

Clean or green – Nitrogen in temperate estuaries

Nitrogen input thresholds for nutrient enrichment identified.

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Australia's coastal waterways were formed over the past 7000 years, after sea levels rose during the most recent climate warming phase and flooded the continent's river valleys. Continental weathering, sediment discharges and incessant tide and wave action have subsequently shaped the waterways we now see around the coastline.

Coastal waterways of temperate southern Australia are mainly wave-dominated. High wave energy at the southern coastlines of these systems results in the accumulation of sands from the continental shelf into barriers that restrict the discharge of sediments, water and nutrients into the sea.

Estuarine evolution, sediment and nutrient flushing

Some catchments have experienced low sediment erosion rates since the rise of sea level, while others have experienced high rates. These differences also play an important role in shaping coastal waterways (figure 1).

Immature (unfilled) wave-dominated estuaries are characterised by freshwater and sediment run-off, restricted entrances, poor flushing and small tidal ranges. A comparatively large, low-energy central basin is a characteristic feature of immature estuaries (Heap et al 2004; figures 1 and 2a) where phytoplankton productivity is predominant and intertidal sedimentary environments are very small. Lagoons also have restricted entrances but receive only small fluvial discharges from the catchment. Strand plains are beach ridges and dunes that trap 'ponds' of water, which also have restricted entrances and also receive very little fluvial discharge.

ICOLLS (intermittently closed and open estuaries and lagoons) is a term often used to describe immature wave-dominated estuaries, lagoons and strand plains. The residence time of water in these systems is generally longer than 100 days. Some estuaries remain naturally open, while others have training walls at their entrances that keep them permanently open, resulting in typical water residence times of 20 to 100 days.

River-dominated estuaries (figures 1 and 2b) are characterised by higher fluvial discharges and deeper tidal penetration into the estuary and more abundant intertidal habitats including salt marshes, salt flats, mangroves and melaleucas (Heap et al 2004). High-energy channels allow increased flushing of sediment, water and nutrients into the sea. The residence time of water in these systems is highly variable, typically two to 20 days (or longer) depending on season and location within the tidal reaches.

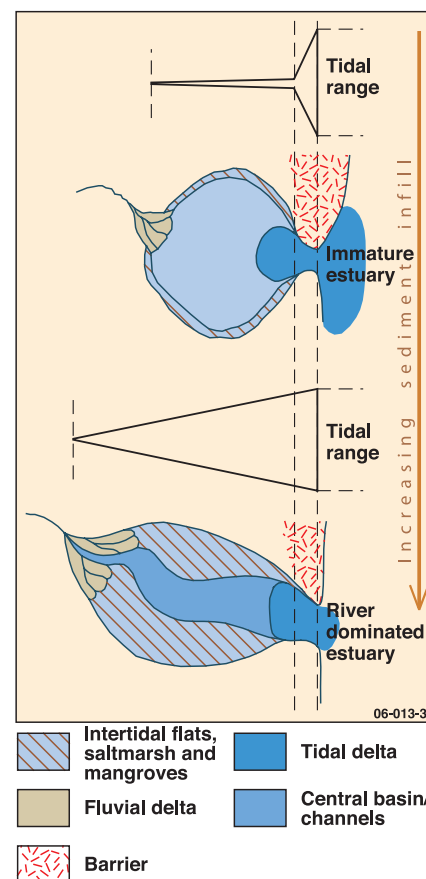
Nitrogen and eutrophication in temperate estuaries

Eutrophication is the process of nutrient enrichment. It is manifested in excessive plant growth, nuisance and sometimes toxic algal blooms, anoxic events such as fish kills, a green appearance and general loss of amenity value. Wave-dominated systems are moderately to very highly susceptible to eutrophication, principally because poor flushing traps sediments and nutrients from the catchment and naturally low turbidity and high light availability stimulate plant growth (figure 3).

Nitrogen is the most important nutrient limiting plant growth and incipient eutrophication in these systems. Geoscience Australia has conducted many surveys of various wave-dominated estuaries to understand nutrient dynamics and identify the key processes controlling nutrient (particularly nitrogen) balances and incipient eutrophication.

The important processes in this nitrogen balance include the following:

- The principal nitrogen input is run-off from the catchment.
- Internal recycling of nitrogen from underlying estuarine sediments can also be a significant internal source of nitrogen in an estuary.
- Flushing to the sea and denitrification in the sediments (a microbial reaction that converts nitrogen in degrading plants into gas, which is lost to the atmosphere) are the two principal nitrogen outputs.



▲ **Figure 1.** Simplified schematic of evolution of wave-dominated systems, showing changing estuarine shapes, sedimentary environments and connectivity with the sea (flushing) with increasing fluvial discharges. (a) Immature estuaries including ICOLLS with low fluvial discharges. (b) River-dominated estuaries with higher fluvial discharges.

- Denitrification efficiency decreases with increasing nitrogen inputs. If denitrification ceases, the internal recycled nitrogen input increases significantly and the potential for eutrophication increases.
- Diatoms—small but dense phytoplankton that rapidly sink into sediments—were found to be an important vector to transport nitrogen to the sediments where denitrification occurs (see 'Diatoms – keeping estuaries clean' in this issue).

Ask ENiD

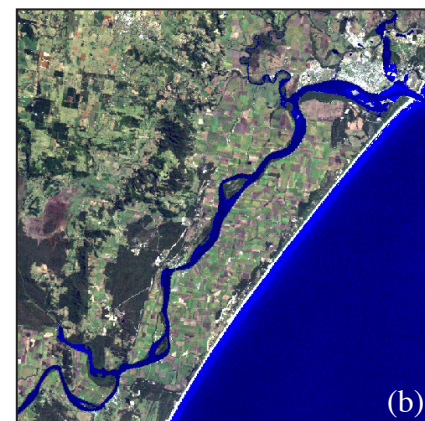
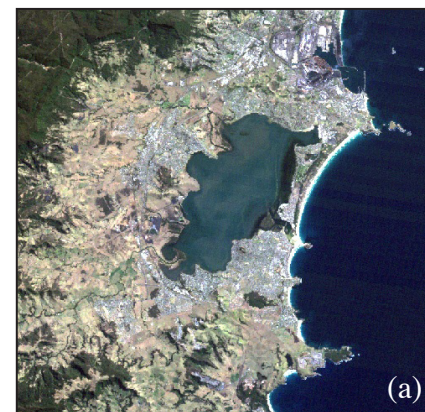
Geoscience Australia has developed a calculator (Estuarine Nitrogen Dynamics, or ENiD) to estimate the maximum amounts of nitrogen that can be added to estuaries without causing eutrophication, depending on their different morphologies and flushing times.

The results of this exercise (figure 4) show that sustainable nitrogen loads at high denitrification efficiencies are about three to four-fold those at low denitrification efficiencies across all estuarine morphologies at residence times of between about 100 days (ICOLLS) and two days (river-dominated estuaries).

In contrast, the sustainable nitrogen load (at low denitrification efficiencies) increases only about 10% ($45\text{--}50\text{ mg N m}^{-2}\text{ day}^{-1}$) for a five-fold increase in the flushing evident between ICOLLS (residence times >100 days) and permanently open immature estuaries with residence times as short as 20 days. This suggests that construction of breakwaters or training walls to maintain permanent openings and increase flushing is relatively ineffective in controlling eutrophication. The sustainable nitrogen input increases significantly to $155\text{ mg N m}^{-2}\text{ day}^{-1}$ (at low denitrification efficiencies) only when the flushing becomes significant with residence times of, for example, two days in river-dominated estuaries and deltas.

This knowledge of biogeochemical and nutrient enrichment processes suggests that denitrification is a more effective process than flushing to prevent eutrophication. An appreciation by stakeholder groups of estuarine morphologies, flushing characteristics and denitrification are therefore important to enable them to develop sensible strategies to prevent eutrophication. These include limiting the discharge of sediments and nitrogen from catchments and maintaining a healthy and active benthos.

A conservative perspective suggests that nitrogen inputs of less than about $50\text{ mg N m}^{-2}\text{ day}^{-1}$ for most estuaries of temperate Australia will not result in eutrophication and trigger significant ecological changes.



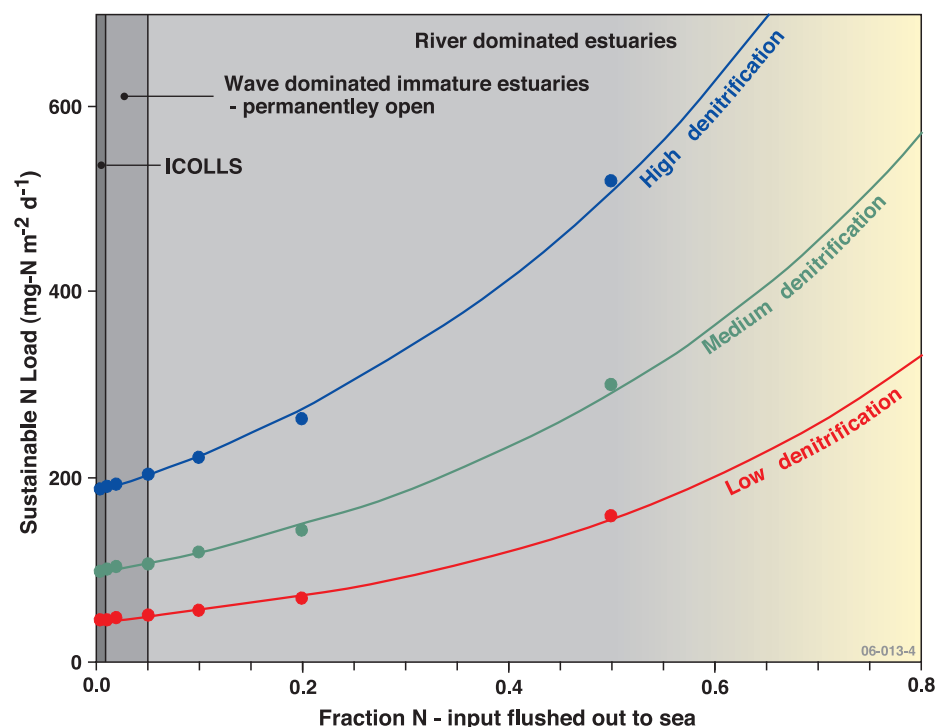
▲ **Figure 2.** Satellite images of (a) an immature estuary and (b) a river dominated estuary.

◀ **Figure 3.** Susceptibility of wave-dominated systems to eutrophication.

◀ **Figure 4.** Sustainable nitrogen loads, sediment denitrification efficiencies and flushing.

Type of Coastal Waterway	Sediment-nutrient Trapping	Natural Turbidity	Flushing (water)	Susceptibility to Eutrophication
 Wave-dominated Delta	LOW	LOW	GOOD	MODERATE
 Wave-dominated Estuary	HIGH	LOW	POOR	* HIGH VERY HIGH
 Strand Plains	LOW	LOW	POOR	MODERATE
 Lagoon	MODERATE	LOW	POOR	MODERATE

* Includes coastal lakes



References

1. Heap AD, Bryce S & Ryan D. 2004. Facies evolution of Holocene estuaries and deltas: a large sample statistical study from Australia. *Sedimentary Geology* 168:1–17.

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