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Bracing for Super Floyd
How Storm Surge Barriers Could Protect the New York Region

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Overview

Reported by Christine Van Lenten | posted May 31, 2005

The waters are rising; awareness is not

With so many grave issues to worry about already, New Yorkers scarcely need another. But one threat to the region—directly related to climate change and not yet widely recognized—commanded close attention at the Academy when researchers with the Storm Surge Research Group at Stony Brook University reported on it.

Malcolm Bowman and **Douglas Hill** described their investigation into the likelihood that, during this century, rising sea levels will aggravate storm surges along the New York City metro region coast, causing more severe flooding and causing severe flooding more frequently. Bowman and Hill also explained how the construction of storm-surge barriers at three strategic locations could significantly reduce flooding caused by, for example, a "Super Floyd"—a fiercer version of Hurricane Floyd, which pounded the East Coast in 1999.

Sponsored by the Environmental Sciences Section, the January 12, 2005 event brought home a dramatic physical reality that tends to be forgotten: the region abuts a vast amount of water, and much shoreline is low-lying. Indeed, Lower Manhattan is practically at sea level. Higher storm surges could flood costly real estate, fragile ecosystems, and vital infrastructure—including the city's transit systems, above and below ground; wastewater treatment systems; and roadways. Lives could be lost. Recovery could take years and cost billions of dollars.

PATH station in Hoboken during a 1992 nor'easter. (Source: Metro New York Hurricane Transportation Study, 1995).

And we can't say we haven't been warned! In 1992, flooding caused by a severe nor'easter shut down the PATH system between New York City and New Jersey and shorted out the entire New York City subway system, stranding people on trains and in stations. Had the flood been 1 foot higher, lives would have been lost.

Hill stated flatly that, regarding severe flooding, "The question is when." Significantly, he noted, one sponsor of the Storm Surge Research Project is the New York City Department of Environmental Protection. "They deserve credit for foresight and perhaps courage in supporting this work."

In turn, discussant **Klaus Jacob** of Columbia University applauded Bowman and Hill for pursuing their investigations, and he posed some of the tough policy questions their work raises.

Highlights

- Within the metro New York City region, roughly 100 square miles (nearly 260 square kilometers) of low-lying land—including most of Lower Manhattan—lie vulnerable to rising waters.
- Sea level, tides, wind strength, and atmospheric pressure together determine how high coastal waters rise.
- Historically, sea level around Manhattan has risen steadily. Climate change will accelerate this. In

the future, powerful storm surges will occur more frequently; flood waters will rise higher.

- Hydrologic studies demonstrate that a strategically located set of three storm-surge barriers—gates that could be opened and closed—could avert much flooding.
- Further studies are needed to determine engineering feasibility, cost, and environmental impacts.
- But far-reaching policy questions require debate. For example, with sea level steadily rising, how high should barriers be? Would they simply forestall inevitable flooding? What alternatives to barriers could minimize harm?
- The scientific and engineering communities must mobilize to put this issue squarely on the public policy agenda.
- Meanwhile, the computer modeling used to simulate storm surges can be used operationally, in real time, to predict the actual risk of flooding from approaching storms.

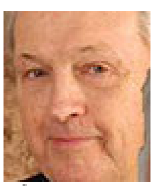
Proposed barrier locations.

Christine Van Lenten is a freelance writer who has written about widely varied subjects for the Academy. ***more >***

Storm Surges and Engineered Barriers

Speaker: **Douglas Hill**, EngScD, PE
Marine Sciences Research Center, Stony Brook

Redefining the 100-year flood zone



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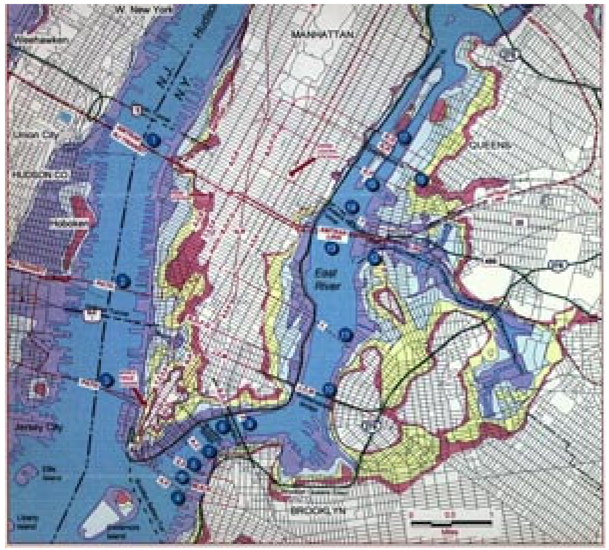
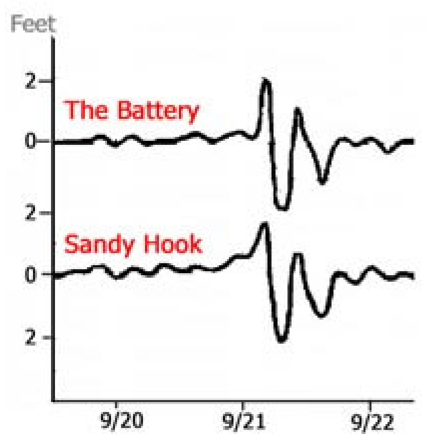
Technically, **Doug Hill** explained, storm surges are the deviations above the normal rise and fall of the tide that are caused when water driven by hurricanes and nor'easters floods low-lying regions. On the **map** on the preceding page, the shaded area lies within the 10-foot (3-meter) contour line, which defines the 100-year flood zone. That is, in any one year, there's one chance in 100 of a flood up to the 10-foot line. That shaded area totals around 100 square miles (nearly 260 square kilometers).

If New York City bore the brunt of a category 1 hurricane (74 mph winds and a 10-foot storm surge at the Battery), parts of Lower Manhattan, Jersey City, Queens, and Brooklyn would be flooded (the light purple zone on the map below). A category 3 hurricane (110 mph winds and a 24-foot [7.3-meter] surge at the Battery) would sever Lower Manhattan; City Hall would be sitting on a new island (yellow zone).



New York City hurricane flooding
(Source: Metro New York Hurricane Transportation Study, 1995)

Storm surges follow patterns. A hurricane storm surge comes on abruptly, drops sharply, rises again. Hurricanes in the region are infrequent, but inevitable. Nor'easters are both inevitable and frequent, and they present a different pattern: surges they create can last for several days and cause flooding on successive high tides.



1938 hurricane storm surge.
(Source: Pore, N. A., & C. S. Barrientos. 1976. Marine EcoSystems Analysis Program, NY Sea Grant Institute.)

The record of sea levels around Manhattan dates back to nearly 1850, Hill said, so it's known that sea level has been rising about 1 foot (about a third of a meter) a century, because of warming of the oceans and tectonic subsidence dating from the last ice age. This historical trend is expected to continue, and to be aggravated by climate change.

So how will rising sea level affect the frequency of floods that reach that 100-year flood mark?

- Projecting the current trend of a 1-foot rise in sea level each century, by the 2090s flood waters need rise only 10 feet minus 1.1 feet to reach that mark; flood waters will be "boosted" by higher sea levels. By the 2090s, in any one year there will be 1 chance in 30 that the 10-foot contour line will be reached. Our 100-year flood will have become the 30-year flood.
- Taking climate change into account reveals a different story. To determine how climate change may affect sea level, Columbia University researcher Vivien Gornitz used two general circulation, global climate change models and two sets of assumptions about the presence in the atmosphere of aerosols, which shade and cool the earth. This yielded four scenarios for the decade of the 2090s. The most

Sea level has been rising about 1 foot a century. It will continue to rise. Hurricanes and nor'easters will continue to pound the coast.

extreme shows climate change raising sea level by 3.8 feet (well over 1 meter); in that case, it only takes a storm surge of about 6 feet (1.8 meters) to reach the 10-foot contour line; "sea level has taken care of the rest of it." And that happens every 2 years. So every year there's a 50-50 chance of flooding up to the current 10-foot contour line.

Within each of the four scenarios, researchers defined ranges of uncertainty for flooding up to today's 10-foot contour line, for three decades. For the 2050s, for example, flooding could recur from between every 20 to 70 years.

Of the 100-square-mile area that lies within the 100-year flood zone, about half could be protected from flooding if barriers were erected at the Narrows, at the mouth of New York Harbor; on the upper East River; and near Perth Amboy, New Jersey, at the mouth of the Arthur Kill, which runs between Staten Island and New Jersey, Hill said.

Existing barriers in the United States and Europe

Hill took his audience on an illustrated tour of storm-surge barriers in the United States and Europe. First stop: Providence, Rhode Island. In 1955, after that city was badly damaged by successive floods, federal legislation was enacted authorizing the U.S. Army Corps of Engineers to construct hurricane protection structures in five cities.

In three of them—Providence; New Bedford, Massachusetts; and Stamford, Connecticut—barriers were constructed across waterways vulnerable to storm surges. Essentially, the barriers are gates, and they remain open except when they're closed to prevent flooding. Such barriers are what Hill and Bowman propose for the New York region.

Construction of barriers for both the Thames River and the Netherlands was prompted by a huge storm in the North Sea in 1953 that took over 2000 lives. One Dutch barrier was originally intended to be a dam, but concerns about environmental impacts resulted in a design modification, which increased the cost sixfold. Venice is also building a barrier system.

Typically, preventive measures are taken after a catastrophe has occurred. With the exception of one set of barriers in the Netherlands, 25 years or more elapsed from the time of a catastrophic flood until protection was in place; Venice is approaching half a century. That's not how long it takes to build barriers; small ones can be built in a year or two. "All this time is spent trying to figure out what to do, designing the barriers, doing the environmental studies, getting the legislation passed, and so on." A lot of this work can and should be done before a disaster, Hill stressed.

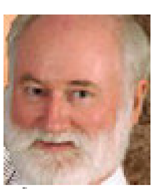
Typically, decades elapse between a catastrophe and the erection of barriers.

Would barriers work for New York? That, Hill explained, was the focus of their study. "It's a study of hydrologic feasibility, not engineering feasibility; not whether you could build them; not how much they cost; not how they compare with alternatives. But whether they would work."

An Integrated Storm Surge Model

Speaker: **Malcolm J. Bowman**, PhD
Marine Sciences Research Center, Stony Brook

Building—and validating—the model



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Malcolm Bowman, who leads the Storm Surge Research Group, picked up the story at this point. While researchers know that historically sea level has risen 1 foot per century and that global warming will raise it further, his research team is not trying to project the rate of sea-level rise, he stated.

Rather, they're engaged in scenario planning: they assume different rates of sea-level rise and then examine different storm events and the implications for officials responsible for protecting regional infrastructure.

(While it's generally assumed that climate change will cause storms to be become more frequent and severe, the research team makes no assumptions about this in its scenarios.)

Of course this research proceeds by way of computer modeling:

- A mesoscale meteorological research model, MM5, covers the area extending from Cape Hatteras, North Carolina, up to Nova Scotia, Canada. It's nested inside the continental-scale meteorological model that the National Weather Service uses to create short-term weather forecasts, and it's three times more detailed, running at 12-kilometer (roughly 7½-mile) resolution compared with the 36 kilometer (over 22 mile) resolution of the continental model.

  The winds and pressure around the perimeter of the New York region, taken from the continental model, drive the ocean flow inside the MM5 model. Using data received twice a day from the Weather Service on wind strength and barometric pressure, the model can predict the weather 60 hours into the future.

- A hydrodynamic (ocean) model, ADCIRC, solves dynamical equations to describe the behavior of tides and currents. Supplied with actual data on tides recorded around the perimeter of the modeled region and data from MM5 on winds and pressure, the model predicts the daily rise and fall of the tides and wind-driven currents in the model interior, including along the coasts and into New York Harbor's intricate waterways, for a 60-hour time horizon.

Piling up water against the coast

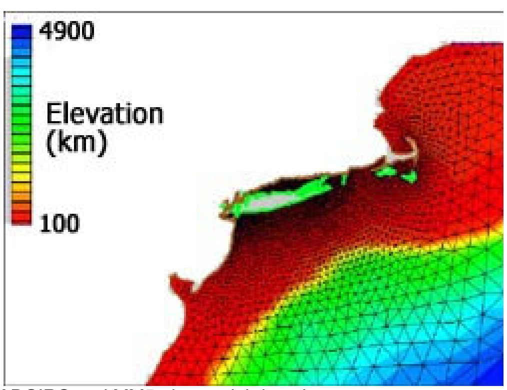
Low atmospheric pressure, always associated with nor'easters and hurricanes, means the atmosphere weighs less and the ocean, supporting less weight, rises, Bowman explained: "We're using the meteorological model to create winds and a pressure system that are realistic," then using those forces to blow the water around in the ocean model interior.

In effect, the meteorological model is sitting squarely on top of the ocean storm model, and its winds are blowing the water underneath it around. At the same time, the gravitational forces of the sun and moon are pulling the water up and down twice daily, creating the tides.

High-resolution topographic data (the altitude of land along the coast) and bathymetric data (ocean depths) are integrated into the model. Modeling extends up to 25 feet (7.6 meters) above present mean sea level.

For each elemental grid in the ocean model, the computer calculates the storm surge—the additional rise in sea level due to both wind blowing on the ocean, "piling up water against the coast," and low barometric pressure. The models can be used to reproduce or simulate actual events. To generate storms, modelers crank up the wind and reduce atmospheric pressure.

Modelers crank up the wind and reduce atmospheric pressure, "to blow water around."



ADCIRC and MM5: the model domain.

"So we're going to be able to handle some pretty powerful storms," and to examine flooding in great detail all around Metropolitan New York, including Jamaica Bay and up the Hudson River to Hastings-on-Hudson. Future extensions will include the south shore of Long Island and Long Island Sound.

Bowman presented animations that display an example of the opposite of forecasting: hindcasting—a simulation of something that's already happened. For Hurricane Floyd, which pounded the New York area in 1999, the National Weather Service archived a lot of data. Researchers use it to "wind the clock back, rerun the model as if it were 1999, and sweep that storm through the area, from Cape Hatteras up the coast." By running the hindcast for, say, one week and comparing the results with archived data, they can gain confidence in the accuracy of their model.

Does this modeling accurately reproduce what actually happened? Graphs comparing model predictions with actual observations of storm surges caused by Floyd in 1999 and a 2002 nor'easter show the model "did a pretty good job," though discrepancies occur following the storm surge.

Games you can play with computers

Now, for the fun part: what if's.

Bowman explained "a game you can play with a computer." Run Hurricane Floyd, which didn't produce much if any coastal

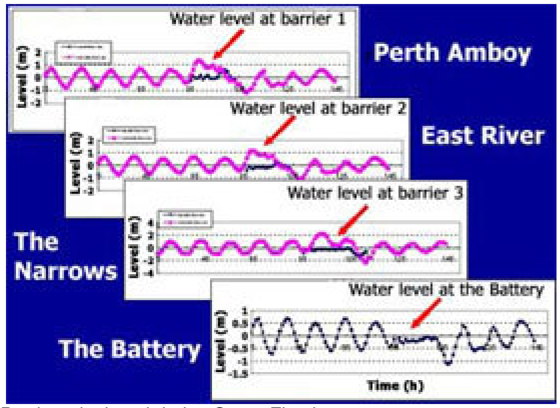
Presto! You've created Super

flooding. Then use the same storm characteristics but speed up the wind by 50%, keeping the hurricane track and the low-pressure system the same. Presto! You've created Super Floyd.

Floyd

Bowman narrated computer animations of Super Floyd's performance with a sportscaster's enthusiasm. "This is the storm surge: the rising of the sea in response to the hurricane. Coming up from the south. The ocean is lifting up ... The hurricane is coming up, filling up New York Harbor, filling up Long Island Sound; the whole ocean is lifting up. The storm moves up to the north and empties out again ... While all this is going on, the tides are going back and forth through the Narrows of New York Harbor."

Not surprisingly, Super Floyd produces coastal flooding, and because the model can be run at fine resolution, local flooding can be identified. Bowman showed aerial photos on which grids had been superimposed to indicate its extent.



Barriers deployed during Super Floyd.

To determine the effect of barriers, researchers reran the models and closed the three barriers. Flooding was averted. "The effect is quite dramatic."

The law of unintended consequences?

But what happens on the other side of a barrier? If you have a barrier in the East River and a storm is blowing winds down the Long Island Sound, won't water pile up against the eastern side of the barrier? New York City is protected, but what about communities on the other side? Will barriers make things worse?

Bowman explained that by modeling the 2002 nor'easter with and without barriers, researchers determined that closing the East River barrier would raise waters to the east of it by only an additional 10½ inches (27 centimeters). But "there are obvious tradeoffs on all these solutions." Some people will benefit; some may be worse off. "Through our research we can say by how much."

Swollen Rivers, Coastal Warnings, Work Ahead

Speakers: **Douglas Hill**, **Malcolm Bowman**
Marine Sciences Research Center, Stony Brook

The other side, the river side

audio
slides

Doug Hill now turned to "the other side, the inside, the river side.... Old Man Hudson River will keep on rolling along, swollen with rains." So will the New Jersey rivers that empty into Newark Bay, which in turn empties into New York Harbor.

Would closing storm surge barriers effectively dam up the swollen rivers behind them, creating freshwater flooding? "In any one storm, there are two distinct, mutually exclusive flooding threats" related to rainfall: flash flooding in New Jersey rivers and the possibility of a prolonged flood as the rain-swollen Hudson River continues to flow down to the city," Hill explained.

"Old Man Hudson River will keep on rolling along, swollen with rains."

Hurricane Floyd, "the worst rainfall event of the past half-century around here," offers a good test of whether rainfall flooding will be a problem.

- *New Jersey rivers.* Researchers used data collected on river volume during Floyd and modeled the effects of closing barriers. Filtering out the normal rise and fall of the tide, they identified a little more than 1 foot of additional rise in flood water levels due to runoff. Because the normal rise in tide is 3 feet (almost 1 meter), closing the barriers at midtide or below would not have caused any flooding from New Jersey rivers.
- *The Hudson River.* The Hudson's drainage area is about sixteen times larger than the area

drained by those New Jersey rivers, and it takes a while for rainfall to swell the Hudson. Comparing model runs with barriers closed and open and with and without Floyd-level rainfall runoff revealed only a slight accumulation of fresh water.

Hill offered a striking way to consider this. Along the 25 miles (over 40 kilometers) between New York City and Tarrytown, the surface of the Hudson rises only about 0.7 feet (0.2 meters). Imagine the crest of that water flowing into a wedge-shaped storage area at the mouth of the river. Running Floyd with the barrier closed for 20 hours would raise the water level there by less than a foot; for 40 hours, by less than 16 inches (0.4 meters). "At present sea level, the possibility of serious flooding from accumulated water coming down the Hudson River is not great."

Malcolm Bowman later remarked that another research focus is water quality issues, which New York City's Department of Environmental Protection is very interested in. If you dam up the harbor for, say, 16 hours, you're pooling contaminants from sewage effluents that would normally flush out to the ocean.

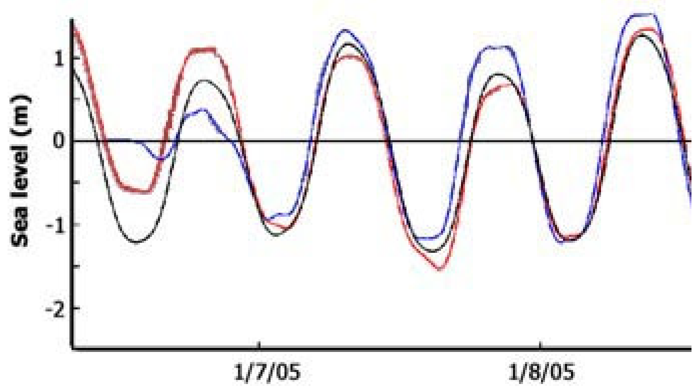
How bad is that likely to be? Will plankton bloom? The project's researchers will use coupled hydrodynamic-water quality models to examine the extent of plankton blooms, if they receive funding for this research.

A real-time, coastal early warning system

Bowman summarized the project's modeling capabilities. "We can look at a number of scenarios of rising sea level and see what the flooding potential is and what the frequency of storms will do" in terms of threatening the city's infrastructure. "The question arises: can we develop an early warning system? Can we use this computer model in an operational sense?"

Two models will be running all the time, so if a hurricane is coming up the coast, why not use the models to predict how serious flooding will be, and if necessary, provide information to the State Emergency Management Office, FEMA, the Coast Guard, and the police? Why not make some predictions about what areas are at risk and what decisions might be made about evacuation?

Indeed, the research team is developing an integrated, state-of-the-art, meteorological/ storm surge prediction model for early warning of coastal flooding. It's expected to significantly improve techniques for forecasting, with a 57-hour time horizon, the location, timing, and severity of coastal flooding from extreme storms.



Kings Point water level, January 2005: predictions (blue), observed (red), and astronomical (black).

The graph above illustrates the model's predictive power, using data for Kings Point, on the upper East River. The astronomical tide—the rise and fall of the tide without the weather—can be predicted for hundreds or thousands of years based on precise knowledge of the orbits of the sun and moon. Data on tides are collected by NOAA at tide stations. The blue line indicates the height of coastal water predicted by the researchers' integrated storm surge model. "It's got the storm built in. Although this is just a research project, "it's pretty good!"

What's been learned? What's ahead?

Hill summarized the project's major findings: "We wanted to find out in the first place if [barriers] would work, and we conclude they would"—if all three were closed. Closing just one or two wouldn't work. The barriers probably wouldn't aggravate flooding caused by rainfall runoff into rivers. Siting a barrier on the East River might be controversial among residents on the South Bronx side, because water levels on their side could rise a bit.

Researchers' current goals are these:

- Operationalizing the real-time, coastal early-warning system and putting storm surge forecasts on

a web site.
- Adding Long Island's south shore and Long Island Sound to the modeling domains.
- Upgrading the hydrodynamic (storm surge) model from a 2-D model (ADCIRC) to a 3-D model (known as FVCOM) that will also support water quality studies and model stratification of water within waterways—typically, warm water atop denser cold water, and, in the Hudson River, fresh water that's flowed downstream layered above denser salt water that's flowed upstream from the ocean.
- Upgrading the meteorological MM5 model to the more powerful Weather Research and Forecasting community model (WRF).
- Directly inputting river flows measured by gauging stations along the Hudson River north of Hastings-on-Hudson and along New Jersey rivers, to better model rainfall runoff.

With the hydrologic feasibility of barriers established, engineering, cost, and environmental studies (all closely related) can proceed. But will they?

Without public awareness, political support for barriers won't materialize.

Hill reminded his listeners that barriers in New England and Europe demonstrably prevent flooding, without adverse effects. But decisions to build them were taken, in most cases, after disastrous floods that cost many dollars and lives. And decades pass before barriers are in place and operating. "With the increasing likelihood of major flooding in the metro region ... such delays should be minimized," he cautioned.

But the public isn't aware of this increasing threat, and without such awareness, political support won't materialize for a project that will certainly cost billions of dollars. "It's incumbent on professional communities—scientists and engineers, in and out of government"—to pick up this agenda.

Klaus H. Jacob
Tough Policy Calls

Discussant: **Klaus H. Jacob**, PhD
Lamont-Doherty Earth Observatory, Columbia University

The lag between science and policy

Klaus Jacob opened his commentary humorously, disclosing his personal vested interests. In 1999 Hurricane Floyd dumped 5 feet of water from a branch of New Jersey's Hackensack River into his kitchen. Now, on his wife's initiative, they live on the Hudson River, in a flood zone. He wants the barriers built!

But even if they're never built—"and there's a good chance they might not be"—Bowman and Hill "will have done an extraordinary service ... because their modeling will have all sorts of applications" and their project sets the stage for public education.

Their work raises scientific, engineering, environmental, and cost questions, "and probably overriding all of this, public policy questions ... Science can move faster than decision makers. Decision makers usually procrastinate. And we're all part of that process. We shouldn't point at politicians; it's we [citizens] who create problems for politicians" by not demonstrating that we do support positions they should take.

We shouldn't blame politicians for delays; we citizens make their jobs harder.

With respect to scientific issues, Jacob suggested that while the research team has run three major models—Floyd, Super Floyd, and the 2002 nor'easter—it will be useful to model larger, artificial storms and to examine effects outside and inside the barriers.

False alarms? False confidence?

Another question concerns the discrepancies between researchers' model predictions and actual observations of storm surge height. While modest, would the discrepancies increase as a storm's amplitude increases? Would they become large enough to jeopardize predictive capability? Would they raise false alarms that cause more harm than good?

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? Will New York City still exist 1,000 years from now? Would building barriers simply postpone the inevitable: if sea level continues to rise, are we setting a trap in which we feel safe behind barriers and continue to invest in areas that ultimately will be flooded?

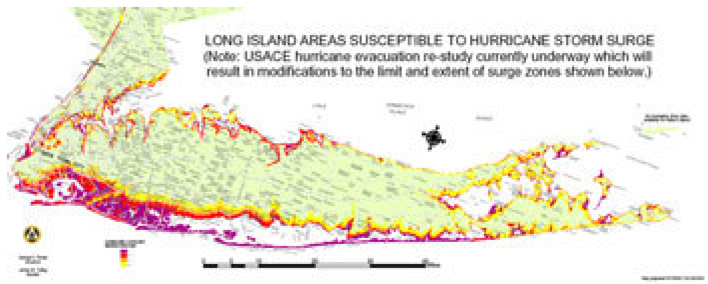
So far, the U.S. Army Corps of Engineers has been able to protect New Orleans. But the current director of the U.S. Geological Survey has stated publicly that New Orleans probably won't exist 100 years from now. Discussion of such issues is going on nationally, Jacob said, citing Dennis Mileti's book, *Disasters by Design.*

New Orleans probably won't exist 100 years from now.

If Greenland ice goes, it will add another 7 meters (23 feet) to sea-level rise, Jacob reflected. If some Antarctic ice goes, it could add tens of meters. Ultimately, if all ice goes, that adds 100 meters (328 feet). What is our responsibility to future generations? Should we pursue engineering studies? "I think we should," if only to learn how expensive barriers would be.

But, Jacob cautioned, in discussions about barriers it's important to make clear they can't solve all storm-related problems: they protect only against storm surge flooding, and only in the inner harbor that's behind barriers. Large portions of the Atlantic coast outside the barriers would be flooded.

And coastal flooding is just one cost. A major hurricane will cause rain flooding and wind damage. Bridges will have to be closed; businesses will shut down. The subway system extends to areas outside the barriers; engineering studies are needed to determine whether it could be flooded. "And so these are some of the issues that undoubtedly will come into play if you translate your very meritorious scientific approach into public policy," Jacob explained.



Hurricane evacuation zones as currently defined by the New York State Emergency Management Office. They may be modified when an Army Corps of Engineers study is concluded.
Click here to download PDF (1.8 MB).

Malcolm Bowman was quick to reply, thanking Jacob "for those profound and provocative comments. I agree with all of the questions." And, he noted, the Thames barrier system that's protecting the city of London was designed to function for 50 years. What happens in year 51? London is now upgrading its barriers.

Multimedia

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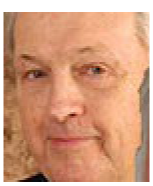
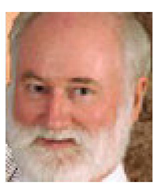
Presentations



Storm Surges and Engineered Barriers
Douglas Hill
slides w/ audio



An Integrated Storm Surge Model
Malcolm Bowman
slides w/ audio

Rainfall Runoff Flooding
Malcolm Bowman, Douglas Hill
slides w/ audio

Q & A Summary

Q: Do your models reflect the complexities of actual water flow?

Observing that the way water flows locally is complex, a questioner asked if research models reflect these complexities, including the reversing tides in the lower Hudson River. Malcolm Bowman replied that his research team has gone to great lengths "to get the tidal motions correct in the model. And we have variable high resolution for certain areas we want to look at in detail."

Q: Do your models reflect where waters diverted by barriers would flow?

A questioner pointed out that if barriers divert water from one area, the water will move into another, perhaps causing flooding. Could the models identify new areas that might be flooded?

Bowman explained that the models calculate the level of excess flooding in areas outside the barriers. The level depends on where the barriers are located.

"For the ocean barriers, Perth Amboy and The Narrows, the problem outside the barriers is almost nil." The ocean is essentially infinite in size, and potential excess flooding is spread out over many miles of coastline. But experiments using Super Floyd show that coastal locations in western Long Island Sound, just east of the upper East River barrier, could experience excess flooding of about 8 inches (20 centimeters) above the flooding that would result with no barriers in operation.

Q: If future flooding is not an act of God but predictable, what are the legal and insurance implications?

Michael Bobker, chair of the Environmental Sciences Section steering committee, said that as an engineer he appreciates the statement that engineers must carry scientific discoveries forward. But in his experience engineers generally carry out orders. He wondered about legal responsibilities and the insurance implications of flooding in light of gains made in scientific predictions: "The science makes it less like acts of God than predictable events."

Klaus Jacob pointed out that, in the United States, the only flood insurance for private property is commercial. "We have a National Flood Insurance Program because the commercial industry walked away from insuring floods in the '60s."

(The federal government established that program in 1968. Nearly 20000 communities participate, by adopting and enforcing floodplain management ordinances. Parties in these communities who want to obtain secured financing to buy, build, or improve structures in Special Flood Hazard Areas must buy flood insurance, which is federally backed.)

The problem, Jacobs continued, is "not the lawyers; it's the professional communities that set standards and rules-codes. For instance, the flood insurance map is made by engineers, not lawyers, and it doesn't include sea-level rise. So we have a serious problem: the engineering community isn't quite in tune with the science community, and the lawyers simply decide whether someone follows the code or not." If the code hasn't been followed, they file a lawsuit.

The flood insurance map doesn't include sea-level rise. We have to pound on FEMA.

"The key is code, which for flooding means the National Flood Insurance Program. So what we have to do as a scientific-technical community is pound on FEMA ... to keep up with the science." At present, the flood insurance map locks in investments, to the billions of dollars. But in 20, 50, or 100 years, those investments will be totally wasted. "So the lawyers have a relatively subservient function for once."

Q: What environmental impacts could barriers cause?

A number of concerns were voiced on this subject. One questioner asked if anyone has conducted an exhaustive review of environmental impacts and, if so, what might be expected in the New York region. And might barriers cause changes in sedimentation or habitat that would diminish the landscape's natural ability to buffer storm surges in wetlands and other landscapes?

Doug Hill said the New England District of the U.S Army Corps of Engineers had reported that the barriers they'd erected (in New Bedford, Massachusetts; Providence, Rhode Island; and Stamford, Connecticut) have had virtually no effect on sedimentation. Only minimal dredging has been done, in the 1990s.

But those three barriers were built in the 1960s, before environmental concerns were as pronounced as they are today. A few studies have been done on water quality in the bay at New Bedford. In the Netherlands, the Eastern Scheldt was redesigned to be a barrier that could be opened, instead of a dam, because of environmental objections to closing off that water.

Another questioner asked whether members of the Storm Surge Research Group are personally concerned about environmental impacts. Bowman reflected, "It gets back to what Klaus was saying: In the long-term, what is the fate of major cities?"

In the long term, what is the fate of major coastal cities?

That question has many dimensions. Of course the environment is important. "But what is the long-term situation going to be for New York City? Is the city going to end up being destroyed in a thousand years-and therefore defeated in the temporary cocoon of protection we provide? And at what cost do we provide this cocoon?

"These are the societal questions, the policy questions beyond the scope of our study; but they're behind everything we do. We haven't done any cost estimates or environmental studies. Our project is funded to see if these barriers would work. It's the first step in a long series of studies that would need to be done."

In response to a question about impacts on riverine and coastal habitats, Bowman stressed that barriers could be closed only for short periods of time-a day or less, not weeks. Major rivers flow into the harbor; you can't just block them off. Barriers provide temporary, short-term protection against a big storm. Metropolitan New York can't be protected like the City of New Orleans, which is below sea level and is kept dry by continuous pumping. "This is a very different situation: you've got major rivers flowing through the harbor; you've got to let them exit to the ocean."

The Thames barriers are used up to 12 times a year for brief periods, he observed. The Thames flows through the heart of the City of London. "You can't just block the Thames River off."

Q: How do the coupled MM5 and ADCIRC models generate forecasts?

(**Bowman** offered this lively reply to an email inquiry following the NYAS event.)

The models are coupled in a complicated but automated way. Every day at about 1 a.m. and 1 p.m., MM5 accepts initializing data from the National Weather Service and runs its 60-hour weather forecast. Doing this takes about 2 hours. A computer program linked to ADCIRC lies in wait, and, as soon as the MM5 predictions become available, it snatches them and uses winds and sea-level pressure for the next 58 hours to initialize and run ADCIRC (a little like relay runners transferring the baton during a relay race).

ADCIRC then calculates its own ocean tides and storm-surge predictions. This takes 3 more hours. So by the time the ADCIRC prediction is ready, 5 hours have elapsed, leaving 55 hours of prediction time available.

The ADCIRC storm-surge predictions are then compared to (1) NOAA astronomical tide predictions (that is, predictions based on knowledge of the orbits of the sun and the moon without regard to weather) and (2) actual observations of the tidal heights, at twelve regional primary reference stations, from Portland, Maine, to Lewes, Delaware. The whole process repeats every 12 hours, updating the 55 hour storm-surge forecast with the latest information.

"We're always interested in observations and predictions for our most central station, which is located at the Battery on the southern tip of Manhattan." (In almost continuous operation as a primary tide station since 1850, it's useful for calculating long-term sea-level rise.)

"An automatic, continually updated error analysis routine tells us how skillful our predictions are. Various fail-safe correction mechanisms are in place in case the MM5 forecast is missing, is running late." (MM5 may have received its own input data late due to a malfunction further up the line at the National Weather Service, network problems, or an overload in the ADIRC computing cluster.)

All results are posted on the Stony Brook Storm Surge Research Group's Web site, along with NOAA predictions and observations for comparison. The data are updated every 15 minutes.

Open Questions

- When will the New York State Emergency Management Office modify its flood insurance maps to reflect the fact that sea levels are rising?

- How will the insurance industry respond to the growing risk of stronger storm surges?
- Will the science and engineering communities mobilize to put the issue of barriers squarely on the public policy agenda? Will a broader constituency, with political clout, emerge?
- How can proposals for engineering/cost/environmental studies of barriers compete with urgent demands for repairs of crumbling public infrastructure: bridges, dams, water and wastewater systems, and roads?
- Will the State of New Jersey and other local governments join New York City's Department of Environmental Protection in supporting further studies?
- Will the availability—and visibility—of Web-based storm surge forecasting help create demand for barriers?
- The barriers proposed would work as a set: all three are needed. But for areas along the Upper East River lying east of a barrier, flooding could be about 10½ inches higher (about 27 centimeters). Would residents of those communities accept a barrier that protects communities to the west at the cost of higher flood levels for themselves?
- Damming off New York Harbor temporarily would pool the contaminants in sewage effluents that would normally flush out to the ocean, possibly promoting plankton blooms and affecting water quality. How fast might plankton blooms actually grow and with what consequences for water quality? Can protections against storm surges be compatible with environmental regulations?
- What more can be learned about the likely environmental impacts of barriers? What would it cost to build barriers that are environmentally benign?
- Given that sea level will continue to rise, how tall should barriers be? That is, for how far into the future should they be designed to function? Are they just an expensive delaying tactic, forestalling an inevitable catastrophic flood?
- What more can be learned from the experiences of cities that have erected barriers?
- How will advances in computer modeling and the acquisition of more data refine understanding of storm surges and improve predictions of flooding?
- What alternatives to storm barriers—such as land use policies, zoning, and codes that regulate critical heights for construction—should be considered?

Web Sites

Climate Change Information Resources

An Earth Institute initiative, this site includes a page with links to information about coastal zone impacts for the New York metropolitan region.

Deltawerken
This site offers a fascinating look at the Netherlands's extensive coastal water management system. Note the map that displays the locations of storm surge infrastructure.

DHI Water and Environment
This independent consulting and research organization is authorized as a Technological Service Institute by the Danish government. Among its broad range of services: hindcast studies of major storms; a Web-based service employing operational hydrodynamic models and real-time data to provide real-time forecasts of storm behavior. Its staff numbers approximately 450; it has conducted projects in more than 140 countries.

ESCAPE
ESCAPE (European Solutions by Co-operation and Planning in Emergencies for coastal flooding) offers detailed information on flood prevention measures. Its Delta 2003 web pages describe the evolution of the Netherlands's storm surge barriers, including the effects of environmental concerns on engineering design.

National Flood Insurance Program
Administered by the U.S. Federal Emergency Management Administration (FEMA), this program makes federally backed flood insurance available to homeowners, renters, and business owners. A summary of its 1998 Metro New York Hurricane Transportation Study is available online, prepared in conjunction with the U.S. Army Corps of Engineers, the National Weather Service, and emergency management agencies in New York, Connecticut, and New Jersey.

New York Sea Grant
Part of NOAA's National Sea Grant Program, this statewide network of research, education, and extension services promotes wise use and protection of marine and Great Lakes resources—as NYSG puts it, "bringing science to the shore." Its institute is located at Stony Brook, where Malcolm Bowman and Doug Hill conduct their research, and it's a co-sponsor of their projects, formally titled "Hydrologic Feasibility of Storm Surge Barriers to Protect the Metropolitan New York-New Jersey Region" and "Coastal Early Warning for Emergency Response and Protection against Flooding in Metropolitan New York."

Stony Brook Storm Surge Research Group
This is speakers' research project. Its Web site includes descriptions of the MM5 and ADCIRC models, as well as data and predictions for each of the group's research stations.

Publications

Bowman, M. J., B. Colle, R. Flood et al. 2004. **Hydrologic feasibility of storm surge barriers to protect the metropolitan New York: New Jersey region**. Stony Brook Storm Surge Research Group, Marine Sciences Research Center, Stony Brook University. FULL TEXT [PDF, 2.2 MB]

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Mileti, D. S. 1999. **Disasters by Design: A Reassessment of Natural Hazards in the United States**. Joseph Henry/National Academies Press, Washington, DC. FULL TEXT

Rosenzweig, C., W. Solecki, C. Paine et al. 2001. **Climate change and a global city: the potential consequences of climate variability and change**. CIESIN/Metropolitan East Coast Assessment, Columbia University. FULL TEXT
Doug Hill was one of many contributors to this study, which was one of eighteen organized by the U.S. Global Change Research Program.

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A brief, interesting look at this country's state-of-the-art water-management system.

From the Academy

The slow-motion tsunami: how climate change could change the world, featuring Rajendra K. Pachauri et al. 2005. New York Academy of Sciences **eBriefing**, sponsored by the Environmental Sciences Section.

Why worry? the threat of abrupt climate change, featuring Gavin A. Schmidt & Ronald L. Miller. 2005. New York Academy of Sciences **eBriefing**, sponsored by the Atmospheric Sciences and Geology Section.

Life, not a movie: how climate change could affect New Yorkers, featuring Joyce Rosenthal and Kim Knowlton. 2004. New York Academy of Sciences **eBriefing**, sponsored by the Environmental Sciences Section.

Can we avert a global Nineveh? Paul Ehrlich considers our prospects. 2004. New York Academy of Sciences **eBriefing**, sponsored by the Environmental Sciences Section and the New York Science Alliance.

Who needs Kyoto to slow global warming? CO_2 emitters face rising risks, featuring Peter Lehner and J. Kevin Healey. 2004. New York Academy of Sciences **eBriefing**, sponsored by the Environmental Sciences Section.

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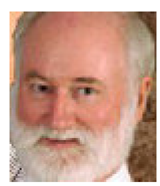
description | contents/full text | purchase volume

Hill D., Ed. 1996. **The Baked Apple? Metropolitan New York in the Greenhouse**. **Annals of the New York Academy of Sciences**, Vol. 790.
A report on the first conference on the consequences of climate change for the New York Region, this volume offers comprehensive look at future scenarios and what can be done to sustain the quality of life in the region.
description

Hill, D., Ed. 1994. **East River Tidal Barrage: A Symposium on a Multipurpose Addition to New York City's Infrastructure**. **Annals of the New York Academy of Sciences**, Vol. 742. This symposium examined the concept of a multipurpose set of tidal flood gates located in the East River.
description

Speakers

Malcolm J. Bowman, PhD
Marine Sciences Research Center, Stony Brook University
email | web site
An Integrated Storm Surge Model

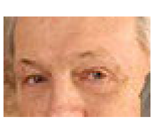


Malcolm J. Bowman is professor of physical oceanography and distinguished service professor at Stony Brook University's Marine Science Research Center, which he joined in 1971. He leads the Stony Brook Storm Surge Research Group, which works to model and predict storm surges that threaten the New York metropolitan area. The group is also investigating how the region can be protected from flooding from extreme weather events that will be aggravated by global warming and sea level rise.

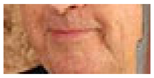
Between 1996 and 1999, Bowman took leave from Stony Brook University to return to his native New Zealand to serve as founding head of the School of Environmental and Marine Sciences at Auckland University. There he developed a keen awareness of and interest in the role marine reserves and wilderness areas can play in marine conservation and fisheries rehabilitation. He is a director of the Environmental Defence Society (NZ), an honorary professor of physics at Auckland University, and a distinguished member of the National Society of Collegiate Scholars.

He obtained his BS and MS degrees in physics and mathematics at the University of Auckland and his PhD in engineering physics at the University of Saskatchewan, Canada.

Douglas Hill, EngScD, PE
Marine Sciences Research Center, Stony Brook University
email | web site
Storm Surges and Engineered Barriers



Douglas Hill is a consulting engineer and an adjunct lecturer at Stony Brook University's Marine Sciences Research Center. He is involved in both research and policy concerning global climate change and its consequences for the New York metropolitan area. Hill has focused on issues related to urban planning and energy infrastructure within the context of climate change. He has



served as a consultant to several energy-related agencies and organizations, including the Regional Plan Association, the International Energy Agency, and Brookhaven National Laboratory, where he helped to develop the MARKAL model of the New York State energy system for projecting future energy supply and demand technologies.

Hill has edited two volumes in Annals of the New York Academy of Sciences: **The East River Tidal Barrage: A Symposium on a Multipurpose Addition to New York City's Infrastructure** (1994) and **The Baked Apple? Metropolitan New York in the Greenhouse** (1996). He has also contributed to a Columbia Earth Institute's study, *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change: Metro East Coast* (2001).

Hill holds doctor of engineering science and MS degrees from Columbia University and is licensed as a professional engineer in New York State.

Klaus H. Jacob, PhD
Lamont-Doherty Earth Observatory, Columbia University
email | web site
Tough Policy Calls

Klaus H. Jacob is senior research scientist at Columbia University's Lamont-Doherty Earth Observatory. He received his PhD in geophysics (seismology) from the University of Frankfurt in 1968. During the first two of his almost four decades at Columbia, his research focused on basic seismotectonics and plate-tectonic processes. From 1986 to 1998 his focus shifted to probabilistic seismic hazard assessment and engineering seismology, mostly for large infrastructure projects.

Jacob served on the review panel for the USGS/NEHRP National Seismic Hazard Maps for the contiguous United States and Alaska and coauthored the national model and the New York City seismic building codes. He developed methods of wireless vibration measurements for modal spectral analysis of large bridges and skyscrapers.

Since 1998 his focus has been multihazard assessment, quantitative disaster loss estimation, and disaster mitigation research. Recent research focuses on improving earthquake loss estimates for New York City by developing soil category maps for use with FEMA's HAZUS software. He is also studying how global climate change and related sea-level rise affect the risks from coastal storm surges, flooding, and inundation, primarily of infrastructure systems in global megacities, including the New York City metropolitan region.

Christine Van Lenten is a freelance writer who has written about widely varied subjects for the Academy. She has also written about public policy issues and technical and scientific subjects—many of them in the environmental field—for federal and state agencies, nonprofit organizations, and private sector firms.
