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Update

NEW YORK ACADEMY OF SCIENCES MAGAZINE
NOVEMBER/DECEMBER 2005

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Storm Surge Barriers for New York Harbor?

Experts Say It's Not an Idle Question

As 21st century climate change accelerates the rise of sea levels, what could a monster storm like Hurricane Katrina do to low-lying coastal regions – such as New York's?

THE CITY THE ACADEMY CALLS home has roughly 580 miles of coastline. The metro region has many times as much. Within the region, roughly 100 square miles of coastal land lies vulnerable to rising waters. On a map, New York Harbor looks like a gigantic catch basin.

Some people have been doing more than wondering about future local flooding: They've been seriously researching the matter, and they began long before Katrina hove into view. Academy members who attended a January 2005 talk sponsored by the Environmental Sciences Section heard in detail about one such research project: **Malcolm Bowman**, who leads the Storm Surge Research Group at Stony Brook University, and **Douglas Hill**, an engineer who's a member of the group, discussed their 2004 study, *Hydrologic Feasibility of Storm Surge Barriers to Protect the Metropolitan New York – New Jersey Region.*

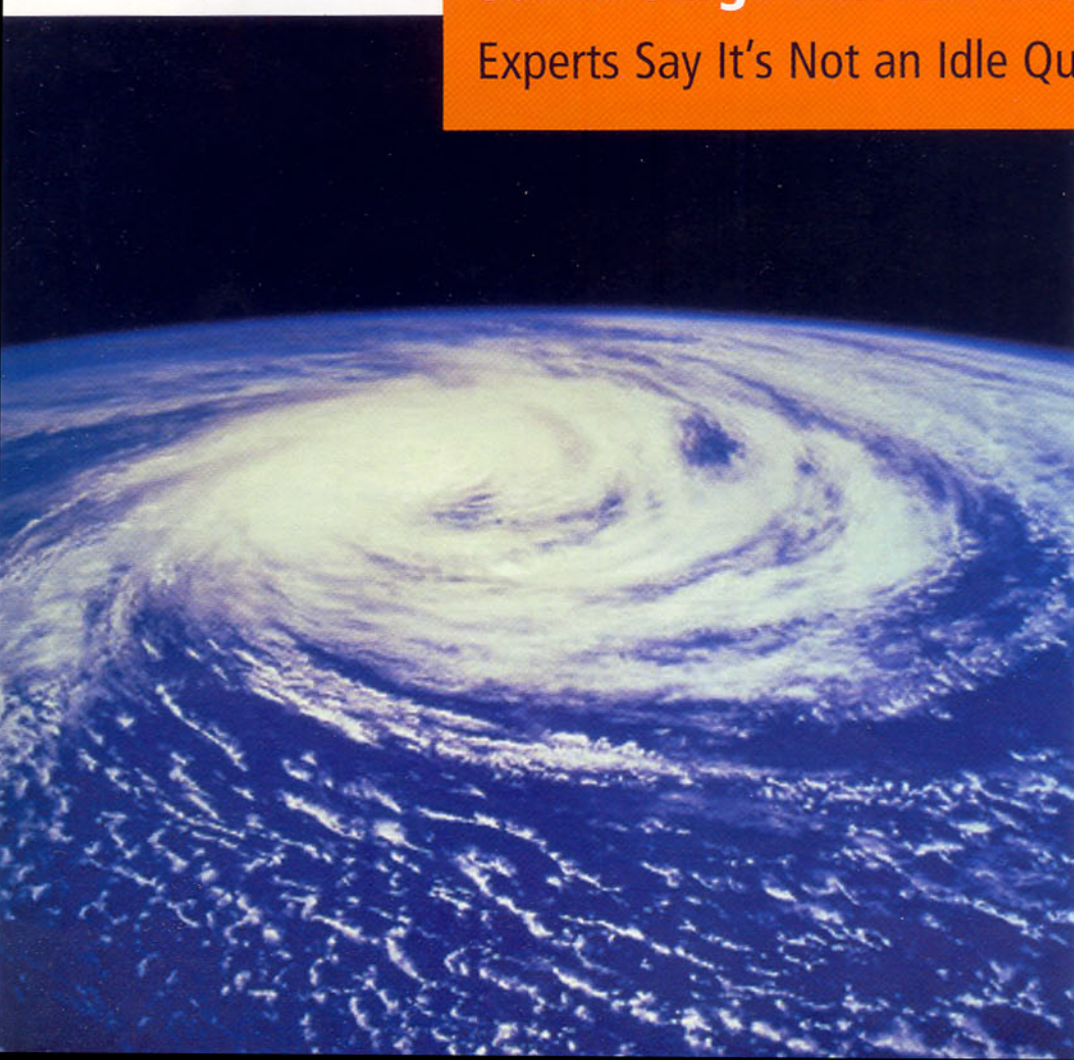
Extreme flooding in the region, both Bowman and Hill flatly insist, is not a matter of *if* but *when*. What needs protecting? Some of New York City is not just low-lying; it's underground. Bowman's Web site offers this inventory:

Infrastructure at risk includes subway entrances that are close to sea level, tunnels and their air and vent shafts, subway track and signal systems, bridge access roads, small bridges, airports, port freight-handling facilities, water pollution control plants and their tide-gate regulators, combined sewer outfalls, landfills, solid-waste transfer stations, pipelines, power plants, and buildings in areas with high property values and dense population.

This last item would include lower Manhattan's fabled real estate and Jersey City and Hoboken, in New Jersey.

In December 1992 a powerful nor'-easter delivered a sobering preview that

- shorted out the entire New York City subway system, stranding people on trains and in stations (salt water conducts electricity, causing shorting, and it's corrosive);
- shut down the PATH transportation link between New York City and New Jersey;
- forced LaGuardia Airport to close;
- submerged part of the FDR Drive in Manhattan under four feet of water and flooded other roadways;
- raised sea level at the southern tip of Manhattan by about eight-and-a-half feet;
- flooded Battery Park Tunnel with six feet of water.



A more severe storm surge would have far-reaching effects if Manhattan's low-lying financial district were badly flooded.

Modeling a Mitigation Strategy

Historically, sea level around Manhattan has risen about one foot per century, because of ocean warming and tectonic subsidence. As climate change accelerates this trend, storm surges produced by storms as severe as the '92 nor'easter and "boosted" by higher sea levels will cause flood waters to rise higher and cover a wider area. Severe floods will occur more often, Hill cautions, redefining the 100-year flood zone.

Conversely, as Bowman puts it neatly, "In the future, a weaker storm will do the same damage that a severe storm does today." Magnifying damage, population growth and dense coastal development will have put more people and infrastructure in harm's way.

PHOTO: SPACE FRONTIERS

Coastal flooding is a complex phenomenon, and the Storm Surge Research Group uses a suite of computer models to simulate and predict it. Their MM5 meteorological model computes, at high resolution, winds and barometric pressure, and that output drives their ADCIRC hydrodynamic model. Using "hindcasting," they've validated their coupled models against actual storm data.

The researchers hypothesized that significant flooding could be averted if barriers were erected at three strategic locations: The Narrows at the mouth of New York Harbor, across the upper East River, and at the mouth of the Arthur Kill. To test this, they assumed different storm scenarios and ran models of them using sea level predictions for the 2050s developed by **Vivien Gornitz**, a scientist at NASA Goddard Institute of Space Studies who contributed to a 2000 study, *Metropolitan East Coast Assessment of Impacts of Potential Climate Variability and Change.*

To model a future extreme storm, the researchers cranked up the winds for 1999's Hurricane Floyd. While that storm had diminished in strength by the time it reached New York, the abundant data on its characteristics and effects made it an ideal prototype. "Super Floyd" produced significant coastal flooding. Because the models can be run at fine resolution, local flooding could be identified and mapped. Then the researchers reran "Super Floyd," assuming that barriers were closed and that dikes high enough to deflect the severe storm surge were extended inland. Their study was complex, but the bottom line was clear: "The effect is quite dramatic," Bowman reports: at least through 2050, with a sea level rise of 7 to 24 inches, half of the 100-square-mile area within the 100-year flood zone would be protected.

Unlike sea walls, breakwaters, dikes, levees, and dams constructed in many coastal cities, the barriers Bowman and Hill envision would be moveable. They'd be closed for only a few hours at a time, perhaps repeatedly during a prolonged nor'easter. They'd be unlikely to cause flooding from rainfall runoff that collected behind them. They would not interfere with shipping.

The barriers would operate as a set: All three would have to be built to be effective.

Precedents in the U.S. and Europe

Moveable barriers are not without precedent. Following damaging local storms, they were built in the 1960s in Providence, Rhode Island, New Bedford, Massachusetts, and Stamford, Connecticut.

Barriers in the Netherlands, the most extensive in the world, were constructed after a huge storm in the North Sea claimed more than 2,000 lives in 1953.

That same storm took over 300 lives in England and led to construction of a barrier in the Thames River. Since 1982 it's been closed more than 80 times. Because of the barrier's striking design, it's become a tourist attraction.

Barriers are now being constructed in St. Petersburg, Russia, and Venice, Italy.

No two installations are alike, but most have this in common: *decades* elapsed between severe flooding and the start of barrier operations.

Barriers have proved effective – so far. The Thames barrier was built to avert flooding up to 2030. The UK Environment Agency is now planning for flood management up to 2100.

Science-Driven Design and Environmental Studies

Having demonstrated that barriers could avert flooding in a computer-modeled world, Bowman and Hill advocate establishing design criteria for the real world. Criteria would be based on preliminary conceptual designs, studies of environmental impacts and benefits, and cost estimates.

Where, exactly, should the barriers be sited? Preferred sites would be determined by geology, topography, bathymetry, and adjacent infrastructure. How high should barriers be? "The worse the storm you design for, the costlier the structure," Hill observes. Climate change science would be the crucial input here.

Proposed locations of storm surge barriers: The mouth of the Arthur Kill between Staten Island and New Jersey, The Narrows at the mouth of New York Harbor, and across the Upper East River.

The design of each barrier would be tailored to its site. A major engineering task would be calculating how size, shape, and location would affect the hydraulic forces operating on the barriers when they were open, closed, and in motion, under normal and severe-storm conditions. Because The Narrows is a deep, fast-moving body of water, dynamic forces at work there would be particularly complex.

For each site, hydrodynamic models, which simulate water currents and elevations in detail, would be refined to estimate these forces. A meteorological model capable of simulating the most intense hurricanes and a coastal ocean wave model would be developed and coupled with existing storm surge models. The results of coupled-model runs would be fed back to improve designs. A range of storm conditions, sea level rise, and many combinations of structural loads resulting from storm surges, waves, and interior rainfall flooding would be examined.

Hydrodynamic modeling would support water quality modeling and marine ecological studies; hydrodynamic conditions that barriers would have to satisfy to maintain or improve water quality would be defined. Other ecological effects would be assessed, too.

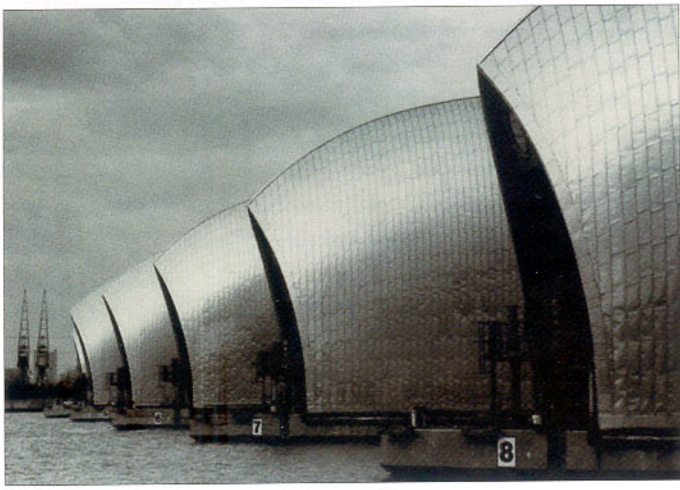


PHOTO: JON ARNOLD

The Thames Barrier protects London. It's operated by the UK's Environment Agency, which is responsible for controlling flooding.

A Precursor Concept: East River Tidal Gates

In developing design criteria, engineers wouldn't be starting from scratch. The concept of tide gates for the East River was first advanced by Bowman in 1976, for a different purpose: to dramatically improve water quality.

The East River and the western end of Long Island Sound receive large quantities of effluent discharged from New York City wastewater treatment plants. Laden with nitrogen, effluent reduces levels of the dissolved oxygen that promotes healthy aquatic life – an environmental problem requiring costly levels of wastewater treatment. A barrier that could be closed and opened daily would permit pulses of clean water from the Sound to continually flush the East River and New York Harbor basins, diluting effluent as it flows to the ocean. When incoming tides reversed currents in the East River, the gates would be closed. Daily, the harbor would be replenished with healthy, oxygenated water from eastern Long Island Sound.

MALCOLM BOWMAN DOUGLAS HILL KLAUS JACOB

In 1994 such gates were the subject of a national symposium, for which major engineering firms prepared two conceptual designs. (Hill edited the proceedings; the Academy published them, as *The East River Tidal Barrage, Annals* Volume 742, 1994.)

It was imagined that the gates "might also serve other purposes: as a bridge, to mount water turbines to generate electricity, as a place for the public to enjoy the waterfront." No mention was made of storm surge protection. Costs were estimated at around $1 billion. The structures were perceived by some as too intrusive to be acceptable, and the concept never progressed to the design stage.

If a set of storm surge barriers were to be constructed, the East River barrier could do double duty, paying a substantial water-quality dividend.

Who Will Champion This Cause?

Whatever the benefits of barriers, where, post-Katrina, would the billions of dollars required to build them come from? Beyond the ballooning U.S. federal deficit lies another problem: the American Society of Civil Engineers' chilling "2005 Report Card for America's Infrastructure" rates 15 categories (example: waste-water facilities: D-) and estimates that we should invest $1.6 *trillion* over the next five years toward making our infrastructure sound.

The Report Card was compiled before Katrina hit the Gulf Coast. What will the 2006 Report Card say? Storm surge barriers for New York Harbor would be competing with many screaming priorities. Should studies be undertaken for a project that may never be funded?

Who will champion this problematic cause? So far, no one has taken the lead, although Bowman and Hill are keeping the idea of barriers alive. They contend that the science, engineering, and environmental communities have a responsibility to advance the issue – and to ensure that if barriers are built they satisfy sound criteria. They cite New Orleans's failed levees as a caution here.

The panel that reviews their work is now in its fourth year. Its impressive membership includes the U.S. Army Corps of Engineers, EPA Region II, and FEMA Region 2; the New York State Office of Emergency Management and the Department of State's Division of Coastal Resources; the Port Authority of New York & New Jersey; and New York City's Office of Emergency Management and Department of Environmental Protection (NYCDEP).

The Port Authority, Army Corps, and NYCDEP could be candidates for managing a large-scale infrastructure project in harbor waters. Complex economic, institutional, and political factors would surely shape it.

Placing Big Bets on a New Science

Far more is in play than the issue of storm surge barriers. All infrastructure embodies design criteria that codify the science that was current when the criteria were formulated. Now climate science is moving front and center. What existing infrastructure should be "hardened?" What should the design criteria be for future infrastructure?

Public agencies are in the unenviable position of having to place big bets on future scenarios that rest on a science that is still new and is fiendishly complex. And there is nowhere to hide: To *not* plan is to make assumptions that could have far-reaching consequences in tomorrow's world.

NYCDEP was one source of funding for Stony Brook's barrier study. In 2004 its commissioner created an agencywide task force on climate change that is formulating strategies for adapting to it. The goal is to mitigate effects on NYCDEP's water supply and wastewater infrastructure and on the quantity and quality of the City's water supply. The task force recognizes that the challenge for the agency will be to integrate climate science into routine long-term strategic and capital planning, project design, and policy making. Among the many adaptation strategies it's examining is construction of storm surge barriers. As noted above, an East River barrier would also help solve some water quality problems.

The task force works with Columbia University's Center for Climate Systems Research, whose scientists are synthesizing current research to help NYCDEP understand what climate trends mean for the region. For example, projections of sea level rise have been integrated with the Stony Brook storm surge models to identify areas that could be flooded in the future. **Kate Demong**, the task force project manager, reflects that because climate science will continue to evolve, the agency will be engaged in a process of continuous learning.

The federal government is grappling with this, too. The U.S. Climate Change Science Program has a congressional mandate to integrate federal climate change research; OMB is one overseer. Its November 2005 workshop will address "the capability of climate science to inform decision making." This rings a loud bell, but how clearly it will be heard by an administration that has been criticized for slighting science remains to be seen.

Beyond Science

But even the best science in the world can only go so far. Finally, societal questions like those raised by Professor **Klaus Jacob** of Columbia University, an expert on disaster risk management, must be answered.

In formally commenting on Bowman and Hill's talk at the Academy, he observed that a basic engineering question – how high should barriers be? – goes directly to a tough policy question: With sea level rising steadily, for how many years of service should the barriers be designed? Would building barriers simply postpone the inevitable: As sea level rise accelerates, would we be setting a trap in which we feel safe behind barriers and continue to invest in areas that ultimately will be flooded? What is our responsibility to future generations?

In a Sep. 5, 2005, op-ed piece in the *Washington Post*, Jacob contended that the destruction caused by Hurricane Katrina

. . . is not a natural disaster. It is a social, political, human and – to a lesser degree – engineering disaster. To many experts, it is a disaster that was waiting to happen.

While no single storm can be definitively attributed to climate change, Katrina brings into sharp focus what climate change may bring. Over coming decades, as public agencies work to adapt to "the new normal," they'll be challenged as never before to think through, deeply, what our duties to future generations are and what our posture in regard to powerful natural forces should be.

What is, or is not, constructed in the waters of New York Harbor will turn in part on our collective conviction about these grave matters.

Perhaps nothing has ever brought the future closer than inexorably rising seas.

–Christine Van Lenten

A Coastal Early Warning System

New York Sea Grant, which contributed funding for the hydrologic feasibilty study, continues to fund the Storm Surge Research Group for work to predict storm surges and coastal flooding. The Storm Surge Group's Coastal Early Warning System computer model, now running 24/7 and updated twice daily in beta-testing mode, will significantly improve current methods of forecasting the location, timing, and severity of storm surges.

The goal is to provide timely warnings that emergency management personnel can rely on to broadcast advisories and evacuation orders for low-lying coastal areas – with a degree of precision that avoids the kind of needless mass evacuations that caused such havoc this year when Hurricane Rita threatened Houston and Galveston. The beta version is posted at **http://stormy.msrc.sunysb.edu/**.

The Storm Surge Research Group's studies can be found at **http://stormy.msrc.sunysb.edu/**.

The eBriefing on Bowman and Hill's talk at NYAS is posted at **www.nyas.org/superfloyd**.
Coverage includes an overview, meeting report, Q&A, open questions, resource links to publications, and Web sites, and synchronized audio + slide presentation.

The Environmental Sciences Section has hosted a number of talks on climate change; eBriefings on them are posted at **www.nyas.org/environ**.