FORUM

Earth Scientists and Public Policy: Have We Failed New Orleans?

Earth scientists rarely influence public policy or urban planning. In defiance of geologic reality, cities are established on or expanded into floodplains, wetlands, earthquake faults, and active volcanoes. One exception to our lack of influence is that shortly after a major natural disaster, there is a brief window of heightened public awareness that may lead to sensible regulation or relocation of infrastructure. After the 1933 Long Beach earthquake, for example, California building codes were improved to reduce earthquake hazard. After Mississippi River flooding in 1993, several U.S. cities designated parts of their low-lying floodplain as green space.

How have we done with New Orleans and southern Louisiana, devastated by hurricanes Katrina and Rita in 2005? Unfortunately, not very well. In the aftermath of those storms, an opportunity existed to educate engineers, policy makers, and the public about long-term hazards associated with land subsidence and sea level rise. This message was not conveyed, and expensive rebuilding has proceeded under the false assumption of relative coastal stability and slow sea level rise.

While many social and economic issues are involved, at least the science is clear: The area is a delta; it is low lying and getting lower all the time; it will flood again; lowest elevations are most at risk; and levees must be periodically augmented to keep up with subsidence, sea level rise, and future storms. Why were Earth scientists not able to deliver this simple message? This is an important issue not only for New Orleans, but also for society in general. In a world increasingly exposed to natural and man-made hazards from population growth, resource depletion, pollution, sea level rise, and related problems, scientists need to be able to communicate relevant information clearly and quickly. Yet too often our wisdom is ignored. Why?

Part of the problem is that when Earth scientists are asked to make policy statements, we tend to speak to our peers rather than to the public. We use technical jargon, and we are cautious, emphasizing measurement uncertainty and placing caveats on our conclusions. Obvious, commonsense statements are often avoided. Also, public policy statements tend to come from committees, where clarity is sacrificed for consensus.

Forensic analysis has shown that New Orleans would not have flooded if man-made flood protection systems had not failed. But there is less appreciation for the fact that most failure can be attributed to ongoing subsidence. Subsidence lowers levee defenses over time, and it can cause systematic errors in the vertical control system (a local geodetic system) that engineers use to design, build, and assess levee protection. New space-based geodetic techniques eliminate problems associated with local datums and clarify current subsidence rates.

However, instead of providing a simple picture of how low elevation, unrelenting subsidence, and sediment starvation set the stage for coastal flooding, the Earth science community emphasized the complexity of the problem and disagreements among scientists. A report on New Orleans by a committee of experts convened by the American Geophysical Union [*AGU*, 2006] concluded, "Presently, there is considerable discussion and debate among the scientific community regarding mechanisms and rates of subsidence in the Mississippi delta area." *González and Törnqvist* [2006] review available subsidence data for Louisiana and conclude that there is a "subsidence controversy."

Until recently, subsidence estimates relied mainly on millennial-scale or longer time-averaged rates based on chronostratigraphic data, and the estimates suggested relative coastal stability. These geological estimates underpin the current, long-standing paradigm for coastal engineering of hurricane surge protection. New geodetic data challenge this paradigm, at least for the delta. The two data types are not necessarily in conflict if one recognizes that there are likely to be significant spatial and, especially, temporal variations in subsidence rates and patterns. While the Holocene history is scientifically interesting, it is less relevant to current hazard assessment and engineering requirements for New Orleans, where rates and processes over the past approximately 100–150 years define the problem. In short, we need geologic insights but geodetic measurements. Below, we summarize the roots of the vulnerability of New Orleans and southern Louisiana, and we provide what we hope are clear recommendations.

Geologic Background

All deltas subside, but on average the sediment-water interface is maintained near sea level by seasonal flooding, new terrigenous sediment deposition, and in situ organic accumulation. In the Mississippi delta, this balance was maintained until the construction of levees for flood control and river navigation began in the 1800s. The interruption of this sensitive natural system by river channelization stopped overbank flooding and curtailed biologic sedimentation, while natural subsidence continued.

Subsidence can be defined as vertical motion of the land surface relative to a precise datum, e.g., the Earth's center of mass. When we consider tide gauge data and some geologic indicators of relative sea level, it is important to distinguish land subsidence, a local process, from regional and global sea level rise. All contribute to local relative sea level rise and flood hazard. For New Orleans and many parts of the delta, geodetic data show that current land subsidence (approximately 5–25 millimeters per year) is much faster than global average sea level rise (approximately 2–3 millimeters per year) due to three main processes:

1. Compaction and consolidation of young (Holocene) sediments. Older sediments also compact, but at lower rates. Organic-rich marshy sediments are susceptible to extreme compaction when drained for agriculture or urbanization. As the sediments desiccate, carbon-rich material oxidizes to CO_2, diffusing into the atmosphere with consequent mass and volume loss in the soil.

2. Subsidence due to mass loading. If sediment flux is steady, the delta attains a state close to isostatic equilibrium. However, the Mississippi delta received a large sediment load near the end of Holocene glaciation. The delayed response of the viscous upper mantle means that the delta is still adjusting to this load, possibly causing several millimeters per year of subsidence [*Ivins et al.*, 2007]. Clearing the continental interior for agriculture in the past 150 years may also have increased sediment supply and recent loading.

3. Tectonic subsidence. Gravity sliding (downslope movement of a delta due to the gravitational load of the sediments) also contributes to subsidence. For the Mississippi delta, GPS data show approximately 2 ± 1 millimeters per year of southward motion toward the Gulf of Mexico [*Dokka et al.*, 2006]. Associated subsidence is less precisely known and may vary as a function of distance from active normal faults accommodating the motion. The mean rate of GPS-measured delta subsidence (5 ± 2 millimeters per year [*Dokka et al.*, 2006]) represents the sum of several effects, including mass loading and tectonic subsidence.

In terms of spatial variation, we know that the delta currently subsides faster than most other parts of the Gulf coast, e.g., from tide gauge and leveling data [*Penland and Ramsay*, 1990; *Shinkle and Dokka*, 2004]. Different parts of the delta may also subside at different rates. In terms of temporal variation, rates have likely been faster in the past approximately 100–150 years compared with earlier times. In particular, drainage of former marshes and other organic-rich soils can lead to very high rates of subsidence for many decades after drainage, in excess of 30 millimeters per year [*Stephens et al.*, 1984]. In terms of hazard, we are interested mainly in subsidence of the city and nearby delta, and only for the past 100–150 years.

Recent subsidence is well defined in New Orleans. The spatially averaged subsidence rate in New Orleans from synthetic aperture radar (SAR) (6 ± 2 millimeters per year [*Dixon et al.*, 2006]) is similar to the delta average from GPS (5 ± 2 millimeters per year [*Dokka et al.*, 2006]) and to earlier leveling data for New Orleans (5 millimeters per year [*Burkett et al.*, 2003]). Some parts of the city now lie 3 or more meters below sea level, and they presumably experienced more rapid subsidence in the past. Major drainage and levee construction began after 1850. Assuming low elevations are related to this construction, and assuming starting elevations close to sea level, a subsidence rate of 20 millimeters per year averaged over the past 150 years is required to generate an elevation of 3 meters below sea level. Similar high rates of subsidence are observed in the past few years in parts of New Orleans with SAR and GPS [*Dixon et al.*, 2006] and earlier leveling data spanning several decades [*Shinkle and Dokka*, 2004]. The simplest interpretation is that rates of subsidence measured today are typical of subsidence over the past 100–150 years, explaining the current low elevation.

Thus, three independent data (current elevation, space geodesy, and leveling) indicate rapid modern subsidence. Note that both the average (approximately 5–6 millimeters per year) and maximum (approximately 15–25 millimeters per year) rates of current subsidence are well in excess of global average sea level rise (approximately 2–3 millimeters per year). In terms of flood susceptibility, the rate of relative sea level rise (land subsidence plus eustatic sea level rise) is critical and for New Orleans mainly reflects land subsidence.

In summary, current high rates of subsidence in New Orleans, corroborated by several independent techniques, are representative of rates over the past approximately 100–150 years and explain the current low elevation of the city. Subsidence is increasing the region's vulnerability to storms and flooding, and it needs to be considered in planning and reconstruction. Geodetic data from the past 50 years offer the most reliable rates for planning and rebuilding in New Orleans over the next 50 years.

Acknowledgments

This study was supported by U.S. National Science Foundation grant EAR 0609742. We thank an anonymous reviewer for comments that greatly improved this article.

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