

Adjustable adaptation

Humans have been responding to fluctuating sea levels for millennia. Adapting to future change will require a swift start on developing innovative infrastructure while keeping the option to adjust in the long term.

Over thousands of years, humans have evolved against the backdrop of fast-changing coastlines. Written flood myths — such as the Sumerian tale recounted in the epic of Gilgamesh, and Noah's flood that is pivotal to the Jewish, Christian and Muslim traditions — date back at least 3,000 years. Their oral traditions are probably centuries or millennia older.

Sea level rose by up to one metre per century between 11,000 to 6,000 years ago, when the last remnant of the glacial age, the Laurentide ice sheet, finally disintegrated (*Nature Geosci.* **1**, 620–624; 2008). Such rapid change could easily have necessitated a retreat of humans to higher ground, leading to the loss of settlements. Between that time and the most recent past, the volume of the oceans has been much more stable. But in some scenarios of future climate change, similar rates of global mean sea-level rise emerge once again as a plausible (if not necessarily probable) worst-case consequence.

The Commentary and book review on pages 450 and 459 of this issue, respectively, discuss the two baseline strategies for adapting to such changes: defence or retreat.

Simply leaving the land to inundation could work in coastal regions that are only sparsely inhabited. Coastal defence by brute force of engineering is expensive and needs continued close attention if disasters are to be prevented. In addition, closing part of a coastline off when the waters rise in a storm surge adds pressure to adjacent areas. Therefore, the potential for straightforward retreat should be considered before embarking on technologically more advanced options of adaptation.

But moving entire cities and their residents back to higher ground is hardly practical. Today's population density — in the coastal areas as well as inland — would make such an effort unfeasible and expensive. For example, in Vietnam, one of the countries predicted to be hardest hit by sea-level rise, 11% of the population would need to be moved, in the face of a 5% loss of land and a related 10% decline in



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gross domestic product (*Climatic Change* **93**, 379–388; 2009).

Yet retreat can take different forms. Building homes that are capable of withstanding flooding — an ancient and widespread solution to potential inundation — means coping with the water, rather than keeping it out. Following Hurricane Katrina, pilot projects on flood-resilient buildings were started in New Orleans (*Nature Geosci.* **1**, 805–807; 2008). Houses on stilts or floating houses could be the building style of the future in low-lying coastal areas.

Whether we choose to defend or retreat, strategies for adapting to the rising seas cannot yet be set in stone for centuries to come; at this point in time, the uncertainties in future projections of global mean sea-level rise are too large. The 2007 report from the Intergovernmental Panel on Climate Change (IPCC) gave a range of 0.18 to 0.59 m for the rise by the last decade of the twenty-first century, but these values explicitly exclude future rapid dynamical changes in ice flow, which the IPCC deemed too uncertain to quantify. Regional deviations from global mean

sea-level rise are also poorly quantified, and could be important, as pointed out in the Review Article on page 471 of this issue. Furthermore, contributions from land-water storage are essentially unconstrained (see Commentary on page 452). It is fairly certain, however, that sea-level rise will continue long after atmospheric greenhouse gas concentrations have settled down.

As better projections of future changes in ocean volume become available, along with more quantitative estimates of the factors that influence regional sea-level patterns, such as changes in the distribution of ice mass around the globe and the ocean circulation, it will become clearer how much change in its coastline each country needs to prepare for.

No time should be lost in developing innovative technologies for both defence and retreat, and in deciding on a path towards an infrastructure that will withstand rising sea levels. How far we need to go down that path can be decided when we have a more quantitative idea of the magnitude of the change. □