are present in the estuary. Most are located in the sandier parts of the well flushed lower estuary, although oysters are present throughout the estuary where substrate has allowed beds to establish. Bathing water monitoring results indicate faecal indicators in water are generally at low concentrations under low flow conditions, but are elevated following rain, inputs particularly concentrated around smaller tributaries entering the estuary. Because shellfish filter-feed and concentrate faecal bacteria and pathogens from the water column, it is likely that shellfish criteria will often be exceeded. Gillespie and Asher (1999) reported faecal indicator bacteria levels in shellfish at sites throughout the estuary had concentrations unsuitable for human consumption at different times. Based on the bathing water data, impacts from the Bells Island WTP discharge are likely to be confined to localised areas downstream of the outfall. Shellfish monitoring as part of the assessment of effects of biosolids disposal adjacent to Rough and Rabbit Islands (Gillespie and Asher 2004) showed highly variable faecal coliform concentrations in shellfish (cockles), with values either marginal or unacceptable for human consumption according to MOH guidelines. These results were not considered to be biosolids-related as similar and higher concentrations had been reported for a variety of other sites in Waimea Inlet. Overall a HIGH level of expression is attributed to exceedance of shellfish guidelines in estuary water. A MODERATE rating is applied to river and stream mouths because few shellfish are present in these areas.
Faecal Indicators - Stock drinking water	Sampling of tributary streams and the Waimea River under base flow and rain influenced conditions (Gillespie et al. 2001) indicate stockwater drinking guidelines (1000 faecal coliforms/100mls, ANZECC 1992) were exceeded in several locations on a few occasions. Because of its saltiness and poor accessibility, the estuary itself is unlikely to be used for stockwater. An overall LOW level of expression is attributed to symptoms of exceedance of stockwater guidelines.

OVERALL EXPRESSION OF DISEASE RISK CONDITIONS	Combining the LOW, MODERATE and HIGH ratings of the three primary symptoms (taking area of usage into account) gives an overall rating of MODERATE-HIGH. There is evidence of existing disease risk symptoms in the estuary water affecting human use of the estuary.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.3 DISEASE RISK (CONT.)

EXPRESSION OF DISEASE RISK CONDITIONS

PHYSICAL SUSCEPTIBILITY (DILUTION AND FLUSHING POTENTIAL)	The combination of low dilution and high flushing (Section 2) gives a MODERATE overall susceptibility to disease risk. This means the Waimea Inlet has a strong ability to flush faecal bacteria but not to dilute it. The estuary may also have localised areas where flushing is poor and faecal bacteria are elevated. As the Bells Island WTP discharge only occurs on the outgoing tide, tidal flushing confines impacts from this source to the lower estuary.
INFLUENCE OF STRESSORS	Table 5 identified the following stressors contributing to disease risk symptoms: pathogen inputs from catchment run off including from bio-solids disposal areas on Rabbit and Bells Islands, point source discharges (primarily the Bells Island WTP effluent discharge), and to a lesser extent, climate change and margin grazing. The source and significance of different faecal bacterial loads to Waimea Inlet from the catchment and Bells Island WTP has been estimated (Table 13). The highest export per hectare is from dairy and sheep and beef landuse (both 1 x 10^{11} FC's per ha/yr). Because sheep and beef landuse occupies a larger area than dairying (Appendix 5), it is the major source of runoff of faecal bacteria and disease risk to the estuary. The total faecal coliform load from the catchment is estimated at 2.2 x 10^{15} faecal coliforms per year, with the contribution from the Bells Island Oxidation Pond discharge (1.3 x 10^{14} FC's/yr) contributing ~6% of the estimated total. Table 14 estimates the total FC loadings to the estuary based on monitoring data in Gillespie et al. (2001), and from the Bells Island WTP 2008 NRSBU annual data summary. The estimates predict 17% of the total FC inputs enter the estuary from small streams spread throughout the estuary, despite these only contributing 5.6% of the flow, with the Waimea River contributing 47% of the load (92.7% of flow), and the Bells Island WTP discharge 36% (1.7% of flow). Under rain influenced conditions, the contribution from the Waimea River increases to 75% of the load, and drops to 14% under dry conditions. The contribution of the Bells Island WTP (36%) estimated above is relatively high compared to inputs based on landuse estimates (6%). It is likely that Gillespie's data underestimate total runoff inputs because they do not include flood estimates. Gillespie et al. (2001) measured *Enterococci* concentrations in the Waimea River and many of the smaller streams entering the estuary under base flow and rainfall influenced conditions. Results showed *Enterococci* concentrations in small streams were elevated well above the concentrations measured in the Waimea River at the same time, indicating that the smaller streams are a significant local source of bacteria. This pattern was present under both base flow and rainfall influenced conditions (Figure 9). No data are available on flood flow bacterial loadings for the Waimea Inlet but based on sampling in the Aorere catchment (Nottage 2001) and data from the Motueka catchment (e.g. Davies-Colley et al. 2008) loadings are likely to be substantial when flood inputs are included in estimates, and therefore the influence of catchment inputs is predicted to be substantial during flood events (Table 15). The major conduit of faecal bacteria to the estuary is assumed to be from the Waimea River during rain events because of its dominating flow (91%). Climate change is expected to increase runoff and therefore inputs of disease causing organisms. Another very minor stressor is the direct input of effluent from animals grazing in the estuary and margins. Because monitoring data seldom includes rain or flood events, the influence of faecal bacteria on the estuary was estimated based on existing symptoms (previous page). A MODERATE-HIGH faecal bacteria influence rating for the estuary was applied. This rating is based on occasional exceedance of estuary bathing water guidelines (commonly linked to rainfall events), and the regular exceedance of shellfish guidelines in estuary water meaning shellfish are unlikely to be safe for human consumption.
EFFECT ON HUMAN USES	The major existing impact on human uses of the estuary is the risk of faecal bacterial or pathogen related illnesses to people collecting shellfish for consumption, bathing near the beach, boating, canoeing, fishing, playing in the sand and paddling. A minor risk related to stock drinking water is present. There are no known reports of waterborne disease to humans occurring through swimming or eating shellfish and no known reports of waterborne disease to stock through drinking from the estuary.
EFFECT ON ECOLOGICAL VALUES	The presence of faecal bacteria are not expected to influence ecological values.
FUTURE INFLUENCE	Future disease risk is predicted to increase. The main source of faecal bacteria to the estuary is currently from non-point catchment runoff during rain events. Pressure to reduce catchment faecal bacteria yields from agricultural and urban landuse is a national priority at present. But given the past inaction in this area, and ongoing population expansion, a conservative approach is recommended of assuming that the future faecal bacterial load remains the same or increases. Population pressure will increase loading on the Bells Island WTP. This treatment facility has significantly improved effluent quality discharged to the estuary, but the operational capacity of the facility will need to match increasing population demands.

SUPPORTING INFORMATION: ESTIMATION DETAILS - DISEASE RISK: SOURCES AND LOADS

Waimea Inlet: Bathing water monitoring data and guidelines

Table 12 presents results for the 2007/08 bathing season (representative of the overall monitoring period) from 3 sites within the estuary and the lower Waimea River.

The faecal indicator bacteria, *E. coli* (*Escherichia coli*) is commonly used to assess human disease risk. It can both cause disease and indicate the presence of other disease causing organisms (e.g. *Cryptosporidium* and *Campylobacter*). *Enterococci* are used to indicate disease risk in marine waters. Ministry for Environment (2003) and ANZECC (2000) Guidelines for freshwater (and estuarine) and marine water contact recreation are summarised in Table 13.

Results show *E. coli* in the Waimea River ranged between <10->2000 (median 40) cfu/100ml and exceeded alert levels on 4 occasions. In the estuary, *Enterococci* concentrations ranged from <10->2000 (median <10) and exceeded alert criteria in 5 samples. On all occasions, high estuary readings coincided with elevated Waimea River readings, and elevated readings corresponded to rainfall events.

Table 12. Summary of representative bathing water monitoring results in Waimea River and Inlet.

TDC Bathing Water Monitoring Data	Waimea River SH60 (*E. coli*)	Best Island (*Enterococci*)	Rabbit I. (Back Beach) (*Enterococci*)	Mapua (Leisure Park) (*Enterococci*)
28-Nov-2007	40	-	<10	<10
4-Dec-2007	<10	<10	<10	10
11-Dec-2007	531	75	30	<10
13-Dec-2007	40	-	-	<10
18-Dec-2007	>2000	>2000	1700	<10
21-Dec-2007	111	10	150	-
27-Dec-2007	40	10	<10	30
3-Jan-2008	30	<10	<10	<10
10-Jan-2008	40	-	-	<10
8-Jan-2008	>2000	150	40	<10
15-Jan-2008	30	30	<10	<10
22-Jan-2008	659	75	<10	207
29-Jan-2008	10	<10	<10	<10
5-Feb-2008	20	<10	<10	<10
13-Feb-2008	40	10	<10	<10
19-Feb-2008	10	<10	<10	10
26-Feb-2008	53	<10	<10	<10
Median	40	<10	<10	<10
Minimum	<10	<10	<10	<10
Maximum	>2000	>2000	1700	207
ANZECC 2000: seasonal median should not exceed: (based on minimum of 5 samples taken at regular intervals not exceeding 1 month, with 4 out of 5 samples containing <600FC/100 mL)	150 FC/100 mL (median)	35/100mL, (max. in any 1 sample 60-100/100mLs)		
MoH and MfE (2003) **Surveillance/Green Mode:**	No single sample greater than 260 *E. coli* cfu/100mL	No single sample greater than 140 *Enterococci*/100 mL		
Alert/Amber Mode:	Single sample between 260 and 550 *E. coli* cfu/100mL	Single sample greater than 140 *Enterococci*/100 mL		
Action/Red Mode:	>550 *E. coli* cfu/100mL	Two consecutive single samples greater than 280 *Enterococci*/100 mL (re-sample within 24 hours)		

Table 13. Estimated annual faecal coliform loads entering Waimea Inlet.

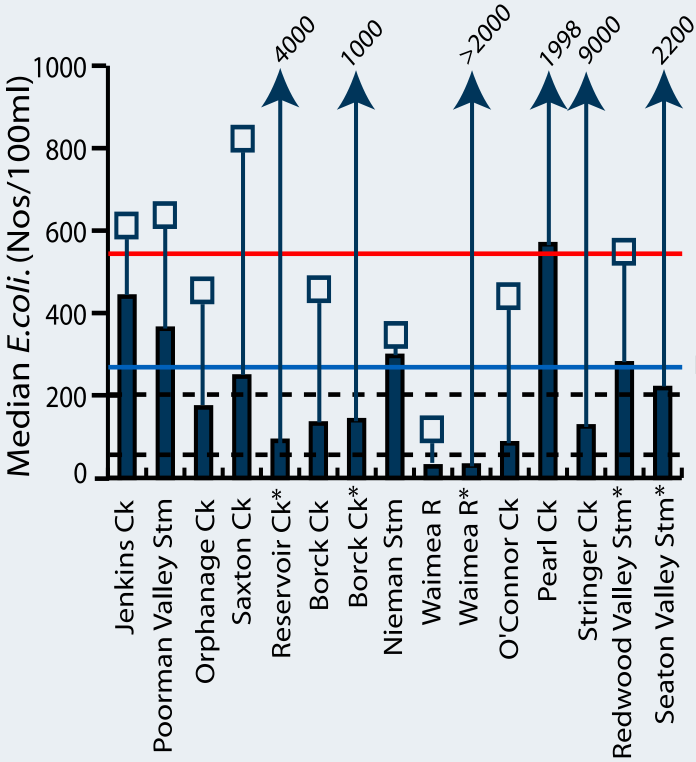
Calculations: Estimation of Waimea Catchment - Faecal Coliform or *E. coli* Loads (FC/yr)				
SOURCE	LOADING X AREA	LOADING	%	SOURCE OF LOADING ESTIMATE
Native Forest	Negligible	Negligible	Negligible	* Summary of loadings to Waikato farm waterways from Wilcock (2006). **Source E. coli/ha-pasture/yr** Surface runoff from dairy and sheep/beef 1 x 10^{11} Cattle crossings 3 x 10^{10} Drains (dairy) 3 x 10^{10} Oxidation ponds 2 x 10^{10} Runoff from laneways (20%) 9 x 10^{9} Direct deposition (cattle in stream) 5 x 10^{9} Runoff from grazed seeps and wetlands 1 x 10^{8}
Scrub	Negligible	Negligible	Negligible	
Exotic Forest	Negligible	Negligible	Negligible	
Horticulture	Negligible	Negligible	Negligible	
Dairy (runoff)*	1,766ha 1 x 10^{11} =	1.8 x10^{14} FC/yr	8%	
Dairy (drains)*	1,766ha x 3 x10^{10} =	5.3 x10^{13} FC/yr	2%	
Dairy Oxidation Ponds*	1,766ha x 2 x10^{10} =	3.5 x10^{13} FC/yr	2%	
Pasture* (e.g. sheep/beef)	17,823ha x 10^{11} =	1.8 x10^{15} FC/yr	81%	
Urban Areas**	2,507ha x 8.4 x 10^{9} =	2.1 x 10^{13}FC/yr	1%	Residential catchment 8.4 x 10^{9} cfu/ha/yr **Sinclair et al. (2008)
Bells Island Wastewater	See note at right	1.3 x 10^{14} FC/yr	6%	Bells Island Human Treated Wastewater (2008 NRSBU oxidation ponds discharge data): Median 2.5 x 10^{3} FC/100ml and 13,767 m^3/d discharge = 2.5 x 10^{3} x 10,000 x 13,767 x 365 = 1.3 x 10^{14} FC/yr.
TOTAL		2.2 x10^{15} FC/yr	100%	

Table 14. Estimated annual faecal coliform loads entering Waimea Inlet based on Gillespie et al. (2001) data.

Estimated Faecal Coliform inputs to Waimea Inlet based on data in Gillespie et al. 2001. Bells Island data NRSBU 2008 annual summary.	Rain Affected Flows						Base Flows						Totals		
	Rain Affected Flow m^3/s	Rain Affected Days	Volume Rain Affected Flow m^3/yr	Mean FC During Rain cfu/100ml*	Total Rain Affected Input FC/yr	Percent Contribution During Rain	Base Flow m^3/s	Base Flow Days	Volume Base Flow m^3/yr	Median FC During Base Flow cfu/100ml**	Total Base Flow Input FC/yr	Percent Contribution During Base Flow	Total Flow m^3/yr	Total Input FC/yr	Total % FC Contribution
Jenkins Creek	0.083	60	$4.32x10^{5}$	362	$1.57x10^{12}$	0.8	0.006	305	$1.53x10^{5}$	296	$4.52x10^{11}$	0.3	$5.85x10^{5}$	$2.02x10^{12}$	0.6
Poorman Valley	0.190	60	$9.86x10^{5}$	257	$2.54x10^{12}$	1.3	0.017	305	$4.47x10^{5}$	362	$1.62x10^{12}$	1.0	$1.43x10^{6}$	$4.16x10^{12}$	1.2
Orphanage Creek	0.148	60	$7.68x10^{5}$	309	$2.37x10^{12}$	1.2	0.015	305	$3.93x10^{5}$	171	$6.70x10^{11}$	0.4	$1.16x10^{6}$	$3.04x10^{12}$	0.9
Saxton Creek	0.074	60	$3.84x10^{5}$	546	$2.10x10^{12}$	1.1	0.009	305	$2.37x10^{5}$	246	$5.83x10^{11}$	0.4	$6.21x10^{5}$	$2.68x10^{12}$	0.8
Borck Stream	0.094	60	$4.89x10^{5}$	322	$1.57x10^{12}$	0.8	0.030	305	$8.02x10^{5}$	132	$1.06x10^{12}$	0.7	$1.29x10^{6}$	$2.63x10^{12}$	0.8
Nieman Creek	0.145	60	$7.53x10^{5}$	234	$1.76x10^{12}$	0.9	0.053	305	$1.40x10^{6}$	296	$4.14x10^{12}$	2.6	$2.15x10^{6}$	$5.90x10^{12}$	1.7
Waimea River	38.72	60	$2.01x10^{8}$	71	$1.43x10^{14}$	75.0	2.900	305	$7.64x10^{7}$	28	$2.15x10^{13}$	13.8	$2.77x10^{8}$	$1.64x10^{14}$	47.4
Pearl Creek	0.236	60	$1.22x10^{6}$	286	$3.49x10^{12}$	1.8	0.175	305	$4.62x10^{6}$	84	$3.89x10^{12}$	2.5	$5.85x10^{6}$	$7.38x10^{12}$	2.1
O'Connor Creek	0.408	60	$2.12x10^{6}$	523	$1.11x10^{13}$	5.8	0.050	305	$1.30x10^{6}$	1347	$1.76x10^{13}$	11.2	$3.42x10^{6}$	$2.87x10^{13}$	8.3
Stringer Creek	0.023	60	$1.18x10^{5}$	424	$4.99x10^{11}$	0.3	0.003	305	$6.59x10^{4}$	204	$1.34x10^{11}$	0.1	$1.84x10^{5}$	$6.33x10^{11}$	0.2
Bells Island WTP	0.16	60	$8.24x10^{5}$	2500	$2.06x10^{13}$	10.8	0.16	305	$4.19x10^{6}$	2500	$1.05x10^{14}$	67.0	$5.01x10^{6}$	$1.25x10^{14}$	36.1
TOTAL	40.14		$2.08x10^{8}$	351	$1.70x10^{14}$	100	3.27		$9.48x10^{8}$	335	$5.36x10^{13}$	100	$2.94x10^{8}$	$3.47x10^{14}$	100

*mean of 2 samples, **median of 3 samples. (total loads likely to be underestimated as floods are not captured by these data)

Figure 9. River and stream *E. coli* concentrations and bathing guideline criteria (median and maximum values presented).



Maximum value

Red line is single sample action level of 550.

Blue line is single sample "alert" level of 260.

Dashed lines are reference medians for pastoral (upper) and natural (lower) catchments

*Indicates actual *E.coli* data. All others values calculated from *Enterococci*. Waimea R* data includes bathing water monitoring results which include rainfall events.

Table 15. Annual faecal coliform loads from the Waimea River estimated using flood and base flow inputs.

Waimea River estimate (low flow data from TDC, flood data estimated based on Nottage 2001)												
Calculation of Faecal Coliform estimates to Waimea Inlet from the Waimea River	Rain Flow m^3/s	Low Flow m^3/s	Flood Days	Baseflow Days	Volume Floods m^3/yr	Volume Baseflow m^3/yr	Total Flow m^3/yr	Mean FC Flood cfu/100ml	Mean FC Base cfu/100ml	Flood FC/yr	Baseflow FC/yr	Total FC/yr
Waimea River	200	9	10	355	1.73×10^8	2.76×10^8	4.49×10^8	2000	10	3.46×10^{15}	2.76×10^{13}	3.48×10^{15}

SUPPORTING INFORMATION: ESTIMATION DETAILS - DISEASE RISK: SOURCES AND LOADS

Waimea Inlet: Estimated Disease Risk

The concentration of faecal bacteria indicates whether there is a disease risk to users of estuary water (e.g. for bathing, drinking, canoeing, fishing, shellfish collection, etc). An assessment of disease risk in the estuary has been made assuming that faecal coliform concentrations are the main indicator of disease risk, and that the key sources of faecal coliforms are the Waimea River, smaller tributaries entering Waimea Inlet, and the Bells Island WTP discharge. In the absence of flood flow data or specific enumeration of faecal coliform numbers from most streams and rivers, the flood flow or rain affected values are approximate only, and probably underestimate tributary inputs. Based on the monitoring data summarised in Table 7, concentrations of faecal coliforms (numbers per 100ml) in flood flows and base-flows from each of these sources are estimated as follows:

Flow Regime	Waimea River	Waimea Inlet tributaries	Bells Island WTP effluent
Base-flows	10	335	2,500
Flood Flows	>2000	350	2,500

Section 2 determined that there is likely to be little dilution of faecal inputs within the estuary, and in particular very little dilution expected when streams discharge to the estuary via low tide channels. For the assessment here it is estimated that dilution will be in the order of at 0-10%. Dilution is expected to initially occur in the upper 0.25m of the water column where freshwater inflows float on top of underlying seawater, before deeper mixing by wind and wave action.

To relate faecal coliform data to guidelines used to assess the disease risk associated with bathing, the ANZECC (2000) FC guidelines have been modified to provide a ballpark of single sample risks for faecal coliforms as follows:

Alert/Amber Mode: Single sample greater than 150 x 140/35 = 600 FC/100 mL
Action/Red Mode: 2 consecutive single samples greater than 150 x 280/35 = 1,200 FC/100 mL

Currently the guidelines used to assess the disease risk associated with shellfish consumption are as follows:

The median faecal coliform content of samples taken over a shellfish-gathering season shall not exceed a Most Probable Number (MPN) of 14/100 mL, and not more than 10% of samples should exceed an MPN of 43/100 mL (using a five-tube decimal dilution test).

The most significant input of faecal bacteria to the estuary is the Bells Island WTP effluent discharge because of its relatively high concentration combined with its regular input. To meet shellfish criteria there will need to be approximately 200 fold dilution of the effluent, something unlikely to be achieved within the estuary based on the expected scenario of 0-10% dilution.

Consequently, faecal coliforms are predicted to exceed shellfish limits near the Bells Island outfall much of the time, as well as downstream of the Waimea River mouth during flood conditions. Bathing guidelines are likely to be met beyond a zone of initial mixing downstream of the Bells Island WTP, and for discharges from most of the smaller tributaries most of the time. Shellfish consumption criteria are likely to be regularly exceeded throughout the estuary based on existing data (Tables 7 and 13, Figure 9) The Waimea River stands out as the cleanest of the freshwater inputs monitored, but this may simply reflect the median result for a large number of samples collected under base flow conditions when clean water from the forested upper catchment will dilute any inputs. Although the greatest inputs are known to occur during rainfall influenced events, monitoring data seldom includes rain or flood conditions, or upper estimates of bacterial indicators are not enumerated, greatly limiting evaluation of mass loads or concentrations.

The situation in the small tributary streams draining developed parts of the catchment is likely to be variable, and the available data (e.g. Gillespie et al. 2001) indicates problem conditions exist, not only during rainfall events but also under low flow conditions.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.4 TOXINS

The approach adopted to assess the existing condition and susceptibility to toxins uses a combination of expert opinion and available information to provide likely ratings.

TOXINS VULNERABILITY	
OVERALL RATING	LOW
Human Use	HIGH
Ecological Value	HIGH
Physical Susceptibility	MODERATE
Existing Condition	VERY GOOD
Presence of Stressors	LOW

Key For Rating			
Expression of Indicator to Issue			Existing Condition
High	🟥	🟥	Poor
Moderate	🟫	🟫	Fair
Low	🟨	🟨	Good
Very Low	⬜	⬜	Very Good

		HABITAT TYPE												
		Estuary Water	Estuary Soft Mud	Estuary Firm Mud/Sand	Estuary Gravel/Cobble	Aquatic Macrophytes	Biogenic Structures	Estuary Saltmarsh	Terrestrial Margin	Stream & River Mouths	Mean Bulk of Estuary	Impact on Human Use	Impact on Ecological Value	Predicted Future Increase in Symptoms
	TOXICANT MONITORING INDICATORS	EXISTING CONDITION												
Primary Symptoms	Heavy Metals		⬜							⬜	⬜	🟨	🟨	🟫
	SVOC's		⬜							⬜	⬜	🟫	🟨	🟫
	Toxic algae											⬜	⬜	🟨
2° Symptoms	Macroinvertebrates											⬜	⬜	🟨

EXPRESSION OF TOXICANT CONDITIONS

Heavy Metals	Monitoring of trace metals used as indicators of toxicants in the lower intertidal estuary sediments (NEMP approach) shows low concentrations of heavy metals in sediments (Robertson and Stevens 2009). Slightly elevated nickel and chromium levels reflect naturally elevated catchment sediment sources. Biosolids applications at Rabbit Island were not found to have caused an increase of heavy metals in sediments (Gillespie and Asher 2004). Arsenic and nickel in shellfish (cockles) were recorded at concentrations slightly above NZ food regulation guidelines at both impact and control sites, and were attributed to naturally elevated catchment sediment concentrations (Gillespie and Asher 2004). The Bells Island WTP discharge was found to have caused no ecologically significant long term accumulation of metal concentrations in sediment or shellfish over a 10 year monitoring period (Gillespie et al. 2001). Sediment monitoring (TDC 2004 data) found concentrations of metals (Arsenic, Copper, Lead, Zinc, Tributyl Tin (TBT)) in sediment adjacent to a range of stormwater outfalls near Richmond were elevated above background levels in the estuary. Several values exceeded ANZECC guidelines, with the highest values being located closest to developed industrial areas. TBT (timber preservative) was recorded from a very small section of the estuary at low concentrations, a legacy of an historical spill and runoff from the Beach Road industrial area. Overall a LOW level of expression is applied for heavy metals.
SVOCs (Semi-Volatile Organic Compounds)	Stormwater monitoring (TDC 2004 data) found localised low level sediment concentrations of PAHs adjacent to a range of stormwater outfalls near Richmond. PAHs are commonly associated with road runoff. Monitoring of organochlorine pesticides (e.g. DDT, DDD, DDE (=DDX), and Aldrin, Dieldrin, Lindane (=ADL)) following remediation of the former Fruitgrowers Chemical Company site at Mapua (Davidson et al. 2010) found marine sediment concentrations at control sites were very low or below detection limits. In close proximity to the remediation site, concentrations commonly exceeded soil acceptance criteria but were dramatically lower than values recorded prior to remediation. Present levels were not considered to have resulted in a decrease in invertebrate community diversity or abundance. In addition to the above, compliance monitoring is undertaken by TDC to ensure toxicant inputs remain within parameters specified in individually assessed resource consents (e.g. Nelson Pine Industries, Dynea NZ Limited). Overall a LOW level of expression is applied for SVOCs.
Toxic Algae	No reports of ocean sources of toxic algae entering the estuary are known. A LOW level of expression is assumed.
Macroinvertebrates	Macroinvertebrates were rated as representing "slightly polluted" conditions with shift towards a community more tolerant of muddy or enriched conditions from 2001 and 2006 (Robertson and Stevens 2009). This is thought to reflect measured increases in muddiness and to a lesser extent, enrichment. However, the absence of a multi-year baseline mean the changes cannot reliably be distinguished from natural variation. Because levels of toxins measured in the estuary are low, a LOW level of expression is assumed.

OVERALL EXPRESSION OF TOXIC CONDITIONS	Combining the ratings of the primary and secondary symptoms gives an overall rating of LOW. There is little indication of existing toxin symptoms in the estuary other than small localised areas adjacent to point source discharges.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.4 TOXINS (CONT.)

EXPRESSION OF TOXICANT CONDITIONS

PHYSICAL SUSCEPTIBILITY (DILUTION AND FLUSHING POTENTIAL)	The capacity of an estuary to either flush or dilute and spread incoming toxicants determines its physical susceptibility. Generally, well flushed estuaries with a large area have the greatest potential for assimilation. Flushing is likely to have a controlling influence on water borne contaminants, while sediment bound toxicants will reflect sediment deposition and retention within the estuary. Based on the relatively large intertidal area of the estuary (2793ha) a MODERATE capacity to spread and assimilate sediment bound inputs is applied. Combined with HIGH flushing within the estuary (Section 2) a MODERATE overall susceptibility to toxicants is assumed.
INFLUENCE OF STRESSORS	Table 5 identified the following stressors contributing to toxicant inputs to the estuary: catchment runoff, point source discharges (primarily stormwater discharges, the Bells Island WTP effluent discharge, and historical discharges from the FCC site at Mapua), spills and, to a lesser extent, algal blooms. Of these, the key stressor is terrestrial inputs from point source discharges, primarily stormwater. Inputs are likely to be greatest in the eastern arm of the estuary which has the highest urban and industrial development. Because many toxic contaminants preferentially adsorb to fine particulate, fine estuary sediment near source inputs is where toxicants are most likely to accumulate. The influence of toxins on the estuary was estimated based on existing symptoms (previous page), which indicate that toxicant concentrations are low across the vast majority of the estuary. Naturally high levels of some metals (e.g. chromium, nickel) are introduced to the estuary due to erosional input from the ultramafic rock in the catchment. The presence of other toxins at concentrations elevated above background levels were generally localised in extent and directly related to a point source input e.g. stormwater outfall. Sediments impacted by stormwater outfalls are commonly restricted to a few metres to 10s of metres in extent. There has been a general reduction in the use of the more toxic chemicals (eg organo-chlorine or organophoshorus pesticides) particularly in the horticulture industry. The chemicals now used are carefully controlled under the grow-safe scheme. As such, the current toxicant influence on the estuary is rated as LOW. Contaminant inputs from the remediated FCC site at Mapua are of significant local interest and subject to detailed monitoring (e.g. Davidson et al. 2010). Overall, organochlorine concentrations adjacent to the site were comparable to values recorded from other estuaries close to large cities (Davidson et al. 2010), and confined to a small area immediately adjacent to the site.
EFFECT ON HUMAN USES	Uncertainty over whether fish/shellfish are safe to eat, or whether it is safe to play in the estuary is the major existing impact on human use of the estuary. Monitoring results indicate that the risk of toxins affecting contact recreation activities, or from seafood collected for human consumption is very low, and the risk of toxic algal blooms from the sea is also low. Therefore, effects on human use are more likely to be driven by other issues such as disease risk (shellfish from the estuary generally unsafe to eat).
EFFECT ON ECOLOGICAL VALUES	The toxins present are at levels which are not considered likely to adversely impact invertebrate community diversity or abundance.
FUTURE INFLUENCE	Future toxicant inputs are predicted to increase. The main source of toxicants to the estuary is currently from terrestrial runoff, particularly stormwater during rain events. Management of catchment toxicant inputs from agricultural and urban landuse is encapsulated in the provisions of the Resource Management Act 1991. Despite increased awareness and management of inputs from urban and industrial sources, past inaction combined with ongoing population expansion, means a conservative approach is recommended of assuming that the future toxicant inputs remain the same or increase. Any increase in inputs is unlikely to shift the influence above LOW for the vast bulk of the estuary, but may result in localised issues.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.5 HABITAT LOSS

The approach adopted to assess the existing condition and susceptibility to habitat uses a combination of expert opinion and available information to provide likely ratings.

HABITAT LOSS VULNERABILITY	
OVERALL RATING	HIGH
Human Use	HIGH
Ecological Value	HIGH
Physical Susceptibility	MODERATE
Existing Condition	POOR
Presence of Stressors	MODERATE

Key For Rating

Expression of Indicator to Issue			Existing Condition
High	🟧	🟧	Poor
Moderate	🟫	🟫	Fair
Low	🟨	🟨	Good
Very Low	⬜	⬜	Very Good

	HABITAT LOSS MONITORING INDICATORS	Estuary Water	Estuary Soft Mud	Estuary Firm Mud/Sand	Estuary Gravel/Cobble	Aquatic Macrophytes	Biogenic Structures	Estuary Saltmarsh	Terrestrial Margin	Stream & River Mouths	Mean Bulk of Estuary	Impact on Human Use	Impact on Ecological Value	Predicted Future Increase in Symptoms
		EXISTING CONDITION												
Primary Symptoms	Substrate		🟧								🟨	🟫	🟨	🟫
	Macrophytes (Seagrass)					🟧					🟧	⬜	🟧	🟫
	Saltmarsh							🟫			🟫	⬜	🟧	🟨
	Vegetated Terrestrial Margin								🟧		🟧	⬜	🟧	🟨
Secondary Symptoms	Birds		🟫	🟨	🟨	🟨	🟨	🟫	🟫	🟨	🟫	⬜	⬜	🟫
	Fish	🟨						🟨		🟨	🟫	⬜	⬜	🟨
	Invasive species		🟫	🟫	🟫			🟫	🟫		🟫	⬜	⬜	🟨
	Benthic invertebrates		🟨	🟨	🟨	🟨	🟨				🟫	⬜	⬜	🟨
	Shellfish		🟨	🟨	🟨	🟨	🟨				🟫	⬜	⬜	🟨
	Sea Level										🟧	🟧	🟧	🟧

EXPRESSION OF HABITAT LOSS CONDITIONS

Substrate	Baseline established in 1999 through broad scale habitat mapping (NEMP approach - Robertson et al. 2001). Diverse range of habitats present, although estuary dominated by soft mud and an increase in area of soft mud (26% increase between 2001 and 2006) reported by Clarke et al. (2008). A HIGH level of expression is applied due to soft mud often overlying sand, gravel and cobble habitat on intertidal flats and near stream mouths, establishment of Pacific oysters on tidal flats in middle and lower estuary, and a few localised macroalgal blooms causing sediment enrichment.
Macrophytes	Aquatic macrophytes (seagrass) are present in good condition on intertidal flats in the middle and lower estuary, although the area remaining is small. Seagrass area has steadily declined from 1988 to 2006 - 64% loss (Robertson and Stevens 2009). A HIGH level of expression is applied. Susceptibility to stress is MODERATE based on moderate presence of stressors (low clarity, sedimentation, nutrient enrichment and anoxic sediments, and sea level rise) and low dilution potential and high flushing potential.
Saltmarsh	A moderate area of saltmarsh remains, and is in good condition, but the area is significantly reduced from its original extent due to clearance, reclamation, drainage, and impoundment (27% loss from 1946-2001). Since 2001 net losses have been relatively small, and some local increases achieved through declamations. A HIGH level of expression is applied. Susceptibility of saltmarsh to stress is MODERATE based on moderate presence of stressors (sediment, nutrients, sea level rise), and low dilution potential and high flushing potential. Low risk of further reclamations.
Vegetated Terrestrial Margin	The 200m terrestrial margin is highly modified (grassland, urban development, forestry) and few densely vegetated buffer areas remain. Changes unable to be accurately assessed due to absence of a baseline. A HIGH level of expression is assumed (existing condition is poor), but susceptibility to further change is LOW.
Birds	Internationally important feeding and roosting area for wading birds (esp. pied and variable oyster catchers, wrybill, bar tailed godwit) (Schuckard 2002). Nationally important for a range of native waders and seabirds including Caspian terns white heron, spoonbill; and marsh species (e.g. banded rail, marsh crake, spotless crake, bittern). A HIGH level of expression is assumed based on past development of terrestrial margin, loss of saltmarsh and increases in soft mud areas.
Fish	Recent data on fish populations are limited but high diversity and abundance reported previously (Davidson and Moffat 1990). Significant past habitat loss, particularly whitebait spawning sites in the upper tidal reaches of the estuary. Existing condition is rated FAIR. Susceptibility of fish populations to stress is LOW-MODERATE based on moderate presence of stressors (particularly anoxic sediments, sedimentation, macroalgal blooms) and low dilution potential and high flushing potential.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.5 HABITAT LOSS (CONT.)

EXPRESSION OF HABITAT LOSS CONDITIONS

Invasive Species	No major invasive plant species have been identified in the estuary. Pacific oysters are abundant in the lower and mid estuary. *Spartina*, once widespread, has been sprayed and is largely eradicated. Ice plant is present near the upper tidal margins. A range of common terrestrial weeds are present in the terrestrial margin e.g. gorse, blackberry, and introduced grasses. Tamarisk is slowly spreading from areas around the Greenacres Golf Club and Creeping Bent is spreading from the Neimans Creek area. Existing condition is rated FAIR and susceptibility to further change is LOW-MODERATE.
Benthic invertebrates	The types of animals found in and on the estuary sediments reflect their ability to tolerate various levels of pollution. Macro-invertebrate monitoring has shown a slight change in community composition from unpolluted in 1988 (Davidson and Moffat 1990) to slightly polluted in 2001 and 2006 (Robertson and Stevens 2009). This is thought to reflect measured increases in muddiness and to a lesser extent, enrichment. Existing data make displacement of species difficult to assess, particularly in the absence of a baseline of natural variation. A LOW level of expression is assumed. Susceptibility to stress is MODERATE based on moderate presence of stressors (particularly anoxic sediments, sedimentation, macroalgal blooms).
Shellfish	Recent data on shellfish distribution is limited but high diversity and abundance reported previously (Davidson and Moffat 1990), and is consistent with recent field observations. Existing condition is rated FAIR. Susceptibility to stress is MODERATE based on moderate presence of stressors (anoxic sediments, sedimentation, macroalgal blooms and sea level rise), and low dilution potential and high flushing potential.
Sea Level	Increases in sea level of approximately 0.16m over the past 100 years up to the year 2000 are reported in Wratt et al. (2008), with sea level predicted to continue to accelerate over the 21st Century and beyond. This gives a HIGH level of expression.
OVERALL EXPRESSION OF HABITAT LOSS CONDITIONS	Combining the HIGH and MODERATE ratings of the primary symptoms (taking area of past habitat loss into account), and the HIGH and MODERATE secondary symptoms, gives an overall rating of HIGH. There are significant indications that habitat loss adversely impacts the estuary.
INFLUENCE OF STRESSORS	Table 5 identified a range of stressors contributing to habitat losses in the estuary. Historically, the greatest habitat losses have resulted from clearance of saltmarsh and terrestrial vegetation, and drainage and reclamation of estuary margins. The rate of loss has decreased significantly over the past 20 years. Vegetation removal has caused direct habitat loss for both plants and animals - especially birds, as well as native fish (loss of whitebait spawning areas). In addition, it has also facilitated the introduction of weeds and pests into margin areas, contributing to reduced biodiversity. Pacific oysters are a significant pest species because of their tendency to trap fine sediments where they colonise, as well as making walking in the estuary difficult. Iceplant tends to smother and outcompete many native herbfield species in the upper estuary fringes. Vegetation losses have also greatly reduced the capacity of the estuary to assimilate catchment runoff of sediment and nutrients, particularly during flood events. The reduced assimilative capacity has contributed to changes in habitat within the estuary, primarily an increase in soft mud habitat. Development of estuary margins including the establishment seawalls and causeways has also been widespread. Such development greatly restricts the ability of the estuary to respond to sea level rise, and further loss of estuary saltmarsh is likely where it is unable to retreat inland in response to rising sea levels. The use of flapgates and stopbanks to prevent flooding of low-lying land has also resulted in a significant reduction in estuary habitat, particularly restricting fish passage, access to whitebait spawning sites and reducing areas that would otherwise naturally grow saltmarsh. Within the estuary itself, vehicle damage is a minor but direct stressor in localised parts of the estuary, as are spills and margin grazing. Fire and freshwater abstraction are minor stressors. Sea level rise remains the dominant stressor (see Future Influence section below). Climate change is expected to increase runoff, and estuary sediment and nutrient inputs are predicted to increase. Inputs will be exacerbated by any further loss of saltmarsh and the consequent reduction in assimilative capacity. Increased development of margins also increases the potential for weed and pest introductions, and disturbance of wildlife, particularly bird nesting including predation by domestic pets. Overall, the current influence of habitat loss on the estuary is rated as HIGH.
EFFECT ON HUMAN USES	Estuary habitat loss is predominantly caused by human activity and has been driven by perceived or direct benefits such as creation of land for roading, farming, industry or residential uses. Adverse effects from the loss of vegetated margins around the estuary include reduced aesthetic values, loss of wildlife, degraded fisheries (esp. whitebait), reduced access, a reduced capacity to assimilate sediment and nutrient inputs, increased risk of pest introductions.
EFFECT ON ECOLOGICAL VALUES	A wide range of plants and animals are adversely affected by habitat loss. Increased sedimentation alters the composition of the benthic invertebrate community by displacing sensitive species, reduces water clarity (directly impacting on macrophyte (seagrass) growth), and reduces the quality of bird foraging habitat. It reduces the habitat diversity of the estuary, and leads to a decrease in biodiversity. Loss of saltmarsh and the terrestrial vegetated margin reduces habitat for a range species, particularly birds, and the facilitation of pest plants and animal introductions is a significant pressure.

6. ECOLOGICAL VULNERABILITY ASSESSMENT (CONT.)

6.5 HABITAT LOSS (CONT.)

EXPRESSION OF HABITAT LOSS CONDITIONS

FUTURE INFLUENCE

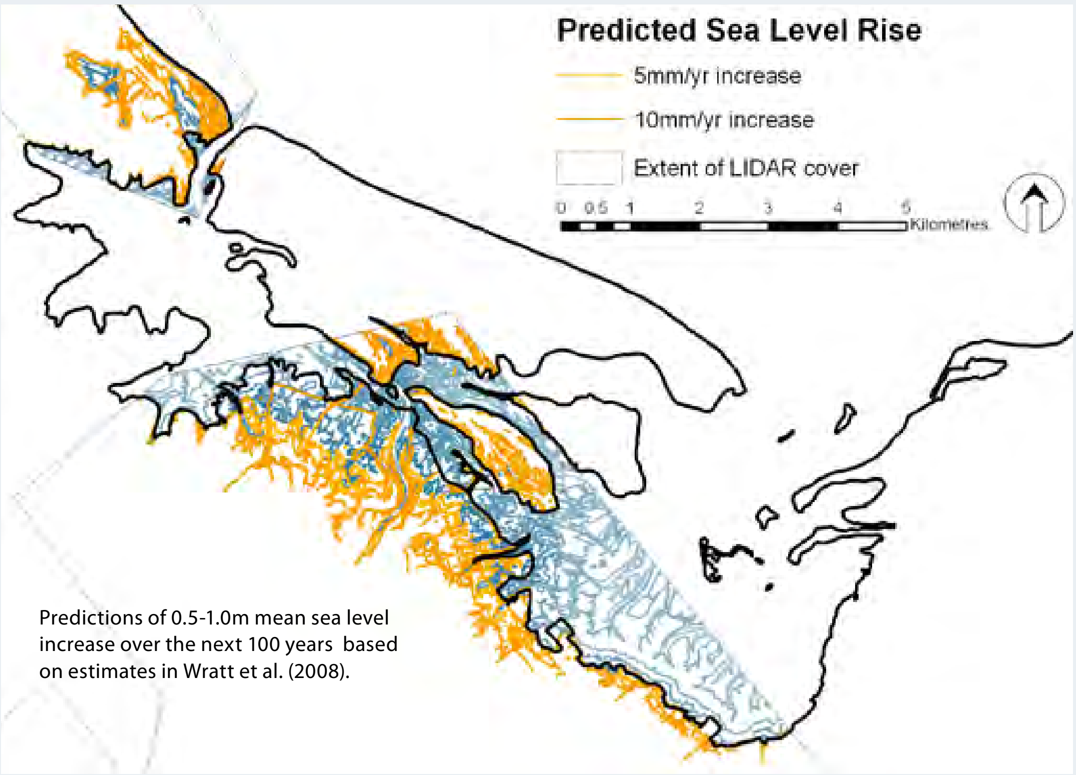
Habitat loss is predicted to increase in future. The key pressure the limited capacity of the estuary to respond to rising sea level, particularly vegetation which will need to migrate inland to survive. The current capacity to respond is greatly limited by the extensive roading, industry, infrastructure (e.g. sewage works) and housing around the estuary margins. Sea level rise is also likely to displace birds from current high tide roosting sites within the estuary. Direct habitat loss (e.g. through reclamation and drainage) has diminished significantly since the 1990's. However, losses have continued (e.g. Ruby Bay bypass in 2009) despite the high value of remaining saltmarsh and terrestrial vegetated habitat around Waimea Inlet being clearly identified (e.g. Davidson and Moffat 1990). Consequently while further losses should be discouraged, a conservative approach is recommended of assuming that future habitat loss remains the same.

It is also recognised that significant planting initiatives have been undertaken by both NCC and TDC along the terrestrial margins of Stoke and Richmond, and by landcare groups and landowners around the margin of the estuary.

Waimea Inlet:
Habitat Loss

A major limitation in assessing potential sea level impacts has been the absence of detail on the topography of the estuary and margins. This is currently being addressed through the independent collection of LIDAR (detailed contour) data by both NCC and TDC which will allow areas susceptible to sea level inundation to be identified and planned for appropriately (e.g. orange areas in Figure 10). These areas are also those where estuary saltmarsh will naturally migrate to in the absence of barriers.

Figure 10. TDC LIDAR data showing areas adjacent to Waimea Inlet susceptible to sea level rise based on current predictions.



Predictions of 0.5-1.0m mean sea level increase over the next 100 years based on estimates in Wratt et al. (2008).

SPARTINA:

The exotic cord grass *Spartina angelica* was introduced to the estuary in the 1948 to promote reclamation and stabilisation of the increasing inputs of soft muds from catchment development onto tidal flats (Tuckey and Robertson 2003). However while the rapid and aggressive growth of *Spartina* in unvegetated tidal flat areas trapped large amounts of sediment, it was declared an invasive weed to the area In the 1970's because of concern over the loss of habitat favoured by wading birds, flatfish, and shellfish, and adverse impacts by displacing important fish spawning and marine nursery areas, competing with native plants and contributing to flooding. *Spartina* has now been largely eradicated from the estuary with trapped sediments gradually released into the estuary as the root systems decay.

7. SUMMARY AND CONCLUSIONS

The ecological vulnerability assessment, summarised in matrix form on pages 42-43, shows that the Waimea Inlet has high ecological values, is widely used by humans, and is vulnerable particularly to sediment inputs and further habitat loss. Much of the estuary was found to be in good condition. However, it is muddier than it should be and has lost large areas of saltmarsh and terrestrial margin vegetation. Because the estuary is relatively large and well flushed, it is only moderately susceptible to water quality problems or nuisance phytoplankton blooms. Further, moderate nutrient loads mean that the estuary is able to assimilate current nutrient inputs, and the estuary is not showing signs of excessive enrichment. However, sediment oxygenation is relatively low across much of the estuary due to the fine sediment present.

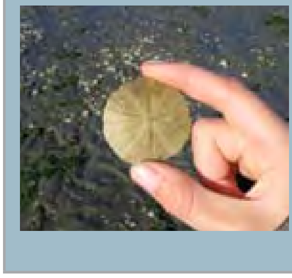
In terms of the five key issues that affect most tidal lagoon estuaries (i.e. sedimentation, eutrophication, disease risk, toxicity and habitat loss), the findings from the vulnerability assessment indicate that the Waimea Inlet has problems with sedimentation and habitat loss, and to a lesser extent, disease risk and eutrophication. Toxicity is not currently a concern. Where there are problems however, they are generally restricted to certain "at risk" locations within the estuary as follows:

- Excessive muddy sediments in the mid and upper tidal reaches of both arms of the estuary, associated with depletion of dissolved oxygen.
- Mid and lower estuary shellfish health risk, particularly associated with small streams draining the intensively farmed lower catchment and immediately downstream of the Bells Island WTP.
- Loss of saltmarsh and the terrestrial vegetated margin from the upper, mid and lower estuary.
- Saltmarsh and seagrass degradation through sedimentation effects, as well as sea level rise (a potential issue in the future).
- Invasion by Pacific oyster throughout much of the estuary, and ice plant and introduced grasses and weeds at the upper tidal margins.
- Localised nuisance macroalgal growths, primarily in the eastern arm.

The major stressors identified were:

- Catchment runoff from intensive land use (primarily sediment and, to a lesser extent, faecal coliforms and nutrients), and the Bells Island WTP in relation to faecal coliforms.
- Climate change - sea level rise and changes to temperature and rainfall,
- Drainage and reclamation (mostly historical).
- Less important stressors included; causeways and flapgates (restricting tidal flows and fish passage), seawalls (limiting saltmarsh habitat and potential retreat in response to sea level rise), increased population pressure and margin encroachment (wildlife disturbance, predator introductions, habitat loss, depletion of living resources), invasive species (e.g. Pacific oysters and iceplant), spills, vehicle damage, and point source discharges (e.g. stormwater, treated sewage, contaminated sites).

The widest range of stressors were present in the saltmarsh and terrestrial margins of the estuary, with habitat loss the issue affected by the most stressors.

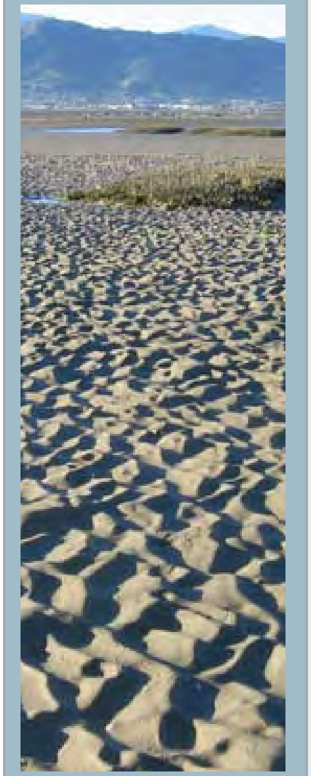


Based on the combination of high ecological and human use values, poor existing condition for some issues (primarily sedimentation and habitat loss), moderate susceptibility (driven by past habitat degradation but good flushing of the estuary), and a moderate risk of the stressors causing issues, Waimea Inlet was given a "moderate" overall ecological vulnerability rating.

A summary of findings for each issue is presented below. Monitoring and management recommended to address identified issues is presented in the following section.

7. SUMMARY AND CONCLUSIONS (CONT.)

7.1 EUTROPHICATION



OVERALL VULNERABILITY RATING - EUTROPHICATION	MODERATE

The overall rating for eutrophication is MODERATE based on the combination of a LOW-MODERATE expression of symptoms, MODERATE flushing and dilution potential, and a MODERATE nutrient input influence. The moderate nutrient influence means that the eutrophication symptoms observed in the estuary are moderately related to nutrient additions and therefore eutrophication symptoms are expected to increase if future inputs increase.

- Human use and ecological value of the estuary is high, and the estuary has a moderate physical susceptibility to eutrophication driven by low dilution but strong tidal flushing and a short (0.6 day) residence time in the estuary.
- Waimea Inlet currently expresses “low” symptoms of eutrophication, consistent with it being in an unenriched (oligiotrophic) state, and does not experience problems with phytoplankton blooms. There are no known instances of algal blooms from the sea causing problems in the estuary.
- Nuisance macroalgal growths in the estuary were localised and relatively small in extent (see Appendix 2) and were near obvious nutrient sources or where inputs are concentrated, for example, in poorly flushed areas behind causeways.
- Heaviest growths were near the mouth of the Waimea River (e.g. between Best and Bells Islands - the causeway restricting flushing and trapping sediment and nutrients), and in the upper eastern arm (e.g. adjacent to the Bark Processors site). Macroalgae accumulating and growing in these areas traps fine sediment, and when it rots, causes sediment oxygen depletion and nuisance odours. An abundant growth of macroalgae was present downstream of the Bells Island WTP discharge but was not causing nuisance conditions.
- Most of the smaller streams supported periphyton in the stream beds and macroalgae growth in associated intertidal channels within the estuary, but not at nuisance levels.
- Current impact on human and ecological values is low outside of areas with localised macroalgal growths.
- The major stressor was attributed to catchment runoff of nutrients sourced from intensive farming and horticulture in the lower catchment (see Appendix 5), and to a lesser extent, point source inputs from the Bells Island WTP outfall.
- The main driver of the existing state is the combination of moderate catchment nutrient inputs, combined with the strong tidal flushing and short residence time in the estuary. Landuse intensification is predicted to increase nutrient inputs, with a corresponding increase in macroalgal growth and associated estuary degradation. This is likely to be exacerbated by predicted climate change (wetter weather increasing catchment run off and warmer temperatures promoting growth).
- Recommended indicators to monitor ongoing status and change are:
    - nutrient inputs to the estuary, particularly during rainfall and flood events,
    - sediment RPD depth, and
    - macroalgal growth.
- An interim areal loading guideline of 50 mg.m^2.d^{-1} of N for the estuary is recommended (based on Heggie, 2006). Current catchment estimates (based on WRENZ) need to be verified, and sub-catchment synoptic surveys are recommended to rapidly identify catchment “hotspots” and target management where appropriate
- Although the greatest loads of nutrients enter the estuary from the Waimea River, the elevated concentrations from smaller streams highlight these sources as a priority.

7. SUMMARY AND CONCLUSIONS (CONT.)

7.2 SEDIMENTATION

OVERALL VULNERABILITY RATING - SEDIMENTATION	HIGH
The overall rating for sedimentation is HIGH based on the combination of a HIGH expression of symptoms, MODERATE flushing and dilution potential, and a HIGH sediment influence. The high sediment influence means that the sedimentation symptoms observed in the estuary are strongly related to sediment inputs. Sedimentation symptoms are expected to increase based on current inputs, expected future catchment development, and the influence of climate change.	

- Human use and ecological value of the estuary is high, and the estuary is rated as having a moderate physical susceptibility to sedimentation based on the presence of extensive muddy areas in both arms despite high flushing.
- Waimea Inlet currently expresses high symptoms of sedimentation. A large percentage of the estuary surface is dominated by soft mud (55%), cobble, gravel and sand habitats have been buried in the upper tidal reaches, clarity and sediment oxygen levels are lowered, macrophyte area (seagrass) is small, and the sediment macroinvertebrate community reflects slightly polluted (muddy) conditions.
- The major stressor was attributed to catchment runoff of sediments from land disturbance. Most inputs are expected to enter the estuary from the intensively developed Waimea Plains as well as plantation forestry (concentrated within the moderately sloping middle of the catchment). The major point source discharge to the estuary, the Bells Island WTP outfall, was a relatively minor contributor of suspended solids.
- Current impact on human and ecological values is high.
- Landuse intensification is predicted to increase sediment inputs, with a corresponding increase in soft mud deposition and associated degradation of the estuary is expected. This is likely to be exacerbated by predicted climate change (wetter weather increasing catchment run off). The presence of fine glacial silts increases the susceptibility of the estuary to sediment problems, while future susceptibility is rated high based on the monitored increase in mud area.
- Recommended indicators to monitor ongoing status and change are:
  - changes in landuse within the catchment,
  - area of soft mud in the estuary (5 yearly broad scale mapping),
  - sediment RPD depth, and
  - sedimentation rate (using buried plates).
- The average sediment rate should be reduced to 1.0-2.0mm/year, to preserve the estuarine features of the inlet, as recommended by Gibbs and Cox (2009) for Porirua Harbour. Without such a reduction, the inlet will become a brackish swamp.
- Data are required during rainfall and flood events when the majority of sediment inputs are expected to enter the estuary. The current lack of data make predicting likely sediment settlement and export loads from the estuary very difficult. Despite this, inputs are sufficiently high that catchment management is necessary.
- Specific inputs from key land disturbance activities such as plantation forest harvesting, subdivision, roading and horticultural redevelopment should be measured or modelled, and sub-catchment synoptic surveys are recommended to rapidly identify catchment "hotspots" for targeted management.
- The above findings indicate that the issue of sedimentation of the Waimea Inlet is a priority for further investigation, monitoring, and management. Targeted programmes such as the sedimentation workshops recently run by TDC should be continued.

Sediment covered flounder in the western arm.

7. SUMMARY AND CONCLUSIONS (CONT.)

7.3 DISEASE RISK

OVERALL VULNERABILITY RATING - DISEASE RISK	MODERATE-HIGH
The overall rating for disease risk is MODERATE-HIGH based on the combination of a HIGH expression of symptoms, MODERATE flushing and dilution potential, and a MODERATE-HIGH disease risk influence. This means that the disease risk symptoms observed in the estuary are strongly related to disease risk inputs and the limited ability of the estuary to dilute incoming faecal bacteria. Disease risk symptoms are expected to remain similar or increase based on current inputs and expected future catchment development.	

- Human use and ecological value of the estuary is high, and the estuary has a moderate physical susceptibility to disease driven by a low dilution capacity but strong tidal flushing.
- Waimea Inlet currently expresses moderate-high symptoms of disease risk. These symptoms have a detrimental effect on shellfish collection and, to a lesser extent, bathing.
- The major non-point stressor was attributed to catchment runoff of faecal bacteria from pasture. Most inputs are predicted to enter the estuary from the intensively developed Waimea Plains. A major limitation in assessing disease risk is that few data are available for the small streams entering the estuary (but which appear to contribute significantly to the estuary loadings), and the absence of information during rainfall and flood events which is when the majority of inputs are expected.
- The major point source input is the Bells Island WTP outfall. The Bells Island WTP has significantly improved effluent quality in the estuary since 2006, and monitoring indicates impacts are largely confined to within the 500m effluent mixing zone. However, because it discharges adjacent to the most important wading bird habitat and largest shellfish beds in the estuary it is important to ensure it does not compromise shellfish quality or bathing standards.
- Current impact on human values is moderate based on occasional exceedance of bathing guidelines, and high based on regular exceedance of shellfish bacterial guidelines. The highest non-point disease risk is from freshwater streams entering the estuary following rainfall events, although high bacterial indicators were also reported under dry flow conditions for some tributary streams.
- Current impact on ecological values is low, with stress on existing plant and animal communities unlikely.
- Landuse intensification is predicted to increase faecal bacteria inputs, with a corresponding increase in disease risk. This is likely to be exacerbated by predicted climate change (wetter weather increasing catchment run off).
- Recommended indicators to monitor ongoing status and change are:
    - changes in landuse within the catchment,
    - bathing water quality (as part of existing programme),
    - shellfish quality.
- Catchment inputs should be reduced to levels that meet bathing and shellfish guidelines, targeting tributary streams as a priority.
- In addition, few data are available on faecal bacteria inputs during rainfall and flood events when the majority of inputs are expected to enter the estuary. This information is needed to enable modelling of mass loads and to target catchment "hotspots" for management action.
- The above findings indicate that the issue of disease risk of the Waimea Inlet is a priority for further investigation, monitoring, and management. In particular, there is a need to ensure inputs from pastoral grazing are adequately managed. Sub-catchment synoptic surveys are recommended to rapidly identify catchment "hotspots", and targeted programmes to minimise inputs initiated as appropriate.

7. SUMMARY AND CONCLUSIONS (CONT.)

7.4 TOXINS

OVERALL VULNERABILITY RATING - TOXINS	LOW
The overall rating for toxins is LOW based on the combination of a LOW expression of symptoms (e.g. very low contaminant concentrations in sediments or biota), MODERATE flushing and dilution potential, and a LOW toxicant influence. This means that although toxin symptoms observed in the estuary are strongly related to inputs, they are generally concentrated close to sources and are not causing significant degradation of the estuary. Toxin symptoms are expected to remain similar or increase based on current inputs and expected future catchment development.	

- Human use and ecological value of the estuary is high, and the estuary has a moderate physical susceptibility to toxins driven by strong tidal flushing but a moderate dilution capacity and spreading potential.
- Waimea Inlet currently expresses low symptoms of toxins and current concentrations are unlikely to place stress on plant and animal communities. However, the perception that symptoms may exist can have a detrimental effect on human seafood collection and use of the estuary.
- The major stressor was attributed to terrestrial inputs of toxins. Most inputs are predicted to enter the estuary from the developed urban and industrial areas of Tahunanui, Stoke and Richmond via stormwater, air discharges, or spills.
- The major point source inputs are stormwater outfalls. The Bells Island WTP outfall is not a significant source of toxicants to the estuary.
- Current impact on human values is moderate based on uncertainty over whether fish/shellfish are safe to eat, or whether it is safe to play in the estuary. Greatest concerns relate to the FCC site at Mapua where low concentrations of organochlorine pesticides are present in sediments and shellfish. Elsewhere, risk is highest adjacent to urban stormwater outfalls. Symptoms are currently restricted to within a few metres to 10s of metres from outfalls.
- Current impact on ecological values is low.
- Landuse intensification is predicted to increase toxicant inputs, with a corresponding increase in risk.
- Recommended indicators to monitor ongoing status and change are:
    - changes in landuse within the catchment,
    - urban stormwater discharge quality,
    - sediment quality,
    - shellfish/macrofauna quality.
- The above findings indicate that the issue of toxins in Waimea Inlet is a moderate priority for further investigation and monitoring, but management initiatives to reduce inputs is recommended. The primary focus should be on inputs from urban and industrial stormwater.
- Sub-catchment synoptic surveys are recommended to identify catchment "hotspots", and targeted programmes to minimise inputs initiated as appropriate.
- Monitoring should include a watching brief on urban stormwater quality. Sediment and shellfish quality should be coordinated with SOE and consent monitoring where possible.

7. SUMMARY AND CONCLUSIONS (CONT.)

7.5 HABITAT LOSS

OVERALL VULNERABILITY RATING - HABITAT LOSS	HIGH
The overall rating for habitat loss is HIGH based on the combination of a HIGH expression of symptoms (e.g. significant losses of saltmarsh and vegetated margins), and a HIGH habitat loss influence. This means that habitat loss has caused significant degradation of the estuary. Habitat losses are expected to remain similar or increase based on the combination of current inputs, expected future catchment development, and the relatively small areas of remaining saltmarsh. Waimea Inlet was rated as being highly susceptible to further loss of saltmarsh and seagrass through predicted sea level rise.	

- Human use and ecological value of the estuary is high, and the estuary has a moderate susceptibility to intertidal habitat loss driven by strong tidal flushing but a moderate dilution capacity and spreading potential. Susceptibility of remaining saltmarsh, terrestrial margin vegetation, and seagrass is high based on moderate presence of stressors, but limited extent of remaining habitat, ongoing development pressure, and the predicted impact of protecting existing infrastructure from sea level rise.
- Waimea Inlet currently expresses high symptoms of habitat loss overall with a significant reduced terrestrial vegetated margin, saltmarsh, and seagrass habitat.
- The major historical stressor was drainage and reclamation, with sea level rise predicted to be the most significant future stressor, particularly to saltmarsh, and high tide bird roosting and nesting areas.
- Current impact on human values is moderate. The presence of extensive commercial and residential infrastructure near the estuary margin (e.g. Bells Island WTP, Best Island houses, Lower Queen Street industrial zone, Richmond and Ruby Bay bypasses) means there will be strong pressure to protect human infrastructure from rising sea levels. Infrastructure protection is likely to be in direct conflict with natural or managed retreat of the estuary.
- Current impact on ecological values is high. Habitat loss has occurred by excessive sedimentation reducing intertidal habitat diversity by smothering sand, gravel and cobble beds and causing a decline in seagrass. In addition, invasion of tidal flats and channel areas with Pacific oysters, invasion of estuary margins with iceplant, and the presence of causeways and flapgates restricting tidal flows have all contributed to reduced biodiversity. There has been a decline in habitat quality through weed and pest invasion and increased human disturbance of wildlife. Ongoing saltmarsh losses have continued to occur through roading, drainage, and reclamation over the past 20 years.
- Landuse intensification is predicted to increase pressure on remaining vegetated habitat and increase sediment and nutrient inputs.
- Recommended indicators to monitor ongoing status and change are:
    - changes in landuse within the catchment,
    - changes in estuary saltmarsh, seagrass, terrestrial margin, and substrate.
- Habitat loss in Waimea Inlet has been extensive, and monitoring should continue based on 5-10 yearly broad scale habitat mapping using the NEMP approach.
- A high priority should be placed on management initiatives to protect all remaining saltmarsh and enhance vegetated margins. This should include identifying opportunities to improve ecological value during maintenance upgrades of culverts, drains and causeways, etc., establishment of suitable buffer areas to protect key species such as banded rail, and control of vehicle access points.
- Key areas for protection are located in the western arm and central part of the estuary by Waimea River (significant banded rail habitat). Important bird roosting and feeding areas are also located at the Bells Island shellbank, No mans Island, and the eastern end of Rabbit Island.

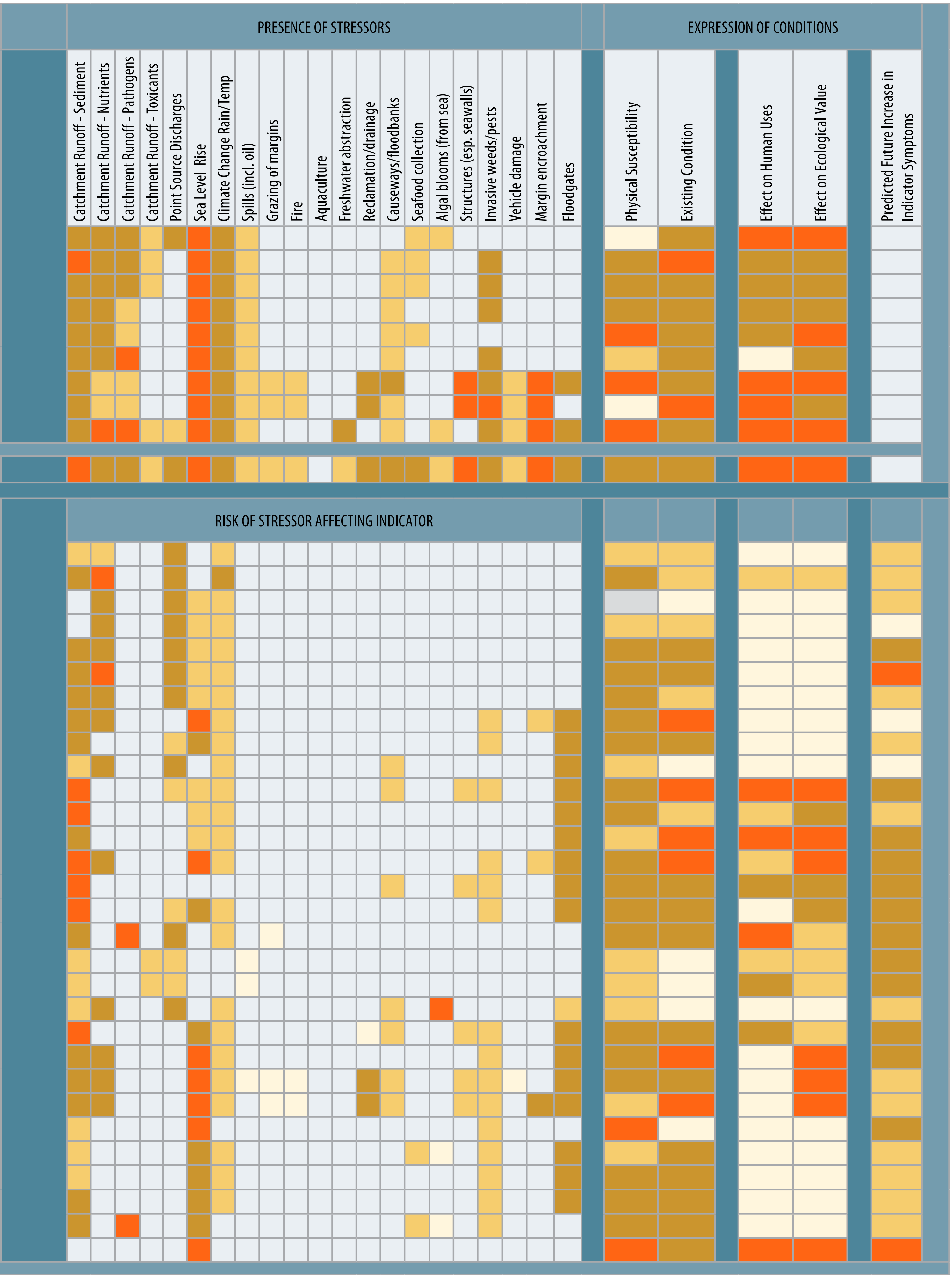
WAIMEA INLET ECOLOGICAL VULNERABILITY ASSESSMENT
SUMMARY MATRIX

OVERALL RISK SCORE = MODERATE

Key For Ratings					
Human Uses/Ecol. Values		Existing Condition		All others	
Very High	■	Poor	🟧	High	🟧
High	▩	Fair	🟫	Moderate	🟫
Moderate	▨	Good	🟨	Low	🟨
Low	□	Very Good	⬜	Very Low	⬜

HUMAN USES AND ECOLOGICAL VALUES

			Bathing	Shellfish collection	Natural character, aesthetic	Boating	Fishing/hunting	Waste assimilation	Birds	Vegetation	Other Biota	Fish
Habitat Type		Estuary Water	■	▨	■	■	■	■	■	▩	■	■
		Estuary Soft Mud	□	▨	■		▨	▩	■	▨	▨	▩
		Estuary Firm Mud/Sand	▩	▨	■		■	■	■	▩	▩	▩
		Estuary Gravel/Cobble/Rock	▩	□	■		■	□	■	▩	▩	▩
		Aquatic Macrophytes			■		□	▩	■	■	▩	▩
		Biogenic (living) Structures		▨	▨				■	▨	▨	▩
		Estuary Saltmarsh			▩		■	■	■	■	■	▩
		Terrestrial Margin			■		■	■	■	▨	■	
		Stream & River Mouths	■		■	▨	■	▩	■	■	■	■
		OVERALL RATING	■	▨	■	■	■	■	■	▩	■	■
ISSUE		MONITORING INDICATORS (+overall sensitivity of indicator to stressor presence)	LIKELIHOOD OF ISSUE AFFECTING USES / VALUES									
Eutrophication	🟫	Chlorophyll-*a* in Water	▩	▩	▩	□	▩	■	▩	□	▩	▩
		🟧 Macroalgal Condition Rating (% cover)	▩	▩	■	▩	▩	■	■	■	■	■
		Benthic Microalgal Mats	□	■	▩	□	■	□	▩	■	■	■
		Dissolved Oxygen in Water	□	■	▩	□	■	□	▩	■	■	■
		🟫 Oxygen in Sediment (RPD depth)/Smell	■	■	■	▩	■	■	■	■	■	■
		🟫 Nutrients	□	▩	□	□	▩	■	▩	▩	□	▩
		Sediment Organic Carbon	□	■	□	□	▩	■	□	■	■	□
		Macrophyte Loss	□	□	■	□	▩	■	■	■	■	■
		Macroinvertebrates	□	■	▩	□	■	□	■	▩	■	■
		Phytoplankton Blooms	▩	▩	▩	□	▩	▩	▨	□	▨	▩
Sediment	🟧	🟧 Muddiness (% cover of soft mud)	■	■	■	▩	■	■	▨	■	■	■
		🟫 Sedimentation rate	▩	▩	▩	▨	■	■	▨	■	■	■
		🟧 Clarity	▩	▩	▩	▩	■	■	▨	■	■	■
		Macrophyte Loss	□	□	■	□	▩	■	■	■	■	■
		Sediment Grain Size	■	■	□	□	▩	▨	▩	▩	▩	▩
		Macroinvertebrates	□	■	▩	□	■	□	■	▩	■	■
Disease	🟫	🟧 Faecal Indicators	■	■	□	□	□	■	□	□	□	□
Toxicity	🟨	🟫 Heavy Metals	□	■	□	□	□	■	▩	▩	▩	▩
		🟨 SVOCs	□	■	□	□	□	■	▩	▩	▩	▩
		Toxic algae	■	■	□	□	▩	□	▨	□	▨	▩
Habitat Loss	🟧	🟧 Substrate	□	□	■	□	■	■	■	■	■	■
		🟧 Macrophytes (Seagrass)	▩	▩	■	□	▩	■	■	■	■	■
		🟧 Saltmarsh	□	□	■	□	■	■	■	■	■	■
		🟧 Vegetated Terrestrial Margin	□	□	■	□	■	■	▩	▩	▩	▩
		🟫 Birds	□	□	■	□	■	□	■	■	■	■
		Fish	□	■	□	▩	■	□	■	□	■	■
		🟫 Invasive species	■	▩	▨	□	▨	▩	▨	▩	▩	□
		Benthic invertebrates	□	■	□	□	■	□	■	▩	■	■
		Shellfish	□	■	□	□	■	□	■	□	■	■
		🟧 Sea Level	□	▩	□	□	□	□	▩	▩	▩	▩



PRESENCE OF STRESSORS

EXPRESSION OF CONDITIONS

RISK OF STRESSOR AFFECTING INDICATOR

8. MONITORING AND MANAGEMENT

Issues, Causes, and Recommended Management and Monitoring

Sedimentation

Condition ratings indicate the estuary is too muddy and is infilling rapidly. If sediment inputs are not reduced, the estuary will become a saline swamp in the next few hundred years.

The main cause is runoff from land disturbance in the catchment and shoreline erosion. This load is likely to increase with predicted increased storm runoff associated with climate change and predicted accelerated sea level rise.

To address this issue it is recommended that **catchment sediment inputs be reduced to a level that maintains the estuary sedimentation rate below 2.0mm/year**. This process should involve the production of a long-term catchment sediment budget that identifies areas of high sediment release in the catchment, i.e. sediment "hot spot" areas. Meeting the target sedimentation rate of 2mm/yr will involve the reduction of "hot spot" sediment yields to appropriate levels.

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Continue to map the extent and condition of the major estuary habitats at 5 yearly intervals (i.e. Broad Scale Habitat Mapping).
- Continue to monitor the sedimentation rate in the estuary annually using plates buried in representative areas.
- Continue to monitor the condition of the dominant habitat type in the estuary at 5 year intervals following the completion of a 3-4 year baseline survey (i.e. Fine Scale Monitoring).
- Monitor the major sediment inputs to the estuary, including high and low flow periods, in sufficient detail to determine annual sediment budgets.

Habitat Loss/Degradation

Extensive areas of valuable estuary habitat, important for the health of the estuary, have been lost. These should be restored where possible or the estuary will continue to function well below its full potential.

The main causes are reclamation of saltmarsh, and terrestrial margin modification for urban and agricultural development (primarily historical), excessive sedimentation, and human/animal presence disturbing wildlife. In the future, this loss is likely to be further exacerbated by predicted accelerated sea level rise associated with climate change as many structures along the margins restrict the movement of these habitats inland.

To address this issue it is recommended that **important degraded areas be restored and existing high value saltmarsh habitat be allowed to migrate inland as sea level rises** as follows:

- Identify those areas of degraded habitat which, if restored, would lead to a significant increase in estuary functioning ability (particularly the terrestrial margin, saltmarsh, seagrass, raised sand banks, shellfish beds, and muddy tidal flats).
- Develop restoration plans and undertake restoration of these priority areas in a staged manner.
- Protect and enhance important bird roosting and nesting areas through initiatives such as predator control and managed access.
- Identify low lying land areas likely to be inundated by sea level rise and plan for changing human use, vegetation and wildlife needs.
- Develop long term plans to maintain or improve estuary function by ensuring inland habitat migration as a result of sea level rise. Remove artificial barriers in key locations.

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Continue to map the extent and condition of the major estuary habitats at 5 yearly intervals (i.e. Broad Scale Habitat Mapping).
- Continue to monitor the sedimentation rate in the estuary annually using plates buried in representative areas.

Disease Risk (Shellfish Consumption and Bathing)

Shellfish in the estuary are currently unfit for human consumption due to their excessive faecal bacterial content and high disease risk. Disease risk also restricts bathing in the estuary during high river flow periods. Such degradation seriously diminishes human use values and consequently needs to be reversed.

The main causes are the Bells Island wastewater treatment plant discharge, runoff from urban areas (particularly dog and duck faeces as well as imperfections in the sewerage network) and runoff from sheep, beef and dairy farms. Runoff is likely to be exacerbated by predicted increased storm runoff associated with climate change.

To address this issue it is recommended that **catchment faecal coliform inputs be reduced to a level that allows shellfish consumption and bathing in the estuary**. This process should involve the production of a long-term catchment faecal bacterial budget that identifies areas of high faecal bacterial release in the catchment, i.e. faecal bacterial "hot spot" areas. Meeting the target level should involve reduction in "hot spot" yields to appropriate levels. Because the Bells Island WTP discharge is the largest and most regular source of faecal bacteria to the estuary, ensure discharge limits meet shellfish criteria prior to impacting major shellfish beds in the estuary (e.g. within 100m-500m from the outfall).

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Monitor the major faecal bacterial inputs to the estuary, including high and low flow periods, in sufficient detail to determine annual faecal bacterial budgets.
- Monitor shellfish and bathing disease risk at key estuary locations during both high and low river flow periods.

Issues, Causes, and Recommended Management and Monitoring

Eutrophication (Excessive Nutrients)

Waimea Estuary shows little sign of excessive nutrients (i.e. nuisance macroalgal or phytoplankton blooms) except for around the mouths of the Waimea River and the various small streams that enter the estuary. Such localised eutrophication needs to be minimised as it reduces estuary values in such areas and serves as a warning of the potential for more widespread problems if nutrient loads were to increase.

The likely main cause is runoff from urban areas and sheep, beef and dairy farms and is likely to be exacerbated by predicted increased storm runoff associated with climate change.

To address this issue it is recommended that **catchment nitrogen inputs be maintained at a level below that which causes nuisance conditions in the estuary** (i.e. areal N loading less than 50 $mg.m^2.d^{-1}$). This process should involve the production of a long-term catchment nutrient budget that identifies areas of high nutrient release in the catchment, i.e. nutrient "hot spot" areas. Meeting the target level should involve the reduction of "hot spot" nutrient yields to appropriate levels.

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Monitor the major nutrient inputs to the estuary, including high and low flow periods, in sufficient detail to determine annual nutrient budgets.
- Map the presence of nuisance macroalgal conditions and sediment oxygenation (RPD depth) at 5 yearly intervals (i.e. Broad Scale Macroalgal Mapping).
- Monitor the condition of the dominant habitat type in the estuary at 5 year intervals following the completion of a 3-4 year baseline survey (i.e. Fine Scale Monitoring).

Toxicity

Waimea Estuary shows little sign of excessive toxicants except for around of small urban streams and discharges that enter the estuary. Such localised toxicity needs to be minimised as it reduces estuary values in such areas and serves as a warning of the potential for more widespread problems if toxicant loads were to increase.

The main cause is stormwater runoff from urban and industrial areas and is likely to be exacerbated by predicted increased storm runoff associated with climate change.

To address this issue it is recommended that the cumulative effects from **all urban and industrial stormwater and effluent discharges to streams in the catchment meet ANZECC (2000) ISQG-low sediment toxicity criteria within 50m of the discharge outfall**. If there are problems in meeting these criteria then the process should involve the production of a long-term catchment toxicant budget that identifies areas of high toxicant release in the catchment, i.e. toxicant "hot spot" areas. Meeting the target level should involve the reduction of "hot spot" toxicant yields to appropriate levels.

To assess the ongoing condition and success of management actions the following monitoring is recommended:

- Monitor the major toxicant inputs to the estuary, including high and low flow periods, in sufficient detail to determine annual toxicant budgets.
- Continue to monitor sediment toxicant quality within 50m of all problem outfalls.
- Monitor the toxicant condition of the dominant habitat type in the estuary at 5 year intervals following the completion of a 3-4 year baseline survey (i.e. Fine Scale Monitoring).

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APPENDIX 1. MONITORING SUMMARY

WAIMEA INLET - MONITORING INFORMATION (source: Robertson and Stevens 2009)

A summary of relevant monitoring information is presented in the following table:

Category	Results
Broad Scale Habitat Mapping (2001, 2006, also retrospective mapping for 1946, 1985) Method: National Estuary Monitoring Protocol, NEMP (Robertson et al. 2002, incl. GIS layers)	In April 2001, the total estuary area was 3,206 ha (intertidal 2,793 ha, subtidal 457 ha), and included: • Unvegetated habitat dominated by sands/mud sands (1,105 ha), soft mud (1,140 ha), cobbles/gravel (252 ha). • Vegetated habitat was dominated by saltmarsh species; glasswort (*Sarcocornia quinqueflora*), searush (*Juncus kraussii*) and small areas of jointed wire rush (*Apodasmia similis*) (224 ha). Seagrass (*Zostera* sp) occupied 28 ha. • Beds of sabellariids (a polychaete worm that lives in thick-walled sand and shell fragment tubes) and the invasive Pacific oyster (*Crassostrea gigas*) occupied 1.7 ha and 32 ha respectively. • Macroalgal growth (dominated by *Enteromorpha* sp. and *Gracilaria* sp.) occupied 7 ha. Mapping of 1947 and 1988 habitats using historical aerial photographs indicated significant loss of saltmarsh habitat (86 ha), since 1946. The most recent mapping, 2006, shows that the area of soft mud has increased from 1,140 ha in 2001 to 1,541 ha in 2006 resulting in a reduction in firm muddy sand habitat. In addition, areas of herbfield (dominated by glasswort (*Sarcocornia quinqueflora*), increased from 124 ha to 154 ha, attributed in part to opening of the Traverse (an artificially closed embayment). Macroalgal growth occupied 32 ha.
Fine Scale Habitat Mapping (Feb 2001, April 2006). Method: National Estuary Monitoring Protocol, NEMP (Robertson et al. 2002)	In February 2001, 4 sites located in intertidal, dominant mid-low tide habitat (12 replicates at each site) were monitored. Results were as follows. • Grain Size; was dominated by sand (57-89%) with mud at approximately 9.6-40%. • Organic Content and Nutrients; organic carbon was low (<1%), total nitrogen (TN 279-783 mg/kg) was low-moderate and total phosphorus (TP 273-539 mg/kg) was also low-moderate. • Heavy Metals; were low with all values less than the ANZECC (2000) ISQG-Low trigger levels except for nickel at all four sites and chromium at one site. The elevated levels are attributed to erosional input of sediment from local catchments containing naturally high nickel and chromium concentrations, and are typical of other coastal and estuarine locations in the Nelson region. • Macro-invertebrates; infauna abundance and diversity was dominated by polychaetes and, to a lesser extent, bivalves. Mean abundance ranged from 2,148 to 5,463 m^{-2} and mean number of species from 10 to 13 per core. The spectrum of feeding groups recorded at these sites was typical of those generally encountered within New Zealand estuarine sediments. Results of the 2006 fine scale monitoring of the same sites indicate little change since 2006.
Fine Scale Monitoring (11-29 Jan 1988) Method: Davidson and Moffatt (1990)	Includes biological monitoring only (except for a few salinity measurements) and was undertaken between 11 and 29 January 1988. It included the following: • **Intertidal and subtidal macro-invertebrates;** sediment cores or quadrats or transects sampled from all major habitats (57 intertidal and 4 subtidal sites). Data showed that the highest number of species were recorded in low-midwater gravel/cobble and seagrass habitats - mean=17 species. Mean species numbers at other habitats were 12 for mud and fine sand, 5 for saltmarsh, 11 for subtidal, 4 for high water flats, and 3 for mobile sand. Abundance of macro-invertebrates was greatest in the gravel/cobble sites (mean 19,756 m^{-2}). Mean abundance (per m^2) at other habitats were 2,629 for mud, 1,660 for seagrass, 1,375 for fine sand, 8,358 for saltmarsh, 3,876 for subtidal, 483 for high water flats, and 93 for mobile sand. The high abundance and diversity at the gravel cobble sites is important given the moderate extent of this substrate type in the estuary (200 ha or 6% of the estuary area in 1988). However, the dominant sand/mudflat /seagrass habitat (60% of estuary) also had significant numbers of species and abundances and has therefore been chosen as the primary habitat for longterm monitoring. • **Fish;** SCUBA and liaison with fishermen was used to assess fishlife in the estuary. Results recorded a high number of marine species (31), 18 of which were regarded as commercial species. Data do not include abundance. • **Birds**; Rated as "outstanding" value partly as a result of its variety of birdlife (Walker 1987). Results showed Waimea is of most significance regionally for 3 groups of birds: waders (e.g. oystercatchers, godwits, knots, and dotterels); herons, egrets and spoonbills; and rails, crakes and bitterns.
Drains - TDC Sediment Monitoring Aug 2004	In August 2004 TDC monitoring of potential toxicants in sediments near and within drains discharging to the Waimea Estuary near Richmond showed some exceedances of ANZECC sediment criteria for arsenic, copper, lead, zinc, polycyclic aromatic hydrocarbons (PAHs) and tributyl tin (TBT).
Consent Monitoring	**Nelson Pine Industries Limited Discharges** Nelson Pine has two consents that authorise the discharge of contaminants to the air, and one resource consent to discharge stormwater into the Waimea Estuary. Nelson Pine's air discharge consent requires annual monitoring of sediments and inter-tidal biota in the Waimea Estuary for the purpose of assessing the impact of formaldehyde and ammonia on the estuary ecosystem (e.g. Dunmore 2008). No exceedences were recorded in concentrations of formaldehyde or the other measures required under the consents. No stormwater discharge monitoring occurred during the period.

APPENDIX 1. MONITORING SUMMARY

WAIMEA INLET - MONITORING INFORMATION (source: Robertson and Stevens 2009)

Category	Results
Consent Monitoring	**Nelson (Bell Island) Regional Wastewater Outfall discharge** Outfall discharges to the main channel on the outgoing tide in a well-flushed area near the estuary mouth. Monitoring of 11 sediment sites, all located within 1 km of the outfall (6 upstream and the rest downstream), at 5 yearly intervals since 1991. The results indicate the effluent discharge has not resulted in any significant eutrophication of benthic habitats, and that rapid flushing of the estuary sees localised nutrient enrichment of receiving waters quickly return to background concentrations (within 1.6 km from the outfall) (Gillespie et al. 2001a, Gillespie et al. 2001b). The most recent available receiving water monitoring results showed dilution of nutrients to levels below which eutrophication is likely within 500m of the outfall (Gillespie et al. 2006). In addition, studies of faecal indicator bacteria concentrations in shellfish indicate that the inlet (with the exception of the immediate mixing zone down current from the Bell Island wastewater outfall) is suitable for contact recreational activities, but unsuitable for gathering shellfish for human consumption (Gillespie et al. 2006). **Discharge of Biosolids on Rabbit Island** Nelson Regional Sewage Business Unit has resource consent to discharge stabilised sludge (biosolids from Bells Island treatment plant) to 1000 ha of forest land on Rabbit Island (<7.8 t/ha, once every 3yrs and <40mm depth/application). **Dynea NZ Limited Discharge** Dynea NZ Ltd has resource consent to discharge contaminants into the air from the production of phenol and formaldehyde resins and resource consent to discharge stormwater into the Waimea Estuary. Over the 2006/2007 year all stormwater was collected and recycled back into the plant and used in the production of phenolic and formaldehyde resins. There was no discharge into the Waimea Inlet.

WAIMEA INLET CONDITION RATINGS

Issue	Indicator (result)	Rating 2001	Rating 2006
Sedimentation	Soft Mud Area 2001: 42%; 2006: 55%.	POOR	POOR
	Sedimentation Rate (monitoring initiated in 2009)	Not Measured	Not Measured
	Increase in Area Soft Mud (400ha (26%) increase since 2001)	Baseline Year	POOR
Eutrophication	Nuisance Macroalgal Cover 2001: 0.3%; 2006: 1.1%	VERY GOOD	VERY GOOD
	Organic and Nutrient Enrichment	VERY GOOD-GOOD	VERY GOOD-GOOD
	Redox Profile	Not Measured	Not Measured
	Phytoplankton Blooms (upper estuary)	VERY GOOD	VERY GOOD
Toxins	Contamination of Estuary Sediments	VERY GOOD-GOOD	VERY GOOD-GOOD
Range of Issues	Macro-invertebrates (BCCR = 1.3 - 3.3)	SLIGHTLY POLLUTED	SLIGHTLY POLLUTED
Habitat	Saltmarsh Area 2001, 8.3%; 2006, 9.3% of intertidal area	MODERATE	MODERATE
	Seagrass Area 2001, 0.8%; 2006, 0.9% of intertidal area	POOR	POOR
	Vegetated Terrestrial Buffer	POOR	POOR
Habitat Loss	Saltmarsh Area Decline (6% loss 1946 to 2001, no loss since)	FAIR	VERY GOOD
	Seagrass Area Decline (1988-2001: 30ha 52%; 2001-06: 7ha 25%)	POOR	POOR

MONITORING RECOMMENDATIONS

Issues	Lack of information, particularly a vulnerability assessment (to identify the main drivers of estuary issues) and baseline monitoring. Sedimentation (possibly related to *Spartina* removal). Sea level rise. Point and nonpoint discharges. Weeds and pests. Past reclamation and toxicity.
Monitoring	Undertake Vulnerability Assessment. Map intensive landuse (5 yearly). Broad scale habitat map (5 yearly). Fine scale phys/chem/biota in sediments 5 yearly (after 3-4yr baseline). Sedimentation rate monitoring.
Management	Requires vulnerability assessment prior to finalising management options (this will identify the main sources of sediment, nutrients, organic matter, metals and disease-risk). Limit main inputs of fine sediment, nutrients and disease-risk indicators. Plan for estuary expansion with sea level rise.

APPENDIX 2. MACROALGAL MAPPING

MACROALGAL COVER

To assist with the assessment of eutrophication, the percentage cover of intertidal macroalgae in Waimea Inlet was mapped in October 2009. This is because in nutrient-enriched estuaries certain types of macroalgae can grow to nuisance levels causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota. The macroalgae mapping procedure, originally described for use in NZ estuaries by Robertson et al. (2002), combines ground-truthing, aerial photography, and ArcMap 9.3 GIS-based digital mapping to create a GIS layer of macroalgal cover in the estuary (e.g. Robertson and Stevens 2007).

The results are presented in Table A2.1 below and (Figure A2.1) as the percentage cover of macroalgae within the estuary. The macroalgal condition rating (presented below) is used to assess estuary condition and recommend management actions.

MACROALGAE CONDITION RATING

A continuous index (the macroalgae coefficient - MC) has been developed to rate macroalgal condition based on the percentage cover of macroalgae in defined categories using the following equation: ***MC=((0 x %macroalgal cover <1%)+(0.5 x %cover 1-5%)+(1 x %cover 5-10%)+(3 x %cover 10-20%)+(4.5 x %cover 20-50%)+(6 x %cover 50-80%)+(7.5 x %cover >80%))/100.*** Overriding the MC is the presence of either nuisance conditions within the estuary, or where >5% of the intertidal area has macroalgal cover >50%. In these situations the estuary is given a minimum rating of FAIR and should be monitored annually with an Evaluation & Response Plan initiated.

MACROALGAE CONDITION RATING

RATING	DEFINITION (+Macroalgae Coefficient)	RECOMMENDED RESPONSE
Over-riding rating: Fair	Nuisance conditions exist, or >50% cover over >5% of estuary	Monitor yearly. Initiate Evaluation & Response Plan
Very Good	Very Low (0.0 - 0.2)	Monitor at 5 year intervals after baseline established
Good	Low (0.2 - 0.8)	Monitor at 5 year intervals after baseline established
	Low Low-Moderate (0.8 - 1.5)	Monitor at 5 year intervals after baseline established
Fair	Low-Moderate (1.5 - 2.2)	Monitor yearly. Initiate Evaluation & Response Plan
	Moderate (2.2 - 4.5)	Monitor yearly. Initiate Evaluation & Response Plan
Poor	High (4.5 - 7.0)	Monitor yearly. Initiate Evaluation & Response Plan
	Very High (>7.0)	Monitor yearly. Initiate Evaluation & Response Plan
Early Warning Trigger	Trend of increasing Macroalgae Coefficient	Initiate Evaluation and Response Plan

RESULTS

2009 MACROALGAL COVER CONDITION RATING
VERY GOOD

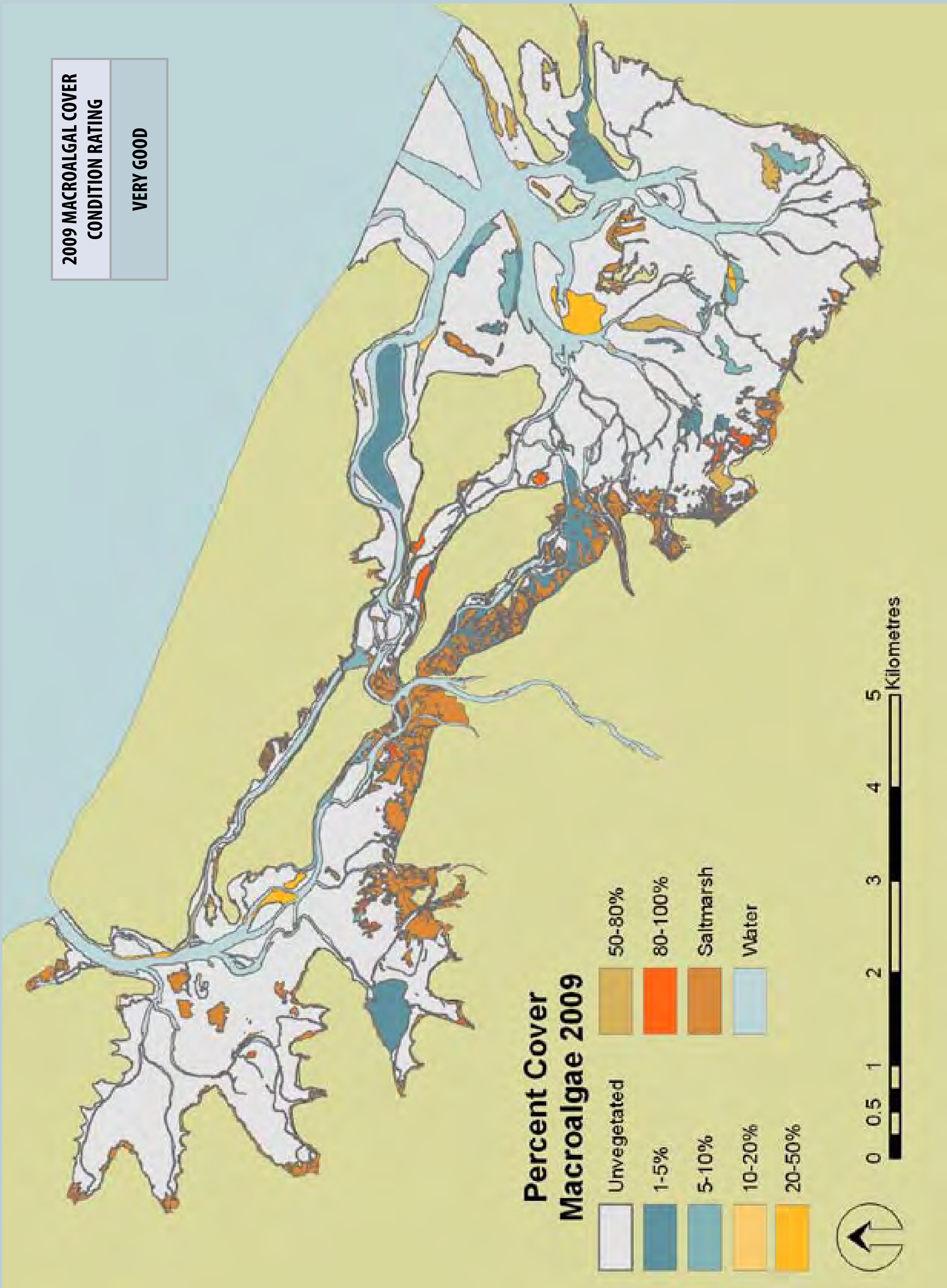
The 2009 Macroalgae Coefficient (MC) for the estuary was 0.2, which equates to a condition rating of "very good". *Gracilaria* was most common, often in dense beds, with *Enteromorpha* with *Ulva* (sea lettuce) more commonly present at lower densities.

Macroalgal cover was >50% over 56 Ha (2.2%) of the estuary. This cover was associated with nuisance conditions of anoxic muds and sulphide odours and were located near obvious inputs of nutrients to the estuary (Bells I. sewage outfall, bark processors seepage, Waimea River). While not yet at the threshold triggering a shift to a rating of "fair", macroalgal cover has extended since 2001 and should continue to be monitored.

Table A2.1. Summary of macroalgal cover results, October 2009.

MACROALGAE % Cover	Ha	%	Dominant species
Unvegetated	2233.4	89.0	-
1-5%	145.1	5.8	*Enteromorpha, Gracilaria, Ulva*
5-10%	42.7	1.7	*Gracilaria, Enteromorpha, Ulva*
10-20%	3.3	0.1	*Gracilaria, Enteromorpha, Ulva*
20-50%	28.1	1.1	*Ulva, Gracilaria, Enteromorpha*
50-80%	36.5	1.5	*Gracilaria, Enteromorpha, Ulva*
>80%	19.4	0.8	*Gracilaria, Enteromorpha, Ulva*
TOTAL	**2505**	**100**	

FIGURE A2.1 MACROALGAE PERCENT COVER



APPENDIX 3. REDOX POTENTIAL DISCONTINUITY MAPPING

REDOX POTENTIAL DISCONTINUITY (RPD)

Another important eutrophication indicator is the Redox Potential Discontinuity (RPD). The RPD is the grey layer which marks the transition between the oxygenated yellow-brown sediments near the surface and the deeper anoxic (reduced) black sediments. The RPD is an effective ecological barrier for most but not all sediment-dwelling species and a rising RPD will force most macrofauna towards the sediment surface to where oxygen is available. In addition, nutrient availability in estuaries is generally much greater where sediments are anoxic, with consequent exacerbation of the eutrophication process. Because the RPD provides a good early indicator of sediment eutrophication, the RPD depth in Waimea Inlet was mapped in October 2009.

The results are presented as a generalised map of the RPD depth within the estuary (Figure A3.1), and a summary table of the depths in different substrate types (Table A3.1). The RPD condition rating (presented below) is used to assess estuary condition and recommend management actions.

REDOX POTENTIAL DISCONTINUITY CONDITION RATING

RPD CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	5-10+cm depth below surface	Monitor at 5 year intervals after baseline established
Good	3-5cm depth below sediment surface	Monitor at 5 year intervals after baseline established
Fair	1-3cm depth below sediment surface	Post baseline, monitor 2 yearly. Initiate ERP
Poor	<1cm depth below sediment surface	Post baseline, monitor 2 yearly. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate ERP (Evaluation and Response Plan)

RESULTS

2009 RPD DEPTH CONDITION RATING

FAIR

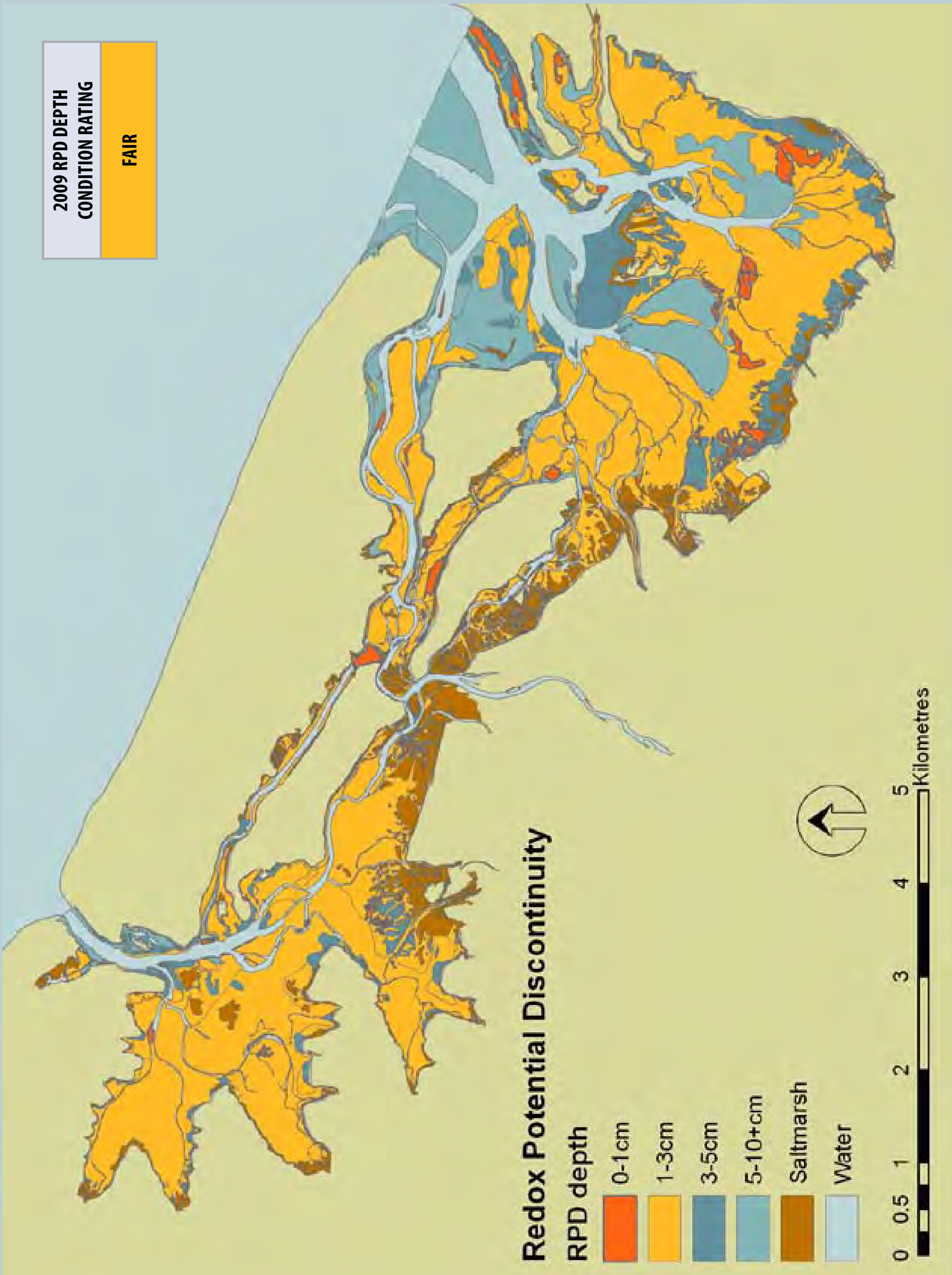
The 2009 RPD rating for the vast majority (68%) of the estuary was "fair" with the RPD depth in the 1-3cm depth range. This was most common in the fine and often soft muds that dominate the upper tidal reaches of both the eastern and western arms. In these areas the muds tended to be tightly packed with few spaces between the sediment particles. Consequently, only those sediments near the surface were being replenished by oxygen from tidal flows. It was also notable in these sediments that the RPD layer was not marked as it usually is by a clear colour change from grey to black. This is thought to be because sulphide reduction (which causes the black layer) is not occurring due to the relatively the low organic and nutrient content of the sediments.

Elsewhere in the estuary, poor conditions (RPD <1cm) were almost exclusively associated with the presence of thick macroalgal cover. These areas were located in both arms of the estuary but were more common in the eastern arm, particularly where *Gracilaria* was growing in soft mud. Although macroalgal growth was common around the discharge zone of the Bells Island WTP outfall, the sediment RDP depth was generally in the 1-5cm range because of the combined influence of sandy sediments and high flushing. This was a similar pattern throughout most of the lower estuary where sandy sediments, good flushing, and low organic content in the sediments all contribute to well oxygenated sediments.

Table A3.1 Percent of intertidal substrate in each RPD depth class, October 2009.

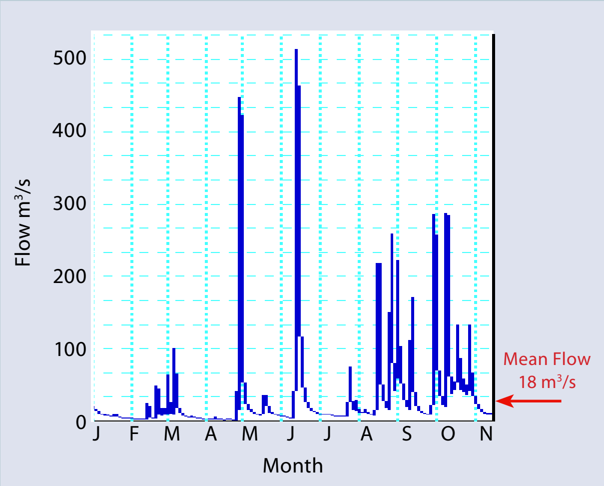
Rating	"POOR"	"FAIR"	"GOOD"	"VERY GOOD"
RPD Depth	<1cm	1-3cm	3-5cm	5-10+cm
Percent	3.2	68.3	12.0	16.5

FIGURE A3.1 REDOX POTENTIAL DISCONTINUITY MAPPING



APPENDIX 4. CATCHMENT FEATURES

Figure A5-1. Waimea River 2009 daily flow.



Several features of the catchment surrounding Waimea Inlet are important factors determining its condition and susceptibility to change. They are; rainfall, catchment rock type and soil, and dominant landuse - particularly the presence of intensive farming.

Rainfall:

Rainfall volume and frequency directly influence catchment runoff and freshwater flushing within the estuary. Figure A5-1 shows rainfall (annual mean=1495mm) causes relatively high and frequent elevated flows in the Waimea River, particularly during winter and spring. Consequently the river will regularly flush fine sediment, nutrients and pathogens into the estuary.

Rock Type and Soil:

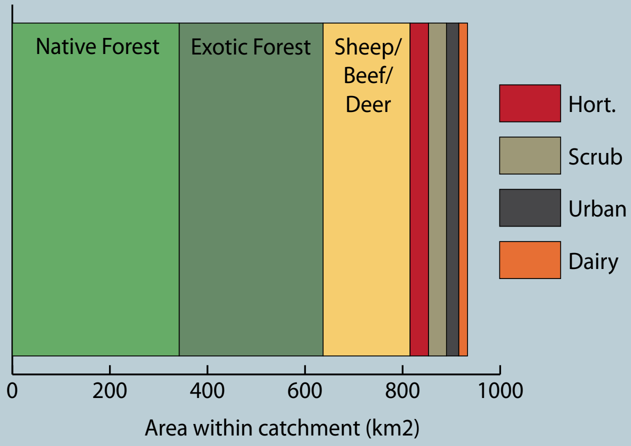
Catchment slope and geology influence erosion and runoff rates, with steep soft rock catchments generally contributing the highest loads. Figures A5-2 and A5-3 show that the relatively steep upper catchment comprises hard, low-fertility greywacke (66% of the catchment), while the low lying flat alluvial plains comprise well-drained soils formed from old sedimentary alluvium of greywacke, sand-, mud- or lime-stone. Fertile, deep, fine soils are present on the Waimea River plain (11% of the catchment), while historic glacial outwash in the moderately fertile Moutere gravels (22%) provide a source of fine clay silts to the estuary. Ultramafic rock in the upper catchment Dun Mountain 'mineral belt' contains metals such as copper, nickel and chromium. Consequently, fine sediment inputs are likely to be sourced primarily from the plains, while lower inputs from the upper catchment may contain naturally high metal concentrations.

Figure A5-2. Slope of the Waimea Inlet catchment.

Figure A5-3. Dominant soil types of the Waimea Inlet catchment.

APPENDIX 4. CATCHMENT FEATURES (CONT.)

Figure A5-4. Landuse in the Waimea Inlet catchment (data from LCDB2, 2000).



Dominant Landuse:
Landuse provides a good indication of catchment sediment nutrient and pathogen loads, the lowest inputs generally coming from forested catchments.

The catchment was dominated by native forest (37%) and exotic (mostly pine) plantations (32%) (Figures A5-4 and A5-5). Because the majority of the native forest was located in the steep, low fertility, upper catchment, and pine plantations and scrub dominated in the moderately sloping foothills (Figure A5-5), runoff from these areas is likely to be relatively clean. This will dilute river-borne inputs of nutrients, sediment and faecal bacteria from the intensively farmed lower catchment (Figure A5-6).

Intensive Farming:
Overall, ~20% of the catchment (mostly on the low lying Waimea Plains) is intensively developed, with high productivity grassland, horticulture (including vineyards) and rotational cropping. Pastoral farming (sheep, beef and deer) was the dominant landuse (19% of the catchment). Dairy farming accounted for only a small portion (2%) of the catchment (Figure A5-6), with 1645 cows at a low density of ~1 cow/ha.

Relatively clean runoff from the upper catchment is expected to strongly dilute any inputs, particularly in the Waimea River, while smaller streams draining only the lower catchment are expected to receive much less dilution and have higher concentrations.

The nutrient, faecal bacteria and sediment loads from the catchment have been estimated in Section 6.3.

Figure A5-5. Landuse in the Waimea Inlet catchment.

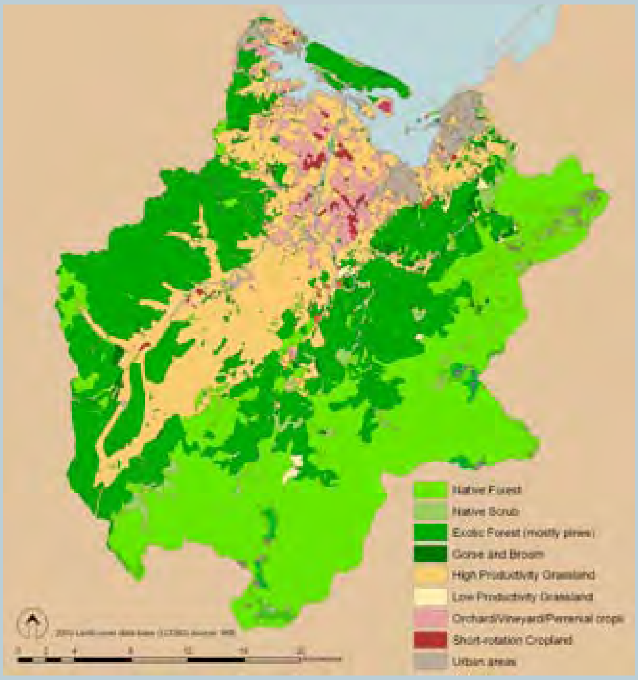
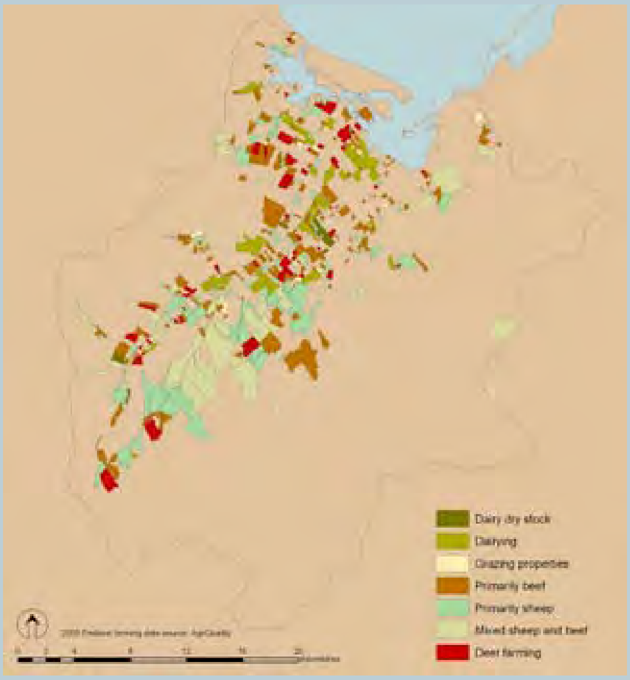
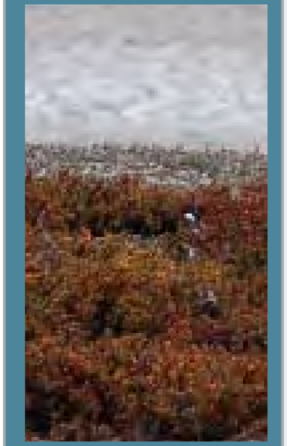


Figure A5-6. Location of pastoral farming within the Waimea Inlet catchment.

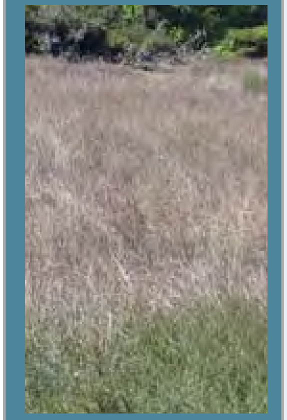


APPENDIX 5. ESTUARY HABITAT DETAILS

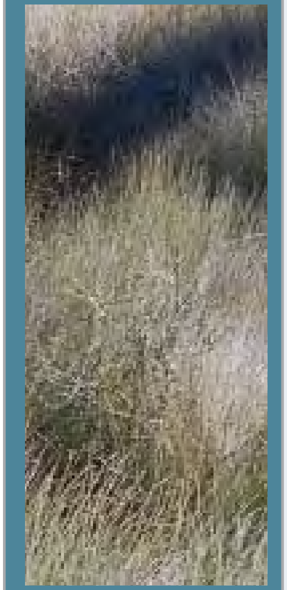
SALTMARSH HABITAT



Glasswort



Searush



Jointed wire rush

Description: A saltmarsh is classified as being the intertidal area of fine sediment that has been transported by water and is stabilised by vegetation (Boorman et al., 1998). Extensive saltmarshes tend to be present if the coastal plain is gently sloping and wide (Freidrichs and Perry 2001). In general, marsh grasses cannot survive below mean tide level (the midway point between MLW and MHW) and are outcompeted by terrestrial plants above spring high tide (Pethick 1984). Saltmarsh communities are ften present in distinct communities;

- a "rushland/sedge" community consisting of primarily searush (*Juncus kraussii*), oioi (*Apodasmia similis*) and three square (*Schoenoplectus pungens*);
- a "saltmarsh ribbonwood/rush" community consisting of a mix of saltmarsh ribbonwood (*Plagianthus divaricans*) and rushes;
- a "salt meadow" community consisting of small herb-like plants including, sea primrose (*Samolus repens*), remuremu (*Selliera radicans*), glasswort (*Sarcocornia quinqueflora*) and in more brackish areas batchelor's button (*Cotula coronapifolia*), leptinella (*Leptinella doica*), slender clubrush (*Isolepis cernua*) and arrow grass (*Triglochin striata*), and
- a "weed" community consisting of extensive patches of iceplant (*Carpobrotus edulis*), gorse and various introduced grasses, particularly tall fescue.

Importance: Saltmarsh is one of the most productive environments on earth, and serve as important nursery grounds and wildlife habitat. They provide nutrients to surrounding areas, fuelling other marine food webs. These dynamic ecosystems provide tremendous additional benefits for humans including flood and erosion control, water quality improvements, opportunities for recreation and for atmospheric gas regulation - estuaries tend to be "carbon sinks," since carbon dioxide is absorbed in the photosynthesis carried out by the prolific plant growth.

Threats: Tidal saltmarshes have the ability to respond rapidly to physical stressors, and their condition is often a dynamic balance between relative sea level rise, sediment supply and the frequency/duration of inundation (Freidrichs and Perry 2001). However, if sea level rises too much, or the sediment supply or inundation through flooding is excessive, then the balance can be upset and the saltmarsh is lost or its condition deteriorates. This balance varies between different types of estuaries but their response centres around how each reacts to sediment inputs and inundation (the latter is particularly important in face of predicted accelerated sea level rise through global warming).

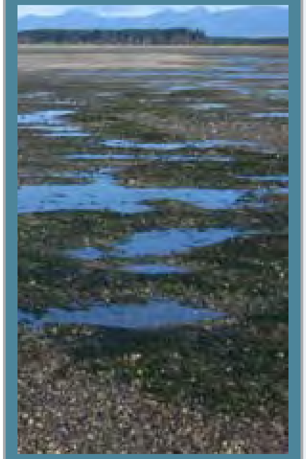
- **Sedimentation**: Sedimentation within saltmarshes is relatively high [approximately 5 times that of adjacent unvegetated flats (Eisma and Dijkema 1997)] with most of the sediment depositing close to the sediment source (e.g. tidal creek) or spread evenly if sourced from the main body of the estuary. Sedimentation rates increase with grass stem density and because most New Zealand saltmarsh plants tend to grow in dense stands [e.g. searush (*Juncus kraussii*) and oioi (*Apodasmia similis*)], sedimentation rates in NZ saltmarsh are expected to be relatively high. The increase in sedimentation and subsurface plant growth results in an elevation of bed level for most NZ estuaries.
- **Inundation**: The vulnerability to inundation of saltmarsh habitat in tidal lagoon estuaries of New Zealand is mainly from sea level rise. There are two processes by which sea level can increase relative to the marsh surface: (1) sea level rises because of increases in the volume of the oceans, and (2) the marsh surface sinks (subsides) because of soil compaction and other geologic processes [coastal fringe marshes with a thin layer of sediment deposits have low rates of sinking, whereas areas underlain with thick, unconsolidated sediments have higher subsidence rates (e.g. Mississippi delta)]. Under current conditions, we know that the majority of marsh environments tend to keep pace with sea level changes due to sedimentation and subsurface plant growth (Bartholdy, 2000). These environments are capable of responding very rapidly to changing conditions, be it sea level rise or alteration of current patterns. However, under an accelerated rate of sea-level rise it is expected that bed elevation through sedimentation will lag further behind relative sea-level rise and plant stress will increase until the plants die, the soil volume collapses, and the marsh becomes submerged. The vulnerability to saltmarsh decline is expected to vary between estuaries with different tidal ranges. The most vulnerable are the microtidal estuaries (those with a tidal range of less than 2 m) because a relatively small increase in sea level or decrease in sedimentation rate can submerge the marsh vegetation to a level that is too stressful for survival. Conversely, when sedimentation is high, microtidal marshes will expand seaward more quickly than systems in higher tidal ranges. This is because it takes relatively little upward growth to significantly reduce submersion, causing available suspended sediment to be deposited further seaward. The potential for massive marsh expansion in such systems in the presence of plentiful sediment is highlighted by historical mapping studies (Wells and Coleman 1987) which document horizontal marsh expansion rates of hundreds of meters per year on the Mississippi Delta, soon followed by equally remarkable marsh loss rates once the sediment supply decreased.

Saltmarsh is also vulnerable to increased nutrient inputs, particularly nitrogen. Added nutrients stimulate saltmarsh growth but, if excessive, may lower dissolved oxygen levels, change food web dynamics, alter community composition and stimulate the growth of algae and weeds (Deegan 2002, Pennings et al. 2002).

In addition, although the Water and Soil Conservation Act (1967) and the Resource Management Act (1991) introduced wide-ranging controls over the destruction of salt marshes and other wetlands, since 1967 the legacy of detrimental saltmarsh impacts remains visible in the undersized culverts below roads, railways and stopbanks that prevent adequate salt-water flow into these environments, and drainage and reclamation. The reduced salinity alters the plant community and facilitates the spread of the invasive species (e.g. reed *Phragmites australis*), which outcompetes other saltmarsh vegetation. Because of its lower habitat value for many species, biodiversity is reduced in areas where *Phragmites* becomes dominant. Boardwalks of jetties that span the width of the saltmarsh shade the vegetation and can cause reduced growth rates or death of the plants.

TECHNICAL ANNEX: ESTUARY DETAILS (CONTINUED)

SEAGRASS BEDS (AQUATIC MACROPHYTES)



Description: New Zealand has primarily one species of seagrass, *(Zostera muelleri)*, called eelgrass. Apart from its common intertidal habitat, eelgrass can also grow as subtidal fringes in New Zealand estuaries if water clarity is high enough (i.e. there is sufficient light penetration). Eelgrass can grow in bottom sediments ranging from coarse sand to mud.

Importance: New Zealand eelgrass beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. They are one of the most productive marine habitat types and rival the productivity of intensively managed farmland (Thayer et al. 1984). They are also important for their role as a forerunner for the establishment of a saltmarsh on tidal mudflats. They promote sedimentation of muds and increasingly fertile underlying soils. When the soil becomes too fertile, the eelgrass can no longer grow, but saltmarsh plants can (often beginning with salt meadow communities like glasswort, remuremu and sea primrose and/or searush communities).

Threats: These submerged plants need sunlight to survive. Decreased water clarity due to elevated sediment inputs and re-suspension are a direct threat, as is direct smothering through excess sediment. Another widespread current threat comes from the excess input of nitrogen to estuaries which stimulate the growth of macroalgae and phytoplankton that shade out the seagrass. In terms of global warming impacts, it is predicted that eelgrass may be detrimentally affected by a rise in sea temperature (its tolerance to low salinities decreases as temperature increases - Burns et al. 1990). Sea level rise may also be detrimental in that plants become light limited as water depth increases. Seagrass beds are difficult to restore once they have become degraded.

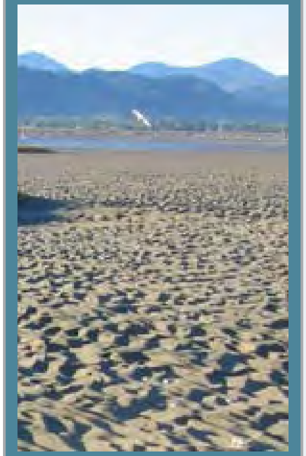
MUD HABITAT

Description: Mud flats are areas of unconsolidated fine-grained sediments that are either unvegetated or sparsely to densely vegetated by algae and/or diatoms. They are found in sheltered environments and support high biodiversity (snails, crabs, burrowing polychaete worms, shellfish and other macroinvertebrates). Most of the organisms inhabit the upper 10cm, because below that level, mud often becomes anoxic (low in oxygen or oxygen depleted). To adjust to these harsh physical conditions, many organisms build and maintain burrows or tubes to access oxygen in the air or water, or have adaptations such as siphons.

Importance: They provide a number of important ecosystem services including; primary and secondary production; habitat for polychaetes, crustaceans, flatfish and shellfish; refuge and nursery habitat for juvenile fish; and interception, uptake and processing of nutrients and contaminants from watershed drainage. Bacteria living in the sediments of estuaries can also help to break down certain pollutants.

Threats: The major threats are from agricultural and urban development and include: excessive sedimentation leading to infilling, contamination with toxicants and disease causing microbes, reclamation and drainage, building of structures, and spread of introduced species, e.g. Pacific oyster.

SAND HABITAT



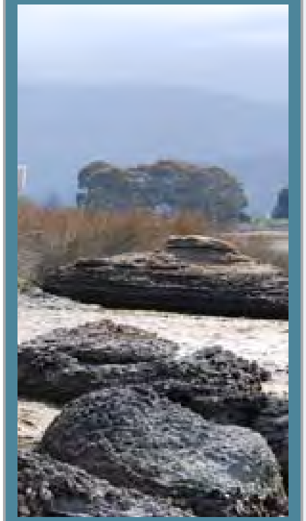
Description: This habitat includes both dune areas near the mouth and along the sand barrier spits, as well as extensive areas of sand flats in the main basin (which often include a mud or silt component and shell fragments) and sandy channel areas. In these highly dynamic environments, sand is moved by tides, winds, and storm surges, and this movement is responsible for shaping these habitats. Sand flats typically occur in higher energy areas than mud flats where the substrate is predominantly sand and is exposed to sorting from wave and current action.

Importance: Sand habitat tends to be the area most intensively used by humans for recreation. Shellfish, polychaetes, crustaceans and young fish are typical animals that inhabit sand flats. Sand channels generally occur in open, deeper areas where channels form. These open areas are typically inhabited by bivalve shellfish, polychaetes, young flat fish, and sand loving algae. They are also important for provision of refugia and food for anadromous, resident, and marine fishes, and transport of sediments.

Threats: Major threats are excessive sedimentation leading to muddy sediments and/or infilling, contamination with toxicants and disease causing microbes, reclamation and drainage, building of structures, and spread of introduced species. In addition, commercial and residential development on sand dunes, as well as by developing just landward of dunes, humans have prevented the natural movement of these landforms away from the sea. Trampling and grazing of dune vegetation can also lead to dune demise. Erosion can threaten sand beaches, especially when natural migration of sand is disrupted by jetties, groins, and seawalls. Off-road vehicles threaten sandy beach and sand flat inhabitants by compacting the sand, making burying and burrowing more difficult. These vehicles can also crush organisms that live just below the surface, and disturb crabs and nesting birds. Sand mining for beach nourishment poses a threat to communities inhabiting sandy bottoms, especially if large quantities of sand are continually removed from one area.

TECHNICAL ANNEX: ESTUARY DETAILS (CONTINUED)

GRAVEL, COBBLE AND ROCK HABITAT



Rock habitat.

Description: Includes a range of larger material from solid rock ledges and boulders to cobble and gravel. This size regime strongly influences the composition of the biological community in the rocky habitat. A typical intertidal rock ledge community, for example, includes attached organisms with relatively long life spans (such as brown algae, anemones, barnacles, and mussels), while cobble beaches that are frequently disturbed by wave action tend to host small and ephemeral creatures, such as amphipods and isopods (e.g. beach hoppers and scuds). Rocky subtidal habitats commonly harbour seaweeds, crabs, sea urchins, and a variety of fish species. Some of the organisms found attached to rock ledges and boulders include mussels, oysters, limpets, chitons, and anemones. Finally, the biota of subtidal rocky habitats is distinct—many of the species found in these habitat types can only be found attached to rocky substrates.

Importance: The physical structure provided by both the rocks, and the plants and animals that adhere to them, provide valuable habitat for many other organisms, especially small invertebrates and juvenile fish. This structure is important for spawning and for providing protection from predation by larger organisms that cannot access the small spaces between rocks. Seaweed in the subtidal zone and the other algae in the intertidal zone are vitally important because they provide shelter and structure. Intertidal algae protect snails, mussels, barnacles, and crabs from exposure to sun, wind, rain, and predators when the tide is low. Because of their high productivity, algae in these rocky habitats also serve as important food source. The high abundance of animals that occur in subtidal rocky habitats also support larger species such as diving birds and large fish and humans that target these habitat types while fishing.

Threats: Coastal and catchment development can degrade rocky intertidal habitats, so that sediments accumulate on rocky shores. Human presence can damage habitat through trampling or excessive harvest. Rocky intertidal shores have been the subject of scientific scrutiny for decades and recent shifts in species distributions (i.e., declines in cold-tolerant species and increases in the relative abundance of warmer water species), which are potentially linked to climate change, have been documented.

SHELLFISH BEDS (BIOGENIC STRUCTURES)

Pipi bed.

Description: In dense groupings, bivalve molluscs (e.g. mussels, cockles, oysters and pipi), form a habitat type known as shellfish beds. Small organisms, such as polychaete worms, juvenile crabs and snails find refuge in the spaces between the shells, while other organisms attach to the shells' hard surfaces, which provide an anchor unavailable in the surrounding soft sediments. Each species of bed-forming shellfish has different habitat requirements, which means that shellfish beds can be found in a range of depths, salinities, or substrates (surfaces, such as sand, rock, or mud).

Importance: Humans, crabs, fish, and seabirds all consume large quantities of shellfish. For coastal residents and tourists, collecting shellfish is an important pastime, while in some estuaries, shellfish beds support a significant commercial fishery. Through filter-feeding, shellfish improve water quality by removing suspended material and particulate pollutants from the water column. Shellfish beds also provide an important link between benthic (bottom) and pelagic (open water) habitats by capturing small food particles from the water column and transferring them to the benthos.

Threats: Intensification of landuse and excessive runoff of nutrients, sediment, pathogens and toxicants represent the largest threat to nearshore shellfish beds, through diminished water quality. Increased temperature through global warming is another significant threat. Overfishing of shellfish can also diminish their filtering function, potentially leading to increased turbidity (cloudiness due to sediments or other substances in the water) and diminished light penetration to the seafloor. Shellfish beds can be destroyed if they are dredged or if dredged material is deposited nearby or in upstream locations. Some introduced shellfish e.g. Pacific oyster can become nuisance organisms.

WATER COLUMN (SUBTIDAL AREA)

Mullet.

Description: The water column is a dynamic environment subject to waves, currents, tides, and riverine influences. In New Zealand estuaries it is generally well supplied with sunlight and consequently phytoplankton (tiny plants suspended in the water column) are major primary producers. Phytoplankton include a wide range of species, but are generally dominated by diatoms in healthy waters. The water column also includes a variety of animal life including; zooplankton (tiny animals suspended in the water column), fish and jellyfish.

Importance: Water is vital to the functioning of an estuary, providing dilution and flushing, transporting nutrients and sediments, and providing habitat and refuge for fish and shellfish and birds. Human use of estuaries almost always involves an aquatic component be it swimming, fishing, boating or aesthetic appreciation.

Threats: Non-point source pollution is currently the greatest threat to estuary water quality. Harmful algal blooms (HABs) (which are caused by a superabundance of toxin-producing planktonic plants known as dinoflagellates) are also becoming increasingly prominent along the New Zealand coast. HABs can lead to shellfish closures through risk of shellfish poisoning in humans. Overfishing may also strongly influence the species found in the water column. For example, the dramatic increases in the abundance of jellyfish in coastal waters has been linked to the depletion of fish stocks. Many jellies eat similar food items as fish, and food that was formerly consumed by fish is now available for jellyfish (Mills 2001). Global climate change, and the associated change in weather and current patterns, pose another threat to water column habitats.