ESTUARIES / RESOURCE MANAGEMENT

Assessing human impacts on estuaries: it's a risky business

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A team of modellers at NIWA Hamilton has developed a way to help environmental managers assess "risk" in sediment-impacted estuaries.

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Estuaries are often muddy – ask any *Helice crassa* (mud crab). The reason is that clay, mud and silt are continuously being eroded from the land and then delivered to the estuary by streams and rivers. Most sediment arrives during and after heavy rainfall. Some moves straight through to the coastal ocean, but the rest settles in the estuary, usually on intertidal flats or in "fringe habitats" such as mangroves or marshes.

Is this a problem, and what is the risk here?

Too much mud can smother and kill shellfish, cause siltation of navigation channels, turn clear water brown, and encourage the spread of fringe habitats, including mangroves. In short, sediments are irreversibly changing our estuaries. Some changes are natural, but others are definitely not. Tree-felling, building and river/stream bank disturbances can all create soil erosion. Construction of marinas, bridges and navigation channels can alter the water circulation in an estuary that might otherwise help it to "digest" its sediment diet.

"Risk", then, relates to the prospect that human activities might result in damage to the estuary and its ecosystem.

Soil eroded during heavy rainfall has deposited a thick layer of mud on an intertidal flat in this estuary, smothering and killing any shellfish beneath it.

Risk = damage x probability

We define risk as the combination of damage and the probability that this damage will occur. As well as ecological damage (for example, decline in shellfish productivity) there can be social damage (such as loss of aesthetic appeal, restricted access for boats).

Defining damage and its probability of occurrence can be difficult. For example, damage caused by a given sediment input may be harmful in an estuary that is already under pressure, but hardly noticed in a pristine estuary. There might be a threshold of damage: for example, no harmful effects on the ecosystem until turbidity reaches a certain level. Some damage is reversible and some is not. On top of all this, there is still a lot to learn about the way estuarine ecosystems function. All these factors need to be taken into account in any risk assessment.

To help untangle these complexities, we can devise a "risk index". This is done by multiplying the extent of the damage by the probability that damage will occur. The range of levels of risk can then be debated – usually involving regulatory authorities and the general public – and decisions taken on what risks are acceptable or unacceptable.

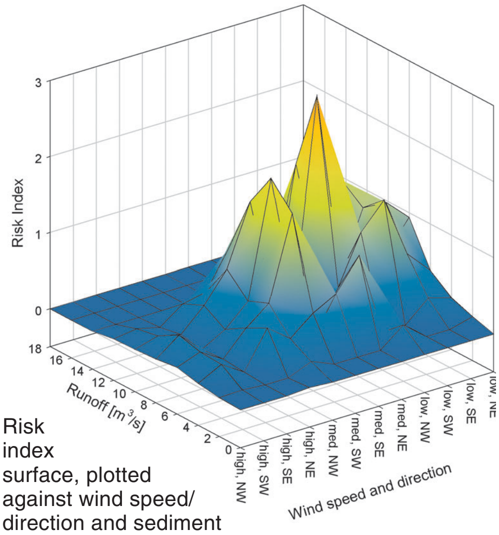
One of the big unknowns in devising a risk index is that it is not easy to predict what will happen to sediment once it reaches the estuary, even though we can predict quite accurately how much extra sediment will be produced on land. A host of factors – winds, waves, tidal currents, freshwater discharge, etc. – influence sediment distribution within an estuary. Fortunately we have a computer model that can help with such predictions (see panel on facing page).

The matrix simulation method

We have developed the so-called "matrix simulation method" for estimating the risk index. The method can be used to investigate a range of issues.

Imagine a shellfish bed that has high productivity and cultural values. Development in the catchment is going to cause increased sediment inputs into the estuary. The volume of sediment runoff from the land and the wind speed/direction are the major factors controlling sedimentation at the shellfish site.

Using the computer model, we can predict the amount of sediment likely to be deposited on the shellfish bed for every realistic combination of sediment runoff and wind speed/direction. For each combination, the damage to the estuary is the expected decline in shellfish production (based on what we



Risk index surface, plotted against wind speed/direction and sediment runoff from the land. The highest risk is associated with medium sediment runoff and a medium-strength north-east wind.

know about how shellfish respond to sediment deposition). We can then use weather records to estimate the probability of each wind speed/direction occurring. We can also relate sediment runoff from the land to rainfall and then estimate probability of rainfall. Multiplying those probabilities by the damage produces the risk index. This can be illustrated as a 3-D plot of risk against sediment runoff and wind speed/direction to create a "risk index surface".

The figure (above) shows that in this example the highest risk is associated with medium sediment runoff combined with a medium-strength north-east wind. The risk associated with smaller sediment runoff is lower, simply because less sediment is available for deposition on the shellfish bed. The risk associated with larger sediment runoff and stronger winds is less, because this combination is less likely to occur.

The debate on choosing an acceptable level of risk can now focus on the analysis of risk presented in the graph. Suppose there are options available for controlling soil erosion on the land: is it worth the cost to implement those controls? We could build another risk index surface based on the lower sediment runoffs that would occur if these controls were in place, and compare the two surfaces to see if the reduction in risk is worth the cost of the controls.

The matrix simulation method can be extended to any level of complexity. Each time we add a new variable into the analysis – perhaps waves or tides, for example – we add another dimension to the simulation matrix. Combining this matrix with a "probability matrix" of the same dimension will generate a risk index matrix, again of the same dimension. Research continues on ways to improve the method, including the development of a decision-support scheme based on the procedure.

The matrix simulation method, which is based on sophisticated computer models of how estuaries function, is a transparent and repeatable way of estimating risk that can provide environmental managers with better information that will improve decision-making.

Planning for the future may not be such a risky business after all! ■

A computer model of an estuary

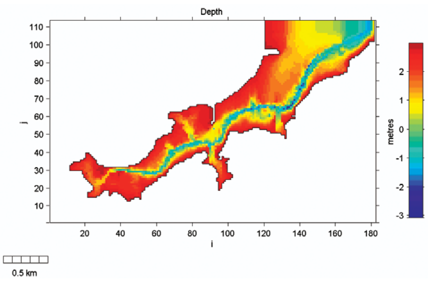
A computer model can predict sediment movement and deposition in an estuary. We use mathematical equations to describe the physical processes that control sediment movement and deposition (tidal currents, waves, etc.) and then write them into a computer code.

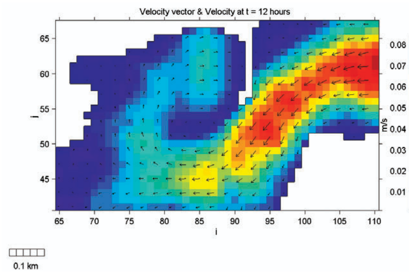
To apply the computer model to a particular estuary, the bathymetry (the shape of the estuary bed) is input first. The model is then controlled by boundary conditions, which specify, for instance, how the tide rises and falls at the seaward entrance of the estuary, how much fresh water and sediment is discharged into the estuary from streams, and the strength and direction of the wind.

For example, one scenario may represent a moderate flood by applying a freshwater discharge of 20 m^3/s and a strong onshore wind continuously over the period of the simulation (typically between four days and one month). A second scenario may investigate the effect of an offshore, rather than an onshore, wind.

From the model, we can obtain results such as the speed and direction of water currents, the tide height, and the amount of sediment (both in suspension and deposited on the bed) at any location within the estuary, and at any time within the simulated period.

Research continues on the physical processes driving sediment transport in estuaries. New knowledge is being incorporated into computer models, which improves their accuracy and increases the range of situations that can be simulated.





above:
Bathymetry of Okura estuary, as input to a computer model.

left:
Output from a computer model, showing currents flowing round a sand ridge during an incoming tide. Sediment deposition is more likely to occur where the water currents are low (smaller arrows).