MEMORANDUM

BAY OF PLENTY REGIONAL COUNCIL TOI MOANA

To:	Shane Iremonger **Team Leader - Coastal Land & Air**	
From:	Stephen Park **Senior Environmental Scientist - Marine Ecology**	**Date:** 16 November 2018
File Ref:	A2984492	
Subject:	**Setting interim guidelines for nutrient loads to Maketū and Waihi Estuaries**	

1 Introduction

As required by the National Policy Statement for Freshwater Management (NPS-FM), Bay of Plenty Regional Council must implement freshwater objectives, limits and methods for achieving agreed (with community input) sustainable freshwater quality and quantity in the region. To achieve these goals BOPRC has divided the task up into Water Management Areas (WMAs) comprising defined individual surface water catchments and has commenced this process on the Rangitāiki and Kaituna-Pongakawa-Waitahanui WMA's. The NPS-FM requires Councils to have regard to the connections between freshwater bodies and coastal water, and seeks to improve integrated management of fresh water and land in whole catchments, including interactions with the coastal environment. Amendments made in 2017 strengthened this direction.

With respect to the coastal receiving environment, the first stage of working towards implementation of appropriate freshwater quality objectives and limits was to assess the sensitivity of estuaries in these WMAs to nutrients loads from catchment inflows. This involved field surveys of the estuaries characteristics and current state (Park 2018a & b). Assessment of survey data also utilised the New Zealand Estuarine Trophic Index (ETI) framework (Robertson et al. 2016) to provide a consistent national assessment approach. Kaituna River Estuary, Rangitāiki (Thornton) Estuary and Waitahanui Stream mouth were found to have limited (if any for Waitahanui Stream) estuarine ecology and the estuarine or near ocean sections of these coastal receiving environments are of low sensitivity to current catchment nutrient loads.

For Waihī and Maketū Estuaries, earlier reports had documented sensitivity to catchment inflows and the extent to which ecological health had been impacted (Hamill 2014, Park 2016). This was later updated in 2018 and sensitivity to catchment inflows was assessed using the ETI Tool 1. Both Maketū and Waihī Estuaries are in poor ecological condition with the highest stressor for both estuaries being eutrophication. Assessment of susceptibility to eutrophication placed Maketū Estuary at high risk and Waihī Estuary at very high risk of degradation as a result of the current nutrient loads (Park 2018b, Hamill 2018).

Based on the current assessments and results for Maketū and Waihī estuaries there is a clear need to implement appropriate catchment nutrient load limits to protect the estuaries from ecological degradation or loss of mauri. Waihī Estuary currently has no model or hydrological and water quality data suitable for setting robust regulatory guidelines. Hence interim guidelines for nutrient limitation will be set. This will later be assessed more robustly using additional data and modelling which has been funded as part of Bay of Plenty Regional Council's Long Term Plan. For Maketū Estuary the same approach is taken as extensive consented changes are currently being implemented. Those changes include an increase in re-diversion of the Kaituna River back into Maketū Estuary (currently

153,700 m^3/tidal cycle, changing to 574,500 m^3) and restoration of around 40 Ha of wetland back to the estuary. These changes are expected to result in improvement in the export of sediment and nutrient from the estuary and a period of monitoring is required to assess the effects of the changes.

For sediment loads, there is currently no modelling or data suitable for determining limits to protect the ecological integrity of the estuaries. From assessments of the estuary, it is clear that sedimentation has historically contributed to ecological degradation and loss of mauri. The Bay of Plenty Proposed Regional Coastal Environment Plan has an objective "*Objective 6 Sediment accumulation in harbours and estuaries resulting from land use and accelerated erosion is minimised and reduced over time compared to 2014 levels*." This objective is linked to the issue of sedimentation in estuaries and the associated impacts on biological diversity, functioning and kaimoana values. However it is not currently possible to determine if "2014" loads are at levels that would prevent further ecological degradation, or whether much lower loads are needed. Monitoring has been put in place to determine what the current levels of sedimentation are and whether the ecosystem is still degrading. This will enable assessments to be made over time to establish trends and whether improvement is required.

In the interim, guidelines values for sediment load limits for the estuary would need to default to being set at the 2014 levels. These have not been measured in any robust fashion, but can obviously be estimated from the catchment modelling. This provides a maximum value for the rivers and streams, but the reality is that it is not monitored. The in-estuary monitoring of sediment accumulation rate can address this requirement and the modelling that will be undertaken in the 2019 – 2021 period will include components to address any reduction required in sediment loads to maintain ecological and kaimoana values.

2 Background – nutrients and eutrophication

Eutrophication is a global issue in shallow coastal ecological systems. It is generally defined as the excessive input of nutrients from surrounding catchments (point source and diffuse) which then causes excessive algal growth and subsequent changes in the functioning of biological, chemical and physical processes of shallow coastal ecosystems. In New Zealand's shallow and sheltered estuarine systems, particularly those with high flushing rates and short water residence time, it is more likely for blooms of macroalgae to occur. These blooms lead to the accumulation of high algal biomass which then causes increased organic enrichment, deoxygenation, increases in toxic sulphide levels and increases in mud content of the sediments. All of these changes are detrimental to benthic biological assemblages which may be lost and replaced by less diverse opportunistic pollution tolerant species.

In New Zealand and in temperate regions globally, it is generally accepted that of the two main nutrients that limit algal growth (nitrogen and phosphorus), that nitrogen is the main limiting nutrient (Rees 2009, Robertson & Stevens 2012, Lapointe et al. 1992), particularly in summer when bacterial denitrification rates are high (Christensen et al. 2003, Zeldis 2008). However research on sea lettuce (Ulva spp.) in Tauranga Harbour, New Zealand shows that nitrogen is not always clearly limiting (Park 2011) and that in some instances it may be appropriate to manage both phosphorus and nitrogen in estuaries (Rees 2009).

A range of factors affect the sensitivity of a shallow coastal ecosystem to excessive nutrient loading. These include the physical nature of the system, including the depth, water residence time and the dilution potential of inflowing fresh water. These features form the basis of the US "ASSETS" approach (Bricker 1999) to assessing sensitivity of nutrient loads from catchments. In New Zealand the majority of coastal estuaries are small and very shallow with high flushing rates and as a consequence do not fit well in the ASSETS approach, particularly with use of phytoplankton abundance. An adapted version of the ASSETS approach has been developed for New Zealand's shallow intertidal and riverine dominated estuaries (Robertson et al. 2016).

3 Nutrient loads to Maketū and Waihī Estuaries

Nutrient loading into Maketū and Waihī Estuaries has been assessed by the use of models (NIWA - Clues data in Coastal Explorer, Williamson – eWater Source 2018) and a simple calculation approach (Hamill 2018). These results for each method are presented in Table 1 below which provides the estimated annual loading for total nitrogen and total phosphorus into the estuaries along with the areal loading in terms of the daily load per square metre of the estuary area on a mean high tide.

Rates of sediment and nutrient load into rivers and streams are generally linked closely with rainfall. In particular sediment and phosphorus concentrations tend to be much higher during heavy rainfall and significantly increased flow levels. As a consequence, unless these loads are measured over the full range of rain and flow conditions for extensive periods of time, the true loads will not be known. As stated by Hamill (2018) the simple calculation method relied on data collected predominantly during base flow conditions, with limited rain event data which limited ability to determine relationships with flow levels. This means that results below for the calculation method will present figures that will under estimate the true total nutrient loads into Maketū and Waihī Estuaries. The modelling approaches take into account the interactions established between influences such as land cover/use, soil types and slope, which are then run under scenarios of typical rainfall patterns seen over a number of years.

Table 1: Estimates of the annual load of Total Nitrogen and Total Phosphorus entering Maketū and Waihī Estuaries and the daily areal loading in the estuaries.

Estuary	Data source	Tons/year-TN	Tons/year-TP	mg/day/m^2-TN	mg/day/m^2-TP
Maketū*	Hamill	267.0	20.1	298.6	22.5
	Source	477.4	22.2	533.8	24.8
	Clues	354.8	26.6	396.8	29.8
Waihī*	Hamill	517.0	50.1	488.4	47.3
	Source	618.2	57.2	584.0	54.1
	Clues	514.9	38.0	486.4	35.9

*Area of estuaries used for areal load is estimated mean high tide area - Maketū = 245 Ha, Waihī = 290 Ha.

In Table 1 above, the loading estimates for total nitrogen and phosphorus into Maketū Estuary is lowest for the simple calculation method which is what would be expected. The Clues model estimate is lower than the Source model for total nitrogen but higher for the total phosphorus load. However, the NIWA Clues model data is generated from a national coverage model that has not had the benefit of extensive local data refinement and updating, or additional water quality survey data collected for further calibration. For that reason it is likely that the Source model which has had extensive development work done, will likely represent the most accurate nutrient load estimates.

The estimates for nutrient load into Waihī Estuary presented in Table 1 are all in a narrower range for estimates of total nitrogen load with the Clues estimate being the lowest. For total phosphorus load the Clues estimates are lower than the calculation method. This may be due to springs in the headwaters of the Waihī Estuary catchment that have high nutrient concentrations (Hamill 2018) that have not been taken into account by the Clues model.

Overall the three estimates of nutrient loads are reasonably close if the methods and biases of those methods are taken into account. The most reliable estimate will be that of the Source model which has the benefit of extensive calibration and additional work to improve datasets while the simple calculation method sets an absolute minimum for the nutrient loads coming out of the catchments.

3.1 Other nutrient inputs

Other potential pathways for nutrient loading into Maketū and Waihī Estuaries include groundwater inflows, nutrient recycling and atmospheric deposition. Atmospheric deposition is highly variable depending on anthropogenic sources, the physical dynamics and characteristics of the water body. For example it has been estimated that atmospheric nitrogen deposition on the surface waters of the Gulf Stream region (Western North Atlantic) increases surface nitrate concentrations by around 2% on average over a year (St-Laurent et al. 2017). For Maketū and Waihī Estuaries the atmospheric contributions are will be much lower as a percentage of the total loads, hence they are not considered further in assessments of nutrient loading and limits.

Groundwater inflows to Maketū and Waihī Estuaries have been estimated with the use of models, although no significant inputs have been noted from extensive field surveys over many years. Model results (JACOBS, 2018) indicate that groundwater inflows to both estuaries are likely to be negligible. A key reason for this is that both estuaries are very shallow (both average 1.6m – NIWA Coastal Explorer) and surrounded by extensive flat low lying land consisting of alluvial and marine sediment deposits with uniform uncontained flow paths which are drained either by tidal flap gates or pump drainage. These drains effectively intercept the shallow groundwater that would in the absence of the drains, flow towards the estuary flats. Hence groundwater nutrient inflows are considered to be negligible and not included in further assessments.

Extensive survey work in both Maketū and Waihī Estuaries has been undertaken to determine the state of sediment nutrient concentrations and macroalgal cover (Park 2018b). Results show that these are high (poor condition) for both estuaries, which means that nitrogen recycling from the sediment is likely to be a significant contributor to the overall load available for macroalgal growth. This contribution has been estimated by modelling rates, determined from a range of studies on similar estuaries in New Zealand, based on key variables such as the extent and state of the sediments and the tidal exposure (Needham 2018). One key issue identified in estimating the efflux of nitrogen from the sediments is that current studies do not adequately cover the high end of the range with respect to mud, organic enrichment and nitrogen in the sediments. For that reason Needham (2018) suggests that the 90 percentiles of the estimate bounds may best represent the level of nitrogen being released from the sediments. For Waihī and Maketū Estuaries the annual 50 and 90 percentile load of nitrogen being released from sediments is; Waihī – 3.9 & 15.2 t, Maketū 4.1 & 17.8 t.

Based on these additional nitrogen inputs to Waihī and Maketū estuaries the total areal loading of nitrogen is provided in Table 2 below for the 50 and 90 percentile values. The nitrogen load estimates are added to the catchment loads estimated from the Source model.

Table 2: Estimates of the total annual load of Total Nitrogen from catchment and internal nutrient recycling in Maketū and Waihī Estuaries and the daily areal loading in the estuaries.

Estuary	Percentile	N efflux – T/year	Catchment TN - T/year	Total TN load/year	N efflux as % total TN load	Areal load TN - mg/day/m^2
Maketū	50	4.1	477.4	481.5	0.9	538.4
	90	17.8	477.4	495.2	3.6	553.7
Waihī	50	3.9	618.2	622.1	0.6	587.7
	90	15.2	618.2	633.4	2.4	598.4

As shown in Table 2 the estimates of nitrogen efflux from sediments have a wide range and at the 50 percentile level it only represents around 1% of the total nitrogen input to Maketū Estuary. However it needs to be considered that if the inflows from the catchment were at lower levels then it would be a significant portion of the total nitrogen available for algae growth. In addition the nitrogen released from sediments is in a bioavailable form (DIN) whereas total nitrogen includes a portion which isn't and this means that a greater proportion of the sediment load may be utilised by algae. In anoxic sediments the nitrogen being released may also be non-oxidised ammonium nitrogen which can be preferentially and more effectively taken up by algae (Dortch et al. 1991, Robertson & Savage 2018). Given these points and that the nitrogen efflux levels may be more accurately represented by the 90 percentile values, and then the proportion effectively contributed from sediments to the total nitrogen load may be high, even with the current high catchment loads.

4 Nutrient and sediment inputs under natural and future scenarios

The Source model has been used to predict the estimated nutrient loads in Waihī and Maketū Estuaries under scenarios based on the natural state of the catchment (pre-human impact) and two possible future development cases based on extensive consultation with industry sectors. The specifications of the two development scenarios are set out in detail in a memo (BOPRC, 2017). In brief the two cases are:

“Scenario C” – urban growth, horticulture expansion, unmitigated sea level rise, new forestry & mānuka in upper catchment.

“Scenario D” – urban growth, dairy expansion, mitigated sea level rise, new forestry & mānuka in upper catchment.

Modelling results in Table 3 for catchment loads and areal loading in the estuary highlight the large increase in loads of nitrogen, phosphorus and total suspended solids that have occurred compared to the natural state of the catchments flowing into each of the Maketū and Waihī Estuaries. Waihī Estuary in particular now has an areal nitrogen loading that is nearly six times its original state.

Under the future scenarios for both estuaries the Source model predicts that nitrogen loads could significantly decrease, while phosphorus does so to a lesser extent. The model also predicts a decrease in suspended solids loads to Maketū Estuary, but an increase for Waihī Estuary.

Table 3: Catchment load of annual total nitrogen, phosphorus and total suspended solids (tons per year) and the areal loading rate in the Maketū and Waihī Estuaries based on the Source model estimates for natural state, current state and two future scenarios.

Estuary	Scenario	T/y - TN	T/y - TP	T/y - SS	mg/day/m^2-TN	mg/day/m^2-TP	g/day/m^2-TSS
Maketu	Natural*	155.5	12.2	1,262.4	174	14	1.4
	current	477.4	22.2	4,647.2	534	25	9.0
	“C”	310.4	17.1	5,478.9	374	19	6.1
	“D”	427.1	20.5	5,485.6	478	23	6.1
Waihi	natural	106.5	36.8	3,356.9	101	35	3.2
	current	618.2	57.2	80,75.8	584	54	7.6
	“C”	240.5	40.9	11,131.9	227	39	10.5
	“D”	386.0	47.8	10,728.9	365	45	10.1

*Note that this is taking 23.7% of the Kaituna flow through Maketū Estuary which is not the original natural physical flow state but uses the natural catchment state contributions to allow comparison to current and future modelled scenarios.

5 Guidelines for nutrient limits

Due to eutrophication of estuaries being a widespread issue globally as a result of catchment development, there is an extensive body of research available to draw upon for managing the issue of nutrient enrichment and excessive algal growth. Research results and guidelines can be presented in terms of either nutrient loadings or overlying water concentrations. There is however general agreement that nutrient loadings better reflect associated changes of increases in macroalgal growth (Robertson et al. 2016, Rees 2009), as it is possible for algae to rapidly take up available nutrients in the water column and as a result appear comparable to areas receiving low nutrient loadings.

The New Zealand Estuarine Trophic Index (ETI) framework (Robertson et al. 2016) is essentially a management tool focused on eutrophication which has been adapted for nutrient loadings to New Zealand estuaries which can be underestimated using the ASSETTS approach (Garmendia et al. 2012). Borja et al. (2006) have also modified the ASSETTS approach to grade eutrophication levels for smaller volume Basque estuaries by taking into account the estuary area and physical susceptibility (export potential). As these two grading frameworks are similar, they are shown in the matrix below for determining the susceptibility of shallow intertidal dominated estuaries to total nitrogen loading.

	Reference	**N load susceptibility (mg/m^2/day)**			
		Very high	High	Moderate	Low
Physical susceptibility	Robertson et al. 2016	>250	50-250	10-50	<10
	Borja et al. 2006	>300	200-300	100-200	<100
High		Very high	High	High	Moderate
Moderate		Very high	High	Moderate	Low
Low		High	Moderate	Moderate	Low

Both Maketū and Waihī Estuary have a moderate physical susceptibility under the ETI framework which is only a broad guideline as a number of physical characteristics including shape, shelter or substrate type and condition can vary susceptibility at localised scales. In terms of the ETI framework, both Maketū and Waihī Estuary with nitrogen loadings above 250 mg/m^2/day currently sit in the “very high” susceptibility band.

Another study looking at eutrophication and the issue of macroalgal growth and the loss of seagrass from shallow temperate estuaries as a result of nitrogen loading was that of Valiela et al. (1992, 1997). In this study seven estuaries from Waquoit Bay, Massachusetts, were assessed to determine the relationship between the abundance of macroalgae and seagrass cover and the loading of total nitrogen. At levels as low as 20 mg/m^2/day of total nitrogen, significant losses of seagrass occurred and around 100 mg/m^2/day of total nitrogen, seagrass became absent and macroalgal biomass was high. A similar result was found by Fox et al. (2008) in a comparison of three shallow sub-estuaries of Waquoit Bay with different total nitrogen loads over a six year period. The findings showed a shift to high macroalgal blooms at total nitrogen loads of around 100 mg/m^2/day.

Seagrasses are generally adapted to low nutrient environments and gain a significant portion of their nutrient requirements through the root systems. When nutrient levels become enriched seagrasses are both outcompeted by other algae and may also suffer impacts from a number of other mechanisms which include toxicity (nitrate, ammonia and sulphide) and light reduction. As a result, seagrass can start declining in abundance earlier than the occurrence of extensive macroalgal blooms. Below are a range of studies and loading estimates that relate to impacts on seagrasses in shallow estuaries of temperate regions (as reviewed by Schallenberg & Schallenberg 2012).

Reference	**Region**	**Level of decline**	**Loading threshold TN – mg/m^2/day**
Sanderson & Coade (2010)	Australian lagoons	some loss	10
Hauxwell et al. (2003)	Waquoit Bay, USA	some loss	17
Boynton et al. (1996)	Chincoteague Bay, USA	some loss	14
Scanes (2012)	Australian lagoons	some loss	25
Viaroli et al. (2008)	Mediterranean lagoons	high loss	27*
Latimer & Rego (2010)	New England	some/high	18/37
Burkholder et al. (2007)	Global - temperate	some/high loss	27/80
Fox et al. (2008)	Waquoit Bay, USA	high loss	100

*DIN value which may equate to around 20-40 for TN load.

The loading values above include of range of estuarine systems with varying residence time, export potential (flushing/dilution) and species of seagrass, so the values present a range that shallower coastal systems are likely to fall within. As expected, the range of values reflects nitrogen loading susceptibility of the ETI Tool 1 (Robertson et al. 2016) which takes into account impacts on seagrass.

Salinity also adds another level of complexity to the success of seagrass survival that needs to be taken into account. Seagrass (*Zostera spp.*) is known to flower more frequently, increase seed production and have higher germination rates in lower salinity (Philips et al. 1983, Conacher et al. 1994, Tanner & Parham 2010, Ramage & Schiel 1998). *Z. muelleri,* the New Zealand species also has wide salinity tolerance and has been shown to produce the highest shoot density at 12 psu after ten weeks (Collier et al. 2014) compared to higher or lower salinities. In addition estuarine seagrass has been shown to have lower vitality at higher salinities in the presence of high nutrient loads (Katwijk et al., 1999). Hence at lower salinities seagrass survival will be higher than indicated by many of the overseas studies and as an example when Maketū Estuary was in its natural state (full river flow), seagrass appeared to be thriving (Park 2014) at relatively high areal TN loading rates (721mg/m^2/day) bearing in mind that the extensive surrounding wetlands may have reduced the load to some extent.

5.1 **Interim nutrient limits for Maketū and Waihī Estuaries**

Reviews of temperate shallow intertidal dominated estuaries (Burkholder et al. 2007, Schallenberg & Schallenberg 2012, Robertson et al. 2016) clearly show that moderate eutrophication and impacts on ecological communities and in particular seagrass extent, start to occur at around levels of 15 - 50 mg/m^2/d – TN. At around 50 to 100 mg/m^2/d – TN, high eutrophication will generally start to occur so that in most estuaries of this type, seagrass will become absent.

Both Maketū and Waihī Estuaries clearly reflect the impacts of nitrogen loading. Maketū Estuary with a catchment loading of 534 mg/m^2/d and Waihī Estuary at 584 mg/m^2/d –TN are both around 2 - 10 times the load that would generally be expected to result in high eutrophication taking into account physical susceptibility. Source modelling estimates that the relative comparable natural state catchment contribution to Maketū Estuary is a TN load (mg/m^2/d) of 174 while Waihī had 101. For Maketū Estuary the original natural state TN load is 721(mg/m^2/d) but the estuary had much higher freshwater inflow (41.8 m^3/s = flushing potential 3, compared to 10.1 m^3/s & 0.75) placing it into the less sensitive river dominated estuary category compared to its current shallow intertidal dominated state.

As a consequence the natural state for Maketū Estuary no longer provides a relevant reference point as the current physical susceptibility makes it more sensitive to nitrogen loading. For Waihī Estuary the estimated natural state TN load of 101 mg/m^2/day provides a reference level at which the estuary was formerly in a healthy minimal eutrophication state. Given that Maketū Estuary is now very similar in terms of physical susceptibility to Waihī Estuary (flushing potential will be 0.75 compared to Waihī Estuary at 0.35 once the new Kaituna River diversion flows commence in 2020), then a TN load of 100 mg/m^2/day may also be an appropriate reference point for minimal eutrophication state.

Another relevant point that needs to be considered for an appropriate interim guideline for nutrient levels is that it will not be possible to achieve a natural state for Maketū and Waihī Estuaries due to significant changes that have taken place over time. These changes include channelised freshwater inflows by-passing wetland filtration, sedimentation/nutrient accumulation, loss of fringing wetlands and extensive catchment development. Given the physical characteristics of Waihi and Maketū Estuaries, particularly the relatively high flushing rates, the changes that have taken place and the guidance of the overseas research and frameworks, then both estuaries may remain in no more than a moderately eutrophic state if TN is kept to a maximum areal load of 200 mg/m^2/day. If the higher estimation for nutrient recycling were used and included as part of the total load then the catchment load would have to be reduced by around 10%.
Applying a target TN load to Maketū and Waihī Estuaries of 200 mg/m^2/day equates to an annual TN load of 178.7 and 211.9 tons respectively. For Maketū Estuary this is near an equivalent natural state estimate of TN load and only half the Source model estimate of “Scenario C”, hence may

have to be moderated if later more rigorous modelling doesn't show a higher acceptable target. For Waihī Estuary the Source modelling shows that under "Scenario C" the catchment TN annual load would be only around 13% higher than the 200 mg/m^2/day target for areal loading of TN in Waihī Estuary which shows that it may be an achievable target.

As raised in the section on nutrients and eutrophication, both nitrogen and phosphorus should be considered for management as either can become a limiting nutrient to growth if concentrations fall below critical levels, as there is an ideal ratio of both required for growth depending on structural requirements (Atkinson and Smith 1983) and climatic zone (Lapointe *et al.* 1992). These studies and other such as Sfriso *et al.* (1995) show an N:P ratio of 30:1 to be a relevant standard for assessing nutrient limitation. At this ideal ratio of 30:1 for N:P, an interim maximum areal TN load target of 200 mg/m^2/day would mean that the phosphorus limit would be 14.7 mg/m^2/day. This equates to an annual load of TP for Maketū Estuary of 13.768 tons and 18.228 tons for Waihī Estuary.

For Maketū Estuary, the interim target TP load is above but close to the Source model estimate of equivalent natural state catchment load (12.2 tons/yr) and 19% lower than the estimated catchment load under "Scenario C". This is similar to results for the TN target reduction and suggests that although it appears to be an appropriate target when assessed against relevant research information, it may be difficult to achieve.

In Waihī Estuary the modelled natural state for Waihī Estuary has a naturally high TP load of 36.8 tons per year which results in a very low N:P ratio around 6.4:1. This means it is nitrogen limited and sensitive to any nitrogen increase. It also places a focus on managing nitrogen rather than phosphorus until that ideal N:P ratio of 30:1 is reached. The natural state of Waihī Estuary also shows that trying to achieve a balanced N:P ratio management approach is not possible in any case due to the ideal annual TP load for the estuary being half the natural state. Under "Scenario C" which is close to the interim target required for TN loading to the estuary, the N:P ratio would be around 13:1 which indicates continued nitrogen limitation. This implies that a TP load close to that of "Scenario C" and ideally slightly less (ie around 39-40 tons per year) should be acceptable and in line with the TN loading target.

6 Summary

Appropriate areal nutrient loads are considered here to keep Maketū and Waihī Estuary in a moderately healthy ecological state that supports biodiversity, ecological functioning, mahinga kai, taunga ika and other cultural values. This is based on research reviews and applicable frameworks for assessing eutrophication. Using this information, the following interim guidelines are recommended;

- For TN an areal load of 200 mg/m^2/day; and
- For TP an areal load of 14.74 mg/m^2/day.

For Maketū Estuary these values are close to the natural state and this infers they may be too ambitious. Modelling of Waihī Estuary nutrient loads shows that the TN load target may be achievable as it is close to the "Scenario C" model loads. However the high natural TP loads to Waihī Estuary mean the ideal TP load is clearly not achievable and that a load to the estuary around and preferably slightly lower than "Scenario C" result would be appropriate. The ETI framework (Robertson et al. 2016) stresses that for regulatory purposes, a modelling approach is recommended. A modelling approach would increase the accuracy and robustness of any estimates and give better resolution within the estuaries of where, and to what extent, eutrophication issues could be expected to occur.

References

Atkinson, M.J. & Smith, S.V. (1983): C:N:P ratios of benthic marine plants. Limnol. Oceanogr. 28(3): 568-574.

Bay of Plenty Regional Council (2017): FINAL future land use specifications for catchment modelling. Internal memo – 10 p, Objective ID:A2855842.

Bricker, S.B., Clement, C.G., Pirhalla, D.E. & Orlando, S.P. (1999): National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries.

Borja, A., Galparsoro, I., Solaun, O., Muxika, I., Tello, E.M., Uriarte, A., & Valencia, V. (2006):Thr European Water Framework Directive and the SPSIR, a methodological approach to assess the risk of failing to achieve good ecological status. Estuarine, Coastal and Shelf Science, 66(1-2): 84-96.

Boynton, W., Murray, L., Hagy, J. & Stokes, C. (1996): A comparative analysis of eutrophication patterns in a temperate coastal lagoon. Estuaries, 19: 408-421.

Burkholder, J.M., Tomasko, D.A. & Touchette, B.W. (2007): Seagrasses and eutrophication. J. Experimental Marine Biology & Ecology 350: 46-72.

Collier, C.J., Vilcorta-Rath, C., van Dijk, K., Takahashi, M. & Waycott, M. 2014: Seagrass proliferation Precedes mortality during hypo-salinity events: A stress-induced morphometric response. PloS ONE 9(4): e94014 doi:10 1371/journal pone 0094014.

Conacher, C.A., Poiner, I.R., Butler, J., Pun, S. & Tree, D.J. 1994: Germination, storage and viability testing of seeds of *Zostera capricorni Aschers*, from a tropical bay in Australia. Aquatic Botany. 49(1): 47-58.

Christensen, P.B., Glud, R.N., Dalsgaard, T. & Gillespie, P. (2003). Impacts of longline mussel farming on oxygen and nitrogen dynamics and biological communities of coastal sediments. Aquaculture 218, 567-588.

Dortch, Q., Thompson, P.A. & Harrison, P.J. (1991): Short-term interaction between nitrate and ammonium uptake in Thalassiosira pseudonanna: effect of preconditioning nitrogen source and growth rate. Marine Biology 110: 183-193.

Fox, S.E., Stieve, E., Valiela, I., Hauxwell, J. & McClelland, J. (2008): Macrophyte abundance in Waiquoit Bay:Effects of land-derived nitrogen loads on seasonal and multi-year biomass patterns. Estuaries and Coasts. 31: 532-541.

Garmendia, M., Bricker, S., Revilla, M., Borja, A., Franco, J., Bald, J. & Valencia, V. (2012): Eutrophication assessment in Basque Estuaries: Comparing a North American and a European method. Estuaries and Coasts 35: 991-1006.

Hamill, K.D. (2014): Kaituna River Re-diversion Project: Ongatoro/Maketū Estuary condition and potential ecological effects. Prepared for Bay of Plenty Regional Council.

Hamill, K.D. (2018): Catchment water quality and loads to Maketū Estuary and Waihī Estuary. Prepared for Bay of Plenty Regional Council by River Lake Limited. 36p.

Hauxwell, J., Cebrian, J. & Valiela, I. (2003): Eelgrass Zostera marina loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae. Mar. Ecol. Prog. Ser. 247: 59-73.

JACOBS (2018): MT3D Nitrate Flux Modelling: Kaituna-Maketū-Pongakawa Groundwater Model Additional Scenarios. Memorandum prepared for Bay of Plenty Regional Council by Ruolin Wu & Gillian Holmes. 11p.

Van Katwijk M.M., Schmitz, G.H.W., Gasseling, A.P., van Avesaath, P.H. (1999): Effects of salinity and nutrient load and their interaction on Zostera marina. Marine Ecology Progress Series. 1999;190:155–165. doi: 10.3354/meps190155.

Lapointe, B.E., Littler, M.M. & Littler, D.S. (1992): Nutrient availability to marine macroalgae in siliciclastic versus carbonate-rich coastal waters. Estuaries 15(1): 75-82.

Latimer, J.S. & Rego, S.A. (2010): Empirical relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. Estuarine Coastal and Shelf Science 90: 231-240.

Needham, H.R. (2018): Estimating the efflux of NH4+ from intertidal sediment in Waihī and Maketū Estuaries. Report prepared for Bay of Plenty Regional Council. 9 p.

OSPAR, (2008): Second integrated report on the eutrophication status of the OSPAR maritime area. Eutrophication Series, OSPAR Commission, 107p.

Park, S.G. (2011): Sea Lettuce and Nutrient Monitoring in Tauranga Harbour 1991-2010. *Environment BOP Environmental Publication 2011/06*: 54 p.

Park, S.G. (2014): Extent of wetland vegetation in Maketū Estuary – 1939 to 2011. Bay of Plenty Regional Council *Environmental Publication 2014/05*: 54 p.

Park, S.G. (2016): Ecological health of Waihi Estuary. BOPRC internal memo, Objective ID-A2272466.

Park, S.G. (2018a): Preliminary investigation of ecological sensitivity of Waitahanui, Kaituna and Rangitāiki (Thornton) estuaries. BOPRC internal memo, Objective ID-A2908752.

Park, S.G. (2018b): State (health) of benthic ecology in Waihi and Maketu Estuaries. BOPRC internal memo, Objective ID-A2892930.

Philips R.C., Grant, W.S. & McRoy, C.P. (1983): Reproductive strategies of eelgrass (Zostera marina L.). Aquatic Botany. 16:1-20.

Ramage, D.L. & Schiel, D.R. (1998): Reproduction in the seagrass *(Zostera novzelandica)* on intertidal platforms in southern New Zealand. Marine Biology. 130: 479-489.

Rees, T.A.V. (2009): Effects of nutrients on marine algae: Eutrophication globally and in New Zealand. Report published by Leigh Marine Laboratory, University of Auckland. 42p.

Robertson , B.P. & Savage, C. (2018): Mud-entrained macroalgae utilise porewater and overlying water column nutrients to grow in a eutrophic intertidal estuary. Biogeochemistry 139: 53-68.

Robertson, B.M. & Stevens, L. (2012): Guidance Document: Nutrient Load Criteria to Limit Eutrophication in Three Typical New Zealand Estuary Types – ICOLL's, Tidal Lagoon, and Tidal River Estuaries. Report prepared by Wriggle Coastal Management for Environment Southland. 9p.

Robertson, B.M, Stevens, L., Robertson, B., Zeldis, J., Green. M., Madarasz-Smith. A., Plew. D., Storey. R., Hume. T. & Oliver. M. (2016): NZ Estuary Trophic Index Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data. Prepared for the Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No. C01X1420. 47 p.

Sanderson, B. & Coade, G. (2010): Scaling the potential for eutrophication and ecosystem state in lagoons. Environmental Modelling & Sofyware. 25: 724-736.

Scanes, P. (2012): Nutrient loads to protect environmental values in Waituna Lagoon. Report prepared for Environment Southland NZ. 11 pp.

Schallenberg, M. & Schallenberg, L.A. (2012): Eutrophication of coastal lagoons: a literature review. Report prepared for Environment Southland. Invercargill, New Zealand.

Schallneberg, M., Hamilton, D.P., Hicks, A.S., Robertson, H.A., Scarsbrook, M., Robertson, B., Wilson, K., Whaanga, D., Jones, H.F.E & Hamill, K. (2017): Multiple lines of evidence determine robust nutrient load limits required to safeguard a threatened lake/lagoon system. New Zealand Journal Marine & Freshwater Research 18 p.

Sfriso, A., Marcomini, A. & Pavoni, B. (1987): Relationships between macroalgal biomass and nutrient concentrations in a hypertrophic area of the Venice Lagoon. Marine Environ. Res. Pp: 297-312.

St-Laurent, P., Friedrichs, M.M., Najjar, R.G., Martins, D.K., Herrmann, M., Miller, S.K. & Wilkin, J. (2017): Impacts of Atmospheric Nitrogen Deposition on Surface Waters of the Western North Atlantic Mitigated by Multiple Feedbacks. Published 10 October 2017, https://doi.org/10.1002/2017JC013072

Tanner, C.E. & Parham, T. (2010): Growing *Zostera marina* (eelgrass) from seeds in land-based culture systems for use in restoration projects. Restoration Ecology Vol 18 (4): 527-537.

Valiela, I. & others (1992): Couplings of water sheds and coastal waters: Sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts. Estuaries, 15: 443-457.

Valiela, I., McClelland, J., Hauxwell, J., Behr, P.J., Hersh, D. & Foreman, K. (1997): Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. Limnology & Oceanography, Vol 42 (5): 1105-1118.

Viaroli, P., Bartoli, M., Giordani, G., Naldi, M., Orfanidis, S. & Zalddivar, J. (2008): Community shifts, alternative stable states, biogeochemical control and feedbacks in eutrophic coastal lagoons: a brief overview. Aquatic Conservation; Marine and freshwater Ecosystems. 18: 105-117.

Zeldis, J. (2008): Exploring the Carrying Capacity of the Firth of Thames for Finfish Farming: a Nutrient Mass-balance Approach. Prepared by National Institute of Water and Atmospheric Research Limited for Environment Waikato. Environment Waikato Technical Report 2008/16. 28 pages.