Updated total nitrogen load limits for Southland estuaries

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Version 1.0	Final version sent to client	20 October 2023
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Executive summary

Suggested nutrient load limits for Southland's estuaries were proposed by NIWA in a 2020 study using approaches based on the Estuary Trophic Index tools. Total nitrogen (TN) bands were proposed for nuisance macroalgae based on a relationship between macroalgal Ecological Quality Rating (EQR – a measure of macroalgal cover and biomass) and predicted in-estuary TN concentrations derived from observations from 21 New Zealand estuaries. Since that time, more data have been collected and made available (46 observations from 37 estuaries), allowing the potential TN concentrations corresponding to different levels of macroalgal impact to be revised. Environment Southland have requested an update of TN load bands for nuisance macroalgae incorporating these more recent data.

Using the revised dataset, annual TN load thresholds corresponding to different bandings of EQR have been recalculated for eight Southland estuaries. The revised load thresholds are set at levels that provides a 75% probability that the desired EQR band will be achieved. The revised load bands are 40% to 87% higher than the values proposed previously. Recommendations are made on how the thresholds should be applied in the context of catchment limit-setting for TN loads.

Table 1-1: Revised annual total nitrogen load bands (t/y) for macroalgae in Southland estuaries. The revised load bands are set at a level such that at the higher end of the load band, there is a 75% probability that EQR is above the minimum for that band.

Band	A	B	C	D
EQR	1.0 > EQR ≥ 0.8	0.8 > EQR ≥ 0.6	0.6 > EQR ≥ 0.4	EQR < 0.4
Eutrophication level	Minimal	Moderate	High	Very high
Waikawa Harbour	< 89.9	89.9 – 207	207 – 325	> 325
Haldane Estuary	< 25.7	25.7 – 59.2	59.2 – 92.7	> 92.7
Lake Brunton (open state)	< 3.3	3.3 – 7.3	7.3 – 11.3	> 11.3
Toetoes (Fortrose) Estuary	< 771	771 – 1619	1619 – 2467	> 2467
Bluff Harbour	< 304	304 – 763	763 – 1223	> 1223
New River (Oreti) Estuary	< 1303	1303 – 3062	3062 – 4822	> 4822
Waimatuku Estuary	< 12.6	12.6 – 24.2	24.2 – 35.8	> 35.8
Jacobs River Estuary	< 340	340 – 759	759 – 1178	> 1178

1 Introduction

In 2020, NIWA conducted a desktop analysis to estimate nutrient load thresholds for Southland estuaries (Plew 2020), which contributed to a wider assessment of nutrient load reductions required to achieve freshwater objectives in Southland rivers, lakes and estuaries (Snelder 2021).

The prediction of nutrient load thresholds for estuaries was based on the New Zealand Estuary Trophic Index (ETI) tool 1 (Plew, Zeldis et al. 2020), where relationships between modelled in-estuary total nitrogen (TN) concentrations and observed algal response were used to set TN concentration thresholds corresponding to bands of macroalgal Ecological Quality Rating (EQR). Since that work, a larger dataset of EQR scores for estuaries is now available, and the TN concentration thresholds corresponding to ETI bands have been adjusted. In many cases, this is likely to lead to less conservative TN load bands (i.e., higher TN loads than previously estimated) for estuaries. Also, work has recently been conducted by NIWA to improve setting of default dilution model tuning parameters for those estuaries where observations or modelling to set these parameters are not available. Environment Southland requested an update to TN load bands incorporating these recent developments.

This report describes updates of the TN load thresholds for macroalgae in Southland estuaries proposed in 2020 in line with the revision of ETI TN concentration bands. The following estuaries, which based on physical characteristics may be suitable for nuisance macroalgae to populate, are considered in this report:

- Waikawa Harbour
- Haldane Estuary
- Lake Brunton (open state)
- Toetoes (Fortrose) Estuary
- Bluff Harbour
- New River (Oreti) Estuary
- Waimatuku Estuary
- Jacobs River Estuary.

Macroalgal growth is more commonly limited by nitrogen (N) availability than phosphorus (P) because macroalgae require considerably more N than P, and ocean inputs of P supply much of the required P in many estuaries (Howarth and Marino 2006; Barr 2007; Dudley, Barr et al. 2022). Consequently, the ETI approach for predicting macroalgal growth is based on TN concentrations, so nutrient load bands for macroalgae are presented for TN. Phytoplankton band thresholds and their calculation methods have not changed since NIWA's previous load band estimates for Southland's estuaries, and are provided in NIWA client report 2020216CH (Plew 2020).

2 Methods

2.1 Updated potential total nitrogen concentration thresholds

Macroalgal EQR is a metric for nuisance macroalgal abundance that incorporates both biomass and spatial coverage (Water Framework Directive - United Kingdom Advisory Group 2014). It is calculated from measurements taken in summer (usually January, February, or March) when biomass is typically highest. Macroalgal EQR is a score from 1 (no nuisance macroalgae) to 0 (persistent very high % cover and/or biomass). A modified version of the EQR scoring system is used in New Zealand with lower algal biomass band thresholds (Plew, Zeldis et al. 2020) and a refinement to better calculate EQR where there is low coverage (Stevens, Forrest et al. 2022).

At the time of writing, macroalgal EQR has been proposed as an attribute to be added to the National Policy Statement for Freshwater Management (NPSFM), which currently requires that receiving water bodies including estuaries be considered but does not provide explicit attributes, bandings, or national bottom lines for estuaries.

Table 2-1: Macroalgal bands with eutrophication level, Ecological Quality Rating (EQR) range, and descriptions of expected ecological state. The method for calculating EQR is as described by the Water Framework Directive - United Kingdom Advisory Group (2014) with modifications for New Zealand estuaries (Plew, Zeldis et al. 2020; Stevens, Forrest et al. 2022).

Macroalgae susceptibility band	A	B	C	D
Eutrophication level	Minimal	Moderate	High	Very high
Ecological Quality Rating (EQR)	1.0 > EQR ≥ 0.8	0.8 > EQR ≥ 0.6	0.6 > EQR ≥ 0.4	EQR < 0.4
Expected ecological state	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are healthy and resilient. Algal cover <5% and low biomass of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality high.	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are slightly impacted by additional macroalgal growth arising from nutrients levels that are elevated. Limited macroalgal cover (5–20%) and low biomass of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality transitional.	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are moderately to strongly impacted by macroalgae. Persistent, high % macroalgal cover (25–50%) and/or biomass, often with entrainment in sediment. Sediment quality degraded.	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are strongly impacted by macroalgae. Persistent very high % macroalgal cover (>75%) and/or biomass, with entrainment in sediment. Sediment quality degraded with sulphidic conditions near the sediment surface.

Plew, Zeldis et al. (2020) found a relationship between potential TN concentrations and observed macroalgal ecological quality ranking (EQR) in New Zealand estuaries. Potential TN concentrations were calculated using catchment annual TN loads and mean freshwater inflow, with mixing in the estuary accounted for using a tidal-prism type dilution model and ocean TN concentration. The dilution model provides an estimate of the average estuary TN concentration at high tide under mean flow conditions, assuming no uptake of N by algae, losses of N via denitrification pathways, and storage or release of N from sediments. Potential TN represents the availability of water column TN, averaged over both time and space within the estuary.

Here, potential TN concentration band thresholds have been updated using more recent EQR observations (Leigh Stevens – Salt Ecology, pers. comm., Feb 2023) and nutrient load estimates. A regression fit through EQR and potential TN is used to estimate the concentrations corresponding to the EQR band thresholds of 0.8, 0.6 and 0.4 (Figure 2-1). The new regression is based on 46 EQR – potential TN data points from a total of 37 estuaries (data from multiple years are available for some estuaries), compared to the 21 points (from 21 estuaries) used in the original regression (Plew, Zeldis et al. 2020).

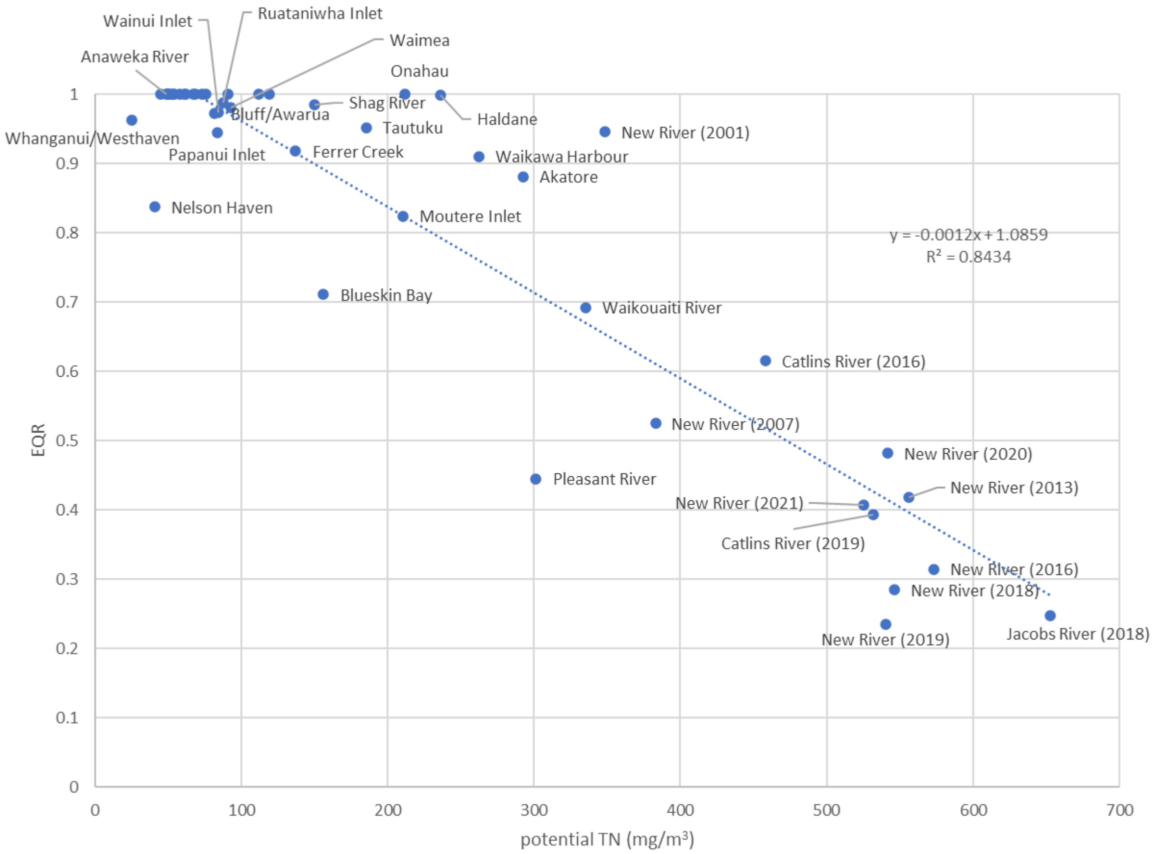

Figure 2-1: Updated regression between EQR and estimated potential TN concentrations in New Zealand estuaries. EQR values provided by Leigh Stevens (Salt Ecology). TN band thresholds (Table 2-1) are set where the regression fit crosses EQR values of 0.8, 0.6 and 0.4.

As Figure 2-1 illustrates, there is scatter in data either side of the fitted least-squares linear regression. This scatter is due to uncertainty in nutrient loads, estimation of dilution within estuaries (tuned dilution models are available for few estuaries), and factors other than TN loads influencing the expression of macroalgal response within estuaries. Examples of such factors include scour by high flows, climate variability, lags between macroalgal response and changing nutrient loads, and potential algal growth limitation by other nutrients. The use of a linear least-squares regression assumes that its residuals are normally distributed around the fitted line and that there is an equal probability that the EQR is above or below the regression line. Accordingly, the uncertainty associated with predicting values of EQR corresponding to a potential TN concentration can be calculated using predictor intervals based on the assumption of normally distributed residuals. Predictor intervals for the regression are shown in Figure 2-2.

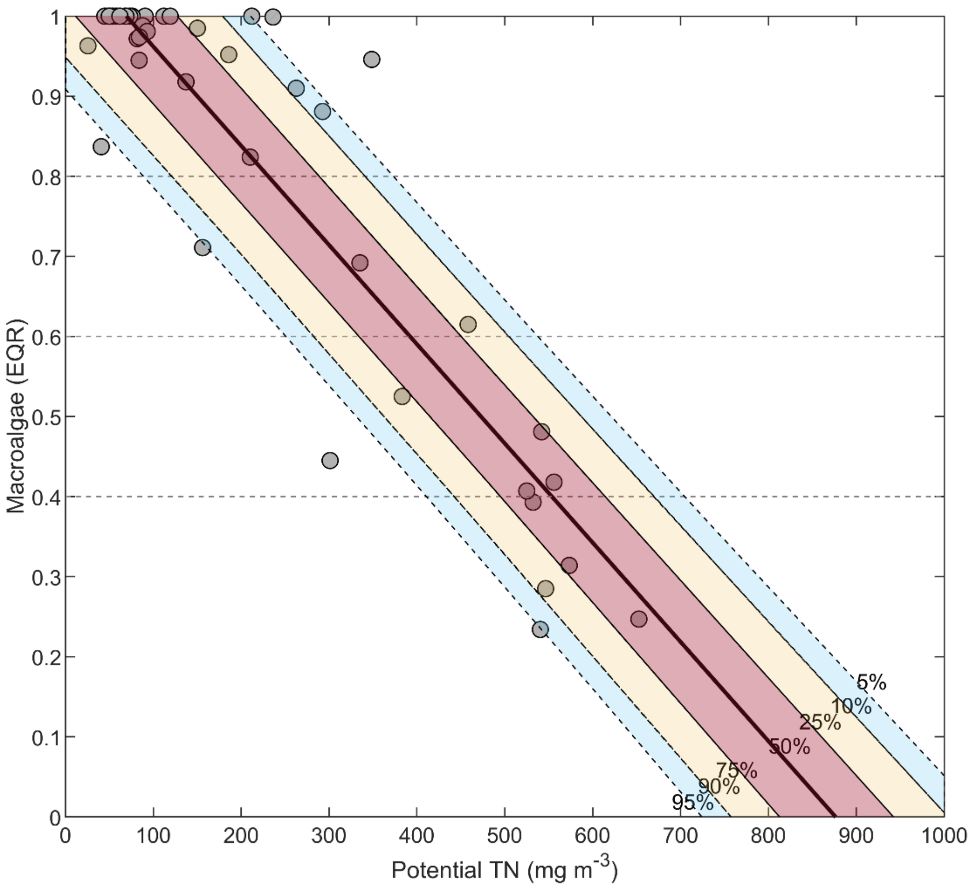

Figure 2-2: EQR vs potential TN concentration relationship with predictor intervals. The predictor interval is the uncertainty associated with predicting values of EQR from potential TN values using a linear regression. The coloured bands show the range encompassed either side of the regression for predictor intervals of 90% (blue band), 80% (yellow band) and 50% (red band). Note that bands overlap, with the narrowest bands (smallest predictor intervals) overlying wider bands. Values in % next to each diagonal line indicate the probability that the associated EQR will be exceeded at that potential TN concentration.

The predictor intervals can be used to estimate the uncertainty in relation to concentration band thresholds (Table 2-2), as well as the probability that an EQR band will be achieved for a given potential TN concentration (Figure 2-2 and Table 2-3). For example, there is a 95% probability of the EQR being higher than 0.4 (i.e., band C or better) for potential TN = 410 mg/m^3, 80% probability at TN = 480 mg/m^3, but only 5% probability at TN = 705 mg/m^3.

Table 2-2: Macroalgal susceptibility bands. Macroalgae Ecological Quality Rating (EQR) band thresholds details.

	EQR band threshold		
	A/B	B/C	C/D
EQR value	0.8	0.6	0.4
Old potential TN concentration (mg/m³)	*80*	*200*	*320*
Revised potential TN concentration (mg/m³)	230	390	555
90% confidence interval (mg/m³)	90 – 370	250 – 540	410 – 705

Table 2-3: Potential total nitrogen band thresholds with different protection probabilities. The protection probability indicates the probability that the EQR band will be obtained if the given potential TN concentration is not exceeded.

EQR band threshold	Maximum potential TN concentration to meet band (mg/m³)		
Protection probability	A	B	C
95%	90	250	410
90%	120	280	440
80%	160	320	480
75%	175	335	495
50%	230	390	555
25%	285	450	615
20%	300	465	630
10%	340	505	670
5%	370	540	705

2.2 Estuary properties

The dilution model used to estimate potential TN concentrations in estuaries uses tidal prism and freshwater inflow (Plew, Dudley et al. 2018). The dilution model and EQR vs potential TN regression relationship has been developed using mean flow, tidal prism at spring tide, and annual TN loads largely due to the availability of these data compared to other metrics. Few estuaries have had detailed bathymetry surveys conducted (of the estuaries considered here, recent bathymetry is available only for New River Estuary and Toetoes (Fortrose) Estuary), so estuary properties are largely derived from aerial/satellite photographs, topographic maps, and predicted tidal range at the coast (Hume and Herdendorf 1988; Hume, Snelder et al. 2007; Hume, Gerbeaux et al. 2016). In the absence of bathymetry data and in-estuary measurements of water level fluctuations, tidal prism (P) is estimated from area at high tide (A_h), area at low tide (A_l) and tidal range (H_t).

$$P = \frac{A_h + A_l}{2} H_t \tag{1}$$

Estuary properties used here are summarised in Table 2-4.

Table 2-4: Key estuary properties used for dilution modelling calculations. Volumes, tidal prisms, and areas are at spring high tide. Tuning factors for New River Estuary and Toetoes (Fortrose) Estuary are based on hydrodynamic modelling and observation, respectively. Tuning factors for other estuaries are based on flow, tidal prism, and geomorphic similarity to other estuaries. ETI type refers to the estuary classification used in the Estuary Trophic Index, and NZCHS code and NZCHS type refer to the estuary classification in the New Zealand Coastal Hydrosystem.

Estuary	ETI type	NZCHS code	NZCHS type	Tidal prism (m^3)	Volume (m^3)	Area (m^2)	Intertidal area (%)	Mean flow (m^3/s)	Tuning factor	Data source
Waikawa Harbour	SIDE	7A	Tidal lagoon (permanently open)	7,574,506	9,835,149	6,422,282	82	5.8	0.895	Coastal Explorer
Haldane Estuary	SIDE	7A	Tidal lagoon (permanently open)	2,064,020	2,337,221	1,886,750	93	1.7	0.891	Coastal Explorer
Lake Brunton (open state)	Coastal lake	7B	Tidal lagoon (intermittently open)	172,300	258,506	258,506	60	0.3	0.866	Tidal prism estimated as 2/3rds of volume, and estimated 60% intertidal area
Toetoes (Fortrose) Estuary	SSRTRE	7A	Tidal lagoon (permanently open)	6,059,260	7,531,400	4,277,900	68	97.4	0.187	Plew, Dudley et al. (2020)
Bluff Harbour	Coastal lake	8	Shallow drowned valley	89,628,434	121,988,796	54,580,551	52	0.9	0.955	Coastal Explorer
New River (Oreti) Estuary	SIDE	8	Shallow drowned valley	62,288,413	102,935,087	39,823,925	42	67.26	0.793	(Measures 2016; Plew 2017; Plew, Zeldis et al. 2018)
Waimatuku Estuary	SSRTRE	6D	Tidal river mouth (intermittent with ribbon lagoon)	52,437	87,654	162,092	48	2.27	0.200	Salt Ecology
Jacobs River Estuary	SIDE	7A	Tidal lagoon (permanently open)	1,015,1391	14,697,352	6,697,056	66	29.3	0.747	Coastal Explorer

3 Results

3.1 Macroalgal EQR total nitrogen bands

Estimated maximum TN loads to achieve EQR bands of A, B and C are given in Table 3-1, Table 3-2, and Table 3-3 respectively. Each table provides maximum loads according to the probability of achieving that band. For example, for New River Estuary, there is 95% probability that band C or better will be achieved with an annual TN load of < 3887 t/y, a 75% probability for < 4822 t/y, and a 50% probability of achieving band C or better at < 5481 t/y.

Table 3-1: Maximum annual total nitrogen load (t/y) to achieve a macroalgal band A for different protection probabilities. A protection probability of 75% (shaded blue) indicates there is a 75% probability that an A band will be achieved if the load is less than the given value.

Estuary	95%	90%	80%	75%	50%	20%	10%	5%
Waikawa Harbour	27.5	49.5	78.9	89.9	130	182	211	233
Haldane Estuary	7.9	14.2	22.6	25.7	37.3	51.9	60.3	66.6
Lake Brunton (open state)	1.2	1.9	2.9	3.3	4.7	6.4	7.4	8.2
Toetoes (Fortrose) Estuary	321	480	692	771	1063	1433	1645	1804
Bluff Harbour	59.4	146	261	304	462	663	778	864
New River (Oreti) Estuary	368	698	1138	1303	1908	2677	3117	3447
Waimatuku Estuary	6.5	8.6	11.5	12.6	16.6	21.7	24.6	26.8
Jacobs River Estuary	117	196	300	340	484	667	772	850

Table 3-2: Maximum annual total nitrogen load (t/y) to achieve a macroalgal band B for different protection probabilities. A protection probability of 75% (shaded blue) indicates there is a 75% probability that a B band will be achieved if the load is less than the given value.

Estuary	95%	90%	80%	75%	50%	20%	10%	5%
Waikawa Harbour	145	167	196	207	248	303	332	358
Haldane Estuary	41.4	47.7	56.1	59.2	70.8	86.5	94.8	102
Lake Brunton (open state)	5.2	5.9	6.9	7.3	8.7	10.6	11.6	12.5
Toetoes (Fortrose) Estuary	1169	1327	1539	1619	1910	2308	2519	2705
Bluff Harbour	519	605	720	763	921	1137	1252	1352
New River (Oreti) Estuary	2128	2458	2897	3062	3667	4492	4932	5316
Waimatuku Estuary	18.1	20.2	23.1	24.2	28.2	33.7	36.6	39.1
Jacobs River Estuary	536	615	719	759	903	1099	1024	1295

Table 3-3: Maximum annual total nitrogen load (t/y) to achieve a macroalgal band C for different protection probabilities. A protection probability of 75% (shaded blue) indicates there is a 75% probability that a C band will be achieved if the load is less than the given value.

Estuary	95%	90%	80%	75%	50%	20%	10%	5%
Waikawa Harbour	262	284	314	325	369	424	453	479
Haldane Estuary	74.9	81.2	89.6	92.7	105	121	129	137
Lake Brunton (open state)	9.2	10.0	11.0	11.3	12.8	14.7	15.7	16.6
Toetoes (Fortrose) Estuary	2016	2175	2387	2467	2784	3182	3394	3579
Bluff Harbour	979	1065	1180	1223	1395	1611	1725	1826
New River (Oreti) Estuary	3887	4217	4657	4822	5481	6306	6746	7131
Waimatuku Estuary	29.7	31.9	34.8	35.8	40.2	45.6	48.5	51.1
Jacobs River Estuary	955	1034	1138	1178	1135	1531	1636	1727

4 Discussion and recommendations

The revised potential TN band thresholds are a significant increase from the values used in the previous assessment (see Table 2-2). This results in higher nutrient load thresholds than were proposed in the previous study (Plew 2020). The regression fit gives an estimate of the mean EQR expected for a given potential TN concentration. Noting the uncertainty in band thresholds, and the risk of irreversible ecological changes due to eutrophication, it is prudent to set nutrient load targets at a lower level to provide a greater probability (i.e., lower risk) of obtaining the desired ecological condition. The level of risk considered tolerable, as well as the desired ecological state (band A, B or C) is a policy/management decision. We suggest that the load thresholds for the 75% protection probability (shaded blue in Table 3-1, Table 3-2 and Table 3-3) be considered as providing a high confidence of obtaining the desired EQR band without being overly conservative. This may also be considered as a 25% under protection risk (there is a 25% probability that the desired EQR is not obtained). This level of protection is consistent with international recommendations for setting of ecologically relevant nutrient thresholds (Phillips, Kelly et al. 2019; Kelly, Phillips et al. 2022). These load thresholds are shown alongside the previously proposed thresholds in Table 4-1. At the C/D band threshold, the revised TN load thresholds are 40% to 87% higher than the previous values.

Table 4-1: Revised TN band thresholds compared with values proposed in 2020. The revised TN band thresholds at set at the 75% protection probability. Previous TN load thresholds are described in Plew (2020).

Estuary	Revised TN band threshold (t/y)			Previous TN band threshold (t/y)		
	A/B	B/C	C/D	A/B	B/C	C/D
Waikawa Harbour	89.9	207	325	20.5	106	193
Haldane Estuary	25.7	59.2	92.7	5.9	30.6	55.2
Lake Brunton (open state)	3.3	7.3	11.3	1.0	4.51	8.0
Toetoes (Fortrose) Estuary	771	1619	2467	269	894	1516
Bluff Harbour	304	763	1223	32	368	702
New River (Oreti) Estuary	1303	3062	4822	248	1410	2570
Waimatuku Estuary	12.6	24.2	35.8	-	-	-
Jacobs River Estuary	340	759	1178	92	400	708

Although choosing a protection probability reduces the risk of setting nutrient load bands too high to achieve a desired ecological state, we recommend that the proposed load bands be used primarily to identify estuaries where current nutrient loads result in a high susceptibility to excessive nuisance macroalgal growth, and to prioritise estuaries where more detailed assessments be considered to set load limits. Other than New River Estuary and Toetoes (Fortrose) Estuary, the data used in the dilution models are from Coastal Explorer (summarised in Hume, Gerbeaux et al. 2016) and are often estimates with variable accuracy. Tidal prism values can be inaccurate because of the challenge in identifying surface area at high and low tides from photographs, the implicit assumption that estuary area increases linearly with water depth, and because tidal range inside an estuary is usually smaller than on the open coast due to the constriction caused by the estuary mouth and backwater effects. Furthermore, the dilution models are un-tuned (except New River Estuary and Toetoes Estuary), introducing further uncertainty that is not considered here.

It is important that point sources (e.g., wastewater discharges) are included in loading calculations when using the load thresholds proposed here. Land use models such as CLUES may not include point source discharges to estuaries, and these must be added to avoid underestimating the total load.

For estuaries where more robust load band thresholds are required, a higher degree of certainty may be obtained via a combination of field observations (bathymetry surveying and measurements of salinity to tune dilution models), hydrodynamic modelling to assess spatial variability, and ecological monitoring to calibrate and validate predictions.

5 Acknowledgements

Data used to revise the potential TN thresholds for macroalgal EQR were provided by Leigh Stevens (Salt Ecology).

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