Like New Orleans, Venice is slowly subsiding. Several decades and $10 billion of research have not settled the debate over what to do about the "Venice problem," but studies of the city's famed lagoon are providing insights for other coastal cities on pollution and climate change

A Sinking City Yields Some Secrets

Venice, Italy—With a few expert motions of his oar, Fabio Carrera sends the long batèla boat gliding around a corner in this maze of canals. Suddenly, a dim patch of stars is the only light and the gentle swish of water the only sound. The experience evokes a centuries-old past, when Venice was one of the most powerful city-states in the Western world. But times have changed. One clue is the outboard motors protruding from beneath the tarps of moored boats. Another comes in the approach to the tunnel beneath Santo Stefano Church.

Although it is low tide, Carrera has to stoop to clear the moist stone ceiling. "At high tide, this passage is completely inaccessible," says Carrera, an urban information scientist and native Venetian who now divides his time between Worcester Polytechnic Institute in Massachusetts and his watery hometown. Elsewhere in the city, the *acqua alta* overflows the streets, fills the ground floors of buildings, and nibbles away at bricks and plaster.

New Orleans isn't the only coastal city threatened by encroaching waters. Little by little each year, Venice is being swallowed by the sea. Although this has been a problem since the Middle Ages, an accelerating rise in sea levels linked to global warming has turned the sporadic flooding from a nuisance into a looming catastrophe. Crisis already hit once, in 1966, when most of the city's streets were submerged under a meter of water. After 3 decades of debate, construction has now begun on a series of enormous tidal gates to defend the city. The $5 billion plan is controversial, with some critics arguing for different protective measures and others predicting that the coming decades of sea-level rise will render the gates obsolete (see sidebar, p. 1979).

But there's good news as well. The "Venice problem" has made the city a hot spot for scientific research, and there's no shortage of questions to tackle. "Every time we focus on one aspect of the practical problem, we discover another gap in our knowledge," says Pierpaolo Campostrini, an electrical engineer who directs CORILA, the organization that orchestrates Venice's scientific activities. Venice is providing other coastal cities with insights on what global climate change looks like at the local level. The city and its lagoon have also become a model system for studying how physical, biological, and urban processes interact in a marine setting.

Complex interactions. A computer model, overlaid on a satellite image, divides the Venice Lagoon into thousands of interacting triangles to enable study of its processes, such as water flow and sediment transport.

If Italy's Ministry of Education, Universities, and Research has its way, Venice will soon receive 1.5%—$60 million—of the $5 billion allocated for the tidal gates. City officials hope that the fivefold increase in national funding for basic science institutions will attract young people by creating more academic and high-tech jobs in a city whose population is rapidly shrinking. But whether science can revitalize the city or save it from the encroaching sea remains an open question.

At the battlefront of climate change

Zipping across the chalky green water in a motorboat, Campostrini points out a 16th century stone fortress with windows half-submerged. "It's not enough to estimate sea level as a global average," he says. Determining a particular city's risk—and what to do about it—requires an understanding of how climate change plays out locally. Even so, Venice is a "microcosm of the larger changes" taking place, says Trevor Davies, an atmospheric scientist at the University of East Anglia in Norwich, U.K.

For instance, Venice's record of sea-level change is now the most comprehensive in the world. Modern records of watermarks go back to the late 19th century, and researchers are finding ways to push the data farther back in time. A Venetian tradition of painting scenes with the help of *camera obscura* projections, the pinhole predecessor to photography, has left researchers with accurately scaled images of the green algae lines

CREDITS (TOP TO BOTTOM): ASSOCIATED PRESS; NASA/CORILA (SUPERIMPOSED GRID: GEORG UMGIESSER) on walls that mark the average high-water level. A team led by Dario Camuffo, a climatologist at the University of Padua, Italy, has used them to extend sea-level records back another 300 years. Archaeologists are going back to the Middle Ages by estimating water levels based on the buried remains of former walls and bridges. And geologists are estimating the local sea level 2000 years ago by dating the remains of salt marsh plants that once poked above the water.

To fit these data into the global picture, researchers must also account for Venice's steady sinking due to a combination of moving continental plates and compressing sediments. The effect of a "little Ice Age" that hit Europe in the Middle Ages appears as a spike in sea levels even higher than today, whereas the levels at the time of the Roman Empire were about 1.5 meters lower. The most troubling trend, says geophysicist Alberto Tomasin of the University of Venice, is that sea levels have risen rapidly over the past 50 years.

Rising sea level isn't the only way climate change is affecting the city. Venice is a perfect natural lab for studying these effects, says Davies, because changes in weather patterns are "amplified" as changes in the frequency and severity of flooding events. Davies and Isabel Trigo, a climate scientist at the University of Lisbon, Portugal, have been teasing apart the different factors that cause the flooding.

The first task has been a postmortem of the 1966 disaster. Even without global warming, Venice would be prone to flooding, both because it was built only a couple of meters above the water and because of the city's location at the end of the narrow Adriatic Sea. The mountains to the north create low-pressure systems that suck the water level higher up around the lagoon, and wind tends to blow in from the sea, piling the water higher. And because of the shape of the Adriatic, sometimes swells generated by storms in the Mediterranean fall in phase with the tides, doubling the load of water that rushes into Venice's lagoon. These factors all conspired in 1966, causing the second tide of the day to push into the lagoon before the first could drain out, swamping the city.

With these mechanisms mapped out, Davies and Trigo are finding that climate change can also have a protective effect at the local level, at least in the short term. Venice would be in much deeper trouble by now, says Davies, were it not for a northward drift of the Atlantic storm track over the past 40 years, a trend linked to global warming. As a knock-on effect, storms in the Mediterranean have become less severe, likely saving the city from more 1966-style catastrophes. What happens if climate change nudges the Atlantic circulation farther off track is hard to predict. By studying Venice, says Davies, "you can start to draw out these subtle effects."

Deep knowledge of a shallow lagoon

In the past 3 decades, Rome has spent more than $10 billion studying and coping with the "Venice problem." In comparison, Italy's national research foundation receives about $1 billion per year. "By the mid-1990s, people began saying that the Venice funding was a *torta*," a giant cake free for the taking, recalls Philippe Pypaert, an environmental scientist at the United Nations Educational, Scientific, and Cultural Organization's European science bureau in Venice. In 2000, the newly established CORILA began reining in the projects by controlling the flow of funds and organizing projects under a few broad goals. "Things are under much better control now," says Pypaert.

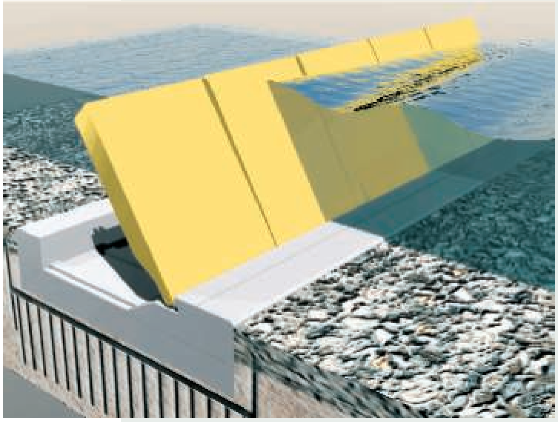
Still, Campostrini says that climate change and flooding aren't Venice's only problems. The city's art and architectural treasures require protection and restoration, and there are environmental threats to the surrounding lagoon, which is a bustling seaport and one of Europe's largest protected wetlands.

To help understand the troubles besetting the lagoon, scientists of every stripe are building a model that can not only help them manage the fragile environment but also shed light on the physical and biological aspects of a wetland. "This is our ulti-

Holding Back the Sea

Understanding climate impacts is useful. But the goal is to protect Venice. Dams would do the trick, says Campostrini, but the city would lose its income as a port and the lagoon would die without the daily tides. Injecting water into the underground aquifer that was nearly drained 40 years ago would lift the city, but uneven rising could also destroy it.

The compromise solution, called MOSE, is a series of 78 hollow, 300-ton steel gates. The gates will sit flat underwater at the lagoon's three inlets. But in anticipation of a flood, air will be pumped into the structures to make them stand upright and block tides up to a meter higher than those of 1966. Dredging has begun for the massive concrete foundations, but they won't be operational before 2011.



From below. The MOSE gates will rest underwater until floods are predicted and air is forced into their interiors.

The two questions hanging over MOSE are how often they will be used and how high sea levels will rise. By official estimates, the gates will be needed only two or three times a year. But critics say it could be as often as 50, enough to make the lagoon a sewage-contaminated swamp. And if the worst-case scenario of a 1-meter sea-level rise by 2100 comes true, the gates could be useless.

Outsiders' opinions are as mixed as those of Venetians. "Something like the MOSE gates are needed because controlling tidal surges is the only solution," says Caroline Fletcher, a coastal scientist at the University of Cambridge, U.K. But building gates is not enough, according to John Day, an ecologist at Louisiana State University in Baton Rouge who, until 2 years ago, led a long-term study of the Venice lagoon. Day says his study, one of many supported by national funds devoted to Venice, revealed that returning the flow of diverted rivers back into the lagoon would not only deposit sediments to compensate for subsidence but also would support lush wetland vegetation that would act as a buffer to slow the surges. With this natural defense, says Day, the gates would not be needed nearly as often. "Venice's situation is unique, as is New Orleans's," he says, "but they share the long-term problem of subsidence and wetland loss." Day contends that the consortium of industrial partners behind the MOSE project "[doesn't] want to hear about" natural versus engineered solutions.

Meanwhile, some Venetians argue that the entire debate has fallen far from the mark. "The take-home lesson from all this," says Fabio Carrera, an urban information scientist who divides his time between Venice and Worcester Polytechnic Institute in Massachusetts, "is that the cheapest solution is to stop global warming, but no one seems to be talking about that." –J.B.

CREDIT: MOSE

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mate goal," says Roberto Pastres, a marine scientist at the University of Venice, but it's easier said than done.

Just predicting how the water behaves is mind-boggling. Water flow alters the lagoon's shape by moving sediments, which then changes the flow, and so forth. Add to that feedback loop the many urban and biological influences, and the hopeful modeler faces "an impossibly complex system," says Giampaolo Di Silvio, a hydraulic engineer at the University of Padua.

Fortunately, the researchers already have enormous amounts of information, from the movement of sediments to the distribution of sea life. "The Venice lagoon is the best studied in the world," says Di Silvio. One of the big questions to be answered with the final model, of course, is how the lagoon will react to the new tidal gates. But it will also help scientists around the world study how pollutants are shuttled through marine systems and the factors that lead to oxygen-choking algal blooms. The model may also help answer fundamental questions involving biodiversity and nutrient transport in sea-land systems.

Turning Venice into a science mecca could also save it from a ruinous brain drain. "Venice is in danger of becoming a dead city, like a museum," says Carrera. Driven away by the high waters and high prices, the population has plummeted from 150,000 in the 1950s to 64,000 today. Nearly half of the city's income now comes from the 14 million tourists who flock to Venice each year, with most of the rest coming from port traffic. "We desperately need more young people," says Campostrini, and "one way to attract them is to build up the university and high-tech sectors." Otherwise, Venice may end up being saved from the sea but abandoned by its own people.

–JOHN BOHANNON

John Bohannon is a writer in Berlin, Germany.

After Katrina

Displaced Researchers Scramble To Keep Their Science Going

Despite huge personal losses, New Orleans scientists are hurrying to recreate their labs and lives with some help from the government

Tulane University biochemist Arthur Lustig is still reeling from Hurricane Katrina. He spent 4 days hunkered down in his New Orleans lab before being evacuated by helicopter, then another miserable night in a shelter. His house was likely lost to flooding, and he's not sure whether the 20 years' worth of yeast strains he uses to study telomeres survived the power outage.

Rescue mission. Staff from Tulane's gene-therapy center bring Dewars of liquid nitrogen to retrieve adult stem cells from flooded research labs.

But things could be a lot worse. Showered with invitations from colleagues around the country, Lustig is now living with his wife's family in Chicago and working at Northwestern University, with lab space for his four students and one postdoc. "It's a traumatic time. But I think most of us have a positive attitude that we can get over this," Lustig says.

Thousands of scientists face similar challenges. The flooding that displaced New Orleans residents after Katrina slammed into the Gulf Coast on 29 August exiled faculty members, graduate students, and postdocs from a half-dozen institutions in New Orleans. Thanks to Internet message boards and cell phone calls, many are regrouping in temporary labs and office spaces at other universities. "People have been really wonderful. They realize [Katrina] is a huge impact on careers," says Arthur Haas, chair of biochemistry and molecular biology at the Louisiana State University (LSU) Health Sciences Center in New Orleans. Scientific societies have also rushed to help, posting Web sites for those who haven't yet found spots (www.aaas.org/katrina).

For some, the disruption may be short-lived. Tulane medical school officials hope to get a handle soon on mold in air conditioning ducts, the main obstacle to reopening buildings in their now-dry part of the city. But many researchers have already enrolled their children in schools elsewhere and don't expect to return until January, when university classes resume. Although they are trying to view the forced exile as a minisabbatical, it's hard to be too optimistic about their research. "Will it slow us up competitively? Absolutely," says Lustig.

Against all odds, researchers did what they could to preserve their research materials. In the days after the storm, researchers from Tulane and LSU ventured back by boat, truck, and helicopter with armed guards to top off the liquid nitrogen covering storage containers and retrieve samples hastily ordered by priority. Tulane gene-therapy center director Darwin Prockop organized a convoy from Baton Rouge on 10 September to salvage their National Institutes of Health (NIH)–funded adult human stem cell bank, with staff lugging 36-kg Dewars up four flights of stairs to collect racks of vials.

Tulane scientists saved transgenic mice but had to euthanize most other animals; LSU animal caretakers destroyed or lost to flooding about 8000 animals in four vivariums, says Joseph Moerschbaecher, vice chancellor for academic affairs at LSU's Health Sciences Center. Also lost at Tulane were freezers of blood and urine samples, including those from the Bogalusa (Louisiana) Heart Study, which has followed thousands of children since 1972 to tease out heart disease risk factors. "It's a national tragedy," says Paul Whelton, Tulane senior vice president for health sciences.

Other scientists fear that mold has destroyed animal and plant collections built up over decades. Tulane ecologist Lee Dyer sneaked back and put desiccant and mold killer in drawers containing preserved insects. University of New Orleans (UNO) butterfly expert Phil DeVries and his wife, systematist Carla Penz, fear a severe toll on 30 years' work: preserved butterflies, hundreds of photographs, as well as rare identification books and countless field notebooks. Physical scientists, for their

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