environment SOUTHLAND
REGIONAL COUNCIL
Te Taiao Tonga

Memorandum

For Your Information

To:	Karen Wilson, Ned Norton
From:	Dr Keryn Roberts Environmental Scientist – Estuaries and Lakes
Date:	Tuesday, 11 August 2020
Subject:	***Reference conditions in Southland lakes: Review of data and high-level literature review***

Message:

1. Purpose of this memo

This memorandum provides information pertaining to reference condition in Southland lakes for the Values and Objectives workstream in the People, Water and Land programme. This memo has been prepared as requested supplementary material for the following report:

> Bartlett M., Kitson, J., Norton, N., and Wilson, K. (2020). Draft *Murihiku Southland Freshwater Objectives: Providing for hauora, the health and well-being of waterbodies in Murihiku Southland.* Environment Southland and Te Ao Marama Inc. publication number 2020-06: Invercargill. ISBN 978-0-909043-67-4.

The bands (e.g. A, B, C, D) used in this report are described more fully in Ward and Roberts (2020) and Norton and Wilson (2019).

2. Summary of reference conditions in Southland lakes

Table ***1*** provides a summary of the reference condition attribute state bands for proposed Southland lake attributes and classes, as described in Norton and Wilson (2019) and updated in Norton et al., (2019). The following sections (i.e. sections 3 to 7) show how the information in Table 1 was derived.

Table 1: Summary of draft reference state conditions for Southland lakes by proposed lake classes.

	Natural state lakes	Lowland shallow lakes	Upland shallow lakes	Deep lakes	Brackish lakes and lagoons
National Compulsory Attributes					
Phytoplankton (Chl-*a*; mg/m^3)	no change	A+ to B	A+ to B	A+ to A	A+ to B
Total Phosphorus (mg/m^3)		A to B	A+ to B	A+ to A	A+ to B
Total Nitrogen (mg/m^3)		A+ to B	A+ to A	A+ to A	A to C
Ammonia Toxicity (mg/L)		A	A	A	A to B
Cyanobacteria (biovolume mm^3/L)		A	A	A	A
E. Coli (*E. coli*/ 100mL)[2]		A (estimate)	A (estimate)	A	A (estimate)
Southland Attributes					
E. Coli (at "Popular Bathing Sites")[2]		A (estimate)	A (estimate)	A	A (estimate)
Trophic Level Index (TLI)	no change	A to B	A+ to B	A+ to A	A to B
Macrophytes (percent cover)		A to C[3]	Not determined	NA	A to C
LakeSPI (overall score)[4]		A+ to A	A+ to A	A+ to A	NA
LakeSPI (nativeness)[4]		A	A	A	NA
LakeSPI (invasiveness)[4]		A	A	A	NA
Nitrate Toxicity (mg/L)		A	A	A	A[5]

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). It is important to note that the assessment of state made in this memo does not fully meet the required statistic 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 the proposed reference state conditions.

2: There is not enough information available to make this assessment. However, as stated in Roberts and Ward (2020) 'Reference conditions for Southland estuaries': "*given most sources of E. coli […] 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*." In the case of deep lakes current state is A.

3: Based on current state data, there are no other sources of information to support a higher state range of C band. More information is required for this attribute to be assessed properly under reference conditions for lowland shallow lakes.

4: Lake SPI is a metric that assesses nativeness and invasiveness of the macrophyte community it is assumed that under reference conditions there would have been no invasive macrophytes present.

5: Nitrate toxicity is based on the concentrations below which acute toxicity will be observed in sensitive species. Nitrate is one form of nitrogen that makes up Total Nitrogen (i.e. nitrate cannot exceed TN because TN = Nitrate + Nitrite + Ammonium + Organic-N). Given the median concentration of Total Nitrogen under reference conditions is between 128 – 380 mg m^{-3} (Table 9) it is unlikely the median concentration of nitrate will exceed an A band (<1000mg m^{-3}) under reference conditions acknowledging that this assumption does not take into account the 95th percentile statistical requirement of the proposed nitrate toxicity attribute state option table.

3. Reference conditions in New Zealand lakes

3.1 Background

Freshwater objectives[1] for lakes will be set as part of the limit setting process in Southland under the obligations set out in the National Policy Statement for Freshwater Management (NPSFM)[2]. To ensure the freshwater objectives are achievable and fit within a realistic state range for a lake there needs to be an understanding of the natural or reference state range for each attribute. An understanding of 'natural state' or 'reference' conditions also can provide a benchmark against which contemporary monitoring data can be compared.

However, for New Zealand lakes 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 lake due to the high degree of human disturbance that has occurred over time (e.g. change hydrology, land reclamation etc). As such reference conditions requires various approaches to establish a reasonable baseline or 'reference state range.' This approach has been applied 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 included, in order of relevance:

- Pre-human condition data (paleolimnological, oral histories)
- Modelling of historical and pre-human conditions
- 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 the data is not available (e.g. models, literature, expert opinion).

3.2 Defining 'reference conditions' in lakes

There are several different definitions to describe reference conditions in New Zealand lakes and as such there should be a degree of caution applied when making comparisons between approaches to define 'reference conditions'. A summary of literature definitions of reference conditions is below:

1. **Waituna Lagoon Technical Group** "Clear waters with minimal algal blooms, strong seagrass growth and good fish assemblages".
2. **Schallenberg (2019)** "an ecosystem that has not been affected by human activities" with the more detailed definition, "reference condition is the ecological integrity of an ecosystem immediately prior to the first anthropogenic impacts".

[1] As defined in the National Policy Statement for Freshwater Management 2014 (amended 2017).

[2] Unless otherwise stated, the NPSFM 2014 (amended 2017) is the version referred to in this memo. It is noted that the NPSFM was subsequently updated in 2020, however, this occurred after the material in this memo was originally produced and is therefore not considered.

   a. Data approach: Used lakes that most closely reflected reference conditions e.g. with high ecological integrity and high % catchment in nature vegetation (generally >90%).
   b. Paleolimnological approach: qualitatively assess the condition of the lake prior to human occupation to determine historical water quality (assessment made from sediment cores).
3. **Plew et al (2018)** modelled reference conditions under two scenarios. From the two scenarios tested "pristine" conditions are more reflective of the definition proposed above, however this is within the current hydrological landscape[3] and does not account for pre-human vegetation cover. It should also be noted that these scenarios do not account for wetlands in the pre-human or pristine estimates, this likely has led to an overestimation of nutrient loads because wetlands typically remove up to 30-45% nitrogen (Plew 2020, pers comm).
   a. Pre-human Land Cover: incorporates pre-human land cover and current nitrogen deposition rates (assess the effects of land cover change only)
   b. Pristine: incorporates pre-human land cover and estimated pre-industrial atmospheric nitrogen deposition rates (it assesses combine effects of land cover and atmospheric nitrogen changes).
4. **Abell et al (2018)** described reference conditions as those that "correspond to baseline conditions in the absence of human disturbance" using the reference conditions of riverine inputs to calculate reference in-lake concentrations based on the same principles as Plew et al (2018)[1].
5. **Schallenberg and Kelly (2013)** reference condition refers to the "likely natural, pre-impacted condition of lakes." The approach was to examine lakes with high ecological integrity and high catchment native vegetation the state of which are considered 'modern reference lakes' which reflect similar conditions prior to anthropogenic impacts on lakes in the context of current climatic conditions and nitrogen atmospheric deposition rates.
6. **Cosgrove (2012)** reference condition refers to the "lagoon before anthropogenic disturbance"

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**. For the purposes of understanding reference conditions in Southland lakes this is the definition that will be used going forward. The term 'reference' state or 'reference condition' will be used in preference to natural state to avoid confusion with the 'Natural State' classification of water bodies.

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'[4] estuary class.

Several literatures sources pertaining to the determination of 'reference conditions' in lakes are listed in Table 2.

[3] 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 state cover (e.g. forest/tussock).

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

Table 2: Key literature sources for defining reference conditions in New Zealand lakes.

Lake Type	Literature source
Shallow Lakes	Schallenberg and Kelly (2013) Schallenberg et al (2019) Abell et al (2018) Lakes 380 data State of the environment data
Brackish Lakes	Schallenberg et al (2019) Plew et al (2018) Ecological guidelines for Waituna Lagoon (2013) Cosgrove (2012) Schallenberg et al (2017) State of the environment data
Deep Lakes	Schallenberg et al (2019) Abell et al (2018) Lakes 380 data State of the environment data

4. Lowland shallow lakes

4.1 Relevant literature

Reference conditions in shallow lakes are described as lower chlorophyll-*a* and nutrient levels compared to current condition (Schallenberg 2019). All flora and fauna was native, extensive macrophyte beds and there were low levels of cyanobacteria. Low sediment and nutrient inputs from the catchment.

Figure **1: Descriptive characteristics of reference conditions for shallow lowland lakes from paleolimnological studies considering both pre-Polynesian and pre-European condition (Schallenberg 2019).**

Table *3* summarises three studies on shallow lakes:

- Schallenberg (2019) using lake data collected in field surveys to assess 'reference condition' for lakes across New Zealand. Note the depth of a shallow lake described in Schallenberg (2019) is typically < 10m. The classification of Southland shallow lakes is < 15m based on Verburg (2012);
- Schallenberg and Kelly (2013) using lake data collected in field surveys to assess 'reference condition' in lakes across the Southland region. Lakes included Ship Creek Lagoon, Maori Lake, Lake Otuhie, Lake Sheila, Lake Calder; and,
- Abell et al (2018) modelled reference condition in lakes across New Zealand. This study did not specifically distinguish between the three lake classes proposed in the People, Water and Land process (shallow, brackish and deep). However, this study provides a point of comparison against field assessments. The combined reference concentrations based on all lakes has been removed in
- Figure **1: Descriptive characteristics of reference conditions for shallow lowland lakes from paleolimnological studies considering both pre-Polynesian and pre-European condition (Schallenberg 2019).**

- **Table *3*** because it combines deep and shallow lakes, two lake types that behave very differently. However, the supplementary material supporting this report presents the TLI of each lake and therefore TLI for each lake type in Southland can be determined. These have been tabulated, for Lowland Shallow lakes in Southland the range TLI 3.06 – 3.92 and average TLI 3.56 ± 0.25 which corresponds to a mesotrophic state the limits of which are presented in
- Figure **1: Descriptive characteristics of reference conditions for shallow lowland lakes from paleolimnological studies considering both pre-Polynesian and pre-European condition (Schallenberg 2019).**

- **Table *3*** and sourced from Burns and Bryers (2000).

PRE-POLYNESIAN CONDITION	PRE-EUROPEAN CONDITION	LAKES/LAGOONS INTERPRETED
Shallow freshwater lakes		
• Very low rates of sediment and nutrient inputs from the catchment • Very low productivity and turbidity • Extensive native macrophyte beds dominated by *Nitella* sp. (Lake Emma)	• Low rates of sediment and nutrient inputs from the catchment • Low productivity and turbidity • Shift in macrophyte community to mixed charophytes (Lake Emma)	• Lake Waihola • Lake Taumatawhana • Lake Emma

Figure 1: Descriptive characteristics of reference conditions for shallow lowland lakes from paleolimnological studies considering both pre-Polynesian and pre-European condition (Schallenberg 2019).

Table 3: Reference conditions for lowland shallow lakes in New Zealand and Southland literature. Note that the reference conditions proposed by Schallenberg (2019) and Schallenberg and Kelly (2013) were the same with the exception of the cyanobacteria cell count in which case the Southland lakes limit is provided below.

Attribute	Units	Schallenberg (2019) and (2013)	Modelled TLI for shallow lakes[3]	Modelled reference condition based on all lakes[2]	Applicable attribute banding from literature	
Nativeness						
% native fish species	%	100	-	-	Attribute not developed	
% native macrophytes	%	100	-	-	Not equivalent to LakeSPI however would indicate a high score (likely A band).	
Pristineness						
Chlorophyll-a	µg/L	≤3.2	2 – 5	~~1.5~~	A (≤2) to	B (≤5)
Total Phosphorus	µg/L	≤11.7	9 – 20	~~6.6~~	A (≤10) to	B (≤20)
Total Nitrogen	µg/L	≤277	157 - 337	~~164~~	A (≤300) to	B (≤500)
Ammonia Toxicity	mg/L	-	-	-	-	
Nitrate Toxicity	mg/L	-	-	-	-	
Trophic Level Index	-	≤3.5	>3 – 4[5]	~~2.60~~	B (>3 and ≤4)	
Resilience						
Cyanobacteria	cells/mL	≤500			NA (not comparable units)	
E. coli	*E. coli*/ 100mL	-	-	-	-	

4.2 Review of available data

Lakes 380 data (unpubl.)

Lakes 380 is a national programme that is collecting water quality and sediment cores from 380 lakes across New Zealand with the purpose of creating historical records of lake condition dating back to pre-human condition. In 2019 several lake types in the "natural state" classification were sampled in Southland for water quality, no "unimpacted" lowland shallow lakes were sampled. Analysis of sediment cores is underway and will be available in 2023 which will improve our understanding of reference conditions in lakes nationally and within Southland. The state assessment undertaken as part of the Values and Objectives package (Norton et al., 2019) may be revised when this information becomes available.

[5] Modelled TLI for Lowland Shallow Lakes in Southland 3.56 ± 0.25 based on the data presented https://www.lernz.co.nz/uploads/tlimap2.html. This assessment aligns with Figure 31 in Abell and van Dam-Bates (2018) which shows many shallow lakes that would fit within geomorphic types (e.g. Aeolian, shoreline, riverine, peat) are between 3-4 TLI.

Table 4: Data available for Southland lakes from the Lakes 380 project and state of the environment monitoring. The data does not represent pre-human conditions.

Attribute	Units	Proposed reference state		
National compulsory attributes				
Chlorophyll-*a*	µg/L	A+	to	B
Total phosphorus	µg/L	A	to	B
Total nitrogen	µg/L	A+	to	B
Ammonia toxicity	mg/L	A		
Cyanobacteria	Biovolume mm^3/mL	A		
E. coli	*E. coli*/100mL	~A (unknown)[1]		
Southland attributes				
Trophic state (TLI)	Trophic Level Index	A	to	B
Macrophytes	% cover	A	to	C[2]
Trophic state (Lake SPI)	LakeSPI score	A+	to	A[3]
Submerged plants (natives)	LakeSPI native index	A		
Submerged plants (invasive species)	LakeSPI invasive index	A		
Nitrate toxicity	mg/L	A		

[1]There is not enough information available to make this assessment. However, as stated in the memo by Roberts and Ward (2020) ' Reference conditions for Southland estuaries': "*…given most sources of E. coli* […] *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*."

[2]Based on current state data, there are no other sources of information to support a higher state range of C band. More information is required for this attribute to be assessed properly under reference conditions.

[3]Lake SPI is a metric that assesses nativeness and invasiveness of the macrophyte community it is assumed that under reference conditions there would have been no invasive macrophytes present.

4.3 Summary of reference conditions for lowland shallow lakes

The proposed reference conditions are based on the state ranges from New Zealand literature and modelling, unless contemporary data indicates that the current state range is better than the proposed reference conditions from the literature (e.g. A+ current state vs proposed upper banding of an A based on the literature). It is important to note that for the assessment of reference state made in this memo the data does not meet the required attribute state option statistic and should therefore be used as an indication of reference state only. Further research will be required to confirm the proposed reference state conditions.

Table 5: Summary of reference conditions in Southland assessing available information in Tables 3 and 4.

Attribute	Units	Lakes 380 data (not reference state)	Southland state range between 2010 to 2019
Nativeness			
Macrophytes	% cover	NA	A to C
Trophic state (LakeSPI)	LakeSPI score	NA	A+ to B
Submerged plants (natives)	LakeSPI native index	NA	A to B
Submerged plants (invasive species)	LakeSPI invasive index	NA	A to C
Pristineness			
Chlorophyll-*a*	µg/L	A+ to D	A to D
Total phosphorus	µg/L	A to D	A to C
Total nitrogen	µg/L	A+ to D	A to D
Ammonia toxicity	mg/L	A	A
Nitrate toxicity	mg/L	A	A
Trophic state (TLI)	Trophic Level Index	A to D	A to C
Resilience			
Cyanobacteria	Biovolume mm^3/mL	NA	
E. coli	*E. coli*/100mL	NA	A to D

5. Upland shallow lakes

5.1 Relevant literature

The literature used in the assessment is described in section 4. The literature on reference state condition in shallow lakes are not separated into lowland and upland lakes (Schallenberg 2019 and Schallenberg and Kelly 2013). Therefore, the only difference in Table 6 in comparison to the Lowland Shallow lakes class in

Figure **1: Descriptive characteristics of reference conditions for shallow lowland lakes from paleolimnological studies considering both pre-Polynesian and pre-European condition (Schallenberg 2019).**

Table *3* is the modelled TLI for upland shallow lakes (2 to 3 in oligotrophic state). However, this should be treated with some caution because only two upland shallow lakes were modelled for Southland. Descriptive characteristics from paleolimnological studies are shown in

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Table 6: Reference conditions for upland shallow lakes in New Zealand and Southland literature. Note the depth of a shallow lake descriped in Schallenberg (2019) is typically less than 10 metres. The classification of Southland shallow lakes is less than 15 metres based on Verburg (2012).

Attribute	Units	Schallenberg (2019) and (2013)	Modelled TIL for shallow lakes[1]	Modelled reference based on all lakes[2]	Applicable attribute band based on literature		
Nativeness							
Native fish species	%	100	-	-	-[4]		
Native macrophytes	%	100	-	-	-[5]		
Pristineness							
Chlorophyll-*a*	µg/L	≤3.2	0.20 - 2	~~1.5~~	A (≤2)	to	B (≤5)
Total phosphorus	µg/L	≤11.7	4.1 - 9	~~6.6~~	A (≤10)	to	B (≤20)
Total nitrogen	µg/L	≤277	73 - 157	~~164~~	A+ (<160)	to	A (≤200)
Ammonia toxicity	mg/L	-	-	-	-		
Nitrate toxicity	mg/L	-	-	-	-		
Trophic state (TLI)	Index	≤3.5	2-3[3]	~~2.60~~	A (≤3)	to	B (>3 to ≤4)
Resilience							
Cyanobacteria	Biovolume mm^3/mL	≤500	-	-	NA[6]		
E. coli	*E. coli*/100mL	-	-	-	-		

[1] Abell et al (2018) see appended spreadsheet for Southland lake modelled TLI values.
[2] Abell et al (2018) includes all lakes (deep and shallow) in the final output and therefore does not appropriately represent shallow lakes only.
[3] Modelled TLI for Upland Shallow lakes in Southland 2.58 ± 0.07 based on the data presented https://www.lernz.co.nz/uploads/tlimap2.html.
[4] Attribute not proposed
[5] Not equivalent to LakeSPI however would indicate a high score. Likely an A band.
[6] Not comparable units

5.2 Review of available data

The Lakes 380 programme is described under Lowland Shallow lakes. In 2019 several lakes in the Natural State lake class were sampled for water quality, and these included six upland shallow lakes presented in **Error! Reference source not found.**. Environment Southland does not currently monitor any upland shallow lakes in its state of the environment (long term) monitoring programme.

Table 7: Data available for Southland lakes from the Lakes 380 project and state of the environment monitoring. The data for Lakes 380 represents upland shallow lakes in the natural state class, however this data is current and may not reflect reference conditions as defined in this memo.

Attribute	Units	Lakes 380 data (upland shallow lake in 'natural state')	Southland state range between 2010 to 2019
Nativeness			
Macrophytes	% cover	NA	No data
Trophic state (LakeSPI)	LakeSPI score	NA	
Submerged plants (natives)	LakeSPI native index	NA	
Submerged plants (invasive species)	LakeSPI invasive index	NA	
Pristineness			
Chlorophyll-*a*	µg/L	A+	No data – ES does not monitor any upland shallow lakes
Total phosphorus	µg/L	A+ to C	
Total nitrogen	µg/L	A+ to A	
Ammonia toxicity	mg/L	A	
Nitrate toxicity	mg/L		
Trophic state (TLI)	Trophic Level Index	A+ to A	
Resilience			
Cyanobacteria	Biovolume mm^3/mL	NA	No data
E. coli	*E. coli*/100mL	NA	

5.3 Summary of reference conditions for upland shallow lakes

The proposed reference conditions are based on the state ranges from New Zealand literature and modelling, unless contemporary data indicates that the current state range is better than the proposed reference conditions from the literature (e.g. A+ current state vs proposed upper banding of an A based on the literature). It is important to note that for the assessment of reference state made in this memo the data does not meet the required attribute state option statistic and should therefore be used as an indication of reference state only. Because only a small number of lakes were monitored in the one-off Lakes 380 sampling, a precautionary approach has been taken where the bottom of the reference state range has been retained from the literature estimates even if the state range from the Lakes 380 work indicates a better state. For TLI and chlorophyll-*a*, for example, the current state is at the higher end of the proposed reference state conditions in the literature. Further research will be required to confirm the proposed reference state conditions.

Table 8: Summary of reference conditions in Southland assessing available information in Tables 5 and 6.

Attribute	Units	Proposed reference state		
National compulsory attributes				
Chlorophyll-*a*	µg/L	A+	to	B
Total phosphorus	µg/L	A+	to	B
Total nitrogen	µg/L	A+	to	A
Ammonia toxicity	mg/L	A		
Cyanobacteria	Biovolume mm^3/mL	~A[1]		
E. coli	*E. coli*/100mL	A	to	D
Southland attributes				
Trophic state (TLI)	Trophic Level Index	A+	to	B
Macrophytes	% cover	No information available		
Trophic state (LakeSPI)	LakeSPI score	A+	to	A[2]
Submerged plants (natives)	LakeSPI native index	A		
Submerged plants (invasive species)	LakeSPI invasive index	A		
Nitrate toxicity	mg/L	A		

[1] [1]There is not enough information available to make this assessment. However, as stated in the memo by Roberts and Ward (2020) ' Reference conditions for Southland estuaries': "…*given most sources of E. coli* […] *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*."

[2] Lake SPI is a metric that assesses nativeness and invasiveness of the macrophyte community it is assumed that under reference conditions there would have been no invasive macrophytes present.

6. Brackish lakes and lagoons

6.1 Relevant literature

Reference conditions in brackish lakes are described as lower chlorophyll-*a* and nutrient levels compared to current condition (Schallenberg 2019). All flora and fauna was native, extensive macrophyte beds and there were low levels of cyanobacteria. Fewer openings to the sea and either more pronounced or persistent alternating marine and freshwater phases or no marine influence. Table 9 summarises four studies on brackish lakes and lagoons:

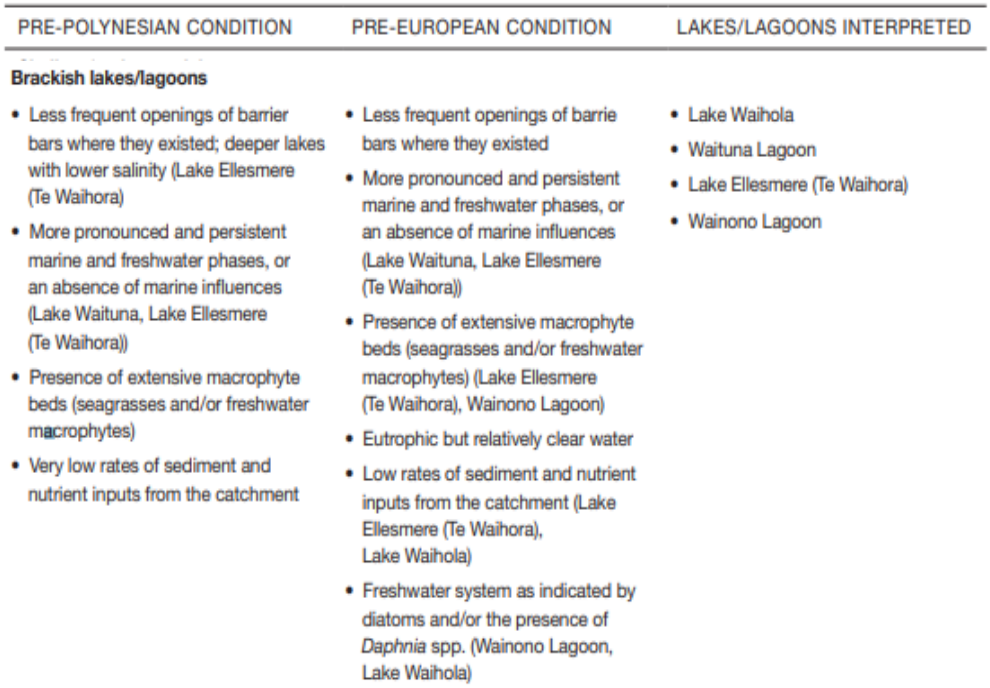
- Schallenberg (2019) proposes reference conditions for brackish lakes however these limits presented should be treated with great caution because there was not a large enough sample size to assess multiple reference lakes these are considered preliminary ratings.
- The "Ecological Guidelines for Waituna Lagoon" (2013) are presented in Table 9, however, the term 'reference conditions' does not implicitly state that these were the expected conditions pre-human. Therefore, this does not directly align with the proposed definition of 'reference condition' that refers to the state of the ecosystem prior to anthropogenic (human) impacts.
- Abell and Van Dam-Bates (2018) modelled TLI in lakes across New Zealand. The output is presented in a report and https://www.lernz.co.nz/uploads/tlimap2.html. The interactive map allowed for brackish lakes to be identified and the TLI determined for each individual lakes. Because there are very few brackish lakes in Southland the numbers presented in Table 9 are from known brackish lakes and ICOLLS across New Zealand. The average modelled TLI rating for brackish lakes was 3.69 ± 0.36. This value is only indicative there are limitations to modelling and national scale models are not intended to give lake specific information, they are intended to represent general trends.
- Plew et al (2018) modelled eutrophication susceptibility under several different scenarios as described at the beginning of this document. The ranges presented here for TN represent pristine conditions because they are the most representative of 'pre-human' impact on lakes. Note only known brackish lakes and ICOLLS were included in the assessment. There were several more 'Coastal Lakes' presented in Plew et al (2018) but on closer inspection they appear to be more estuarine and therefore were not included in this analysis. This data is represented in supplementary spreadsheet "Reference Conditions in Lakes".

Table 9: Reference conditions for brackish lakes and lagoons in New Zealand and Southland literature.

Attribute	Units	Schallenberg (2019)[1]	Waituna guidelines (2013)	Abell and van Dam-Bates (2018)	Plew (2018)	Applicable attribute bands		
Pristineness								
Chlorophyll-*a*	µg/L	≤128	<337	157 to 337	125 to 380	A	to	C
Total Phosphorus	µg/L	≤2.4	<20	9 to 20	-	A	to	B
Total Nitrogen	µg/L	≤0.3	<5	2 to 5	-	A+	to	B
Trophic Level Index	-	≤2.5	Inferred 3-4	3 to 4[2]	-	A	to	B
Macrophytes	% cover	-	>30 to 60	-	-	B	to	C
Resilience								
Cyanobacteria	cells/mL	≤500	≤500	-	-	A (≤0.5 mm^3/L)		

[1] Paleolimnological survey indicated that the pre-European data from 4 brackish lakes suggests these systems have been in a eutrophic state (TLI 4-5). This has not been presented because this is pre-European data. The TLI presented in the other studies it indicates a mesotrophic state is more appropriate.

[32] Modelled TLI for brackish lakes and lagoons in Southland 3.69 ± 0.36 based on the data presented https://www.lernz.co.nz/uploads/tlimap2.html. This assessment aligns with Figure 31 in Abell and van Dam-Bates (2018) which shows many shallow lakes that would fit within the geomorphic type shoreline (TLI 3-4).



PRE-POLYNESIAN CONDITION	PRE-EUROPEAN CONDITION	LAKES/LAGOONS INTERPRETED
Brackish lakes/lagoons		
• Less frequent openings of barrier bars where they existed; deeper lakes with lower salinity (Lake Ellesmere (Te Waihora) • More pronounced and persistent marine and freshwater phases, or an absence of marine influences (Lake Waituna, Lake Ellesmere (Te Waihora)) • Presence of extensive macrophyte beds (seagrasses and/or freshwater macrophytes) • Very low rates of sediment and nutrient inputs from the catchment	• Less frequent openings of barrie bars where they existed • More pronounced and persistent marine and freshwater phases, or an absence of marine influences (Lake Waituna, Lake Ellesmere (Te Waihora)) • Presence of extensive macrophyte beds (seagrasses and/or freshwater macrophytes) (Lake Ellesmere (Te Waihora), Wainono Lagoon) • Eutrophic but relatively clear water • Low rates of sediment and nutrient inputs from the catchment (Lake Ellesmere (Te Waihora), Lake Waihola) • Freshwater system as indicated by diatoms and/or the presence of *Daphnia* spp. (Wainono Lagoon, Lake Waihola)	• Lake Waihola • Waituna Lagoon • Lake Ellesmere (Te Waihora) • Wainono Lagoon

Figure 2: Descriptive characteristics of reference conditions for brackish lakes and lagoons from paleolimnological studies (Schallenberg 2019).

3.2 Review of available data

The Lakes 380 programme did not monitor brackish lakes. State of the environment monitoring data is sourced from Norton et al., (2019): 'Current Environmental State and the "Gap" to Draft Freshwater Objectives for Southland' and summarised in Table 10.

Table 10: State of the environment monitoring results for brackish lakes and lagoons. No brackish lakes were sampled in the Reference conditions for brackish lakes and lagoons in New Zealand and Southland.

Attribute	Units	Lakes 380 data	Southland state range between 2010 to 2019		
Nativeness					
Macrophytes	% cover	No data collected	A	to	D
Trophic state (LakeSPI)	LakeSPI score		NA		
Submerged plants (natives)	LakeSPI native index		NA		
Submerged plants (invasive species)	LakeSPI invasive index		NA		
Pristineness					
Chlorophyll-*a*	µg/L	No data collected	A	to	D
Total phosphorus	µg/L		B	to	C
Total nitrogen	µg/L		B	to	D
Ammonia toxicity	mg/L		A	to	B
Nitrate toxicity	mg/L		A	to	C
Trophic state (TLI)	Trophic Level Index		B	to	C
Resilience					
Cyanobacteria	Biovolume mm^3/mL	No data collected	A	to	C
E. coli	*E. coli*/100mL		A	to	D

3.2 Summary of reference condition in brackish lakes and lagoons

The proposed reference conditions are based on the state ranges from New Zealand literature and modelling, unless contemporary data indicates that the current state range is better than the proposed reference conditions from the literature (e.g. A+ current state vs proposed upper banding of an A based on the literature). It is important to note that for the assessment of reference state made in this memo the data does not meet the required attribute state option statistic and should therefore be used as an indication of reference state only. Further research will be required to confirm the proposed reference state conditions.

Table 11: Summary of reference conditions in Southland brackish lakes and lagoons assessing information in Tables 9 and 10.

Attribute	Units	Proposed reference state		
National compulsory attributes				
Chlorophyll-*a*	µg/L	A+	to	B
Total phosphorus	µg/L	A	to	B
Total nitrogen	µg/L	A	to	C
Ammonia toxicity	mg/L	A	to	B
Cyanobacteria	Biovolume mm^3/mL	A		
E. coli	*E. coli*/100mL	A (estimate)[1]		
Southland attributes				
Trophic state (TLI)	Trophic Level Index	A	to	B
Macrophytes	% cover	A	to	C
Trophic state (LakeSPI)	LakeSPI score	NA		
Submerged plants (natives)	LakeSPI native index	NA		
Submerged plants (invasive species)	LakeSPI invasive index	NA		
Nitrate toxicity	mg/L	A[2]		

[1] [1]There is not enough information available to make this assessment. However, as stated in the memo by Roberts and Ward (2020) ' Reference conditions for Southland estuaries': "*…given most sources of E. coli* […] *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*."

[2] Nitrate toxicity is based on the concentrations below which acute toxicity will be observed in sensitive species. Nitrate is one form of nitrogen that makes up Total Nitrogen (i.e. nitrate cannot exceed TN because TN = Nitrate + Nitrite + Ammonium + Organic-N). Given the median concentration of Total Nitrogen under reference conditions is between 128 – 380 mg m^{-3} (Table 9) it is unlikely the median concentration of nitrate will exceed an A band (<1000mg m^{-3}) under reference conditions acknowledging that this assumption does not take into account the 95th percentile statistical requirement of the proposed nitrate toxicity attribute state option table.

7. Deep lakes

7.1 Relevant literature

Reference conditions in deep lakes are described as lower chlorophyll-*a* and nutrient levels compared to current condition (Schallenberg 2019). All flora and fauna was native, extensive and more diverse macrophyte beds and low diversity of phytoplankton. In deep lakes there was a higher ratio of dissolved inorganic nitrogen to total phosphorus suggesting strong P limitation. Table 12 summarises three studies on shallow lakes:

- Schallenberg (2019) proposed reference conditions for deep lakes based on data collected in field surveys.
- Abell and Van Dam-Bates (2018) modelled TLI in lakes across New Zealand. The output is presented in a report and https://www.lernz.co.nz/uploads/tlimap2.html. The interactive map allowed for deep lakes to be identified outside of the natural state class and the TLI determined for each individual lake. The average modelled TLI rating for deep lakes was 2.49 ± 0.24 (including Te Anau and Manapouri). This value is only indicative there are limitation to modelling and national scale models are not intended to give lake specific information they are intended to represent general trends.

LakeSPI score or indicators of nativeness of macrophytes are intuitively 100% under reference state (pre-human) conditions.

Table 12: Summary of reference conditions for deep lakes in New Zealand and Southland literature.

Attribute	Unit	Schallenberg (2019)	Abell and van Dam-Bates (2018)	Applicable attribute bands
Chlorophyll-*a*	µg/L	≤1	0.82 to 2	A (<2)
Total phosphorus	µg/L	≤3.1	4.1 to 9	A+ (≤4) to A (≤10)
Total nitrogen[1]	µg/L	≤164	73 to 157	A (<160)
Cyanobacteria[1]	Biovolume mm^3/mL	-	2 to 3[2]	A (≤3)
Trophic state (TLI) [1]	Trophic Level Index	-		-
Macrophytes[1]	% cover	-		-

[1]These attributes were not recommended for assessment of reference conditions in Schallenberg (2019) given the large range of values spread across the lakes included in the study as reference lakes. This indicates that a larger dataset it required to improve this assessment based on this method as there may be site specific features that cause the wide range of values

[2] Modelled TLI for deep lakes in Southland 2.49 ± 0.24 based on the data presented https://www.lernz.co.nz/uploads/tlimap2.html.

PRE-POLYNESIAN CONDITION	PRE-EUROPEAN CONDITION	LAKES/LAGOONS INTERPRETED
Deep lakes		
• Oligotrophic • Very low rates of sediment and nutrient inputs from the catchment	• Oligotrophic to mesotrophic (Lake Pupuke) • Slightly increased (but still low sediment and nutrient inputs from the catchment • Slightly increased (but still low) levels of phytoplankton • Clear water and presence of macrophyte beds • Increase in macrophyte productivity (Lake Grasmere)	• Lake Tutira • Lake Rotonuiaha • Lake Grasmere • Lake Pupuke

Figure 3: Descriptive characteristics of reference conditions for deep lakes from paleolimnological studies (Schallenberg 2019).

7.2 Review of available data

Lakes 380 data (unpubl.)

The Lakes 380 programme is described under lowland shallow lakes (section 4). Deep lakes were monitored in the program in 2019 where lakes are also within the Natural State class. The following estimates can be revised when the paleolinological data becomes available.

State of the environment monitoring data is sourced from Norton et al., (2019): 'Current Environmental State and the "Gap" to Draft Freshwater Objectives for Southland'.

Table 13: Data available for Southland lakes from the Lakes 380 project and state of the environment monitoring. The data does not represent pre-human conditions.

Attribute	Units	Lakes 380 data Deep lakes in 'Natural State'			Southland state range between 2010 to 2019		
Nativeness							
Macrophytes	% cover	NA			NA		
Trophic state (LakeSPI)	LakeSPI score	NA			B	to	C
Submerged plants (natives)	LakeSPI native index	NA			B	to	C
Submerged plants (invasive species)	LakeSPI invasive index	NA			B	to	C
Pristineness							
Chlorophyll-*a*	µg/L	A+	to	A	A+	to	A
Total phosphorus	µg/L	A+	to	C	A+	to	A
Total nitrogen	µg/L	A+	to	C	A+	to	A
Ammonia toxicity	mg/L	A	to	B	A		
Nitrate toxicity	mg/L	A			A		
Trophic state (TLI)	Trophic Level Index	A+	to	A	A+	to	A
Resilience							
Cyanobacteria	Biovolume mm^3/mL	NA			A		
E. coli	*E. coli*/100mL	NA			A		

7.3 Summary of reference conditions for deep lakes

The proposed reference conditions are based on the state ranges from New Zealand literature and modelling, unless contemporary data indicates that the current state range is better than the proposed reference conditions from the literature (e.g. A+ current state vs proposed upper banding of an A based on the literature). It is important to note that for the assessment of reference state made in this memo the data does not meet the required attribute state option statistic and should therefore be used as an indication of reference state only. Further research will be required to confirm the proposed reference state conditions.

Table 14: Summary of reference conditions in Southland deep lakes assessing information in Tables 12 and 13.

Attribute	Units	Proposed reference state		
National compulsory attributes				
Chlorophyll-*a*	µg/L	A+	to	A
Total phosphorus	µg/L	A+	to	A
Total nitrogen	µg/L	A+	to	A
Ammonia toxicity	mg/L	A		
Cyanobacteria	Biovolume mm^3/mL	A		
E. coli	*E. coli*/100mL	A[1]		
Southland attributes				
Trophic state (TLI)	Trophic Level Index	A+	to	A
Macrophytes	% cover	No information available		
Trophic state (LakeSPI)	LakeSPI score	A+	to	A[2]
Submerged plants (natives)	LakeSPI native index	A		
Submerged plants (invasive species)	LakeSPI invasive index	A		
Nitrate toxicity	mg/L	A		

[1] [1]There is not enough information available to make this assessment. However, as stated in the memo by Roberts and Ward (2020) ' Reference conditions for Southland estuaries': "*…given most sources of E. coli* […] *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*." In the case of deep lakes current state is A band (see Table 13).

[2] LakeSPI is a metric that assess nativeness and invasiveness of the macrophyte community it is assumed that under reference conditions there would have been no invasive macrophytes present.

References

Abell, J. and van Dam-Bates, P. (2018) 'New Zealand Lakes Resilience: Modelling Reference and Current Trophic Level Index for New Zealand Lakes,' Report prepared for University of Waikato by Ecofish Research Ltd. Modelled output displayed online: https://www.lernz.co.nz/uploads/tlimap2.html

ANZECC ARMCANZ (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

Arundel, Helen P., Pope, Adam J. and Quinn, Gerald P. (2009) Victorian index of estuary condition: recommended themes and measures, Deakin University for the Department of Sustainability & Environment, Warrnambool, Vic

Bartlett, M., Kitson, J., Norton, N., and Wilson, K. (2020). Draft Murihiku Southland Freshwater Objectives – providing for hauora, the health and well-being of waterbodies in Murihiku Southland. Environment Southland and Te Ao Marama Inc. publication number 2020-06. Environment Southland and Te Ao Marama Inc: Invercargill. ISBN 978-0-909043-67-4.

Cosgrove, S (2012). Anthropogenic impacts on Waituna Lagoon: Reconstructing the environmental history. Prepared for Master's Thesis, University of Otago, Retrieved from http://hdl.handle.net/10523/2294

Crawford, C. (2006). Indicators for the condition of estuaries and coastal waters. Tasmania Aquaculture & Fisheries Institute Internal Report 41p

Ministry for the Environment (MFE), (2017). National Policy Statement for Freshwater Management 2014 – updated 2017. https://www.mfe.govt.nz/publications/fresh-water/national-policy-statement-freshwater-management-2014-amended-2017 (11/08/2020).

Norton, N., and Wilson, K. (2019). Developing draft freshwater objectives for Southland. Environment Southland publication 2019-06. Environment Southland: Invercargill. ISBN 978-0-909043-55-1.

Norton, N., Wilson, K., Rodway, E., Hodson, R., Roberts, K., Ward, N., O'Connell-Milne, S., DeSilva, N. and Greer, M. (2019) Current Environmental State and the "Gap" to Draft Freshwater Objectives for Southland. Environment Southland publication number 2019-12. Environment Southland: Invercargill. ISBN 987-0-909043-68-1.

Plew, D, Zeldis, J, Dudley, B, Shankar, U (2018) "Assessment of the eutrophication susceptibility of New Zealand Estuaries" prepared for the Ministry of Environment, New Zealand

Roberts, K., and Ward, N. (2020). Proposed reference conditions in Southland estuaries: review of historical data and literature. Environment Southland publication number 2020-08. Environment Southland: Invercargill. ISBN 978-0-909043-670-4.

Scanes, P. (2016) Assessing estuary ecosystem health: Sampling, data analysis and reporting protocols. Prepared for the New South Wales Government, Office of Environment and Heritage. DOI: 10.13140/RG.2.2.22492.90242

Schallenberg, M (2019). Determining reference conditions for New Zealand lakes. Prepared for Department of Conservation, 50p

Schallenberg, M and Kelly, D (2013). Estimates of Reference Conditions for Southlands Shallow, Lowland Lakes. Prepared for Environment Southland, 44p

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group). (2014) UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool.

Appendix 1: Data analysis

Data analysis from the Abell et al. (2018) modelling and the Lakes 380 programme is detailed in the spreadsheet "Reference conditions in Lakes data analysis Aug_2020" (Environment Southland document reference: A584584)

Data analysis for the state and gap report is described in Norton et al (2019) and detailed in the spreadsheet "Southland Lakes Data Analysis State and gap Report Oct_2019" (Environment Southland document reference: A550425) and "Statistical criteria for State and Gap Analysis – Lakes Oct-2019" (Environment Southland document reference: A552242).

Appendix 2: Literature notes

Schallenberg (2019). Determining reference conditions for New Zealand lakes. Prepared for Department of Conservation.

'Reference condition':

- Used in ecological literature to reference to an ecosystem that has not been affected by human activities. In New Zealand, anthropogenic impacts when compared to pre-human condition can be attributed to two time periods; Maori occupation and European settlement.
- However, there are other ways that the term 'reference conditions' can be applied:
    (a) a minimally disturbed condition;
    (b) a historic condition;
    (c) the least disturbed condition;, and
    (d) the attainable condition.
- "an ecosystem that has not been affected by human activities" with the more detailed definition, "reference condition is the ecological integrity of an ecosystem immediately prior to the first anthropogenic impacts".

'Reference conditions' from the combined survey-calibration and palaeolimnological approach:

Table 19. General reference conditions for the three classes of lakes used in this study based on a combination of the survey-calibration and palaeolimnological approaches. Unless otherwise stated, interpretations are compared with modern conditions. Proposed quantitative reference condition limits can be found in tables in section 3.

SHALLOW FRESHWATER LAKES	BRACKISH LAKES AND LAGOONS	DEEP LAKES
Lower chlorophyll *a* and nutrient levels	Lower chlorophyll *a* and nutrient levels	Lower chlorophyll *a* and nutrient levels
Lower nutrient inputs	100% native flora and fauna	100% native flora and fauna
100% native flora and fauna	More extensive and deeper macrophyte beds	More extensive and deeper macrophyte beds
Low levels of cyanobacteria	Increased diversity of benthic macroinvertebrates	Lower rotifer and phytoplankton diversity
More extensive macrophyte beds	Decreased diversity of phytoplankton species	Greater macrophyte diversity
	Low levels of cyanobacteria	High ratios of dissolved inorganic nitrogen to total phosphorus (DIN:TP), suggesting strong P limitation
	Fewer openings of barrier bars (in intermittently closed and open lakes/ lagoons; ICOLLs)	
	Either more pronounced and persistent alternating marine and freshwater phases, or no marine influence (in ICOLLs)	

Table 18. Reference conditions for shallow freshwater lakes, brackish lakes and lagoons, and deep lakes as inferred from palaeolimnological studies. Unless otherwise stated, interpretations are compared with modern conditions.

PRE-POLYNESIAN CONDITION	PRE-EUROPEAN CONDITION	LAKES/LAGOONS INTERPRETED
Shallow freshwater lakes		
• Very low rates of sediment and nutrient inputs from the catchment • Very low productivity and turbidity • Extensive native macrophyte beds dominated by *Nitella* sp. (Lake Emma)	• Low rates of sediment and nutrient inputs from the catchment • Low productivity and turbidity • Shift in macrophyte community to mixed charophytes (Lake Emma)	• Lake Waihola • Lake Taumatawhana • Lake Emma
Brackish lakes/lagoons		
• Less frequent openings of barrier bars where they existed; deeper lakes with lower salinity (Lake Ellesmere (Te Waihora) • More pronounced and persistent marine and freshwater phases, or an absence of marine influences (Lake Waituna, Lake Ellesmere (Te Waihora)) • Presence of extensive macrophyte beds (seagrasses and/or freshwater macrophytes) • Very low rates of sediment and nutrient inputs from the catchment	• Less frequent openings of barrie bars where they existed • More pronounced and persistent marine and freshwater phases, or an absence of marine influences (Lake Waituna, Lake Ellesmere (Te Waihora)) • Presence of extensive macrophyte beds (seagrasses and/or freshwater macrophytes) (Lake Ellesmere (Te Waihora), Wainono Lagoon) • Eutrophic but relatively clear water • Low rates of sediment and nutrient inputs from the catchment (Lake Ellesmere (Te Waihora), Lake Waihola) • Freshwater system as indicated by diatoms and/or the presence of *Daphnia* spp. (Wainono Lagoon, Lake Waihola)	• Lake Waihola • Waituna Lagoon • Lake Ellesmere (Te Waihora) • Wainono Lagoon
Deep lakes		
• Oligotrophic • Very low rates of sediment and nutrient inputs from the catchment	• Oligotrophic to mesotrophic (Lake Pupuke) • Slightly increased (but still low sediment and nutrient inputs from the catchment • Slightly increased (but still low) levels of phytoplankton • Clear water and presence of macrophyte beds • Increase in macrophyte productivity (Lake Grasmere)	• Lake Tutira • Lake Rotonuiaha • Lake Grasmere • Lake Pupuke

Survey Calibration Method in Schallenberg (2019)

Shallow Lakes

Attribute	Units	Range for reference lakes	Limit
Nativeness			
Native fish species	%	100	100
Native macrophyte species	%	75-100	100
Native macrophyte cover[1]	%	90-100	100
Pristineness			
Total Nitrogen	µg/L	235 - 277	≤277
Total Phosphorus	µg/L	2.0 - 11.7	≤11.7
Chlorophyll-a	µg/L	0.7 - 3.2	≤3.2
Trophic Level Index	No units	1.8 - 3.5	≤3.5
Macrophyte Cover[1, 2]	%	31 - 98	100
Diversity			
No relationships identified for reference lakes			
Resilience			
Cyanobacteria	Cells/mL	<500 - 1000	≤1000

1: Attribute was not recommended for assessment of reference conditions in Schallenberg (2019) given the large range of values spread across the lakes included in the study as reference lakes. This indicates that a larger dataset it required to improve this assessment as there may be site specific features that cause the wide range of values.
2: Recommended as a reference indicator

Brackish Lakes and Lagoons

Attribute	Unit	Range for all lakes[6]	Limit
Nativeness			
No relationships			
Pristineness			
Total Nitrogen	µg/L	128 - 2163	≤128
Total Phosphorus	µg/L	2.4 - 510	≤2.4
Chlorophyll-a	µg/L	0.3 - 80	≤0.3
Trophic Level Index	No units	2.5 – 7.2	≤2.5
Macrophyte Cover[1, 2]	%	0 - 81	100
Diversity			
No applicable to proposed attributes			
Resilience			
Cyanobacteria	Cells/mL	<500 – 940,000	≤500

1: Attribute was not recommended for assessment of reference conditions in Schallenberg (2019) given the large range of values spread across the lakes included in the study as reference lakes. This indicates that a larger dataset it required to improve this assessment as there may be site specific features that cause the wide range of values.
2: Recommended as a reference indicator

[6] There was not a large enough sample dataset to assess multiple reference lakes these are considered preliminary ratings.

Deep Lakes

Attribute	Unit	Range for all lakes[2]	Limit
Nativeness			
Lake SPI Score[1]	%	26 - 80	100
Invasive Macrophyte score[1]	%	11 - 69	
Pristineness			
Total Nitrogen	µg/L	47 - 164	≤164
Total Phosphorus	µg/L	1.8 - 3.1	≤3.1
Chlorophyll-a	µg/L	0.6 - 1	≤1
Trophic Level Index[1]	Not presented for deep lakes		
Macrophytes[1]	% cover	-	
Diversity			
No applicable to proposed attributes			
Resilience			
Cyanobacteria[1]	Not presented for deep lakes		

1: Attribute was not recommended for assessment of reference conditions in Schallenberg (2019) given the large range of values spread across the lakes included in the study as reference lakes. This indicates that a larger dataset it required to improve this assessment as there may be site specific features that cause the wide range of values.
2: There was not a large enough sample dataset to assess multiple reference lakes these are considered preliminary ratings.

Schallenberg and Kelly (2013) 'Estimates of Reference Conditions for Southlands Shallow, Lowland Lakes' Report prepared for Environment Southland

Survey Calibration Method in Schallenberg (2013)

- Criteria to be included as a reference lake: >90% native land cover in the lake catchments, High ecological integrity (score close to 100).
- Southland specific assessment of reference conditions in shallow lowland lakes. The lakes included in the assessment Ship Creek Lagoon, Maori Lake, Lake Otuhie, Lake Sheila, Lake Calder.

** Note the thresholds are the same as the DOC report.

Lowland shallow lakes

Indicator	Unit	Range for Reference Lakes	Limit
Nativeness			
Native fish species	%	100	100
Native macrophyte species	%	75-100	100
Native macrophyte cover[1]	%	90-100	100
Pristineness			
Total nitrogen	µg/L	235 - 277	≤277
Total phosphorus	µg/L	2.0 - 11.7	≤11.7
Chlorophyll-*a*	µg/L	0.7 - 3.2	≤3.2
Trophic Level Index	No units	1.8 - 3.5	≤3.5
Macrophytes[1, 2]	% cover	31 - 98	100
Diversity			
No relationships identified for reference lakes			
Resilience			
Cyanobacteria	Cells/mL	<500 - 1000	≤500

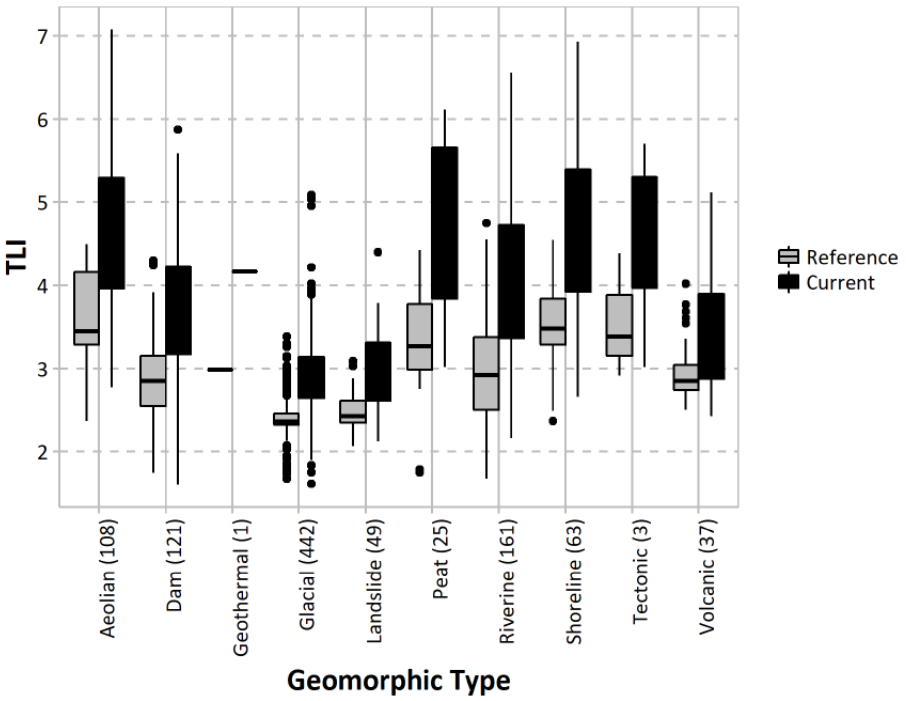
1: Attribute was not recommended for assessment of reference conditions in Schallenberg (2019) given the large range of values spread across the lakes included in the study as reference lakes. This indicates that a larger dataset it required to improve this assessment as there may be site specific features that cause the wide range of values.
2: Recommended as a reference indicator

Abell and van Dam-Bates (2018). New Zealand Lakes Resilience: Modelling Reference and Current Trophic Level Index for New Zealand Lakes. Prepared for University of Waikato

- Additional output: https://www.lernz.co.nz/uploads/tlimap2.html
- Modelled lakes based on TN/TP concentrations in 'least disturbed' lakes.
- 'least disturbed' lakes were chosen based on a subjective process that balanced lakes that were expected to be least departed from reference state with a large enough sample size to develop a robust model.
- Lakes that had inflow concentrations that were equal to or less than maximum concentrations estimated to occur in New Zealand streams under reference state.
- 30 lakes were chosen for TN and 27 lakes for TP modelling
- Study looked at national scale trends not site scale so these could be variable.
- TLI's from the additional outputs were compared against lake type and grouped to determine the range and average TLI for a particular lake type. See amended excel sheet.

Table 23. Summary of predictions of TLI variables for WONI lakes.

Variable	State	Units	*n*	Maximum	Minimum	Mean	Median
TN	Current	mg m^{-3}	1038	7076	42	449	217
	Reference	mg m^{-3}	1040	758	59	214	164
TP	Current	mg m^{-3}	1033	580.5	3.3	43.3	22.0
	Reference	mg m^{-3}	1033	60.6	3.3	10.4	6.6
Chl *a*	Current	mg m^{-3}	1031	150.3	0.5	8.3	3.0
	Reference	mg m^{-3}	1033	13.6	0.6	2.4	1.5
Secchi depth	Current	m	1031	15.89	0.10	6.48	5.88
	Reference	m	1031	14.79	3.35	9.60	10.34
TLI	Current	TLI units	1031	7.08	1.61	3.58	3.28
	Reference	TLI units	1031	4.75	1.68	2.81	2.60



Plew, D, Zeldis, J, Dudley, B, Shankar, U (2018). Assessment of the eutrophication susceptibility of New Zealand estuaries. Prepared for the Ministry of Environment, New Zealand.

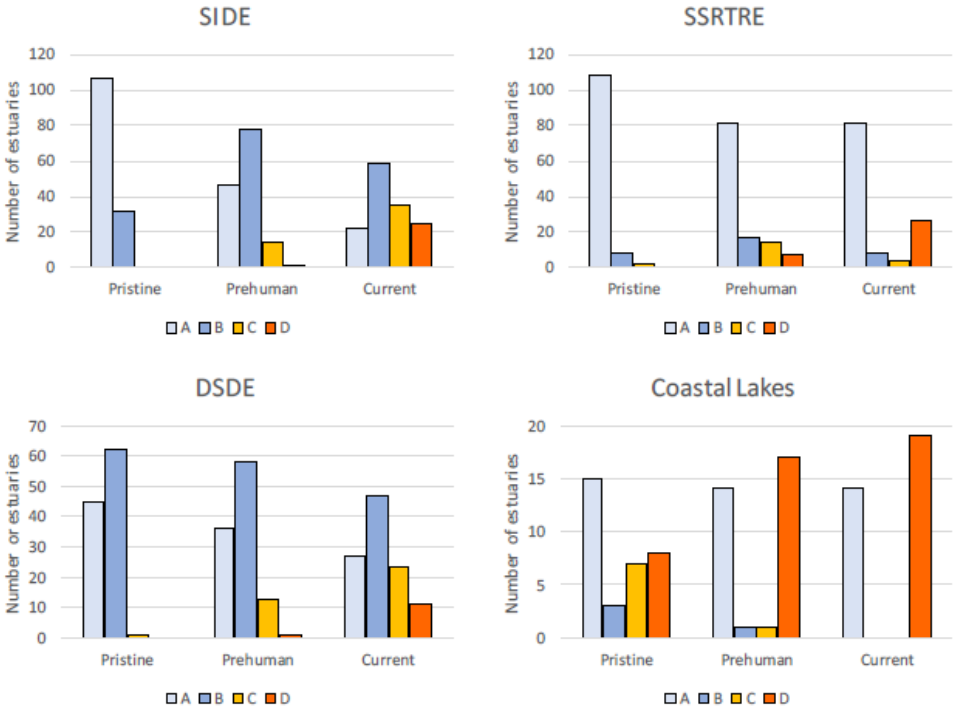
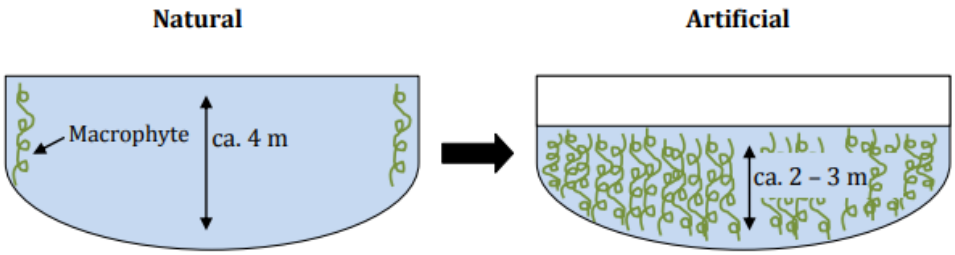


Figure 3-14: Eutrophication susceptibility of New Zealand estuaries predicted under the 'pristine', 'pre-human land cover' and 'current land cover' scenarios. Susceptibility bands plotted by counts of estuary type. A = low susceptibility, B = moderate susceptibility, C = high susceptibility, D = very high susceptibility. See Tables 2-3 and 2-7 for descriptions of ecological conditions expected for ETI susceptibility bandings.

Cosgrove (2012). Anthropogenic impacts on Waituna Lagoon: Reconstructing the environmental history. Prepared for Master's Thesis University of Otago



- Lake with rare openings	- Estuary/lake with frequent openings
- Higher water level (ca. 4 m)	- Lower water level (ca. 2 – 3 m)
- Macrophyte growth limited	- Extensive macrophyte beds
- *Ruppia* absent	- *Ruppia* dominant
- Water leakage through barrier	- Little water leakage through barrier
- Long closed periods	- Short closed periods
- Large hydraulic head	- Small hydraulic head
- Large openings when barrier is breached	- Small openings when barrier is breached
- Large exchange with the sea when open (influx of sand, etcetera)	- Less exchange with the sea when open, but more frequent marine influence

Figure 9: A conceptual model showing the hypothesized natural state of Waituna Lagoon alongside the present conditions under artificial management

- Waituna Lagoon naturally a lake which infrequently opened to the sea
- As water level rose lagoon leakage through the barrier increased allowing the lagoon to stay closed longer
- Extended periods of high water levels limited *Ruppia* growth to shallow margins (high humic content of the water)
- *Ruppia* is a natural component of the Waituna Lagoon ecosystem
- 1908 artificial management of the opening regime began with more frequent openings than under natural regime – conditions have become more estuarine