# Where sinking land meets rising water

Photo credit: U.S. Geological Survey

Five hundred million people living on the world's deltas now face the twin threats of subsidence and rising sea levels. **Christina Reed** reports from the edge.

Hidden along the edge of a cornfield and behind a three-metre-tall thicket of cattails and tubular stalks of a plant called tules, the telltale signs of a crawdad feast are scattered over a wooden plank that stretches across a dark pond. A thin layer of chartreuse-coloured milfoil blankets part of the marsh. The shading that the vegetation provides has a dramatic effect on the pond's temperature. Despite the Californian summer heat, the shallow water (0.3m) is cool to the touch. A family of otters has found this wetland, situated on an island in the Sacramento-San Joaquin River Delta, a perfect spot for lunchtime meals.

Whereas most deltas around the world are coastal features, California's largest delta is found far inland, where the San Joaquin and Sacramento Rivers merge and thread together into several distributaries that eventually lead to the San Francisco Bay. Deltas are the connection between river drainage basins and the world's oceans. They are inherently influenced by both of these physical domains as well as by the 500 million people who live in these highly productive, ecologically rich systems, according to a recent report from IGBP's Land-Ocean Interactions in the Coastal Zone project (LOICZ). Deltas are one of LOICZ's top priorities.

**Deltas are dangerous, though highly sought after, places to live.**

"We are developing plans to marshal our respective scientific communities to work together and better understand the scale and function of deltas," write three leading academics in the report's prologue, James Syvitski, the executive director of the Community Surface Dynamics Modeling System (CSDMS), LOICZ executive officer Hartwig Kremer and Janos Bogardi, executive officer of an IGBP joint project, the Global Water System Project (GWSP).

For more than a century, farmers in the Sacramento-San Joaquin River Delta have been draining peat soils on the delta's islands to grow crops that prefer dry roots, such as corn. Exposing the soils to air converts the peat into a giant buffet for aerobic microbes that rapidly start decomposing the organics. Wind and rain further erode the old peat. As a result, much of the land along the delta now sits six metres below sea level. Over the last 150 years, the delta in some parts has sunk two to five centimetres a year. A grid of levees keeps the rivers from flooding the land. But as the land continues to sink the pressure on the levees increases, and breaks in the system lead to floods. The most recent case of failure occurred on 3 June 2004, on a stretch of the levee where the farmland on the opposite side of the levee wall was three metres lower than the river's surface.

The wetland the otters found is part of a pilot project that scientists with the US Geological Survey started in the in the early 1990s with the intent of reducing the rate of subsidence. The pre-

liminary study was designed to assess the use of various wetland types to mitigate subsidence of organic substrates in the delta.

"This is based on the idea that anaerobic decomposition is slower than aerobic decomposition, so decomposition, or loss of the underlying organic substrates, would be slower in wetlands than in drained soils," says biogeochemist Robin Miller who has led the USGS research on the project for the last 12 years. The experimental wetlands are located on two seven-acre test plots on Twitchell Island, which is about 40 miles south of Sacramento. Between 1997 and 2005 the wetlands gained more than 25 cm in elevation. "The rates of accumulation are coming as a surprise to everyone – including ourselves," Miller says.

## Carbon trap

But that's not all. "We are seeing, in addition to subsidence reversal, huge net greenhouse gas benefits," says Roger Fujii, Bay-Delta programme chief for the USGS California Water Science Center. During their experiment they discovered that the new peat soils were storing much of the carbon that the plants were taking out of the atmosphere during their growing phase. "We didn't realise you could store so much carbon so quickly," Miller says.

The reason, she explains, is California's long growing season. "I don't think you could do this in Minnesota," she adds. The winters there are too long. "Our plants start growing in February and don't die until November; they are taking up carbon dioxide for all but two months of the year."

When they do die and start forming fresh organic peat soils, the slow decomposition, Miller estimates, produces less than five percent methane – another form of carbon and also an important greenhouse gas. In other words, an estimated 95 percent of the carbon that the plants take up during their growing phase is stored each year. But the funding to accurately measure methane and other greenhouse gases released during the decomposition phase and test what the scientists are now calling "carbon farming" on a larger scale is currently on hold.

**The fresh water behind the levees is delivered to 23 million Californians.**

In July 2008, the California Department of Water Resources awarded USGS and UC Davis a three-year $12.3 million research grant to "take the concept of carbon-capture farming to full scale in a scientifically and environmentally sound way". But state budget cuts this year have left the project in limbo. "There is no funding for the current wetland, or for the larger wetland that is supposed to be established on Twitchell," Miller says. The previous annual costs to support the pilot project's research in the wetlands and surrounding drained fields had ranged from about $0.4-1 million per year over 11 years, from 1997 to 2008.

If peat soils drained of water and eroded through exposure to wind and rain can grow back in California, and trap carbon in the process with minimum release of additional greenhouse gases, then the restoration of marshes in the area could potentially relieve

Photo credit: U.S. Geological Survey

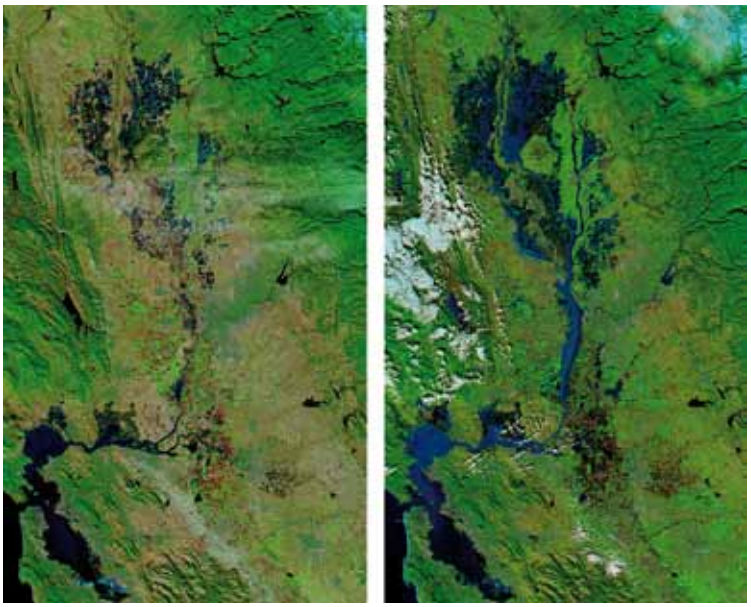
the stress on the levee system as well as combat climate change. Such a solution, the scientists hope, may even be economically beneficial to local farmers.

## Sinking fast

In deltas around the world, the land is sinking faster than sea level is rising. For the most part the reason for the sinking is because dams and levees prevent the annual load of river sediment from reaching what are now lowland areas. The peat soils in California, however, are not starved of sediment, but rather starved of water. In other words, California's peat soils, while somewhat unique, give us good insights into the workings of a delta.

So how applicable are the insights gained from the California project to other deltas? It turns out that the draining of wetlands is common to other deltas too. As the LOICZ report mentions: "Draining wetlands can cause soil organic matter oxidation and increase subsidence rates far above geologic subsidence rates. There have been enhanced rates of subsidence in the Rhine and Sacramento deltas because of soil oxidation."

In the 20 September issue of *Nature Geoscience* the same editors of the LOICZ report, Irina Overeem and Syvitski, along with other colleagues at the University of Colorado in Boulder, published a survey of 33 deltas around the world. They concluded that globally most deltas are vulnerable to flooding as "a result of sediment compaction from the removal of oil, gas, and water from the delta's underlying sediments, the trapping of sediment in reservoirs upstream, and floodplain engineering in combination with rising global sea level". They did not include the Sacramento-San Joaquin River Delta or the Rhine Delta in their study. But they found that Italy's Po Delta, where people mined methane gas during the 1960s and early 1970s, had subsided 3.7 metres during the 20th century, with 81 percent of the subsidence attributed to the gas mining. Groundwater withdrawal from the Chao Phraya Delta in Thailand is causing the land to sink 50 to 150 mm per year.



NASA image courtesy the MODIS Rapid Response Team, Goddard Space Flight Center

This pair of images shows flooding in the Sacramento-San Joaquin Valley region inland of San Francisco Bay. The image on the left was captured on 10 December 2005, while the image on the right was captured on 4 January 2006, just days after the severe storms passed through.

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Nurturing organic soils is not a likely solution for these areas. In the Po Delta the levees are upwards of 12 to 15 metres above the lowlands, higher than the rooftops of the houses that have been developed on the agricultural land. The percentage of peat in the delta is minimal, roughly three to four percent, says Annamaria Correggiati of the Istituto di Scienze Marine-Consiglio Nazionale delle Ricerche Sede di Bologna. There is an experimental effort to reduce subsidence by pumping water back into the substrate during natural-gas capture, but this she says is "very experimental and very new". As for the Chao Phrya Delta, it was never peat. "Chao Phrya is all shrimp farms, and presently these are replacing the mangrove forests," Syvitski says.

Syvitski's team found 85 percent of the deltas they surveyed had experienced severe flooding during the past decade, "resulting in the temporary submergence of 260,000 km$^2$". They estimate that at the current projections for sea-level rise, the surface of delta land vulnerable to flooding could increase by 50 percent in the future. Of the deltas they surveyed they found that most are "sinking at rates many times faster than global sea level is rising".

In order of increasing risk they identified three categories of deltas: those that have reduced sediment accumulation that can no longer keep up with local sea-level rise (including Brahmani, Godavari, Indus, Mahanadi, Parana and Vistula); those that have reduced sediment accumulation plus accelerated compaction of their sediments, which combined are overwhelming the effects of global sea-level rise (including Ganges, Irrawaddy, Magdalena, Mekong, Mississippi, Niger and Tigris); and finally those with virtually no sediment accumulation and/or very high compaction (for example Chao Phraya, Colorado, Krishna, Nile, Pearl, Po, Rhone, Sao Francisco, Tone, Yangtze and Yellow).

## Creaking levees

From the wetland on Twitchell Island, the levee looks like a long, flat hill. It is only by driving up on top of the levee that the expansive Sacramento River is visible on the other side. A sealion in middle of the river barks loudly on a buoy. Miller explains the growing strain on the levee system by comparing the weight of the water on the river side of the levee with the weight of the air on the lower, farmed side of the levee. "If I have a bucket of water in my hand it's heavy. For every centimetre higher the water level rises or every foot lower the land sinks, that's added water weight the levee has to hold," she says. The difference in the height of the levee and the low-lying ground coupled by the weight of the water behind the levee is a universal risk among deltas. But Sacramento-San Joaquin River Delta has another risk factor that other deltas don't usually have to worry about: earthquakes. "The worst case scenario is if this levee breaks during an earthquake and the water rushes across the farmlands and takes out the levee on the other side," Miller says. Following the disaster that happened during Hurricane Katrina in New Orleans, she says these levees are now potentially the worst in the country. The fresh water behind the levees is delivered to 23 million Californians. "Should salt water flow back into the pumps it might take up to two years to flush out the salt water again," she says. She is echoing the estimate the late Marc Reisner proposed in his 2003 article that was posthumously published, 'A Dangerous Place: California's Unsettling Fate.'

Photo credit: U.S. Geological Survey

Robin Miller has been studying the Sacramento Delta for the past twelve years.

## Danger zone

Deltas are indeed a dangerous, though highly sought after, place to live. As the LOICZ report explains, "Both the river and the ocean nourish the delta system with fluxes of water, sediment and nutrients. Consequently, deltas are highly productive, ecologically rich systems and have been attractive areas for settlement of humans from the earliest civilisations. Deltas are immensely important for food production and aquaculture." In the *Nature Geoscience* survey, Syvitski and colleagues report that: "In 2007–08 alone, the following deltas experienced substantial flooding: Ganges, Mekong, Irrawaddy, Chao Phraya, Brahmani, Mahanadi, Krishna and Godavari, with more than 100,000 lives lost and more than a million habitants displaced." Syvitski considers subsidence a considerable threat.

This is reflected also in the LOICZ report's call for a "multidisciplinary, problem-driven approach with experts from the fields of engineering, ecology, geography and human dimensions," to address the "urgent needs of our world deltas and their vulnerabilities, resilience and risks".

They conclude that the technology envisioned for an integrated framework for delta research and management will incorporate "morphological models that predict natural delta dynamics as a function of changing processes, combined with GIS tools that help exploring socioeconomic scenarios. Risk mapping would then include a variety of parameters like risk of flooding due to river floods, risk associated with tsunamis and hurricanes, risk of accelerated subsidence, risk of habitat loss for threatened species". ▮

**We didn't realise you could store so much carbon so quickly.**

CHRISTINA REED is a science writer.

### MORE INFORMATION

Overeem I & Syvitski J P M (2009) Dynamics and vulnerability of delta systems. *LOICZ Reports & Studies* 35. GKSS Research Center, Geesthacht.

The CSDMS Integration Facility based in Boulder, Colorado, is a "virtual home for a diverse community of experts, presently from 22 countries and 135 institutions, who foster and promote the modelling of Earth-surface processes."

The Global Water System Project, GWSP, is a joint project of the Earth System Science Partnership committed to analysing the effects of global change on the planet's water system.