Te Akaaka eutrophication susceptibility assessment

Prepared for Environment Canterbury Regional Council

March 2018

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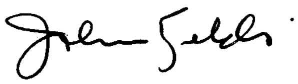
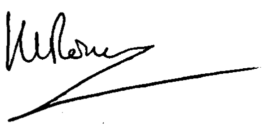
NIWA CLIENT REPORT No: 2017041CH
Report date: March 2018
NIWA Project: ENC17507

Quality Assurance Statement		
	Reviewed by:	John Zeldis
	Formatting checked by:	Fenella Falconer
	Approved for release by:	Helen Rouse

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Executive summary

Environment Canterbury(ECan) is undertaking assessments of the water quality and ecological state of the Ashley River/Rakahuri Saltwater Creek Estuary/Te Akaaka (Te Akaaka). As part of this work, ECan commissioned NIWA to calculate the eutrophication susceptibility of Te Akaaka according to the recently released Envirolink screening tool 1 for the New Zealand Estuary Trophic Index (Robertson, Stevens et al. 2016a; Zeldis, Plew et al. 2017b). Nitrogen (N)-load and flow data for this work were provided by ECan for four land use scenarios.

- Current Management Practice (CMP).
- Good Management Practice (GMP).
- Plan Change 5 Permitted Activity Rules (PC5PA).
- PC5PA x 0.5 scenario.

A further estimate for current eutrophication susceptibility is included, using current N-loading to the estuary estimated from NIWA's CLUES (Catchment Land Use for Environmental Sustainability) model.

Two methods were used to determine the eutrophication susceptibility of Te Akaaka. The first method is the Assessment of Estuarine Trophic Status (ASSETS) approach. Using the ASSETS approach, flow conditions under all scenarios give a flushing potential banding of 'High' and a dilution potential banding of 'Low'. This resulted in a 'Moderate' physical susceptibility banding.

Te Akaaka has a 'very high N-load susceptibility' based on the N-load and flow data for the all ECan scenarios and NIWA's CLUES model. The combination of a 'Moderate' physical susceptibility, and a 'Very High' N load susceptibility results in a very high combined physical and nutrient load susceptibility (Band D), for all ECan scenarios according to the approach in ETI tool 1. CLUES model data also gives a result in Band D - the highest possible nutrient load susceptibility banding.

Because the dilution potential for this estuary is substantially below those for which the ASSETS approach was designed, it is likely to underestimate the physical susceptibility of Te Akaaka. Hence, we also used a second method, CLUES-Estuary, to determine eutrophication susceptibility for this estuary. Using the CLUES-Estuary estimate of eutrophication susceptibility, N-loads to the estuary at the 5% (lower) likelihood percentile for all four ECan scenarios gave a result of Band C (High) for susceptibility to macroalgal eutrophication, and Band A (Low) for susceptibility to phytoplankton eutrophication. N-loads to the estuary at the 95% (upper) likelihood percentile for all four ECan scenarios, as well as CLUES current N-loading estimates, gave a result of Band D (Very High) for susceptibility to macroalgal eutrophication, and Band A (Low) for susceptibility to phytoplankton eutrophication.

We note that if increased loadings are predicted, they would likely result in increased dissolved nitrogen concentrations in the estuary. These increased concentrations are likely to lead to increased macroalgal growth in the estuary, so it would be appropriate to consider their impact and to regularly monitor changes in ecological condition in this estuary.

1 Introduction

To gain an understanding of how future changes to nutrient flows may affect the ecological health of Te Akaaka, Environment Canterbury(ECan) requested that NIWA determines Te Akaaka's eutrophication susceptibility using Tool 1 of the New Zealand Estuary Trophic Index (ETI) (Robertson, Stevens et al. 2016a; Zeldis, Plew et al. 2017b) under four land use scenarios in the tributary catchments for this estuary (Etheridge 2018).

This work includes the following.

- Determining estuary type for Te Akaaka according to ETI tool 1.
- Applying ETI tool 1 methods for N loads resulting from four land use scenarios CMP, GMP, PC5PA, and PC5PAx0.5, as well as an estimate of current N-loading to the estuary based on NIWA's Catchment Land Use for Environmental Sustainability (CLUES) model.
- Determining the flushing and dilution potential of Te Akaaka under these scenarios according to ETI tool 1 using freshwater inflow data provided by ECan, and estuary volume and tidal height data available to NIWA.
- Calculating the physical susceptibility of Te Akaaka according to ETI tool 1.
- Calculating estuary areal N loads for each scenario as well as an estimate of current areal N-loading to the estuary based on NIWA's CLUES model.
- From the estuary volume and area, and nutrient and freshwater loads from the previous steps, calculating combined physical and nutrient load susceptibility of Te Akaaka for each scenario, according to ETI tool 1.
- Because the Assessment of Estuarine Trophic Status (ASSETS) approach employed in ETI tool 1 frequently underestimates susceptibility for small estuaries (such as Te Akaaka: Robertson et al. 2016, page 30), this work also required use of the CLUES-Estuary tool (Plew, Zeldis et al. 2018) to predict potential nutrient concentrations from which we could assess eutrophication susceptibility.
- Brief narrative guidance on the ecological condition that corresponded to the combined physical and nutrient load susceptibility for Te Akaaka for each scenario, and comparison of this information with recent ecological monitoring data.

The main sources of freshwater flow and nutrients for Te Akaaka are the Ashley River/Rakahuri, Saltwater Creek, Waikuku Stream and Taranaki Creek. Both freshwater flows from rivers and the nutrient loads they carry are heavily dependent on land use within catchments (Larned, Snelder et al. 2015). The ocean also provides a source of nutrients.

Nitrogen (N) availability most commonly limits peak seasonal algal growth in estuaries (Howarth and Marino 2006). Hence, N supplies from inflows and nutrient retention within estuaries are used to gauge estuarine eutrophication susceptibility. Freshwater inflow volumes influence the susceptibility of estuaries to eutrophication because flow rates affect the residence time of water within the estuary. Longer residence times have the potential to produce more eutrophic conditions because algae in the water column (phytoplankton) have time to grow and multiply within the estuary, and freshwater-derived nutrient loads that supply both phytoplankton and macroalgae are less quickly exported from estuaries and diluted by mixing with ocean water.

Here, we assess the susceptibility of Te Akaaka to eutrophication based on the N-loading and flow information provided to NIWA, calculated for the CMP, GMP, PC5PA and PC5PA x 0.5 land use scenarios, as well as current N-loading to the estuary calculated using NIWA's CLUES model.

2 Estuary type

The physical characteristics of an estuary, such as depth and intertidal area, strongly influence its susceptibility to eutrophication caused by nutrient loads from land. We classified Te Akaaka estuary by physiographical type according to ETI tool 1. Mean depth, total surface area and intertidal area data for Te Akaaka were obtained from NIWA's Coastal Explorer Database. Te Akaaka has the following characteristics:

- A mean depth of 1.49 m at mean high water on a spring tide (MHWS).
- A surface area of 1.522 km^2 at MHWS.
- An intertidal area of 78.35% of total estuarine area.
- A tidal range of 1.64 m (Coastal Explorer Database).

Based on these data, Te Akaaka is a Shallow Intertidal-Dominated Estuary (SIDE), defined in ETI tool 1 as <3 m depth, residence time <3 days and intertidal area comprising >40% of total estuary area. Eutrophication susceptibility calculations appropriate to that estuary type are applied in the following sections. We note that the estuary's area obtained from the Coastal Explorer database was derived from LINZ high water lines defined from aerial photographs. We recalculated Te Akaaka's area using recent satellite imagery (GoogleEarth, imagery dated 11/1/2015), and obtained a similar estimate of 1.598 km^2 (cf. 1.522 km^2). The recent New Zealand Coastal Hydrosystems typology classifies Te Akaaka as a H¬āpua-type lagoon (intermittent) (Hume, Gerbeaux et al. 2016).

3 Flushing potential

Flushing potential was calculated according to the Assessment of Estuarine Trophic Status (ASSETS) approach described in ETI tool 1. This approach defines an estuary's flushing potential as:

- daily freshwater inflow (m3/d)/ estuary volume (m^3).

Estuaries can then be classified using the resulting value as having a high, moderate or low flushing potential. Applying this to Te Akaaka with a moderate tidal range (as defined in ASSETS) reveals total mean annual flow into the estuary in the range of 1.65 x 106 m^3/day, and an estuary volume of 2,272,805 m^3, resulting in a flushing potential of 0.72 days (Table 3-1). Comparison with the Coastal Explorer database bandings of flushing potentials (high – 100 – 10-1; moderate – 10-2, and low – 10-3 – 10-4) shows that Te Akaaka's flushing potential is high.

Table 3-1: Calculated flushing potentials for Te Akaaka under all land use scenarios provided by Environment Canterbury. Based on Robertson et al.'s (2016) Estuarine Trophic Index Tool 1. Data for Current pathways and Alternative pathways flow scenarios were provided by ECan. Ashley= Ashley River/Rakahuri (at State Highway 1); Saltwater= Saltwater Creek (at Factory Road); Taranaki= Taranaki Creek (at Preeces Road); Waikuku= Waikuku Stream (at State Highway 1).

Flow scenario	Mean annual flow Ashley (m^3/day)	Mean annual flow Saltwater (m^3/day)	Mean annual flow Taranaki (m^3/day)	Mean annual flow Waikuku (m^3/day)	Sum of mean annual flow - all tributaries (m^3/day)	Estuary volume at spring high tide (m^3)	Flushing potential	Flushing potentia l band (ETI tool 1)
All scenarios	1.43×10^6	1.47×10^5	2.16×10^4	5.18×10^4	1.65×10^6	2,272,805	0.72	High

4 Dilution potential

The ASSETS approach defines dilution potential as:

- 1/estuary volume (cubic feet).

Counterintuitively, a smaller dilution potential value indicates that the estuary has a greater capacity (volume) to dilute incoming freshwater. Te Akaaka's dilution potential value is 1.25×10^{-8}, which is outside the range of bands defined in ASSETS (we assumed no or minimal water column stratification within Te Akaaka). The dilution potential band for the ASSETS approach that corresponds to the least dilution ('Low') ranges from 10^{-10}-10^{-9}. The ASSETS classification is based on substantially larger estuaries, and appears untested for estuaries as small as Te Akaaka. Thus, in the absence of defined dilution potential bandings for small estuaries, we define Te Akaaka has having 'Low' dilution potential.

5 Physical susceptibility

The ASSETS categories (Table 5-1) were used to determine the physical susceptibility of Te Akaaka to eutrophication.

Table 5-1: ASSETS physical susceptibility classification system for shallow intertidal-dominated estuaries. Table from ETI Tool 1 (Robertson, Stevens et al. 2016b).

		Dilution potential		
		High	**Moderate**	**Low**
Flushing potential	**High**	Low physical susceptibility	Low physical susceptibility	Moderate physical susceptibility
	Moderate	Low physical susceptibility	Moderate physical susceptibility	High physical susceptibility
	Low	Moderate physical susceptibility	High physical susceptibility	High physical susceptibility

Under all scenarios, the high flushing potential and low dilution potential scores identify Te Akaaka as having a moderate physical susceptibility.

We note that the dilution potential for this estuary is substantially less than that for which the ASSETS approach was developed, and consider that this approach appears to under-estimate the physical susceptibility of Te Akaaka. Hence, we recommend considering the CLUES-Estuary-derived calculation of eutrophication susceptibility for this estuary (see section 8 below).

6 Te Akaaka’s nitrogen loads and nutrient load susceptibility

Data for the four land use scenarios were provided to NIWA by ECan. Modelled N loads provided to NIWA corresponded to 5%, 10%, 25%, 50% ,75%, 90% and 95% likelihood percentiles for each scenario. N loads corresponding to 5% and 95% likelihood percentiles were used in eutrophication susceptibility analysis. More information on the derivation of the data in these scenarios is available in Etheridge (2018).

Estuary N loads and the N loads per unit area within the estuary are presented in Table 6-1. These loads (399.5-1,358 mg/m^2/d) show that Te Akaaka has a very high N-load susceptibility under all modelled scenarios, according to the ASSETS approach. We note however that there is a wide range of results under all scenarios, and that the 5% percentile of the GMP scenario sits closest to the threshold of the high N-load susceptibility band.

Nitrogen loads were also estimated using CLUES (Elliott, Semadeni-Davies et al. 2016). Combined annual nitrogen loads from the four catchments predicted by CLUES (1358 mg/m^2/d) were substantially different from those of the four land use scenarios, provided by ECan (Table 6-1). Further investigation into why individual catchment loads differed between models may warrant investigation (e.g., by comparing the methods of Elliott, Semadeni-Davies et al. (2016) and Etheridge (2018)).

Table 6-1: Areal N-load susceptibility for Te Akaaka under scenarios provided by Environment Canterbury. Based on Robertson et al.'s (2016) Estuarine Trophic Index Tool 1. Data for Current pathways and Alternative pathways nitrogen loading scenarios were provided by ECan. CLUES nitrogen loads are derived from NIWA's CLUES model (Elliot et al. 2016).

Scenario	Sum of mean annual N-loads - all tributaries (T/year) 5% Likelihood percentile	Sum of mean annual N-loads - all tributaries (kg/year) 95% Likelihood percentile	Estuary surface area at mean high tide (km^2)	Areal N load ($mg/m^2/day$) 5% Likelihood percentile	Areal N load ($mg/m^2/day$) 95% Likelihood percentile	N load susceptibility band (ETI tool 1) - 5% Likelihood percentile N load	N load susceptibility band (ETI tool 1) - 95% Likelihood percentile N load
CMP	293	598	1.522	527.3	1076.1	Very high (>250 $mg/m^2/day$)	Very high (>250 $mg/m^2/day$)
GMP	222	504	1.522	399.5	906.9	Very high (>250 $mg/m^2/day$)	Very high (>250 $mg/m^2/day$)
PC5PA	303	686	1.522	545.2	1234.5	Very high (>250 $mg/m^2/day$)	Very high (>250 $mg/m^2/day$)
PC5PA x 0.5	255	577	1.522	458.9	1038.3	Very high (>250 $mg/m^2/day$)	Very high (>250 $mg/m^2/day$)
CLUES (modelled current conditions, no error bands)	755		1.522	1 358		Very high (>250 $mg/m^2/day$)	

7 Combined physical and nutrient load susceptibility

The ASSETS categories (Table 5-1 and Table 6-1) were used to determine the eutrophication susceptibility band (Table 7-1) for Te Akaaka.

Table 7-1: Combined physical and nutrient load susceptibility bandings for shallow intertidal-dominated estuaries. Table from ETI Tool 1 (Robertson, Stevens et al. 2016b).

		N load susceptibility (mg/m²/day)			
		Very high (>250)	High (50-250)	Moderate (10-50)	Low (<10)
Physical susceptibility	**High**	Band D Very High	Band C High	Band C High	Band B Moderate
	Moderate	Band D Very High	Band C High	Band B Moderate	Band A Low
	Low	Band C High	Band B Moderate	Band B Moderate	Band A Low

We assessed Te Akaaka as having a moderate physical susceptibility and a very high N load susceptibility under all scenarios, based on its estuary volume and area, nutrient loads and freshwater flows. According to the ASSETS approach in ETI tool 1, this combination results in a combined very high physical and nutrient load susceptibility (Band D) (Table 7-1). This rating does not change when applying any of the scenario N-load estimates.

8 CLUES-Estuary estimate of eutrophication susceptibility

Because the ASSETS approach employed in the ETI tool under-estimates susceptibility for small estuaries, such as Te Akaaka with volumes <2.8 million m^3 (Robertson et al. 2016, page 30), we used the CLUES-Estuary approach (Plew, Zeldis et al. 2018) to estimate potential nutrient concentrations, as an alternative way to assess eutrophication susceptibility. The CLUES-Estuary approach scores susceptibility to excessive phytoplankton growth and to excessive macroalgal growth separately, as two predictors of ecological impact, as described in the ETI Tool 1 (Zeldis, Plew et al. 2017a) (Table 8-1)

The CLUES-Estuary approach predicts the average potential total nitrogen (TN) concentration in the estuary. Potential nutrient concentrations are those that would occur in the absence of nutrient sources or sinks in the estuary, such as uptake into algae or losses through denitrification. Potential concentrations are expected to be higher than observed concentrations, because observed concentrations show the remaining nutrients in the water column after some have been removed or taken up. Thus, potential nutrient concentrations are a stronger indicator of eutrophication susceptibility than observed values (Plew, Zeldis et al. 2018).

We propose the following TN concentration bandings for susceptibility to eutrophication due to opportunistic macroalgae blooms:

- A: < 55 mg/m^3.
- B: 55 mg/m^3 - 110 mg/m^3.
- C: 110 mg/m^3 - 320 mg/m^3.
- D: >320 mg/m^3.

The expected condition of the estuary for each band is described in Table 8-1. The thresholds between each band are based on a comparison of potential TN concentrations with observations of opportunistic macroalgal from over 20 New Zealand estuaries (Plew, Zeldis et al. in prep). Observations of macroalgae impact were taken in summertime, while the potential TN concentrations were calculated from annual nitrogen loads and mean flow. The thresholds between bandings should not be regarded as absolute, rather they are indicative of shifts along a continuum of eutrophic state. The changes between ecological conditions described in Table 8-1 occur gradually with increasing concentration rather than abruptly. The thresholds between the concentration bands are indicative of where transitions between these ecological conditions are expected. We caution that other factors may influence the macroalgae response in an estuary besides nutrient load, for example the availability of suitable substrate for macroalgal growth and bioavailability of nutrients (i.e., the dissolved vs particulate ratios in the TN).

Note that the TN concentration bands have been adjusted slightly from those in our earlier report on the Avon-Heathcote, Le Bons Bay and Okains Bay estuaries (Plew, Dudley et al. 2017) due to a recent reanalysis of available data. However, the shift in band thresholds do not change the susceptibility bandings of any of those estuaries.

Susceptibility to phytoplankton blooms are determined from potential TN concentration and flushing time using a growth model (Table 8-1). The growth model is used to estimate the chlorophyll-a concentration, which related to a susceptibility band as reported in Table 8-1. The growth model shows that estuaries with short flushing times (<2.5 days) are highly unlikely to have phytoplankton blooms as they are flushed from the system faster than they can grow.

Table 8-1: Description of ecological quality for macroalgal and phytoplankton bandings. Adapted from ETI tool 2 (Robertson, Stevens et al. 2016b) and Plew, Zeldis et al. (in prep).

Band	A Minimal eutrophication	B Moderate eutrophication	C High eutrophication	D Very high eutrophication
Opportunistic Macroalgae	TN_{est} < 55 mg/m^3 Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are healthy and resilient. Algal cover <5% and low biomass (<50 g/m^2 wet weight) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality high	55 ≤ TN_{est} < 110 mg/m^3 Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are slightly impacted by additional macroalgal growth arising from nutrients levels that are elevated. Limited macroalgal cover (5-20%) and low biomass (50-200 g/m^2 wet weight) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality transitional	110 ≤ TN_{est} < 320 mg/m^3 Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are moderately to strongly impacted by macroalgae. Persistent, high % macroalgal cover (25-50%) and/or biomass (>200- 1000 g/m^2 wet weight), often with entrainment in sediment. Sediment quality degraded	TN_{est} ≥ 320 mg/m^3 Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are strongly impacted by macroalgae. Persistent very high % macroalgal cover (>75%) and/or biomass (>1000 g/m^2 wet weight), with entrainment in sediment. Sediment quality degraded with sulphidic conditions near the sediment surface
Phytoplankton	Chl-a < 5 µg/l Ecological communities are healthy and resilient	5 ≤ Chl-a < 10 µg/l Ecological communities are slightly impacted by additional phytoplankton growth arising from nutrients levels that are elevated	10 ≤ Chl-a < 16 µg/l Ecological communities are moderately impacted by phytoplankton biomass elevated well above natural conditions. Reduced water clarity likely to affect habitat available for native macrophytes	Chl-a ≥ 16 µg/l Excessive algal growth making ecological communities at high risk of undergoing a regime shift to a persistent, degraded state without macrophyte/seagrass cover

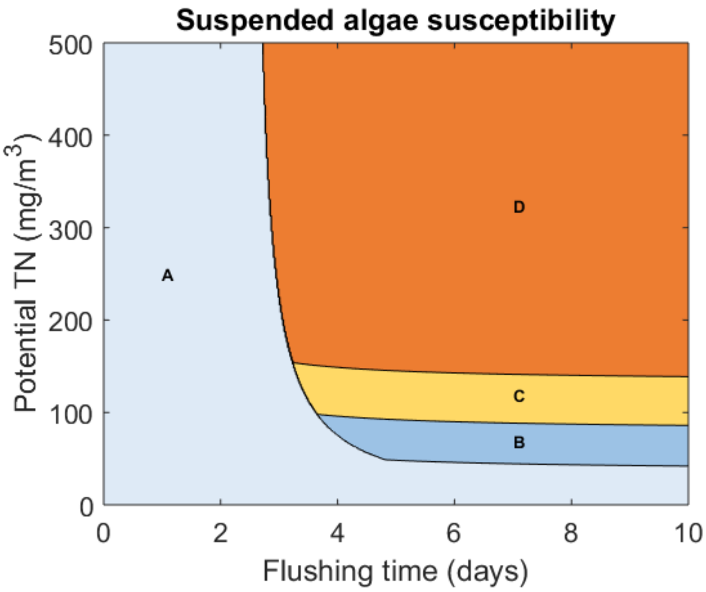

Figure 8-1: ETI susceptibility bandings for phytoplankton based on flushing time and potential total nitrogen concentrations. This graph shows model output based on an assumed half saturation coefficient of 45 mg/m^3 TN and a net specific growth rate of 0.4 day-1.

The CLUES-Estuary approach uses simple models to account for the mixing between the inflowing river and sea waters, providing an estimate of the potential nutrient concentration (concentration present in the absence of denitrification or uptake) in the estuary averaged over time and space. The potential nutrient concentration in the estuary NEst is calculated according to the following equation:

$$N_{Est} = \frac{N_R + N_O(1-D)}{D} \quad (1)$$

The nitrogen concentration in the river inflows NR is calculated by dividing the total annual nitrogen load by the total mean inflow from all of the river sources. The ocean nitrogen concentration NO is obtained from the CARS (CSIRO Atlas of Regional Seas) climatology (CSIRO 2011). This value, 34.7 mg/m^3, is close to the mean recorded dissolved inorganic N concentration at sites at 3 km the Canterbury coast over the duration of ECan records for these sites, 55 mg/m3 (Dudley, Zeldis et al. 2017). The dilution factor D is the ratio by which freshwater is diluted by sea water within the estuary. For example, a value of D = 10 would indicate that the estuary volume consists of 1/10 parts freshwater (i.e., percent freshwater).

For Te Akaaka, a modified tidal prism model (Luketina 1998) is used to calculate dilution. This model includes a tuning parameter to account for return flow back into the estuary and incomplete mixing within the estuary. In the absence of empirical data, this parameter was determined from the ratio of freshwater inflow to tidal prism (Plew, Zeldis et al. 2018). Alternatively, this factor can be estimated from estuary-averaged salinity at high tide. While some salinity data were available from two locations in the estuary (near the mouth and the outlet of Taranaki Creek), data from these locations did not give a true estuary-averaged high tide value. However, the predicted estuary salinity of 16.3 ppt (Table 8-2) compares favourably with mean salinity at the mouth (14.4 ppt), indicating that the model was reasonably well tuned.

Results from the CLUES-Estuary approach show that:

- The estuary is poorly flushed, with ca. 55% of the estuary's high tide volume originating from river inflow, and a low estuary dilution factor (1.87).
- The 5% likelihood percentile results of the estuary's potential-N concentration under all management scenarios range from of 220 mg/m^3 (GMP scenario) to 294 mg/m^3 (PC5PA scenario), and result in a placement in ETI macroalgal band C (Table 8-3).
- The 95% likelihood percentile results of the estuary's potential-N concentration under all management scenarios range from of 478 mg/m^3 (GMP scenario) to 645 mg/m^3 (PC5PA scenario) and are consistent with placement in ETI macroalgal band D (Table 8-3).

If loadings and freshwater flows predicted by the CLUES model accurately indicate present day conditions, then the predicted estuary potential N concentration is 709 mg/m^3, suggesting a highly eutrophic estuary with persistent high macroalgal cover (D band). This assessment is consistent with anecdotal reports of Te Akaaka's present condition.

Due to Te Akaaka's short flushing time (less than 1 day, Table 8-2), phytoplankton blooms are unlikely to extend over most of the estuary under any of the scenarios, although localised phytoplankton blooms may form in poorly flushed arms of the estuary.

Estuaries with large intertidal areas are generally more susceptible to macroalgal blooms, whereas deeper estuaries with small intertidal areas are relatively more susceptible to eutrophication driven by excessive phytoplankton growth. Te Akaaka's large intertidal area (78%) indicates that macroalgal blooms are more likely than phytoplankton blooms.

Table 8-2: Dilution modelling calculations for Te Akaaka at a mean inflow of 18.5 m^3/s. These values are used to derive the estuary nutrient concentrations for each scenario.

Inflow (m^3/s)	Return flow/ mixing factor	Dilution factor	Mean salinity (ppt)	Flushing time (days)	Ocean nitrogen conc. (mg/m^3)
18.5	0.401	1.87	16.3	0.76	34.7

Table 8-3: CLUES-Estuary estimate of eutrophication susceptibility. Calculated using the CLUES-Estuary tool, applying macroalgae and phytoplankton bandings from Plew, Zeldis et al. (in prep). Nitrogen loading and flow scenarios were provided by ECan for each scenario.

Scenario	5% likelihood percentile				95% likelihood percentile			
	Nitrogen load (T/year)	Estuary potential TN concentration, (mg/m^3)	Macroalgae band	Phyto-plankton band	Nitrogen load (T/year)	Estuary potential TN concentration, 5% likelihood percentile (mg/m^3)	Macroalgae band	Phyto-plankton band
CMP	293	285	C	A	598	565	D	A
GMP	222	220	C	A	504	478	D	A
PC5PA	303	294	C	A	686	645	D	A
PC5PA x 0.5	255	250	C	A	557	545	D	A

Table 8-4: CLUES-Estuary estimate of eutrophication susceptibility using nitrogen loads from CLUES.

Scenario	Nitrogen load (T/year)	Estuary potential TN concentration, (mg/m^3)	Macroalgae band	Phyto-plankton band
CLUES	755	709	D	A

To aid management decisions in Te Akaaka, we present the catchment loadings for N (in tonnes/yr) required to obtain an A, B, C or D grade for macro-algal susceptibility based on the CLUES-Estuary approach (Table 8-5). These loading bands are derived from the potential TN concentration bandings presented in Table 8-1. As described previously, eutrophic state occurs along a continuum, and the thresholds between bands indicate transitional conditions rather than abrupt changes in estuary ecological health. Gradual shifts in eutrophic state will be seen as these thresholds are approached. With this in mind, the loading bands are intended as a guide to what catchment loads would be required to achieve various estuary eutrophic states.

Note that flow has an important influence on the load bands as it affects both the concentration of the inflow and the amount of dilution in the estuary. The load bandings in Table 8-5 will change if flow is increased or decreased from 18.5 m^3/s.

Table 8-5: Annual freshwater N loads to Te Akaaka required to meet each ETI tool 1 band of eutrophication susceptibility from macroalgal growth. Based on the Plew et al. (in prep.) CLUES-Estuary tool.

Mean inflow	Macro-algal banding			
(m^3/s)	Band A (T/yr)	Band B (T/yr)	Band C (T/yr)	Band D (T/yr)
18.5	<42	42 – 100	100 - 320	>320

9 Comparison of susceptibility metrics with observed estuarine state

According to ETI tool 1, the ecological qualities expected from SIDE type estuaries, like Te Akaaka, that have a very high combined ASSETS physical and N-load susceptibility are:

- Significant, persistent stress on a range of aquatic biota.
- A likelihood of extinctions of keystone species and loss of ecological integrity.
- Algal-dominated, turbid systems where seagrass is absent or reduced.

The latter point is in partial agreement with the results of the CLUES-Estuary eutrophication susceptibility assessment for Te Akaaka. The description of a turbid system is less applicable to estuaries like Te Akaaka, where flushing times are short and intertidal area is high; such estuaries are more susceptible to eutrophication through high macroalgal growth.

These results are in general agreement with recent ecological and water quality assessments of the estuary. Time-series of nutrient concentrations from two locations (Figure 9-1) show higher TN near one tributary (Taranaki Creek) than near the mouth (Figure 9-2). The lower salinity at the mouth (data not shown) indicate that the estuary contained predominantly river water at the time of sampling. Data from near the estuary mouth site likely better indicate estuary-averaged nutrient concentrations. Total nitrogen concentration averaged 378 mg/m3 over ten years (18 Sep 2007-6 Dec 2017), and 274 mg m^3 for the most recent two years (3 December 2015 to 6 December 2017). However, when we compare our calculated estuarine potential N concentration (based on CLUES loading data) to time series of nutrient concentrations data from inflows to Te Akaaka (provided by ECan), the calculated estuarine potential N concentration is much higher than the mean inflow in the Ashley River/Rakahuri, which under present conditions we estimate contributes over 90% of the nitrogen loading to the estuary. The mean concentration at the monitoring site at the river mouth (378 mg/m^3) is also higher than a current flow-weighted concentration averaged across all the inflows (277 mg/m^3). This is a counter-intuitive finding, suggesting that the monitoring site may be influenced by high nutrient concentrations originating from point sources or other inflows such as groundwater (Stewart, Bryan et al. 2018).

Figure 9-1: Approximate locations of nutrient sampling stations in Te Akaaka. Note that the location and width of the estuary mouth changes over time, and so the estuary mouth sampling site also changes position through time.

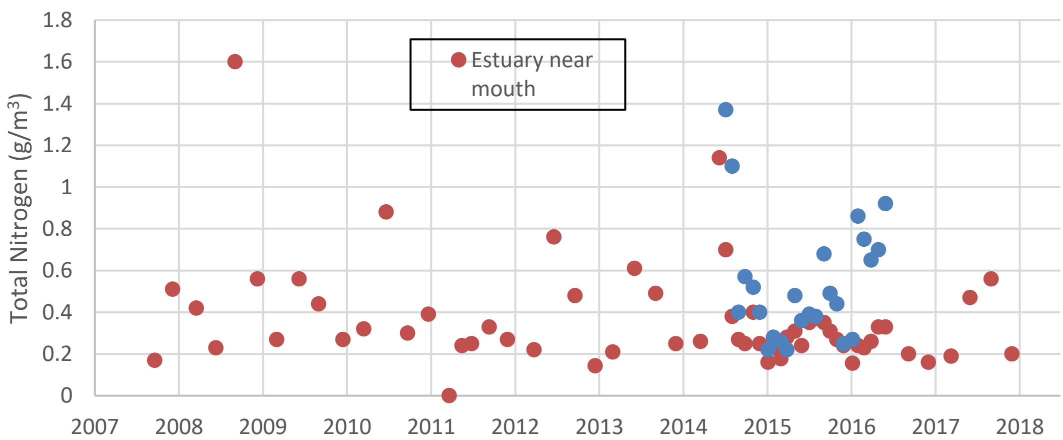

Figure 9-2: Total nitrogen concentrations at two locations in the estuary. Data provided by ECan.

The results presented here are also in accordance with the findings of Bolton-Ritchie (2016) who observed that total dissolved N (TDN) concentrations at the Taranaki Creek inflow site frequently exceeded regional water quality standards (Environment Canterbury 2012). We note also that these TDN concentrations were substantially above the average of all sites monitored by regional councils in shallow, intertidal-dominated estuaries nationally (Dudley, Zeldis et al. 2017). Bolton-Ritchie (2016) also observed that significant areas of the estuary were covered in macroalgae, as expected based on the ASSETS and CLUES-Estuary assessments detailed above.

We suggest that increased future concentrations of nitrogen in this estuary may lead to increased macroalgal growth, and, based on these results, both consideration of the impact of these increases on the estuary and continued regular monitoring of Te Akaaka's ecological condition are warranted.

10 References

Bolton-Ritchie, L. (2016) Ecological and water quality assessment, Ashley River/Rakahuri - Saltwater Creek Estuary (Te Akaaka).

CSIRO (2011) CSIRO Atlas of Regional Seas (CARS). www.cmar.csiro.au/cars.

Dudley, B.D., Zeldis, J., Burge, O. (2017) New Zealand Coastal Water Quality Assessment. *NIWA report to Ministry for the Environment*, 2016093CH.

Elliott, A.H., Semadeni-Davies, A.F., Shankar, U., Zeldis, J.R., Wheeler, D.M., Plew, D.R., Rys, G.J., Harris, S.R. (2016) A national-scale GIS-based system for modelling impacts of land use on water quality. *Environmental Modelling & Software*, 86: 131-144. http://dx.doi.org/10.1016/j.envsoft.2016.09.011.

Environment Canterbury (2012) Regional Coastal Environment Plan for the Canterbury Region (RCEP) 2012. (incorporating plan changes 1, 2, and 4, and deleting all references to Restricted Coastal Activities).

Etheridge, Z. (2018) Nitrate concentration and loads in Te Aka Aka memo.

Howarth, R.W., Marino, R. (2006) Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: Evolving views over three decades. *Limnology and Oceanography*, 51(1part2): 364-376. 10.4319/lo.2006.51.1_part_2.0364

Hume, T., Gerbeaux, P., Hart, D., Kettles, H., Neale, D. (2016) A classification of New Zealand's coastal hydrosystems, CR 254: 120. http://www.mfe.govt.nz/publications/marine/classification-of-new-zealands-coastal-hydrosystems

Larned, S., Snelder, T., Unwin, M., McBride, G., Verburg, P., McMillan, H. (2015) Analysis of Water Quality in New Zealand Lakes and Rivers. *NIWA Client Report* MFE15503: 73.

Luketina, D. (1998) Simple Tidal Prism Models Revisited. *Estuarine, Coastal and Shelf Science*, 46(1): 77-84. http://dx.doi.org/10.1006/ecss.1997.0235

Plew, D., Dudley, B., Bind, J. (2017) Canterbury region estuary eutrophication susceptibity assessment. *NIWA Client Report*, 2017154CH: 26. https://api.ecan.govt.nz/TrimPublicAPI/documents/download/3208268

Plew, D.R., Zeldis, J., Dudley, B., Robertson, B., Stevens, L. (in prep) Predicting estuary eutrophication susceptability using a dilution modelling approach: New Zealand.

Plew, D.R., Zeldis, J.R., Shankar, U., Elliot, A.H. (2018) Using simple dilution models to predict New Zealand estuarine water quality. *Estuaries and Coasts*, in press.

Robertson, B.M., Stevens, L., Robertson, B., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T., Oliver, M. (2016a) NZ Estuary Trophic Index Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data. *Prepared for Environlink Tools Project: Estuarine Trophic Index*: 47. http://envirolink.govt.nz/assets/Envirolink-reports/R10-

120NZ20Estuary20trophic20index20Screening20Tool20120-20Determining20eutrophication20susceptibility20using20physical20and20nutrient20load20data.PDF

Robertson, B.M., Stevens, L., Robertson, B., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Oliver, M. (2016b) NZ Estuary Trophic Index Screen Tool 2. Determining Monitoring Indicators adn Assessing Estuary Trophic State. *Prepared for Environlink Tools Project: Estuarine Trophic Index*: 68.

Stewart, B.T., Bryan, K.R., Pilditch, C.A., Santos, I.R. (2018) Submarine Groundwater Discharge Estimates Using Radium Isotopes and Related Nutrient Inputs into Tauranga Harbour (New Zealand). *Estuaries and Coasts*, 41(2): 384-403. 10.1007/s12237-017-0290-6

Zeldis, J., Plew, D., Whitehead, A., Madarasz-Smith, A., Oliver, M., Stevens, L., Robertson, B., Burge, O., Dudley, B. (2017a) The New Zealand Estuary Trophic Index (ETI) Tools: Tool 1 - Determining Eutrophication Susceptibility: Ministry of Business, Innovation and Employment Envirolink Tools Contract : C01X1420 https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/

Zeldis, J., Plew, D., Whitehead, A., Madarasz-Smith, A., Oliver, M., Stevens, L., Robertson, B., Burge, O., Dudley, B. (2017b) The New Zealand Estuary Trophic Index (ETI) Tools: Tool 1 - Determining Eutrophication Susceptibility using Physical and Nutrient Load Data. Ministry of Business, Innovation and Employment Envirolink Tools: C01X1420. https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/