ALLIANCE FOR INNOVATION
BIG IDEAS
THE FUTURE OF LOCAL GOVERNMENT 2014

Building Infrastructure Resilience to Changing Weather Patterns

Prepared by

Clark A. Miller
Chair, Human and Social Dimensions of Science and Technology
Associate Director, Consortium for Science, Policy & Outcomes
Arizona State University

Prepared for

The Alliance for Innovation
BIG Ideas: The Future of Local Government
October 24-26, 2014
Fort Lauderdale, FL

Introduction

Over the past decade, it has become increasingly clear that US climate patterns are changing in ways that create new challenges for US cities. Highlighting these challenges have been a series of high profile disasters, including Hurricane Katrina and Hurricane Sandy. Yet these disasters are only a small piece of the puzzle. Much more modest shifts in weather and climate patterns are nonetheless proving sufficiently powerful to create widespread problems. A few notable examples include:

- California and the US Southwest have experienced a persistent, debilitating drought, which is now reaching crisis proportions, emptying reservoirs, straining water resources, and creating ripe conditions for widespread wildfires. Despite the drought, record-breaking flooding events continue to strike the region, e.g., in Phoenix in the past few weeks.
- According to a recent report from the Union of Concerned Scientists, cities along the US coasts are experiencing the slow but relentless pressure of sea level rise, subtly altering the interactions of ocean and land, routinely lapping coastal infrastructures, while creating the conditions for damaging storm surges.
- In the summer of 2013, an odd climatic pattern—predicted to increase in frequency in the future—left cities in the US Midwest facing extreme hot and dry conditions for much of the summer.
- Only two years earlier, the same region had faced severe flooding along the Mississippi and Missouri rivers that forced the US Army Corps of Engineers to take extreme action (demolishing a section of the Mississippi flood control system, flooding extensive farmland, and opening flood gates into the Morganza Spillway and Atchafalaya Basin) in order to save downstream cities and prevent flooding in New Orleans and Baton Rouge.

These and other changes in weather and climate patterns pose a unique and escalating threat to the resilience of US communities and the infrastructures they rely on for protection. Over the past century, the United States has largely approached weather-related risks through the construction of large-scale infrastructures. Dams, canals, and levees along rivers and coastal defense works are the most visible, but these infrastructures also include a plethora of much more mundane engineering efforts designed to protect against floods, hurricanes, droughts, heat waves, storm surges, blizzards, and other extreme events. ***Yet, in almost every case, engineers built these infrastructures assuming that the regular patterns of weather events—their statistical frequency and scale—would be constant and remain the same over time. This is increasingly not true, as weather and climate patterns change, and so the infrastructures built to protect cities and towns are increasingly falling short.***

Several factors make the problem even worse.

- First, the US has built other infrastructures—from roads and buildings to electricity grids, water infrastructures, and communications systems—designed to significantly enhance urban (and rural) life. These infrastructures were also built on the assumption that weather and climate patterns would be constant over time, and so are also increasingly vulnerable.
- Second, all infrastructures increasingly depend upon one another to function properly. Water pumps require electricity to function, for example, and so do communication systems. Most power plants require water for cooling. Interdependency means that vulnerabilities in one system may propagate to other systems, decreasing overall infrastructure resilience.
- Third, when infrastructures that provide protection ultimately fail, such as the levees in New Orleans, the problem is far worse than had the protective infrastructure not been built in the first place. This is partly because the infrastructure itself magnifies the problem. Dam failures, for

example, release far more water held in storage reservoirs, all at once, than would occur in a natural flooding event. But it is also because the relative safety provided by the infrastructure in the first place entices greater development, e.g., in flood zones below the dam, than might otherwise have occurred.

- Fourth, US infrastructure is aging, and US cities are, in general, investing too little to rebuild, repair, and replace declining infrastructures. This magnifies vulnerabilities.

Changing Climate and Weather

The 2014 US National Climate Assessment report makes clear that changes to US climate and weather patterns are already significant. This is true nationally—average US temperatures and precipitation have been increasing, as has the frost-free growing season—but the more locally one focuses one attention, the clearer and more stark the trends become. National trends don't really matter, at the end of the day. What matters is what's happening locally, in each city and around each infrastructure that the city depends on.

Drought in the US Southwest and California offers a clear illustration of the problem. Rainfall is increasing nationally and may increase further if climate model predictions turn out to be correct. For the past 15 years, however, overall rainfall levels in the US Southwest have been significantly below average, creating a deep drought that now poses real threats to regional water supplies. In scientific terms, drought means a period of below-average rainfall, so I suppose it's okay to call it a drought, except that we no longer know what average rainfall is for the region. The very idea of average presumes that there is a normal level of rainfall that doesn't change. Maybe there was a normal before, but no longer. Given current understanding among scientists of how the climate works, rainfall levels in the region have declined and are expected to continue to decline further in the future. It's probably not actually a drought. It's probably a systematic and ongoing decline in available water.

According to the National Climate Assessment, systematic changes are underway, regionally, in a wide variety of important weather and climate dynamics, including but not necessarily limited to:

- Amount and timing of rainfall and snowfall, humidity levels, and consequences that flow from these, such as wildfire frequency
- Temperature, including highs, lows, consecutive days of heat and cold, dates of first and last freezes
- Timing and severity of extreme weather events, including heavy rainfall events, winter storms, hurricanes

These changes are due to a wide variety of factors. Some of them are undoubtedly the result of rising levels of atmospheric carbon dioxide. Others result from other human activities. Urbanization, for example, is creating heat island effects with severe effects in some cases. In Phoenix, for example, nighttime temperatures in the summer months have risen 20 degrees (F) due almost entirely to the city's heat island. Still other causes are natural. From a city management perspective, the cause ultimately doesn't matter nearly so much as the scope of impact.

Infrastructure Vulnerability

Urban infrastructure around the country is increasingly vulnerable to changes in weather and climate for one simple reason: it was designed on the assumption that weather and climate parameters would be relatively constant. As that assumption begins to break down, there is a growing need to reassess infrastructures, their vulnerability to changing weather and climate patterns, and the possibility that they may be unable to continue to provide services to the communities that depend on them.

Nevada has faced up to this challenge, hopefully in time. In 2012, the Southern Nevada Water Authority, which provides water to Las Vegas, began constructing a new $1 billion tunnel from Lake Mead, the city's primary water supply on the Colorado River. The reason: since 2000, water levels in Lake Mead have been dropping precipitously, fed by a growing mismatch between lower rainfall levels due to the region's "drought" and water allocations to cities and agriculture around the Southwest. Dropping water levels threaten to leave the city high and dry. If they drop far enough, the city's two existing water intake tunnels will become exposed, and the city's water supply will be cut off, unless they can finish tunnel three in time. Of course, Lake Mead is currently less than half full. If water supplies continue to drop, it may not matter how deep the new intake level is.

The new Lake Mead tunnel project is a stark example of the vulnerability of infrastructure to changing weather and climate patterns. When Hoover Dam and the original water infrastructure for Las Vegas were built, engineers assumed that, even as rainfall levels fluctuated randomly from year-to-year, the long-term average rainfall in the Colorado River Basin would remain the same. Unfortunately, that assumption is no longer true. Scientifically, we say that the rainfall statistics in the basis are not stationary. This means that the average rainfall is changing and the degree of randomness around that average is also changing. In turn, our management of the infrastructure, and, as in the case of the third intake tunnel, sometimes even the design of the infrastructure itself, now must change.

Virtually every infrastructure in the country suffers from this same flaw, whether it is buildings, roads, airport tarmacs, electricity grids, canals, dams, levees, coastal protection measures, etc. In the 2013 heat wave in the upper Midwest, transmission lines sagged, airport tarmacs and roads melted, and blackouts occurred due to inadequate energy generation to meet air conditioning needs. The after the fact review of the events of Hurricane Katrina by the American Society of Civil Engineering showed that levees around the city had been designed based on statistics for hurricane frequency and intensity that were already out of date by the time construction of the levees began—and which have only become less accurate as time has gone by. The city was far less protected against hurricanes by 2005 than its leaders and residents believed.

In these examples, we see two key facets of infrastructure vulnerability, one of which is vulnerability to changes in short-duration, high-frequency events like storms or heat waves. These statistical anomalies—the really heavy rainfalls, strong storms, or high or low temperatures—can be highly disruptive, and changes in their magnitude and frequency will be highly significant. At the same time, infrastructures can also be vulnerable to long-term, secular changes, such as the decreasing rainfall totals within the Colorado River basin. Planners and managers need to attend to both.

Early action to identify and assess the vulnerability of infrastructure under different plausible future scenarios of weather and climate patterns can hopefully help cities and communities avoid both major catastrophes and the need for costly retrofit projects. Given future uncertainties, nothing is guaranteed. Nonetheless, early detection can potentially lead to management and operational solutions that allow cities to avoid major reconstruction projects, at least in the short term. Dynamic weather and climate patterns—rather than stationary assumptions—can also be factored into new project developments and routinely scheduled upgrades, generally at much lower costs than last minute retrofits. Some engineering firms are even beginning to integrate the potential for future shifts in weather and climate patterns into infrastructure plans and designs for cities, although this remains scattershot.

Broadly construed, there are two major strategies for assessing infrastructure vulnerability to changing weather and climate patterns. At the end of the day, vulnerability grows as a product of how big the expected changes are in weather and climate patterns and how susceptible the infrastructure is to those changes.

- The first strategy might be called *working forward* and begins by looking for large changes in weather and climate patterns that might impact infrastructure. This is by far the most common approach. It begins by assessing both past changes in weather and climate patterns (locally or, if there are significant interdependencies that one is trying to account for, distantly) and plausible/possible scenarios of future changes. These can then be compared to the tolerances of existing infrastructures to see where and when vulnerabilities might arise. The potential limitation of this strategy is that it tends to focus first and most extensively on those changes to weather and climate patterns that are likely to be the largest, rather than those to which the infrastructure is most susceptible.
- The second strategy—which we might term *working backward*—is to identify inherent vulnerabilities in infrastructure systems that may be particularly susceptible to shifts in climate and weather and then to assess the likelihood of those shifts. This is particularly valuable as a strategy when there are non-obvious pathways via which infrastructures are highly susceptible to even small changes in weather and climate patterns. In some agricultural settings, for example, insurance programs have significantly reduced the vulnerability of farm incomes to annual weather variability—which is the normal metric of climate vulnerability used in agriculture. However, these same farms were highly vulnerable to small changes in annual equipment repair costs. Working with scientists, they identified several pathways via which shifts in weather and climate patterns might raise these costs and thus significantly reduce farm incomes.

Infrastructure Interdependence

A second major facet of the problem of infrastructure vulnerability stems from the interdependence of diverse infrastructures. For example, air transportation networks depend on road and rail networks to enable people to get to and from airports, on communication networks to enable people and planes to find out information about system status, and on airport security systems to prevent terrorism. Road and rail networks in turn depend on fuel systems, as does the air transportation system. Security and communication systems in turn depend on the electricity grid, as does other airport operations. Failures in one system can thus propagate to other systems in an unanticipated fashion, and vulnerabilities may be invisible to system operators when they occur in another system—especially if those dependencies are distant geographically.

In considering the vulnerability of interdependent infrastructures to changes in weather and climate, it is useful to think about three different pathways via which climate impacts can occur:

- **Local, direct effects**: These are the direct vulnerabilities of a given infrastructure to changes in its own local environmental conditions. For example, flood control infrastructures may be designed to handle a maximum instantaneous flow of water (e.g., a levee) or to store a maximum amount of water accumulated over time (e.g., behind a dam). If basin-wide rainfall levels exceed these measures, the infrastructure will fail. Similarly, sea level rise may, over time, disrupt certain coastal infrastructures that are not protected against it.
- **Local, indirect effects**: These are the indirect vulnerabilities of a given infrastructure to changes in local environmental conditions that impact separate but interdependent infrastructures. For

example, ground water pumps are typically dependent on electricity grids to provide the energy necessary to pump water. The pumps themselves may not be vulnerable to an increasing frequency of storms but may be vulnerable to a loss of electricity that stems from more frequent high wind events that knock down power lines or lightning strikes that destroy electrical grid equipment.

- **Distant, indirect effects**: These are the indirect vulnerabilities of a given infrastructure to changes in distant environmental conditions that impact separate but interdependent infrastructures. For example, the tsunami that destroyed the Fukushima nuclear power plant also ravaged Japanese industry. Due to highly interdependent supply chains between the US and Japanese manufacturing sector, the tsunami had a negative effect on numerous US industries that could not get necessary parts for their products.

Thoughts on Building Resilience

The President of the United States observed last month: “For all the immediate challenges that we gather to address this week—terrorism, instability, inequality, disease—there’s one issue that will define the contours of this century more dramatically than any other, and that is the urgent and growing threat of a changing climate.” The President’s remarks highlight the powerful significance of an issue that we have each only begun to address, individually and in communities. Many people view climate adaptation as a problem for poor nations and poor communities that are already vulnerable to change. This is no doubt true. But rich nations and rich communities are also vulnerable—and maybe more vulnerable—due to infrastructure designs that are maladapted to likely future environmental conditions. All cities are on the frontlines of meeting that challenge.

Create New Knowledge Systems: While federal spending on climate and weather-related data has increased dramatically over the past two decades, spending on local capacities to mobilize that information, such as state climatology offices, has dropped. Consequently, cities and communities may need to build new systems and partnerships that enable them to understand and assess vulnerability and resilience. All cities should consider what they know about the vulnerability of each of their infrastructures and whether that is sufficient. Here are a few ideas:

- Conduct a city-level assessment of changing weather and climate patterns, looking especially at trends over the past 30-50 years. Climate models may be helpful, but don’t assume you need them. Far more significant are comprehensive pictures of actual trends in local weather and climate variables and multiple projections of potential future scenarios that can be used to think with. Local universities may have faculty and students willing to help.
- Evaluate lifeline infrastructure vulnerability to diverse scenarios of future weather and climate patterns. Conduct this evaluation using both working forward and working backward strategies and looking at both high frequency variations and long-term, secular trends. Build public-private partnerships to carry these out where public infrastructures are under private management or where private infrastructures are critical to city resilience.
- Evaluate other infrastructures that may be interdependent with lifeline infrastructures or may otherwise be significant. Don’t ignore private sector infrastructures, such as manufacturing facilities and supply chains that have significant impacts on social and economic resilience.

Create Capacity for Resilience Thinking and Planning: Formal assessments should be supplemented by creating a distributed capacity across infrastructure management and operations to think about infrastructure vulnerability and resilience and to integrate that thinking into infrastructure design, planning, and operations.

- Ensure that high-level infrastructure management is aware of the challenge and factoring it into their planning activities. Insist that managers and contractors factor changing weather and climate patterns appropriately into infrastructure planning and design.
- Develop a distributed cadre of resilience specialists across diverse infrastructures who can help one another develop knowledge and strategies and who can assess the propagation of vulnerability across interdependent infrastructures.
- Build alliances across cities and communities, universities, the private sector, and others on a regional basis, or with others who face similar challenges to you.
- Federal help is growing, in the form of information, advice, and assistance.

Engaging Publics and Stakeholders in Infrastructure Transitions: Infrastructure governance can sometimes tend to emphasize relatively low levels of public and stakeholder participation, due to the complexity of engagement processes, especially in controversial contexts. Long-term changes in weather and climate patterns create a moment of infrastructure transition that likely will require greater attention to and care with stakeholder and public engagement.

- Engage publics in productive conversations about community resilience and infrastructure resilience. These are not necessarily the same thing, although they are sometimes related. A deeper shared understanding of these concepts may help facilitate the projects necessary to reduce vulnerabilities and enhance resilience.
- Identify the community's goals for how it wants to live with changing weather and climate patterns, as a basis for beginning to assess whether these goals are realistic, socially, economically, and politically.
- Deliberate on diverse strategies for meeting community goals and strengthening the community's ability to respond effectively to uncertain futures as they evolve and to provide political support for decisions taken in infrastructure development.

Hosted by the Alliance for Innovation, BIG Ideas is an invitation only event that gathers progressive leaders to explore critical issues for the future of communities. The Alliance for Innovation is inspiring innovation to advance communities. As the premiere resource for emerging practices in local government, the Alliance is building cultures of innovation and connecting thought leaders in the profession with the help of our partners International City/County Management Association and Arizona State University. We are accessible and valuable to all levels of an organization.