Guidance Document: Nutrient Load Criteria to Limit Eutrophication in Three Typical New Zealand Estuary Types - ICOLL's, Tidal Lagoon, and Tidal River Estuaries.

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Catchment runoff and point source discharges can carry excessive nutrients to the coast. Excessive nutrients (nitrogen and phosphorus) lead to eutrophic coastal habitats, particularly estuaries and inshore coastal areas, which reduces human use and ecological values. Eutrophication is defined as "enrichment of water by nutrients, especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned" (Websters On-Line Dictionary).

Eutrophication causes changes in plant and animal communities, favouring rapidly reproducing opportunistic algal and animal species. Opportunistic algal species in particular can adversely affect ecosystems. For example, mass occurrences of phytoplankton and/or macroalgae and epiphytes often lead to the loss of long-lived seagrass species through direct displacement, or creation of sub-optimal growing conditions. When the nutrients fuelling excessive algal growth have been depleted, the algal blooms decay, leading to oxygen depletion, possible kills of fish and benthic invertebrates, and the formation of toxic hydrogen sulphide (H_2S).

As well as causing impacts on the ecosystem, eutrophication can also affect human activities. For example, algal blooms and decaying algae can clog fishing nets, create unsightly foam masses on beaches, and cause unpleasant smells that interfere with tourism and recreation. Although some algae produce toxins that can harm humans through consumption of contaminated shellfish, the link to nutrient enrichment is uncertain.

In many countries around the world, nutrient guidelines for coastal waters have been set or are close to being set. A summary of the various approaches is provided in Appendix 1. In Australia and New Zealand (NZ), the ANZECC (2000) guidelines, developed primarily for freshwaters, provide some precautionary and limited guidance for estuaries and marine waters. However, they are widely acknowledged as being inappropriate for NZ estuaries and coastal waters, particularly the common shallow well-flushed tidal lagoon and tidal river estuaries.

In NZ, significant eutrophication problems generally only occur in shallow estuaries and bays with restricted circulation. This is attributed to the fact that in well-flushed estuaries (e.g. tidal river and lagoon estuaries), the majority of the nutrient loads are flushed out to sea. In shallow intermittently open closed lakes or coastal lagoons (ICOLL's) where residence time often greater than 100 days - e.g. Waituna Lagoon, Southland, nutrient loads are retained to an increasing extent as water residence time increases.

As such, sensitivity to nutrient loads, and consequent eutrophication, is greatest in shallow ICOLL's. Sensitivity to eutrophication is in the moderate category for shallow tidal lagoon estuaries (water residence times <3 days and always open to sea - e.g. New River Estuary, Southland), and least sensitive in shallow tidal river estuaries with limited stratification (residence time < 0.1 day - e.g. Rowallan Burn, Southland). The following sections provide information to help identify appropriate nutrient load criteria for each of these three estuary types.

PROPOSED NUTRIENT LOAD CRITERIA FOR NZ ESTUARIES

1. ICOLL's - Most Sensitive to Nutrient Loads

Maintenance of a healthy rooted aquatic plant community (particularly seagrasses like *Ruppia* sp.) is considered the most appropriate guideline for ensuring no eutrophication of ICOLL's (Lagoon Technical Report 2011). To achieve this, co-management of both N and P is likely to be required given that nutrient limitation can vary with salinity, season, and/or plant species composition (Boesch 2002). Management options that aim to reduce only one nutrient should be considered with caution and need to extend beyond the sole consideration of limiting planktonic biomass.

Scanes (2012) examined 57 ICOLLs in New South Wales, Australia and assessed their condition as described by chlorophyll a, TN and TP, as well as the nutrient and sediment loads derived from their catchments. From this dataset, nutrient load criteria were derived to provide for "moderate environmental quality" (including maintenance of seagrass communities) as follows; 25 $mg.m^{-2}.d^{-1}$ for N, and 1.6 $mg.m^{-2}.d^{-1}$ for P.

A recent review of nutrient loading thresholds for NZ, Australian and overseas ICOLL's by Schallenberg and Schallenberg (2012), found that although variable factors such as water residence time, opening regime, fetch, and sediment characteristics will also affect the thresholds in specific systems, there was convergence with regard to nitrogen loading rates that negatively affect seagrass communities. Their review indicated N areal loading rates of <30 $mg.m^{-2}.d^{-1}$ were needed to safeguard seagrass communities in ICOLL's.

2. Tidal Lagoon Estuaries - Moderately Sensitive to Nutrient Loads

Maintenance of an estuary with a low abundance of nuisance macroalgae is considered the most appropriate guideline for ensuring no eutrophication of shallow tidal lagoon estuaries. These are estuaries with large basins that are mostly drained at low tide and where phytoplankton growth is limited by the high flushing rate. By meeting this criteria, a healthy seagrass community is expected to be maintained. While, a number of variables (e.g. tidal range, wind fetch, and sediment loads) can influence macroalgal growth in shallow estuaries, in general the major driver is considered to be nutrient loads. Management of nitrogen is recommended as tidal lagoon estuaries are generally nitrogen-limited with respect to the potential for the development of eutrophic conditions (USEPA 2010).

A review of available monitoring data for representative NZ shallow tidal lagoon estuaries with short residence times and variable areas of saltmarsh (Appendix 1, Figure 1), indicated that nuisance macroalgal blooms occur when N areal loads exceed ~50 $mg.m^{-2}.d^{-1}$ (Figure 1). This is consistent with guidelines and results for overseas estuaries as follows:

- 50 $mg.m^{-2}.d^{-1}$ guideline set by Heggie (2006) as a conservative estimate to avoid eutrophication and triggering of significant ecological changes for tidal lagoon estuaries of temperate Australia.
- Eelgrass loss began to occur at N loads above 18.2 $mg.m^{-2}.d^{-1}$ and eelgrass disappeared at 36.5 $mg.m^{-2}.d^{-1}$ (Latimer and Rego 2010), in New England estuarine systems.

3. Tidal River Estuaries - Moderately Sensitive to Nutrient Loads

Like tidal lagoon estuaries, maintenance of a low abundance of nuisance macroalgae is considered the most appropriate guideline for ensuring no eutrophication of shallow tidal river estuaries. These are estuaries with relatively narrow channels/basins, and where phytoplankton growth is very limited by the high flushing rate. Seagrass growth is often limited in such estuaries by low salinities and muddy conditions.

These estuaries are much less sensitive to nutrient inputs and available monitoring data indicates that nuisance macroalgal blooms do not occur until N areal loads exceed much higher loads (preliminary data indicates a load of approximately 750 $mg.m^{-2}.d^{-1}$ for such estuaries - Appendix 1, Figure 2). While such a limit appears appropriate to protect against nuisance blooms within tidal river estuaries, the supply of high concentrations of nutrients can still result in localised blooms of nuisance algae like *Bachelotia* in the nearshore coastal zone.

PROPOSED NUTRIENT LOAD CRITERIA FOR NZ ESTUARIES

Preliminary guidance for determining appropriate nutrient loading criteria to limit eutrophication symptoms in three typical NZ estuary types is proposed as follows:

Estuary Type	N Areal Load	P Areal Load
Shallow NZ ICOLL's	<30 mg.m^{-2}.d^{-1}	<1.5 mg.m^{-2}.d^{-1}
Shallow Tidal Lagoon Estuaries	<50 mg.m^{-2}.d^{-1}	Not applicable
Shallow Tidal River Estuaries:	<750 mg.m^{-2}.d^{-1}	Not applicable

Nitrogen has been identified as the element most limiting to algal production in most coastal marine ecosystems in the temperate zone and is therefore the preferred target for eutrophication management (Howarth and Marino 2006). In ICOLL's, which vary between marine and near-freshwater salinities, a co-limiting situation between N and P is expected and management of both N and P is likely to be required.

It is anticipated that the above criteria will facilitate decision-making in relation to setting appropriate nutrient loading criteria for Waituna Lagoon, Southland, and in particular help support the catchment nutrient load recommendations to be used in the Waituna Lagoon model scenarios. It is emphasised that the 2010 estimated N and P areal loads to Waituna Lagoon were approximately 50 mgN.m^{-2}.d^{-1} and 2 mgP.m^{-2}.d^{-1}, and therefore well above the preliminary criteria recommended for shallow NZ ICOLL's.

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APPENDIX 1: REVIEW OF INTERNATIONAL GUIDELINES FOR ESTUARY AND COASTAL WATERS

In many countries around the world, nutrient guidelines for coastal waters have been set or are close to being set. In the Central Europe area, guidelines were put in place in the 1990's to achieve in the order of 50% reductions in inputs of nitrogen and phosphorus from 1985 levels to areas affected or likely to be affected by eutrophication (OSPAR 2008). In 2005, six of nine reporting countries met the 50% reduction target for phosphorus, and three for nitrogen. In the US, the EPA is currently setting numeric criteria for estuaries and coastal waters (deadline August 2012). Currently, NZ has not set numeric nutrient guidelines for its estuaries and coastal waters.

Nitrogen has been identified as the element most limiting to algal production in most coastal marine ecosystems in the temperate zone and is therefore the preferred target for eutrophication management (Howarth and Marino 2006). In intermittently open/closed coastal lakes and lagoons (ICOLL's), which vary between marine and close to freshwater salinities, a co-limiting situation between N and P is expected (P limitation during the closed freshwater dominated period, and N limited during the open seawater dominated period).

Predictive methods for assessing the vulnerability of coastal ecosystems to eutrophication in other countries have primarily revolved around three main approaches:

- the setting of guidelines or thresholds based on available data and expert judgement,
- the establishment of empirical relationships, and
- the development of numerical modelling tools.

Guidelines or thresholds and empirical relationships (e.g. nutrient loads that cause eutrophication) are the most preferred methods for assessing eutrophication susceptibility and existing condition. Numerical modelling tools are available but are considered too complex and waterbody-specific for application in a broad-brush coastal risk assessment process.

In Australia and New Zealand, the ANZECC (2000) guidelines, developed primarily for freshwaters, provide some precautionary and limited guidance for estuaries and marine waters. However, the relevant ANZECC values are limited in scope, are very conservative when compared with European and US threshold values, and are widely acknowledged as being inappropriate for New Zealand estuaries and coastal waters. More recently, nutrient loading guidelines for Australian temperate estuaries have been put forward by Heggie (2006) and for Australian ICOLLs by Scanes (2012), which are more applicable to NZ conditions.

Internationally, simple thresholds for assessing the eutrophic status of estuaries and coastal waters (see Table 1 summary), similar to freshwater guidelines (OECD 1982), were developed by CSTT (1994, 1997 - Scotland), and more recently in Europe by OSPAR (2001, 2003) and the Swedish EPA (2002). In the US, more comprehensive guidelines have been developed which include both primary and secondary symptoms of eutrophication (Bricker et al. 1999). The primary symptoms are high levels of phytoplankton (as measured by chlorophyll a), epiphytes, and/or macroalgae. The presence of primary symptoms at high levels indicates that an estuary is in the first stages of displaying undesirable eutrophic conditions. The second, much more degraded state, occurs when secondary symptoms of depleted dissolved oxygen, sulphide-rich sediments, seagrass loss, and nuisance/toxic algal blooms begin to appear.

The primary and secondary symptom approach of the US (Bricker et al. 1999) is a comprehensive methodology for reliably detecting symptoms of eutrophication. However, it has a number of critical limitations for the shallow, macrotidal estuaries with very short residence times (<1 day) that typify many NZ tidal lagoon and river estuaries. Such limitations indicate a requirement for a modified approach for NZ estuaries. This is primarily because the US approach averages the scores of the three primary symptom expressions (phytoplankton, macroalgae and epiphytes) to define eutrophic status. However, phytoplankton is not a primary symptom in most NZ estuaries. Although phytoplankton populations have the potential to increase four-fold per day in short residence time estuaries, they are generally flushed from the system as fast as they can grow, reducing the estuary's susceptibility to eutrophication and harmful algal blooms (HABs). Therefore in such shallow estuaries, epiphytes and particularly macroalgae, along with sediment oxygenation and nutrients, become the primary symptoms of eutrophication rather than phytoplankton.

Applying an unmodified US approach to NZ estuaries that are expressing eutrophication symptoms (high macroalgal growth, surface RPD, muddy sulphide rich sediments, elevated nutrients, loss of seagrass, and a poor macroinvertebrate condition index), yet have low water column chlorophyll and elevated oxygen levels, results in a low or low/moderate rating of eutrophication symptoms, and a consequent underestimation of vulnerability.

APPENDIX 1: REVIEW OF INTERNATIONAL GUIDELINES FOR ESTUARY AND COASTAL WATERS

Table 1. Existing 'thresholds' for assessing eutrophic status.

Australia and New Zealand			
ANZECC (2000)		Summer Max Chlor. *a*	>10mg.m^{-3} (S.E. Australia default used for NZ)
		DIN, TN, DRP, TP	DIN >30mg.m^{-3}, TN 300, DRP 5, TP 30 (S.E. Australia default used for NZ)
		DO water column	60% saturation (used S.E. Australia default for NZ)
Australian Guidelines (Scanes, unpub. 2012)		Nitrogen Estuary Areal Loading (mg.m^{-2}.d^{-1})	Pristine ICOLLs 7.7, (clear waters, minimal algal blooms, strong seagrass growth, good fish assemblages) Moderately disturbed ICOLLs 17.5, (some eutrophic symptoms, but healthy seagrass and fish communities) Highly disturbed ICOLLs 38.4, (algal dominated, turbid systems, seagrass absent or reduced)
(Heggie 2006)			50mg.m^{-2}.d^{-1} Conservative estimate to avoid eutrophication and triggering of significant ecological changes for most other estuaries of temperate Australia.
United States of America			
ASSETS Approach Bricker et al. (1999)	1^{ary} Symptom	Phytoplankton (Chlorophyll *a*)	Maximum values observed over a typical annual cycle. Hypereutrophic (>60µg chl-a/l), High (>20, ≤60), Medium (>5, ≤20), Low (>0, ≤5)
	1^{ary} Symptom	Nuisance Macroalgae	Poor (significant impact upon biological resources), Low (no significant impact)
	1^{ary} Symptom	Nuisance Epiphytes	Poor (significant impact upon biological resources), Low (no significant impact)
	2^{dnary} Symptom	DO in Water Column	Very Poor (anoxia) (0 mg/l), Poor (Hypoxia) (>0 ≤ 2), Fair (Biol. Stress) (>2 ≤ 5) , Low (>5)
	2^{dnary} Symptom	Secchi Disc Clarity	Poor (<1m), Medium (1≥m, ≤3m), Low (>3m)
	2^{dnary} Symptom	Seagrass/Salt Marsh Loss	Maximum Spatial Coverage (% of habitat); High (>50, ≤100%), Medium (>25, ≤50), Low (>10, ≤25), Very Low (>0, ≤10)
	2^{dnary} Symptom	Harmful Algae	Problem (significant impact upon biological resources), No Problem (no significant impact)
	N	Nitrogen water	Maximum dissolved surface concentration: High (≥1mg/l), Medium (≥0.1, <1mg/l), Low (≥0, < 0.1mg/l)
	Physical Susceptibility - Dilution and Flushing	Dilution Potential	Calculated as 1 ÷ estuary volume (m^3). If answer = 10^{-12}-10^{-13} then rating is High; 10^{-11} then rating is Moderate; 10^{-9}-10^{-10} then rating is Low
	Physical Susceptibility - Dilution and Flushing	Flushing Potential	A flushing rating, calculated as freshwater inflow (m^3.d^{-1}) divided by estuary volume (m^3) and adjusted for tidal height (m). For FW inflow/Est Vol; Macrotidal (>1.8m): 0.01-1 High, 0.0001-0.001 Moderate. Mesotidal (0.8m-1.8): 0.1-1 High, 0.01 Moderate, 0.001-0.0001 Low
	Physical Susceptibility - Dilution and Flushing	Export Potential	(see matrix below)

Flushing Potential	Dilution potential: High	Dilution potential: Moderate	Dilution potential: Low
High	HIgh EXP & Low Susceptibility	HIgh EXP & Low Susceptibility	Moderate EXP & Moderate Susceptibility
Mod.	HIgh EXP & Low Susceptibility	Moderate EXP & Moderate Susceptibility	Low EXP & Susceptibility
Low	Moderate EXP & Moderate Susceptibility	Low EXP & High Susceptibility	Low EXP & High Susceptibility

Estuaries in the upper left portion of the matrix generally have a high EXP (export potential) that suggests an ability to dilute and flush nutrient loads. Estuaries in the lower right portion of the matrix have the opposite capacity, making them more susceptible to nutrient input. Note; ICOLLs are assigned into the "Low EXP and High Susceptibility" category.

Europe		
CSTT (1994, 1997)	Winter DIN	>168mg.m^{-3}
	Summer Max Chlor. *a*	>10mg.m^{-3}
EEA (1999)	Nitrate-N	Good <91, Fair 91-126, Poor 126-224, Bad >224mg.m^{-3}
European EWU and OSPAR Approach OSPAR (2001, 2003)	Winter DIN default	>210mg.m^{-3}
	Winter N:P Ratio	>25:1
	Growing Season Chlor. *a*	>50% above background
	Macroalgae	Maximal seasonal cover <15%, max seasonal biomass <1kg.m^{-2}
	DO	Minimum DO in deep water below pynocline >4.6mg.l^{-1}
	Sediment oxic layer	Depth of RPD >2cm
	Seagrass loss	Decrease 3% per annum
	Epiphytic algal cover	55% cover of leaves
Swedish Guidelines. Swedish EPA 2002.	Chlorophyll *a*	in August (Summer) (ug/l); very low <1.5, low, 1.5-2.2, moderate 2.2-3.2, high 3.2-5.0, very high >5.0.
	TN Winter	(ug/l); very low <266, low 266 to 350, moderate 350 to 490, high 490 to 756, very high >756.
	TN Summer	(ug/l): very low <252, low 252 to 308, moderate 308 to 364, high 364 to 448, very high >448.
	DIN Winter	(ug/l): very low <87 low 87 to 118, moderate 118 to 170, high 170 to 424, very high >424.

APPENDIX 2: PROPOSED EUTROPHICATION GUIDELINES FOR NZ TIDAL LAGOON AND TIDAL RIVER ESTUARIES

The proposed approach for setting eutrophication guidelines for well-flushed NZ shallow tidal lagoon estuaries (0.5 to <3 day water residence time), and the even more well flushed shallow tidal river estuaries, is a stressor-response approach that links nitrogen areal loading with macroalgal areal cover. It uses the long term estuary monitoring data from various Regional Councils to estimate macroalgal cover, and CLUES model outputs to estimate catchment nitrogen loads. The choice of macroalgal cover as the primary response indicator and nitrogen loads as the primary driver is based on the following:

- Nutrient loading to estuaries is the main driver of eutrophication and nutrient concentrations are "response variables" in that they reflect long term loading rates (USEPA 2010, 2011).
- Estuaries are generally nitrogen-limited with respect to nutrient balance and the potential for the development of eutrophic conditions (USEPA 2010).
- Chlorophyll a measures phytoplankton biomass and is not a good indicator of total primary production, particularly for shallow, macrotidal estuaries with very short residence times and high flushing rates (<1day), which is the case for many NZ tidal lagoon and river estuaries. In such shallow estuaries, the loss of seagrass, and the growth of epiphytes and particularly macroalgae, become the primary symptoms of eutrophication rather than phytoplankton.

Different types of estuaries react to nitrogen loading in different ways. The presence of an extensive margin of saltmarsh is known to ameliorate the N load to the estuary and thus reduce the potential for macroalgal blooms (Valliella et al. 1997). Likewise, water residence times can also affect the eutrophication process by influencing nutrient budgets. In general, the shorter the estuarine residence time the greater the nitrogen export to open coastal waters.

Available monitoring data for representative NZ shallow tidal lagoon estuaries with variable areas of saltmarsh but short residence times, indicate nuisance macroalgal blooms typically occur only when N areal loads exceed approximately 50 $mg.m^{-2}.d^{-1}$ (Figure 1).

For tidal river estuaries where the flushing potential greatly exceeds that for tidal lagoon estuaries, the ameliorating effect of increased freshwater flushing on nitrogen load and macroalgal growth is significant. These tidal river estuaries are much less sensitive to nutrient inputs and available monitoring data indicates that nuisance macroalgal blooms do not occur until N areal loads exceed much higher loads (preliminary data indicates loads of approximately 750 $mg.m^{-2}.d^{-1}$ for such estuaries - Figure 2).

In contrast, because shallow intermittently open closed lakes or coastal lagoons (ICOLLs) often have long residence times, particularly when the lagoon is closed, they are much more susceptible to eutrophication. For example, Waituna Lagoon, which is often closed for 100 days or longer, experiences heavy nuisance macroalgal and epiphyte blooms at an estimated N areal load of approximately 50 $mg.m^{-2}.d^{-1}$ (Robertson and Stevens 2009).

Scanes (2012) in a recent analysis of catchment loads from NSW ICOLLs that are similar to Waituna Lagoon, indicated the loads required to sustain a moderate environmental quality (some eutrophic symptoms but still supporting healthy seagrass and fish communities) for such ICOLL's would be TN and TP loads of 24 and 1.52 $mg.m^{-2}.d^{-1}$ (respectively) clearly demonstrating the increased susceptibility of ICOLLs to eutrophication at lower nutrient loadings. For Waituna Lagoon, meeting such loads would represent a 52% reduction in TN load and a 23% reduction in TP load over 2010 conditions.

In conclusion, preliminary data from representative shallow tidal lagoon and tidal river estuaries in New Zealand suggest that the susceptibility to eutrophication symptoms, as indicated by macroalgal cover (the primary eutrophic symptom for such waterbodies), increases as the flushing potential declines, and reaches nuisance conditions at the following approximate N areal loadings:

- Tidal lagoon estuaries 50 $mgN.m^{-2}.d^{-1}$
- Tidal river estuaries 750 $mgN.m^{-2}.d^{-1}$

Such findings, strongly suggest that for estuaries with even lower flushing potentials and water residence times to tidal lagoon estuaries (e.g. ICOLL's like Waituna Lagoon), one can expect nuisance algal growth at nitrogen areal loadings much lower than 50 $mgN.m^{-2}.d^{-1}$.

NITROGEN AREAL LOAD AND MACROAGAL RATING FOR SHALLOW NZ TIDAL LAGOON ESTUARIES

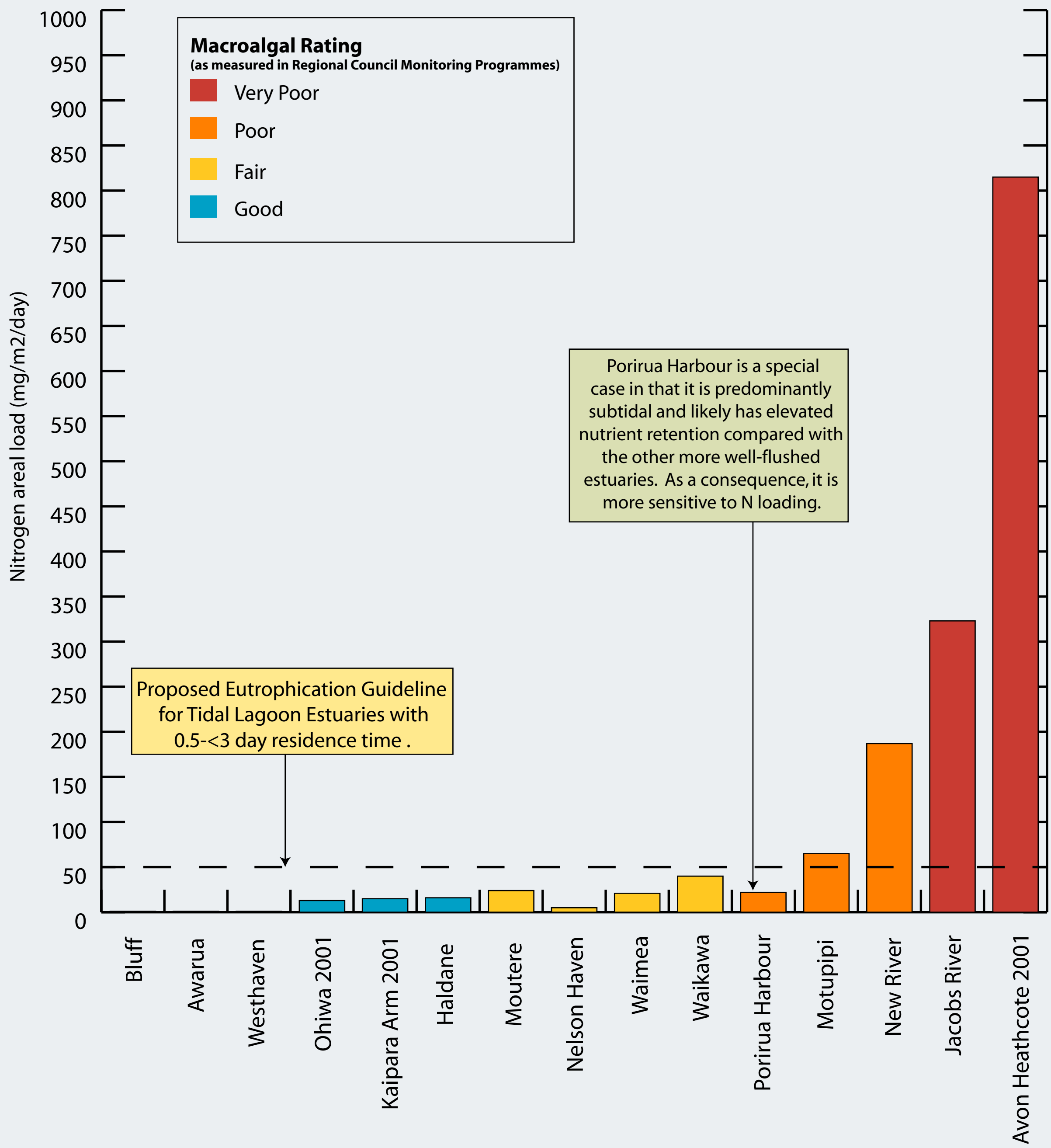

Figure 1. Nitrogen Areal Load and Macroagal Rating (details Appendix 1) for shallow Tidal Lagoon Estuaries with low water residence times (0.5- <3 days) and flushing potentials (all <0.16). Flushing Potential = freshwater inflow ($m^3.d^{-1}$) divided by estuary volume (m^3).

NITROGEN AREAL LOAD AND MACROAGAL RATING FOR SHALLOW NZ TIDAL RIVER ESTUARIES

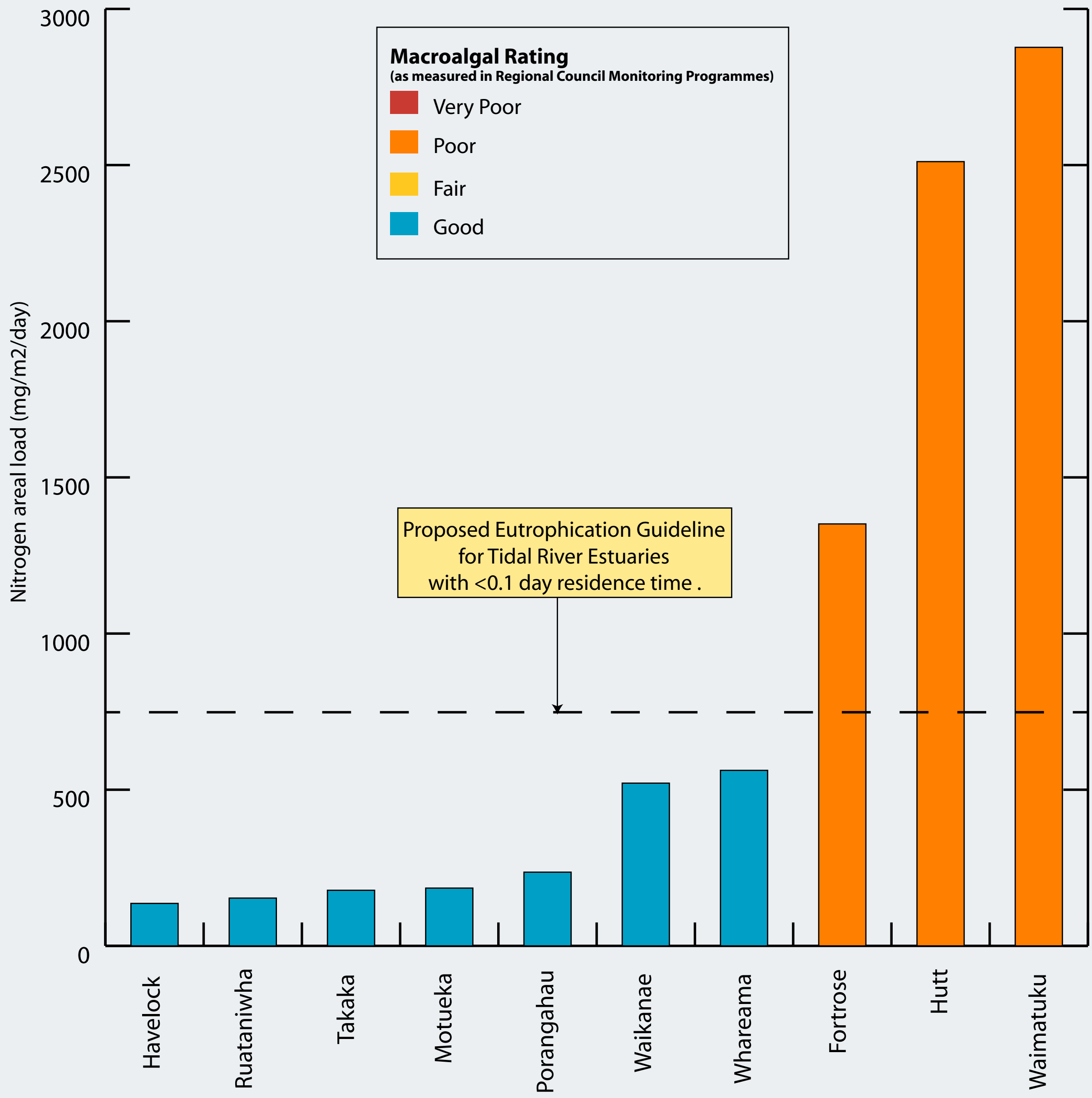

Figure 2. Nitrogen Areal Load and Macroagal Rating (details Appendix 1) for shallow Tidal River Estuaries with high flushing potentials (all >0.16). Flushing Potential = freshwater inflow ($m^3.d^{-1}$) divided by estuary volume (m^3).

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