Chapter 3

Vulnerability Assessment

INTRODUCTION

After a utility's hazard summary has been completed, the effect of the hazards on water system components and on water quality and quantity should be determined. Each water system is unique, but each can be described and analyzed in terms of its components and expected level of service. Both the strengths and the weaknesses of an individual water supply system must be understood in relation to specific disaster hazards before attempting to draft emergency operational plans.

A vulnerability assessment is essentially a four-step procedure:

1. Identify and describe the separate components of the water supply total system.
2. Estimate the potential effects of probable disaster hazards (determined in chapter 2) on each component of the system.
3. Establish performance goals and acceptable levels of service for the system.
4. If under potential disaster conditions the system fails to meet the goals, identify the key or critical components of the system that are primarily responsible for the failure.

Definitions

Water system. The facilities and equipment constructed and operated to supply drinking water for residential or commercial uses. A water system has the following subsystems: source, transmission, treatment, storage, and distribution. Within each of these subsystems are critical components, such as power, personnel, materials and supplies, equipment, structures, transportation, gas and liquid fuels, and communications, that must be examined in developing an emergency plan.

Total system. A concept that incorporates a whole system, such as a water supply system, including the interrelationship or interdependency of various other lifelines. For example, a water utility constitutes a system, but the "total system" incorporates the water facilities, water users, maintenance facilities, administration, and other lifelines, such as communications, transportation, gas and liquid fuels, and electrical power.

Component. A discrete part of a system that is capable of operating independently but is designed, constructed, and operated so as to become an integral part of the total system. Examples of individual components of a water system are wells, booster stations, and reservoirs.

STEP ONE: IDENTIFY MAJOR SYSTEM COMPONENTS

Key elements of the total system should be listed and described as components under the following general headings: source water, transmission system, storage, treatment facilities, distribution system, administration, electric power, transportation, and communications. The headings represent the major categories of system components. Of course, each system is unique, and when identifying major components each utility should include components that may not have been mentioned or place the ones mentioned in a more appropriate category. The following is a list of major components:

Administration and operations
- Personnel
- Facilities and equipment (buildings and computers)
- Records (accounting, customer lists, and system maps)
- Emergency plan

Source water
- Watersheds and surface water sources
- Reservoirs and dams
- Groundwater sources
- Wells and galleries

Transmission
- Intake structures
- Aqueducts
- Pump stations
- Pipelines, valves, and other appurtenances

Treatment
- Facility structures (buildings, basins, and tanks)
- Controls (manual and computer)
- Equipment (feeder, pumps, and piping)
- Chemicals

Storage
- Tanks
- Valves
- Piping

Distribution
- Pipelines, valves, and other appurtenances in place
- Pump or pressure-reducing stations
- Materials (extra pipe, valves, hydrants, and so forth)

Electric power
- Substations
- Transmission lines
- Transformers
- Standby generators

Transportation
- Vehicles (including construction equipment)
- Maintenance facilities
- Supplies, parts, and fuel
- Roadway infrastructure

Communications
- Telephone
- Radio
- Telemetry
- Mass media outlets (such as newspaper, radio, and television)

The system components should be described as specifically as possible, as this will make the vulnerability assessment easier. For example, personnel should be grouped according to position, such as managers, engineers, treatment plant operators, field crews, or administrative clerks. System maps or geographic information systems (GIS) files will help with the process, and they should be included with the list. For components with many pieces, as with the distribution system, a more general description accompanied with a detailed map is adequate. Typical items to include in a general description are pressure zones, location of pressure-relief valves, pipe sizes, pipe material and ages, typical distance between hydrants, and major valve locations.

A larger utility may have to divide its system into regions to perform an assessment at an adequate level of detail, but a systemwide assessment should include a combined regional analysis. The example of a vulnerability assessment found at the end of this chapter will elaborate on this step.

STEP TWO: DETERMINE THE EFFECTS OF PROBABLE DISASTER HAZARDS ON SYSTEM COMPONENTS

Disaster hazards can degrade the quality and/or quantity of potable water supplies. Each hazard has particular impacts on different components of the utility, and the damage to one part of the system may or may not affect other parts of the utility. For example, a tornado would not likely rupture pipes underground, but could destroy all the power sources necessary for continuous operation of the water system. A dam break and loss of reservoir water might not destroy pumping stations or disrupt the communications system, but without a source of water, the system could not continue to operate. The following is a case study of the damage from Hurricane Hugo (Buehrer 1989).

Case Study: Charleston Utility Weathers Hugo's Devastation

"We were ready for it—as ready as we could have been—but you can't imagine the magnitude of the disaster here."

That was Steve Kinard's assessment of Hurricane Hugo's devastation and the readiness of the Charleston Commission of Public Works when the storm thrashed the South Carolina seaboard.

Kinard, commission manager, estimated utility damages may total $1 million: "I don't know what the final number will be. We're still counting."

Hugo hit Thursday night, September 21 — 30 years and 2 days since the last major hurricane, Gracie, pelted the Charleston coast

continued next page

Case Study: Charleston Utility Weathers Hugo's Devastation (continued)

John Cook, director of engineering for the commission, said, "We anticipated a power outage, but we didn't anticipate such ferocious winds. The winds stirred up the sedimentation basins so badly that filters in the treatment plant were severely clogged." The stoppage cut off the water supply at about 2 a.m. Friday, September 22, except for gravity-fed supplies. Utility personnel began cleaning filters, and water was restored to some areas by 11 a.m.

Service was then hampered by a tremendous drop in pressure caused by system interruptions when trees were uprooted and debris went flying. "There were broken service lines everywhere, damage to hydrants, and main breaks," Cook said. "A major 40-in. (1,000-mm) main had the end of it blown off."

Sprinkler systems released streams of water in buildings damaged by trees and debris. Demand on the system surged, and pressure dropped below operable levels. There were at least 1,500 service-line and main breaks.

Repair crews worked feverishly to fix breaks and turn off flows to renegade sprinklers. Cook said expedient repairs and a backflow-prevention system, which has been in place for about 10 years, enabled the utility to restore water service to most areas by Friday evening.

The utility's customer service department worked 24 hours a day for a week. Repair crews walked all the water lines in the streets and checked meters and readings of lines beneath rivers and in marshes for leaks and breaks.

The state Department of Health and Environmental Control issued a boil-water order Friday morning, triggered by the drop in pressure. Sampling began throughout the 450-mi^2 (1,200-km^2) system, but no contamination was found. The state rescinded the order by 5 p.m. Monday.

Inundated with repair orders, the utility also began receiving complaints about the water's taste and odor. The cause was finally traced to Hugo's devastation of South Carolina's forests.

The storm ravaged 60–80 percent of the pine trees. Phenols from the felled trees in the Charleston utility's watershed contaminated the groundwater, which flowed into the drainage basin and the treatment plant. Although the water was safe to drink, the contamination caused an objectionable odor and taste. Kinard recalled, "The smell was the talk of the town for several days."

Cook said the initial tests showed about 50–100 mg/L of phenols coming into the plant. "We tried several methods for removing the phenols, but we didn't find anything that did a good job. Toward the end of the week our jar tests revealed the phenols diminished to 30 mg/L. We concluded it was best to let the problem rectify itself, which it did."

Prior to the storm the objective of the commission's hurricane disaster-preparedness plan was to provide uninterrupted service. "We anticipated power outages and installed diesel-driven pumps and generators. We got fuel supplies and additional treatment chemicals, and set up a communications network," Kinard said.

A crew of about 200 staffed the treatment plant, customer service, and repair center. Food, cots, first-aid kits, chain saws, and other supplies were stockpiled at the plant.

The utility evacuated its downtown offices because of hurricane advisories and surge waves predicted in the storm's aftermath. Surge waves peaked at 12 ft (4 m), enough to wreak havoc on the utility's building and much of downtown.

Kinard described the magnitude of the disaster: "It's the worst. You can't imagine the destruction. Every house in Charleston (a city of 1.5 million) has some kind of damage."

Disaster Hazard-Effects Summary

The following paragraphs summarize disaster hazard effects on system components.

Personnel shortages. The most critical component of a system is the trained personnel needed for operations. Any disaster could potentially cause a shortage of employees, either through evacuation, death or injury, or because of personal situations. For example, during Hurricane Andrew, 268 employees of Miami–Dade

Water and Sewer Authority staff (15 percent of the total) had homes that were destroyed or severely damaged. The employees' first responsibility is to their personal safety and wellness and that of their families.

Along with hurricanes, earthquakes can cause the type of widespread damage that can injure or keep large numbers of personnel away from their jobs. Similarly, a chlorine leak could disable all of a plant's operators. A small utility with few employees could conceivably have all of its personnel unavailable for service

Besides a direct impact on employees, a disaster may prevent employees from reporting to work because of damage to the transportation system. Roads can be blocked by fallen trees, downed power lines, collapsed structures, or loss of road surface. An epidemic of flat tires occurred after Hurricane Andrew because of an abundance of nails on the roads. Also, gasoline was in short supply, adding to the transportation problem.

In many disasters, communications are disrupted. Employees cannot contact their supervisors to find out what is required of them. And supervisors cannot contact employees to find out their status. The lack of communication can cause employee shortages.

Contamination of water supplies. Disaster hazards can cause both raw and finished water supplies to be contaminated. In the broadest sense, contamination can be considered as the addition at any point (watershed area, groundwater, surface reservoir, storage tank, or distribution system) of any material that appears in higher than normal concentration or has a high nuisance or harmful effect on the consumer or the system.

When rain falls on the watershed, some of the water will flow overland to the collection point; another portion of the rainfall will pond or soak into the ground. The overland flow will pick up sediment and any other substances, organic or inorganic, toxic or nontoxic. Excessive quantities of sediment entering a reservoir because of a watershed fire, flood, or landslide is contamination in that it will cause undue strain on treatment plant facilities.

The addition of toxic chemicals to a storage tank or reservoir is also contamination, which would require the use of special monitoring and detection equipment as well as the capability of isolating a portion of the system. One of the most likely sources of contamination is the accidental spillage of gasoline, oil, chemicals, or other hazardous materials. Debris or chemicals can be scattered in high winds and contaminate water supplies.

Many disaster hazards cause numerous pipe breaks, which in turn reduce system pressure. Contamination can enter the distribution system through the breaks or through backflow. Likewise, contamination can enter wells if the sanitary seal or casing is broken.

Contamination of air. Disaster hazards cannot only contaminate water supplies but also the air. A release of chlorine is one of the most severe effects and can be deadly. Air can be contaminated from releases of other hazardous materials including radioactive particles. The primary effects of air contamination on water systems are employee shortage and inaccessibility to system components. Civilians in the area are also potentially affected.

Well and pump damage. Wells are susceptible to damage from earthquakes. Well casings can be bent through lateral spreading due to liquefaction (Figure 3-1), making pumps inoperable. Ground shaking can cause sanding problems, particularly in older wells with slotted casings. Connecting pipes can break due to relative movements. Pump or motor castings can shatter from shaking.

Source D B Ballantyne

Figure 3-1 Well casing bent by lateral spreading in Daugpan, Philippines, 1990

Flooding can cause similar problems to earthquakes, such as bent casings, mud in casings, and damaged pumps or piping

Wells can be contaminated from sewage flowing from broken sewer lines or septic tanks.

Pipeline breaks and appurtenance damage. Pipeline breaks deplete supplies and lower system pressure. Widespread pipeline breaks are typical of earthquake damage. Earthquake hazard effects include failure due to

- bending
- shear
- tension
- compression
- collapsed-structure impacts

Pipeline joints are vulnerable, as they are typically weaker than the pipe. Appurtenances such as valves are vulnerable to the same hazards as pipe. Valves can become inoperable when bent

Other hazards that can cause widespread breaks include severe freezing temperatures, structure damage due to hurricanes or tornados, uncontrolled water hammer, or pipes weakened by corrosion. Particularly harmful to systems are breaks in large transmission lines. Piping in structures is at risk when connections are rigid and differential settlement occurs (Figure 3-2).

Structure damage. Water system structures that are vulnerable to disaster hazards include dams, intake facilities, treatment plants, pump stations, administrative