The Science of Saving Venice

PLAGUED BY RECORD HIGH TIDES AND A SETTLING LANDMASS, THE CITY PRESENTS ONE OF THE WORLD'S GREAT CONSERVATION CHALLENGES

by Anna Somers Cocks

Oh Venice! Oh Venice! When thy marble walls
Are level with the waters, there shall be
A cry of nations o'er thy sunken halls
A loud lament along the sweeping sea!

—Lord Byron, *Ode to Venice*, June 28, 1819

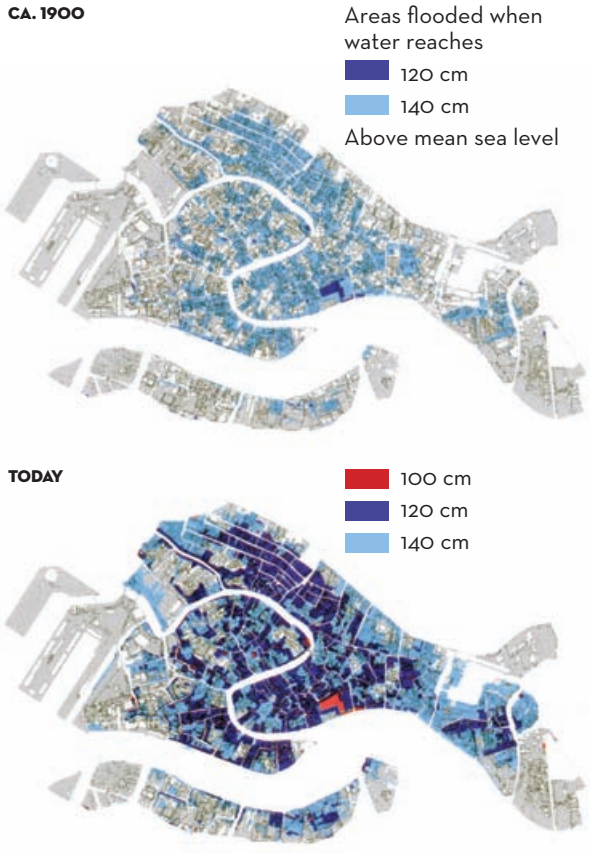
In the old days of the Venetian Republic, the doge would board his golden barge on Ascension Day to be rowed out beyond the lagoon into the waters of the Adriatic. There, he would throw a consecrated ring into the sea, saying "Desponsamus te, mare," (We wed thee, O sea).

On the night of 3 November 1966, that marriage—more than a millennium in the making—failed as a violent storm surge rolled into the city, flooding its labyrinthine canals to a depth of nearly two meters above mean sea level. Miraculously, no one perished. Yet Venice was forever changed. As debris and pollution from oil spills flowed throughout the city, its most basic services rendered inoperable, the flood threw a harsh spotlight onto the crumbling architectural fabric of Venice, which had been slowly but surely sinking into the waters of the lagoon that had given it life, unbenownst to the outside world.

Within weeks, the international community responded, pledging to aid Venice in its recovery. Working closely with the *soprintendenti*, or cultural heritage officials in the Italian government, UNESCO drew up a list of more than 100 structures in urgent need of stabilization and conservation and launched an appeal for funds and technical assistance. Among the first to step forward were the British Art and Archives Rescue Fund (renamed Venice in Peril in 1971) and the U.S. Committee to Rescue Italian Art (CRIA). The World Monuments Fund (WMF)—known at that time as the International Fund for Monuments—partnered with the latter and established the Venice Committee to carry out restoration work. Its example was soon followed by the formation of a number of national committees dedicated to the preservation of the city.

In that time WMF has supported some 30 restoration projects in Venice, making it one of the largest beneficiaries of the organization's time and resources, while Venice in Peril has restored more than 40 buildings and works of art, as well as

DURING ACQUA ALTA, LITERALLY HIGH WATER, PEDESTRIAN TRAFFIC MOVES ALONG ELEVATED PLANKS SET UP IN LOW-LYING PARTS OF THE CITY. MAPS OF VENICE, BELOW, SHOW THE DRAMATIC INCREASE IN SEASONAL FLOODING OVER THE PAST CENTURY. IN 1900, ST. MARK'S SQUARE FLOODED WHEN WATERS REACHED 120 CM ABOVE MEAN SEA LEVEL, A THIRD OF THE CITY WAS FLOODED AT 140 CM. TODAY, ST. MARK'S IS INUNDATED WHEN TIDES EXCEED 100 CM ABOVE MEAN SEA LEVEL, ONE THIRD OF THE CITY AT 120 CM.



financed bursaries for students of conservation to study in Venice. Other organizations have also done their part to salvage what they can of one of the world's great cities. Yet, the task is far from complete, and perhaps today more daunting than ever. The challenge is not merely to conserve monuments, but to arrest further decay as the city continues to sink and waters continue to rise at an alarming rate.

Venice is built atop a group of 117 small islands—part natural, part artificial, created by driving millions of piles deep into the clays underlying the lagoon—connected by some 378 bridges. Archaeological digs have shown that Venice has been sinking at the rate of about ten centimeters a century since its founding in the late first millennium, but in the past 100 years it sank an extra ten centimeters. Industry on the mainland, which depleted natural underground reservoirs of their freshwater reserves, has caused the subsoil to compact, resulting in a water level some 25 centimeters above a mean sea level reference point established in 1897. Although this practice was stopped in the 1970s, the damage was done. As Albert Ammerman of Colgate University has put it, "Venice has lost a century in its battle with the sea."

This reduction in the margin between ground level relative to sea level, which is eroding the fabric of the city itself, is omnipresent. A line of green algae that grows at high tide is evident on the brickwork above the protective Istrian stone bases of the buildings. As the brick absorbs seawater, salts within it crystallize and degrade building materials. Within St. Mark's Basilica, one of the world's great architectural treasures, the damp has reached as high as the vaults and is causing the individual mosaic pieces to fall off.

In addition to the chronically high water level, there are the *acque alte*, seasonal floods that invade the alleys and squares most frequently in late fall, forcing the populace and visitors to walk on duckboards. These occur as a result of a high tide, a low-pressure system, and either a strong southeast wind (*sci*rocco) that drives in extra water from the Adriatic or a northeast wind (*bora*) that drives a high surge of water across the lagoon.

The incidence of flooding has increased ten-fold in the past century because of adverse environmental changes in the lagoon. In 1900, St. Mark's Square, the lowest lying part of the city, was flooded perhaps six times a year; today, that number is more like 60. While the lagoon used to be embraced by salt marshes, capable of absorbing substantial amounts of water, kilometer after kilometer of these have been drained and paved over with cement. Moreover, the sandbanks and shallows that once broke up and slowed down the volumes of water are today only a third of their extent a century ago.

The lagoon is also getting deeper and saltier, behaving more and more like open water, pollution having killed off sea grasses that stopped erosion. And the deep-water channel dug in the twentieth century to let tankers into the port is causing more sediment to be sucked out of the lagoon with each waning tide.

Compounding the physical damage, the city is suffering a social prob-

lem—abandonment, the population of the city dropping from 150,000 inhabitants in the 1950s to 64,000 today. Residents are fed up with trying to lead a normal life under abnormal conditions, fomenting a poor environment in which to conduct business. Mayor after mayor has lamented the fact that Venice is losing its socio-economic diversity and turning into a mono-economy anchored in tourism. Yet when the physical condition of Venice induces people to think short-term, tourism seems an attractive option with its quick return on investment.

When I became chairman of Venice in Peril in 1999, I realized that if we were to truly help the city, we would need to look beyond the individual restoration projects our organizations were carrying out and begin addressing the underlying problems; in other words, to treat the disease as well as the symptoms.

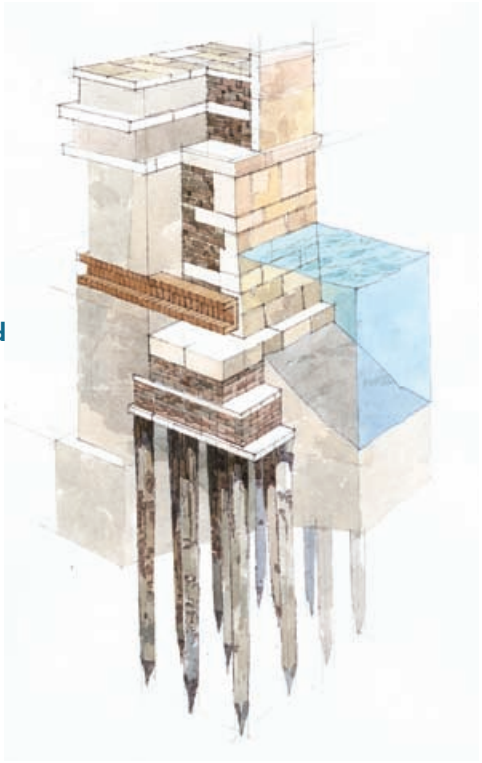
For years, politicians, engineers, developers, and environmentalists had been arguing over how to save the city. Many believed its problems could be solved with the construction of a mobile barrier between the lagoon and the Adriatic, which would hold back elevated tides. Others contend that the environmental impact of such a contraption will be disastrous if measures are not taken to address the ecological health of the lagoon.

I realized that amid all of the political shouting the scientists were not being heard. I rang up an old friend, Sir John Boyd, head of Churchill College, Cambridge, and said, "There must be some way of finding out where the truth lies." He agreed, and arranged for lunch with some of the best scientific and engineering minds at the university. By coffee, we had decided that a way forward was to found a three-year fellowship to gather all the extant scientific research on Venice and the lagoon, after which we would convene an international meeting of scientists from relevant backgrounds to ascertain where the balance of proof lay, and see whether there were any serious gaps in the research.

By autumn 2001, we had identified two researchers to carry out the work—Caroline Fletcher, an environmental chemist, would take up the Venice in Peril Fellowship at Churchill, while Jane Da Mosto working with the Consortium for the Coordination of Research into the Lagoon (Corila), a Venetian interdisciplinary university body, would be her counterpart in Italy. Chief of the project in Cambridge was Tom Spencer, head of the Coastal Research Unit. His calm, clear, expert guidance would prove invaluable.

City on Stilts

When Venice went from temporary refuge to a permanent city in the ninth century A.D., its citizens found they could build on the marshy land by driving piles deep into the dense clay subsoil beneath the lagoon. More than 10,000 such pilings support the Rialto Bridge while the Chiesa della Salute on the Grand Canal is supported by no fewer than a million. To form building foundations, layers of oak were laid atop the piles, which would then be capped with Istrian stone, a tough marble impermeable to water. For building construction above the water line, lighter and more flexible materials were used to reduce stress on the foundations and increase the capacity to respond to ever shifting subsoils. To make repairs to foundations and underwater sewage pipes, below, canals must be dammed and drained.



The first thing to emerge was that research conducted since 1966 was not always easy to find, divided as it was between different organizations, and much of it unpublished. Nonetheless, by September 2002, the project was ready to hold scientific and technical workshops. Each—attended by 12 to 15 people, from Venice, Cambridge, and elsewhere—looked at four areas: flooding and its implications for the buildings of the city; physical and ecological processes of the Venice lagoon; modelling of the hydrodynamics, morphology, and water quality of the lagoon; and global environmental change, uncertainty, risk, and sea level rise in the northern Adriatic.

Twelve months later, the largest interdisciplinary meeting of scientists to discuss the Venice problem since 1969 took place at Churchill College. For three days, Italians, Britons, Americans, Russians, Dutchmen, Lithuanians, Danes, and Spaniards discussed issues of flooding and environmental change in the city in an apolitical, tension-free setting—something that, unfortunately, is very difficult in Venice itself. They considered possible solutions and compared them to the situation in other places, such as the Netherlands, the Thames estuary, and St. Petersburg, each of which had approached the problem of flooding in novel ways.

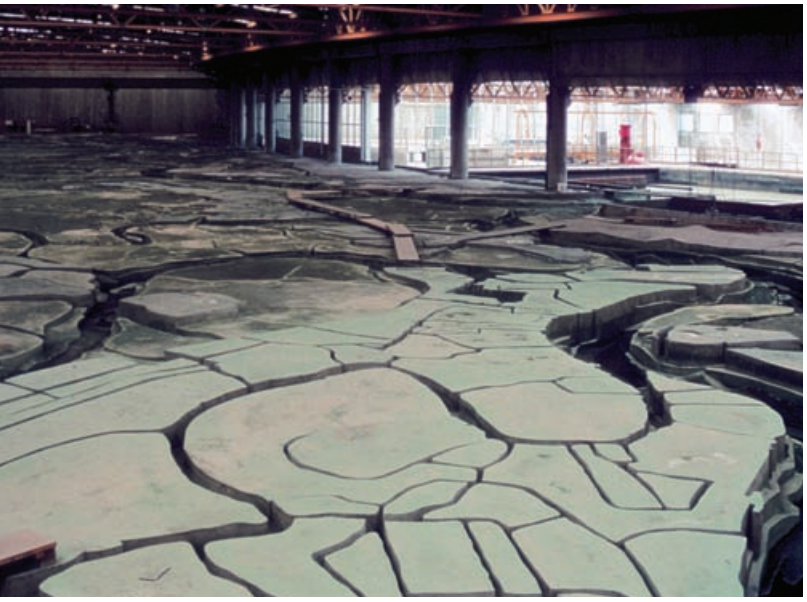
The most striking thing that emerged from the discussions was that no scientist present thought Venice could survive without the installation of a mobile barrier system (see page 28). Yet, they also agreed that the barriers were only part of the solution, a way to buy Venice time and that we needed to be researching and planning for the next expedient. Informally, the Dutch suggested that one day, it might be necessary to cut Venice off from the sea permanently and convert the lagoon into a sweet water lake, as they have done with a part of the Eastern Scheldt estuary. More recently, scientists from Padua University have suggested that it might be possible to pump water into the subsoil and raise the area under and around Venice by 30 cm. Both at the conference and in the years since, nearly all have agreed that there will ever be a single, definitive solution to the flooding problem.

Critical to carrying out any sound diagnostic and planning work on the flooding is clear communication between the various research institutions and government agencies tackling the problem. This, at present, does not exist because of fragmentation of institutional responsibilities within Italy. Reducing the pollution in the lagoon watershed, for example, is the job of the Veneto regional administration, while pollution of the actual lagoon is policed by the Magistrato alle Acque, a branch of the Ministry of Public Works. One tide-gauge network is run by a branch of central government, the Agency for the Protection of the Environment, while forecasting storm surges is the job of the town council, which in turn, has its own tide-gauges.

The conference also exposed the need for an integrated long-term plan for Venice in which risk analyses and cost benefit assessments are used to help guide major decisions. For example, the Dutch, who have engaged in this type of long-term planning, have decided in the future to sacrifice some of the valuable *polders* (re-

Revitalizing the Marshes

In addition to its extraordinary cultural patrimony, Venice boasts a world-renowned wildlife habitat, being the largest wetland in Italy and one of the most important, yet complex ecosystems in the whole of the Mediterranean. Its dramatic ebb and flow of tides and brackish mix of fresh and saltwater support a rich biodiversity. Yet the city's saltmarshes and mudflats have been reduced by nearly 30 percent since the close of the nineteenth century, having given way to industry and coastal development. Those that survive have been starved of sediment, poisoned by pollution, and eroded by waves as the lagoon continues to be dredged to accommodate large passenger ships. At present, a number of schemes are underway to restrict further development, revitalize existing marshes and create new one with silts dredged from the lagoon.



At the Malamocco inlet, above, one of three through which the Adriatic enters the lagoon, construction of a breakwater in preparation for the installation of the MOSE barrier system (see page 28) began in 2003. A scale model of the lagoon, left, is used to assess the impact of the barrier system.

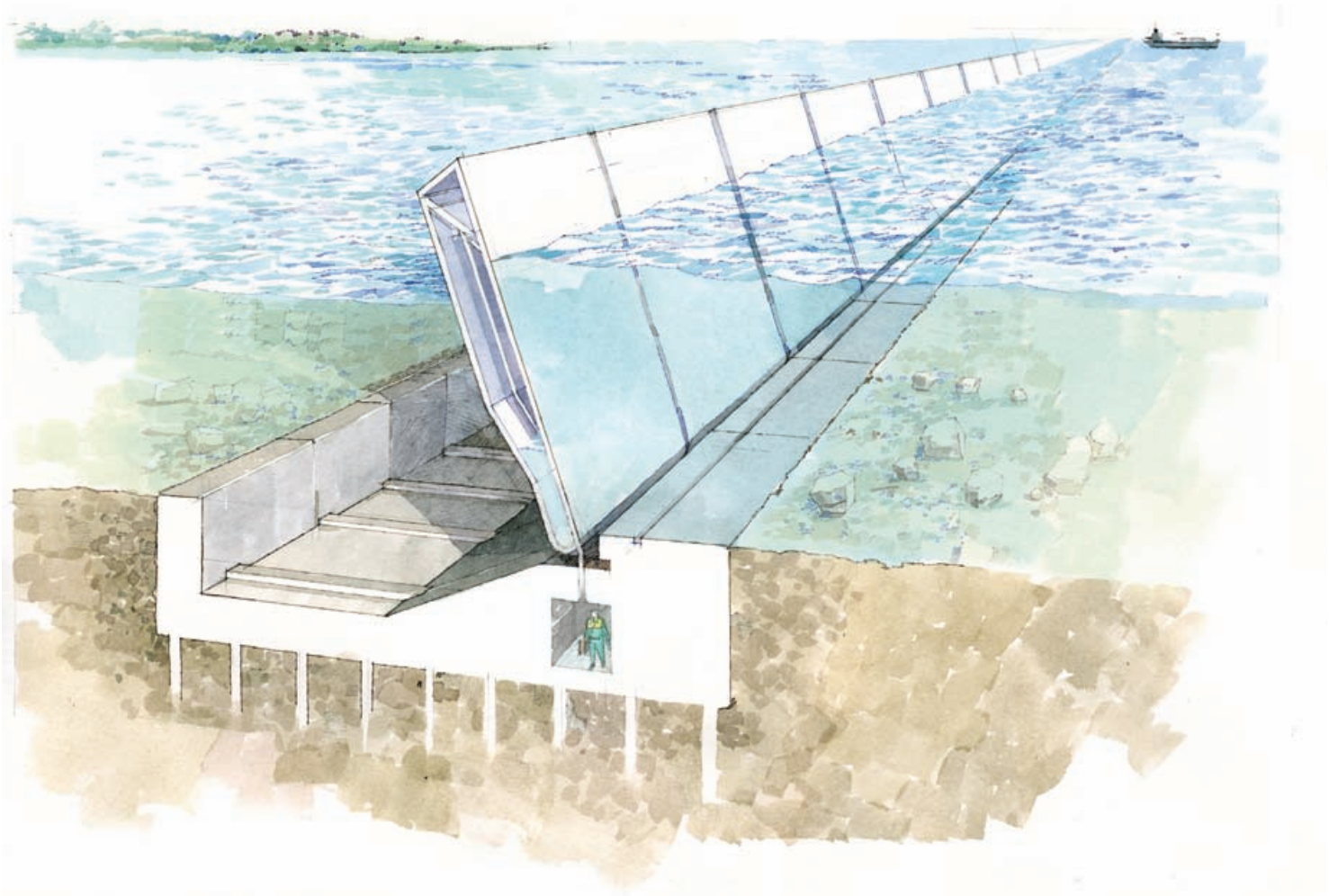
claimed low-lying land) to the sea as part of their defence against anticipated sea-level rise. Defending them would simply cost too much.

Which brings us to a crucial question: what is the survival of Venice worth in the long term? This is not a crass, philistine question but one that the Italian government needs to consider. It cannot be left as an ordinary, ad hoc item of governmental budgeting, decided at best on a three-year basis and subject to the changing priorities of different governments.

This past autumn, Prime Minister Silvio Berlusconi decided that the main construction phase of the barriers should go ahead. The cost of these is variously given as €3.5 or 4.3 billion, depending on what ancillary work is included. Many Venetians, including the current mayor, fear that if all this money goes on the barriers, there will be none left for the work of equal importance: the environmental recovery of the lagoon; the research on what is to follow the barriers; the maintenance of the canals and fabric of Venice itself.

Finding a solution to Venice's sinking and flooding will not be an easy task, one made all the more difficult by poor communication and misinformation. In an effort to address these issues, Venice in Peril has produced a booklet *La Scienza per Venezia,* or *The Science of Saving Venice* (see page 42), based on the results of the Cambridge conference. Prepared with the help of a scientific educator from London's Natural History Museum, the publication has been sent to every member of parliament in Rome and the relevant local government politicians in Venice and the Veneto. For those interested in the complete proceedings of the meeting, they too have been issued by Cambridge University Press in a comprehensive volume, *Flooding and Environmental Challenges for Venice and its Lagoon: State of Knowledge* (C.A. Fletcher and T. Spencer, eds.).

Shortly after Hurricane Katrina struck the Gulf Coast Region, I rang up a friend and colleague, John W. Day of Louisiana State University at Baton Rouge, an expert both on the Mississippi Delta and the Venice lagoon, who described Venice's problem most succinctly. "Venice is not at risk from hurricanes," he said, "because the Adriatic is too small a sea for them to develop. Yet Venice and New Orleans have much in common; they are both entirely artificial entities in environmental terms and they will survive only as long as we want them to survive. After that, Nature will reclaim them." ■



The MOSE Gates

IN CONVERSATION WITH GEOTECHNICAL PIONEER MICHELE JAMIOLKOWSKI

Although Venice has been slowly sinking into the marshy soil upon which it is built for centuries, the historic city is confronting a modern-era condition that is threatening coastal regions throughout the world, global warming. In Venice, global warming has exacerbated the effects of extreme storms, which batter the city four to six times a year. Over the past decade, the Italian government has embarked on a massive and complex plan to preserve the city with measures ranging from raising the city's sidewalks to installing new breakwaters in the lagoon. The costly and controversial centerpiece of the plan, however, is the installation of the so-called MOSE (Modulo Sperimentale Elettromeccanico) Gates, a system of 78 300-ton barriers across the three inlets to the lagoon that are intended to protect the city during the worst of storms.

ICON correspondent, Alex Ulam, recently caught up with Michele Jamiolkowski, president of Studio Geotecnico Italiano, a firm which is helping to design the gates. A professor at the Technical University of Turin and a geotechnical engineer known for his innovative approaches to solving such problems as reducing the precarious tilt of the Leaning Tower of Pisa, Jamiolkowski explains why the gates are critical to saving Venice.

ICON: *The extraction of water from the underground aquifers and the extraction of natural gas have been blamed for Venice's sinking. To what extent is the annual flooding in Venice related to these activities?*

MJ: Human induced subsidence was triggered first by the extraction (pumping) of water and later by the extraction of gas, which began around 1920. More than a decade ago, the Italian government stopped the extraction of the gas from the upper Adriatic and moved the pumping of water to deeper strata. Generally, they have also forbidden deep wells in the historic part of Venice. Once they curtailed these activities, the problems of human induced subsidence was reduced practically to zero.

Today, the problems caused by the human induced subsidence are quite small in comparison to the rise in the sea level and the high tides, which are caused by very specific weather conditions. Yet, the city continues to sink as a result of natural

subsidence caused by the compression of the subsoil under the weight of recent river deposits, especially those of the Po River Delta. The rise in the sea level is linked to global warming and the melting of the polar ice caps. The special weather conditions in the Adriatic, where there is an unusual combination of low barometric pressure and high winds, are causing the frequent high tides.

The historical areas of Venice are extremely vulnerable as they are located at very low elevations with respect to the mean sea level. This past November, for example, a large part of the historical part of the town was flooded during high tides, which rose to elevations of 1.36 meters above sea level, the Venice datum for which is close to the Church of Santa Maria della Salute.

ICON: *How is Studio Geotecnico involved in the design and construction of MOSE Gates?*
MJ: SGI is acting as Geotechnical Consultant to the Engineering Company TECHNITAL, responsible for the design.

ICON: *Has Studio Geotenico worked on any other World Heritage Sites aside from Venice?*
MJ: Yes, we have also been involved in safeguarding the Bell Tower in St. Mark's Square.

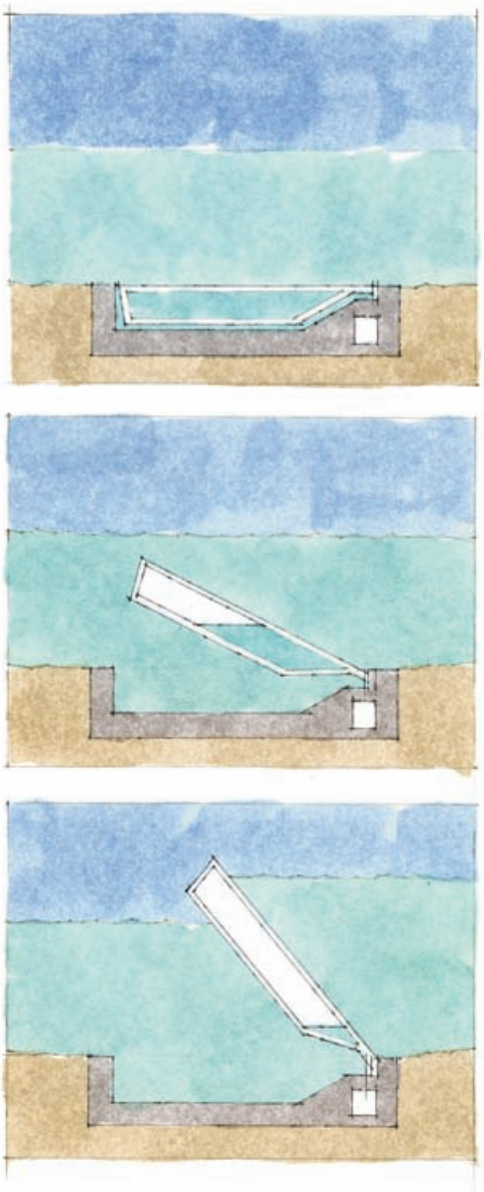
ICON: *What is most challenging aspect to designing and installing the MOSE Gates?*
MJ: The baseless opposition by the Green Party, both from a scientific and an environmental point of view, as well as the differential settlements of the MOSE caissons and the maintenance of the mobile gates in the lagoon environment.

ICON: *Will the barriers be completely watertight?*
MJ: No. One cannot have the steel gates touch each other, so there are some small gaps between them, which will allow some seepage of the water from the sea into the Venice lagoon. However, this will not cause any significant rise in the Venice lagoon during high tides.

ICON: *There has been some concern that the water in the canals will stagnate during the periods when the gates are up. How will you avoid this?*
MJ: The gates will only be operating when the high tides exceed 1.1. meters above mean sea level. Under the present conditions they will only be raised a few days a year. Of course, the longer the gates need to be closed, the greater concern there will be about the adverse environmental impact resulting from a lack of circulation within the lagoon.

ICON: *You mentioned that the MOSE Gates wouldn't necessarily help with the problems in New Orleans.*
MJ: New Orleans flood was caused by an accident—failure of the dikes—while MOSE is conceived to defend a relatively small area from high tides occurring roughly every year. In the case of Venice, three relatively narrow inlets will be fitted with gates. The area to be protected in New Orleans, however, is so large that a system such as the MOSE would not be affordable. The way out for New Orleans is to make the dikes safer and to implement an efficient monitoring and maintenance procedure.

WHEN THE MOSE GATES ARE INSTALLED, 78 HINGED STEEL FLOOD BARRIERS WILL STRETCH ACROSS THE THREE INLETS—LIDO (41 GATES SEPARATED BY AN ARTIFICIAL ISLAND), MALAMOCCO (19 GATES), AND CHIOGGIA (18 GATES)—THAT ALLOW ADRIATIC WATERS INTO THE LAGOON. THE BARRIERS WILL RETRACT INTO CAISSONS SUNK INTO THE LAGOON.



ICON: *This past fall, you were asked to evaluate a proposal put forth by scientists from the University of Padua, which would involve the injection of water into the depleted aquifers to elevate the city. Would this help protect Venice against the floods.*
MJ: Injecting water into the aquifers is not technically feasible. Even if it were, this intervention would raise Venice not more than a hundred millimeters, which is not enough to provide any degree of protection from the floods. Further, this solution would result in a differential heave to the soil, which would damage historical buildings. This solution would also cause a great deal of environmental harm because it would contaminate the freshwater aquifers with salt water.

ICON: *In addition to Venice, you have worked on the containment of Chernobyl and on reducing the tilt of the Leaning Tower of Pisa. Of these projects, which has been your most challenging?*
MJ: The Leaning Tower of Pisa was much more challenging and difficult to solve for several reasons. As one of the most important icons in Italy, any work on the tower was politically charged, with the public opinion and the media being particularly sensitive to even a slightly invasive intervention on the monument. Every attempt to solve the problem of the lean since the close of the eighteenth century had failed. When we began our project in 1993, the tower was on the verge of collapse, so any intervention to its foundation or masonry was highly risky. By excavating sediments beneath the north side of the tower and installing thousands of pounds of counterweights, we were able to reduce its lean by .5°, buying the tower another three centuries (see ICON Spring 2003). ■