# Linking land-use change scenarios with predicted water quality improvements within the GBR lagoon

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## Project Results

### *Objective:*

To develop a methodology that facilitates the spatial linkage between end-of-catchment water quality scenarios and the follow-on flood plume dilution across the GBR lagoon.

### *Introduction:*

Previous analysis undertaken within Project 2.5i.4 has highlighted the potential for regional water quality on the GBR to contribute to the differential susceptibility of specific reef locations to thermal stress. In particular, the concentration of dissolved inorganic nitrogen (DIN) has been suggested to be a particularly relevant water quality parameter. Within the inner-shelf region of the GBR lagoon, the availability of DIN is dominated by terrestrial sources (Furnas et al. 1995; Furnas 2003). For the many catchments that drain into the GBR lagoon (Fig. 1), DIN is typically sourced from fertilized cropping lands (viz. sugarcane / bananas) that tend to be located within close proximity of the coast (Brodie et al. 2003). Given the short travel times and absence of significant reservoirs, it is not surprising that the lagoon concentrations of DIN reaches peak annual values during summer flood events, associated with tropical cyclones and monsoon rainfall (Brodie et al. 2007).

In this report, I outline a modelling methodology that enables end-of-river values of DIN to be spatially extrapolated across the inner-shelf region of the GBR lagoon. Importantly, this allows the end-of-river outcomes of modelled land-use improvement scenarios to be tested for their relevance in terms of improving inshore reef water quality. To demonstrate this new modelling capability, I consider two recently modelled land-use scenarios for the future management of sugarcane land within the Tully River Basin (i) Scenario B1 = 18% reduction in fertiliser N application, (ii) Scenario B2 = 35% reduction in fertiliser N application. For interested readers, further information regarding the development of the scenarios can be found in Armour et al. 2007.

### *Modelling Background:*

Measures of phytoplankton biomass usually provide a better indicator of the nutrient status of reef waters than actual measured nutrient concentrations, since fast growing phytoplankton populations quickly respond to, and subsequently deplete, all available stocks of bio-available nutrients; resulting in localised 'blooms' in population densities (Edwards et al., 2003; Furnas et al., 2005). The photosynthetic pigment, chlorophyll *a* (Chl *a*), is the most commonly used measure of phytoplankton biomass. For the lagoonal waters of the GBR, previous studies have shown that that the availability of DIN usually limits summer phytoplankton biomass (Furnas et al., 2005), thereby facilitating the development of direct relationships between the plume concentrations of DIN and Chl *a* (Devlin et al. 2001)

Not surprisingly, during summer flood events, DIN concentrations are greatest near the river mouth in undiluted flood plume waters. As plumes spread, mix and age, nutrient concentrations decline as a result of dilution, sedimentation, biological uptake and chemical reactions. For fresh plumes within the GBR lagoon - where biological uptake and chemical interactions have not greatly influenced in situ nutrient levels - DIN concentrations are directly related to the salinity of the plume water, reflecting the degree of dilution by low-nutrient shelf waters (Devlin and Brodie, 2005).

In a recent study, Wooldridge et al. (2006) utilised this *conservative* mixing attribute of DIN to infer the enriching impact of runoff events from the various river systems that drain the GBR catchments – the rationale being that for a given runoff:seawater dilution ratio, any broad-scale differences in the in situ Chl *a* concentration observed between river systems, could largely be attributed to the initial concentration of DIN in the discharging runoff.

Underpinning the analysis of Wooldridge et al. (2006) was the development of a spatially-explicit regression relationship between Chl *a* (response variable) and runoff:seawater dilution (explanatory variable):

$$\text{Chl } a(\theta) = \alpha(\theta) + \beta(\theta)(\text{runoff:seawater dilution}) + \varepsilon \qquad (1.)$$

where $\alpha$ and $\beta$ are location-specific parameters (for which the spatial coordinates are provided by the vector $\theta$) that represent the intercept and slope of the linear regression respectively, and $\varepsilon$ is a residual error term. For a specific location within the GBR lagoon, $\alpha$ represents the background summer level of Chl *a* regardless of any runoff impact, whilst $\beta$ captures the sensitivity of the Chl *a* response to a specific river runoff volume. Conceptually, the scaling behaviour of $\beta$ performs in a similar fashion to a nutrient concentration gradient, i.e., as $\beta$ increases, the level of nutrient enrichment (per unit runoff input) increases. Figure 2 demonstrates the spatial variability of $\beta$ over the entire length of the runoff mixing zone of the GBR lagoon – with the value reducing by a factor 5-10 from south–north, indicative of lower concentrations of DIN (per unit runoff volume) for river discharges in the northern areas of the GBR lagoon compared to southern areas. The close connection between the south–north 'enrichment' gradient of $\beta$ and the flood concentrations of DIN for the regional river systems (Fig 3.) is well captured by the relationship:

$$\beta = 2.6669 \ln [\text{DIN (ug/L)}] - 10.597 \qquad (2.)$$

***Extended Methodology:***

In this study, the transform relationship identified between end-of-river DIN and lagoonal $\beta$ (Eqn. 2) is utilised as the basis for an extrapolative methodology that enables river-specific reductions in DIN concentration to be interpreted in terms of improvements in water quality within the GBR - as indicated by Chl *a* (ug/L) levels within the lagoon. In theory, the modelling process is straightforward: (1.)
Utilise Eqn. 2 to alter the river-specific value of $\beta$ to reflect the altered end-of-river DIN concentration (ug/L), (2.) Update the spatial extrapolation of $\beta$ (i.e. Fig. 2) to reflect the river-specific changes in the integrated plume enrichment, and (3) Utilise Eqn 1. to re-calculate the new lagoonal values of Chl *a*. Unfortunately, Step 2 is complicated by the fact that detailed information on the plume extent (i.e. dilution) for each specific river is difficult to predict with certainty. The problem arises from the fact that during moderate to large runoff events, the individual plumes tend to merge together into a single 'integrated' plume (King et al. 2001; 2002). As such, the problem becomes one of identifying the contribution that each individual river plume makes to the merged plume dilution (and enrichment) at a specific location in space. The most elegant solution to this problem would be to utilise a flood plume model to undertake river-specific simulations whilst keeping the other rivers artificially 'turned-off'. In this way, the integrated value of $\beta$ needed for Step 2 would result from summing together the proportional dilution and enrichment values for each contributing river at ever point within the flood plume mixing zone, i.e.,

$$\beta_{\text{integrated}} = \sum \text{Prop}_{\text{river(i)}} \times \beta_{\text{river(i)}} \qquad (3.)$$

As a compromise to not having access to this river-specific plume information, a number of simplifying assumptions were made based on the previous flood plume considerations outlined in Devlin et al. 2003.

*Flood plume dilution zone*: a specific 'integrated' flood plume dilution was chosen that represented a 75$^{th}$ percentile (~1 in 15 year) flood event (Fig. 4). The choice of such a flood dilution zone, attempts to capture the situation where all rivers are discharging. For such an event, the Burdekin River plume will be a significant contributor to the integrated flood plume dilution, even within the Wet Tropics.

*Inverse distance factor*: Within the flood plume dilution zone, an inverse distance (1/d) factor was utilised to weight the proportional contribution of each individual river. For the river plumes arising from the rivers of the Wet Tropics and Far Northern regions, a maximum dilution range of 120 km was adopted. For the Burdekin River plume, the maximum dilution range was extended out to 300 km in an effort to reflect the considerably larger river discharge volume arising from this catchment.

*Plume direction factor*: Plume waters are typically observed to spread out in a northerly (NW, N, NE) direction driven by the prevailing south-easterly wind regime and Coriolis effects. Movement to east is less frequent, whilst movement of waters to the south of the river mouth is least common. To account for these preferential plume directions, the inverse (1/d) distance factor was modified accordingly: For the mixing zone at an angle of 180$^{o}$-045$^{o}$ the 1/d weighting factor was left unaltered. For 045$^{0}$-90$^{o}$, the 1/d weighting factor was increased by 50%. For 90$^{0}$-135$^{0}$, the 1/d weighting factor was increased by 75%. Whilst for 135$^{0}$-180$^{o}$ the 1/d weighting factor was increased by 66%.

### *Linkage land-use scenarios with GBR water quality*

Landscape nutrient budget models have been developed for various GBR catchments; thus facilitating end-of-river estimates for DIN subject to scenario selection for future land-use change and management (see e.g., Brodie et al. 2003; Armour et al. 2007). It is not the intent of this document to consider the theory and assumptions that underpin these predictions. Instead, attention is focussed on the linkage of these land-use scenarios with the flood plume modelling methodology that has been outlined above. In particular, consideration is given to the *potential* level of improvement in lagoon water quality that may be achieved in response to land-use management strategies that would seek to reduce fertiliser N application on sugarcane cropping areas. Recent fertiliser reduction scenarios developed for the Tully River basin (see, Armour et al. 2007) provide the basic input for this study.

### *Scenario Modelling: Reduced fertiliser N application in the Tully River basin*

Fertilizer application on sugarcane is a well known source of DIN to the GBR lagoon. For example, although sugarcane cropping is only implemented on ~13% of the total land area in the Tully catchment, model estimates suggest that it contributes disproportionately (77%) to the total DIN load (888 t/year) - which is based on a current fertiliser N application rate of 170 kg/ha/year. Scenario modelling results suggest that reducing this application rate to 140 kg/ha/ year will lower end-of-river DIN in the Tully by ~29% (= Scenario B1). Additional reductions in application rates to 110 kg/ha/year is predicted to further reduce end-of-river DIN by ~59% (= Scenario B2). Application of the methodology developed in this paper allows the follow-on improvements in water quality (i.e. % reduction in Chl a) to be extrapolated across the GBR lagoon for both Scenarios B1 (Fig. 5a) and B2 (Fig. 5b). It is important to remember that these predictions are based on a relatively large (= 75$^{th}$ percentile) flood event. For such an event, the Burdekin and Herbert River are expected to contribute to the DIN load of the Tully River plume – though displaying the result as a percent improvement in Chl *a* standardises for their combined impact.

## Concluding Comments

Future work to be undertaken within Project 2.5i.4 will focus attention upon the extent to which these (and other) demonstrated improvements in water quality can be expected to benefit the inshore ecosystems of the GBR – especially in light of future thermal stress scenarios. For now, it is simply noted that the outlined methodology successfully facilitates a robust spatial linkage between end-of-catchment water quality scenarios and the follow-on flood plume dilution across the GBR lagoon.

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## List of Figures

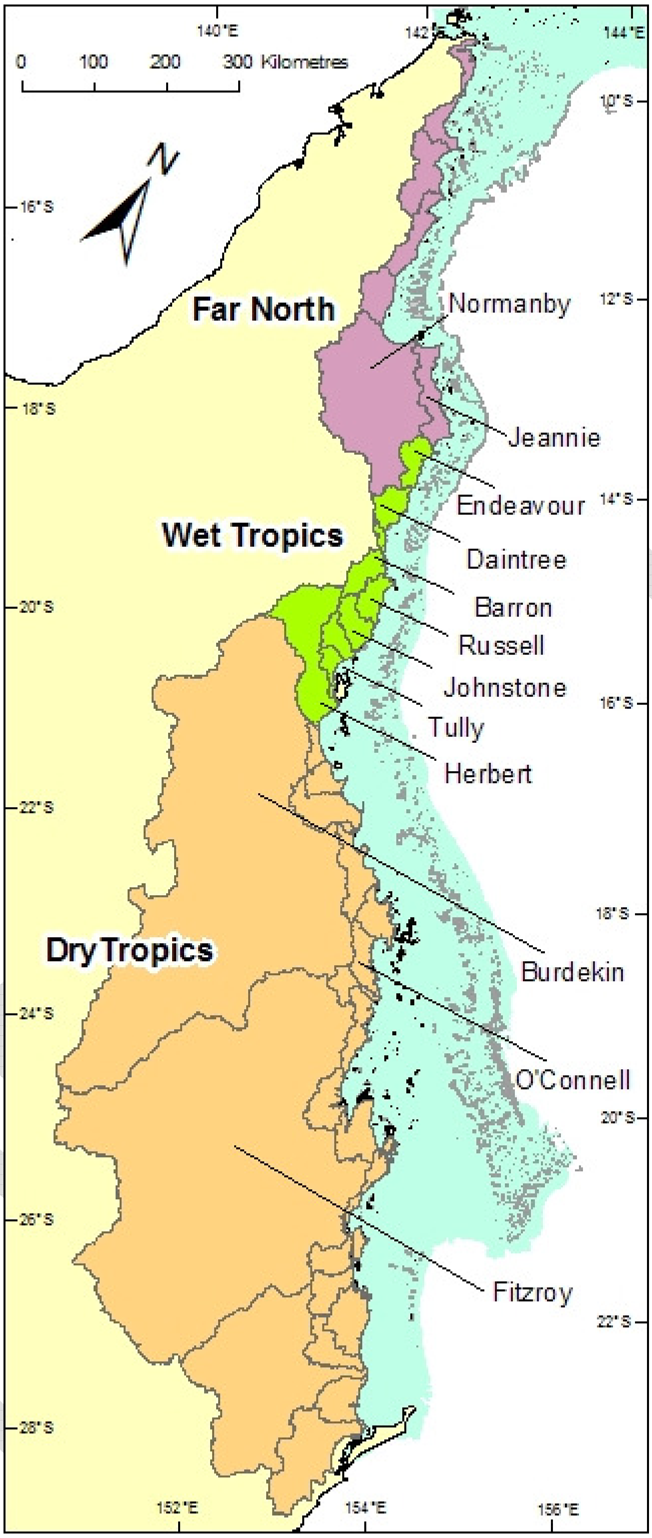


**Figure 1:** The Great Barrier Reef and its catchments

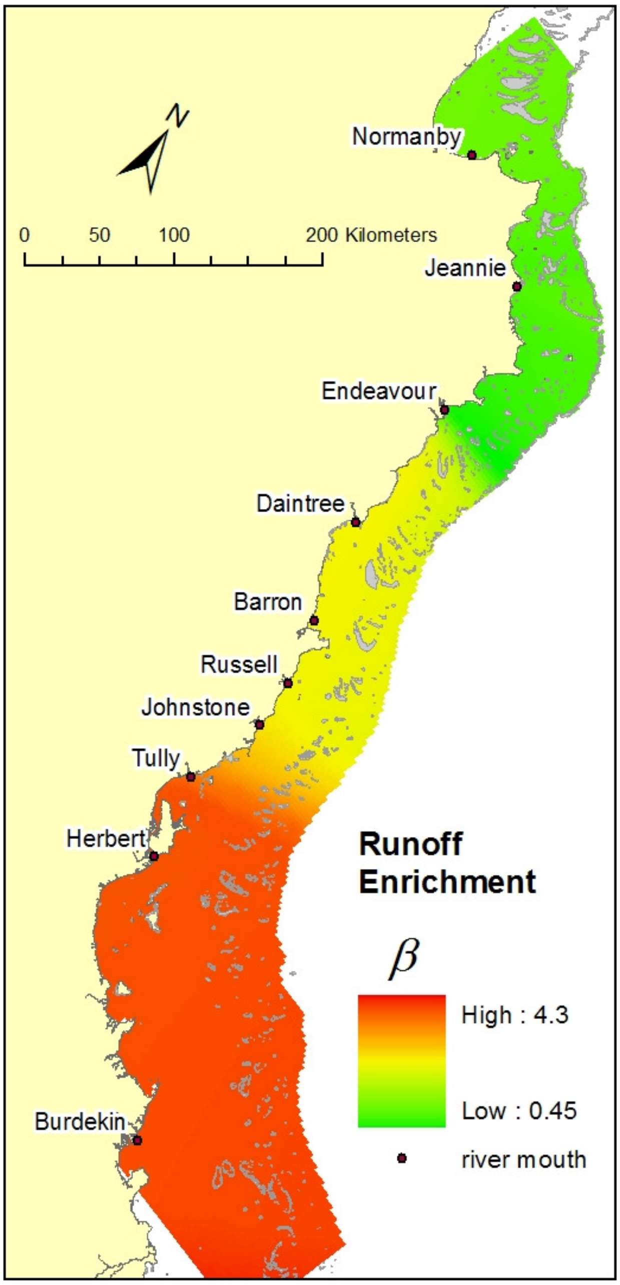


**Figure 2:** Spatial variation in the modelled nutrient enrichment parameter, $\beta$, across the mixing zone of the GBR lagoon.

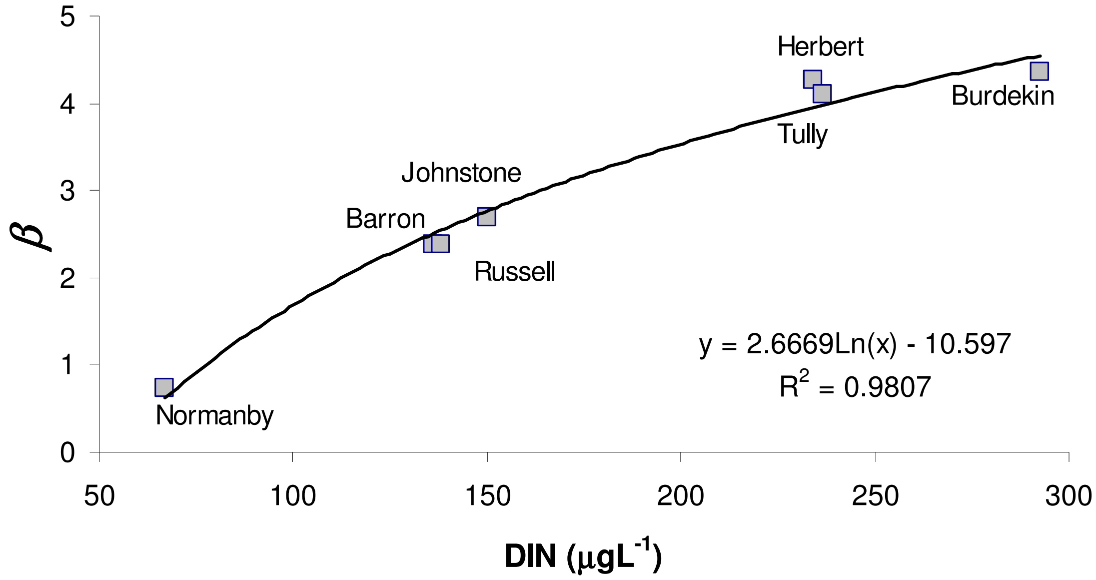


**Figure 3:** Relationship between the modelled nutrient enrichment parameter, $\beta$, and the flood concentration (95th percentile) of DIN for various GBR rivers

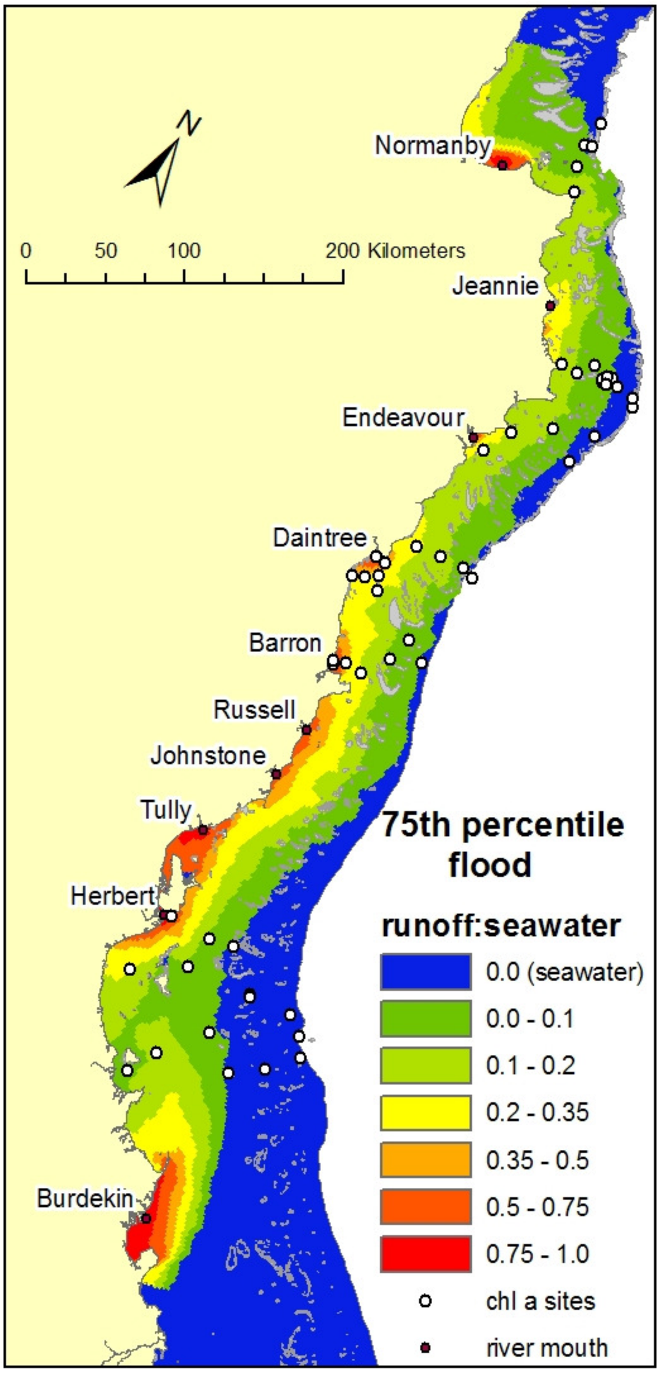


**Figure 4:** Runoff:seawater dilution rates within the GBR lagoon for a 75$^{th}$ percentile flood event. Also shown are the sampling locations of the long-term Chlorophyll *a* monitoring network (Brodie et al., in press).

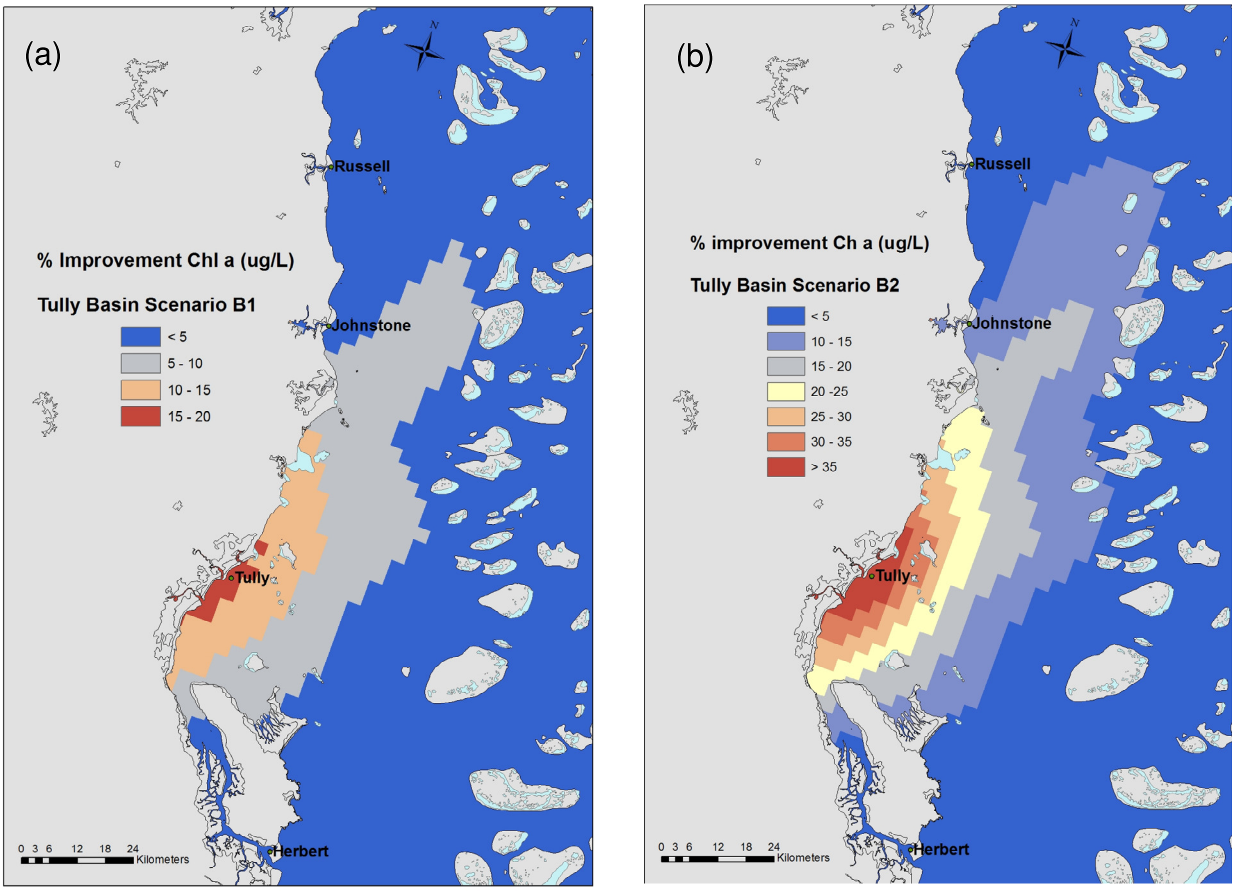


**Figure 5:** Reduction (%) in lagoonal Chl a (ug/L) resulting from lowered fertilizer N application rates in the Tully River Basin: (a) Scenario B1 = 18% reduction, (b) Scenario B2 = 35% reduction