ANTICIPATING CLIMATE CHANGE

When engineers at the Port Authority of New York and New Jersey assessed the possible effects of climate change on the region's most critical transportation infrastructure, they made some surprising discoveries. In some cases, recent infrastructure upgrades that had been undertaken for other reasons conferred the unexpected benefit of increasing the infrastructure's resilience; in other cases, additional actions will be required.

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THE PORT AUTHORITY of New York and New Jersey is a bistate agency that conceives, builds, operates, and maintains infrastructure critical to the trade and transportation network of the New York City metropolitan area. These facilities include America's busiest airport system, marine terminals and ports, the Port Authority Trans-Hudson (PATH) rail system, six tunnels and bridges linking New York and New Jersey, the Port Authority Bus Terminal, in Manhattan, and the World Trade Center. For more than eight decades, the Port Authority has worked to improve the quality of life for the more than 17 million people who live and work in New York and New Jersey, a region that supports 8.6 million jobs and has an estimated gross regional product of more than $929 billion.

The publication in 2007 of projections of potential climate change effects by the Intergovernmental Panel on Climate Change—an international body established by the United Nations Environment Programme and the World Meteorological Organization—has made the public more aware of climate change issues. This has led many state and local government bodies to launch evaluations of the vulnerability of their critical infrastructure to the possible effects of climate change. Port Authority facilities are vital to the economy of the New York City metropolitan area, and their safe and efficient operation is of the utmost importance. Thus an assessment of climate change effects was seen as warranted. Many of these facilities are in close proximity to coastal waters and may be vulnerable to climate change, which includes sustained sea level increases with associated storm surges, increased precipitation, and higher temperatures.

For this reason, the Port Authority became involved in a climate change assessment led by New York City's Long-Term Planning and Sustainability Office, part of the Mayor's Office of Operations, which was conducted between August 2008 and March 2010. The team was called the Climate Change Adaptation Task Force, and its work was part of a comprehensive sustainability plan for New York City called PlanNYC. The Port Authority's Office of Environmental and Energy Programs coordinated and led the evaluation effort within the agency.

As part of this effort, the Port Authority evaluated the vulnerability of its infrastructure to a range of climate change effects. The goal was to determine which facets of infrastructure might be affected by the climate change projections for three decades: the 2020s, the 2050s, and the 2080s. Our experience can provide insight into the challenges of undertaking such an effort and the way in which climate change projections can inform design guidelines, maintenance programs, and long-term planning.

The two main goals of the Climate Change Adaptation Task Force were as follows: determine which facets of infrastructure could be at risk from the effects of climate change and develop coordinated adaptation strategies so that these assets would be protected and their protection could be incorporated into long-term planning processes.

The task force comprised five working groups: energy, policy, transportation, communication, and water and waste. The Port Authority participated in the transportation working group along with other public and private entities that own or operate transportation infrastructure within the New York City metropolitan area. This group included Amtrak; CSX, of Jacksonville, Florida; the Metropolitan Transportation Authority; New Jersey Transit; the New York State Department of Transportation; and the New York City Department of Transportation. Members of the group were asked to create an inventory of infrastructure that might be at risk and to develop adaptation strategies, the overall goal of the group being to develop coordinated adaptation strategies.

The assessment process comprised six major tasks: defining the climate change variables and projections, developing asset inventories, assessing vulnerabilities, analyzing risks, prioritizing the assets, and developing adaptation strategies. The tasks were generally performed in that order, although there was some degree of iteration involved in the various steps.

The New York City Panel on Climate Change (NPCC)—a panel of academics, scientists, and other experts convened by New York City's mayor, Michael R. Bloomberg, in 2008—provided guidance, analysis, and information on the regional climate change variables and associated risks. The group provided the scientific expertise and technical tools for this effort in the form of a report entitled *Climate Risk Information,* which was published in February 2009. This publication describes the projections and probabilities associated with climate change variables, including temperature, precipitation, sea level rise, and coastal storms. Figure 1 provides a summary of the projections provided for these climate variables for the 2020s, 2050s, and 2080s in the New York City region. Midway through the effort, the NPCC provided updated projections on sea level rises reflecting the possibility that the Greenland and West Antarctica ice sheets might melt faster than previously predicted. In view of the uncertainty associated with these projections and the time frame in which they were provided, these projections were not incorporated into the Port Authority's internal process.

The first step in the Climate Change Adaptation Task Force's effort involved generating a list of assets that might be vulnerable to the climate change variables provided by the NPCC. Because it operates airports, marine terminals, vehicular tunnels, major bridges, a rail mass transit system, bus stations, and many other, smaller facilities, this was a significant undertaking for the Port Authority. The Port Authority facilities that were

Such coastal facilities as Port Newark, *foreground,* and Newark Liberty International Airport, *background,* may be vulnerable to the effect of sea level increase coupled with storm surges associated with intense coastal storms.

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FIGURE 1: PROJECTIONS OF THE NEW YORK CITY PANEL ON CLIMATE CHANGE

	Baseline (1971–2000)	2020s	2050s	2080s
Air temperature	12.8°C (annual mean)	Increase by 0.8°C–1.7°C	Increase by 1.7°C–2.8°C	Increase by 2.7°C–4.2°C
Precipitation	118.1 cm (annual mean)	Increase by as much as 5%	Increase by as much as 10%	Increase by 5%–10%
Sea level rise	NA	5.1–12.7 cm	17.8–30.5 cm	30.5–58.4 cm
Coastal storms:				
100-year return period	Roughly once every 100 years	Roughly once every 65 to 80 years	Roughly once every 35 to 55 years	Roughly once every 15 to 35 years
500-year retun period	Roughly once every 500 years	Roughly once every 380 to 450 years	Roughly once every 250 to 330 years	Roughly once every 120 to 250 years
PROJECTIONS OF SEA LEVEL RISE FROM RAPID ICE MELTING				
Sea level rise	NA	12.7–25.4 cm	48.3–73.7 cm	104.1–139.7 cm

Source: C. Rosenzweig and W. Solecki, New York City Panel on Climate Change, "Climate Change Adaptation in New York City: Building a Risk Management Response," *Annals of the New York Academy of Sciences* 1196, (2010).

0885-7024/04-0011-0050/$25.00 PER ARTICLE

Figure 2: Sample Inventory of Infrastructure at Risk

Class	Location	Climate variable	Effect of climate change
Berth and roadway	Piers, slips, and roadways at Port Newark, Elizabeth–Port Authority Marine Terminal, Howland Hook Marine Terminal, Brooklyn–Port Authority Marine Terminal, and Hoboken waterfront	Extreme events and storm surge with sea level rise	Increased flooding risk from nor'easters and hurricanes
Rail	Port Authority Trans-Hudson (PATH) stations and open and subsurface track; PATH tunnels	Extreme events and storm surge with sea level rise	Increased flooding risk from nor'easters and hurricanes
Airfield	John F. Kennedy International Airport and LaGuardia Airport (runways and taxiways)	Extreme events and storm surge with sea level rise	Increased flooding risk from nor'easters and hurricanes
Tunnel	Holland Tunnel	Extreme events and storm surge with sea level rise	Increased flooding risk from nor'easters and hurricanes
Bridge	Bayonne Bridge	Sea level rise	Lower clearances on existing bridges from rises in sea level
Building	Terminal buildings at John F. Kennedy International Airport and LaGuardia Airport	Rising temperatures or heat waves	Increased risk for power failures shutting down baggage-handling systems

Source: Port Authority of New York and New Jersey.

evaluated include John F. Kennedy International Airport, Newark Liberty International Airport, LaGuardia Airport, Stewart International Airport (in Newburg, New York), the PATH system, the Lincoln Tunnel, the Holland Tunnel, the George Washington Bridge, the Outerbridge Crossing, the Goethals Bridge, the Bayonne Bridge, the World Trade Center site, Port Newark, the Elizabeth–Port Authority Marine Terminal, and the Howland Hook Marine Terminal. The Port Authority's engineering department was able to develop an initial list of the major facilities that might be affected by the climate change variable projections provided by the NPCC. The list was circulated to staff throughout the various agency departments to ensure thoroughness.

When selecting the particular infrastructure assets to be classified as at risk—especially with respect to flooding—the criteria used included the asset's topography (including average elevation), proximity to coastal waters, performance during past weather events (especially heavy rainfall), and relative importance. During this phase of the analysis, we discovered that the availability of information about each asset and the ease of access to those data were critical factors. As is the case with most state agencies that manage and operate transportation infrastructure, the Port Authority's information archive systems are extensive, and retrieval was time consuming. Moreover, multiple sources of information were stored in multiple locations. Such intangible sources of information as institutional knowledge proved very valuable, and these sources were tapped through discussions with facility staff during this effort.

Since most Port Authority facilities are situated near the coast, the most significant threat to our infrastructure was deemed to be the storm surges caused by such extreme events as hurricanes and extratropical cyclones (known locally as nor'easters) coupled with the projected sea level rises. This meant that it was crucial to obtain reliable information on site topography. Elevation information was collected from drawings on record, although we recognized that these might not have been truly representative of the as-built condition. We relied on data acquired from topographic site surveys for this evaluation when such data were available. From the challenges we encountered in gathering this information, we recommend the use of topographic site surveys for any entity considering this type of effort, especially when drawings of record are not readily available. This may not only lower costs but also yield data of greater accuracy.

Topographic maps from a variety of sources, as well as flood insurance rate maps produced by the Federal Emergency Management Agency, were useful tools for determining the flood potential for our facilities. It is important to note that these flood maps have traditionally been used to determine which areas are vulnerable to what is known as a 100-year flood. However, during our participation in this effort we discovered that topographic maps acquired from low-altitude flyovers yielded flood limits that differed from those shown on flood maps prepared by the Federal Emergency Management Agency. This difference can probably be attributed to the greater degree of precision available from localized topographic surveys. These various sources of floodplain data were compared to determine which facilities are situated in the vicinity of the current or projected 100-year floodplain so that they could be classified as being at risk.

The effects of such extreme weather events as more frequent heat waves and more intense rainfall were considered in assessing the vulnerability of our building systems and the drainage systems for our roadways and airfields. Such building components as electrical systems and heating, ventilation, and air-conditioning systems typically have a useful life span of less than 25 years and therefore were not considered to be at risk; it was assumed that we would have the opportunity to improve these systems during replacement cycles between 2010 and 2020.

Figure 2 provides a partial listing of the Port Authority facilities deemed to be at risk as a result of this evaluation. The risk analysis completed for each asset was a function of the likelihood of occurrence of a particular climate effect during an asset's useful life and the gravity of the effect on the infrastructure. The magnitude of the consequence was evaluated with respect to the following six factors: internal operations; capital and operating costs; effects on society; patron health; economics; and the environment. The magnitude of the consequence was classified as being low, medium, or high; however, this evaluation was not quantitative.

The operational strategies that are being considered to help protect such facilities as tunnels from the flooding associated with intense coastal storms include the use of sandbags placed along Jersey barriers.

The likelihood of occurrence was measured as low, moderate, high, or virtually certain or already occurring. The key concept when classifying the likelihood of occurrence was that the effect occur within the lifetime of the infrastructure. This type of analysis can be quite subjective in the absence of established quantitative criteria to differentiate the various ratings. Since the primary effect from flooding on Port Authority facilities was determined to result from surges associated with such extreme events as intense coastal storms, possibly coupled with sea level increases, the engineering department established a quantitative scale for use in assessing the likelihood of such events. Figure 3 provides this scale for extreme weather events. Typically, the probability of the occurrence of various flood levels caused by coastal storms is expressed in terms of a return period of years. For example, a flood level that has a 1 percent probability of occurring during a given year is described as occurring once in 100 years. As a starting point, we defined any likelihood of 1 percent or less as low.

Setting priorities for the assets deemed to be at risk was done by using the risk matrix shown in figure 4. An asset having a high likelihood of being adversely affected by climate change and thereby undermining the operations of the Port Authority would warrant the immediate development of strategies to mitigate the deleterious effects. Based on the probability ranges defined by the Port Authority for extreme events, assets deemed to be at risk of damage by such an event were placed in the moderate likelihood of occurrence level. The overall magnitude of consequence for Port Authority facilities in the six sectors was classified as moderate on the basis of discussions with Port Authority staff from various departments with knowledge of these sectors. An important consideration was that during major storm events, populated areas might need to be evacuated and transportation systems would be operating on a limited, emergency basis. Facilities that were

Figure 3: Port Authority Definitions of "Likelihood of Occurrence" for Extreme Weather Events

Likelihood	Definition	Probability of impact	Return period impact range
Virtually certain or already occurring	Nearly certain likelihood of the effect being felt during the useful life of the infrastructure or variable may already be affecting infrastructure	>20%	1 in 5 years or less
High	High likelihood of the effect being felt during the useful life of the infrastructure	>10% and ≤20%	1 in 5 years to 1 in 10 years
Moderate	Moderate likelihood, with some uncertainty remaining, that the effect will be felt during the useful life of the infrastructure	>1% and ≤10%	1 in 10 years to 1 in 100 years
Low	Low likelihood of the effect being felt during the useful life of the infrastructure	≤1%	1 in 100 years or more

Source: Port Authority of New York and New Jersey.

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FIGURE 4: RISK MATRIX

Magnitude of consequence				
Low	Continue evaluations and develop strategies	Develop strategies	Develop strategies	Develop strategies
Medium	Watch	Evaluate further and develop strategies	Develop strategies	Develop strategies
High	Watch	Watch	Continue evaluations and develop strategies	Continue evaluations and develop strategies
	Low	Moderate	High	Virtually certain
	Likelihood of occurrence			

Source: Port Authority of New York and New Jersey.

seen as facing the highest risks were assigned the highest priority for the development of adaptation strategies, while those seen as being at a lower risk were placed in the "watch" category, which means that we will continue to monitor and evaluate these assets.

Adaptation strategies were divided into three categories: maintenance and operations, capital investments, and regulatory. Maintenance and operations strategies include, for example, using sandbags, portable pumps, or temporary floodgates; cleaning drainage systems; repositioning rolling stock; and performing detailed studies. Capital investments could take the form of permanent improvements that could include installing new flood barriers, elevating certain elements of critical infrastructure so that they would be above the projected flood elevations, moving entire facilities to higher ground, and designing new assets for quick restoration after an extreme event. Regulatory strategies could include modifying city building codes and design standards.

An interesting aspect of this study was the discovery that earlier capital improvement investments that involved engineering design redundancy had the unintended consequence of palliating the possible consequences of climate change. For example, security projects that involved the construction of barriers and walls have also provided additional protection against possible storm surges. Another example involves the asphalt concrete pavement mixes used by the Port Authority. Over the years, the agency's civil engineering and materials division has developed asphalt mixes that contain modified polymers designed to improve performance under sustained heavy truck traffic and aircraft loads. These modified asphalt mixes offer the added benefit of performing well through a much higher temperature range.

Another example concerns a project at LaGuardia Airport that involved linking the facility's electrical substations. LaGuardia Airport requires significant amounts of electric power to ensure efficient and reliable operation, its peak load demand measuring 20 million VA. Power is supplied via two independent local utility company networks that feed two airport substations, providing redundancy. During the summer of 2006, a heat wave disabled one of the substations. The connection between the two proved invaluable as it allowed the Port Authority to draw on the other substation, ensuring uninterrupted airport operations. The projections for an increase in temperature, along with more frequent and longer heat waves, make electric grid reliability and redundancy major issues for infrastructure in the New York City metropolitan area. This interconnectivity is expected to serve the airport well as temperatures increase in the future.

The Port Authority has also developed interim design criteria that will call on various departments within the organization to consider the effects of climate change in new construction or major rehabilitation projects. These criteria are shown in figure 5. They will be in effect until additional information is available on climate change projections, and they will be reviewed or updated on a two-year basis. The Port Authority is currently evaluating the ramifications of these design criteria in its future and current capital investment projects.

One of the first projects to consider these criteria involves the replacement of an electrical substation. The engineering design of substation 7 in the PATH system was recently completed and is ready for construction. This substation is part of a larger network of substations that provides power for approximately 7 mi of at-grade rail between Newark Penn Station and the Journal Square Station, in Jersey City, New Jersey. The existing substation has reached the end of its useful life and is situated at an elevation of 10 ft with respect to the North American Vertical Datum of 1988, putting it only 1 ft above the 100-year flood level. The design for the replacement substation was based on the newly established interim design criteria and therefore specifies a base elevation of 11.5 ft, which will help protect this critical facet of infrastructure from future coastal flooding.

Through its involvement in this effort, the Port Authority has begun evaluating its facilities' emergency plans and is in the process of initiating detailed studies to formulate operational and maintenance strategies that will improve these plans. The Port Authority has carried out flood studies of LaGuardia Airport and portions of the PATH system and is in the process of initiating a flood study of the Holland Tunnel.

Among the major capital improvement projects that are currently in the conceptual design phase and will therefore address the interim design criteria are the LaGuardia Airport terminal modernization project and such PATH projects as the Washington Street powerhouse, the Newport Station access point, the Harrison Station replacement, and the Grove Street modernization.

The benefits conferred by the Port Authority's involvement in this assessment include the various lessons that have been learned, which we believe will prove useful to public- and private-sector engineers, administrators, owners, and operators concerned with transportation infrastructure. Indeed, such assessments and studies are likely to become more common in the future. These lessons include the following:

- A comprehensive assessment of an existing transportation network is necessary for determining the degree of vulnerability of assets and setting priorities for protecting them.
- Consistent and quantitative regional climate projections from a single reliable source are of paramount importance to the success of a climate change assessment for a given region. General information on climate change can be obtained from publications by the Intergovernmental Panel on Climate Change, but a regional downscaling of this panel's models should be carried out to determine regional effects, as was accomplished by the NPCC for this effort.
- Institutional knowledge of a facility's performance during major storm events can be invaluable in determining the level of vulnerability of a facility.
- The level of accuracy of the information pertaining to a given facility's construction type, site topography, and layout is of cardinal importance in determining the level of risk faced by the facility. Actual site surveys may save time and money if recorded drawings are not readily available. The Federal Emergency Management Agency's flood insurance rate maps are suitable for determining a rough level of vulnerability, but they may not contain precise topographic information.
- Infrastructure having a useful life of less than 25 years (for example, heating, ventilation, and air-conditioning systems) may not warrant evaluation; upgrades can be incorporated during regularly scheduled replacement projects.
- Former capital improvement investments that involved engineering design redundancy or security improvements may offer the added benefit of helping the infrastructure withstand the effects of climate change.
- Risk analyses should be as quantitative as possible to ensure that facilities are evaluated in a consistent fashion. Whenever possible, regional stakeholders should develop and use these quantitative criteria in a coordinated manner.
- Relatively simple and cost-effective protective measures can be implemented to significantly reduce the potential effects of climate change in the near term. Sandbags and Jersey barriers are two examples.
- The cost of an adaptation measure should be weighed against the costs that would be incurred in the loss of the facility or in repairs and forgone revenue. But the safety of the patrons using the facility is the prime consideration in this evaluation.
- The inclusion of climate change mitigation measures in an agency's ongoing capital project plans, which can cover long periods, can help to distribute and lower the mitigation costs.
- The connectivity of transportation infrastructure under operation by various owners requires a coordinated approach to planning and adaptation.
- While uncertainty exists in the climate data provided by the NPCC, this lack of certainty should not stand in the way of evaluations of facilities and capital projects.

We will continue to monitor climate change projections, and our goal is to carry out detailed assessments of the possible effects of climate change on our facilities. We will also periodically revisit our design criteria to ensure that they reflect the latest projections, and we will continue to seek opportunities to make our infrastructure more resilient and thus better able to meet the future needs of the public. CE

THE INCLUSION OF CLIMATE CHANGE MITIGATION MEASURES IN AN AGENCY'S ONGOING CAPITAL PROJECT PLANS, WHICH CAN COVER LONG PERIODS, CAN HELP TO DISTRIBUTE AND LOWER THE MITIGATION COSTS.

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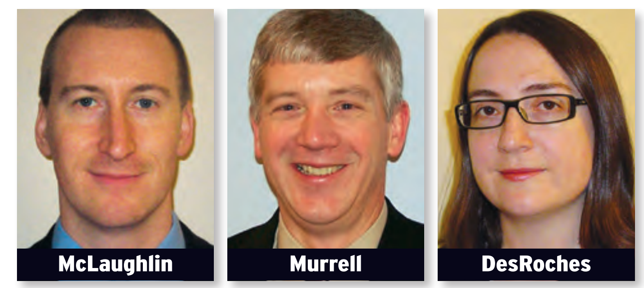
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FIGURE 5: PORT AUTHORITY OF NEW YORK AND NEW JERSEY INTERIM DESIGN CRITERIA

Climate variable	Baseline (1971–2000)	2080s
Air temperature	12.8°C (annual mean)	3.33°C increase over baseline
Precipitation	118.1 cm (annual mean)	10% increase over baseline
Sea level rise	Current mean high water	45.7 cm increase over current mean high water
Flood elevation	45.7 cm increase over the current Federal Emergency Management Agency 100-year flood level plus 30.5 cm (the agency's current 100-year flood level plus 76.2 cm)	

Source: Port Authority of New York and New Jersey.
Note: Where prohibiting factors preclude the application of these design criteria to all project elements, the focus should be on project elements for which any disruption of service would have grave consequences for facility operations.