Building land with a rising sea : cost-efficient nature-based solutions can help to sustain coastal societies

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Building land with a rising sea

Cost-efficient nature-based solutions can help to sustain coastal societies

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Coastal lowlands are increasingly exposed to flood risks from sea-level rise and extreme weather events (1). Megacities like Shanghai, London, New York, and Bangkok that lie in vast river deltas are particularly vulnerable. Dramatic flood disasters include the Indian Ocean tsunami in 2004, Hurricane Katrina in New Orleans in 2005, Hurricane Sandy in New York in 2012, and Typhoon Haiyan in the Philippines in 2013. Managing the risks of such disasters requires investments in short-term emergency response and long-term flood protection (2), including nature- or ecosystem-based engineering (3, 4). On page 638 of this issue, Tessler et al. (5) show that sea-level rise, increasing climate extremes, population growth, and human-induced sinking of deltas threaten the sustainability of many major deltas around the world.

Investments in coastal and river engineering, such as the building of dikes, levees, and dams, are often seen as the ultimate solution to combat flood risks and shoreline erosion. However, Tessler et al. reach a rather different conclusion: Deltas in wealthy countries, which can currently reduce risks by costly engineering solutions, are likely to see the strongest risk increase in the long term, when energy becomes more expensive. Prominent examples of engineered deltas with compromised long-term sustainability, according to the authors, are the Mississippi delta in the United States, the Rhine delta in the Netherlands, and deltas in East Asia where engineering is deployed on vast scales (6).

Apart from the socioeconomic constraints highlighted by Tessler et al., there are additional limitations to conventional engineering. Although it provides effective flood and erosion protection on time scales of years to decades, it disturbs natural delta processes in ways that accelerate local sea-level rise and increase long-term flood risks. A natural delta before engineering (see the figure, panel A) consists of a network of river channels surrounded by wetlands that are regularly inundated by tides and river flooding. Sand and mud supplied during inundations are trapped in the wetland vegetation, a key natural process that has enabled the vertical building and maintenance of deltas in balance with sea-level rise for thousands of years (7).

With human settlement, deltaic wetlands are converted into agricultural, urban, and industrial land. In these deltas, flood-protecting structures such as dikes directly fringe the river channels, leaving almost no space for natural wetlands (see the figure, panel B). When the wetlands are disconnected from the rivers, the land no longer builds up with sea-level rise. Furthermore, upstream dams often reduce the supply of riverine sediment, slowing down the land-building process in remaining wetlands (4). Deltas are also highly susceptible to land subsidence, which is the sinking of land due to soil compaction and which is exacerbated by human activities like soil drainage (4).

In the Mississippi delta, human disruption to natural delta-building processes are deemed responsible for rapid submergence of the delta plain and subsequent land loss rates as high as 100 km2 per year since 1900 (8). In the Netherlands, after centuries of soil drainage and land sinking, 9 million people now live below sea level behind costly dikes. In the Ganges-Brahmaputra delta in Bangladesh and India (with 170 million people, the most populated delta on Earth), land that was embanked in the 1960s now lies 1 to 1.5 m lower than remaining wetlands (9).

Wetland embankment also triggers extra sea-level rise, because storage area for flood waters is lost, causing water levels to rise faster in the remaining channels of a delta. In the Ganges-Brahmaputra delta, this has contributed to an effective sea-level rise of 17 mm per year since 1960; near the coast, this rate is 10 mm per year (10). Similarly in the Rhine-Meuse-Scheldt delta, effective sea-level rise is up to 15 mm per year since 1930, which is five times the rate at the coast (3).

Conventional engineering thus unintentionally exacerbates long-term flood risks and compromises the sustainability of delta communities. In contrast, new nature-based engineering solutions should include the restoration of large wetlands between rivers and human settlements, which can provide extra water storage, slow down flood propagation, and reduce flood risks in populated parts of a delta (3) (see the figure, panel C). At the same time, restored wetlands have a high capacity to build up sediments, regain elevation on formerly embanked and lowered land (11), and survive long-term sea-level rise (7). Unlike conventional engineering, which Tessler et al. argue will become more expensive in the future, nature-based solutions are largely self-sustaining and cost-efficient (3) and could therefore make deltas less vulnerable to rising energy costs.

Ecosystem-based engineering projects are just beginning to be designed and implemented (3, 4). In the Mississippi delta, there are ambitious plans to divert sediment-laden river water back onto the delta plain (see 2 in the figure) (4, 8). These efforts would build or prevent the loss of more than 500,000 ha of wetlands and contribute to reducing annual flooding damage to New Orleans and coastal Louisiana by US$5.3 to $18 billion in 50 years (12). Projects designed to stimulate natural wetland-building processes with sediment delivered through river diversions are estimated to cost about 10 times less than projects with conventional sediment delivery by barge or pipeline (12).

In the Belgian part of the Rhine-Meuse-Scheldt delta (see the photo), around 4000 ha of historically embanked floodplains will be restored by 2030. These efforts should lower a 1-in-100-year storm surge by 60 to 80 cm and are more cost-efficient than conventional heightening of dikes (12). In Bangladesh, unintended dike breaching caused rapid elevation gain of several decimeters within 2 years of tidal flooding, inspiring scientists to propose temporary controlled dike breaches as a method to regain elevation on formerly embanked and lowered land (9). Once the land would be built up, it could be re-embanked, and human land use such as agriculture could start again (see 3 and 4 in the figure).

Building land with a rising sea and a growing coastal population requires strategies that combine conventional engineering with the restoration and maintenance of wetlands and natural delta-building processes. Advances in ecosystem-based engineering may mitigate the risks associated with conventional engineering and rising energy costs. The few existing examples, however, are too recently implemented to fully evaluate their long-term success. More proof-of-concept projects with extensive monitoring are urgently needed in the search for science-based solutions to safeguard delta societies around the world.

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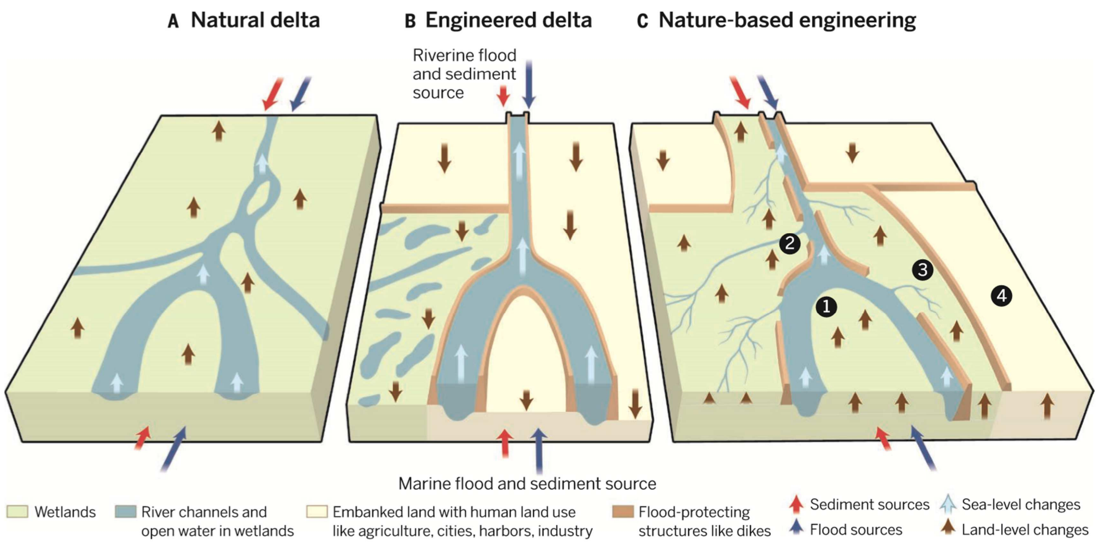
Photo:

Nature-based adaptation to rising sea level. This aerial view of part of the Rhine-Meuse-Scheldt delta in the Netherlands and Belgium shows natural wetlands that build up land with rising sea level, thereby contributing to flood protection of developed lowlands in the back.
PHOTO: JOOP VAN HOUDT/RIJKSWATERSTAAT

Figure:



Sinking or rising deltas. In natural deltas (A), land can rise in balance with sea level through sediment accumulation in regularly inundated wetlands. In deltas with conventional engineering (B), land rise through sedimentation is prevented by flood-protecting structures like dikes and upstream river dams; land sinks due to human activities like soil drainage; and extreme water levels rise due to loss of wetlands. As Tessler et al. show, reliance on conventional engineering of this kind poses a risk to populations living in deltas around the world. In contrast, we propose that nature-based engineering solutions (C) can help to maintain land-building processes and flood storage through wetland conservation and restoration, for instance by dike removal (1), controlled dike breaching and river diversions (2), and temporary dike breaching and subsequent re-embankment (3) and (4).
ILLUSTRATION: ADAPTED BY P. HUEY/SCIENCE