POLICY FORUM: URBAN ECOLOGY

Saving Venice

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Flooding in Venice not only imposes high costs on those who live there but endangers a rich cultural heritage that is unique in the world. Scientists and engineers have not taken a long enough view in their approach to this serious threat. Records for the 20th century show that *acqua alta*, the local name for an exceptionally high tide, is a worsening phenomenon (*1*, *2*). The decade with the highest number of such tidal events is the one that just ended. A project called MOSE (Modulo Sperimentale Elettromeccanico or experimental electromechanical module) was officially put forward in 1981 (*2*) as a potential answer to the problem. It would involve building a system of 79 mobile flood gates at the three inlets to the lagoon that surrounds the city.

This much-debated proposal has slowly worked its way through different review agencies (*3*–*5*), and the project has just reached the point where a final decision on its implementation is to be made by the Council of Ministers of the Italian government. However, new data on the long-term rate of rise in relative sea level (RSL) at Venice (*6*) are raising basic questions about the feasibility of the project. In light of the prospect of global warming (*7*), what is at issue is the high frequency of gate closing that will occur in the later stages of the gates' life and the impact that this will have on the ecology of the lagoon. The purpose of this article is to consider how science and public policy relate to one another at this critical juncture in the current effort to save Venice.

On 4 November 1966, Venice received an unexpected wake-up call in the form of a tidal event that peaked at 1.94 m above the standard for mean sea level established in 1897. The flooding took a heavy toll on the city's art and architecture and left many Venetian families with deep economic losses. This disaster drew worldwide attention to the vulnerability of the city. The tides themselves are driven by astronomical cycles in combination with meteorological conditions. Winds from the southeast, acting together with atmospheric pressure and rainfall, can produce storm surges reaching heights well above normal ones. To avoid flooding, the Venetians have long known from practical experience that a house floor or street pavement has to stand somewhat above the level of high tides and seasonal storms at the time it is built. However, both world sea level and earth-movement processes are contributing to the "sinking" of land surface with respect to the sea at Venice (*8*). On the basis of tide-gauge records, there has been a rise in RSL of about 23 cm over the last century. It is estimated that 10 cm of this change was due to the pumping of groundwater to run the industrial complex of Porto Marghera in the years between 1930 and 1970 (*9*). This means that Venice, because of an ill-conceived industrial policy, has lost more than half a century in its long-standing battle against the sea.

The proposed plan to deal with the worsening situation is for the gates to be raised into position whenever the tide reaches a height of 100 cm above the 1897 standard. When at rest, the gates will be full of water and will lie in a housing dug into the sea bed. When bad weather is approaching, compressed air will be pumped into the gates. This will empty them of water and make them rise until they emerge above sea level and block the flow of the tide. During the time the gates are in use, the lagoon will be completely cut off from the sea. Open circulation with the sea is essential to the life of the lagoon; after any one closing, it will take several tidal cycles to flush out the pollutants that accumulate from various sources and to restore the lagoon's equilibrium. Once approved, the gate system will take 8 years to build; its price tag will run well over US$2 billion.

By 1995, the project had reached a point at which environmental impact studies had to be prepared by various governmental agencies. The assessments have been mixed. For example, the Venice Water Magistracy through its concessionaire, the Consorzio Venezia Nuova, completed its report in July 1997 and saw the project in a positive light (*3*). However, the Consorzio is the same organization that was asked to take the lead in the design of the project, its evaluation, and its eventual construction. Such an arrangement, in fact, runs counter to the laws of the European Union, which insist on the separation of these three functions in large public works projects. In contrast, the national committee of the Ministry of the Environment, in its December 1998 report, was opposed to the project (*5*). At a meeting of the Council of Ministers of the Italian government held on 8 March 1999, it was agreed that the Council itself should sort the matter out and reach a final decision by the end of the year. This did not happen for various reasons, and, with the recent fall of the government after local elections and the formation of a new government, the decision still remains up in the air.

The impact studies conducted by the different agencies all used the same three scenarios for the rise in RSL by the year 2100, the projected life of the gates. Because of a lack of knowledge at the time

A rising tide in Venice. A view of the effects of the *acqua alta* in the area of the Piazza San Marco.

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about the long-term trend in RSL for Venice, the low and middle scenarios (a rise of 4.4 cm and 16.8 cm, respectively) were based on attempts to separate effects of earth subsidence from effects of the behavior of the Adriatic Sea. The only scenario to include a consideration of global warming was the high one (53.4 cm), which was treated as an extreme or unlikely case in the impact studies.

The scenarios were based on a tide-gauge record at Venice that spans a period of only 26 years (1970–1996), and this constitutes the fundamental weakness of the evaluation process. In light of the high level of statistical noise in tide-gauge data, it is widely held that one needs measurement over at least 40 years to establish a reliable trend (*10*). The problem is that Venice's 100-year tide-gauge record has been split into three pieces because of the pumping of groundwater at Porto Marghera. Neither the 1897–1929 nor the 1971–1996 piece is long enough in terms of oceanographic science for a sound projection of the change in RSL at Venice over the next 100 years.

In our view, the evaluation process should not assume the most favorable conditions for the operation of the project; instead, like all engineering projects, allowances should be made for a margin of safety. Recent work at six archaeological sites in Venice now makes it possible to estimate the trend in RSL for the period from A.D. 400 through 1900 and indicates that the estimates used in the impact studies were too low (*6, 11*). If we start with the average, long-term rise in RSL as a baseline (13 cm per century), add a safety margin (4 cm per century), and make a minimal allowance for global warming (13 cm over the next 100 years) (*7*), a value of 30 cm is obtained for a new low projection of the rise in RSL. The "worst-case" scenario (high estimate) would be on the order of 100 cm.

What the new low scenario implies is a large number of gate closures in the later years of the gates' life. At present, there are, on average, seven times each year when a tidal event reaches a height of 100 cm or more above the 1897 standard. With a rise of 30 cm in RSL, the average number of events reaching such a height (when the gates will have to be closed to prevent flooding) will climb to 94 per year (*3, 4*). If one takes into account variability in the number of extreme high tides from one year to the next and also includes false alarms, this means that a given bad year may experience as many as 150 gate closings under a 30-cm rise in RSL. In addition, tidal events in Venice are seasonal in nature. Two-thirds of the *acqua alta* events commonly occur in the months from October through January (*2*). Thus, in the gates' later years, gate closure will end up taking place repeatedly, day after day and week after week, during this 4-month period in a given bad year. This is far from the occasional closing of the lagoon that was envisioned when MOSE was originally proposed. As such a high concentration of gate closure will limit the circulation of water that is essential to biological life in the lagoon, this could have negative impacts on levels of water pollution and the ecology of the lagoon.

For the politican who has to make the final decision on implementation, the project represents a giant headache. There are many different players in the game—the local city governments, the different ministries of the national government, the building companies, the Consorzio, the political parties, the environmentalists, and the international committees to save Venice. There has been no consensus among them about the merits of the project. In addition, global warming represents a major source of uncertainty that hangs over public policy in general and the project in particular. On the one hand, the policy-maker cannot decide simply to do nothing, as the problem in Venice is too urgent. On the other, to spend such a large sum on a solution that will only create new problems of its own does not make good sense. What further complicates the decision-making process is the fact that science and public policy now find themselves out of phase with one another. The assessments in the reports that sit on the officials' desks are based on considerations that are no longer tenable. Should the final decision be made on the basis of what is in the official reports or what is in the scientific literature? For the policy-maker, there is no easy answer to this question.

For the scientist, with an interest in getting to the bottom of things, the answer is different. We would like to see the whole decision-making process started from the beginning, this time with a clearer division between the functions of planning, evaluation, and execution. Given the half-life of Italian governments and potential conflicts of interest on the part of the Consorzio, one might argue that the European Union should take a more active role in the evaluation process. If the new Intergovernmental Panel on Climate Change (IPCC) report that is forthcoming (*7*) sustains its previous position on global warming, then the handwriting could be on the wall regarding the project. There will be a need for fresh thinking in the search for new, alternative solutions. A new international competition may have to be organized in order to accomplish this.

For those living in the fast-paced modern world, the challenge that Venice presents the scientist and the policy-maker is to take the long view. The rise in RSL is a problem with a long history—one that goes back to the origins of the city itself. The RSL will continue to rise in Venice not just over the next 50 or 100 years; but for the next 200 years and more. The problem constitutes part of the historical condition of the city. By the year 2200, there is a good chance that Venice, like many other coastal areas around the world, will have to deal with a rise of 100 cm or more in RSL (*7*). Long before such levels are reached, the mobile flood gates will have ceased to offer any protection for the city. Whatever solution is eventually adopted for Venice, we believe that each new step should build on what has been done before and on sound scientific analysis. The mobile flood gate project does not appear to meet this test; it will not serve as an effective building block toward a long-term solution.

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