Estuaries and Climate Change

(Dr Gina Newton, April 2008)

Nature of Estuaries

Our present estuaries were formed in the narrow boundary zone between the sea and the land when sea level rose at the end of the last glaciation (~ 5000 years ago). Estuaries are usually tidal, and generally exhibit a transition in physical, chemical and biological characteristics from freshwater to seawater. They are complex and dynamic environments where strong coupling and feedback mechanisms exist between the physics, sediments, chemistry and biology. Geologically, Australia's estuaries have important differences from those in other parts of the world[1]. Drowned river valleys are more poorly represented, with most being in central NSW and Tasmania; in the south-east and south-west, shallow barrier estuaries predominate; along the northern coast most estuaries are deltas[1].

Estuaries can also be classified according to circulation and salinity distribution. Three main classes are commonly used: salt-wedge (highly stratified); partially mixed; and homogeneous (or fully mixed). The dominant mixing force of these systems is (respectively for the three types): river flow; river flow and tide; and tide and wind[2]. There is clear evidence globally, that altering the freshwater flow regime can affect the geochemical processes, water quality and abiotic habitats of estuaries[3]. Australia's rivers generally show much greater flow variability, with discharges during flood events compared to mean runoff being far greater than elsewhere in the world[4]. This has implications for the ecology of estuarine communities.

A diversity of species and communities occupy estuaries, ranging from transient to permanent inhabitants that may occupy niches within the spectrum of freshwater to highly saline waters. Estuarine systems are constantly responding to various influences under a variety of time scales. Regular cyclic variations, such as semidurnal tides and spring-neap tides are superimposed with daily to seasonal to annual climatic variations in temperature and rainfall (and therefore flow). These various factors combine to influence processes such as salinity, water mixing, erosion, and transport and deposition of sediments and other particles, including organisms. For example: semidiurnal tidal variations in sea level cyclically flood and expose the intertidal mudflats and marshes of the lower reaches of estuaries; peak seasonal discharge may flush a stagnating salt-wedge, enabling a new one to form when flood waters subside. Consequently, all these factors and processes combine to influence ecosystem structure and function, and the temporal and spatial distribution of estuarine species and communities.

Value of Estuaries

Estuaries are an important resource. Along with tropical rain forests and coral reefs, they are the most productive natural areas on Earth[2]. The land/sea interface where estuaries occur represents a small fraction of the world's surface area, however it is also the zone where human maritime and commercial activity is concentrated. Since colonial times, Australians have used estuaries and their connecting network of rivers for transporting agricultural and other goods. All of Australia's capital cities except Canberra are located on an estuary[5]; with most having substantial port facilities providing a conduit to significant export trade. Importantly, estuaries represent the nursery and fishing grounds of many commercially and recreationally important fisheries. Estuaries also link to unique coastal wetlands (many with international/national significance) and play a significant role in coastal water resources and providing a natural buffer between land and ocean[5]. As such estuaries have significant economic, social and environmental value.

Australia has in the order of 1000 estuaries, of which half are modified to severely modified[6]; in addition most of the estuaries considered to be near-pristine are located in unpopulated areas. For example, estuaries adjacent to human settlements have lost habitat, been polluted, and had natural shorelines replaced with built structures. Construction of impoundments on many Australian rivers has resulted in altered (and in virtually all cases this means reduced) freshwater inflows to estuaries[3]. It is estimated that for 37% of NSW estuaries, more than half of the land in their catchments is cleared of vegetation[7].

Table 1: Likely Impacts of Climate Change on Estuaries *(modified from Newton 2007[8], OzCoasts 2008[3], Sherwood 1988[9], and Voice et al. 2006[5]).*

Climate Change Driver	Potential Impacts
Sea level rise	• inundation of dry and tidal land • existing wetlands may be flooded more often and to a greater depth (ie. may become lagoons) • new wetlands may develop in low lying areas along estuaries • saltwater/freshwater interface moves further inland – as may associated habitats and ecosystems • nursery function of estuary (ie. for fish, crustaceans) may be compromised • erosion and breach of protective dune barriers and sand bars at mouths, allowing greater marine influence
Increased temperature	• may exceed thermal tolerance of sensitive species – could influence phenology, eg. reproduction/growth and therefore distribution, dispersal and community structure • productivity of estuary may be compromised • increased risk of invasion of pests (including algal blooms) or disease • increased potential for nuisance insect problems eg. midges, mosquitoes – and associated diseases eg. Ross River fever • changes to thermal stratification of water column may affect species distribution and movements

Reduced rainfall	• reduced runoff to rivers and estuaries:
	  o reduced base inflows – altering availability and quality of freshwater (including nutrients), with implications for productivity and ecosystem function
	  o reductions in the frequency and size of large inflows
	• reduced sediment inflows resulting in progressive erosion and saltwater inundation
	• reduced flushing leading to increased risk of hypersalinity to system and associated anoxia (low dissolved oxygen) and associated algal blooms
	• productivity of estuary may be compromised
	• nursery function of estuary (ie. for fish, crustaceans) may be compromised
	• changes to dispersion and mixing of particulates, including pollution

Increased rainfall	• increased sediment inflows to estuaries resulting in progressive infilling and enhanced estuary maturation (with potential for eutrophication) • stronger flushing influence of 'high flow' periods – may result in increased loss of local communities and erosion, particularly at mouth • increased periods of freshwater (ie. loss of salt-wedge) may affect sensitive estuarine species
Extreme weather events	• higher reach from storm surge for coastal areas affecting salinity distribution in estuary • flash flooding may affect stability of salt-wedge or lead to abrupt decreases in salinity • strong winds or cyclones may affect mixing and erosion, and adjacent wave climate
Increased acidification	• increased CO_2 concentration in seawater is making oceans more acidic which impacts on calcitic organisms such as corals, molluscs and some plankton (eg. coccolithophores) – this will affect coastal food webs and productivity and have flow-on effects (physical and biological) to estuaries • heavy rain induced runoff from exposed acid sulphate soils can cause the acid water to flow into estuaries - affecting plant and fish growth, and leading to fish kills in severe events
Increased fire and wind	• increased frequency and/or intensity of aeolian dust and fire-born particulates, affecting estuarine productivity and promoting algal blooms • shifts in prevailing winds may influence surge frequency and wave climate

Impacts of Climate Change on Estuaries

Estuaries are generally characterised by lower diversity but higher abundance of flora and fauna than adjacent marine and freshwater systems. 'True' estuarine organisms are typically resistant to a wide range of bio-physical conditions given the dynamic nature of their environment. However, such resilience is dependent upon the scale and nature of the impact. Estuaries can be susceptible to subtle changes in the physical and chemical parameters which determine ecosystem structure and function[5]. They are particularly vulnerable to changes in river runoff which may affect the water balance and associated hydrological features of individual estuary types[5]. As multiple-use resources, estuaries are often subject to intense and often conflicting pressures – particularly where cities and ports are involved. As such, any detrimental changes to estuaries will likely impinge on a large proportion of the population and coastal marine resources. Therefore the need to better understand estuarine systems is now more acute due to the added threat of global climate change, which is already causing rises in sea level, temperature and ocean acidity. Likely impacts of climate change on estuaries are detailed in Table 1.

Our understanding of the sensitivity of estuaries to climate change related drivers varies. For some, such as sea level rise and storm surge it is quite good, however for most other aspects it is poor, particularly as changes to the frequency and/or intensity of climate change drivers is often unpredictable. Linkage of hydrological models for surface waters with ocean-atmosphere models is also needed to integrate marine and terrestrial ecosystem change[3]. Determining vulnerability to future change in already stressed estuaries may require consideration of multiple stresses (many of which may have been operating for decades) including those from climate change. It is likely that some estuaries will change to a different state. For example, some may become more marine dominated, which in turn leads to changes in ecosystem services.

Future Directions and Adaptation Options

Knowledge of Australia's estuarine systems remains limited: we are still in the situation of describing and quantifying hydrological and ecological processes in estuaries and their linkages to catchment land use. This will challenge our ability to firstly identify significant natural changes and secondly enable suitable responses to be developed and implemented[3]. To overcome such limitations, a risk assessment approach would be useful, and could potentially be based on the data held within the *OzCoasts* database (nee *OzEstuaries*) and on previous and current work of the National Land and Water Resources Audit (the Audit).

The 2002 Audit's national assessment highlighted that estuary restoration is expensive and often not possible; protective management arrangements are recognised to be more cost-effective in the long term[6]. It recommended the protection of a representative group of near-pristine estuaries from around Australia to provide a framework for improved nature conservation as well as useful benchmarks for improved understanding and management of Australia's estuaries. (This may be likened to the Commonwealth's *National Representative System of Marine Protected Areas* initiative). A comprehensive classification and assessment of convervation significance conducted for Tasmania's estuaries may serve as a useful model[11]. The Audit's assessment also called for agreed reporting frameworks that make the information collected at local levels up-scaleable to the national level, and for investment in intervention strategies to improve and protect estuarine condition. However, the issue of adaptation to global climate change was not a focal point at the time of the 2002 NLWRA assessment process. Importantly, the Audit are currently overseeing development of a National Estuarine Environment Condition Assessment Framework (NEECAF) with agreed indicators - this will provide direction for reporting on the broad ecological integrity of estuaries at a national level[10].

Incorporating understanding of climate change impacts into management for healthy estuaries will be of economic and ecological benefit to Australia[5,9]. An important component of this will be determining sensitivity thresholds and trigger points for change in representative estuarine systems. Such changes could be either beneficial or detrimental, depending on specific management objectives - for example, raised sea level may improve tidal flushing and/or keep estuary entrances open for longer. However, many experts consider Australia's aquatic systems

generally have limited capacity to adapt to climate change. If so, other stressors will need to be reduced to increase resilience to the likely impacts of climate change. Adaptive measures could include:

- maintaining or establishing appropriate vegetation cover (riparian, marsh and dune)
- using salt tolerant plants when revegetating, if appropriate
- controlling sedimentation processes through use of vegetation filter strips and appropriate trapping and control structures
- restoring/maintaining ecological flows
- reducing nutrient loadings
- minimising the spread of pests, and
- minimising the threat of acid sulphate soils.

With regard to climate change and estuaries, a recent review recommended that for representative and key estuaries, a process should be developed to identify implications for human health (eg. insect vectors), tourism, urban water supply, ports and harbours functioning, mangroves, seagrasses and discharge to oceans for potential impact on fisheries, coral reefs or other relevant ecosystems[5]. Improving understanding, raising awareness, identifying and addressing critical data gaps, and establishing long-term data series will also be essential for effective adaptation to climate change. However, estuaries generally fall within governance interests of State and local jurisdictions – as yet there is no nationally consistent and integrated policy framework or approach to their investigation and management[6]. Given the added pressures of climate change to Australia's estuaries, many of which are already experiencing the cumulative effects of multiple stressors – the longer-term implications for the many benefits and services that these national assets provide remains uncertain.

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