

# Chapter 5

## Resilience and Essential Public Infrastructure



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**Abstract** This chapter begins with a commentary on resilience as the meta-concept for organizational preparedness for disruptive events, and the factors that influence the implementation of a resilience agenda. This is followed by an analysis of resilience in the special context of essential public infrastructure wherein priority is given to reliability and continuity of service, and interdependencies between infrastructures must be dealt with. The resilience agenda of a major public water supply system is then presented to illustrate the broad range of initiatives needed to ensure its resilience. Finally, policy issues are discussed regarding adaptations of resilience to meet concerns about security and sustainability.

**Keywords** Public infrastructure · Resilience · Reliability · Redundancy  
Public water supply · Interdependencies · Safety management

### 5.1 Commentary on Resilience

Resilience is a term commonly used to denote the quality of an organization, structure or system that enables it to resist and recover from disruptive events [1]. As an objective, resilience takes on additional meaning in accordance with the task at hand. Most often, the task is strategic preparedness of a company or other organization for foreseeable types of disruptive events, such as flood, loss of process control, or act of terrorism. Haimes has aptly defined resilience for this task from a systems engineering perspective: “resilience represents the ability of the system to withstand a disruption within acceptable degradation parameters and to recover with acceptable losses and time limits” [2].

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Other concepts lack the strategic breadth or coherence of a resilience-centered approach. The reliability concept, for example, emphasizes redundancy for bypassing potential points of failure in order to maintain continuity of operations. And a risk-based approach dedicated to quantification of risks provides a module of probabilistic information that must be subsequently grounded in a pragmatic organizational strategy. Indeed, conflicts may arise when implementing such concepts separately, such as when improving reliability of operations involves fuel storage on site and thereby creates new risks.

Thus, an organization that seeks to develop a coherent approach to disruptive events can adopt resilience as its meta-concept because it encompasses the many other “R word” concepts for addressing disruptive events: resistance, robustness, reliability, redundancy, risk analysis, risk management, recovery, and restoration [3].

The process of implementing a resilience strategy, and the practices and outcomes, will be shaped by a combination of circumstances, dynamic conditions, and lessons learned from experience that is unique for each organization. For example, an organization that has experienced disruptive events and knows its vulnerabilities, may bypass risk analysis and pragmatically focus on improving the robustness of its infrastructure and striving to prevent those events known to have the types of impacts that would destroy critical parts of its infrastructure [4].

A major factor shaping an organization’s approach to resilience is its safety management system. Disruptions caused by external sources such as a Tsunami or act of terrorism have dominated the academic discourse on resilience. But organizations that have an effective safety management system and workplace protections because of the accident hazards intrinsic to their operations are likely to be more attentive to disruptive events that could arise from internal conditions, especially because they will be held accountable for worker safety and offsite impacts on the public [5]. Notorious accidents at the Chevron Richmond refinery and at BP onshore and offshore facilities are clear examples of catastrophic events that arose from internal causes, including top management neglect, middle management negligence, and worker and contractor error.<sup>1</sup>

Regulation also shapes the approach to resilience. Although there is no broad legal mandate that a company or other private organization make itself resilient, or measure and certify its resilience, this does not mean that resilience is merely left to company discretion. Many local and national regulations, building codes, standards and permit requirements apply to the design, siting and operation of facilities in order to protect public health, safety and environmental quality from harms that may arise from foreseeable types of disruptive events. Similarly, workplace safety regulations, and common law doctrines that impose liability for harms due to a company’s negligence, have the effect of promoting organizational resilience [6]. Thus, regulatory compliance and liability avoidance contribute to resilience.

Those aspects of resilience that are not mandated by law are left to organizational discretion, as may be the case for installing a cyber-defense or backup energy system, for example. Generally, it can be expected that such matters, collectively or separately,

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<sup>1</sup>US Chemical Safety Board reports on these accidents are available at <https://www.csb.gov>.

will undergo a review process regarding their technical and financial feasibility, costs and benefits, value for improving competitiveness and fulfilling contractual obligations, and overall acceptability to top management.

But this review process will also consider insurance as a less-costly alternative to resilience initiatives. A proposed resilience initiative may be rejected when it can be shown that casualty, liability, business interruption and other types of insurance coverage are available, affordable and adequate to cover the estimated losses that would be caused by the type of disruptive event being addressed. According to some policy analysts, this situation obstructs progress towards a safer society because: “insurance regimes reinforce exposure and vulnerability through underwriting a return to the *status quo* rather than enabling adaptive behavior” [7].

A final point for this brief commentary is that improving resilience can be facilitated by recognizing and gaining value from inter-organizational dependencies [8]: for example, by creating effective plans for preventing and responding to disruptive events with the following entities:

- Public infrastructure entities that provide essential services such as water supply, transport and electricity.
- Community and state departments that provide services for emergency response and communications, rescue, evacuation, and medical needs.
- Neighboring industries whose disruption by a major accident would have spill-over disruptive impacts on others.
- Stakeholders and local organizations that can provide public support for measures that prevent risk and cope with consequences, such as by facilitating governmental approval of plans for reconstruction and restoration.

By outreach and discussion of mutual concerns and interests, an organization can develop these dependencies into resilience-improving relationships.

## 5.2 Public Infrastructure

Modern society needs infrastructures that serve essential public needs for energy, water supply, food, waste disposal, transportation, communications, and protection against natural hazards and activities that endanger health, property and the environment [9]. The foregoing discussion of resilience sets the stage for now considering its meaning and application in the infrastructure context.

Context matters. In the company context, resilience must serve the firm’s self interest. In the infrastructure context, it must serve public needs expressed in processes that govern public infrastructures. This is because public-serving infrastructures are mandated by legislation, designed, built, managed and operated by government agencies or public-private partnerships, and funded by the general public, subsets of users, and investors [10].

Another difference is that resilience in the company context is usually seen as an approach to be taken for the purpose of avoiding financial loss and its value will

depend on whether insurance or other loss control measures can produce equivalent results at less cost or less need to change from doing business as usual [7]. But in the infrastructure context, resilience as an objective is unquestioned because it fosters initiatives that protect an essential public service.

The societal value of resilience also differs according to context. Disruption of a company's operations will usually have less harmful consequences for the host community than disruption of an essential infrastructure that may cause a cascade of impacts throughout the community. For example, interruption of a public water supply system may disrupt hospitals, health services, households, human consumption, commercial and industrial activities, schools, and other infrastructures that have water-dependent components such as the regional energy system whose power plants need cooling water. Threats to human health and safety will also require rescue and relief initiatives and connections to any alternate water sources until the water supply infrastructure is restored [11].

Thus, modern society needs to ensure the reliability and continuity of operations of its essential infrastructures despite threats posed by natural hazards, industrial hazards, human error and malicious behavior. Over the last decade, such threats and concerns about their impacts have increased as cyberattacks, terrorism, catastrophic accidents, and extreme weather events attributed to climate change have materialized. As a result, public authorities and advisory groups have come to recognize that the stability and security of a community, indeed its resilience, requires improving the resilience of these essential systems.<sup>2</sup>

Improving the resilience of an essential system to ensure its functional continuity or reliability involves a broad range of initiatives: making its physical and managerial components more robust and capable of resisting the likely impacts of foreseeable events, adding backup energy and other supports, developing the ability to isolate or bypass critical points whose failure would cause system-wide failure and having redundant features in place to replace their functions, enhancing monitoring and maintenance, planning to ensure that alternate services are readily available, and preparing for emergency response, rescue, relief for those who are distressed, and quick repair and restoration of service, for example [12]. As discussed earlier, a coherent approach to resilience will also involve cooperative relationships with other infrastructures, agencies that provide emergency response and relief functions, and stakeholders and local groups who can facilitate implementation of many of the foregoing initiatives.

But the resilience-improving process is complex. It often involves local, state and national levels of government, each with its own priorities and constraints, for approvals and financing, and dealing with competing interest groups and diverse stakeholders. It may also encounter pressures to expand or adjust the infrastructure because of dynamic conditions such as population expansion or dispersion, more

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<sup>2</sup>Critical Infrastructure Sector Resilience Reports, U.S. Department of Homeland Security. As of July 2017, reports on 16 sectors have been published: e.g. chemicals, communications, food and agriculture, energy, financial services, water and wastewater systems, transportation. Available from <https://www.dhs.gov>.

stringent performance standards set by regulators as in the case of water quality, new zoning and environmental constraints, and cultural change in the areas being served such as the transition from an industrial or agricultural community to an upscale residential community. And resilience-improving may be confronted by advocates for those who will feel disregarded by traditional “top down” crisis management approaches to resilience, or those who have been underserved because of historic discrimination.

In the U.S., the federal Department of Homeland Security has taken a lead role in defining the resilience challenges and best practices for several types of essential public infrastructure, such as a public water supply system [13]. To move beyond these generalities, it is instructive to briefly review ongoing efforts by the management of an actual infrastructure to improve its resilience and maintain continuity of operations: the Massachusetts Water Resource Authority (MWRA). This public authority was created to manage and operate a vast public water supply infrastructure to serve eastern Massachusetts, a densely populated region that includes several million residents, several thousand companies, and numerous service firms, universities, hospitals and research facilities.<sup>3</sup>

MWRA draws water from 2 reservoirs in rural central Massachusetts, the Quabbin and Wachusett. The reservoirs are surrounded by watersheds comprised of forested and sparsely populated lands that are state-owned or otherwise state-controlled to prevent developments and activities that would contaminate the water held in the reservoirs or damage the watersheds that replenish the reservoirs with fresh water of high quality. Over 200 million gallons per day are drawn and transported over 100 miles through deeply-buried pipelines and rock tunnels to a treatment facility and thence into a network of pipelines and tunnels that serve Boston and 50 other cities and towns.

The water is tested throughout the system, treated using ozone and UV light, and chlorine when necessary, does not require filtration, and is considered the best in the US for its natural quality and absence of contaminants when delivered to the communities. The communities being served are purchasers of the water and each uses its own pipeline network to bring the water to its ultimate users.

According to MWRA, its objectives are to provide reliable, uninterrupted delivery of water that meets all applicable water quality standards for human consumption, and to have the resilience capacity to prevent and respond to system breakdowns. Knowing that its system is tightly-coupled, it follows an approach adopted by water suppliers and public agencies that calls for identification and evaluation of “single points of failure” that could render the system unable to meet its design basis, and the development of redundancies, controls and security measures to eliminate the single points of failure when possible, or protect them when they cannot be eliminated for technical, economic or other reasons.

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<sup>3</sup>Discussion of the MWRA system is based on numerous public reports and other public documents available at the MWRA website and the website of its Water Supply Citizens Advisory Committee (WSCAC): <https://www.mwra.com> and <https://www.mwra.com/02org/html/wscac.htm>.

This approach has been brought to bear on the main transmission system and involves redundancy projects that create operational flexibilities: for example, construction of redundant tunnels, pipelines, new interconnections and replacement of antiquated and untested control equipment of uncertain functionality with new controls that allow parts of the system to be taken off-line for regular inspection and repair without system shutdown. The large scale projects require substantial capital investment, long term financing, approvals by several tiers of public officials, and coordination with communities and other infrastructures.

The quest for resilience throughout the system also involves many other initiatives. These include physical barriers and law enforcement for protecting key assets, improving the robustness of facilities, and various safety management measures in order to prevent contamination of the water supply and degradation of the watersheds by human activities and natural hazards, e.g.:

- Security measures to prevent access by terrorists or trespassers that include barriers, surveillance, and coordination with police and others.
- Watershed restrictions on construction and installations of fuel and chemical storage tanks, waste disposal, and septic systems.
- Additional watershed and reservoir restrictions that limit public access, boating, camping, mountain biking and other recreational activities.
- Monitoring and actions to prevent invasive aquatic species and invasive plants and insects in order to protect the storage and transmission systems and forested watersheds.
- “Environmental policing” to prevent contamination by wildlife and birds.
- Contingency and emergency response plans, including simulations, for containment of spills from nearby rail and road accidents.
- Maintenance of dams and other fixtures that enable water impoundment, and spillways to deal with excessive stormwater.
- Preparations to draw from alternate sources of water and to carry out repairs as needed.

As this example shows, the resilience-improving agenda for an essential public infrastructure must have redundancy and reliability projects that enhance the capacity to prevent system shutdown. It must also encompass protective measures and barriers that protect assets and enhance robustness and resistance to potentially-disruptive impacts throughout the system. Implementation requires coordination with other units of government that have expertise and resources.

### **5.3 Public Policy**

As the foregoing discussion indicates, the concept of resilience for an essential public infrastructure has been expanded to encompass many sub-concepts such as resistance, reliability, redundancy, robustness, rescue, relief, restoration and recovery. This thematic aggregation provides a formula for maintaining or returning to the

*status quo*, and thereby can cause disregard for adaptive management and use of new technologies when addressing threats of disruption. This situation is reinforced when the infrastructure involves a network of major facilities and the dependency of other infrastructures, such as an energy infrastructure comprised of power plants, transmission lines, pipelines, fuel storage tanks, equipment, and interconnections that are vital for other infrastructures.

The implementation of a resilience agenda for a public infrastructure such as transportation or water supply now includes security-enhancing activities that are exempt from requirements for transparency and public involvement. These activities are designed to prevent intentional malicious acts such as cyberattacks or use of explosives or chemicals and require secrecy to be effective. They usually derive from national security mandates and templates, and involve “top down” command and control management. Their inclusion in infrastructure resilience is necessary but needs to be compartmentalized to prevent infecting other resilience-improving actions with secrecy.

Finally, there is the challenge of ensuring that resilience-improving activities, especially those needed to maintain and restore the *status quo*, are also consistent with and reinforce responsible approaches for infrastructure sustainability [14]. These approaches to sustainability may be focused on addressing components of an infrastructure that are major polluters and contaminators of community air and water, inefficient consumers of limited resources, cause major accidents, or fail to promote conservation and prudent use of the energy, water or other services they provide. Thus, the opportunity is presented to fashion resilience projects that also heed and advance such sustainability initiatives to the extent feasible.

## 5.4 Conclusion

Resilience is a worthy objective for any organization. For an essential public infrastructure, it is a necessary objective that takes on meaning and societal value in accordance with the task at hand. Most often, the task is strategic preparedness for foreseeable types of disruptive events and their cascading consequences. As modern society becomes more complex, its stability is increasingly dependent on the performance of public infrastructures that serve essential needs, are tightly coupled, and function in a complex web of dependencies and interdependencies. Thus, ensuring the resilience of such infrastructures is a challenging core function of a society that strives to effectively govern risk and achieve its own resilience.

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