Nutrient Loads to Protect Environmental Values in Waituna Lagoon, Southland NZ.

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Introduction

Waituna Lagoon is a brackish, intermittently closed open lake/lagoon (ICOLL) in Southland (New Zealand; 46.5º latitude) approx. 20 km to the east of Bluff. In common with most ICOLLs, when Waituna is closed there is no tidal interaction and behaves as terminal lake, with water levels changing in response to catchment runoff, direct rainfall, evaporation, leakage through the barrier beach and groundwater inflows and outflows (Robertson et al. 2011). ICOLLs are recognised as the most sensitive type of estuary to inputs of nutrients and sediments, due to long water residence times and limited interaction with the ocean (Haines et al. 2006, Scanes et al. 2007, Robertson et al. 2011).

In the last 10 years the ecological condition of Waituna has been in rapid decline. It has changed from a high value seagrass (*Ruppia*) dominated state to a more degraded condition with nuisance epiphyte and algal blooms. Consequent sediment anoxia is causing additional stress to the keystone *Ruppia* species (Robertson et al. 2011)

Current expert opinion is that unless urgent intervention occurs, the lagoon will almost certainly undergo a rapid change in state to an even more degraded phytoplankton dominated system (e.g. algal bloom), which would endanger the *Ruppia* community and change the fundamental values and character of the lagoon (Lagoon Technical Group (LTG) 2011, cited in Robertson et al. 2011). These types of system changes often represent a hysteresis function (Petraitis and Dudgeon 2004; Webster and Harris 2004). In an hysteresis, after an initial trajectory of change, only a small additional change in a parameter variable (e.g. nutrient input) can result in a catastrophic shift in a state variable (e.g *Ruppia* decline, phytoplankton increase). The catastrophic shift can not be reversed by a correspondingly small reversal of the parameter variable; i.e. the trajectory of recovery is very different from the pathway of decline (Petraitis and Dudgeon 2004, Lester and Fairweather 2008). In simple terms: if the system tips, the causal factor needs to be changed by a large amount to bring it back – this means that it is much more expensive and difficult to restore than it is to protect.

Intermittently closed or open lakes and lagoons (ICOLLs) are common along the NSW coast (Roy et al. 2001, Haines et al. 2006, Scanes et al.2007) and have been the subject of extensive study, particularly with respect to the impacts of catchment derived nutrients on estuary condition (Baginaska et al.2004, Robson et al. 2004, Webster and Harris 2004, Sanderson et al.2006, Scanes et al. 2007, dela-Cruz 2009, Sanderson 2008, Scanes et al. 2008, Sanderson and Coade 2010, Roper et al. 2011). Dela Cruz and Scanes (2009) described a Coastal Eutrophication Risk Assessment Tool (CERAT) for NSW. CERAT contains 184 catchment models and 184 estuary models to cover the major estuaries along the NSW coast. NSW also has an extensive estuary health monitoring program, sampling health indicators (chlorophyll concentrations, turbidity, dissolved oxygen, seagrass and macrophyte abundance) and explanatory variables (temperature, salinity, nutrient concentrations) during summer in approximately 35 estuaries each year. Data are available from this program for 130 estuaries.

The CERAT models provide a basis to categorise the disturbance levels of estuaries and to explore relationships between catchment loads and estuary condition.

The objective of this report is to recommend interim nutrient load targets to protect the environmental values of Waituna Lagoon. These loads will be based on analyses of loads to similar NSW lagoons.

Methods

NSW Loads

Loads for NSW estuaries were calculated by deriving flows from rainfall and catchment data and multiplying by a landuse/soil/slope specific pollutant generation rate (Dela-Cruz and Scanes 2009).

Flows were obtained from a model known as 2CSalt. The model was chosen because it was developed specifically for Australian catchments and is currently being incorporated into new catchment modelling tools for Australia (*e.g.* eWater's Source Catchments). 2CSalt is considers the main hydrological processes within a catchment, including spatial and temporal variability arising from different land use practices, soil types, climate and terrain. 2CSalt integrates the outputs of existing paddock scale unsaturated zone models with its groundwater model to produce whole of catchment predictions of surface flows, groundwater flows and total flows of water and salt. 2CSalt produces monthly outputs, but for CERAT the monthly outputs were summed to produce the annual flows. The model was run for the period between 1975 and 2008 to provide an average long term ‘steady state’ annual flow for each subcatchment. The model outputs were tested on measured flow data available for the NSW Coast and the model predicted the measured values very well (r^2 = 0.98) (Littleboy et al. 2009).

To estimate the nutrient and sediment exports from each subcatchment, the surface flows were multiplied by measured (median) nutrient and sediment concentration data obtained from the published scientific literature or from past NSW Department of Environment and Climate Change monitoring projects. Concentration data are expressed as event mean concentrations (EMC) and dry weather concentrations (DWC). The EMC is equivalent to the mean concentration of nutrients or sediments in runoff from a rain event. The DWC is equivalent to the mean concentration of nutrients or sediments in the river or stream during dry weather or baseflow conditions. Only total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) EMCs and DWCs were used for the modelling because these were the dominant forms of catchment export data found in the literature. To account for the limited and large variation in the EMC and DWC data, bootstrap techniques (Monte Carlo random sampling of the original data to produce a new data set, Baginska et al. 2003) were used to derive EMC and DWC median, means and confidence intervals for each land use type.

The annual nutrient and sediment loads for each subcatchment were further divided by the area of the subcatchment to produce what is commonly termed a ‘generation rate’ or an ‘export coefficient’, which is the rate at which nutrients and sediments from each land use type are exported to the river or stream. The export coefficients are expressed as kilograms of TN, TP or TSS per square kilometre of catchment per year (kg/km^2/y) and essentially summarise the outputs of the 2CSalt, EMC and DWC calculations described above. In CERAT, the export coefficients were used to define parameters in an export coefficient model, which was developed for each subcatchment:

$$L = \sum_{i=1}^{n} E_i (A_i)$$

Where L = total export of nutrients or sediments from a subcatchment

i = land use type

E = export coefficient ($kg/km^2/y$)

A = area of land use type (km^2)

Catchment models were run for each of the NSW coastal catchments under current conditions to estimate current loads. Each model was then run with landuse set to native vegetation. This produced catchment loads under pre-european conditions. Estuary loading rates (mass/ km^2 waterway area) were calculated for each scenario. An index of catchment disturbance was created by taking the ratio of current:pre-european loading rates. Load ratios less than 1.5 were deemed to represent a low level of catchment disturbance, moderate disturbance were load ratios were between 1.5 and 2.5 and high disturbance was a load ratio greater than 2.5 (Roper et al. 2011). Estuaries were categorised into 5 basic types based on flushing rates and dilution (a function of the ability of the estuary to contain runoff from a rainfall event equal to 10% of 1:10 yr event). The types are drowned river valley, river estuary, coastal lake (large), coastal lagoon (medium) and coastal creek (small). For the analysis described here, only data from coastal lakes and lagoons were used because these types of estuary are most like Waituna in their size, shape, entrance behaviour and flushing.

The validity of the catchment disturbance index was tested against an independent set of estuary health data from the monitoring. It was found that chlorophyll concentrations and turbidity were significantly greatest in highly disturbed catchments (ANOVA $p < 0.05$) and significantly least in low disturbance catchments (ANOVA $p < 0.05$). Chlorophyll and turbidity in estuaries with moderately disturbed catchments were always intermediate, but not always significantly so. There was good correlation between elevated concentrations of chlorophyll and turbidity and other indicators of estuary health such poor seagrass condition and fish community structure.

We can thus summarise estuary status as a function of catchment disturbance as follows:

- Reference condition: clear waters with minimal algal blooms, strong seagrass growth and good fish assemblages
- Moderately Disturbed: some eutrophic symptoms but still supporting healthy seagrass and fish communities
- Highly Disturbed: algal dominated, turbid systems, seagrass absent or reduced with associated changes in fish assemblages

Results

Modelled catchment loads of NSW estuaries for coastal lagoons and coastal lakes were selected for further analysis. Fifty seven estuaries were used for the analysis, 15 were highly disturbed, 20 moderately disturbed and 22 in reference condition. All these estuaries are intermittently opening and closing lagoons and are thus very similar to Waituna Lagoon.

Ensuring Relevance to Waituna

The amount of tidal exchange is an important factor in assessing the effects of catchment derived nutrients. Tidal prisms (the amount of water that enters or leaves the lagoon during a tidal cycle) and flushing rates were used to compare NSW estuaries with waituna Lagoon. Tidal prisms were available for about one third of these estuaries and ranged between 176 and 3,800 ML per tidal cycle. Waituna's mean tidal prism (average 2008, 2009, 2010; Greg Jenkins pers comm.) was 1373 ML per tidal cycle, which is about in the middle of the range from NSW.

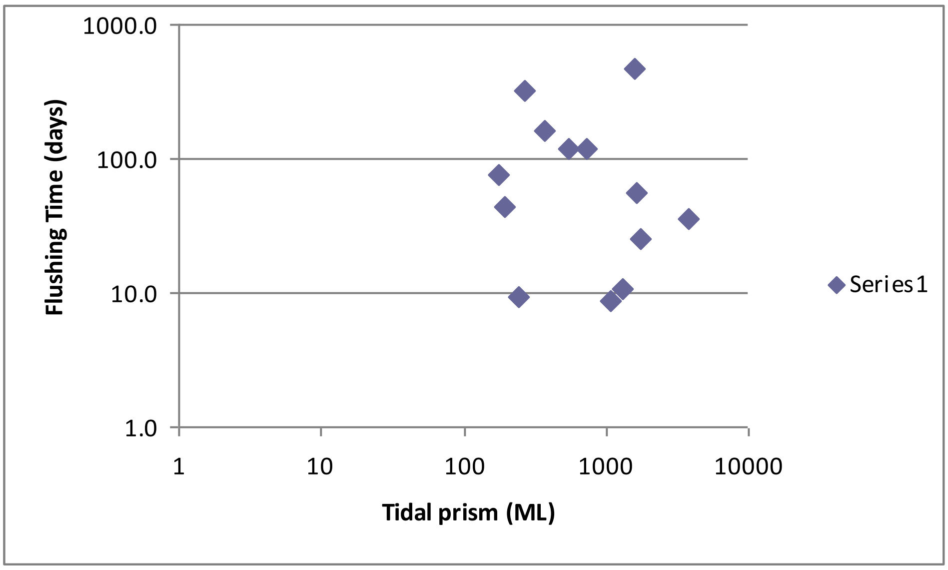

Figure 1 Tidal prisms and flushing times of a sub-set of the estuaries used for calculations of load targets. Mean tidal prism for Waituna was 1373 ML.

The NSW estuaries used for the derivation of target loads spanned a latitudinal (and hence temperature) range from 29°S to 37.5°S (Fig 2). There was no trend for chlorophyll concentrations to increase or decrease with latitude (regression, $r^2 < 0.03$; $p > 0.05$) suggesting that regional temperature is not a strong control on algal abundance. Robertson et al (2011) showed that algal blooms could occur in Waituna Lagoon at any water temperature. This indicates that there is no temperature induced senescence for Waituna algae and that they are able to react to nutrient inputs or other stimuli at any time of the year. For these reasons it is not expected that the greater latitude of Waituna (46.5°S) will affect the relevance of this analysis.

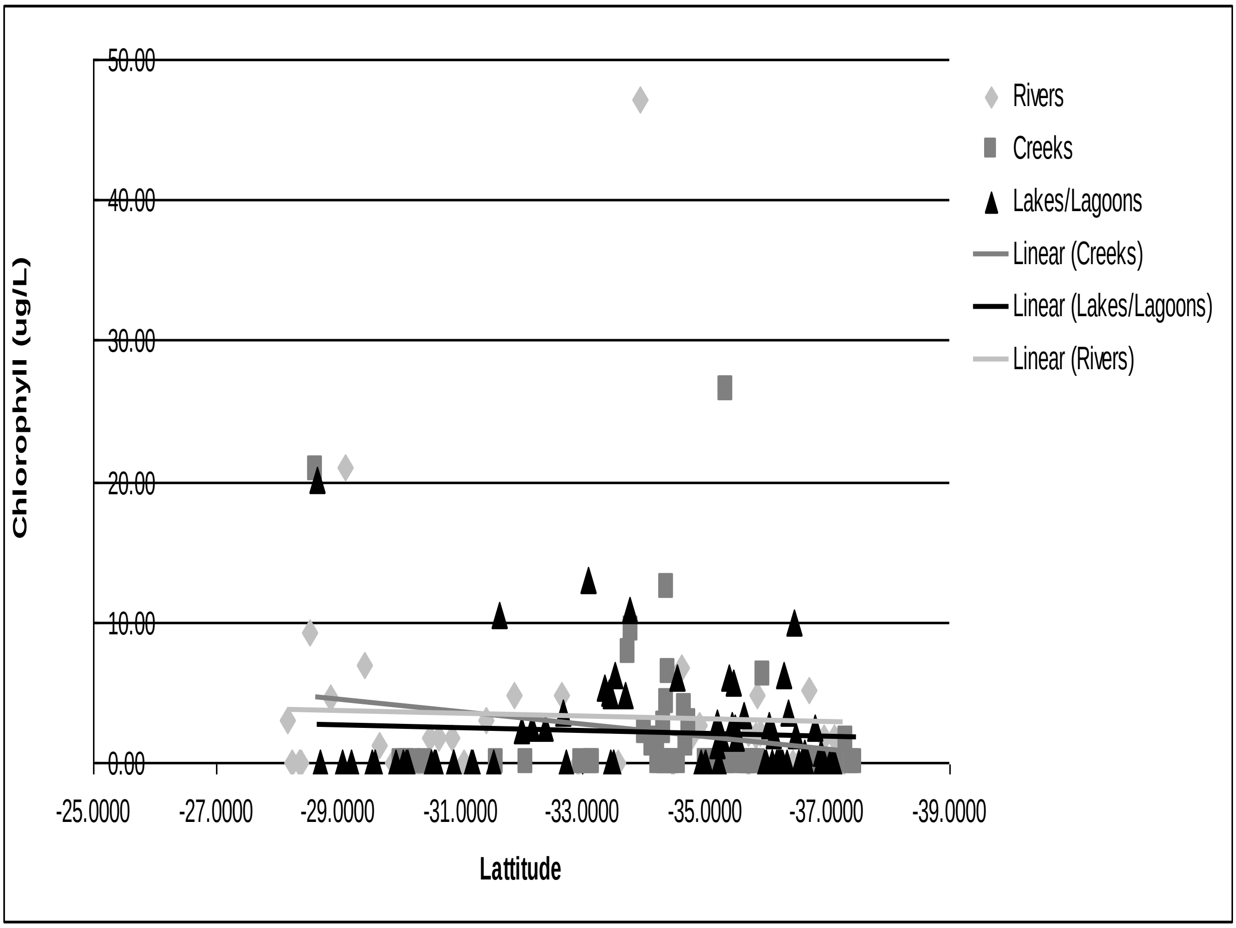

Figure 2 Regression between latitude and chlorophyll concentration for three classes of estuary in NSW. There was clearly no effect of latitude (and hence regional temperature) on the propensity for algal growth.

Load Targets

NSW estuaries selected for analysis were divided into the three disturbance classes and mean (se), median, and 95% confidence intervals calculated for each class (Table 1). The large difference between mean and median TSS values for high disturbance estuaries is a consequence of the presence of very erodable soils in a just a couple of estuaries.

Table 1 Statistics for modelled catchment loads of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) from NSW Lakes/Lagoons. Units are tonnes/km^2/yr. High, Medium and Low refer to levels of catchment disturbance. No TN and TP load data were available for two of the high disturbance estuaries.

TN	n	Mean	s.e.	Median	95% CI
High	13	12.76	3.34	8.14	6.55
Medium	20	9.01	2.04	5.91	3.99
Low	22	3.85	0.64	2.68	1.25

TP	n	Mean	s.e.	Median	95% CI
High	13	1.05	0.21	0.69	0.41
Medium	20	0.57	0.09	0.49	0.18
Low	22	0.21	0.03	0.17	0.06

TSS	n	Mean	s.e.	Median	95% CI
High	15	1799.13	991.96	187.20	1944.20
Medium	20	124.27	23.97	97.83	46.98
Low	22	54.86	7.85	50.35	15.38

Table 2 Current Loads to Waituna Lagoon (adapted from Robertson et al. 2011, Table 5, page 4)

Year	TN (t/yr)	TP (t/yr)	Areal N load to Lagoon (tN/km2/yr)	Areal P Loading to Lagoon (tP/km2/yr)
Waituna TOTAL LOADS 2008	200	5	15	0.37
Waituna TOTAL LOADS 2009	230	7	17	0.52
Waituna TOTAL LOADS 2010	250	10	19	0.74

Conclusions and Recommendations

The ecological condition of Waituna lagoon is clearly deteriorating (Stevens and Roberston 2007, Robertson et al. 2011). Eutrophication and loss of benthic macrophytes is occurring in Waituna, most probably as a result of excessive nutrient loading from the catchment exacerbated by salinity stress, desiccation and loss of habitat from the opening of the lagoon to the sea to alleviate farm inundation. There is a concern that if this trajectory is allowed to continue, then a state change from clear, healthy seagrass dominated community to a turbid pelagic dominated community is a real possibility. If this occurs it will have an extensive impact on the environmental and cultural values of the lagoon. As indicated previously, a common feature of changes of state from benthic dominance to pelagic dominance is a hysteresis response. Given this, it is clearly preferable and considerably cheaper to take action now to prevent the change of state from occurring, than to try and restore the lake in the future.

Comparisons were made between the loads expected for moderately and highly disturbed estuaries in NSW and the estimates for Waituna for 2010. The 2010 estimates for Waituna were used because they are the most recent and the data show a trend for loads to be increasing each year in Waituna.

The TN loads for Waituna estimated for 2010 (Table 2) are well in excess of the mean (and median) values for estuaries with highly disturbed catchments (TN, 19 (Waituna) c.f 12.76 (mean NSW)) and the consequences are evident in the current loss of environmental values being experienced in Waituna. TP loads for Waituna were however slightly lower than highly disturbed NSW estuaries (0.74 (Waituna) c.f 1.05 (mean NSW)). This is most probably a consequence of slightly differing landuses resulting in different proportions of nutrients being generated. It also suggests that Waituna is particularly sensitive to increased P loads, showing symptoms of degradation and lower loads than similar systems from NSW.

The analysis of catchment loads from similar NSW lagoons would suggest that the loads required to maintain a moderate environmental quality (some eutrophic symptoms but still supporting healthy seagrass and fish communities) would be total nitrogen and total phosphorus loads of 9 and 0.57 t/km^2/yr (respectively). This represents a 52% reduction in TN load and a 23% reduction in TP load over 2010 conditions in Waituna Lagoon (Table 3).

In light of the somewhat lower TP load in Waituna, it may be tempting for decision makers to consider reductions in just one nutrient (either N or P), but a recent review by Glibert et al. (2011) has shown that strategies which manage a single nutrient, rather than both N and P, have the potential to significantly skew and alter ecological assemblages resulting in a wide range of unintended consequences including facilitation of invasive organisms.

Table 3 Comparison of TN and TP loads (t/km^2/yr) from NSW and Waituna Lagoon.

	Waituna 2010	NSW mean (moderate disturbance)	% reduction required	NSW mean (low disturbance)	% reduction required
Total Nitrogen	19	9	52%	3.9	79%
Total Phosphorus	0.74	0.57	23%	0.21	72%

Table 4 Recommended interim TN and TP load targets (t/km^2/yr) to maintain Waituna Lagoon in a moderate ecological condition (some eutrophic symptoms but still supporting healthy seagrass and fish communities)

	Interim Target Loads for Waituna Lagoon	% reduction required from current Waituna loads
Total Nitrogen	9	52%
Total Phosphorus	0.57	23%

Overall Conclusion

In order to prevent a drastic and potentially irreversible change to the ecological character of Waituna Lagoon, it is recommended that, as an interim step, the mean nutrient loads of both N and P associated with NSW estuaries that have moderately disturbed catchments be adopted as interim load targets (Table 4) while a more detailed assessment is made of the ecological condition of Waituna Lagoon and it's response to stressors such as catchment derived nutrients, entrance manipulation and salinity stress.

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