



Sinking Cities and Rising Sea Level

Many of the world's great cities, including London, New Orleans, Tokyo, Houston, and Mexico City, are sinking*. With the exception of Mexico City, these cities are located on coasts where they are also vulnerable to a long-term world-wide rise in sea level. In low coastal areas, such as New Orleans, sinking increases the flood risks from the Mississippi River and from tides and storm surges from the Gulf of Mexico. London faces similar problems when storm surges are driven up the Thames River from the English Channel.

Venice is the world's best example of a city already partially submerged by a combination of sinking and rising sea level. Venice is located on several low marshy islands in a lagoon that is connected with the Adriatic Sea. The city has been built on piles driven into soft sediment of the bay, so it's essentially standing in the lagoon waters where it is exposed to tides and storms and is particularly vulnerable to any rise in sea level. Sixty-two percent of Venice is now flooded when tides and storm surge reach 1.2 m. This water level has occurred 14 times in the last 25 years. Flood levels which were of little concern 50 years ago, now cover the Piazzo of San Marco 20 to 30 days a year between October to April, the season of the strong southeasterly winds, the Siroccos.

One result of the sinking is that chemical pollution in the Venetian lagoon has become a much more serious problem to the buildings of Venice. The lagoon is at the end of a drainage basin which supports a population of 1.2 million, in addition to large port and industrial development. Consequently, the lagoon waters that move in and out of Venice with every tide are highly polluted. In fact, Venice itself does not have a sewage system so it depends on the flushing action of the daily tide to rid itself of waste. The lagoon is overloaded with industrial

pollution, raw sewage and urban trash.

Sinking has resulted in fractures, tilting and irregular surfaces throughout Venice. The columns of St. Mark's Basilica lean noticeably and the floor of the church has irregularities up to 30 cm. Evidence of flooding and chemical decay at the base of the buildings where the lagoon waters are on contact is everywhere; however the decay most readily visible is the chemical and physical degradation of the stone buildings and sculptures. Factories in the area discharge tons of sulphur dioxide into the atmosphere each year so the city is being dissolved slowly from the waters of the polluted lagoon and from an acid atmosphere. Experts estimate that 30 percent of the city's ornate fabric has already been lost.

There are three courses of action open to the Venetians: they can raise the city, they can reduce the high-water levels through flood control measures, or they can erect barriers against storm surges. Raising the city is impossible so Venice is trying to control the flood tides by reducing the size of the openings with flood gates between the lagoon and the Adriatic flood gates. However, these can only be considered temporary measures.

In Venice, as in London, New Orleans, Tokyo, Shanghai and Long Beach, all great coastal cities that are sinking, dikes and levees are needed to keep out the sea, massive pumping systems are used to remove flood waters, and innovative (and expensive) movable or expandable dams have been constructed to obstruct storm surge and prevent flooding. For example, the Thames barrier in London cost over \$1 billion. Landfills are used to raise the elevations of parts of the cities, and engineering works are needed to prop up sagging and leaning buildings.

Although almost all of the coastal cities that we have mentioned have both initiated and aggravated their problems by the withdrawal of ground water from beneath them, the continued rise in sea level is really what challenges engineers in their efforts to

*We discussed the problems of sinking cities, with particular emphasis on ground water removal from the aquifers beneath them, in a recently published article in *American Scientist* (Vol. 74, pp. 38-47)

keep out the sea. If the predicted increase in sea level rise occurs due to a global warming, the engineering works which presently keep the ocean out will be severely tested and if the highest sea level predictions that have been projected in recent years are correct, then the results would be disastrous for most of the world's great coastal cities.

Living and working behind high levees like the Dutch will probably be the only solution for the short term. For the longer term, the choice would

appear to be to raise the elevation of the land by filling behind the dikes or actually relocating some of the cities. It will be the largest effort, the greatest challenge, the most expensive undertaking yet faced by man.

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