ESTUARIES

What regulates sedimentation in estuaries?

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Why don't estuaries fill up with all the sediment that is carried in from both the land and the sea? We are developing a picture of what goes on in estuaries to keep them from silting up, and of how we can slow down infilling by managing land use.

ESTUARIES ARE THE MEETING PLACE of land drainage with the sea. They contain many different habitats: shallow open waters, salt marshes, sandy beaches, mud and sand flats, rocky shores, mangrove forests, seagrass beds, river deltas and tidal pools. These habitats form the most productive areas on earth, creating more organic material each year than comparable areas of forest or farmland.

But estuaries are very vulnerable to the effects of human activities and require careful management to keep them in reasonable shape. One of the biggest issues is sediment. In an ongoing research programme we have been examining the various factors that affect sediment in estuaries.

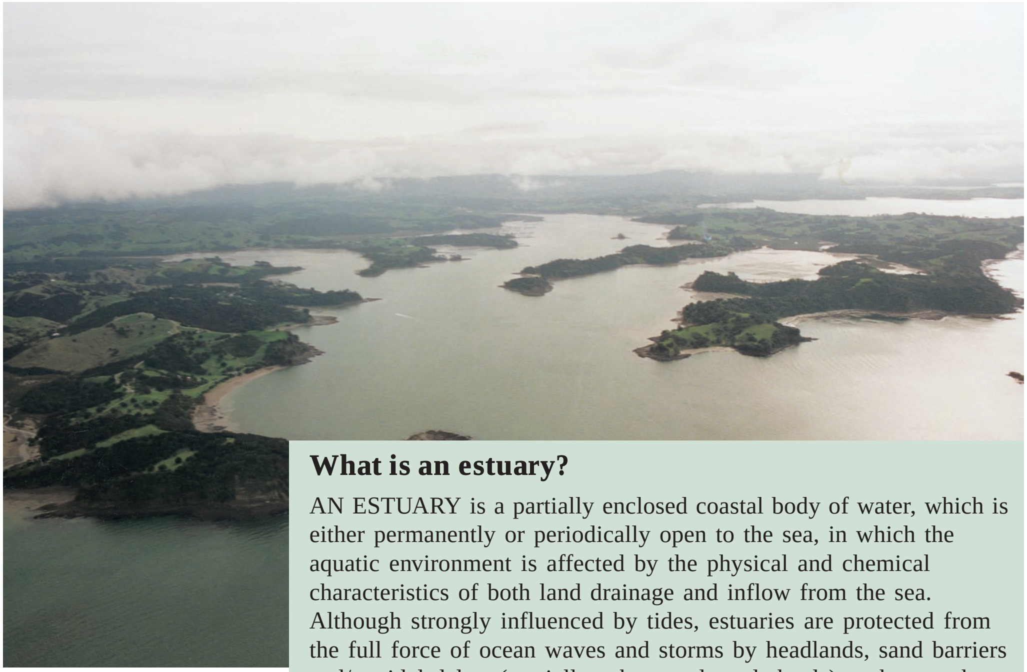
A little history

Today's estuaries in New Zealand are quite recent in geological terms. They formed when river and glacial valleys were flooded as sea level rose quickly during the Holocene – the geological period that started about 10,000 years ago, at the end of the last major ice age. Sea levels stabilised about 6000 years ago and ever since then estuaries have been catching up on their sedimentation. Waves and tides have combed coarse marine sediments from the seabed offshore and built sandy barriers and spits at estuary entrances, which in turn supply sand to an estuary. Meanwhile, rivers have carried in finer sediments. So why haven't all our estuaries simply filled up with sediment?

A changing balance

Whether an estuary fills in or remains deep depends on the balance between sediment entering and leaving the estuary, and on water inputs from rivers or from sea-level rise.

Human activities have changed this balance in estuaries in various ways – mainly by increasing



Mahurangi Harbour (north of Auckland) viewed from above the Hauraki Gulf at high water.

What is an estuary?

AN ESTUARY is a partially enclosed coastal body of water, which is either permanently or periodically open to the sea, in which the aquatic environment is affected by the physical and chemical characteristics of both land drainage and inflow from the sea. Although strongly influenced by tides, estuaries are protected from the full force of ocean waves and storms by headlands, sand barriers and/or tidal deltas (partially submerged sand shoals) at the mouth. Estuaries are also known as harbours, bays, lagoons, inlets or sounds. New Zealand has nearly 300 estuarine systems spread along 11,000 km of coastline. They range in size from a few hectares to over 95,000 hectares (Kaipara Harbour), although most are less than 6000 hectares.

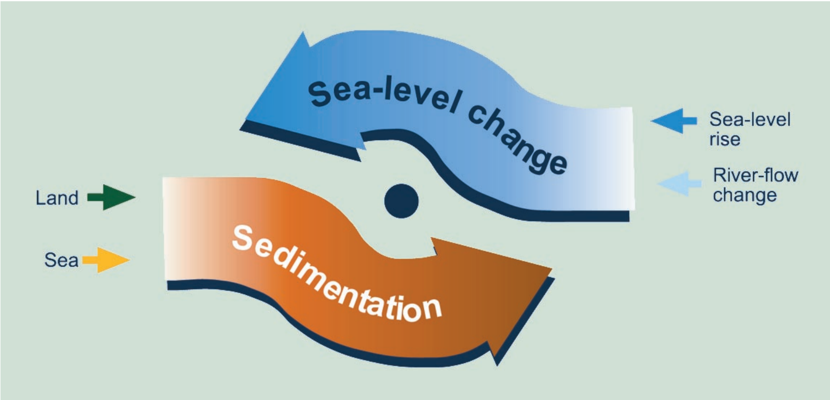


Diagram of long-term balance for estuaries between rates of sea-level and river-flow change and sedimentation in coping with sediment inputs from land and sea.

erosion and by changing water-flow patterns and sediment movements. For example, port or marina developments trap fine sediment, and regular dredging may be required to prevent sediment accumulating. Causeways for roads can change both current patterns and the way sediment is carried in and trapped. Erosion can be caused by the clearfelling of forests and by construction projects such as new subdivisions; the fine particles in eroded material may end up in estuaries. In fact, any activities that lead to extra mud and silt settling on estuary floors pose a threat to New Zealand estuaries. Overdosing on fine sediments can easily push the sedimentation balance towards irreversible infilling. In addition, the estuarine ecosystem may suffer: the many animals that live in estuaries may be harmed if sediment inputs and patterns change too quickly.

Sustaining the balance

To manage an estuary so that it doesn't undergo rapid alterations, we need to know how the estuary responds to changes in sediment input from both the land and the sea. Computer models can then help in assessing whether land use or other changes may upset the fine sedimentary and biological balance.

In the past decade, New Zealand researchers have unravelled part of the complex story of how estuaries handle sediments. Three important physical features play a part: tides, waves and rivers.

Tides

Tidal currents provide the steady supply of energy that moves sediments into and out of estuaries. Most of New Zealand's estuaries have a tidal range of 2–4 metres.

Waves

Especially during storms, waves and swell at the entrances to estuaries can stir up large amounts of sediment, which can then be moved into the estuary by the incoming tide. Inside the estuary basin, smaller waves can comb sediments off the shallow intertidal banks.

Rivers

Fresh river water floats over seawater. So when sediment-laden floodwaters enter an estuary the finer particles that stay in suspension may be flushed out to sea quite quickly. But heavier particles sink to the bottom as the flow meets salt water. This is why sediment deposition is greatest near the upper reaches of an estuary.

Within estuaries we can identify distinct sub-environments in which tides, waves and rivers interact differently.

Tidal inlet

Inlets on sandy shores have narrow entrances to the sea, with sand shoals – tidal deltas – just inside and outside the entrance. These shoals are moulded by waves and by strong tidal currents. Sand circulates in the tidal inlet between the shoals and adjacent beaches and the shallow seabed offshore. The amount of sand in the inlet depends on how much water passes in and out of the estuary during a tidal cycle. The shape of the delta depends mainly on the shape of the bay and on the energy produced by waves. So, on New Zealand's west coast, where waves tend to be big and powerful, deltas are squashed against the shore, but on the more sheltered east coast, deltas can protrude farther offshore.

Channels, sandbanks

Channels are the sediment highways in estuaries and sandbanks are areas where sediment builds up. Channels carry in suspended sediment but are themselves scoured out when currents are stronger. The rush hour for sediment movement occurs around mid-tide on both ebb (outgoing) and flood (incoming) tides, when currents are strongest. Over time, fine material is washed out from channel beds, leaving behind a layer of gravel and shells that stabilises the channels.

In a simple estuary with no sandbanks, flooding tidal currents are stronger than ebbing ones and this leads to gradual infilling. As sandbanks develop, ebbing currents become stronger so that excess sediment can be flushed out again. This changing interaction between the tide and the shape of the estuary floor helps to regulate long-term sedimentation.

The illustration on page 16 shows the result of modelling tidal currents in the interconnected channels of Manukau Harbour, Auckland.

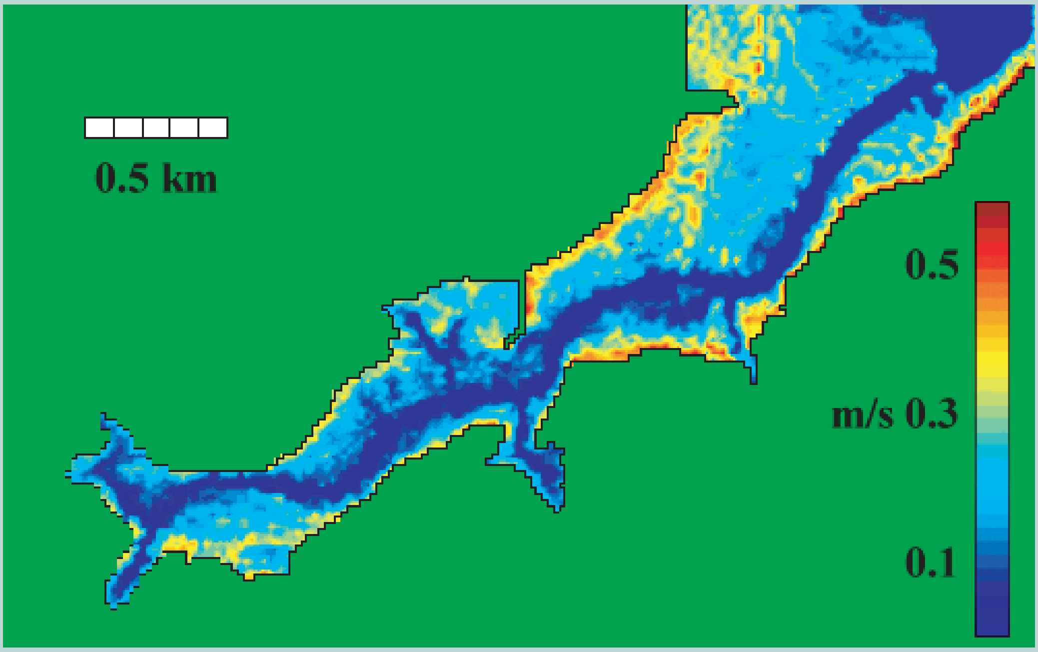
Tools of the trade in estuarine research

Sophisticated instruments are deployed in estuaries to measure sediment processes. The photograph (left) shows the instrumented tripod ALICE, with a full suite of sensors for measuring waves, currents, turbulence, bedforms and sediment movement (see *Water & Atmosphere* 4(2): 8–10). The lower photograph shows a DOBIE wave gauge deployed on an intertidal flat.

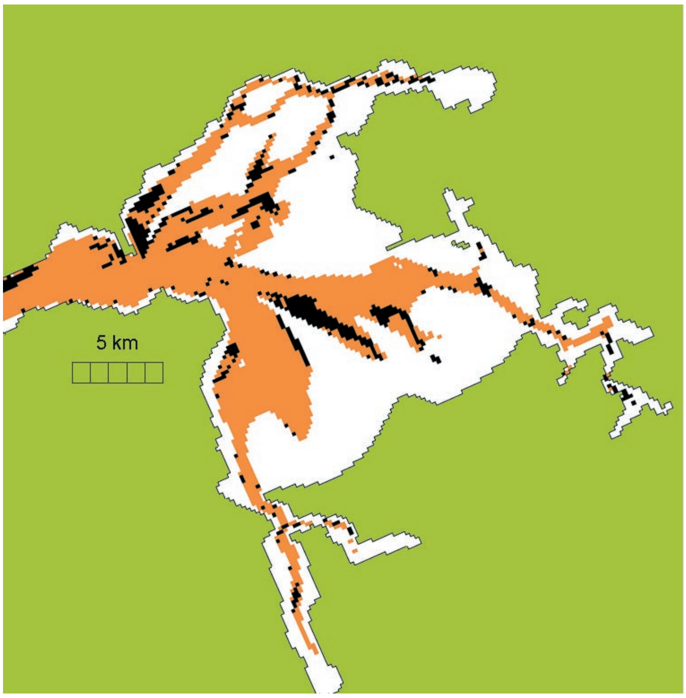
Numerical models simulate water movements caused by tides, winds, waves and rivers, and the resulting sand and silt transport over an entire estuary. Near-bed current velocities predicted by a hydrodynamic model and wave orbital velocities predicted by a wave generation model are used to compute sediment transport, both as migrating bedforms and by picking up and re-depositing suspended sediment. Changes in transport of sediment lead to a change in bed levels (either erosion or accretion). The illustration below shows output from a wave model of Okura Estuary, Auckland.

Instrumented tripod (ALICE) at Okura to measure near-bed currents, turbulence and sediment transport.

DOBIE moored in Okura Estuary (North Shore) for measuring waves on the intertidal flat.



Prediction of the wave velocity (m/s) at the bed in Okura Estuary using the WGEN computer model (developed by Prof. Kerry Black). The channel has low wave stirring, whereas the upper intertidal flats have high values.



Model simulation of the tidal channels of Manukau Harbour (see Green et al. *2000). Brown indicates ebb-tide dominance and black indicates flood-tide dominance. White areas are intertidal sandbanks.*

The modelling showed that there was net seaward transport almost everywhere, except in the short side arms of main channels.

Intertidal flats

Outside the channels, tidal currents are weaker and water on the incoming tide gently floods adjacent shallow intertidal flats. Thus sediment falls out onto the flats, except when waves resuspend it. As the water deepens the waves have less and less effect on the sediment. Some fine silts and muds may be carried out to sea on the outgoing tide through the drainage channels.

Fringes

Along the intertidal margins, the incoming tide can move turbid plumes (originating from intertidal flats or catchment run-off) up into small, sheltered, tidal creeks or side arms. If conditions are calm then fine sediments settle out. These fringes are where mangroves love to grow, further enhancing sedimentation by slowing water movement.

Headwaters

The sediment carried by streams and rivers increases enormously following heavy rainfall. Some of this load is discharged directly into the ocean, but most settles down on intertidal banks and in shallow tidal creeks. Any sediment deposited in channels is soon scoured and re-deposited on intertidal flats and around the fringes of the estuary.

How do estuaries digest their sediment diet?

Despite all the sediment coming in, many New Zealand estuaries have remained as open-water bodies, even after 6000 years. This suggests that, in the long term, sediment build-up is limited by a dynamic balance between the effects of tides, waves and rivers on sediment inputs and outputs in different parts of an estuary. An important effect is the increased stirring of bottom sediment by waves as estuaries get shallower, which curtails further sediment deposition. Storms and floods can sometimes cause siltation, but this is usually washed out quite quickly.

However, there are cases where some of our estuaries have suffered from infilling because of excessive sediment run-off, either from urban development (e.g., Mangere Inlet in the Manukau Harbour) or from clearfelling of forests (e.g., Mahurangi Harbour). Clearly there is a very fine balance in the sedimentary "digestion system" of our estuaries. Their equilibrium can be easily upset by inputs arising from human disturbance, and also by any future changes in sea level. ■

All authors are based at NIWA in Hamilton.

Acknowledgements

This work is part of the FRST-funded research programmes "Effects of Sediments on Estuarine and Coastal Ecosystems" and "Physical Processes Affecting Estuaries, Coasts and the Continental Shelf".

Further reading

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