Proposed reference conditions in Southland estuaries: review of historical data and literature

Values and Objectives Technical Report

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Dr Keryn Roberts and Nicholas Ward

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Prepared by:	Dr Keryn Roberts, Environmental Scientist – Estuaries and Lakes, Environment Southland Nick Ward, Team Leader – Ecosystem Response, Environment Southland		
Reviewed by:	Nuwan DeSilva (ES), Ned Norton (LWP)		
Approved for issue by:	Wilma Falconer, General Manager Strategy and Engagement		
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Executive Summary

Environment Southland and Te Ao Marama (TAMI) have, through their People Water and Land programme, embarked on a community-involved process to further develop the approach to managing land and water in the region. This has included community engagement to support the development of community values and freshwater objectives, and the formation of Regional Forum to help develop limits and both regulatory and non-regulatory methods to achieve them.

The purpose of this report is to contribute to the process of developing draft freshwater objectives for consideration by Environment Southland's Council and the Te Ao Marama board. This report is one of a number of supplementary reports and memos that contribute to the report titled: *Draft Murihiku Southland Freshwater Objectives: Providing for hauora, the health and well-being of waterbodies in Murihiku Southland* (Bartlett et. al, 2020).

This report outlines the results of a review of historical data and literature to develop proposed reference conditions for Southland estuaries. The report highlights the approach taken to develop proposed reference conditions in addition to identifying key knowledge gaps. A summary of reference conditions for Southland estuaries applied to the proposed numeric attributes is summaries below.

Table 1: Summary of reference condition for Southland estuaries using the proposed classes and numeric attribute state option tables from Norton and Wilson (2019).

<table>
<tr><th></th><th>Natural State</th><th>Tidal Lagoon Estuaries (SIDE)</th><th>Tidal River Estuaries (SSRTRE)</th><th>Fiords and Bays (DSDE)</th></tr>
<tr><td colspan="5">National Compulsory Attributes</td></tr>
<tr><td colspan="5">There are no nationally compulsory attributes for estuaries</td></tr>
<tr><td colspan="5">Southland Attributes[1]</td></tr>
<tr><td>Phytoplankton (Chl-a; mg/m^3)</td><td rowspan="12">No change[2]</td><td>A to C</td><td>A</td><td>A to B</td></tr>
<tr><td>Gross Eutrophic Zone (% intertidal area)</td><td>A</td><td>A</td><td>NA</td></tr>
<tr><td>Mud content (% mud at a site)</td><td>Not determined</td><td>Not determined</td><td>NA</td></tr>
<tr><td>Muddiness (>25% mud content in m^2 intertidal area)</td><td>Pass</td><td>Pass</td><td>NA</td></tr>
<tr><td>Sedimentation rate (5 year trend ≤ 2mm/year)</td><td>Pass</td><td>Pass</td><td>NA</td></tr>
<tr><td>Sediment oxygen level (aRPD in mm)</td><td>A to B[2]
A[3]</td><td>A to B[2]
A[3]</td><td>NA</td></tr>
<tr><td>Macroalgae (Ecological Quality Rating)</td><td>A to B</td><td>A to B</td><td>NA</td></tr>
<tr><td>E. coli (E. coli/ 100mL)</td><td>A</td><td>A</td><td>A</td></tr>
<tr><td>E. coli at popular bathing sites (E. coli/ 100mL)</td><td>A</td><td>A</td><td>A</td></tr>
<tr><td>Enterococci (Enterococci / 100mL)</td><td>A</td><td>A</td><td>A</td></tr>
<tr><td>Enterococci at popular bathing sites (Enterococci / 100mL)</td><td>A</td><td>A</td><td>A</td></tr>
<tr><td>Toxic metals in sediment (mg/kg dry weight)</td><td colspan="3">See table below</td></tr>
</table>

[1] The proposed reference conditions are based on the state ranges from New Zealand literature and modelling, unless contemporary data indicates that the state range is better than the proposed reference conditions from the literature (e.g. A+ current state vs proposed upper banding of an A in the literature) or there is no other information available. It is important to note that the assessment of state made in this memo does not fully meet the required statistical test for the attribute state options, and should therefore be used as an indication of reference state only. Further research will be required to confirm these estimates of reference conditions.

[2] Mud

[3] Sand

Table 2: Toxic metals in sediment estimated reference condition for Southland estuaries using the proposed classes and numeric attribute state option tables from Norton and Wilson (2019).

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Tidal Lagoon Estuaries (SIDE)	A to B	A	A to B	A	A	A to B[1]	A	A
Tidal River Estuaries (SSRTRE)	A	A	A	A	A	A	A	A
Fiords and Bays (DSDE)[2]	A	A to B	C to D	C to D	A	C	B	B

[1] A-B band unless caused by natural perturbations (e.g. nickel (Ni) in Jacobs River Estuary and New River Estuary as discussed in text have elevated Ni levels in the soils of the catchment).

[2] Metal concentrations in the sediments of New Zealand fiords are heavily dependent on lithology. It may not be possible to achieve the top of the band range because the concentration of trace metals in Fiordland is strongly linked to provenance. Very few studies exist on trace metals in New Zealand fiords further research is required to confirm these proposed "reference" state ranges and any inferences for comparison against reference state for DSDE type estuaries should be treated with caution.

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1 Introduction

Environment Southland and Te Ao Marama (TAMI) have, through their People, Water and Land – Te Mana o te Tangata, te Wai, te Whenua programme, embarked on a community-involved process to further develop the approach to managing land and water in the region. This has included community engagement to support the development of community values and freshwater objectives, and the formation of Regional Forum to help develop limits and both regulatory and non-regulatory methods to achieve them.

The People, Water and Land programme has three workstreams, one of which is 'Values and Objectives'. The objective of this workstream is to raise awareness of freshwater and to determine the community's values and freshwater objectives in accordance with the requirements of the National Policy Statement for Freshwater Management[1] (NSPFM).

This report is part of a package of work being prepared through the Values and Objectives workstream. Specifically, this report provides supplementary material that was used in the preparation of the report titled: *Draft Murihiku Southland Freshwater Objectives: Providing for hauora, the health and well-being of waterbodies in Murihiku Southland* (Bartlett et al., 2020).

1.1 Report purpose

The purpose of this report is to describe, as best as possible, the reference conditions for Southland estuaries using the estuary classes, attributes and attribute state tables developed through the following sequence of reports: Ward and Roberts, 2020; Norton and Wilson 2019; and Norton et al., 2019. This information will help ensure any freshwater objectives set are achievable and fit within a realistic range. The methodology used was to undertake a review of historical data and literature to develop proposed reference states and to identify key knowledge gaps. An understanding of reference conditions can provide a benchmark against which contemporary monitoring data can be compared.

[1] The NPSFM was first released in 2011 and amended in 2014 and 2017. Unless otherwise stated, this report refers to the 2017 version of the NPSFM. The NPSFM was further amended in 2020, after this report was first prepared.

2 What is 'reference condition'?

There are several different definitions to describe reference conditions in New Zealand estuaries and as such there should be a degree of caution applied when making comparisons between approaches to define reference conditions. From the New Zealand literature there is a general consensus that the term 'reference condition' refers to the state of the ecosystem prior to anthropogenic (human) impacts.

However, for New Zealand estuaries, and many estuaries globally, information on pre-human reference conditions are limited or there is no data available. Further, estimates of reference conditions from paleolimnological studies in some instances may not reflect the current hydrological condition of the estuary due to the high degree of human disturbance that has occurred over time (e.g. a change in hydrology, land reclamation and dredging). As such reference conditions requires various approaches to establish a reasonable baseline or 'reference state range.' This approach has been applied in assessing estuary condition in Australia across Victoria, Tasmania and New South Wales (Arundal et al., 2009; Crawford, 2006; Scanes, 2016) and the UK (WFD-UKTAG, 2014). In those studies, the approaches used to develop reference conditions in order of relevance:

- pre-human condition data (paleolimnological, oral histories);
- modelling of historical and pre-human conditions; and,
- current state of natural or pristine reference estuaries with similar characteristics to the equivalent estuary type and location;
- historical state data;
- current state data;
- exert opinion in the absence of all data based on anecdotal observations, data from other locations and/or incomplete datasets.

This is complementary to the approach taken in developing the ANZECC guidelines section 3.1.4 "Defining a reference condition." ANZECC and ARMCANZ (2000) use a combination of historical data collected before a disturbance, spatial data (comparison against undisturbed sites) and data derived from other sources where data is not available (e.g. models, literature and expert opinion).

The terms 'natural state' and 'reference condition' are sometimes used interchangeably. To align with the New Zealand scientific literature and for the purpose of this report the term 'reference condition' refers to "the state of the ecosystem prior to anthropogenic (human) impacts". As described above several sources of information have been utilised to estimate reference conditions (pre-human) for each of the estuary classes[2], these lines of evidence are presented for each of the proposed attributes and reference conditions estimated from the evidence deemed to appropriately reflect the definition (pre-human). It should be acknowledged that the reference conditions proposed in this report are an estimate based on best available information at the time and should be treated with some caution.

The definition of reference conditions equates to the term 'natural state' used in Bartlett et al., (2020) which refers to pre-human condition rather than pre-European condition. The term 'reference condition' was used in preference to 'natural state' to avoid confusion with the 'natural state'[3] estuary class.

[2] Intermittently closed and open lake or lagoons (ICOLL), are classified under brackish lakes, are not covered in this document. For reference conditions in brackish lakes refer to the memorandum "Reference Conditions in Southland Lakes". Open coast reference state conditions need to be explored further and are not documented here.

[3] As defined in the proposed Southland Water and Land Plan (decisions version)

3 Phytoplankton (Chl-*a*)

3.1 Development of the phytoplankton attribute and establishing reference condition

Revilla et al., (2010) assessed reference conditions for phytoplankton in Basque estuaries (Spain). Because all estuaries in Spain have been impacted historically by human activities there is no data for true 'reference' conditions. As such Revilla et al., (2010) set reference conditions based on data analysis from 1995 to 2001 and expert judgement. Note that the 'A' band for the phytoplankton proposed attribute (Table 3) is based on the 'High/Good' category in Table 4 and these bandings were developed from monitoring data. Basque estuaries are generally well drained like majority of New Zealand estuaries, and therefore it is more relevant to apply reference condition chlorophyll concentrations to New Zealand estuaries in preference to US studies which represent generally deeper, poorly flushed systems (Plew et al., 2020b). The reference condition chl-a concentrations proposed in Revilla et al., (2010) are within an A band for all coastal types (saline, less saline, open coast).

Table 3: Phytoplankton (expressed as Chl-*a* mg/m^3) attribute state option bandings proposed for Southland (90th percentile).

	A Very good	B Good	C Fair	D Poor
Open coast	≤3.5	>3.5 and ≤7.0	>7.0 and ≤10.5	>10.5
Estuaries saline (>30ppt)	≤4	>4 and ≤8	>8 and ≤12	>12
Estuaries less saline (<30ppt)	≤8	>8 and ≤12	>12 and ≤16	>16

Table 4: Revilla (2010) reference conditions and class boundaries based on phytoplankton biomass (90th percentile Chl-*a*). Key: CW = coastal waters; TW = Transitional waters.

Water Category	Salinity stretch	Reference condition (µg L^{-1})	High/Good (µg L^{-1})	Good/ Moderate (µg L^{-1})	Moderate/ Poor (µg L^{-1})	Poor/Bad (µg L^{-1})
CW	Euhaline	2.33	3.5	7.0	10.5	14.0
TW	Euhaline	2.67	4.0	8.0	12.0	16.0
TW	Oligo/Meso/Polyhaline	5.33	8.0	12.0	16.0	32.0

The ANZECC and ARMCANZ (2000) guidelines state that further work is required to develop guidelines for New Zealand estuarine and marine ecosystems and in the interim south-east Australian trigger values should be used (Tables 3.3.2 and 3.3.3; ANZECC and ARMCANZ 2000). In this instance the south-east Australian trigger value is 4 mg m^{-3} Chl-*a* and 1 mg m^{-3} Chl-*a* for estuaries and open coast, respectively. The default trigger values were derived from ecosystem data for "substantially natural to slightly disturbed ecosystems." These trigger values represent an A-band.

Deeper, Subtidal, Dominated Estuaries (DSDE), characteristically have longer residence times[4] (>7 days), are prone to stratification, reduced flushing potential[5] and are generally nitrogen limited. As a result, DSDE type estuaries are more prone to phytoplankton growth (Robertson et al., 2016). Phytoplankton or algal blooms occur naturally, particularly in estuaries with residence time is >3 days, however they can be initiated and enhanced by anthropogenic factors including elevated nutrients. Fiordland has several DSDE type estuaries, in addition to the controlling factors described in Table 5 light limitation in tannin rich surface waters could control phytoplankton growth.

[4] 'Residence time' is the average time a water molecule spends in an estuary

[5] 'Flushing potential' refers to how quickly the volume of freshwater within an estuary is replaced. A higher flushing potential indicates the water is replaced more rapidly.

Table 5: Reference conditions for the phytoplankton attribute bandings proposed for Southland from literature using the bands described in Table 3.

Estuary type	Description	Reference condition	
Shallow, intertidal dominated estuaries (SIDE)	Revilla et al. (2010) and ANZECC and ARMCANZ (2000) indicate that estuaries (both saline and less saline), including SIDEs would naturally have low levels of Chl-*a* or phytoplankton growth.	A	
Shallow, short residence time tidal river, and tidal river with adjoining lagoon estuaries (SSRTRE)	Phytoplankton growth is often limited by the flushing potential in SSRTRE type estuaries (e.g. the residence time is too short to allow growth; Plew et al. 2020c). Further Revilla et al. (2010) and ANZECC and ARMCANZ (2000) indicate reference conditions would represented minimal growth in these estuaries.	A	
Deeper, subtidal, dominated estuaries (DSDE)	Long residence time, stratification and reduced flushing potential mean DSDE type estuaries are prone to higher levels of phytoplankton growth than other shallower estuary types.	A to	B

3.2 Modelling data for Southland estuaries

In a report prepared for the Ministry for the Environment "Assessment of the eutrophication susceptibility of New Zealand estuaries" (Plew et al., 2018) phytoplankton (chlorophyll-*a*) was modelled for three conditions, current, pre-human and pristine conditions:

- **Current land cover**: present day land cover and atmospheric nitrogen deposition;
- **Pre-human land cover**: incorporates pre-human land cover and current nitrogen deposition rates (assess the effects of land cover change only); and,
- **Pristine**: incorporates pre-human land cover and estimated pre-industrial atmospheric nitrogen deposition rates (it assesses combined effects of land cover and atmospheric nitrogen changes).

There are several caveats to the modelled scenarios:

- The scenarios do not account for wetlands in the pre-human estimates, this likely has led to an overestimation of nutrient loads because wetlands typically remove up to 30-45% nitrogen (Plew 2020, pers comm). New Zealand has lost over 90% of its wetlands from human influence with a significant portion of this loss represented in Southland;
- The scenarios tested do not account for pre-disturbance hydrology (e.g. channelization, land reclamation etc). The modelling does not account for changes in flow either through land use change or long term climate shifts;
- The scenarios are based on modelling water quality under current condition against a pressure (e.g. an anthropogenic pressure such as percent pasture) then dialling the pressure down to zero to mimic pre-pressure conditions. It is not indicative of the land cover being reverted back to natural cover (e.g. forest/tussock); and,
- Atmospheric deposition (post and pre-industrial) has been accounted for however historic oceanic nitrogen concentrations have not been accounted for and current nitrogen concentrations in Southland are high compared to other regions (Plew 2020, pers comm).

Table 6 represents the results from national modelling, more recently Snelder et al., (2020) and Plew et al., (2020a) have been working through regional modelling for the People, Water and Land

Programme using regional load estimates for 'reference conditions' in Southland rivers. Plew (2020a; pers comm) used the estimated outputs of pre-human TN and TP loads from the Southland regional modelling to estimate 'reference conditions' in Southland estuaries (Table 7). Waikawa and Haldane estuaries have poorer gradings for the regional estimates because a seasonal flow adjustment was added to the modelling in contrast to the national modelling. In short, summer flows are less than mean flows which reduces the flushing[6] time leading to more phytoplankton growth (a detailed explanation is provided in Appendix 1; Plew (pers comm)). Due to the high flushing potential and low residence time phytoplankton growth in SSRTRE type estuaries is limited by the flushing time of the estuary (e.g., water is exchanged very quickly) rather than nutrients, as such phytoplankton state in these estuaries is expected to be in A state (Table 6 and 7). Phytoplankton growth in SIDE type estuaries however are limited by nutrients. DSDE type estuaries have longer residence times and therefore are more prone to phytoplankton growth, note there is no regional modelling for DSDE type estuaries because these estuaries are within the Fiordland and Islands FMU which is considered to be in the 'natural state' class which requires the current state to be maintained.

Table 6: Modelled phytoplankton (Chl-*a;* mg m^{-3}) concentration using national estimates using the bands described in Table 3. A subset of the estuaries modelled are shown below. [Sourced from Plew et al., (2018)].

System	Estuary type	Pristine	Pre-human	Current[1]	Reference state range
New River Estuary	SIDE	A	C	D	A to C
Jacobs River Estuary	SIDE	A	A	A	
Waikawa Estuary	SIDE	A	B	D	
Haldane Estuary	SIDE	A	A	B	
Bluff Harbour	SIDE	B	B	B	
Toetoes (Fortrose) Estuary	SSRTRE	A	A	A	A
Waiau Estuary	SSRTRE	A	A	A	
Milford Sound	DSDE	A	A	A	A to B
Doubtful Sound	DSDE	A	A	A	
Chalky Inlet	DSDE	A	A	B	
Preservation Inlet	DSDE	B	B	B	
Breaksea/Dusky Sound	DSDE	B	B	B	

[1]See Norton et al., (2019) and Ward and Roberts (2020) for further information on how current state was determined.

Table 7: Modelled phytoplankton (Chl-*a;* mg m^{-3}) using regional estimates sourced from Plew (pers comm) using the bands described in Table 3.

System	Estuary type	Predicted Chl-*a* (µ/L)	Regional		National	
			Pre-human	Reference state	Pre-human	Reference state
New River Estuary	SIDE	3.8	A	A to D	C	A to C
Jacobs River Estuary	SIDE	0.0	A		A	
Waikawa Estuary	SIDE	12.5	C		B	
Haldane Estuary	SIDE	10.2	B		A	
Bluff Harbour	SIDE	7.5	B		B	
Toetoes (Fortrose) Estuary	SSRTRE	0.0	A	A	A	A
Waiau Estuary	SSRTRE	0.0	A		A	

[6] 'Flushing time' refers to the time taken to replace the freshwater within the estuary

3.3 Monitoring data for Southland estuaries

3.3.1 New River Estuary

Water column Chl-*a* (phytoplankton) is not routinely monitored in Southland estuaries with the exception of compliance monitoring for Invercargill City Council's (ICC) Wastewater Treatment Plant's (WWTP) discharge to New River Estuary. ICC's WWTP resource consent conditions have required monitoring every 2 weeks since the early 1990's. An analysis of the earliest data available 1st July 1991 to 30 June 1994 shows that the chlorophyll concentration in the estuary was elevated with the state ranging from A to C band, some sites have shown improvement since 1991.

Prior to the routine consent monitoring programme, ICC carried out specific studies in New River estuary from 1983-1986 which included measurements of water quality, including Chl-*a*. The tables and graphs are presented in the report titled "*Invercargill City Council Report: New River Estuary 1986*" a simplified summary of the report is shown in Table 8 and Figure 1. It should be noted that only the ranges of chlorophyll concentrations are presented and that this is not the representative statistic for the Chl-*a* attribute, as such any inferences made about state should be treated with some caution. However, Table 7 and Figure 1 highlight the large range in Chl-*a* concentrations that occurred within the estuary ~35 years ago, the measurements were taken as part of the ICC WWTP discharge and therefore are not representative of reference conditions however they do provide some indication of the variability in chlorophyll concentrations in the estuary. Figure 1 shows the range of measurements from 1983 to 1986, note with the exception of Ōreti beach the mean concentration at all sites was <30 mg m^{-3}. An estimate of state ranges for the 1983 to 1986 data is presented in Table 9, it should be noted this is an estimate not an absolute state because the data does not represent the desired statistic (90th percentile).

Table 8: Concentrations of Chl-*a* (mg m^{-3}) in New River Estuary for two time periods; 1991 to 1994 and 2016 to 2019. The colours reflect the bands described in Table 3.

New River Estuary sites	State in 1994	Historic range (1994)	Current state (2019)	Current state range (2019)
Omaui Beach (open coast)[1]	5.14	A to C	3.83	A to D
Awarua Farm	9.07		7.56	
Lagoon tip outlet	12.06		9.86	
Stead Street	14.30		18.86	
Dunns Road	7.08		6.64	
Ski Club	6.85		5.13	
Mcoys Beach	6.51		6.05	
Sandy Point	6.48		4.64	

[1] Omaui Beach has been assessed against the Open Coast criteria, all other sites have been assessed against the Estuarine less saline criteria (Table 3).

The results from the 1994 analysis (Table 8) and the 1983-1986 report (Table 9) indicate chlorophyll concentrations in the estuary are highly variable and dependent on location (e.g. upper estuary vs more well flushed lower estuary sites). At the time of sampling the estuary had been highly modified with modern waste water discharges occurring so the period is not appropriate for determining reference conditions. The appropriate statistic has not been calculated because there was not enough data to meet the minimum criteria for analysis. However, based on available information the estimated state range for this time period is from A to D.

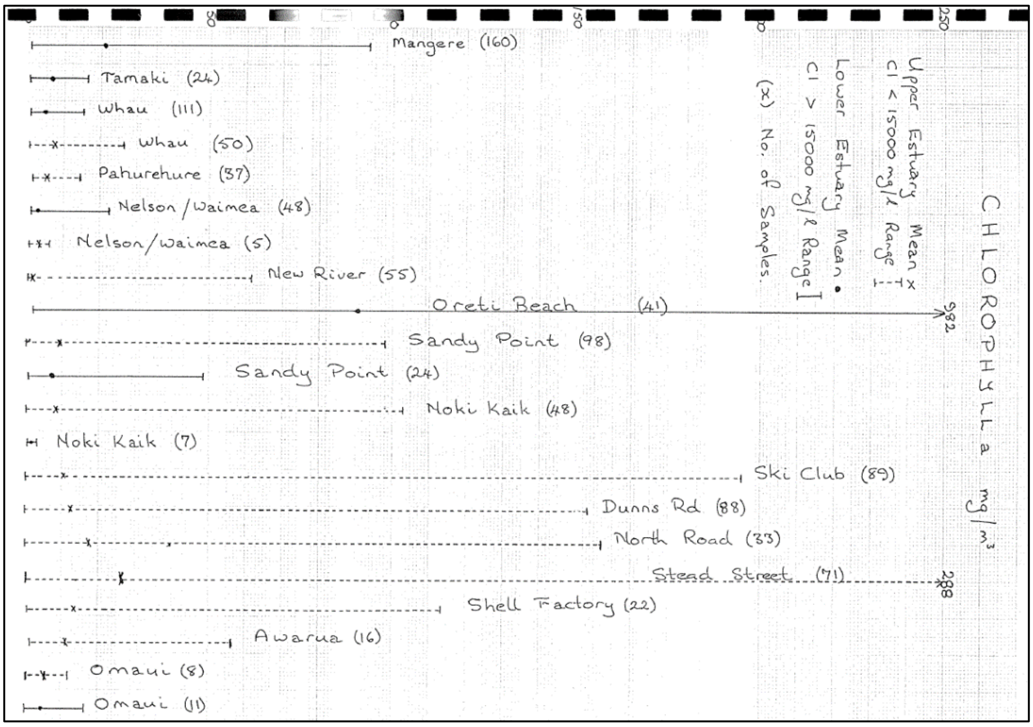


Figure 1: Chl-*a* ranges measured in New River Estuary between 1983 and 1986.

Table 9: **Concentrations of Chl-*a* (mg m^{-3}) in New River Estuary for two time periods; 1983 to 1985 and 1986 using the bands described in Table 3.**

New River Estuary sites	Chl-*a* (max) 1983 to 1985	Chl-*a* (range) 1986 (Mar-Apr)	Estimated State[1]		
Water Ski Club	<200 (LT)	2.0 - 13.7	B	to	D
Shell Banks		3.8 – 10.4	B	to	C
Tip	< 90 (HT)	2.3 - 11.0	B	to	D
Stead Street	<65 (HT)	4.0 - 58.8	C	to	D
Off Hatches Hill		0.7 – 10.4	A	to	C
Whaler Bay		0.5 – 7.1	A	to	B
Bushy Point		0.9 – 8.9	A	to	C
B/n Daffodil Beacon - Bushy Point		1.6 - 6.4	A	to	B
Daffodil Beacon		2.2 - 9.9	B	to	C
Dunns Road Bridge	<160 (LT)	3.8 - 9.2	B	to	D
Moko Moko Inlet		0.4 - 7.5	A	to	B
Sandy Point (low tide)	< 100 (LT)		B	to	C
Shellbanks	<40 (LT)		B	to	C
Awarua	<60 (LT)		B	to	C
Omaui	<20 (LT)		A	to	B

[1]This includes the data in Figure 1

The monitoring data presented here is based on best available information, however, it is representative of more recent conditions (<50 years) rather than reference conditions. New River estuary and the catchment had been heavily modified (reclamation, land use intensification, change in hydrology etc.) at the time of data collection. Although it is not a suitable representation of ‘reference conditions’ or an unimpacted estuary it does show that there is a high amount of variability in Chl-*a* concentrations within the estuary.

3.3.2 Fiordland

Goebel et al., (2005) used Chl-*a* data measured in Doubtful Sound from 1997 to 1999 to identify whether there was a change in Chl-*a* due to the increased thickness of the low salinity layer caused by the discharge of freshwater for the Manapouri Power Station. Average chlorophyll concentration over the eight seasons of monitoring ranged from 1.31 to 2.43 mg m^{-3} at the inner fiord sites between the surface down to 7m. The Chl-*a* increased 2-fold (2.57 to 4.05 mg m^{-3}) toward the entrance of the fiord and was more deeply distributed (up to 15m). Spring blooms led to short periods of high chlorophyll concentrations in the water column (<80mg m^{-3} in spring, 1997).

Peake et al., (2001) monitored Chl-*a* in summer and winter of 1994 and reported an order of magnitude higher concentration than Goebel et al., (2005), even under bloom conditions in Goebel et al., (2005). It is possible there has been an error in reporting the units in Peake et al., (2001) as mg/L as opposed to mg m^{-3} because maximum summer concentrations are reported up to 500 mg m^{-3} Chl-*a* in the inner fiord sites and 1500 mg m^{-3} (or 1.5mg/L) moving closer to the estuary entrance compared to bloom concentrations of 80 mg m^{-3} in Goebel et al., (2005).

Schuller et al., (2014) examined Total Algal Biomass in sediment cores from Doubtful Sound, Breaksea Sound, Dusky Sound and Preservation Inlet. In that study total algal biomass in Fiordland was reasonably constant through time at the monitored sites. It was acknowledged in Schuller et al., (2014) that sedimentary Chl-*a* concentrations do not always reflect water column Chl-*a* concentrations due to lack of water column mixing and the labile nature of the Chl-*a* molecule. In a study of Doubtful Sound Schuller et al., (2013) showed there was a high amount of natural variability in phytoplankton biomass through time, however overall algal biomass was low.

The reported phytoplankton concentrations for the Fiords (DSDE type estuary) is based on more recent data (<25 years), however, the Fiordland and Islands FMU where these DSDE type estuaries are located is within an area where the catchment and the Fiords themselves are largely unimpacted (e.g. classified as the 'natural state' estuary class). Although this data is recent it provides some indication of Chl-*a* concentrations in an unimpacted DSDE estuary and can be used to support the estimate of reference conditions.

3.4 Monitoring data for New Zealand estuaries

Dudley and Todd (2018) analysed water quality data collected in estuaries across New Zealand from the early 1990's up to 2017. The supplementary material provided median, 75th quartile and 95th quartile results for the time period 2013 to 2017 for both SIDE and SSRTRE type estuaries. The monitoring data indicates for sites across New Zealand chlorophyll concentrations are highly variable with the range of states being from A to D (The estuaries presented in Table 10 have been subject to land use modification in the catchment and in many cases modification within the estuary. As such the data presented in Dudley ad Todd (2018) is representative of more recent conditions (<30 years) rather than reference conditions.

Table 10).

The estuaries presented in Table 10 have been subject to land use modification in the catchment and in many cases modification within the estuary. As such the data presented in Dudley ad Todd (2018) is representative of more recent conditions (<30 years) rather than reference conditions.

Table 10: Chl-*a* (mg m^{-3}) median, 75th quartile and 95th quartile for estuaries across New Zealand 2013 to 2017. The colours reflect the bands described in Table 3.

Council	Council site ID	Estuary type	Median	75th quartile	95th quartile
Auckland Council	6842	SIDE	2.4	3.2	6.4
Bay of Plenty Regional Council	ML081799	SIDE	1.1	1.7	4.5
Bay of Plenty Regional Council	CS292034	SIDE	0.4	0.7	1.4
Bay of Plenty Regional Council	EP118190	SIDE	1.1	1.6	4.1
Bay of Plenty Regional Council	CQ956058	SIDE	1.2	2.0	3.4
Bay of Plenty Regional Council	DP709703	SIDE	0.9	1.4	3.1
Bay of Plenty Regional Council	CQ490084	SIDE	1.1	1.8	8.8
Bay of Plenty Regional Council	EP067931	SIDE	0.8	1.2	3.1
Bay of Plenty Regional Council	CR059778	SIDE	0.6	0.9	3.8
Bay of Plenty Regional Council	DP206769	SIDE	1.1	1.8	5.7
Bay of Plenty Regional Council	EP027600	SIDE	0.8	1.1	2.1
Bay of Plenty Regional Council	GO661503	SIDE	0.9	1.2	3.2
Bay of Plenty Regional Council	LM227254	SIDE	0.4	0.6	1.9
Canterbury Regional Council	SQ30541	SIDE	1.4	3.2	25.0
Canterbury Regional Council	SQ30544	SIDE	2.0	7.6	25.5
Canterbury Regional Council	SQ30546	SIDE	1.0	1.8	4.7
Canterbury Regional Council	SQ32575	SIDE	1.5	3.1	8.2
Canterbury Regional Council	SQ32819	SIDE	2.0	4.5	12.4
Canterbury Regional Council	SQ34245	SIDE	2.0	4.7	8.3
Canterbury Regional Council	SQ34656	SIDE	0.7	1.0	2.5
Hawke's Bay Regional Council	45	SIDE	18.0	28.6	63.1
Invercargill City Council	Dunns Road	SIDE	2.4	5.3	11.9
Invercargill City Council	Stead Street	SIDE	4.5	8.9	44.3
Invercargill City Council	Ski Club	SIDE	2.0	3.8	11.5
Invercargill City Council	Ōreti Beach	SIDE	4.4	8.4	48.7
Invercargill City Council	McCoys Beach	SIDE	1.9	3.1	8.3
Invercargill City Council	Sandy Point	SIDE	1.7	3.2	5.8
Invercargill City Council	Awarua	SIDE	2.8	5.4	21.5
Invercargill City Council	Omaui	SIDE	2.5	3.5	6.5
Northland Regional Council	100177	SIDE	2.2	2.9	5.2
Northland Regional Council	100204	SIDE	2.4	5.9	9.4
Northland Regional Council	100211	SIDE	3.4	8.5	28.6
Northland Regional Council	100264	SIDE	1.3	1.7	3.0
Northland Regional Council	106968	SIDE	2.6	4.1	6.7
Northland Regional Council	109233	SIDE	2.8	4.2	12.0
Bay of Plenty Regional Council	GO080582	SSRTRE	1.9	2.5	16.5
Bay of Plenty Regional Council	NL493611	SSRTRE	0.3	0.6	1.2
Bay of Plenty Regional Council	KM083686	SSRTRE	1.6	6.6	11.6
Hawke's Bay Regional Council	3004	SSRTRE	0.7	1.2	2.5
Hawke's Bay Regional Council	3510	SSRTRE	0.6	1.0	2.3
Hawke's Bay Regional Council	3521	SSRTRE	2.9	6.5	24.9
Hawke's Bay Regional Council	3523	SSRTRE	1.3	3.8	23.8
Hawke's Bay Regional Council	3525	SSRTRE	0.6	2.1	5.4
Hawke's Bay Regional Council	3526	SSRTRE	0.6	1.0	4.2

Note: Data downloaded from Stats NZ as supplementary material for Dudley and Todd (2018) on 8/07/2020 Supplementary spreadsheet "Coastal and Estuarine Water Quality State." Actual site names were not made available. https://data.mfe.govt.nz/tables/category/environmental-reporting/marine/water-quality/?mt=Streets&l=52462&cv=0&z=6&c=-41.00000%2C174.00000&mv=0&e=0

3.5 Summary of reference conditions for phytoplankton

The proposed reference conditions are based on best available information. Recent monitoring data presented in section 3.3.1 and 3.4 were not included in the estimation of reference conditions because they represent estuaries in an impacted state. It is reiterated that these are an estimate of reference conditions and further work is required to confirm the proposed reference state ranges for phytoplankton (Table 11).

Table 11: Summary of reference state conditions for phytoplankton (Chl-*a;* mg m^{-3}) using the bands described in Table 3.

System	Estuary type	Reference condition	Proposed reference state range
All estuary types			
Revilla et al., (2010)	All	A	A
SIDE type			
Development of Phytoplankton attribute	SIDE	A	A to C
Modelling (Plew et al., 2018)	SIDE	A to C	
Modelling (Plew, 2020 pers comm)	SIDE	A to C	
Historic data for Southland (New River Estuary)	SIDE	A to D*	
Monitoring data New Zealand estuaries	SIDE	A to D*	
SSRTRE type			
Development of phytoplankton attribute	SSRTRE	A	A
Modelling (Plew et al., 2018)	SSRTRE	A	
Modelling (Plew, 2020 pers comm)	SSRTRE	A	
Monitoring data New Zealand estuaries	SSRTRE	A to D*	
DSDE type			
Development of phytoplankton attribute	DSDE	A to B	A to B
Modelling (Plew et al., 2018)	DSDE	A to B	
Historic data for Doubtful Sound	DSDE	A to B	

* Monitoring data for contemporary estuaries was removed because all of these estuaries have been modified in some way and therefore do not represent reference conditions.

4 Toxic metals in sediment

4.1 Development of toxic metals in sediment attributes and establishing reference condition

ANZECC (2000) developed the toxicant guidelines ranking using both field ecological data and laboratory eco-toxicity effects data from North America. Where toxicant information wasn't available the reference site approach was taken by recommending the 80th percentile of the reference site concentration. Southland has used increments of the default guideline value to represent different state before a critical threshold is met, with the default guideline value being the regional bottom line. Table 12 shows the proposed numeric attribute state options for Southland estuaries.

Table 12: **Default guideline value (DFV) and relative breakpoints for toxic metals in sediment (mg/kg dry weight) in Southland estuaries based on ANZECC interim DGV. Note arsenic (As) is classified as a metalloid.**

Band	Criteria	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
A	<0.2 DGV	20	1.5	80	65	0.15	21	50	200
B	0.2 to <0.5 DGV	10	0.75	40	32.5	0.075	10.5	25	100
C	0.5 to <DGV	4	0.3	16	13	0.03	4.2	10	40
D	≥DGV	<4	<0.3	<16	<13	<0.03	<4.2	<10	<40
GV-High		70	10	370	270	1	52	220	410
Detection limit		0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01

Note: As is arsenic, Cd is cadmium, Cr is chromium, Cu is copper, Hg is mercury, Ni is nickel, Pb is lead and Zn is zinc.

4.2 Data for Southland estuaries

To these authors knowledge, the earliest sediment metal concentration data for Southland estuaries was collected in winter 1990 in Waikawa and Haldane estuaries and 1994 to 1995 in New River Estuary (Robertson, 1994). Metals tend to accumulate in muddy sediments and therefore data presented, where available, for muddy sites within an estuary have been reported (Table 11). Nickel, copper and zinc are found naturally in the environment as a result of rock weathering and volcanic emissions, and can become concentrated in soils (Martin et al., 2015). Elements such as Cu, Ni, Pb, Zn and As are considered mainly pedogenic (soil) in origin, however there are several other sources such as fertilisers, leaded gasoline (1975 to 1986) and municipal, industrial and agricultural wastes. Nickel is high in both New River Estuary and Jacobs River Estuary across all years monitored (Table 11). In a survey of Southland soils, comparatively, there are higher levels of nickel in the Ōreti and Aparima catchments with hotspots ranging between 22 to 278 ppm in A-depth (0 to 30cm) and 24 to 217 ppm in the B-depth (50 to 70cm) soils (

Figure 2; Martin et al., 2015). Similar patterns are observed for copper and chromium in B-depth soils (

Figure 2 to Figure 5). There are no apparent hotpots of zinc within the region, therefore it can be hypothesised that the estuaries across the region should have similar zinc concentrations and if zinc levels are elevated it may be indicative of an alternate source.

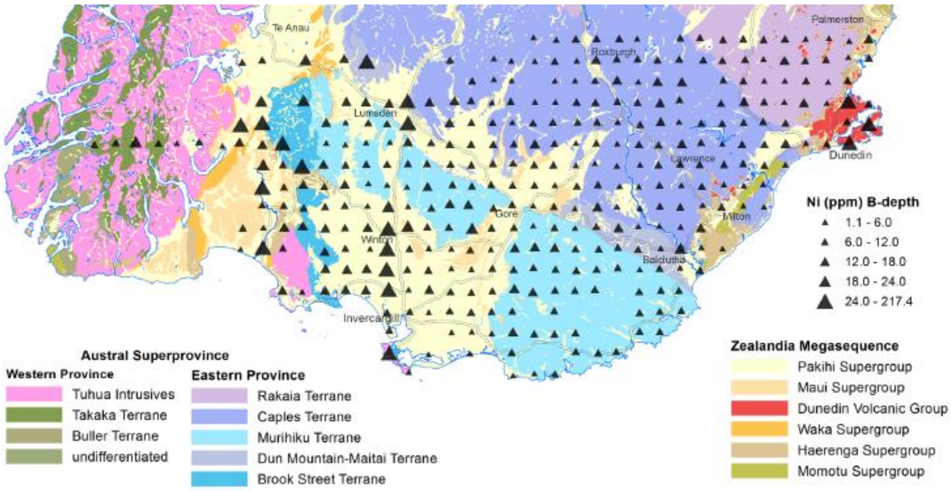


Figure 2: Nickel (ppm) at B-depth across Southland.

Figure 3: Copper (ppm) at B-depth across Southland.

Figure 4: Chromium (ppm) at B-depth across Southland.

Figure 5: Zinc (ppm) at B-depth across Southland.

Table 13: State of the environment sediment monitoring data for metal concentration at muddy estuary sites. The colours reflect the bands described in Table 12.

Estuary	Site	Year	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
SIDE estuaries										
New River Estuary	Waihōpai Arm	2012	10.3*	0.20	36.3	23.3	0.06[1]	31.3	14.3	118
	Waihōpai Arm	2020	10.5	0.14	33.9	26.4	0.06	33.8	13.8	113
	Daffodil Bay	2012	-	<0.1	24.3	14.9	-	19.5	7.1	58.7
	Daffodil Bay	2020	6.8	0.13	31.7	22.9	0.04	29.7	9.9	81.5
Jacobs River Estuary	Northern Flats	2012	-	0.09	22.3	25.7	-	16.2	6.2	54.3
	Northern Flats	2020	6.6	0.08	15.6	28.3	<0.02	15.2	5.0	71.1
	Pourakino Arm	2012	5.6[1]	0.12	17.2	30.7	<0.02[1]	15.4	5.4	65.0
	Pourakino Arm	2020	7.1	0.07	18.2	22.4	<0.02	14.1	5.1	58.1
Waikawa Estuary	site unknown	1990	-	-	-	3	-	-	-	9
	Lower Sand Flats	2008	-	0.02	9.1	3.5	-	5.8	2.0	17.3
	Lower Sand Flats	2020	5.2	0.02	8.2	3.4	<0.02	4.8	2.0	17.5
	Mud Flats	2020	6.9	0.04	15.1	9.0	0.02	9.7	5.5	38.8
Haldane Estuary	Upper estuary (mud-sand)	2009	-	0.03	10.0	5.8	-	7.7	-	28.0
	Upper estuary (mud-sand)	2020	4.1	0.02	9.8	5.5	<0.02	7.2	2.5	30.0
Freshwater Estuary	Upper estuary (sand)	2009	-	<0.01	3.2	1.4	-	2.5	-	6.0
	Upper estuary (sand)	2020	2.8	<0.01	2.9	1.1	<0.02	2.4	0.55	5.8
Reference state range:			**A - C**	**A**	**A - B**	**A - B**	**A - B**	**A – D[2]**	**A - B**	**A - C**
SSRTRE estuaries										
Toetoes Estuary	Upper estuary sand flat	2004	-	-	4.1	1.7	-	1.6	2.7	34.3
	Upper estuary sand flat	2020	4.3	<0.01	5.4	2.3	<0.02	3.5	1.4	14.4
Reference state range			**A - B**	**A**	**A**	**A**	**A**	**A**	**A**	**A**

[2] A to B band unless caused by natural perturbations (e.g. Nickel in Jacobs River Estuary and New River Estuary).

4.2.1 Robertson (1995): "Southland estuaries heavy metal monitoring"

Metal concentrations were measured in surface sediments (<5cm) by Robertson (1995) across five Southland estuaries. The results reported in Table 14 represent muddy depositional areas in the estuary, these areas are likely to accumulate metals. Note that mercury (Hg) and arsenic (As) were not measured in the 1995 study. The results presented in Table 14 are recent and represent concentrations measured after anthropogenic change.

Table 14: Metal concentrations (mg/kg dry weight) measured at muddy sites in five estuaries across Southland in May 1995. The colours reflect the bands described in Table 12.

Site	Type	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
New River Estuary Upper Waihōpai (mud; NR12)	SIDE	-	0.16	36.5	28.0	-	33.1	26.9	159
New River Estuary Upper Ōreti (mud; NR9)	SIDE	-	0.06	28.3	15.6	-	24.7	7.3	57.5
Waikawa Estuary Upper Estuary (mud; W2)	SIDE	-	0.07	19.9	16.5	-	13.3	9.7	58.6
Haldane Estuary Upper Estuary (mud; H4)	SIDE	-	0.05	14.5	9.0	-	8.6	5	38.4
Jacobs River Estuary Upper Pourakino (mud; A3)	SIDE	-	0.10	25.6	30.2	-	17.0	7.6	62.2
Jacobs River Estuary Upper Aparima (mud; A6)	SIDE	-	0.11	19.6	42.4	-	18.7	8.9	83.9
Toetoes (Fortrose) Estuary Mid-Estuary (sand/mud; M2)	SSRTRE	-	0.02	5.7	4.0	-	4.9	2.3	16.8
State range		**-**	**A**	**A-B**	**A-C**	**-**	**B-D**	**A-C**	**A-C**

4.2.2 Brown (2019): "Geochemistry and isotopic composition of sediment cores to understand lithological and anthropogenic controls on eutrophication in the New River Estuary"

Metal concentrations were measured in cores collected in New River Estuary deposition zones in 2017 using a modified aqua regia digestion; 1:1:1 of HCl, HNO_3, and water (Brown, 2019). At three sites within the deposition zone, ^{210}Pb dating showed the core depths represented time periods pre- and post- reclamation (see

Table 15**). Copper, nickel and zinc are found naturally in the environment and are essential to living organisms, however elevated concentrations can be toxic. Zinc and copper are below trigger levels in the New River Estuary deposition areas where as nickel concentrations are elevated in both the pre- and post-reclamation. This is indicative of a natural source in New River estuary (**

Figure 2). Figure 2-3 from Brown (2019; Figure 6) shows nickel concentrations increase above the ANZECC (2000) trigger value post-reclamation, associated with the rise in fine sediment accumulation from land use changes. Brown (2019) highlighted the non-available fraction of nickel remains constant throughout the core, whilst the bioavailable fraction of nickel increases toward the core surface, particularly from 1975 onwards. Reference "baseline" values were established assuming pre-anthropogenic concentrations occur at the bottom portion of the core (Brown, 2019). These values are presented for sites Upper North Waihōpai and Daffodil Bay sites only because Lower Waihōpai core did not extend deep enough for this assessment.

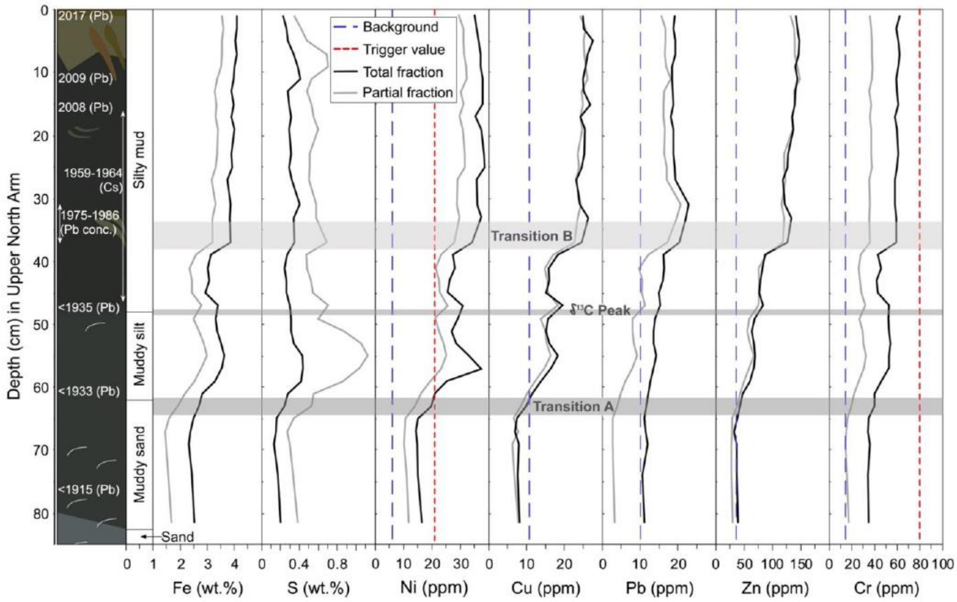


Figure 2-3. Total (after multi-acid digestion) and partial (after modified aqua regia digestion) iron, sulfur, and heavy metal concentrations from the Upper North Arm deep core with background concentrations of Ni, Cu, Pb, Zn, and Cr averaged from medians of rock units present in Southland (n>10) (Cavanagh et al., 2015). Trigger values, which signify contaminated sediment when exceeded, of Ni and Cr are determined by ANZECC and ARMCANZ (2000). Transition "A" (dark-grey shaded area) signifies the onset of terrestrial sediment accumulation (post-1920); the $\delta^{13}C$ Peak marks the plant/shell-rich layer; and transition "B" (light-grey shaded area) signifies increased terrestrial sediment (and pollutant) loads after agricultural intensification and the transition to dairying (post-1984). Plots are shown next to downcore illustrations that signify changes in colour, texture (grain size), material present (whole shells or fragments, plant matter, burrow traces), and calculated ages (based on ^{210}Pb and ^{137}Cs radioisotopes or Pb concentrations).

Figure 6: Figure 2-3 from Brown (2019) illustrates the increase in metal concentrations over time.

Table 15: Metal concentrations (mg/kg dry weight[7]) measured in sediment cores in New River Estuary (only historical concentrations presented). All concentrations in this study were normalised to aluminium to eliminate the effect of grain size distribution[8], standard concentrations were no provided in the study. UNA is Upper North Waihōpai Arm, LW is Lower Waihōpai and DE is Daffodil Bay (these are all sites within New River Estuary).

Site	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
New River Estuary historical State[1]	B	A	A-B	A	A	B-C	A	A
Pre-reclamation								

[7] 1 ppm = 1 mg/kg dry weight

[8] The concentration of metals is partially controlled by grain size distribution, with higher metal concentrations associated with finer sediments due to the greater reactive surface area. Fine-grained sediment is generally correlated to higher aluminium concentrations therefore the concentration of metals down core can be normalised to aluminium concentration to remove the effect of grain size on concentration (Brown, 2019). It is important to note that this is not standard in routine monitoring this was specific for the purpose of the study and ideally non-normalised data should be used for comparison against the guideline values.

New River Estuary UNA[2] <1915 (78cm)	5.8	0.03	15.8	6.7	0.01	11	3.0	27
Post-reclamation								
New River Estuary UNA[2] <1933 (62cm)	7.0	0.04	21.7	10.1	0.02	16	4.9	43
New River Estuary LW[2] <1956 (24cm)	9.0	0.05	25.4	10.1	0.02	16	5.6	40
New River Estuary DE[2] <1927 (74cm)	7.1	0.02	16.9	7.3	0.01	11	2.7	32
Baseline								
New River Estuary UNA[2] 85cm (<1915)	6.4	0.03	17	7.7	0.01	11.8	3.3	30
New River Estuary DE[2] 95cm (<1927)	7.4	0.02	14.7	6.9	<0.01	10.1	2.6	28
Concentrations in the 1990's								
New River Estuary UNA[2] ~1990 (20cm)	9.1	0.14	37.2	24.8	0.07	30.8	16.5	136
New River Estuary LW[2] ~1990 (20cm)	9.7	0.08	27.6	14.4	0.04	20.0	9.4	69.8
New River Estuary DE[2] ~1990 (18cm)	8.6	0.09	22.8	13.4	0.03	17.7	6.9	54.7

[1] Based on baseline data
[2] Tables C-1, C-2 and C-3 in Brown (2019)

4.2.3 Glasby (1978): "Sedimentation and sediment geochemistry of Caswell, Nancy and Milford Sounds"

In a study of Caswell, Nancy and Milford Sounds trace metals were slightly higher in Milford Sound likely due to the geology in the area (Glasby 1978;

Table 16, Figure 7). The samples were dried an analysed via atomic absorption spectrophotometry following HNO_3/$HClO_4$/HF extraction. The differences between the fiords could be due to different lithology between Milford Sound (Milford Formation) and the other two fiords Caswell and Nancy Sounds (Bradshaw Formation). Copper is controlled by "sedimentary processes in South Island fiords, the contents of other metals are controlled dominantly by provenance (Williamson, 1972)."

Table 16: **Metal concentrations (mg/kg dry weight) measured in sediment cores in Caswell, Nancy and Milford Sounds using the bands from Table 12.**

Site	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Milford Sound (0-10cm)	nd*	-	99	173	nd*	83	-	94
Milford Sound (400-405cm)	nd*	-	104	85	nd*	96	50*	74
Caswell Sound (30-35cm)	nd*	-	74	53	nd*	70	-	73
Caswell Sound (400-405cm)	nd*	-	71	62	nd*	70	50*	77
Nancy Sound (0-15cm)	nd*	-	81	48	nd*	64	25*	76
Nancy Sound (457-472cm)	nd*	-	103	49	nd*	73	25*	74

*Semi-quantitative analysis of Fiord sediments by optical emission spectrography. nd represents a non-detect or below detection.

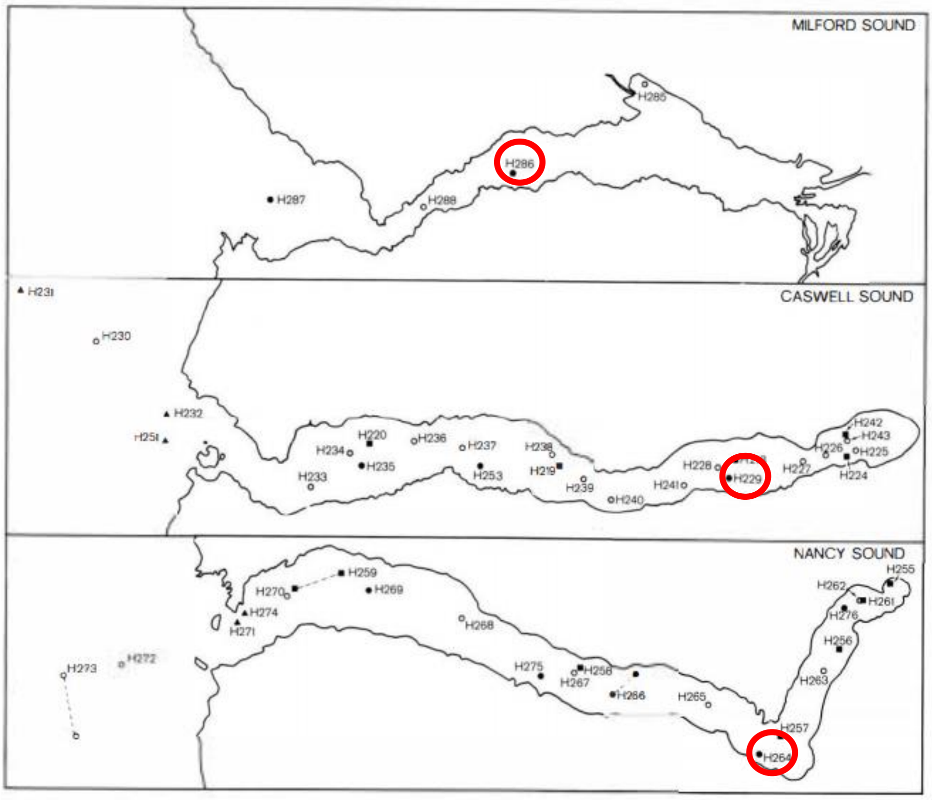


FIG. 1. Schematic diagram showing position of sediment samples in Caswell, Nancy and Milford Sounds. ● Piston core and foram core. o Foram core (H273 also dredge). ▲ Dredge. ■ Grab and underwater camera (H242 and H261 only grab).

Figure 7: Figure 1 from Glasby (1978) represents the location of the sediment samples reported in Table 16.

4.3 International literature for trace metals in Fjords

Marine sediments provide a sink of trace metals and compounds naturally released by erosional processes. Under reference conditions the concentration of trace metals in the sediment over time is determined by the sedimentation rate (e.g. depositional events) and sediment source. This section summarises metal concentration from different literature sources compared against the metals attribute.

4.3.1 Ahumada et al., (2007): "Trace metals in sediments of Southeast Pacific Fjords, north region"

Sediment samples collected in 1995 in southern Chile at 35 stations between Puerto Montt to Laguna San Rafael.

Table 17: **Metal concentrations (mg/kg) measured in Southeast Pacific Fjords using the bands from Table 12.**

	Cd	Cr	Cu	Ni	Pb	Zn
Mean Chilean Fjords	0.36 ± 0.21	50.1 ± 24.5	24.5 ± 10.9	22.4 ± 8.3	20.8 ± 8.7	93.6 ± 20.2

4.3.2 Pelletier et al., (1988): "Trace metals in surface sediment of the Saguenay Fjord, Canada"

Saguenay Fjord, Canada is affected by freshwater inputs of anthropogenic metals (industrial outfalls) upstream of the Fjord and therefore do not represent reference conditions. However, the data shows the heterogeneity of metal concentrations within the Fjord across 18 sites.

Table 18: **Metal concentrations (mg/kg dry weight) measured in Saguenay Fjord, Canada using the bands from Table 12.**

	Cd	Cr	Cu	Hg*	Zn
Range Saguenay Fjord	0.01 – 0.47	12.3 – 71.7	1.3 – 28.1	0.03 – 1.2	36 - 232

*The Fjord is known to be contaminated with mercury.

4.3.3 Loring and Asmund (1995): "Geochemical factors controlling accumulation of major and trace elements in Greenland coastal and fjord sediments"

Surface sediments were collected at 39 sites off Greenland's coastline. Surface sediments were analysed for Total metal concentration and compared against other coastal sediments in the area.

Table 19: **Metal concentrations (mg/kg) measured along Greenland's coast using the bands from Table 12.**

	Cd	Cr	Cu	Ni	Pb	Zn
East Greenland	0.11 ± 0.05	118 ± 45	46 ± 32	59 ± 29	19 ± 7	89 ± 20
West Greenland	0.15 ± 0.16	163 ± 154	49 ± 40	82 ± 96	18 ± 8	77 ± 19

4.3.4 Skei and Paus (1979): "Surface metal enrichment and partitioning of metals in a dated sediment core from a Norwegian Fjord"

Ranafjord is in Northern Norway and since the beginning of the century lead, zinc and copper have been mined in the catchment. Deeper records are more representative of natural conditions due to enrichment trace metals over the last 100 years.

Table 20: **Metal concentrations (mg/kg) measured along Ranafjord, Norway using the bands from Table 12.**

	As	Cu	Hg	Ni	Pb	Zn
Ranafjord, Norway*	6	20	0.05	34	<20	142

*24-24cm, 170 years' old

The studies from Fiordland and international literature indicate that some metals are in the poorer band according to the proposed metals attribute table (Table 12). However, this does not necessarily reflect poor conditions in DSDE type estuaries if the source of metals is natural and owing to the lithology of the region[9]. Because reference conditions are at the bottom of the banding (D-band) system there is no upper limit which means any additional source of metals caused by anthropogenic sources will not be detected using the banding system as a representation of state. There needs to be some consideration to the appropriateness of the bandings for the DSDE type estuaries particularly those in Fiordland, however this is not an immediate issue because Fiordland and Islands FMU is classified as 'natural state' and requires no change from current state. More information however is needed to assess current state.

4.4 Summary of toxic metal concentrations under reference conditions

The proposed reference conditions are based on best available information. Recent monitoring data from impacted estuaries was not included in the estimation of reference conditions unless the state was higher (e.g. A) than a more appropriate information source (e.g. sediment cores). However, only monitoring data was available for SSRTRE type estuaries and therefore the estimate of reference conditions for this estuary type should be treated with caution. Further work is required to assess reference conditions for toxic metal concentrations across all estuary types.

Table 21: Summary of reference state conditions for toxic metal concentrations in estuaries using the bands from Table 12.

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
SIDEs								
SoE monitoring data (SIDE)	A - C[a]	A	A - B	A - B	A - B	A - D	A - B	A - C
1995 Estuary Data (SIDE)	-	A	A - B	A - C	-	B - D	A - C	A - C
New River Estuary (SIDE) Baseline data (Brown, 2019)	B	A	B	A	A	B - C	A	A
Overall:	**A - B**	**A**	**A - B**	**A[b]**	**A**	**A - B[c]**	**A[d]**	**A[d]**
SSRTREs								
SoE monitoring data (SSRTRE)	A - B	A	A	A	A	A	A	A
1995 Estuary Data (SSRTRE)	-	A	A	A	-	B	A	A
Overall:	**A - B[e]**	**A**	**A**	**A**	**A**	**A - B[e]**	**A**	**A**
DSDEs								
New Zealand Fiords	A	-	C - D	C - D	A	C	C[f]	B
International Literature	B	A - B	C - D	B - C	B	D	B	B - C
Overall[g]:	**A**	**A - B**	**C - D**	**B - D**	**A**	**C**	**B**	**B**

[a] C-state is in a highly modified area of New River Estuary and does not reflect reference state conditions. B-state has been observed in both the historical cores and across the other SIDE estuaries monitored.
[b] There is a large shift in the baseline concentration of copper (Cu) with further development in the catchment and post reclamation indicating there is a shift in the source of copper (Cu) since pre-human or reference state conditions. The concentrations measured in contemporary data do not reflect natural reference conditions.
[c] A-B band unless caused by natural perturbations (e.g. nickel in Jacobs River Estuary and New River estuary as discussed in text have elevated nickel levels in the catchment)
[d] Similar to copper (Cu), lead (Pb) and zinc (Zn) increase with anthropogenic activity in the early 1900's in cores collected from New River Estuary indicating contemporary concentrations do not reflect reference state.
[e] There is no additional information to support whether the concentration of arsenic or nickel would have been in an A band in SSRTRE type estuary, reviewing the information from other estuaries (SIDE type) in the region there is an indication that arsenic and nickel is in a B-state when comparing against estuaries within a similar area (Haldane and Waikawa).
[f] Semi-quantitative analysis of Fiord sediments by optical emission spectrography
[g] Where a better state was presented for the local data this was recommended as final state.

[9] A more thorough comparison between the lithology in Fiordland and examples provided from the international literature is required to make direct comparisons of metal concentrations.

5 Macroalgae

5.1 Development of the ecological quality rating (EQR) attribute and establishing a reference condition

The ecological quality rating (EQR) for macroalgae is an index to assess the condition of macroalgae in the intertidal area of transitional and coastal waters (Table 22). This was used as a basis for developing a proposed attribute state option table for macroalgae, as shown in Table 23.

Table 22: Multimetrics used to calculate ecological quality rating (EQR) in the opportunistic blooming tool (OMBT). [Sourced from Robertson et al., 2016]

OMBT Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	**≥0.8 - 1.0**	**≥0.6 - <0.8**	**≥0.4 – <0.6**	**≥0.2 - <0.4**	**0.0 - <0.2**
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 - ≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass (g m^3 wet weight) of AIH	≥0 - 100	≥100 - 500	≥500 – 1000	≥1000 - 3000	≥3000
Average biomass (g m^3 wet weight) of AA	≥0 - 100	≥100 - 500	≥500 – 1000	≥1000 - 3000	≥3000
% algae >3cm deep in sediment (entrained)	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

* Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.

Table 23: Macroalgae attribute state option table proposed for Southland estuaries (measured as EQR).

Estuary type	**A Very good**	**B Good**	**C Fair**	**D Poor**
SIDEs and SSRTREs	≥0.8	≥0.6 and <8.0	≥0.4 and <0.6	<0.4

In 2014 the Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG) utilised published and unpublished literature along with expert opinion to derive critical threshold values suitable for defining quality status classes. The WFD-UKTAG (2014) proposed reference state conditions for transitional and coastal waters, with intertidal areas, would result in a 'High' or 'A-band' (EQR ≥0.8) based on the points below paraphrased from the WFD-UKTAG (2014).

An expert workshop conducted by the Department of the Environment, Transport and the Regions (DETR) suggested reference levels of < 5% cover of available intertidal habitat (AIH, see **Error! Reference source not found.**0) of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted < 5% cover of opportunistic macroalgae in the AIH as equivalent to 'High' status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50 ha may often show signs of adverse effects (Carletti and Heiskanen, 2009; Kolbe, 2007). However, if the overall area was less than 20% of this, adverse effects were not seen, so the High/Good boundary was set at 10 ha. In all cases a reference of 0% cover for truly unaffected areas was assumed. *Note:* opportunistic algae may occur even in pristine water bodies as part of the natural community, but at low levels (WFD-UKTAG 2014).

The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100 g m^{-2} wet weight (WFD-UKTAG 2014). This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of 0 was assumed. An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High/Good boundary of 1% of quadrats assessed was set (WFD-UKTAG 2014).

It should be noted that the EQR rating system was derived for transitional and coastal waters that have intertidal areas of soft sedimentary substratum (i.e areas with available intertidal habitat for opportunistic macroalgal growth). The EQR does not represent saline lagoons (or brackish lakes) due to the challenges in setting suitable reference conditions for those systems. The Estuary Trophic Index Tool 2 proposed interim biomass thresholds to input into the OMBT tool, however further work is required to validate the ICOLL bandings. As such brackish lakes which include Waituna Lagoon and Lake Brunton, are covered in Roberts (2020) and not commented on further here.

5.2 Modelling data for Southland estuaries

In a report prepared for the Ministry for the Environment "Assessment of the eutrophication susceptibility of New Zealand estuaries" (Plew et al., 2018) EQR was modelled for three conditions, current, pre-human and pristine conditions. The same study predicted phytoplankton concentrations under these conditions and a summary of the modelling and definition of pristine and pre-human condition is presented under section 3 phytoplankton (Chl-a).

Table 24 represents the results from national modelling. More recently Snelder et al., (2020) and Plew et al., (2020a) have been working through regional modelling for the People, Water and Land Programme using regional load estimates for 'reference conditions' in Southland rivers. Plew (2020a; pers comm) used the estimated outputs of pre-human TN and TP loads from the Southland regional modelling to estimate 'reference conditions' for EQR and Phytoplankton in Southland estuaries. Coastal TN was input as 70g m^{-3} from CARS, which is close to the A/B band threshold of 80g m^{-3} for macroalgae growth, as a result unless salinity is the limiting factor on macroalgal growth (e.g. Waiau Estuary) there is limited scope for the EQR band to be A under reference conditions. For both the national and regional modelling Bluff harbour is on the A/B band threshold with a potential TN concentration of 75 g m^{-3} and 79 g m^{-3}, respectively, with these concentrations driven by the coastal TN input.

Table 24: Modelled ecological quality rating (EQR) using national estimates, sourced from Plew et al., 2018, using the bands from Table 23.

System	Estuary type	Pristine	Pre-human	Current	Reference state range
New River Estuary	SIDE	B	B	D	A to C
Jacobs River Estuary	SIDE	B	C	D	
Waikawa Estuary	SIDE	B	B	C	
Haldane Estuary	SIDE	B	B	C	
Bluff Harbour	SIDE	A	B	B	
Toetoes (Fortrose) Estuary	SSRTRE	B	C	D	A to C
Waiau Estuary	SSRTRE	A	A	A	

Despite the caveats outlined in section 3, the modelled EQR scores provide a reasonable estimate of reference conditions in Southland estuaries.

Table 25 presents the regional modelling outputs for EQR in Southland estuaries in comparison to the national 'pristine' modelling. The regional modelling and national modelling are comparable, unlike the phytoplankton regional modelling the estimate of potential TN and subsequent score rating is based on mean annual flow in line with the national approach. Summer flows[10] were not used for the

[10] The approach taken for phytoplankton in Section 3.

regional modelling of EQR score because macroalgae is present in the estuary all year round. Despite the caveats outlined in section 3, the modelled EQR scores provide a reasonable estimate of reference conditions in Southland estuaries.

Table 25: Modelled ecological quality rating (EQR) using regional estimates, sourced from Plew et al., (2020), using the bands from Table 23.

System	Estuary type	Regional			National	
		EQR	Pristine	Reference state	Pristine	Reference state
New River Estuary	SIDE	0.78	B	A to B	B	A to B
Jacobs River Estuary	SIDE	0.78	B		B	
Waikawa Estuary	SIDE	0.66	B		B	
Haldane Estuary	SIDE	0.67	B		B	
Bluff Harbour	SIDE	0.80	A		A	
Toetoes (Fortrose) Estuary	SSRTRE	0.75	B	A to B	B	A to B
Waiau Estuary	SSRTRE	1.0[1]	A		A	

[1] Macroalgal growth is limited in the Waiau estuary by the small intertidal area and low salinities.

5.3 Historical monitoring data for Southland estuaries

Monitoring of Southland estuaries began in the early 2000's, Table 26 represents historical data collected for each of the monitored estuaries between 2001 and 2004, it is based on the best available information and does not truly reflect reference conditions. Note Jacobs River estuary is an estimate based on expert judgement the data from the earliest surveys is being reviewed at present with the output due in December 2020, the estimate will be revised then. All monitored estuaries were in very good (A) to good (B) condition in the early 2000's.

Table 26: Modelled ecological quality rating (EQR) using regional estimates, sourced from Plew et al., (2020) using the bands from Table 23.

System	Estuary type	Year	Historic EQR	EQR state	Reference state	Reference
New River Estuary	SIDE	2001	0.616	B	A to B	Stevens (2018a)
Jacobs River Estuary	SIDE	2003	0.355[1]	B		Stevens (pers comm)
Waikawa Estuary	SIDE	2004	0.9[2]	A		Robertson et al. (2016)
Haldane Estuary	SIDE	2004	0.9[2]	A		Robertson et al. (2016)
Toetoes (Fortrose) Estuary	SSRTRE	2003	0.9[2]	A	A	Stevens (2018b)

[1] Placeholder using expert judgement from Leigh Stevens (pers comm). This will be updated when the data is re-analysed later in 2020.
[2]Estimated following re-analysis of existing data (Robertson et al., 2016)

5.4 'Pristine' estuaries in New Zealand

There are several monitored estuaries in New Zealand that are considered in 'near' pristine condition, this means that the catchment is largely unmodified (e.g. >90% native scrub/forest) and there are minimal anthropogenic influences in the estuary or catchment. 'Near' pristine estuaries in instances where there is limited information available can provide an indication of reference state.

However, there are drawbacks to this approach because there is an assumption that there have been no historical land use changes in the estuary catchment. For example, both Whangarae and Whanganui estuaries have been modified historically through logging and slash and burn techniques in the early 1900's which resulted in higher sedimentation rates during those periods, the catchment has since recovered. Freshwater estuary on Stewart Island is a good example of a pristine estuary however the geology and formation of the estuary is different to mainland estuaries making a direct comparison difficult.

Table 27: Ecological quality rating (EQR) using the opportunistic blooming tool (OMBT) for 'near pristine' estuaries across New Zealand, using the bands from Table 23.

System	Estuary type	Region	EQR	Band	Reference
Freshwater Estuary	SIDE	Southland	0.8 – 0.9[1]	A	Stevens (pers comm)
Whangarae Estuary	SIDE	Marlborough	0.82	A	Stevens et al., (2016)
Whanganui Inlet	SIDE	Tasman	0.67	B	Stevens et al., (2017)

[1] Placeholder using expert judgement from Leigh Stevens (pers comm). This will be updated when the data is re-analysed later in 2020.

5.5 Summary of reference conditions for macroalgae (EQR)

The proposed reference condition range is based on best available information (Table 28: Summary of reference state conditions for ecological quality rating (EQR) using the opportunistic blooming tool (OMBT) and bands from Table 23.

System	Estuary type	Reference condition	Proposed reference state range
Transitional and coastal waters (intertidal)			
Development EQR (WFD-UKTAG 2014)	NA	A	
SIDE type			
National Modelling (Plew, 2018)[1]	SIDE	A to C	A to B
Southland Modelling (Plew, 2020)	SIDE	A to B	
Historic Data for Southland	SIDE	A to B	
Near Pristine Estuaries New Zealand	SIDE	A to B	
SSRTRE Type			
National Modelling (Plew, 2018) [1]	SSRTRE	A to C	A to B
Southland Modelling (Plew, 2020)	SSRTRE	A to B	
Historic Data for Southland	SSRTRE	A[2]	

[1] Regional modelling is more relevant to Southland, loads to the estuary have been updated with regional modelling.
[2] Based on one monitored estuary; Toetoes (Fortrose) Estuary

), further work is required to confirm the proposed reference state ranges therefore these estimates should be treated with some caution. Both reference state ranges are provided for the national and regional modelling in Table 26, given the caveats of the modelling and the updated regional modelling it is proposed the regional modelling estimates be referenced in preference to the national modelling output.

Table 28: Summary of reference state conditions for ecological quality rating (EQR) using the opportunistic blooming tool (OMBT) and bands from Table 23.

System	Estuary type	Reference condition	Proposed reference state range
Transitional and coastal waters (intertidal)			
Development EQR (WFD-UKTAG 2014)	NA	A	
SIDE type			
National Modelling (Plew, 2018)[1]	SIDE	A to C	A to B
Southland Modelling (Plew, 2020)	SIDE	A to B	
Historic Data for Southland	SIDE	A to B	
Near Pristine Estuaries New Zealand	SIDE	A to B	
SSRTRE Type			
National Modelling (Plew, 2018) [1]	SSRTRE	A to C	A to B
Southland Modelling (Plew, 2020)	SSRTRE	A to B	
Historic Data for Southland	SSRTRE	A[2]	

[1] Regional modelling is more relevant to Southland, loads to the estuary have been updated with regional modelling.
[2] Based on one monitored estuary; Toetoes (Fortrose) Estuary

6 Gross eutrophic zones (GEZ)

6.1 Development of the GEZ attribute and establishing reference condition

Gross eutrophic zones (GEZ) are represented by mud content >25%, shallow aRPD (<1 cm) and high macroalgae cover (>50%). They represent the physical expression of problem conditions that are likely to be hard to reverse, and may become self-reinforcing due to negative feedback loops promoting anoxic release of sediment bound nutrients. The proposed attribute state option table for GEZ is shown in Table 29.

Table 29: Gross eutrophic zones (GEZs) attribute state option bandings proposed for Southland estuaries.

Estuary type	A Very good	B Good	C Fair	D Poor
SIDEs and SSRTREs (intertidal area)	≤1%	>1% and ≤5%	>5% and ≤10%	>10%
	<0.5ha	>0.5ha and ≤5ha	>5ha and ≤20ha	>20ha

Due to the possibility that GEZ can become self-reinforcing there is a rationale that any area of GEZ in a system is problematic. Because these conditions are potentially irreversible there needs to be early warning sign built in. This is where the ability to use other metrics with earlier signs, such as EQR, is fundamentally important. GEZ should not be considered a stand-alone metric for managing estuaries however it complements the EQR by providing an estimate of GEZ extent in an estuary (e.g. estimate of particularly problematic areas).

"*All potential bloom-forming species are a natural component of intertidal ecosystems, however, the formation of opportunistic macroalgal blooms is considered indicative of anthropogenically elevated nutrient levels when they grow to nuisance proportions*" (WFD-UKTAG, 2014). Estuaries in 'near' pristine state frequently exhibit high macroalgal cover without exhibiting other gross eutrophic symptoms (mud and low oxygen). For example, in 2007 a large portion (26%) of Freshwater Estuary (Stewart Island/Rakiura) was covered in >50% macroalgal cover without exhibiting evidence of gross eutrophic conditions (high mud content and low oxygen; Stevens et al., 2007).

GEZ should not be present in short residence time estuaries such as SSRTRE type estuaries, due to the short residence time and high flushing potential, if present it is indicative that the assimilative capacity of the estuary has been exceeded. Similarly, GEZ should not be present in short residence time tidal lagoon type estuaries (SIDE type estuaries) under reference conditions (Stevens et al., 2018a). If GEZ areas are persistent and extensive in the estuary this provides a clear signal that the assimilative capacity of the estuary has been exceeded (Zaiko et al., 2018).

Table 30: Gross eutrophic zones (GEZ) attribute bandings proposed for Southland from literature.

Estuary type	Description	Reference condition
SIDE	Gross eutrophic conditions should not be present in short residence time tidal lagoon estuaries (SIDE type) under natural reference conditions. GEZ areas indicate the assimilative capacity of the estuary has been exceeded (Stevens et al., 2018a).	A
SSRTRE	The physical characteristics of SSRTRE type estuaries (short residence time and high flushing potential) indicate GEZ will not establish under natural conditions (Stevens, 2018c).	A

6.2 Modelling data for Southland estuaries

The NZ ETI Tool 1 explored the relationship between Nitrogen Areal Load (mg $m^{-2}d^{-1}$) and Macroalgal expression (Figure A7 in ETI Tool 1). The data was sourced from 29 SIDE estuaries across New Zealand and a preliminary N loading of 100 mg $m^{-2}d^{-1}$ was determined, estuaries below this threshold did not express nuisance macroalgal growth and eutrophic symptoms. The relationship between N-areal load and intertidal GEZ (%) was explored further for Southland estuaries in Robertson et al., (2016) with estuaries <100 mg $m^{-2}d^{-1}$ experiencing no eutrophic symptoms (Figure 2.72 Robertson et al., 2016). When this was applied to the New Zealand dataset majority of estuaries expressed 0% GEZ, with all estuaries below the <100 mg $m^{-2}d^{-1}$ with <2.5% GEZ, equivalent to an A to B range for SIDE type estuaries.

If we explore this relationship further for Southland SIDE estuaries and look at the modelled nitrogen loads under pristine and pre-human conditions, we can predict whether GEZ would have occurred under 'reference' conditions (Table 31). Waikawa, Haldane, and New River estuary pristine and pre-human nitrogen areal loads indicate that GEZ was unlikely to develop in these estuaries under reference conditions. Jacobs River estuary however in one modelled scenario indicates that Nitrogen Areal load was above the 100 mg $m^{-2}d^{-1}$ threshold, indicating that some gross eutrophic areas could have developed under these conditions. A discussed in the EQR section the TN loadings calculated in Plew et al., (2018) are likely an overestimation of the true TN loading under reference conditions. Furthermore, in 2003, GEZ in the estuary was rated a B-band (Table 32), under these conditions the N-areal load was >300 mg $m^{-2}d^{-1}$ (CLUES; Robertson et al., 2016) as a such it is unlikely that the pre-human loading of 160 mg $m^{-2}d^{-1}$ would have expressed eutrophic symptoms exceeding a B-band, this is also consistent with the relationship between N-areal load and Intertidal GEZ (%) for Southland estuaries (Figure 2.72 in Robertson et al., 2016).

Table 31: Gross eutrophic zones (GEZ) attribute bands proposed for Southland from modelled pristine and pre-human nitrogen loads (using the bands from Table 29).

System	Modelling	Condition	Reference	N-areal load (mg m^{-2} d^{-1})	GEZ state
Waikawa Estuary	National	Pristine	Plew (2018)	15.59	A
	National	Pre-Human	Plew (2018)	33.97	A
	Regional	Pre-Human	Plew (2020; unpubl)	32.33	A
	National	Current	Plew (2018)	62.62	A
	Regional	Current	Plew (2020; unpubl)	61.66	A
New River Estuary	National	Pristine	Plew (2018)	28.64	A
	National	Pre-Human	Plew (2018)	62.39	A
	Regional	Pre-Human	Plew (2020; unpubl)	21.95	A
	National	Current	Plew (2018)	235.32	C - D
	Regional	Current	Plew (2020; unpubl)	261.60	C - D
Jacobs River Estuary	National	Pristine	Plew (2018)	73.57	A
	National	Pre-Human	Plew (2018)	160.28	B[2]
	Regional	Pre-Human	Plew (2020; unpubl)	49.89	A
	National	Current	Plew (2018)	492.50	C - D
	Regional	Current	Plew (2020; unpubl)	558.69	C - D
Haldane Estuary	National	Pristine	Plew (2018)	13.26	A
	National	Pre-Human	Plew (2018)	29.43	A
	Regional	Pre-Human	Plew (2020; unpubl)	29.43	A
	National	Current	Plew (2018)	56.75	A

[1]The loads presented in Plew (2018) and Plew (2020; unpubl) have been converted from T/y to Nitrogen Areal Load (mg $m^{-2}d^{-1}$) which incorporates individual estuary area then compared against the threshold of <100 mg $m^{-2}d^{-1}$ assuming that this is the threshold at which GEZ occurs and therefore represents the equivalent of an A band.

[2] Estimated from 2003 state in Jacobs River Estuary (Stevens, 2018b) and Figure 2.72 in Robertson et al. (2016).

6.3 Historical monitoring data for Southland estuaries

Historic data is limited for Southland systems. State of the environment (long-term) monitoring data commenced after there had already been substantial modification to the catchment. Table 32 indicates the minimum level of GEZ based on state of environment monitoring data post-2000.

Table 32: Gross eutrophic zones (GEZ intertidal area) attribute bandings proposed for Southland (using the bands from Table 29).

System	Estuary type	Year	GEZ (%)	GEZ (ha)	GEZ Band	Reference
New River Estuary	SIDE	2001	1	23	D	Stevens (2018a)
Jacobs River Estuary	SIDE	2003	<4	<20	B[2]	Stevens (pers comm)
Waikawa Estuary	SIDE	2004	0	0	A	Robertson et al. (2016)
Haldane Estuary	SIDE	2004	0	0	A	Robertson et al. (2016)
Bluff Harbour[1]	SIDE	2004	0	0	A	Robertson et al. (2004)
Freshwater Estuary	SIDE	2007	0	0	A	Stevens et al. (2008)
Toetoes (Fortrose) Estuary	SSRTRE	2003	0	0	A	Stevens (2018c)

[1] Inferred from the 2004 report, <2ha soft mud across whole estuary, no oxygen measurements, 41ha of macroalgae but not comment on dense coverage.

[2] Data currently under review by Leigh Stevens this is an estimated based on expert opinion and will be updated when the data review is complete.

New River estuary, represented by a D state band in 2001 (Table 32), has been heavily modified historically with approximately 1200ha of the Waihōpai Arm reclaimed in the 1920's. The area reclaimed would have represented a large depositional zone where fine sediments would have settled. Present day, in addition to increased sediment loads, the depositional area has been significantly reduced to the western Waihōpai Arm meaning deposition has been exacerbated in the remaining intertidal area (

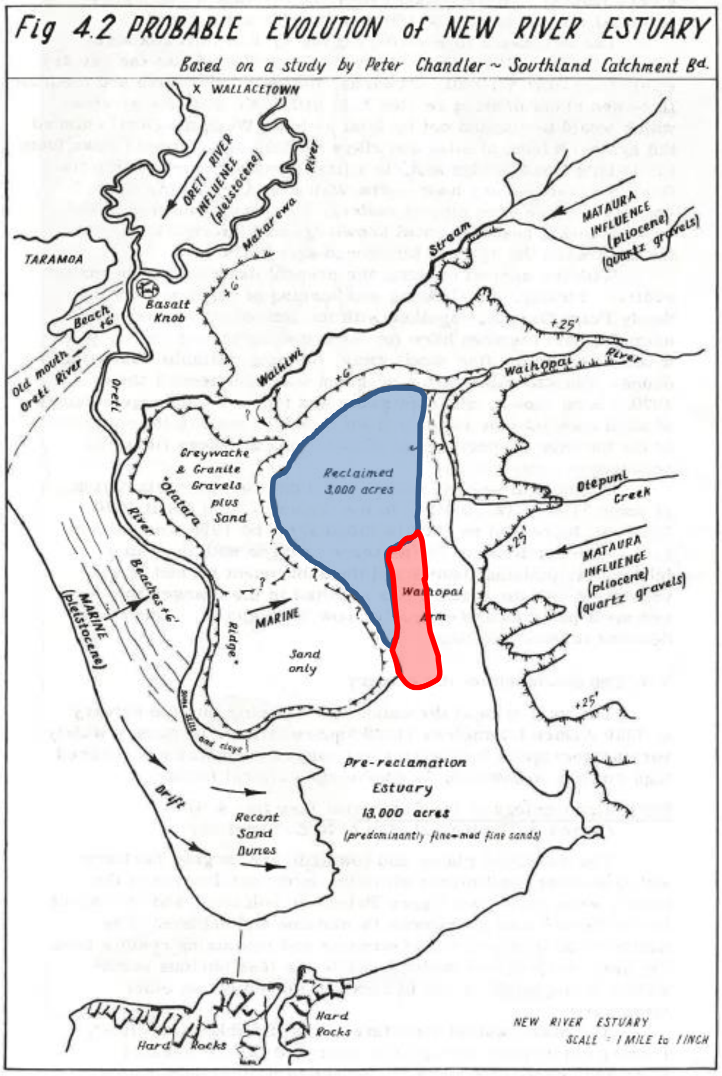


Figure 8: red area). As a result, it is unlikely that GEZ areas would have been present under natural conditions to the same extent as monitored in 2001.

Figure 8: Reclamation in New River Estuary in the 1920's. Blue area represented reclamation and red area is an estimate of deposition zone in the Western Waihōpai Arm. [Source: Figure 4.2 from Blakely (1973) "Sedimentation in New River Estuary"]

6.4 'Pristine' estuaries in New Zealand

Table 33 describes GEZ state under 'pristine' estuaries to provide an indication of pre-disturbance state or reference condition. The caveats of this approach are described in Section 5.4 under Macroalgae (EQR).

Table 33: Gross eutrophic zones (GEZ) for 'near pristine' estuaries across New Zealand, using the bands from Table 29.

System	Estuary type	Region	GEZ	Band	Reference
Freshwater Estuary	SIDE	Southland	0	A	Stevens et al. (2013)
Whangarae Estuary	SIDE	Marlborough	0	A	Stevens et al. (2016)
Whanganui Inlet	SIDE	Tasman	0	A	Stevens et al. (2017)

6.5 Summary of reference conditions for GEZ

The proposed reference state range is based on best available information; further work is required to confirm the proposed reference condition ranges. Both reference condition ranges are provided for the national and regional modelling in Table 34, given the caveats of the modelling and the updated regional modelling it is proposed the regional estimates be referenced in preference to the national modelling output.

Table 34: Summary of reference stat conditions for gross eutrophic zones (GEZ) using the bands from Table 29.

System	Estuary type	Reference condition	Proposed reference state range
SIDE type			
National Modelling (Plew, 2018)	SIDE	A to B	A[2]
Regional Modelling (Plew, 2020 unpubl)	SIDE	A	
Historic Data for Southland	SIDE	A to B[1]	
Near Pristine Estuaries New Zealand	SIDE	A	
SSRTRE type			
Development of GEZ	SSRTRE	A	A
Historical Data for Southland	SSRTRE	A[3]	

[1]As discussed in the Historical data section and shown in Figure 8, New River estuary was significantly modified prior to SoE monitoring and therefore was unlikely to be in a D-state under natural reference conditions.
[2] The estimates for reference state are based on multiple lines of evidence. Monitoring data was only collected post-2000 after significant modification in the catchment and therefore under reference conditions it is unlikely to be represented by a B state.
[3]Based on one monitored estuary; Toetoes (Fortrose) Estuary

7 Sedimentation rate

7.1 Sedimentation rate attribute and establishing reference condition

No national standards exist although Townsend and Lohrer (2015) developed recommendations for estuary guidelines for a default value of 2mm of sediment accumulation per year above the natural annual sedimentation rate (NSR) for the estuary or part of the estuary. The natural sedimentation rate is defined as the rate under native-forested catchment. It is included in the default guideline value as a baseline to account for estuaries or parts of estuaries with naturally high rates of sedimentation. The NSR is the sedimentation rate for the estuary in its reference state (i.e., pre-human vegetation cover and wetland presence), where the NSR is unknown Townsend and Lohrer (2015) recommend 0mm/y.

Table 35: Sedimentation rate (mm/year) attribute state option bandings proposed for Southland estuaries. The rate includes the threshold of 2 mm/year + natural sedimentation rate (NSR). The sedimentation rate is not an estuary wide attribute but is confined to depositional areas. NSR is proposed in Section 7.5, equating to 1mm/y for SIDE type estuaries and 0.2mm/y for SSRTRE type estuaries.

Estuary type	Pass	Fail
SIDEs and SSRTREs	≤2 + NSR*	>2 + NSR
*NSR SIDE 1mm/y; SSRTRE 0.2mm/y		

It is important to note that an estuary with an "overall" average sedimentation rate below a set guideline value may still contain multiple sites where the levels are exceeded. The inclusion of estuary areas with low sedimentation will reduce and 'dilute' the magnitude of the overall sedimentation rate, potentially obscuring instigation of necessary management responses, hence the 'annual sedimentation rate for the estuary, or part of the estuary' is used to address this. This is expected to provide protection to sediment macrofauna in deposition zones from physical impacts (Townsend and Lohrer, 2015). It does not take into account 'indefinite resilience' which refers to the ability of an environment to absorb a given amount of a stressor in perpetuity. Additionally, different estuaries with different catchment geologies and erosion rates have a different natural sensitivity to sediment inputs, and consequently a universal rate of 2mm/yr may not reflect an appropriate management threshold in all estuaries. Representativeness of sampling locations is also fundamental to deriving a measure of overall sedimentation rate of an estuary.

To account for estuaries with naturally high sedimentation rates the ANZECC guideline value is set to 2mm/y in addition to the natural sedimentation rate. Where the natural sedimentation rate is defined at the rate under native-forest catchment. Townsend and Loher (2015) summarise natural sedimentation rates for North Island estuaries ranging from 0.04 – 0.94 mm/y (see Table 36).

Table 36: Natural sedimentation rates for New Zealand estuaries (Townsend and Loher, 2015), using the bands from Table 35.

System	Description	Pre-human (mm/y)
All estuary types	Estuary types according to Hume (2007) classification. Table 2 in Townsend and Lohrer (2015).	0.03 – 0.94* (Pass)
SIDE (Type F)	New River Estuary, Jacobs River Estuary, Bluff Harbour	0.39 – 0.77 (Pass)
SSRTRE (Type C)	Toetoes (Fortrose) Estuary	0.10 – 0.11 (Pass)

*1.5mm/y was approximated for a Tidal Creek system, because this was an approximation it was not included in the range.

7.2 Historical references for Southland estuaries

7.2.1 Hicks (1994): "Sedimentation at Riverton Harbour"

Kirk (1980) suggested Jacobs River estuary would trap sediment however the analysis of the tidal compartment indicated: "There is no conclusive evidence for any reduction in the tidal compartment of the Jacobs River Estuary during the 1970's period, nor for any attendant instability in the tidal inlet leading to net sedimentation." This indicates the estuary was not significantly infilling with sediment during this period of time. Gibb (1980) supported this conclusion "little if any, direct or indirect evidence of a siltation problem at Jacobs River Estuary"

Exploring the relationship between cross sectional area of the inlet vs the tidal compartment using Heath's relationship (explained in Hicks, 1994 pg. 7) determines whether an estuary is in a steady-state, state of erosion or deposition. Jacobs River estuary or Riverton is on the steady-state line indicating there is no net erosion or deposition within the estuary using the data collected in Kirk (1980), shown in Figure 9.

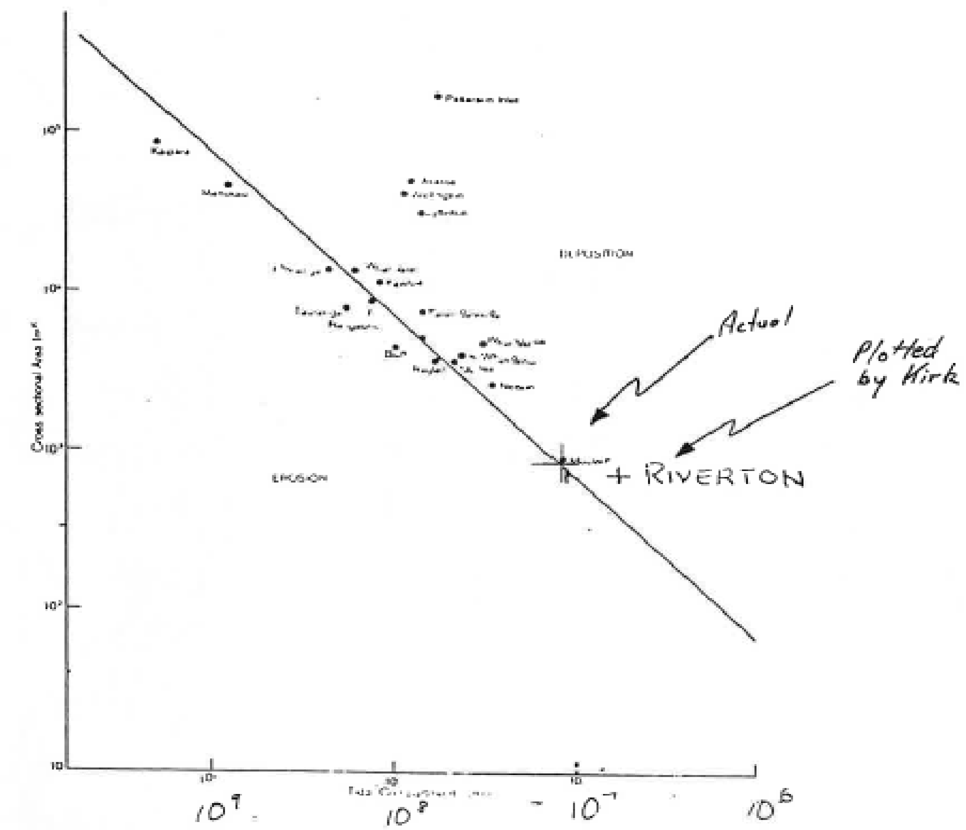


Figure 9: Plot of inlet cross-sectional area vs. tidal compartment for New Zealand inlets from Kirk (1980) with Riverton data point corrected by Hicks (1994; Fig 3.2).

7.2.2 Blakely (1973): "Sedimentation in the New River Estuary"

Blakely (1973) identified that there has been a shift in the sediment grain size profile with depth (indicative of deposition over time) in the Waihōpai Arm. Where surface sediments (<30cm depth) of the Waihōpai Arm were fine (clay) shifting to fine sand below 30cm depth. The map of the estuary in the report (Figure 10) indicates Daffodil Bay historically was sandy flats which are now significant areas of GEZ (fine sediment and macroalgae).

“The basic change over the last 100 years, and more particularly the last 20 years, appears to be an increase in the overall sedimentation rate over the estuary with particular emphasis in the zones of flocculation indicated, (based on changes observed by local people)”

“The sources of sediment contributing to the present day sediment patterns are the fine sediments transported by the Ōreti River (and to a less extent the Waihōpai River), and the find sands supplied by littoral drift from the west.”

“These sources were available twenty or thirty years ago, but the catalyst for the acceleration of the sediment character changes from sand to organic silts in some areas, appears to have been the deterioration in water quality and vegetation build up. These processes have become established to a degree where the natural tolerance of the estuary has been exceeded”

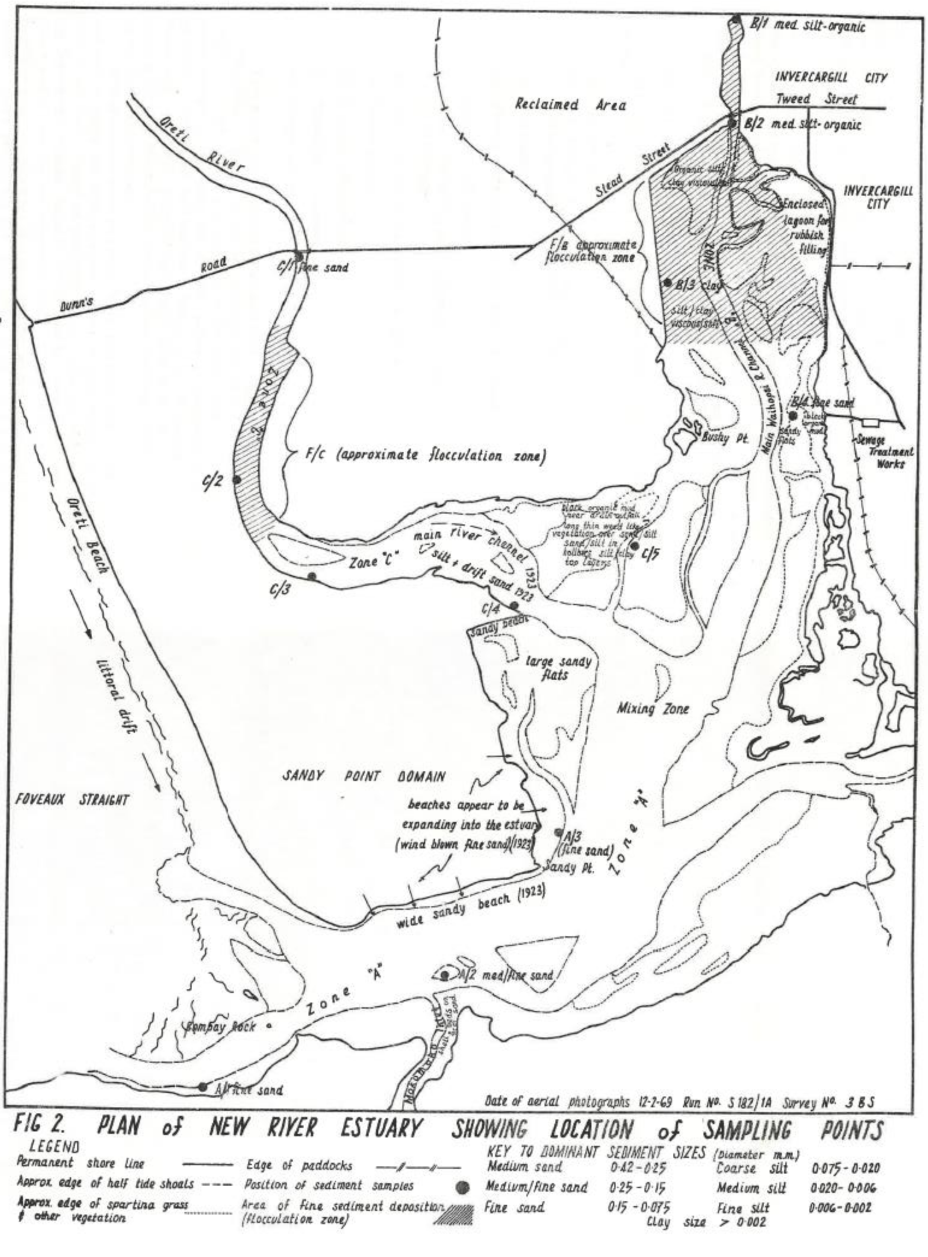


Figure 10: Figure 2 from Blakely (1973) showing areas which were historically sandy (e.g. Daffodil Bay and Lower Waihōpai Arm).

7.2.3 Thoms (1981): "Sedimentation in New River Estuary, Southland"

Thoms (1981) noted in that the upper Waihōpai Arm, lower Waihōpai and other small areas in the estuary were sandy mud (Figure 11). Thoms (1981) concluded that the reclamation of the estuary shifted the estuary from a steady-state to a state of deposition measured in 1981 when compared to the state in 1856 prior to reclamation (Figure 11).

The sediment surface study showed "…that the sedimentation patterns within the New River estuary are variable, both in time and space. Calculations suggested that the estuary is infilling, with the majority of the sediment deposition on the intertidal surface deriving from a marine source." This sedimentation source has changed in contemporary times to fine sediments from the riverine inputs (Ōreti and Waihōpai) which has been identified in more recent state of the environment monitoring.

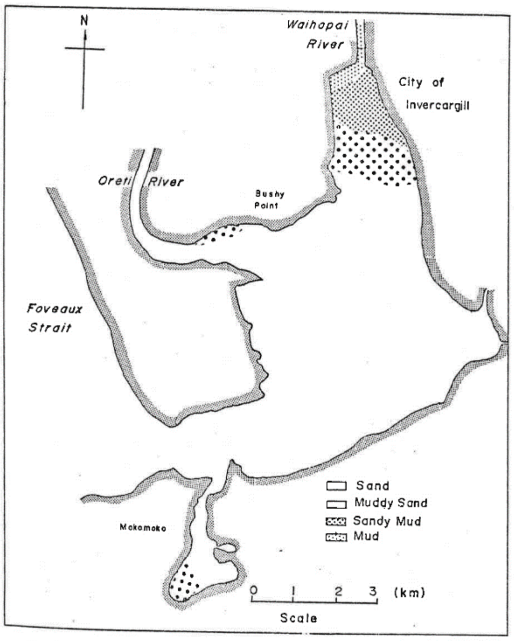


Figure 3.2 Sediment textures.

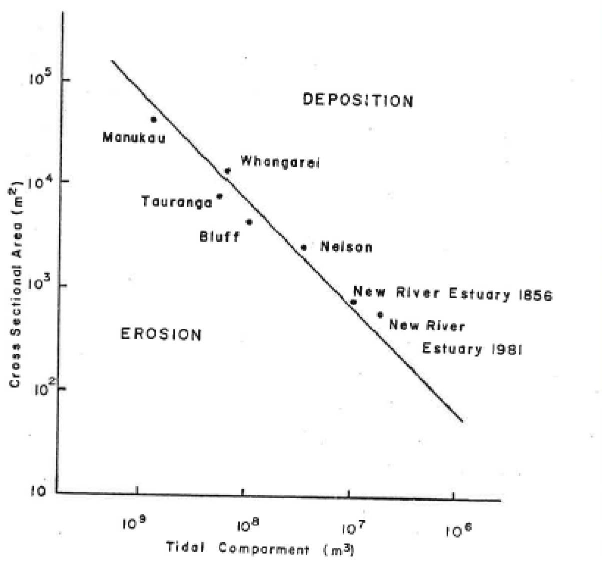


Figure 7.3 Logarithmic plot of tidal compartment against cross-sectional throat area.

Figure 11: Outlines the sediment textures measured in New River Estuary in 1981 through grain size analysis (Thoms, 1981; Figure 3.2 on left). Legend represents sand (<10% mud), muddy sand (10-50% mud), sandy mud (50-90% mud) and mud (>90% mud). On the right, Figure 7.3 from Thoms (1981) shows the deviation of the estuary from the steady-state line to a state of deposition in 1981.

7.2.4 Brown (2019): "Geochemistry and isotopic composition of sediment cores to understand the lithological and anthropogenic controls on eutrophication in the New River Estuary, Southland".

"The calculated rates suggest that sedimentation is not uniform in the depositional areas of New River Estuary; the upper Waihōpai Arm (UNA), being the most developed with fine-sediment accumulating prior to 1981 (Thoms, 1981), has reached the highest rate of sedimentation followed by the lower Waihōpai Arm (LW) and Daffodil Bay (DE), which began to significantly accumulate very-fine sediment by 2001 and 2007, respectively (Ledgard, 2013; Robertson and Stevens, 2007, 2001). Although sediment was already accumulating in the estuary due to agricultural expansion, river channelization, urbanization, and estuary reclamation throughout the 20th century, it is evident from this study that the rate of fine-sedimentation increased most significantly from the 1990's to present day, as also suggested elsewhere (Pearson and Couldrey, 2016; Robertson et al., 2017). Agricultural development, especially on sloped landscapes, as well as the shift to dairying contributed to this increase as farming expansion onto unsuitable land, irrigation, tile drains, and wintering practices enhance the sediment loss to the catchment (Ledgard, 2013; Monaghan et al., 2010)."

7.3 Historical data for Southland estuaries

To derive 'natural sedimentation rates' radioisotopic dating of sediment cores can be used if available. As of 2019 New River estuary and Waikawa estuary are the only two Southland estuaries to have had sediment cores collected with the aim to determine historical sedimentation rates. Sedimentation rates were determined using a range of dating methods (^{7}Be, ^{137}Cs, ^{210}Pb, ^{226}Ra carbon-dating, pollen-dating; Robertson et al., 2007).

In 2007 Waikawa estuary was cored to a depth of 106cm in a soft mud area located in the 'Upper South' of the estuary (Figure 12; Table 37). The data showed that prior to 1879, the upper Waikawa Estuary was still covered with at least 0.5m of smooth grey mud. The absence of shell fragments in this layer is unknown and potentially indicates a period of very rapid sedimentation (perhaps a result of land clearance in the mid-1800s). No grain, metal or other substrate characteristics were measured as part of that work.

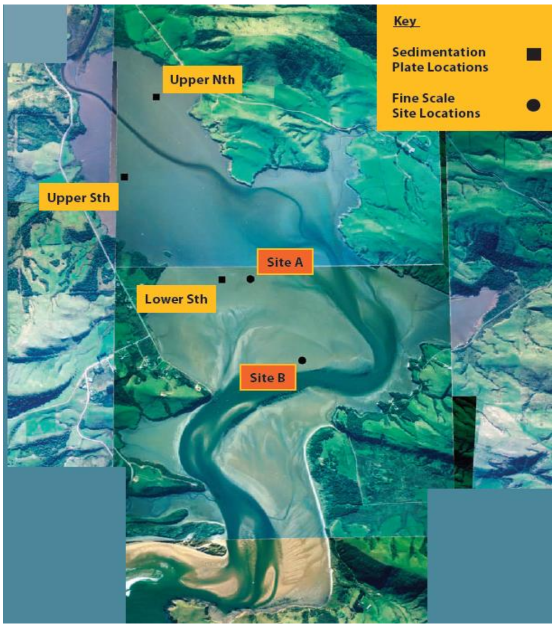


Figure 12: Location of Waikawa Estuary core in 2007 (Upper Sth). [Source: Robertson and Stevens (2007)]

Table 37: Sedimentation estimates from historic cores in Waikawa Estuary conducted by Robertson et al., (2007).

Site	Year	Average sedimentation rate (mm/y)	Band (from Table 35)
Upper South	1996-2007	10.7	Fail
	1967-1996	3.7	Fail
	1879-1967	1.4	Pass

It is important to note that the New River estuary core collected in the Waihōpai Arm was not historically an area of mud deposition. Post-reclamation in the 1920's, the depositional zones within New River estuary shifted to the Waihōpai Arm area and therefore rates prior to the 1920's may not necessarily reflect sedimentation rates in a deposition zone. Furthermore, due to the land reclamation, the hydrology of the whole estuary has been altered thus sedimentation rates for all areas may only be reliable back to ~1920's. A core in the historic mud depositional zone (i.e. reclaimed area) would need to be collected and analysed to derive sedimentation rates pre 1900s. In a geotechnical report on Stead Street Pump Station a core was collected to determine subsoil conditions for the pump station upgrade. Below the surficial fill the underlying estuarine deposit comprised of light grey clayey silt or light brown organic silt which was indicative of the historical deposition area in the estuary (GeoSolve Ltd 2017; Figure 8).

In 2007, a core from New River estuary was collected by Robertson et al., (2007). The core location (Figure 13) was in a high mud content and high modern sedimentation rate depositional zone. The same radioisotopes (^{7}Be, ^{137}Cs, ^{210}Pb and ^{226}Ra) were applied as in the Waikawa core. The results from this core are presented in Table 38.

Table 38: Sedimentation estimates from historic cores in New River Estuary conducted by Robertson et al., (2007).

Site	Year	Average sedimentation rate (mm/y)	Band (from Table 35)
Upper Waihōpai Arm	2001-2007	28	Fail
	1990-2001	7	Fail
	1982-1990	10.4	Fail
	1967-1982	12.4	Fail
	1906-1967	3	Pass

Note: the upper New River Estuary was historically sandy, with surf clams and cockles common in areas now covered by deep soft muds. More modern sedimentation rates from 2007 on are estimated to be approximately 30-40 mm per year from sediment plate monitoring.

A repeat core of the 2007 core was taken in the same area in 2017 by Brown (2019) with the results shown in Figure 13 and Table 39. Note that these samples were taken from depositional areas and do not represent an estuary wide deposition rate. Additional cores were collected in 2019 to assess the change in eutrophication over time (Dudley, pers comm), sediment grainsize and sedimentation rates were not available at the time of writing. No estimates of pre-human sedimentation rate are available for the cores collected.

Table 39: Sedimentation estimates from historic cores in New River Estuary conducted by Brown (2019).

Site	Year	Average sedimentation rate (mm/y)	Band (from Table 35)	Comment
Upper Waihōpai Arm (UNA)	1915-1935	13.3	Fail	Repeat of 2007 core location
	1935-2009	7.3	Fail	
	2009-2017	22.4	Fail	
Lower Waihōpai Arm (LW)	1956-2017	5.9	Fail	
	2007-2017	17.5	Fail	
Daffodil Bay (DE)	1906-1923	7.0	Fail	Sheltered embayment within estuary
	1923-1965	6.3	Fail	
	1965-1997	5.5	Fail	
	1997-2017	10.3	Fail	

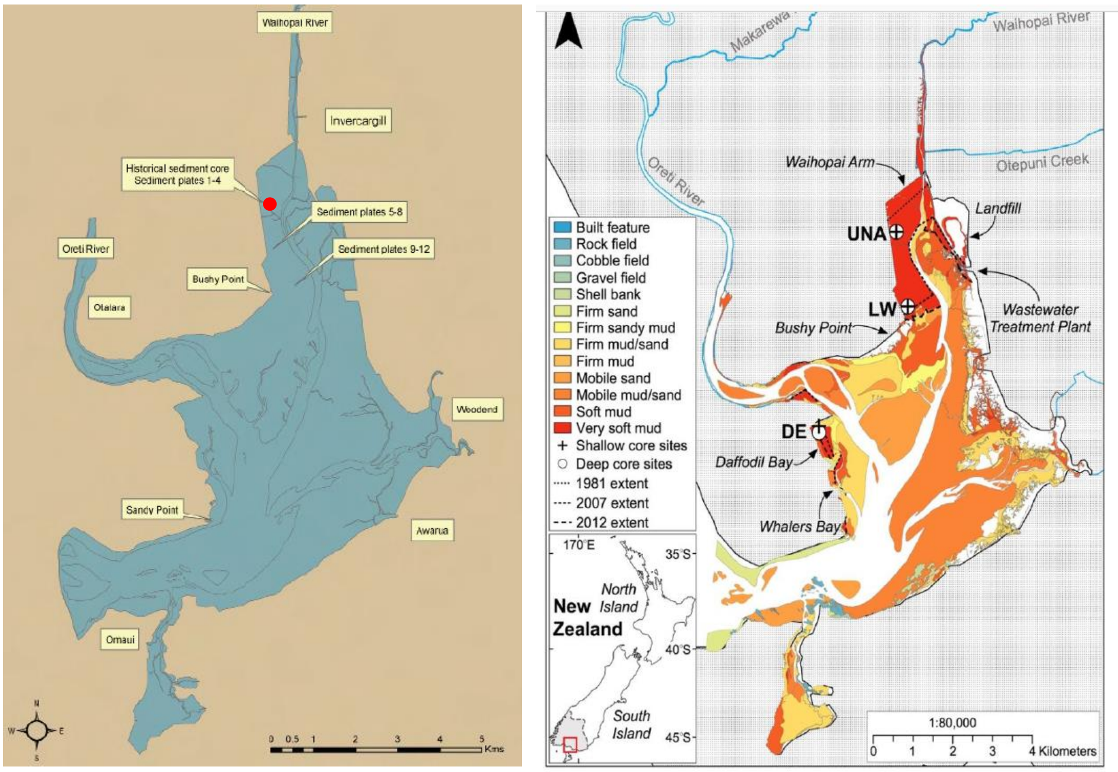


Figure 13: Location of New River Estuary core in 2007 (left) and 2017 (right). UNA is Upper North arm, LW is lower Waihōpai and DE is Daffodil Bay (Right). [Source: Left image from Robertson and Stevens (2007a) and right from Brown (2019)].

7.4 Literature review of sedimentation in New Zealand estuaries

7.4.1 Hunt (2019): “Summary of historic estuarine sedimentation measurement in the Waikato region and formulation of historic baseline sedimentation rate”

Sedimentation rates for tidal lagoon type (SIDE) estuaries in the Waikato region indicate that pre-human sedimentation, based on sediment core analysis, ranged between 0.06 to 0.5 mm/y in the intertidal area of four estuaries. Polynesian and European ranged from 0.1 to 0.9mm/y and 1 to 28.5mm/y, respectively. Hunt (2019) concluded for all estuaries in the region the pre-catchment disturbance sedimentation rate was 0.2mm/y.

Table 40: Sedimentation estimates (mm/y) from North Island estuaries (Hunt, 2019) using bands from Table 35.

System	Estuary type	Pre-human	Pre-European	Current
Tidal lagoon	SIDE	0.06 to 0.5 (Pass)	0.1 to 0.9 (Pass)	1 to 28.5 (Fail)

7.4.2 Hicks et al., (2019): “Updated sediment load estimator for New Zealand”

Hicks et al., (2019) modelled sediment load estimates and disposition across a range of estuary types in New Zealand including tidal lagoon type estuaries (SIDE). The model estimated from historical land use cover that pre-human, pre-European and current sedimentation rates (Table 41). Note the modelling as similar caveats to Plew et al., (2018). The model did not represent the conditions in tidal river mouth estuaries well and therefore the estimates of sedimentation rate are not reported here. It is important to note that the modelling represents an overall estuary sedimentation rate it is not site specific.

Table 41: Modelled sedimentation estimates (mm/y) from Hicks et al., (2019) using bands from Table 35.

System	Estuary type	Pre-human	Pre-European	Current
Tidal lagoon	SIDE	1.86 (Pass)	1.51 (Pass)	1.53 (Pass)

7.5 Definition of natural sedimentation rate (NSR)

Townsend and Lohrer (2015) discussed the impacts of "sedimentation" in the context of fine sediments (<62.5µm) because larger particles such as gravels and sand do not have the same widespread ecological impacts. In the absence of information to define pre-human or NSR Townsend and Lohrer (2015) recommended a NSR of 0mm/y. However, from the modelling information, historical data and other estuaries across New Zealand a NSR rate of 0mm/y is unlikely to reflect sedimentation under reference conditions.

Zaiko et al., (2018) stated that NSR could be estimated from the equation below using modelled load estimates and current sedimentation rate data (Eq. 1).

$$NSR = \text{Current sedimentation rate (CSR)} \times \frac{\text{Reference state sediment load (NSL)}}{\text{Current sediment load (CSL)}} \qquad \text{Eq. 1}$$

Current sediment load estimates have been modelled for Southland estuaries in Plew et al., (2020a) and Hicks et al., (2019). The sediment loads modelled in each of these studies does not account for reference state land cover (e.g. wetlands, native bush etc) as discussed in the caveats for modelling in Section 3.2. The sediment accumulation model only predicts sediment accumulation it does not take into account net erosion; the model cannot estimate sediment export greater than riverine inputs. The models only represent an estuary average they do not take into account high deposition zones within the estuary. The average sedimentation rate for the estuary should be treated with caution because it does not take into account all processes that influence sedimentation and erosion in estuaries (Plew et al., 2020a). This is shown in

Figure 14 where the modelled sedimentation rates are compared against actual sedimentation rates measured in the estuary. Particularly, in Fortrose estuary where the measured sedimentation rate is ~ 0 mm/y and the model predicts 35.6 mm/y (

Figure 14).

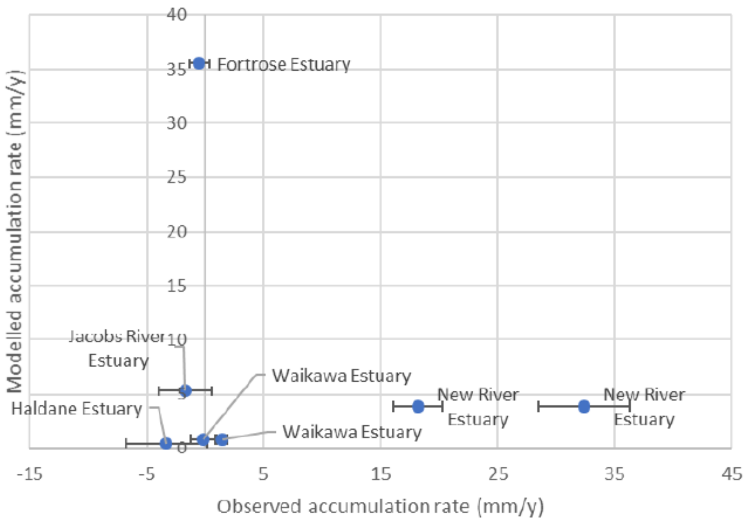


Figure 14: Comparison of modelled and observed sediment accumulation rates in Southland estuaries (Plew et al., 2020a).

Table 42: Modelled reference state, sediment load, current sediment load and sedimentation rate used to calculate natural sedimentation rate using bands from Table 35. The current sediment rate is modelled from Hicks et al., (2019) and Plew et al., (2020a) who used different sediment source models.

System	Estuary type	Reference sediment load (g/m²/d; NSL)	Current sediment load (g/m²/d; CSL)	Current sedimentation rate (mm/y; Hicks et al., 2019)	Calculated NSR (mm/y)	Current sedimentation rate (mm/y; Plew et al., 2020a)	Calculated NSR (mm/y)
Waikawa Estuary	SIDE	5.30	7.57	1.71	1.20	0.86	0.60
New River Estuary	SIDE	8.64	12.84	2.94	1.98	3.9	2.62
Jacobs River Estuary	SIDE	21.46	26.49	5.31	4.30	5.3	4.29
Haldane Estuary	SIDE	5.12	6.27	1.43	1.17	0.47	0.38
Toetoes Estuary	SSRTRE	206.12	187.91	30.8	33.8	35.6	39.1

There is no pre-human data available for Southland estuaries, the earliest data available is from the early 1900's after catchment modification. At present the best estimate of NSR that could be applied to Southland are outlined in Table 36, Table 40, Table 41 and Table 42 which include measured sedimentation rates from sediment cores across New Zealand and a sedimentation rate calculated from modelled sediment loads.

A preliminary NSR is recommended in Table 43. Given the caveats of the modelled sedimentation rates, the preliminary NSR is based on measured sedimentation rates derived from sediment cores across New Zealand estuaries (Table 36 and Table 40). Determining a NSR for Southland estuaries should be prioritised in future work programmes, to determine whether the proposed NSR is appropriate for Southland estuaries and to compare against contemporary sedimentation rates.

Table 43: Natural sedimentation rate (NSR; mm/y) estimates that could be applied to Southland estuaries.

Estuary type	NSR based on literature (mmy/y)	ANZECC guideline + NSR (mm/y)
SIDE	<1.0[1]	<3.0
SSRTRE	<0.2[2]	<2.2

[1] The preliminary sedimentation rate is based on Table 36 and Table 40 and is within the same order of magnitude as the modelled sedimentation rate for SIDE type estuaries Table 41.

[2] Is based on the sedimentation rate reported in Hunt et al., (2019).

7.6 Summary of reference conditions for sedimentation rate

The historical measurements from New River estuary are not representative of reference state and are inclusive of the reclamation period as a result they have been removed from the assessment of reference conditions. This attribute does not reflect sedimentation in DSDE type estuaries, an attribute for DSDE Type estuaries would require further development.

Table 44: Summary of reference state conditions for sedimentation rate (mm/y) using bands from Table 35.

Study	Estuary type	Reference condition	Proposed reference state range
ANZECC Sedimentation Guidelines (Table 2)	ALL	0.4 to 0.94 (Pass)	Pass
National Modelling (Hicks et al. 2019)	SIDE (estuary wide)	1.86 (Pass)	
North Island Estuaries (Natural state)	SIDE (deposition area)	0.06 to 0.5 (Pass)	
New River estuary (1906 – 1967*) 2007 study	SIDE (deposition area)	3 (Pass)	

New River estuary (1906 – 1965*) 2017 study	SIDE (deposition area)	5.5 to 7.0 (Fail)	
Waikawa Estuary (1879 – 1967) 2007 study	SIDE (deposition area)	1.4 (Pass)	
Definition of Natural sedimentation rate	SIDE	1 (Pass)	Pass
	SSRTRE	0.2 (Pass)	
New River estuary historical references (estuary wide)	Estuary shifted from steady-state to net deposition post land reclamation (Thoms, 1981). This was combined with deteriorating water quality and vegetation build up (Blakely, 1973).		
Jacobs River Estuary (estuary wide)	In a 1980 study it was determined that Jacobs River Estuary was in a steady-state not a state of overall estuary deposition (Hicks, 1994).		

* This time period includes post-reclamation in the 1920's therefore it is not reflective of natural sedimentation rate.

8 Oxygen in sediment (aRPD)

8.1 Development of the oxygen in sediment attribute and establishing reference condition

Oxygen in sediment (or apparent redox potential (aRPD)) is a site specific attribute. aRPD provides a measure of whether nutrient enrichment exceeds levels causing nuisance anoxic conditions in surface sediments. There is a correlation between aRPD and community composition, extent and health (e.g. an aRPD closer to the surface forces the infauna toward the surface reducing the available habitat). Oxygen is an important driver of redox potential and oxygen penetration into the sediment is limited by two key physical processes diffusion (in muddy cohesive sediments) and advection (sandy sediment). In finer silt/clay sediments, physical diffusion limits oxygen penetration to <10mm unless bioturbation by infauna oxygenates the sediments (Jørgensen and Revsbech 1985 in Estuary Draft NOF attributes, MfE unpubl.).

Table 45: Oxygen in sediment (aRPD in mm) attribute state option bandings proposed for Southland estuaries.

Estuary type	A+ Excellent	A Very good	B Good	C Fair	D Poor
SIDEs and SSRTREs	≥30	≥20 and <30	≥10 and <20	≥5 and <10	<5

8.2 aRPD in Southland estuaries

Southland estuary data is shown in Figure 15, it should be noted that not all muddy sites (highlighted in red) are associated with low aRPD. Visual observations of aRPD in Waikawa Estuary site C and Haldane Estuary site A1 have high degrees of bioturbation in the sediment and no macroalgal biomass on the sediment surface compared to Jacobs River Estuary site D and E and New River Estuary sites E and F. High organic carbon content is generally associated with fine sediments and in instances were diffusion is the main driver of oxygen replenishment (e.g. no bioturbation) the rate of organic matter decomposition can exceed oxygen replenishment leading to anoxia (Figure 16, 17). In areas with dense Gracilaria cover there is a constant supply of organic carbon for decomposition and resultant oxygen consumption leading to anoxia in the sediment and in extreme conditions the formation of sulphides, these areas are typically described as GEZ. As described in the previous section it is unlikely that GEZ areas would have occurred to the current extent under reference conditions.

In sandy environments such as the lower Matāura flats of Toetoes (Fortrose) Estuary there has been significant oxygen depletion in the sandy sediments with the aRPD measured close to the sediment surface. This observation is likely the result high nutrient concentrations coming down the Matāura River, leading to rapid decomposition rates in the sandy sediments. Under reference conditions nutrient loads in the Matāura River would have been significantly lower than present day and therefore it is unlikely low widespread anoxia (shallow aRPD) would have been present under reference state.

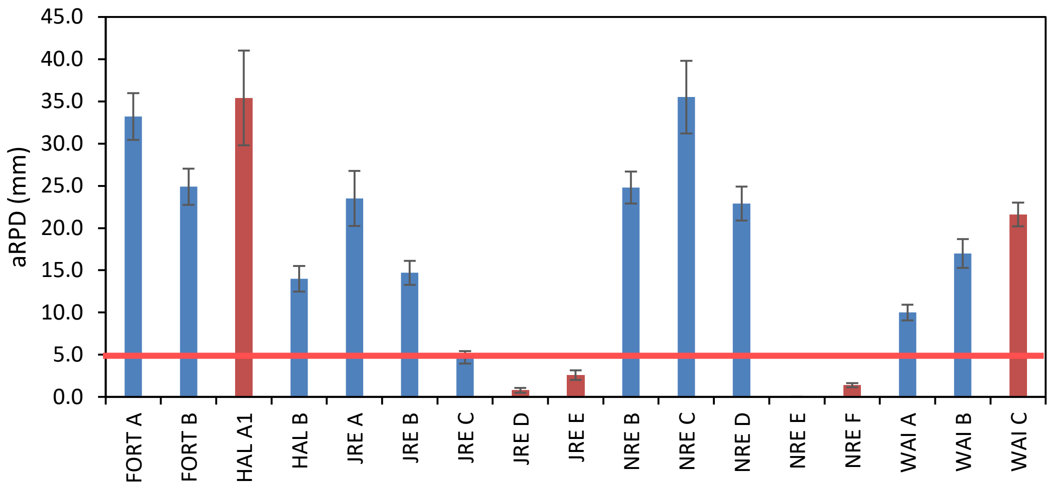


Figure 15: aRPD (mm) for Southland estuaries in 2019. Red represents sites >25% mud content and the red line represents the proposed regional bottom line.

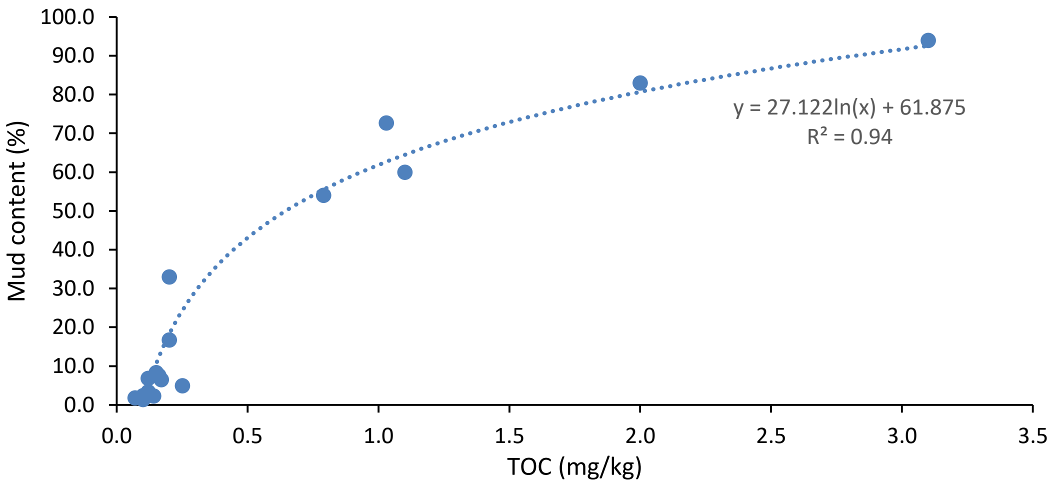


Figure 16: Mud content (%) vs. total organic carbon (TOC, mg/kg) in Southland estuaries in 2019.

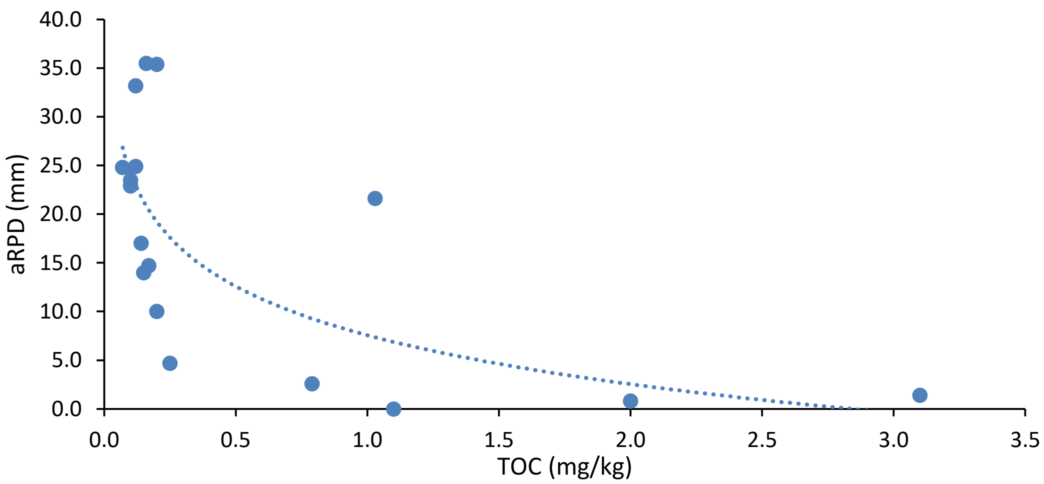


Figure 17: aRPD (mm) vs. total organic carbon (TOC, mg/kg) in Southland estuaries in 2019.

8.3 Summary of reference conditions for aRPD

In cohesive sediments (muddy sediment) it is proposed under reference conditions aRPD would be greater than the limitations of diffusion (~10mm) due to the presence of a healthy macroinvertebrate community that would promote bioturbation unless there are areas within an estuary that have naturally high concentrations of organic carbon in the sediment (Figure 17). In sandy sediments it is proposed that under reference conditions there would be a diverse infauna community and aRPD would exceed 20mm. A more extensive literature review and analysis of Southland data is required to confirm these proposed reference conditions particularly in a Southland context.

Table 46: Summary of aRPD proposed reference state using bands from Table 45.

Substrate type	aRPD (mm)	aRPD reference condition band		
"Muddy sediment" Mud content ≥25% mud	≥10	A+	to	B
"Sandy sediment" Mud content <25% mud	≥20	A+ to A		

9 Muddiness

9.1 Development of the muddiness attribute and establishing a reference condition

Grainsize (% mud content) represents a site specific attribute; mud extent represents the area of the estuary covered in mud (>25% mud). The site specificity of the grainsize attribute is important to detect changes from 'baseline' and is an early warning sign of increased deposition of fine sediments in areas of the estuary where this hasn't been seen previously. The mud extent attribute complements the grainsize attribute by focusing on the area of the estuary that is under poor (D; >25% mud) condition where macroinvertebrates become stressed and there is loss of high value seagrass.

Table 47: Muddiness (% mud content) attribute state option table proposed for Southland estuaries.

Estuary type	A+ Excellent	A Very good	B Good	C Fair	D Poor
SIDEs and SSRTREs	≤5	>5 and ≤10	>10 and ≤15	>15 and ≤25	>25

Site specific monitoring in Southland estuaries began in the early 2000's capturing a few sites in the mid estuary (well flushed areas). Overtime deposition areas have been added to the monitoring programme because the broad scale habitat mapping highlighted widespread and expanding muddy sediments in many of Southland estuaries. Unfortunately, data for these deposition areas is not suitable to use in determining reference conditions because many of these areas were heavily modified at commencement of monitoring (e.g. in 2012 New River estuary Waihōpai Arm sediments contained ~90% mud content).

9.2 Historic Southland data for grainsize

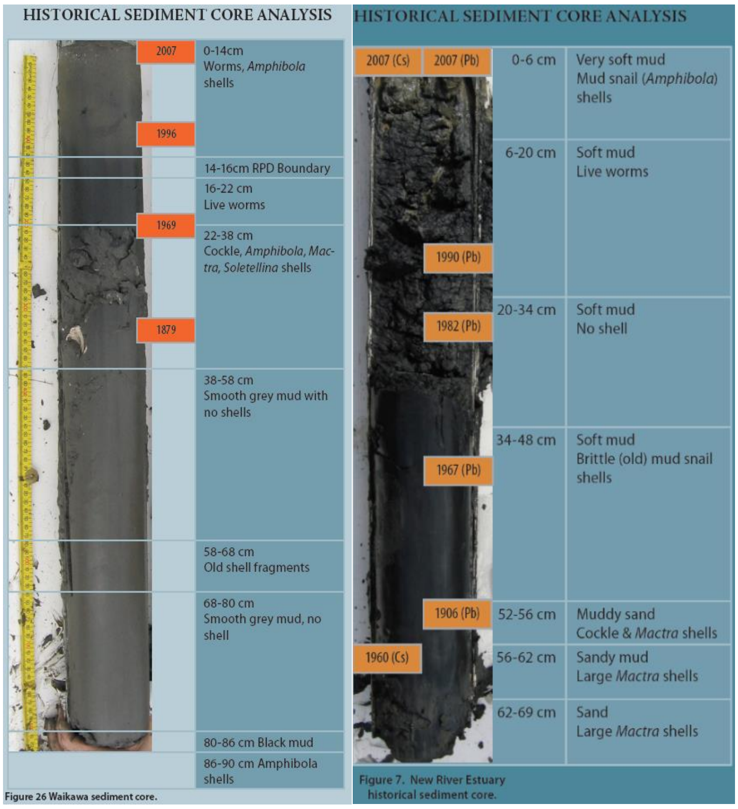


Figure 18: Waikawa Estuary core and New River Estuary core collected in 2007. [Source: Robertson et al., (2007)]

9.2.1 Waikawa Estuary and New River Estuary sediment cores 2007

The sediment core profile of grainsize shows prior to 1879 the upper Waikawa Estuary was covered in at least 0.5m of smooth grey mud. New River Estuary core indicates that prior to 1906 fine sediments were present in the estuary which is confirmed by the GeoSolve Ltd (2017) report that explored the substrata in the reclaimed area.

9.3 Summary of reference conditions for muddiness

The muddiness attribute is challenging to provide one 'reference' state condition due to the natural range of depositional and erosional zones and has been proposed to detect changes from baseline (i.e. is muddiness worsening). Depending on the site location with the estuary there will be large range in % mud content therefore reference state has not been proposed for the mud content attribute because further information is required to determine the historical mud content for the current state of environment monitoring sites. The attribute is important however, because it will detect change from the baseline and any impacts on ecosystem health before the change is detected in the mud extent attribute allowing for management intervention if required.

It is recommended that further research is needed for Southland estuaries to provide an estimate of reference conditions for each of the monitored sites based on their location within the estuary. The level of detail needed to make site specific estimates of mud extent was out of scope in the current report and a reference condition estimate for estuary type was not appropriate.

Table 48: Summary of muddiness (% mud content) proposed reference state using bands from Table 47.

Substrate type	Reason	Reference state
Muddiness (% mud content)	Large range in % mud content depending on the area within the estuary and the hydrodynamics. The attribute it specific to site to detect change over time from proposed baseline.	Not determined

10 Mud extent

10.1 Development of the mud extent attribute and establishing a reference condition

Estuaries naturally infill with sediment overtime from sediment derived from both land and sea. The rate of infilling is dependent on the shape and size of the estuary and the interaction between river processes, tidal exchange and waves (Hume and Swales, 2003). However, of particular concern is when estuaries are infilling with fine sediments (<63µm grainsize), because fine muds can have impacts on seagrass cover, macroinvertebrates, oxygen levels in the sediment and nutrient cycling. The impacts of soft muds in estuaries is detailed in Ward and Roberts (2020).

The mud extent attribute represents the area of the estuary covered in soft muds (>25% mud) and complements the grainsize attribute by focusing on the total area of the estuary that is under poor (D; >25% mud) condition where macroinvertebrates become stressed and there is loss of high value seagrass. Increasing areal extent of soft muds is associated with land use changes that mobilise fine sediments in the catchment which are then deposited in estuaries. The mud extent attribute, using a pass or fail grading, is aimed to prevent the further expansion of soft mud areas within estuaries.

Table 49: Mud extent (>25% mud content in m^2 of intertidal area) attribute state option table proposed for Southland estuaries.

Estuary type	Pass	Fail
SIDEs and SSRTREs	Decrease or no change	Increase

10.2 Data for Southland estuaries

In general, fine sediments are deposited in the upper estuary where flocculation and settling occurs. To assess a change in mud extent over time there needs to be a point of reference, for example, mud extent post-2000 when monitoring began or mud extent under 'reference' or pre-human conditions. With the exception of New River Estuary there is very little information on historical substrate type and extent in Southland estuaries.

State of the environment (long-term) monitoring commenced in early 2000's which includes broad scale habitat and substrate mapping. Two substrate types soft mud (>25% mud content) and very soft mud (>50% mud content) give an indication of mud extent within the estuary. These areas represent estuary state after prolonged and significant anthropogenic impact. Comparing the New River Estuary mud extent in 2001 (**Figure 19**) compared to 1981 (Figure 11) shows that areas have expanded into other parts of the estuary. It is important to note that Daffodil Bay where mud extent has expanded more recently and conditions have deteriorated since monitoring began is represented as sand in Figure 11 (Thoms, 1981). This observation likely applies to other estuaries in Southland where forestry and intensification of farming has increased sediment loads and likely increased mud extent in Southland estuaries.

10.3 'Pristine' estuaries in New Zealand

Using 'pristine' estuaries to provide an indication pre-disturbance state and the caveats around this are described in 5.4. With regard to mud extent of particular importance is historical land clearing, sediment deposition and recovery since disturbance. Substrate mapping for three estuaries are shown in Figure 20, mud extent is dependent on the estuary type and the historical changes within the catchment. Some degree of mud in depositional areas occurs in estuaries within forested catchments (e.g. Freshwater Estuary) however this is localised to small depositional zones and the extent is relatively stable over time (**Figure 19**, 20).

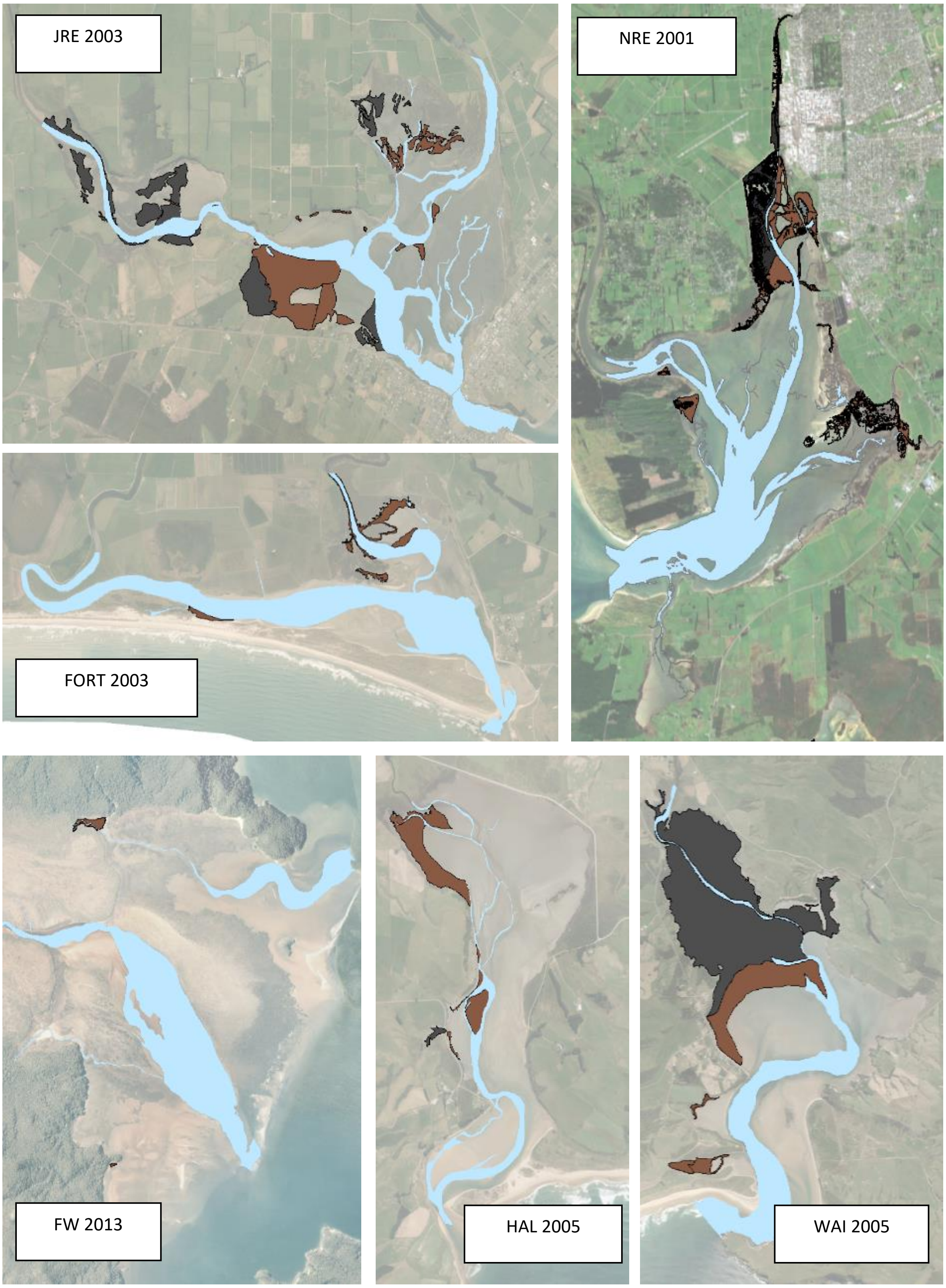


Figure 19: Broad scale habitat mapping of Southland estuaries where black represents very fine mud, brown fine mud and blue the main channels in the estuary[11].

[11] (GIS version saved: M:\GIS\Projects\ArcMap\Environmental Info\Estuaries\Mud extent_ ALL ESTUARIES_2000-2010.mxd)

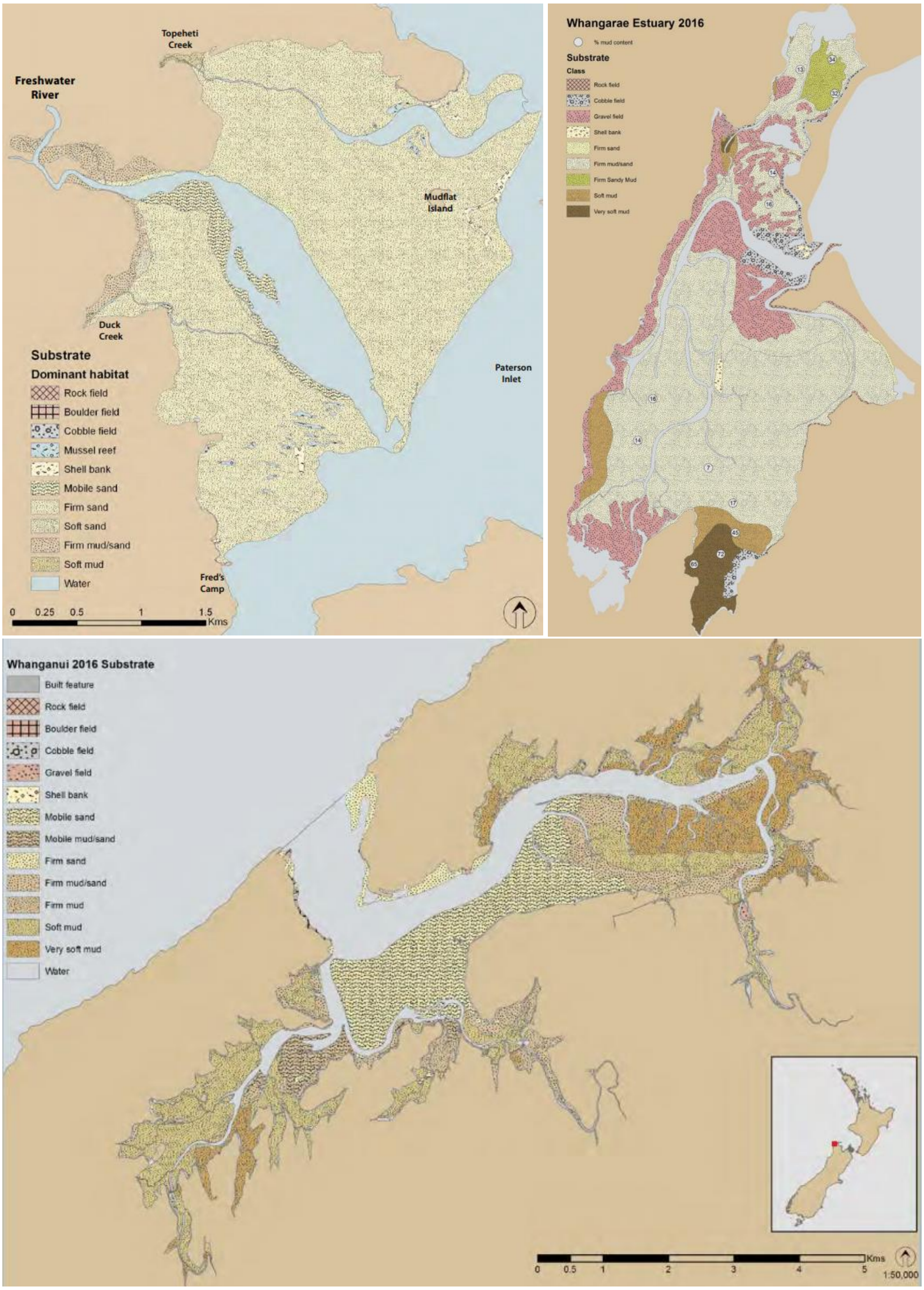


Figure 20: Broad scale substrate mapping of three estuaries proposed to be in near pristine conditions. Freshwater Estuary (top left) on Stewart Island/Rakiura drains a forested catchment, Whangarae Estuary (top right) and Whanganui estuary (bottom) drain forested catchments however, they have known historical land clearing in the catchment.

10.4 Summary of reference conditions for mud extent

The areal extent of mud attribute is designed to detect change from an agreed baseline and a pass or fail grading applied. The baseline used for the mud extent attribute in the assessment of state in Norton et al., (2020) was based on the data presented in

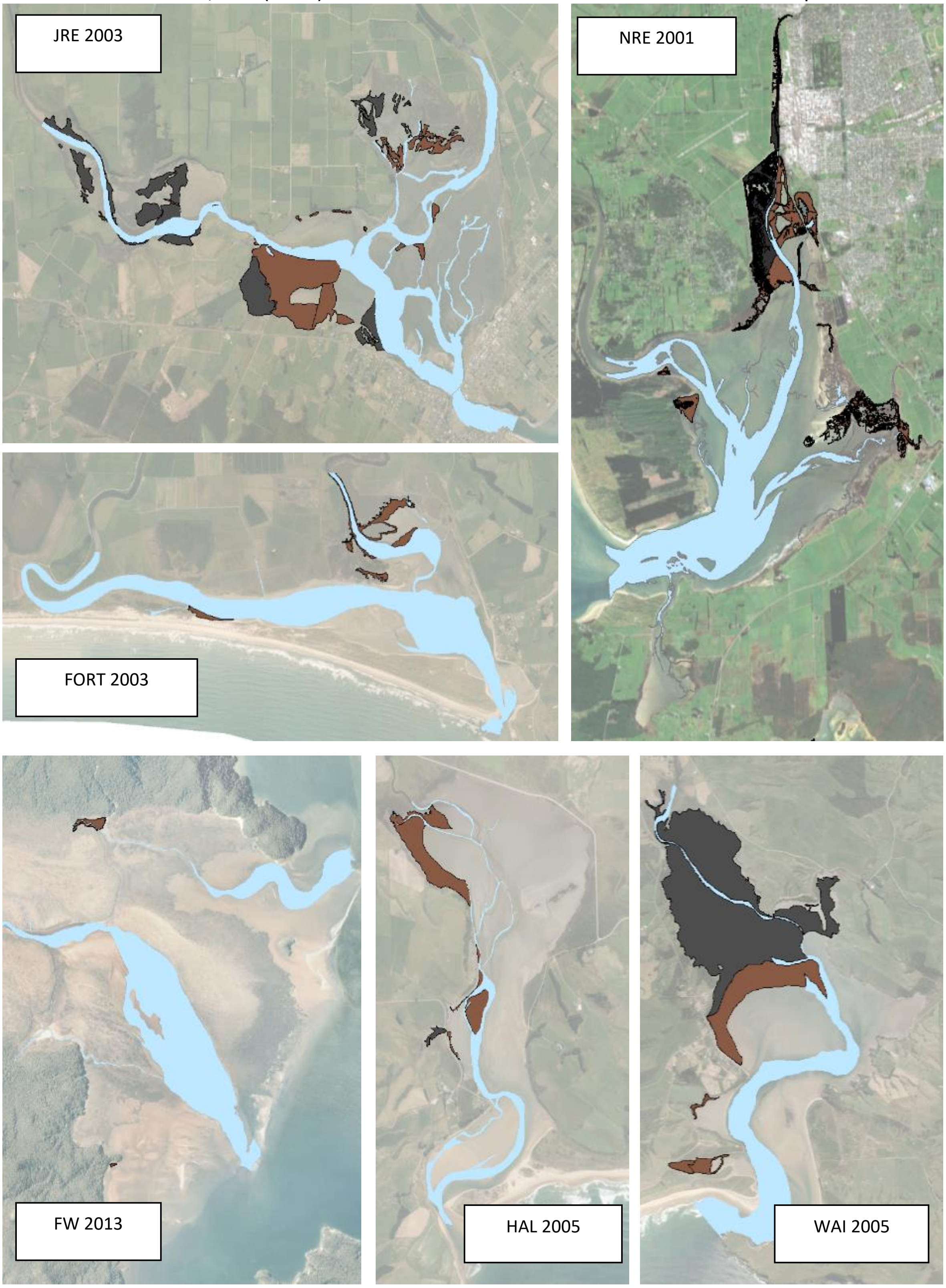


Figure **19**. Given the mud extent attribute is compared to an agreed baseline it is difficult to assess reference conditions in the same way as the other numeric attributes with a range of states (A to D bands).

Previous studies (e.g. Thoms, 1981) and anecdotal evidence indicate that mud extent in estuaries was less widespread prior to the early 2000's (agreed baseline;

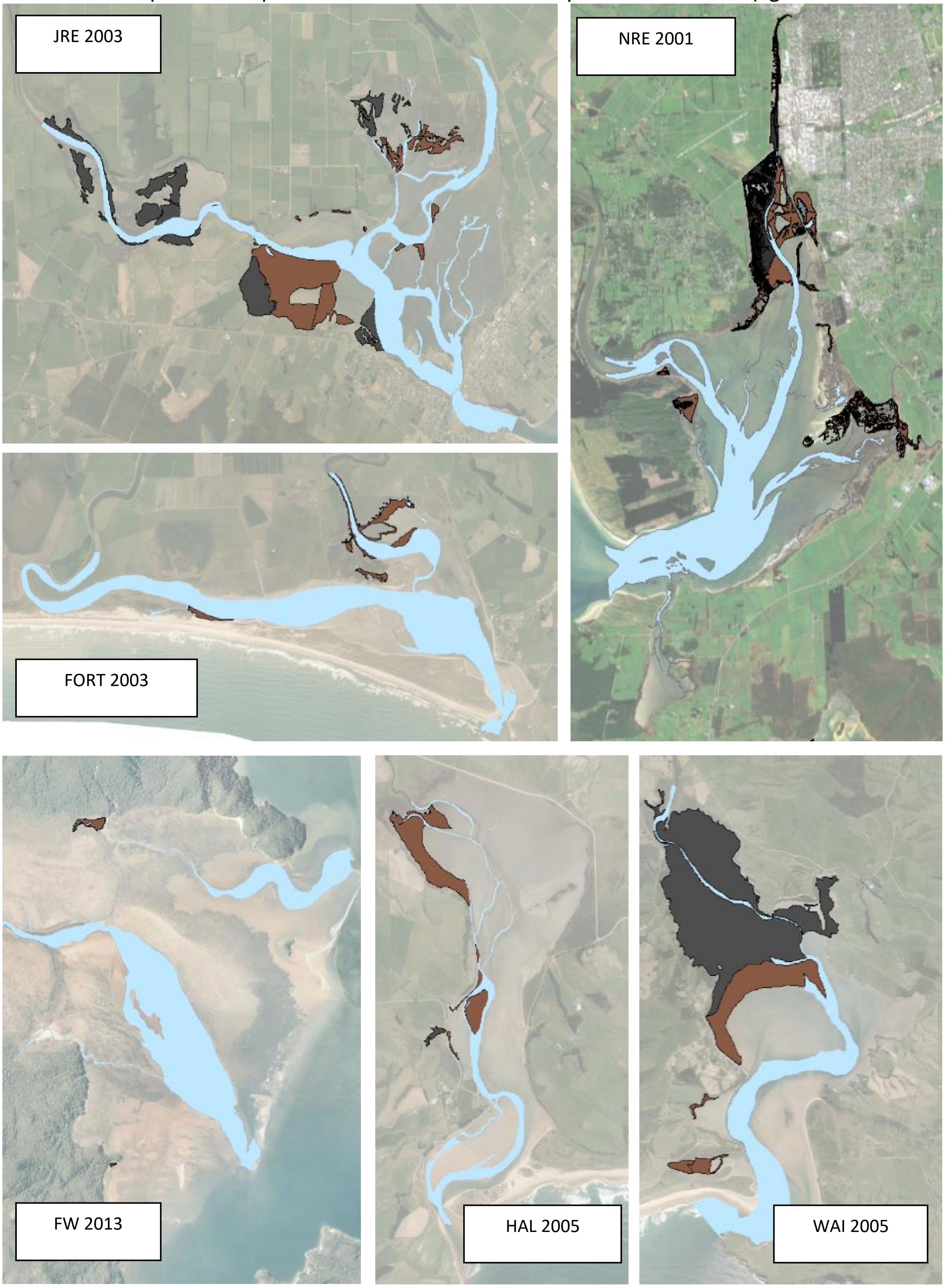
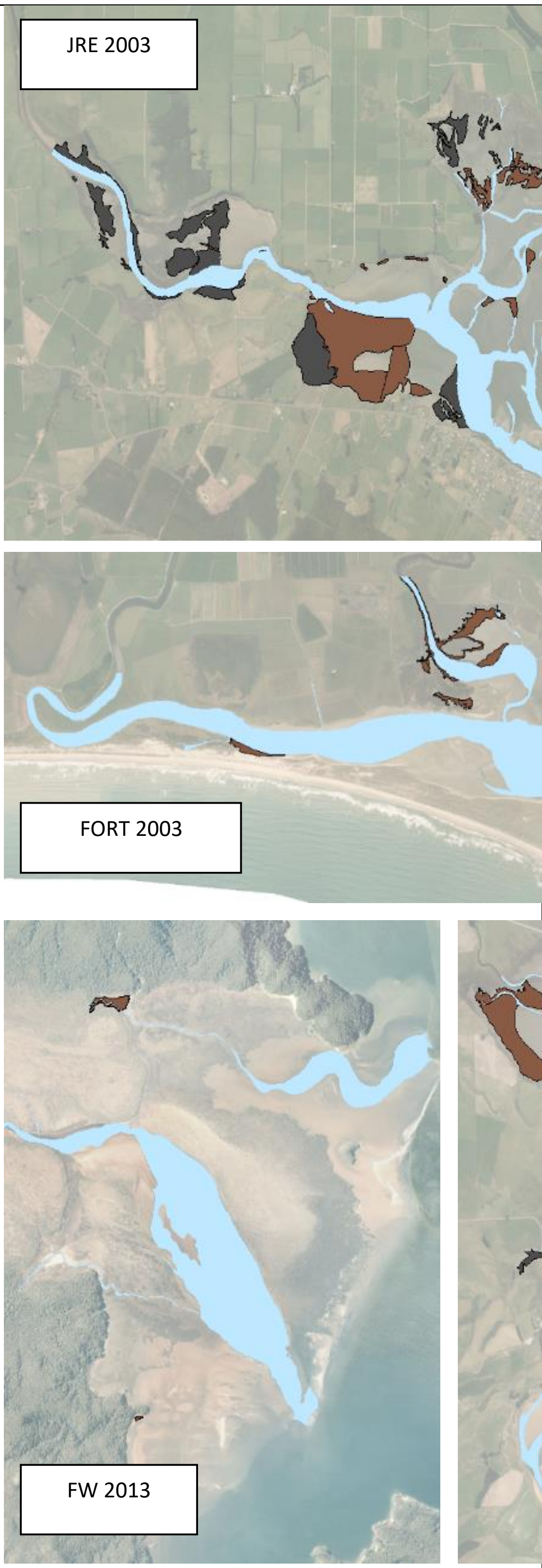


Figure **19**) and therefore applying the mud extent attribute to reference conditions would result in a "decrease" compared to the agreed baseline (early 2000's) and a grade of "Pass".

Whilst this brief analysis provides a grading for mud extent under reference conditions, further work should prioritise understanding mud extent on an estuary scale under reference conditions rather than at an estuary type scale. Depositional areas are specific to each estuary due to a number of physical factors (e.g. hydrology, geomorphology etc), and to determine estuary specific mud extent under reference conditions further research is required. This could include modelling sediment deposition zones, sediment coring to identify deposition zones, reviewing historical imagery and expert opinion. The level of detail needed to make site specific estimates of mud extent was out of scope in the current report.

Table 50: Summary of mud extent (>25% mud content in m^2 of intertidal area) proposed reference state using bands from Table 49.

Estuary types	Reason	Reference state
SIDE and SSRTRE	The mud extent attribute is to detect change from baseline (earliest monitored data;	Pass

	 Figure **19**). Mud extent under reference conditions (pre-human) were likely less than the areas monitored in the early 2000's as shown in the study by Thoms (1981) therefore reference state would be the equivalent of a "Pass" or a "decrease or no change" from baseline.	

11 *Escherichia coli* (*E. coli*) and enterococci

11.1 *E. coli* and enterococci attributes and establishing reference condition

E. coli is a faecal indicator bacteria that is commonly found in warm blooded mammals and birds. The detection of *E. coli* in water suggests it contains faecal matter that could contain a range of disease causing micro-organisms and present a risk to human health. *E. coli* can survive 4-6 weeks outside the human body in freshwater and although survivability is limited in saline waters the presence of *E. coli* can indicate recent flooding or point source discharges to an estuary or the open coast that present a risk to human health. The attribute table is reproduced from the National Policy Statement for Freshwater Management (2017).

Similarly, enterococci are a faecal indicator used in marine environments and naturally occurs in the gut of mammals (including humans), birds, fish and reptiles. It provides an indication of faecal contaminants in coastal waters that would present a risk to human health. The attribute table is reproduced from the Ministry for the Environment Guidelines: Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas (2003).

Table 51: *Escherichia coli* (*E. coli*) attribute state option table proposed for Southland estuaries and open coast waters.

Statistic	A Very good	B Good	C Fair	D Poor	E Very poor
% exceedances over 540 cfu/100 mL	<5	>5 to ≤10	>10 to ≤20	>20 to ≤30	>30
% exceedances over 260 cfu/100 mL	<20	>20 to ≤30	>20 to ≤34	>34	>50
Median concentration (cfu/100 mL)	≤130	≤130	≤130	>130	>260
95th percentile of *E. coli*/100 mL	≤540	≤1,000	≤1,200	>1,200	>1,200

Table 52: Enterococci (Enterococci/100 mL) attribute state option table proposed for Southland estuaries and open coast waters.

Statistic	A Very good	B Good	C Fair	D Poor
95th percentile (MPN/100 mL)	≤40	>40 and ≤200	>200 and ≤500	>500
% exceedances over 280 MPN/100 mL	≤5	>5 and ≤10	>10 and ≤20	>20

11.2 New Zealand data for E. coli and enterococci

E. coli may enter waterways from a range of sources and pathways, including wastewater and stormwater discharges or overflows, runoff from urban and agricultural land, seepage from failing septic tanks, and direct deposition by livestock and wild animals. In the absence of anthropogenic sources under reference conditions, only natural sources (e.g. birds) would have been present and therefore it is likely that high concentration events, that would impact human health, were rare. Birds can be a source of *E. coli* and enterococci to waterbodies, some water bird species (e.g. wildfowl such as Canada geese, Mallard duck) have been introduced to New Zealand since early human settlement and would not have been present under reference conditions with native birds being more prominent in coastal areas. In reference to current wildfowl populations Moriarty et al., (2011) stated "the relative contributions to the microbial pollution of a water body will obviously depend on the sizes of the bird populations in a particular region, and their proximities to waters." New Zealand was considered to be the "land of the birds" under pre-human conditions however it is uncertain what population of water birds would have been present during this period and their contribution to *E. coli* in estuaries.

Land cover under reference conditions consisted of native vegetation cover within catchments, wetlands and extensive marginal habitat surrounding open water bodies such as estuaries and lakes. There are no measured *E. coli* concentrations for estuaries in forested catchments within the Southland region because the risk to human health is considered low in these areas. However, contemporary data for *E. coli* in Southland lakes within native forested catchments ("natural state" lake type) can be used to assert expected *E. coli* concentration under reference conditions in open waters. The measured concentrations in the "natural state" lake type for Southland lakes were consistently low and within the A-band (Norton et al., 2020).

McDowell et al., (2013) defined reference conditions to be expected in stream and rivers with minimal to no anthropogenic influence. In that study, McDowell et al., (2013) assessed monitoring data for a number of streams and rivers across New Zealand and found faecal contamination increased with percent of heavy pasture. For *E. coli* the degree of enrichment comparing current condition versus reference conditions was 118% over reference condition. The estimated reference median concentration of *E. coli was* 58 MPN 100mL^{-1} and comparing the current median to the reference median anthropogenic sources made up to ~87% of the current concentration. This is supported by the analysis of the national rivers dataset, river *E. coli* in native forested catchments had a median concentration <50 cfu/100mL (Figure 21). The spatial modelling output for the Southland region is shown in Figure 22 and confirms low concentrations are observed in native forested catchments, particularly in the Fiordland and Islands FMU.

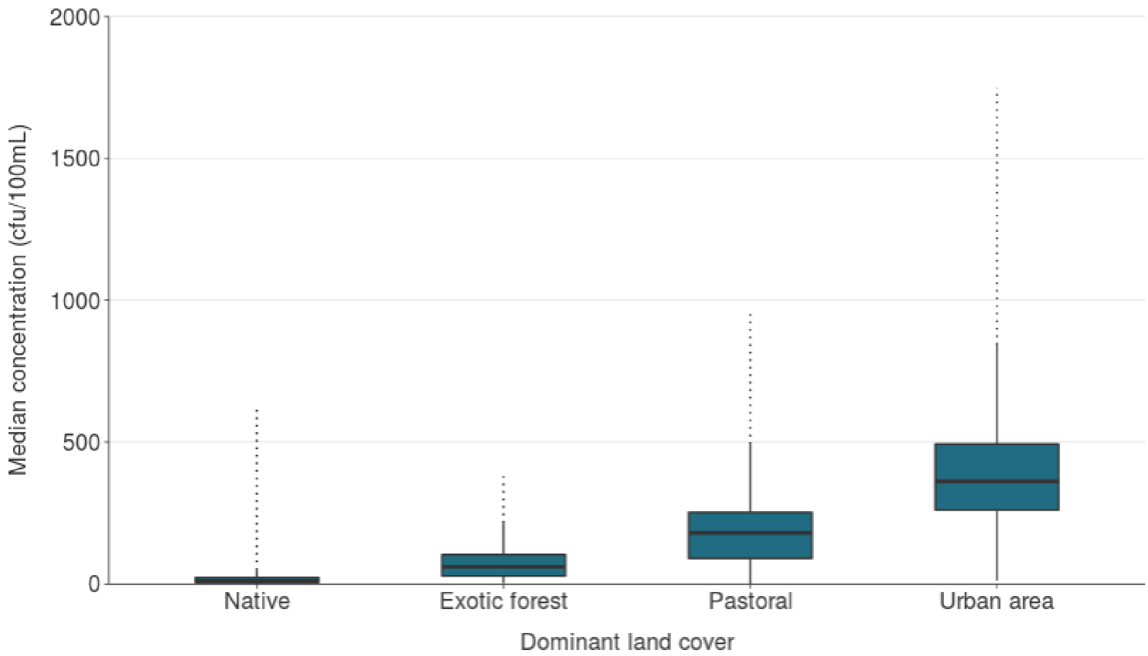


Figure 21: River *E. coli* modelled median concentrations by dominant land cover 2013-2017 [Source: https://www.stats.govt.nz/indicators/river-water-quality-escherichia-coli]

There is limited information on the historical concentrations of *E. coli* and enterococci in transitional and coastal waters. The MfE guidelines require monitoring in freshwater and coastal recreational bathing areas where there is a potential risk to human health. As such there is limited or no monitoring data for sites including estuaries under pristine or 'reference' conditions because there is an assumption that this risk will be low in these environments. It is hypothesised *E. coli* and enterococci would have been present at low concentrations under 'reference' conditions and exceedances or high concentration events would have been limited due to the nature of how these events occur in present day (e.g. point sources or diffuse sources associated with heavy pasture).

Furthermore, the characteristics of SIDE and SSRTRE type estuaries, for example, have short (<3 days) residence time and the conditions that would promote dilution of freshwater sources with marine waters. DSDE type estuaries characteristically have longer residence times and reduced flushing potential, however in Southland these estuary types are in forested catchments with minimal faecal source inputs (Figure 21 and Figure 22).

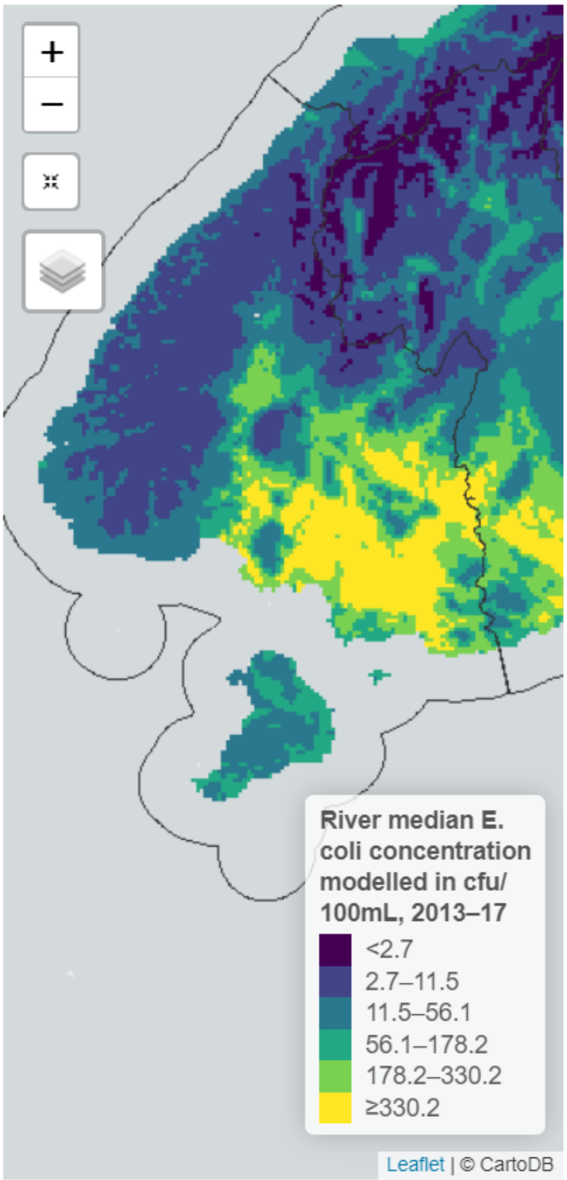


Figure 22: Modelled median concentrations of *E. coli* (cfu/100 mL) between 2013 and 2017. [Source: https://www.stats.govt.nz/indicators/river-water-quality-escherichia-coli]

11.3 Summary of reference conditions for *E. coli* and enterococci

There is limited information on the historical concentrations of *E. coli* and enterococci in transitional and coastal waters and further research is required to confirm the proposed reference state conditions. However, given most sources of *E. coli* and enterococci are a direct result of human settlement such as human wastewater, livestock (cows, sheep and deer), introduced wildfowl and land clearing that increases the risk of run off it is proposed that under reference conditions (pre-human conditions) there would have been fewer sources and a lower risk of high concentration events which is comparable to an A-band (Table 51). This is supported by contemporary data collected in catchments with native vegetation cover.

Table 53: Summary of *E. coli* and enterococci proposed reference state using bands from Table 51 and 52.

Attribute	Reason	Reference state
E. coli (cfu/100 mL)	Fewer exceedances. Median concentration ≤130 cfu/ 100mL	A
enterococci (enterococci/100 ml)	Fewer exceedances. 95th percentile ≤40 enterococci / 100mL	A

12 Summary of reference conditions in Southland estuaries

A summary of reference conditions for Southland estuaries applied to the proposed numeric attributes is in Table 54 and Table 55. The estimate of reference conditions in Southland estuaries was derived from multiple lines of evidence:

- pre-human condition data (paleolimnological, oral histories);
- modelling of historical and pre-human conditions; and,
- current state of natural or pristine reference estuaries with similar characteristics to the equivalent estuary type and location;
- historical state data;
- current state data;
- exert opinion in the absence of all data based on anecdotal observations, data from other locations and/or incomplete datasets.

The estimate of reference conditions summarised in Table 54 and Table 55 is based on best available information at the time of writing and covers what was within scope of the current report. Several knowledge gaps have been identified to prioritise for future work or it has been acknowledged that some attributes (e.g. mud content and aRPD) will require a more detailed analysis at an estuary or specific scale.

Table 54: Summary of reference condition for Southland estuaries using the proposed classes and numeric attribute state option tables from Norton and Wilson (2019).

	Natural State	Tidal Lagoon Estuaries (SIDE)	Tidal River Estuaries (SSRTRE)	Fiords and Bays (DSDE)
National Compulsory Attributes				
There are no nationally compulsory attributes for estuaries				
Southland Attributes				
Phytoplankton (Chl-*a*; mg/m^3)	No change[2]	A to C	A	A to B
Gross Eutrophic Zone (% intertidal area)		A	A	NA
Mud content (% mud at a site)		Not determined	Not determined	NA
Muddiness (>25% mud content in m^2 intertidal area)		Pass	Pass	NA
Sedimentation rate (5 year trend ≤ 2mm/year)		Pass	Pass	NA
Sediment oxygen level (aRPD in mm)		A to B[2] A[3]	A to B[2] A[3]	NA
Macroalgae (Ecological Quality Rating)		A to B	A to B	NA
E. coli (*E. coli*/ 100mL)		A	A	A
E. coli at popular bathing sites (*E. coli*/ 100mL)		A	A	A
Enterococci (Enterococci / 100mL)		A	A	A
Enterococci at popular bathing sites (Enterococci / 100mL)		A	A	A
Toxic metals in sediment (mg/kg dry weight)		See table below		

[1] The proposed reference conditions are based on the state ranges from New Zealand literature and modelling, unless contemporary data indicates that the state range is better than the proposed reference conditions from the literature (e.g. A+ current state vs proposed upper banding of an A in the literature) or there is no other information available. It is important to note that the assessment of state made in this memo does not fully meet the required statistical test for the attribute state options, and should therefore be used as an indication of reference state only. Further research will be required to confirm these estimates of reference conditions.

[2] Mud

[3] Sand

Table 55: Toxic metals in sediment reference condition for Southland estuaries using the proposed classes and numeric attribute state option tables from Norton and Wilson (2019).

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Tidal Lagoon Estuaries (SIDE)	A to B	A	A to B	A	A	A to B[1]	A	A
Tidal River Estuaries (SSRTRE)	A	A	A	A	A	A	A	A
Fiords and Bays (DSDE)[2]	A	A to B	C to D	C to D	A	C	B	B

[1] A-B band unless caused by natural perturbations (e.g. nickel (Ni) in Jacobs River Estuary and New River Estuary as discussed in text have elevated Ni levels in the soils of the catchment).

[2] Metal concentrations in the sediments of New Zealand fiords are heavily dependent on lithology. It may not be possible to achieve the top of the band range because the concentration of trace metals in Fiordland is strongly linked to provenance. Very few studies exist on trace metals in New Zealand fiords further research is required to confirm these proposed "reference" state ranges and any inferences for comparison against reference state for DSDE type estuaries should be treated with caution.

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Appendix 1

Question: What are the differences between the regional and national model estimate for phytoplankton, there is a noticeable difference in state for Haldane and Waikawa estuaries.

Response: David Plew (NIWA) 15/07/2020

There are three changes to the phytoplankton model between the 2018 MfE report and our 2020 paper:

1. Phosphorus has been added to the model
2. The half saturation coefficient for nitrogen was reduced from 45 mg/m^3 to 35 mg/m^3
3. We added the seasonal flow adjustment

Adding **phosphorus** to the model reduces predicted chl-a if phosphorus is limiting (which does not appear to be the case for Haldane or Waikawa).

Reducing the half saturation coefficient can increase the growth rate slightly, resulting in higher Chl-a concentrations.

Half saturation concentration	**45 mg/m^3**	**35 mg/m^3**
Haldane	8.6 ug/l	10.2 ug/l
Waikawa	11.5 ug/l	12.5 ug/l

The seasonal flow adjustment factor does two things. It reduces the inflow, which results in lower potential nutrient concentrations in the estuary, which would, in estuaries with long flushing times, reduce the amount of phytoplankton. But it also increases the estuary flushing time, allowing more time for phytoplankton to grow. There is a minimum flushing time below which phytoplankton is flushed out of an estuary faster than it grows. That minimum flushing time is determined by the specific growth rate (0.3 day^{-1}), the potential N and P concentrations, and the half saturation coefficients for N and P. Low potential N and P concentrations increase the minimum flushing time (to be more precise, it is the ratio of N and P to their half saturation coefficients that is important). If N and P concentrations are very high, then the minimum flushing time would be 1/0.3 = 3.33 days.

This table shows the effect of the seasonal flow adjustment, which is responsible for most of the differences you have noted. In Haldane Estuary, at mean flow, the flushing time is slightly too short for phytoplankton growth to occur, according to the model. Applying the seasonal flow reduction increases the flushing time enough that the model predicts phytoplankton growth can occur, and reach moderately high concentrations.

In Waikawa, the seasonal flow reduction increases the flushing time from slightly above the minimum required (under which circumstances phytoplankton accumulates slowly), to about 65% above minimum, which allows higher chl-a concentrations to be reached

Half saturation concentration	**No seasonal adjustment**				**With seasonal adjustment**			
	Flow (m^3/s)	Flushing time (days)	Minimum flushing time (days)	Chl-a (ug/l)	Flow (m^3/s)	Flushing time (days)	Minimum flushing time (days)	Chl-a (ug/l)
Haldane	1.7	4.07	4.09	0	0.979	5.73	4.12	10.2
Waikawa	5.8	4.90	4.06	9.9	3.24	6.95	4.15	12.5

As you can see, the phytoplankton model is quite sensitive to inputs and the model parameters. And these could have significant impacts on susceptibility bands particularly for estuaries with flushing times around the minimum time required for phytoplankton growth (3-5 days). As a reminder, the model is predicting the maximum likely chl-a concentration (equivalent to the 90th percentile of observations) so is an estimate of the upper bounds.

This is also why we try to be careful about calling these susceptibility bands rather than states.

This figure from our 2020 paper shows a comparison between 90th percentile observations and predicted chl-a. As you can see there is a lot of scatter. There is a statistically significant relationship ($p = 0.018$), but the correlation is not particularly strong ($R^2 = 0.22$). In most cases, the model overestimates chl-a, which for a risk assessment approach is better than underestimating. We also need to consider the accuracy of the observations – the model estimates estuarine phytoplankton, whereas observations can be strongly affected by riverine phytoplankton, and sampling locations are not always representative of whole estuaries.

The model is simplistic and omits mechanisms and processes that may be important in some estuaries. It was designed as a screening tool or rapid assessment that could be used to test the relative impact of nutrient load changes, or prioritise more in-depth investigations.

The short answer is, yes the seasonal flow adjustment (using mean February flows) in the phytoplankton model increases the predicted maximum chl-a concentrations in Haldane and Waikawa.