4.1 INTRODUCTION

This chapter presents some observations on the performance of critical facilities during Hurricane Katrina that identify the various ways in which building and equipment damage, as well as loss of municipal services, can disrupt facility operations. These observations are intended to help people who own, operate, design, and build critical facilities to adjust their building designs, construction, and facility management practices to reflect the needs of comprehensive risk reduction.

During Hurricane Katrina, surging floodwaters and high winds caused considerable and often catastrophic building damage, forcing many critical facilities to cease operations and evacuate their premises even before the storm had passed. In many instances the continued operation of hospitals, police and fire stations, schools, and EOCs was severely compromised by relatively minor damage to the building or building-mounted equipment. Although the structural components of most critical facilities survived the hurricane, other building components performed less well, causing serious disruptions.

The observations highlighted in this chapter, made by a team of building professionals (architects and engineers) experienced in hazard mitigation, document the variety and severity of the building damage, and the corresponding effects on facility operations. Field inspections and discussions with facility managers and other personnel served as the basis for analysis of the experiences of individual facilities. The descriptions of these experiences are accompanied with suggestions on possible mitigation measures that would improve hazard-resistance and protect the facility's functionality in the future. A comprehensive risk assessment of the facility's operation and building components and systems would be required before any specific mitigation measures were implemented. This chapter emphasizes the experiences and lessons learned from facility operation disruptions in particular circumstances, and may not be applicable to all situations.

4.2 HEALTH CARE FACILITIES

4.2.1 BACKGROUND

Health care facilities are at the front line of community protection, especially during and after a natural disaster event. Their capacity to continue to provide services to existing patients, and to respond to the needs of victims following a disaster, depends not only on protecting the integrity of the structure and the building envelope, but on the facilities' ability to carry out their intended functions with little or no interruption. Continued and uninterrupted operation of health care facilities, regardless of the nature of the disaster, is one of the most important elements of a natural disaster safety program.

Health care facilities, especially hospitals, are usually very complex building systems, because they accommodate diverse and highly specialized services in a strictly controlled environment. Hospital buildings must be designed to provide appropriate spatial arrangement for the flawless interaction between staff, patients, and visitors. They also require a complex network of technological infrastructure to support the hospital's functions. Even the smallest breakdown in this complex network can cascade into a serious disruption of operations.

Protecting the functionality of a hospital requires very careful facility planning and design that is in accordance with the most stringent flooding and high-wind mitigation requirements applicable to the site. The damage sustained by hospitals during

Hurricane Katrina emphasized the fact that many of the Nation's hospitals occupy old or inadequate buildings that may not be sufficiently protected against hazards. In particular, some of the hospitals were planned and built before mitigation against natural hazards became common practice.

Considering the expanding gap between the functionality of aging hospitals on the one side, and the requirements of new technologies and the needs of a growing and aging population on the other, it is expected that many of the country's hospitals will have to be replaced, upgraded, or rebuilt in the coming years. Some medical industry forecasts predict that by the end of the decade the United States will spend $20 billion annually for this purpose. Since new or rebuilt hospitals will have to last for a long time, the anticipated construction program provides an opportunity to rethink hospital planning and design, and to consider how to avoid hazard areas and reduce the vulnerability with improved hospital design.

The following observations are based on published sources at the time of Hurricane Katrina, and on the subsequent interviews with providers and regulators in both Louisiana and Mississippi. The damage assessments present a picture of common effects on the medical facilities, which are consistent across the region affected by Hurricane Katrina. Generous contributions by the following institutions and their staff are acknowledged:

- St. Tammany Parish Office of Homeland Security and Emergency Preparedness (Covington, Louisiana)
- Touro Infirmary (New Orleans, Louisiana)
- West Jefferson Medical Center (Jefferson Parish, Louisiana)
- Hancock Medical Center (Bay St. Louis, Mississippi)
- Garden Park Medical Center (Gulfport, Mississippi)
- Guest House of Slidell (Slidell, Louisiana)
- Slidell Memorial Hospital (Slidell, Louisiana)

- LSU Health Sciences Center (New Orleans, Louisiana)
- Charity Hospital (New Orleans, Louisiana)
- University Hospital (New Orleans, Louisiana)

4.2.2 EFFECTS OF FLOODING

The damage caused by Hurricane Katrina flooding was significantly more serious than the damage caused by wind. Along the Gulf Coast, the storm surge was higher than previously experienced, which caught many health care providers by surprise (see Figure 1-2). In most places, the storm surge flooding receded in several hours, but in New Orleans the floodwaters remained for more than a week. Apart from the damage and disruption caused by floodwaters that penetrated the facilities' lower levels, many hospitals in New Orleans were completely surrounded by floodwaters, which cut off all surface access.

As a result of the disrupted access, most hospitals had to manage on their own, without any assistance from the outside. Patients and visitors were stranded, along with staff that could not be relieved for days. The injured, and others in need of emergency care, could not be brought in for treatment. Family and friends of people stranded in the hospitals had no way of communicating with them. Food, water, medical, and other supplies could not be brought in except by small boats and helicopters, or in some instances, by military vehicles. The evacuation of the critically ill patients, and eventually others, was possible only by boat or by helicopter. Hospitals with dedicated or improvised elevated helipads managed the evacuation much better than others.

Hospitals and nursing homes that were inundated during Katrina experienced the greatest damage. Hospital functions located in the areas exposed to floodwaters had to be shut down. In many cases, the elevators and other mechanical and electrical services were shut down by the floodwaters.

Flooding caused considerable disruption of utility services in most hospitals in the New Orleans area. Sewers flooded or pumping stations shorted out, disabling sewage and liquid waste disposal.

The water supply was interrupted and, in many instances, onsite sources were contaminated and could not be used for drinking purposes. Emergency generators and electrical switchgear equipment, as well as underground transformers flooded and were put out of commission.

In several instances, communications panels and other controls were located on the first floor and shorted out. The heat and the buildup of humidity in New Orleans ruined the telephone connections and the fire alarm systems in some hospitals, even though floodwaters did not contact sensitive communications equipment directly.

4.2.3 EFFECTS OF HIGH WINDS

In general, three types of wind damage affected the hospitals: damaged roof coverings, rooftop equipment, and window breakage. Damaged roof coverings that were either peeled off or punctured by wind-borne debris exposed the interior to rainwater penetration and additional damage. Similarly, rooftop equipment displaced by wind left unprotected roof openings exposed to rainwater penetration. Water damage ranged from saturation of interior surfaces, like walls and ceilings, to ruined equipment and considerable mold growth.

Window breakage during the storm was particularly dangerous, because it allowed the penetration of rainwater, and wind that can cause pressurization in the interior. Hospital patient rooms, however, faced the greatest risks from window breakage, because many of their occupants could not be moved away from monitors, medical gases, and other equipment.

4.2.4 SITE DESIGN

Although most of New Orleans is located in the lowlands that are protected by a system of canals and levees, the hospitals were not built to resist the flooding caused by levee failures. As a result of Hurricane Katrina and the failure of levees, only 3 out of more than 20 of the city's hospitals remained open during the storm (see Figure 4-1). Only one of these, the Touro Infirmary, was not completely surrounded by water, retaining access on one side. Access problems affected all hospitals. West Jefferson Medical Center had planned to deploy their staff in two shifts, to allow the second shift to stay at home until the storm had passed and then come to relieve the staff locked down in the hospital. Because of impeded access, the relief staff could not get to the hospital, which put an added burden on the initial staff, already nearing exhaustion.

Figure 4-1: University Hospital surrounded by 4 feet of water

Figure 4-2: Evacuation of New Orleans by helicopter

Hancock Medical Center in Bay St. Louis, Mississippi, although located outside of the 500-year floodplain, experienced 3-foot deep flooding as a result of the storm surge (see Figure 4-3). Access to the hospital was disrupted long before Katrina made landfall because, prior to the storm arrival, there was a 33-mile traffic backup on the road leading out of town. Access was important because all the functioning hospitals needed relief supplies, medical gases, water, and fuel for their emergency generators. In many cases, the only way to resupply the facilities was by air, using large Chinook helicopters. These helicopters are too heavy for most roof structures, and to use them for emergencies in the future, a second helipad may be necessary on the site, requiring sufficient glide angles for landing and takeoff of the largest aircraft.

Access to emergency services was also blocked by the water and, in some cases, by trees and utility lines that were knocked down. Once the hospitals had access restored, they were deluged by the injured from nearby communities. Slidell Memorial Hospital administered 40,000 tetanus shots in the days after the storm. Hancock Medical Center saw 600 to 700 patients a day for up to 2 weeks after the surge water receded.

Figure 4-3:
The lobby of Hancock Medical Center was under 3 feet of water.

Perhaps the most serious consequence of the impeded access was the way it affected the evacuation of hospitals in New Orleans. Serious disruptions in hospital operations required immediate evacuation, which could not take place because the streets were not accessible for up to 5 days. There was a critical need for a helipad, either on the roof or an equivalent landing area on a parking structure, with emergency lighting for night operation. Elevated parking structures were a great asset, providing both a protection for the vehicles and a convenient helicopter landing site on the roof. They were especially useful if the parking structure had an elevated pedestrian bridge to the hospital.

4.2.5 ARCHITECTURAL DESIGN

A typical hospital configuration is based on access requirements that usually place the emergency department on the first floor in order to receive walk-in patients or those brought in by ambulances. Clinical laboratory and imaging are frequently on the first floor as well, as are surgery and intensive care units in many smaller hospitals. All of these are vital services in the event of an emergency and for providing routine patient care. Location on the first floor frequently exposes them to additional risks from natural hazards, especially flooding, as became evident during Hurricane Katrina.

Building configuration and general shape frequently contribute to high-wind damage. Protrusions and projections in walls and roofs cause additional wind turbulence that increases uplift pressures. The penthouse at West Jefferson Medical Center illustrates the vulnerability of projections and corners to high winds (see Figure 4-4). Large portions of metal cladding came loose because they were not designed or constructed to resist these loads.

Canopies, which most hospitals have over drop-off areas, are particularly susceptible to uplift and other damage, if not designed to resist the loads (see Figure 4-5). Glass-enclosed lobbies and atria, common to many hospitals, also proved to be a hazard, because of the large areas of usually unprotected glazing that could easily shatter under the impact of wind-borne debris. In many cases, these areas were closed during the storm, thereby cutting off a major point of access to the hospitals.

Figure 4-4:
Penthouse at the West Jefferson Medical Center

Figure 4-5:
Canopy soffit damage at West Jefferson Medical Center

At Louisiana State University Hospital, the emergency generators in the basement were flooded and shut down, which put the entire hospital out of commission. Similarly, all the major mechanical equipment in Charity Hospital in New Orleans was in the basement, including fifteen 5,000-watt emergency generators. The hospital had to be evacuated soon after the basement flooded and the emergency power supply failed. Touro Infirmary, however, had the emergency power generators located on the third floor. This allowed them to run most of the critical systems, including the air conditioning, without interruption until the generators broke down from prolonged use and contaminated fuel supplies.

Critical operations such as emergency and surgical departments, recovery rooms, ICUs, and other patient bed units and laboratories should not be located in areas below ground or below the elevation of possible flooding and storm surge. These critical functions should be located on upper floors or in areas where communication between floors is easily accomplished. These areas should have no windows, or should have protected glazing to prevent window breakage and rain water penetration.

4.2.6 BUILDING ENVELOPE

Building envelope damage during Hurricane Katrina was widespread and included uplifted roof coverings and flashing, roofing punctured by flying debris or overturned roof-mounted equipment that led to extensive rainwater penetration, wall cladding separation, and window and door breakage.

The building envelope on the Garden Park Medical Center in Gulfport, a relatively new building opened in 2000, sustained considerable damage from 130-mph winds during Hurricane Katrina. The estimated wind speed may appear to have been close to the current design wind speed of 135 mph for this facility, but the actual pressures were below the current design pressures as a result of the 1.15 importance factor required for hospitals. Wall cladding consisting of EIFS was blown off in several areas, allowing water to penetrate wall cavities (see Figure 4-6). Extensive use of EIFS, despite a long track record of failure during hurricanes, contributed to significant damage from water penetration. EIFS is a popular wall cladding system, but not strong enough to prevent damage from wind-borne debris in cases where EIFS is applied over studs. In addition, EIFS design or construction deficiencies frequently make it insufficiently resistant to suction pressures caused by high winds. This is especially significant for hospitals, where such damage can allow water penetration and trigger serious disruptions in the mechanical and electrical systems and damage the building interior. Hospitals in hurricane-prone regions that have EIFS should have field testing performed to evaluate its attachment.

Figure 4-6:
Repair of EIFS wall covering on Garden Park Medical Center

Hancock Medical Center suffered damage to the wall sheathing behind the exterior brick veneer. This damage resulted from standing water at significant depths in various locations around the building. The sheathing retained moisture long enough to compromise its integrity through swelling, and to support the growth of mold and bacteria. There have been numerous examples of the failure of brick veneer. The reasons for this include corroded brick metal ties, insufficient number of metal ties installed, or ties not adequately embedded in the mortar.

Many hospitals have low-slope roofs. There have been many instances of failure of this type of roof, frequently beginning at the edge flashing and progressively spreading to other parts of the roof. Roofs are also susceptible to puncture, as happened at the Hancock Medical Center and Garden Park Medical Center (see Figure 4-7). Rubber walkway pads were blown away and the roof membrane was punctured in several places by displaced equipment and other flying debris. As a result, a substantial amount of water leaked through the roof openings into the top floor, causing considerable damage to the interior. In addition, the aggregate surfacing blew off, damaging glazing on surrounding buildings.

Figure 4-7:
Roof membrane starting to peel off at Hancock Medical Center.

Hancock Medical Center lost substantial portions of its metal roofing. Patients had to be relocated from the top floor to lower floors because of roof leakage (see Figure 4-8). West Jefferson Medical Center lost portions of roofing on the Psychiatry building, when the metal roof covering partially peeled off. The leading edge began to peel back, but did not go any further than the edge flashing, so a minimal amount of water penetrated through the roof. The psychiatry building was not occupied at the time because the hospital evacuated the building before the hurricane landfall.

Figure 4-8:
Roof damage on Hancock Medical Center

The primary cause of window breakage was wind-borne debris. (see Figure 4-9). West Jefferson Medical Center had 76 windows broken, mainly by flying aggregate. Intensive care patients had to be moved to the recovery room in the interior of the building and away from windows. The Psychiatry building had rainwater penetration through windows, even though they were not broken.

Although many important hospital functions are located away from the exterior windows, wind-blown rain can damage expensive equipment even when it is located some distance from the broken window (see Figure 4-10). At West Jefferson Medical Center, the fitness center building sustained $250,000 worth of damage that resulted from water driven through the broken windows and from 30 days of high humidity, before the air-conditioning was restored.

Exterior doors were often pushed in by floodwaters and blown open and damaged by wind pressure. Breakaway doors are particularly vulnerable to opening in high-wind conditions, as wind pressure can build up through the unsecured doors. Ground floor entrance doors at Hancock Medical Center had to be blocked by sandbags and two-by-fours, both on the inside and the outside, to stay closed (see Figure 4-11). The penthouse door at Garden Park Medical Center in Gulfport was blown off its hinges by strong winds.

Figure 4-9:
Broken windows at Touro Infirmary

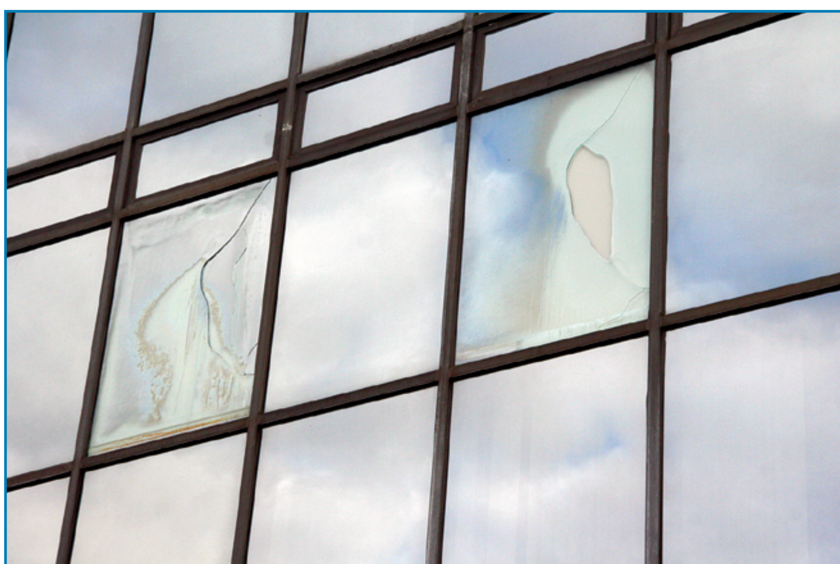

Figure 4-10:
Broken windows at West Jefferson Medical Center

Figure 4-11:
Blocked doors at Hancock Medical Center

Hancock Medical Center lost numerous fan cowlings and other rooftop equipment, which left openings in the roof. Water penetrated the building through these openings, reaching the first floor, and damaged boilers and other equipment. Vent openings in the elevator penthouse in Touro Infirmary were blown off, allowing water penetration. The water damaged the electrical and mechanical equipment and controllers, shutting down the elevators.

West Jefferson Medical Center lost a number of cowlings and other covers causing water damage to equipment in the rooms below the roof. Some motors were sealed and continued to work during the storm.

All rooftop equipment should be safely secured to the curb and stay in place during a high-wind event. Equipment that has a high failure rate in high-wind events includes air-conditioning condensers, HVAC units, exhaust fans and air intake and exhausts.

4.2.7 UTILITY PLUMBING SYSTEMS

Hospitals depend heavily on municipal services and other utilities. While it is possible to go into a minimal function mode and still maintain patient safety, certain utility systems must be operable. In many cases, Hurricane Katrina and the subsequent flooding pushed hospitals beyond the limits of even a minimal function mode. Many had to be shut down, and the patients and staff had to be evacuated. In addition to the loss of electrical power, the most common problem in maintaining the operations proved to be the failure of water supply and sewer systems.

Most hospitals lost water within a day or two following Hurricane Katrina's landfall. Even when the water service was restored, it was suspected of contamination. Drinking water was in short supply in many hospitals. West Jefferson Medical Center received three truck loads of bottled water from a local retailer in the aftermath of the storm, but other hospitals suffered from serious shortages. A running water supply is critical for boilers to produce steam for sterilizing; for the chillers for the air-conditioning system; and for sanitary uses like toilets, washing dishes and linens, bathing patients, etc. The most successful hospitals had their own wells from which they pumped water using an emergency power supply. The hospitals that stayed without water and an emergency power supply had to evacuate patients as quickly as possible. As a consequence of this experience, West Jefferson Medical Center is planning to install two wells to provide both sufficient capacity and redundancy. One well will service the central plant boilers and chillers, and the other will be dedicated to hospital operations.

Potable water service will likely be shut down during and immediately after an event because of line breakages, lack of power to run pumping stations, or repair delays because of blocked roads and access routes. Hospitals, especially those in hurricane-prone regions, need a back-up water supply system in the form of:

- Wells for exclusive hospital use should be supplied with their own emergency generator to run the well pumps.
- Water storage or water recycling systems on site should serve as a back-up to the central water supply.

In many areas, the sewer system broke down shortly after the storm arrived, either because of loss of power required to run municipal pumping stations, sewage back-up or shut down of sewage treatment plants as a result of flooding, or because uprooted trees broke the sewer lines. When the water and sanitary waste systems were disabled, patients and staff were required to use hazardous waste bags (red bags) taped to buckets or toilet bowls to manage bodily waste. At West Jefferson Medical Center, used bags were stored in the hallways for several days and then buried on the hospital site for later disposal.

Hospital design in hurricane-prone regions should also take into consideration the need to provide an onsite sewage-diversion and storage system to prevent sewer backflows from disrupting hospital sanitary system operations. Field observations indicate that in situations where the sanitary sewer system may be damaged, causing a disruption in service, functionality may be protected by:

- Installation of an onsite septic tank as a sanitary back-up system
- Installation of backflow devices in the sanitary lines to prevent sewage from backing up into the hospital
- Designating, as part of the operations plan, a limited number of sanitary systems to use in the hospital, so the onsite storage tank does not fill too quickly
- Creating holding ponds for direct pumping of sewage, if sufficient site area is available

4.2.8 MECHANICAL AND ELECTRICAL SYSTEMS

Hurricane Katrina struck at a time when the temperatures during the daytime reached 95°F. Air-conditioning systems in hospitals were generally not connected to the emergency power supply, nor was there any flexibility to switch emergency power from one system to another to provide some relief. The heat build-up was a significant factor in creating difficult conditions for patients and staff (see Figure 4-12).

Lack of air-conditioning also allowed humidity to build up, which caused problems with switchgear, computers, and other electronic equipment. In many cases dehumidifying and cooling could not resume for months after the event. The excessive humidity damaged the electronic components of mechanical and electrical equipment, such as fire alarm systems, elevator switchgear, or the telephone switchgear, as happened in Touro Infirmary. Mold growth in conditions of high temperatures and humidity caused further damage. At West Jefferson Medical Center, rainwater and high humidity caused considerable damage to the fitness center, requiring all the electrical equipment to be replaced. The ground floor at Hancock Medical Center was flooded 3 feet deep; enough to cover all electrical outlets close to the floor. The damage was irreparable.

Figure 4-12:
Toppled HVAC equipment at Charity Hospital, New Orleans

Air-conditioning systems were also disrupted by a lack of water needed for water-cooled chillers, as happened in Garden Park Medical Center in Gulfport when the municipal water service was shut down. Loss of air-conditioning resulted in interior condensation, and warm and humid air interfered with the normal functioning of electronic medical equipment.

Measures to provide sufficient HVAC capacity for patient-occupied and support areas and to protect the operation of the hospital from humidity-related damages include the following:

- Install emergency electrical generators with capacity to run the air conditioning system. This might also require water for the chillers if this is the method of delivering cold air.

- Install sufficient controls in the hospital to be able to identify the areas with mold and mildew problems, and have them cordoned off quickly.

- Install HVAC duct cleanout locations, so that any mold or mildew that begins to grow in the ductwork can be easily cleaned out.

- Create air-conditioning zones (where practical), so that crucial operations can be cooled with a minimum amount of air-conditioning.

In a storm of Katrina's magnitude, it is expected that power would be lost almost immediately and for a considerable period of time thereafter. For example, Touro Infirmary lost power within minutes of being hit with wind gusts of about 60 mph. Since power is so vital to maintaining functionality in critical facilities during normal periods, it is of paramount importance to provide an emergency power supply for all critical hospital functions.

Most hospitals store up to 72 hours of emergency fuel on site. In the case of Hurricane Katrina, emergency generators needed to run continuously for 5 days or more. Many hospitals had to obtain fuel for their generators from outside sources, usually the military. West Jefferson Medical Center got fuel from a nearby Navy ship. Hancock Medical Center had one of their underground emergency generator fuel tanks flooded, with water covering the fill cap and all vent openings. They could not use this tank, fearing that contaminated fuel would damage the power generators.

The capability to switch power to different locations at different points in time is one of the most important features of emergency power supply systems. However, most of the wiring systems in facilities affected by Hurricane Katrina were not set up with this capability. Emergency power in most cases was not available to run the air-conditioning systems. Redundancy in the emergency power systems that would have allowed maintenance and repair without disruption was lacking in most cases.

Portable generators, where they existed, were invaluable. They could be moved around as needed, but the problem of outside ventilation was difficult to overcome when the power was required away from vent openings. Use of generators indoors is extremely dangerous and should not be attempted in any circumstances.

More and more hospitals are dependent on computerized systems for patient medical records, transmission of X-ray film and other images, reporting laboratory results, patient physiological monitors, and a myriad of other uses. Once the power is lost, these systems are shut down unless they are on emergency power.

Piped oxygen and nitrous oxide supplies are essential for many patients. With electrical systems out, pumping of medical gas was not possible. Most of the hospitals maintained tanks of oxygen that could be brought to the bedside (Figure 4-13), but once the emergency supplies of medical gas ran out, the patients at serious risk had to be evacuated.

The experience of hospitals during Katrina indicates that the requirements for emergency power should have high priority. Generators should be located above the base flood elevation, be protected from flying debris, and have appropriate exhaust vent systems installed. Fuel storage tanks should be located above the flood elevation, or adequately anchored to ensure that the tank will not float off its foundation under pressure from rising floodwaters. Hospitals in hurricane-prone regions should store sufficient fuel to support running generators at full load for at least 96 hours (4 days). Emergency power distribution systems should be able to provide power to every system in the hospital, and have switching capabilities to shift loads to different parts of the hospital as needed.

Figure 4-13:
Oxygen supplies at Hancock Medical Center

4.2.10 COMMUNICATIONS SYSTEMS

Hospitals have a variety of communications systems in addition to the usual telephone and e-mail systems. Many of these are for emergency communications with ambulances and other emergency support services. These include satellite telephones, government line telephones, ham radios, internal radio systems, nurses' call systems, and wireless systems of various sorts. Communications systems are critical for medical uses, but during a storm like Katrina, the ability to contact family members and friends to check on their status meant a lot to both the staff and the patients. The importance of being able to get news from outside, to request restocking of supplies, and to arrange evacuation of patients became obvious in the aftermath of Katrina.

One consistent theme in damage reports was that satellite dishes were toppled, rendering satellite phones, one of the main sources of emergency communications, inoperable. Antennae used for emergency communications frequently broke, disconnecting the hospital systems from the outside world. Hancock Medical Center lost not only the satellite dish, but also the dish for the education system and its television antennae. West Jefferson Medical Center lost only one antenna.

External communication isn't the only important link that can be broken during a hurricane. Internal communications (for example, from surgery to the nursing floor, or from the nursing floor to the supply storage areas) are critical to maintain functionality.

At Hancock Medical Center, the only means for internal communications were 5-Watt Motorola radios. These continued to work well, and were relied upon exclusively when the telephone switchgear flooded and broke down. West Jefferson Medical Center also used radio communication that continued to work throughout the storm. Cellular phones also worked, until the transmission tower was toppled. Hospitals that had ham radio operators bring their equipment in, or had a ham radio set-up in the hospital, found this system very important and useful. Several hospitals plan to have ham radios available for future emergencies.

Charity Hospital and West Jefferson Medical Center lost their computers because the computer network power supplies were not wired into the emergency power supply grid. John Hancock Medical Center also lost its computers when the ground floor flooded (see Figure 4-14).

Since many communication systems are dependent on external networks that may be out of commission, roof antennae should be well anchored, or mounted inside of penthouses. Satellite dish antennae may have to be taken down prior to a hurricane and put back after the storm had passed. Finally, redundancy of systems is important, as proven during Katrina—one system may work where others do not.

Figure 4-14: Damaged computer network equipment at Hancock Medical Center

4.2.11 NONSTRUCTURAL AND OTHER SYSTEMS

Nonstructural systems, among others, include interior non-load-bearing walls, ceilings, and floors. In hospitals flooded with storm surge, floors were destroyed and gypsum board walls were soaked. At Hancock Medical Center the water level reached 3 feet. The hospital must replace all the flooring material, rewire the outlets, and replace the wall sheathing at a level about 2 feet above the high water mark (see Figure 4-15).

In many hospitals humidity buildup damaged floor and ceiling tiles. Touro Infirmary had to replace 60,000 square feet of tile flooring and all of the ceiling tiles in the hospital because of humidity damage. The loss of air-conditioning at West Jefferson Medical Center caused the buildup of humidity in the air, leading to water condensation on terrazzo floors, making them very slippery.

Security was a major issue for most New Orleans hospitals. Members of the community naturally sought the hospital for shelter when their homes were destroyed. When the water rose, people trapped in the city followed the water's edge to the Touro Infirmary and West Jefferson Medical Center, where crowds of people congregated on the front doorsteps. Attempted break-ins and looting were reported, which prompted hospitals to barricade doors, post armed guards at entrances, and "lock down" so that no one could either enter or leave. At University Hospital, the doors were removed and the entrances sealed up.

Hospitals that allowed families to come in with the staff for the duration of the storm encountered numerous problems after a few days. Many of the family members became restless because hospitals had no appropriate accommodations for them. This became a security problem, as it was important to keep guests away from the patients and their caregivers.

Figure 4-15:
Drying of flooded ground floor at Hancock Medical Center

Fire safety should be a concern during a storm since the fire risks are usually greater than at other times. Although the fire alarms are normally connected to emergency power, other types of damage made them inoperable. At Touro Infirmary, the build-up of humidity knocked out the electronic components of the fire alarm system. After the storm, 470 points needed to be repaired before the system was fully operational again. At West Jefferson Medical Center, the fire alarm system was undamaged, but the line to the fire station was cut. Heat-activated fire suppression systems continued to function where sufficient water pressure was available, but dry standpipes might not have been supplied with water in the event of a fire. Directional signs in many hospitals were blown away. In the rush for care after the hospitals were accessible, it was necessary to put up temporary signage to route the large volume of visitors and patients to the right destination.

4.2.12 SUMMARY

The General Accounting Office (GAO) report to Congress on the evacuation of hospitals and nursing homes noted that administrators should "consider several issues when deciding to evacuate or to shelter in place, including the availability of adequate resources to shelter in place, the risks to patients in deciding when to evacuate, the availability of transportation to move patients and of receiving facilities to accept patients, and the destruction of the facility's or community's infrastructure." For new facilities, most of these issues can and should be addressed during site selection, risk assessment, and application of the appropriate planning and design recommendations described in this manual. For existing facilities, careful evaluation and consideration of the recommendations provided in this manual should help ensure greater resilience during flooding and high-wind hazard events. In this way, communities can continue to depend on these facilities both for the care of existing patients and the care of people in disaster emergencies.

4.3 EDUCATIONAL FACILITIES

4.3.1 BACKGROUND

Educational facilities are considered critical facilities because, apart from their vital role in educating children, they are frequently used during and after a storm as emergency shelters, or as staging centers by the National Guard, law enforcement personnel, or critical infrastructure repair crews for emergency operations. Educational facilities, in this case mostly K-12 school buildings, are generally equipped with food preparation facilities, well distributed sanitary facilities, and ample space for personnel and equipment.

The primary function of a place of refuge shelter is the protection of the occupants during a storm. This function is dependent on preservation of the structural integrity of the building and the building envelope. The failure of a structural component or a breach in the building envelope can lead to casualties and can make the buildings unusable as a recovery shelter after the storm.

Educational facilities planned for use as place of refuge shelters must, above all, protect the lives and well-being of evacuees. To do so, they must be constructed to withstand storm surge or inland flooding and wind impact. This means that they must be located in areas that minimize these storm effects. If they are located in the areas subject to flooding and high-wind hazards, they need to be constructed to preserve full functionality, with uninterrupted electricity, communications, water, and sanitary service. This will also allow them to serve as recovery shelters. Educational facilities that may not have served as shelters during the storm, because of their proximity to the coast or their susceptibility to inland flooding, may be useful as recovery shelters provided they are able to survive the hurricane intact.

The primary function of a recovery shelter is to provide a location for resources and manpower after the storm has passed, to centralize the command and distribution functions for recovery work in the community. Recovery shelters require that all building functions and services remain usable in the aftermath of a storm. They are often used by the American Red Cross (ARC), National Guard, or other government agencies as a distribution point of first aid, food, water, and other supplies. They also serve as management or information dissemination hubs concerning recovery efforts.

The following facilities were visited for the preparation of this manual:

- Charles P. Murphy Elementary School (Pearlington, Mississippi)
- Pass Christian Middle School (Pass Christian, Mississippi)
- St. Stanislaus High School (Bay St. Louis, Mississippi)
- Northbay Elementary School (Bay St. Louis, Mississippi)
- Hancock High School (Kiln, Mississippi)
- Pineville Elementary School (Pass Christian, Mississippi)
- D'Iberville High School (D'Iberville, Mississippi)
- D'Iberville Middle School (D'Iberville, Mississippi)
- Lyman Elementary School (Gulfport, Mississippi)
- East Hancock Elementary School (Hancock County, Mississippi)
- Saucier Elementary School (Saucier, Mississippi)
- Port Sulpher School (Port Sulpher, Louisiana)

4.3.2 EFFECTS OF FLOODING

The most devastating damage to educational facilities during Hurricane Katrina was caused by the storm surge. FEMA reported a storm surge of 20 to 30 feet above normal tide levels. In some places the flooding extended up to 6 miles inland. The effect on coastal communities was catastrophic, because most buildings within a quarter of a mile of the shore were virtually washed away, while most of the remaining buildings beyond this area were severely damaged. Virtually all of the educational facilities in Pass Christian, Mississippi, were heavily damaged as a result of their proximity to the coastline.

Inland flooding occurred in low-lying areas farther away from the coastline. D'Iberville Middle School had approximately 8 feet of water, but was not used as a shelter because the school district staff was aware of the potential for flooding from past experience. The structural integrity of the school was not compromised by the flooding, but the water damage to the interior was substantial (see Figure 4-16).

Figure 4-16:
D'Iberville Middle School was flooded to the depth of 8 feet

The experience of Hurricane Katrina shows that the damage caused by rising water generally renders shelters uninhabitable and useless, further aggravating the recovery process. In most cases the mechanical and electrical systems were disabled as a result of flooding, which allowed the internal temperatures to reach intolerable levels. Additionally, the flood-induced back-flow of plumbing systems created unsafe sanitary conditions in most of the facilities.

4.3.3 EFFECTS OF HIGH WINDS

Hurricane Katrina reached maximum gust wind speeds of 130 mph at landfall, with hurricane force winds extending outward 105 miles from the center of the storm (FEMA, 2006). Numerous tornadoes were also spawned by the hurricane, contributing to further damage as the storm moved northward. There were 11 tornadoes recorded in Mississippi, with 17 more in Georgia, and 4 in Alabama. Current model building codes in the areas affected by Hurricane Katrina generally require buildings to be designed to meet 120 to 150 mph design wind speeds. Some buildings, however, were constructed prior to the implementation and enforcement of the current model codes.

Wind damage was most evident on the building envelope, especially roofs, walls, doors, and windows, as well as other exterior elements, such as walkway canopies and exposed mechanical and electrical equipment. The extent of the damage was dependent on the force of the wind, the type of construction, and the configuration of the buildings. Once a building envelope was breached, the interior of the building sustained additional damage, both as a result of pressurization and rainwater penetration. The most severe damage in the interior was observed on the least durable finishes, such as acoustical ceilings, wood doors and trim, and building contents such as office equipment, furniture, and books.

Most of the educational facilities used as place of refuge shelters suffered wind damage to the roofs and windows. When a portion of the roof was lost or a window was broken, rainwater was able to enter the building, causing damage to the interior. In some instances, the occupants were forced to relocate to other buildings during the storm, because of the danger of progressive building failure (see Figure 4-17).

Figure 4-17:
Broken windows at
D'Iberville High School

4.3.4 SITE SELECTION

Most educational facilities that were destroyed or severely damaged by Katrina were located in the areas subject to storm surge flooding. Ideally, educational facilities used as shelters should not be located in floodplains, but since they must be located in proximity to the neighborhoods they serve, some are built on flood-prone sites. Even if buildings can be elevated to reduce the potential for damage, the surrounding area remains susceptible to flooding, which could prevent access and disrupt the delivery of emergency aid. This also underscores the need to provide multiple routes to and from a facility, in case of roadway blockage following a storm.

Pineville Elementary School near Pass Christian, Mississippi, was used as a place of refuge during the storm, but when the water rose to a depth of 2 feet, the people had to be moved by school buses to another shelter (see Figure 4-18). The buses were driven by school bus mechanics struggling to maintain control in rising water and 80 mph winds.

The schools in Pass Christian—mostly one-story buildings located in mapped flood hazard areas—sustained heavy damage from storm surge flooding. The massive storm surge devastated parts of Northbay Elementary School in Bay St. Louis, Mississippi, a single-story building located in a mapped flood zone. Exterior walls collapsed, and most of the interior and contents were destroyed (see Figure 4-19).

Figure 4-18: Pineville Elementary School shelter had to be evacuated when the floodwaters started to rise.

Figure 4-19: Exterior walls at Northbay Elementary School

St. Stanislaus High School in Bay St. Louis, although located right on the coast, was on naturally higher ground, and only the first floors were affected by the storm surge. Within a few months after the storm, the second floors in some of the buildings had been repaired, including restored power, water, and sanitary service, and were back in use (see Figure 4-20).

Figure 4-20:
Lower floors washed away by the storm surge at St. Stanislaus campus

Considerable damage occurred in low-lying areas that were flooded by storm surge ranging in depth from 2 to 8 feet. Such was the case at D'Iberville Middle School in D'Iberville, Mississippi, which sustained severe damage, including the destruction of many exterior walls, when water rose to nearly 8 feet above the floor. Fortunately, it was not used as a shelter, unlike the nearby D'Iberville High School, which is a designated shelter. The high school is built on higher ground and was not affected by flooding.

4.3.5 ARCHITECTURAL DESIGN

Generally, educational facilities have centrally located corridors (with classrooms or other spaces on both sides) that have ready access to sanitary facilities, are at least 8 to 10 feet wide, and are free of all obstructions. These features make them ideally suited for emergency shelter use. Although there are a few exterior openings that can be breached by a storm, the hallways are generally well protected from outside elements. It should be pointed out, however, that in situations where the roof or the exterior walls fall, interior corridor walls may collapse as well. The corridors are usually unfurnished and readily available for a variety of functions. They served well as safe areas during the storm, with only a few notable exceptions. At the D'Iberville High School, the corridors had unprotected windows at each end. These windows were broken during the storm and it was necessary to move people into another building. Unfortunately, there were no enclosed walkways or interior corridors connecting the buildings, and it was necessary to go outside into the storm to reach the other building. Similarly, when the roof structure at Lyman Elementary School shelter started to fail, it became necessary to take the refugees outside before they could reach safety in another building (see Figure 4-21).

For hurricane shelter safety, it would be beneficial to have all of the buildings connected with enclosed corridors, to allow safer movement between buildings during a storm. Other components of the building envelope would have to be sufficiently resistant to wind and wind-borne debris impact to protect the occupants and the services they need. School corridors in particular should either have impact-resistant (or protected) windows or none at all. All exterior doors should also be designed to meet hurricane wind loads and wind-borne debris impact requirements, as described in Section 3.4.3.1).

Figure 4-21:
Collapsed portion of the Lyman Elementary School Building

4.3.6 STRUCTURAL SYSTEMS

Most of the educational facilities observed were one-story buildings with concrete slab-on-grade foundations constructed using concrete masonry load-bearing walls and steel-framed roofs. The roof joists were supported either by masonry walls or steel beams. Some facilities, like the East Hancock Elementary School, used pre-engineered systems consisting of rigid steel frames supporting a standing seam metal roof. Pass Christian Middle School and Saucier Elementary School used structural steel frames with standing seam or built up roofs. St. Stanislaus High School, located on the coast, had a concrete structural frame where the first floor was heavily damaged by the storm surge, but the foundations, concrete structure, and the upper floors survived. This was because the buildings on campus were located on higher ground than the surrounding area.

The storm surge exerted tremendous forces on the buildings in its path, first as the water rose, and again when it receded. The forces were strong enough to knock down exterior masonry walls, as happened in the Northbay, Charles B. Murphy, Pass Christian, and Plaquemines Parish schools (see Figure 4-22). In most cases, the main structural components survived with little or no damage.

Figure 4-22: Damaged exterior walls at Charles B. Murphy Elementary School

Designing the connections between structural components according to loads is critical to maintaining the load path and the structural integrity of school buildings in hurricane-prone regions.

4.3.7 BUILDING ENVELOPE

Newer educational facilities located some distance from the coast sustained mainly wind-induced damage to the building envelope, primarily to roof coverings and windows. Facilities located along the coastline were hit by the storm surge that destroyed most of the building envelope on the ground floor, including large sections of exterior walls. The walls collapsed under flood loads that exceeded all expectations.

At Charles P. Murphy Elementary School, many of the infill masonry walls were displaced, and the concrete slabs on grade were uplifted and severely cracked in several classrooms (see Figure 4-23). A similar slab failure also occurred at D'Iberville Middle School. The cause of this type of failure was an increase in upward hydrostatic pressure below the slab, causing it to burst upward.

Figure 4-23:
Cracked concrete floor slab at Charles B. Murphy Elementary School

The St. Stanislaus High School campus consists of several buildings that used different exterior wall systems, including masonry and precast concrete panels. The masonry walls on the first floor were heavily damaged by the storm surge, but it appears that the precast concrete panels withstood the force of the hurricane much better (see Figure 4-24). Large sections of the exterior masonry walls at St. Stanislaus, as well as in Northbay Elementary in Bay St Louis and Port Sulphur schools in Plaquemines Parish, collapsed under the pressure from storm surge (see Figure 4-25).

Figure 4-24:
Precast concrete paneling at St. Stanislaus High School

Figure 4-25:
Collapsed exterior masonry wall at Port Sulphur school campus

The exterior brick veneer walls at the Pass Christian Middle School and at St. Stanislaus cracked and separated from the wall framing under the impact of storm surge (see Figure 4-26). This kind of damage usually results from a failure of brick ties that did not manage to hold the brick in place. In many cases these attachments can corrode and allow the brick veneer to move under lateral pressure. Such damage allows the penetration of water into the interior, where additional damage to building contents is inevitable.

The wind-induced damage was limited primarily to the roof components at the edge, such as flashing and coping. More substantial damage occurred on a building at St. Stanislaus campus and at Harrison 9th Grade gym, where large sections of metal roof covering were blown away (see Figure 4-27). The standing seam metal roof panels peeled back and away from the roof framing, exposing the interior to rainwater and additional wind damage.

Typically, glazed doors, windows, and roof coverings are the building envelope components most susceptible to damage caused by wind-borne debris. Although glass or shutters designed to resist such wind-borne debris are available, none of the educational facilities had protection on the windows and doors. The corridor windows at D'Iberville High School were broken during the storm, which prompted the complete evacuation of the building.

Figure 4-26:
Cracked brick veneer at
St. Stanislaus High School

Figure 4-27:
Metal roof covering peeled away at a St. Stanislaus campus building

For buildings located in flood hazard areas, especially areas not subject to storm surge, elevation well above the predicted flood level is the most effective damage-reduction measure. Dry floodproofing may be used to provide some degree of protection, although if floodwaters rise higher than the designed level of protection, the damage can be catastrophic. This technique, generally feasible for flood depths of only 2 or 3 feet, is expensive and difficult to implement on existing buildings. Depending on the expected depth of water, local soil properties, and the size and location of openings, the facilities can be designed to limit water infiltration through the walls, openings, and conduits, and prevent envelope failure due to excessive hydrostatic pressure. Dry floodproofed buildings must have detailed emergency plans, with clear instructions for deployment of devices and other measures. Lack of periodic maintenance can render floodproofing measures ineffective.

Another alternative for minimizing structural damage to existing buildings is to provide wet floodproofing. This approach, which is not allowed for new construction, allows water to flood the lower floors protected with water-resistant materials and finishes that can be easily cleaned and restored.

4.3.8 UTILITY SYSTEMS

Educational facilities are typically not equipped with emergency back-up systems, but are mostly dependent on municipal water and sanitary systems. The breakdown of municipal water and sewer services, caused by power outages which shut down water treatment plants and pumping stations, adversely affected most of the facilities. Although a few of the facilities affected by Hurricane Katrina were served by onsite wells and some had septic systems, lack of power prevented their full use. The sanitary sewer system backed up under pressure from floodwaters and, together with the loss of water service, created great difficulties inside facilities used as shelters.

The sanitation problems, especially the unpleasant odors that permeated the facilities, combined with high humidity and heat, posed a serious health risk. At the D'Iberville High School, the loss of water prompted volunteers to haul buckets of water from a nearby ditch to be used for flushing the toilets. After the storm had passed, portable toilets and showers were brought in by the ARC.

4.3.9 MECHANICAL AND ELECTRICAL SYSTEMS

Most mechanical systems depend on the exterior equipment mounted on the roof or attached to the exterior walls. The exposed equipment is the most vulnerable element in the system, because it is commonly damaged by floodwaters, strong wind, and wind-borne debris. Rooftop equipment, such as air-handling units and exhaust fans, typically were not adequately anchored to meet the hurricane-force winds and were frequently damaged or toppled. Through-wall fan coil units installed below classroom windows at the Charles P. Murphy Elementary School in Pearlington were ruined by rising floodwaters (see Figure 4-28).

As a result of HVAC failures, conditions in shelters became very unpleasant because of the heat build-up and the lack of ventilation. The interior temperatures and humidity rose to unbearable levels because of the hot weather that followed Hurricane Katrina. Without the advantage of sufficient natural ventilation, the atmosphere quickly became stuffy. Undamaged mechanical equipment, especially HVAC systems, was not operational because of the power outage and the lack of emergency power supply. At D'Iberville High School, the principal reported using a generator to run a large portable box fan in the corridors to provide some relief. The same generator also provided power for night-time lighting in the corridors.

The Harrison County School District office was one of the few buildings equipped with a generator, and for that reason it was used as an EOC. It served as a command center and provided sleeping and dining facilities for emergency crews. The success of this experience reinforces the importance of having emergency power generator systems and a sufficient fuel supply. Emergency generators should be in a protected enclosure and at an elevation high enough to prevent flooding.

Figure 4-28: Damaged HVAC unit at Charles B. Murphy Elementary School

4.3.10 NONSTRUCTURAL AND OTHER SYSTEMS

It is essential to the operation of educational facilities used as place of refuge and recovery shelters that communications systems remain operational. The place of refuge shelters had a variety of communications systems at their disposal at the beginning of the storm. This included the phone system, cellular telephones, school system radios, and police and fire radios. These systems proved to be unreliable during the storm when antennae and utility lines were damaged. Immediately after the storm, all communications had to be handled through messengers, until portable antennae were brought to restore both cell phone and radio service. The Harrison County school board is now considering the purchase of satellite phones to be used during emergencies.

Nonstructural components and contents of educational facilities sustained the greatest damage from flooding. At D'Iberville Middle School, all interior wood doors, frames, trims, casework, fan coil units, and furniture typically suffered severe damage from water exposure.

The majority of interior walls were constructed of un-reinforced concrete masonry. Portions of these walls and some exterior non-load-bearing walls at Charles P. Murphy Elementary School were knocked down by the storm surge (see Figures 4-29 and 4-30). If the buildings had been occupied during the storm, people could have easily been injured by falling debris. Although many of these walls are used as partitions and are consequently not load-bearing, their mass poses a threat to life and property should they collapse.

Figure 4-29: Damaged non-load-bearing walls at Charles B. Murphy Elementary School

Figure 4-30: Interior damage at Charles B. Murphy Elementary School

4.3.11 EQUIPMENT AND AUXILIARY INSTALLATIONS

School equipment is not necessarily important for the operation of emergency shelters, except for kitchen and dining facilities. Schools that sustained flooding damage usually had all their food preparation and refrigeration equipment ruined. The equipment stored outside consists mainly of buses and other vehicles.

In Pass Christian, many of the school buses stationed in the town were destroyed by the storm surge (see Figure 4-31), although some of them were used during the storm to move people from Pineville Elementary School to another shelter because of rising water.

The Harrison County School District moved all of its buses farther inland before the storm, which ultimately proved prudent and allowed the buses to remain available for use after Katrina. In the aftermath, Harrison County School District had no fuel supply to operate the buses or other vehicles. Several years ago, the school district opted to issue gasoline cards to the bus drivers to fill up at various gas stations rather than at a central depot. After the storm there were few gas stations operating, and it became a time-consuming process to get fuel for any vehicle. In the future, Harrison County School District intends to have its own gasoline supply available on generator power to ensure that school vehicles are kept operational.

Figure 4-31:
School bus washed away by the storm surge

4.3.12 SUMMARY

Educational facilities intended to serve as emergency shelters, together with accompanying parking lots and access roads serving these shelters, should be located inland, away from the coast, and on high enough ground to avoid flooding. Educational facilities that are built closer to the shore because of the school district boundaries should be constructed with the first floor above the highest expected storm surge level. These educational facilities should not be used as shelters during a hurricane, but could serve as relief centers after the storm, as long as they do not sustain significant damage. No educational facilities should be constructed within the immediate area along the shore, where waves are the strongest.

Based on observations, the most resilient school buildings are built using reinforced concrete structural systems, or reinforced masonry construction. The best performing roof decks were cast-in-place concrete, precast concrete, or concrete topping over metal deck. Reinforced concrete or reinforced concrete masonry exterior and interior walls, including precast concrete panels and tilt-up concrete wall panels, seem to have sustained the least flood damage. Other observations indicate that the following measures may help reduce the damage in hurricane-prone regions:

- Doors should be designed to meet the positive and negative design wind pressure and impact resistance, as recommended in Section 3.4.3.1. Windows should use impact-resistant glazing or shutters.

- Educational facilities that will be occupied during a hurricane or needed within a few weeks afterwards should be equipped with an emergency generator.

- All shelters should have protected communications systems linked to the EOC.

- Exterior corridors should be enclosed to allow full access between buildings, so that no one is forced to go outside during a storm to get to another area of a building.

- All educational facilities intended for use as evacuation shelters should be designed according to FEMA 361 guidelines.

4.4 EMERGENCY RESPONSE FACILITIES

4.4.1 BACKGROUND

Emergency response facilities include EOCs, police stations, and fire rescue stations. All of these facilities are considered critical because they must remain functional to manage response and recovery operations during and after a hazard event. EOCs function as incident command centers for coordination and support of all emergency activities. The command and response personnel must remain on duty, in full readiness for action both during and in the aftermath of a disaster. In addition to personnel and resources, EOCs house the information and communications systems that provide feedback to the emergency managers to help them make decisions about efficient and effective deployment of resources. They also relay information to local residents, shelters, media, and other first responders, while providing Continuity of Government (COG) and Continuity of Operations (COOP).

Police and fire rescue facilities are critical to disaster response, because an interruption in their operation as a result of building or equipment failure may prevent rescue operations, evacuation, assistance delivery, or general maintenance of law and order, which can have serious consequences for the community.

While each of the three types of emergency response facilities is used for different operational purposes and their needs are different, most of them require and depend on the following facilities:

Back-Up Communications Equipment: Conventional communications that rely on radio towers with repeater systems cannot be relied upon during high-wind events, because of the high probability that the towers will lose power, as occurred in many jurisdictions in Mississippi and Louisiana. All facilities need back-up communications systems such as very high-frequency (VHF) and ham radios, and adequate back-up communications equipment.

Accommodation Space: Adequate space for all the essential personnel to work, with provisions made for continuous operations, such as sleep areas, kitchens (with supplies for all duty personnel), laundry facilities, and shower facilities for all such personnel. It should also be noted that many residents view the local fire station as a point of shelter, and will seek it as a refuge when winds and conditions become dangerous in their own homes.

Situation Rooms: "Meeting rooms" in which to conduct local government business as well as confer with community members, media, and government officials, and for press conferences and dissemination of information.

Safe Equipment Storage: Patrol and rescue vehicles and other equipment must be adequately protected from flood waters, wind-borne debris, and driving rain, and be accessible and readily available for emergency use.

The observations included in this section are based on the examination of the following facilities:

- Harrison County EOC (Gulfport, Mississippi)
- Jackson County EOC (Pascagoula, Mississippi)
- New Orleans EOC (New Orleans, Louisiana)
- Hancock County EOC (Bay Saint Louis, Mississippi)
- Orleans District Levee Board Police Department (New Orleans, Louisiana)

- New Orleans Police Department (New Orleans, Louisiana)
- Gulfport Police Department (Gulfport, Mississippi)
- Pass Christian Police Department (Pass Christian, Mississippi)
- New Orleans Fire Department (New Orleans, Louisiana)
- Gulfport Fire Department (Gulfport, Mississippi)
- Pass Christian Fire Department (Pass Christian, Mississippi)
- Cuevas Volunteer Fire Department (Pass Christian, Mississippi)
- Back Bay Fire Company #3 (Biloxi, Mississippi)

4.4.2 EFFECTS OF FLOODING

Flooding during Hurricane Katrina, especially the impact of the storm surge and levee failures, caused heavy damage that disrupted the long-term functional capabilities of the emergency response system.

The facilities damaged by rising water were generally rendered uninhabitable after the water receded. As a result, the emergency response teams were forced to relocate the operations elsewhere. Evacuation and relocation was common among damaged fire rescue and police facilities and affected their operations on many levels. Firstly, relocating farther away from their service areas meant that the response time to emergency calls increased substantially. Secondly, the response teams were forced to operate from temporary accommodations with inadequate facilities that were frequently overcrowded. Thirdly, new facilities lacked adequate supplies and services for the extra personnel, which required numerous improvisations, further hampering the operations.

4.4.3 EFFECTS OF HIGH WINDS

The highest gust wind speeds during Hurricane Katrina were typically below the design wind speeds for this area, which range from 120 to 150 mph. Despite this, many emergency response facilities sustained damage that disrupted their operations, and in a few cases shut down the facility. Most of the damage was confined to the building envelope. Portions of metal roofing were lifted and peeled off; aggregate roof surfacing was blown off, becoming wind-borne debris; and roof-mounted equipment, including communication towers and antennae, were toppled or broken. Metal wall-cladding panels detached or peeled off on a number of facilities, exposing the interior to pressurization and rainwater penetration. Doors and windows were damaged by wind-borne debris, allowing the penetration of wind-driven rain.

4.4.4 SITE SELECTION

Ideally, the emergency response facilities should not be located in a floodplain or a site exposed to other types of hazards. However, emergency response facilities, especially fire rescue and police stations, must contend with geographic limitations pertaining to size and adequate coverage of their service areas that frequently place them in hazardous locations. Many of the facilities flooded during Katrina were located in designated floodplains. However, this fact alone does not explain the catastrophic damage sustained by facilities such as the police and fire stations in Pass Christian, Mississippi (see Figure 4-32), because most of the facilities damaged by flooding were built above the minimum required elevations. The primary reason for the widespread damage is the catastrophic nature of the flooding, caused by extremely high storm surge and the failure of levees in New Orleans.

In locations where the emergency response facilities were built to a higher standard than required by local regulations, the adverse effects of Katrina were substantially reduced. The Jackson County EOC occupies the second floor of a municipal building located in Pascagoula, Mississippi. An examination of the storm surge flooding associated with different hurricane scenarios indicated that the site would be inundated during a Category 3 hurricane. Consequently, the county decided to design the building to be approximately 4.5 feet above BFE (see Figure 4-33). During Hurricane Katrina, floodwaters rose to about an inch below the level of the lowest floor. The building was not evacuated prior to the storm, because it was believed that flooding would not exceed the maximum levels recorded during Hurricane Camille. As floodwaters started to rise, the decision was made to evacuate most of the occupants to another building across the street. Despite this action, the EOC operations were not hampered significantly.

The Pass Christian police and west side fire station were less fortunate, as the storm surge flooding at these sites far exceeded the base flood elevation. It was estimated that the storm surge wave that hit the police building was at least 15 to 20 feet high, which rendered the building and the equipment stored inside totally unusable. The facility is currently looking at an alternative site on higher ground as a possible site for relocation and construction of a new station.

The headquarters of the New Orleans Police Department had approximately 2- to 3-foot deep water on the first floor, and a completely flooded basement (see Figure 4-34). The surrounding areas were also under water, isolating the facility and preventing its normal operation. All operations had to be transferred to other police facilities in the city.

Figure 4-32:
Police station in Pass Christian

Figure 4-33:
Jackson County EOC

Figure 4-34:
New Orleans Police Department Headquarters

The Hancock County EOC in Bay St. Louis, Mississippi, is located on naturally high ground outside mapped flood hazard areas. Nevertheless, the floodwaters inundated the ground level, damaging the interior finishes and practically destroying all equipment and contents (see Figure 4-35). Most of the EOC's operations were transferred to an alternate location prior to Katrina's landfall, most likely because the facility is mapped as part of an evacuation zone in case of a hurricane.

Figure 4-35: Hancock County EOC

Site characteristics and landscaping contributed significantly to the extent and type of damage sustained by these facilities. The Gulfport Fire Station #5 in Gulfport, Mississippi, experienced significant disruption because of downed trees. One tree fell on the roof, causing minor damage, while two vehicles parked outside were severely damaged by the fallen trees. Furthermore, it took approximately 12 hours of cutting the trees before firefighters were able to open the access road and start responding to emergency calls. This experience also underscores the need to provide multiple routes into and away from a site, in order to have redundancy and minimize the possibility of isolation as a result of roadway blockage.

The experience during Hurricane Katrina proved the efficacy of preventive evacuation of equipment and personnel to a safe and secure location. It also proved wise to organize back-up facilities in other locations or in adjacent jurisdictions to serve as alternative command and operation centers. Emergency response facilities that did so were better equipped to respond to citizens' needs immediately after the storm.

4.4.5 ARCHITECTURAL DESIGN

Many buildings used as emergency response facilities were not initially designed for that purpose, or for operations under emergency conditions. During and after Hurricane Katrina, most of them experienced significant problems, irrespective of the level of damage. Some of these facilities are located in existing buildings designed as regular office space. These facilities performed poorly, and although they were able to adapt to the circumstances, they did not operate as efficiently as those designed for their particular functions.

For example, EOC facilities in New Orleans were placed into civic center offices, which were not equipped with kitchens, showers, and other facilities essential for the smooth and continuous operation of an EOC (see Figure 4-36). As a consequence, the facility had to be relocated immediately after Katrina because the available accommodations were insufficient and poorly equipped. Some of the buildings occupied by first responders were originally designed for a different purpose and subsequently converted to their current use.

Figure 4-36:
New Orleans EOC in the City Hall building

Generally, any building, whether new or old, that is used as an emergency response facility should be carefully reviewed for compliance with the requirements for uninterrupted operation of the facility. Particular attention should be paid to issues that have historically caused problems in building or operational performance, such as:

- Roof systems not designed for high winds and debris impact
- Rooftop equipment
- Unprotected exterior glazing
- Large, sectional and rolling doors not designed for high winds
- Communications towers
- Large roof overhangs
- Lack of facilities for an extended length of stay, especially emergency sanitary facilities and power supply

Basements are another design feature with a high damage potential, especially when important services and facility functions are located there. The basement at the New Orleans Police Department completely flooded, and all the essential equipment located there was severely damaged, crippling the facility for a long time. Observations indicate that essential functions and service equipment should be transferred from flood-prone basements to safer locations.

The relatively new Back Bay Fire Company #3 station in Biloxi, Mississippi, was built in 1996, and yet its design does not reflect the current needs of its occupants. The spaces are too small to accommodate the duty shifts. The kitchen is inadequate for longer stays, while the sleeping area has unprotected, large, storefront-type windows that represent a serious hazard in high-wind situations (see Figure 4-37). These minor architectural deficiencies may be amplified during the times of crisis and adversely affect the operation of the facility, especially if combined with other building component failures.

Figure 4-37:
Back Bay Fire Company #3

4.4.6 STRUCTURAL SYSTEMS

Concrete and reinforced masonry have traditionally been the most robust structural systems for hurricane-prone areas, since they have a much higher reserve structural strength than other systems. During high-wind conditions, the added weight of the concrete helps counteract the uplift forces, while the mass and depth of concrete and masonry walls provides reserve structural strength that prevents the walls from being breached during high winds and flood conditions. However, with precast concrete elements, attention to design and construction of connections is important. This was generally confirmed during Hurricane Katrina.

The Jackson County EOC, located in Pascagoula, Mississippi, was built in 1977 and is an example of a structurally well-designed facility. The structure is composed of cast-in-place concrete, and performed remarkably well (see Figure 4-38). Although the EOC is located on the second floor of the building, water only came within 1 inch of the ground floor, which is approximately 4 to 5 feet above the surrounding grade. Other structural systems proven to be resistant to flood and wind loads are steel or concrete frames that are covered with precast concrete panels. These systems have very high reserve capacities that perform extremely well during high winds and storm surges.

Figure 4-38:
Reinforced concrete building for Jackson County EOC

In contrast, pre-engineered metal buildings performed less well. Although the main structural components of most of these buildings remained standing, suffering only light damage, the rest of the building components were not able to resist the forces of storm surge. Two prime examples of these buildings are the Pass Christian Police Department Headquarters and the Gulfport Fire Department Station #7 (see Figures 4-32 and 4-39). Both of these buildings were severely damaged and all equipment stored inside was destroyed.

Based on the observations, many existing structures can be retrofitted to perform better during high winds. Although such retrofits may be expensive and generally have limited capacity to strengthen the structure, they definitely increase the overall structural resistance. For example, roof decking can be retrofitted with additional connections to provide increased uplift resistance. Furthermore, roof decks should be attached securely to make the building diaphragm work as a unit and transfer loads adequately to the walls, while simultaneously preventing the deck from being pulled from the structure during high winds.

Figure 4-39: Gulfport Fire Station #7

4.4.7 BUILDING ENVELOPE

When the building envelope is breached, the interior is no longer protected from the outdoor environment and the whole building is exposed to additional forces that may cause its progressive collapse.

The Gulfport Police Department Headquarters and the Pass Christian Police Station are the prime examples of building envelope failure. Both buildings, located near the coast, were exposed to the storm surge that crushed the lightly built exterior walls and destroyed everything in the interior. Fire Station #7 was breached by the storm surge, and practically the entire building envelope was washed away, except for the roof deck. What remained of the building was just a shell (see Figure 4-40). The duty personnel and most of the vehicles were relocated to other facilities until a trailer was provided as a temporary place of operations.

On the other hand, the Gulfport Police Department Headquarters building, constructed with heavy concrete masonry walls, sustained no significant damage to the building envelope. The building only required restoration of flooded building components.

Figure 4-40:
Exterior walls on the Gulfport Fire Station #7 washed away by the storm surge

Longbeach Police Station sustained heavy damage to its roof trusses, metal roof, and siding that allowed wind and rainwater to saturate the interior of the building. The police officers had to scramble to evacuate the prisoners and valuable records before they abandoned the building in the middle of the storm (see Figure 4-41).

Figure 4-41:
Longbeach Police Station

Third District Fire Station in New Orleans is a newer one-story, structural steel-framed building with brick veneer walls, metal fascia panels, steel roof deck, rigid plastic foam roof insulation, and metal roof panels. The estimated maximum wind speed at this location during Hurricane Katrina was significantly lower than the design wind speed. Nevertheless, a large portion of the metal roof covering was blown off the apparatus bay (see Figure 4-42). In some areas, the architectural metal wall panels with standing seams covered by snap-on battens were still in place, but the batten covers had broken away. In other areas, the batten covers were still attached, but they had lifted—it appeared that fatigue cracks occurred along the standing seams (see Figure 4-43). Battens like these are frequently susceptible to blow-off, which allows water infiltration and may lead to panel blow-off. Both the battens and separated panels may become dangerous wind-borne debris. This station was occupied at the time of the storm, but because of the extensive damage to the interior, apparatus bay doors, and the equipment, it could not be used and was consequently evacuated.

Figure 4-42:
Metal roof and wall panels peeled off the Third District Fire Station in New Orleans

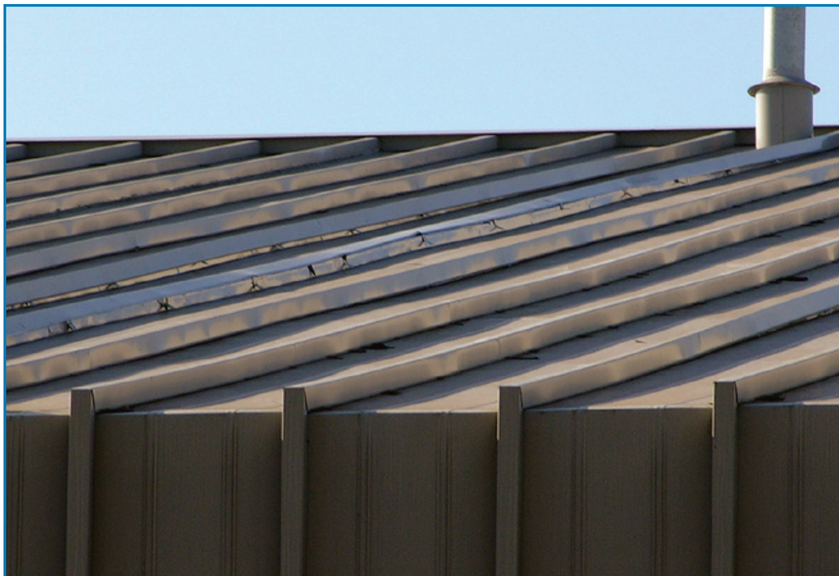

Figure 4-43:
Lifted batten covers on Third District Fire Station metal roof

Although the estimated wind speed in Bay St. Louis was slightly lower than the design wind speed, the wind blew off most of the roof membrane from the Hancock County EOC, located in the city (see Figure 4-44). The damage was initiated with the separation of metal edge flashing that had an uncleated vertical face. In addition to roof damage, the hardware on the exterior door failed and the door blew inward. As a result of rainwater penetration and flooding, most of the interior was ruined. Although most of the facility operations were moved before hurricane landfall, the remaining building occupants had to be evacuated during the event.

Jackson County EOC in Pascagoula experienced similar damage to its roofing when the metal edge flashing peeled off and lifted portions of the roof membrane. However, the roof damage did not cause water damage, because the cast-in-place reinforced concrete roof deck was capable of resisting rainwater penetration. The building's reinforced concrete walls and roof deck resisted the wind loads very well. The walls and roof deck were also extremely resistant to wind-borne debris, as was the exterior glazing retrofitted with shutters that protected the openings.

The edge flashing on low-slope roofs that usually initiates the peeling of roof membranes can be easily retrofitted with additional screws, to prevent it from uplifting and causing a progressive failure of the roofing system.

Figure 4-44:
Roof damage at Hancock County EOC

Fire stations are especially susceptible to breaches of the building envelope, because of their large sectional and rolling doors that are usually not strong enough to resist wind forces, and even less so the hydrodynamic forces of storm surge. The apparatus bay doors failed in many fire stations affected by flooding. (see Figures 4-39 and 4-45).

Water and wind from the storm were able to penetrate the buildings when the doors were breached, causing subsequent damage to other systems and equipment. Large doors should be designed to withstand wind pressures and windborne debris impact as recommended in Section 3.4.3.1.

All doors and windows can also be replaced with modern, impact-resistant systems that would reduce the chances of building pressurization and rainwater infiltration, which resulted in heavy losses to equipment and contents during Katrina. Rooftop units that were blown off and damaged the building envelope by puncturing the roof covering should be securely anchored to prevent such damage in the future.

Figure 4-45:
Damaged apparatus bay doors at Port Sulphur Volunteer Fire Department.

4.4.8 UTILITY PLUMBING SYSTEMS

Failures of public utility systems during Katrina were very common. Many first responder facilities were forced to improvise short-term solutions until public utilities were restored. The Gulfport Fire Department Headquarters was able to back-feed water into its lines by isolating the building's water supply lines from the public municipal supply system. They then fed water directly into the building's water lines in order to have water to shower and wash during the two weeks that they were without water in the facility. This capability should be considered for all emergency response facilities, as it minimizes disruption of basic sanitary functions.

In many facilities, flooding caused sewage to backflow into buildings, causing sanitary crises that directly affected their operations. Valuable time was spent cleaning up the facilities instead of helping others. To prevent this from occurring in future events the installation of backflow inhibitors (check valves) is recommended.

The Pass Christian Fire Department managed the loss of sanitary systems with plastic bags and buckets, while the staff at the Gulfport Police Department was able to acquire and use portable toilets and bottled water until public utility systems were restored. The Jackson County, Mississippi, EOC is equipped with a pressurized underground tank for toilets and washing, which supported the occupants during the 3 to 4 weeks that the facility was without water.

The Cuevas Volunteer Fire Department in Pass Christian, Mississippi, was equipped with an underground septic tank, a drain field, and a well, and did not experience significant disruptions in its plumbing and fresh water systems. These independent septic and fresh water systems do not rely on public municipal systems, and are preferred where possible as they virtually eliminate the chances of disruption during widespread outages.

4.4.9 MECHANICAL AND ELECTRICAL SYSTEMS

Hurricane Katrina also affected facilities by damaging or destroying mechanical systems. Hurricane season occurs in the warmest months of the year, and many of these facilities were not designed to allow natural ventilation. For example, the New Orleans Police Department Headquarters Building is a multi-story building where the main circuitry for the HVAC system, which was located in the basement, was severely damaged by the flood. Since the building was designed as a closed structure, natural ventilation was a problem (see Figure 4-46). All the equipment located in the basement needed to be completely rebuilt or replaced before the building could be occupied again. In the interim, the entire department was forced to relocate its operations to other facilities in the city, placing a strain on facilities not intended to house additional personnel and take on additional responsibilities.

The inability to air-condition buildings because of damaged mechanical and electrical systems allowed internal temperatures and humidity to reach intolerable levels, and in many buildings mold began to form.

Loss of electrical power during and after Hurricane Katrina affected all other essential facility systems. Examples of this were evident at all of the sites visited. Utility, mechanical, and communications systems became partially or completely unusable, either because emergency power was not available, or it had to be rationed as a result of overload or breakdown of generators.

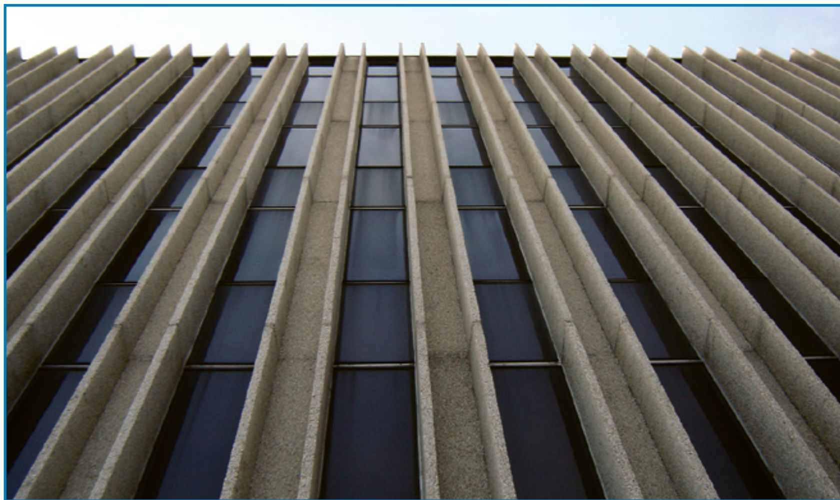

Figure 4-46:
Fixed windows on New Orleans Police Department Headquarters

Cuevas Volunteer Fire Department, located inland at Pass Christian, Mississippi, was without municipal power for approximately 2 to 3 days, but, since its generator functioned properly, their operations were only slightly affected by the storm. In contrast, the indoor generator and electrical panel at the Back Bay Fire Company #3 in Biloxi, Mississippi, became submerged in the flood, even though the generator was mounted several feet above the finished floor. The water flooded the building, putting all the mechanical and electrical equipment, including the generator, out of commission. As the water continued to rise, the firefighters and the local residents that sought refuge in the station had to climb to the top of fire engines until the floodwaters receded.

The New Orleans District 3 Fire Department Headquarters lost power as a result of flooding. The generator was located outside at grade level, and was ruined when approximately 2 feet of water flooded the area (see Figure 4-47). The firefighters were forced to relocate to the nearby West Bank facility for 4 months, until power was restored at the headquarters building.

Facilities that escaped deep flooding were typically operational immediately upon restoration of power. The Gulfport Fire Department Station #1 had water barely enter the station, and was able to get by on their generator for 3 days until municipal power was restored. Although their radios worked intermittently, they were able to perform their search and rescue duties and use their newly acquired chainsaws to help clear the roads of debris.

Figure 4-47: Generator mounted at grade level damaged by flooding

The need to provide a back-up generator at a safe and elevated location is confirmed by the experiences during Hurricane Katrina. Many facilities were without power because of the low elevation and subsequent flooding of their generators. Jackson County EOC had its emergency power station elevated and protected in a separate enclosure, which allowed the facility to operate without interruption (see Figure 4-48).

Figure 4-48: Jackson County EOC's elevated generator enclosure

4.4.10 COMMUNICATIONS SYSTEMS

It is essential for the operation of emergency response facilities to keep their communications systems intact. Loss of communication capability prevents their primary function of responding to community needs and adversely affects their ability to coordinate their actions. If the communications system malfunctions or becomes unavailable, the coordination between command centers will be hindered, affecting management of the response and recovery operations during and after an event. Many jurisdictions in New Orleans and along the Gulf Coast were cut off from each other and could not communicate, even with their own departments. For example, one police officer from the Orleans District Levee Board Police Department was in the heart of New Orleans when the city was flooded, and had no way of communicating with the senior officials in his department. He worked for days with the officers of the New Orleans Police Department (NOPD) assisting the remaining residents in the city. For a period of days, he and his partners from NOPD were operating without communications capabilities of any sort until the military arrived and issued them new radios. It took approximately 2 to 3 weeks for communications to be re-established in a manner that resembled normalcy.

The command and communications center for the police and fire rescue departments in Pass Christian, Mississippi, was located in the police department building, and was crippled as a result of the destruction of their headquarters (see Figure 4-49). The landline communications at the Jackson County, Mississippi, EOC continued to function for a day or two, and other communications systems only experienced minor problems. The building was used during and after the storm.

Hurricane Katrina experience indicates that alternative forms of communication need to be available during and in the aftermath of a storm. High-frequency and ham radios that do not rely on repeater systems should be in place, along with detailed instructions and plans for their use in emergencies. Emergency power supply for communications systems must be available at all times. This relatively low-cost solution would reduce the loss of communications during and after future events.

Figure 4-49:
Broken communications masts at Pass Christian Police Station

4.4.11 EQUIPMENT AND AUXILIARY INSTALLATIONS

Specialized equipment such as vehicles, rescue equipment, and fire pumps were the most common types of equipment lost during Hurricane Katrina. Damage to vehicles and other equipment seriously affected the operations, and frequently prevented speedy rescue and response efforts.

In many cases throughout Mississippi and Louisiana, the vehicles were stored immediately outside on facility parking lots while most of the specialized equipment was stored inside in apparatus bays. In other cases, as in Pass Christian, Mississippi, the police department stationed its vehicles in a remote location that was thought to be safe, but the entire area flooded and all vehicles were rendered useless. In Pass Christian the fire department, located approximately a quarter of a mile from the coastline, had four firefighting trucks and two rescue trucks ruined during the storm, hampering firefighters' efforts in responding to emergencies that required the use of their equipment. Gulfport Police Department and the New Orleans District Levee Board Police Department deployed their vehicles all over the area to ensure that the vehicles would be available on short notice after the storm.

For the 2006 hurricane season, Pass Christian emergency response plans include the evacuation of all vehicles to a staging site away from the coastline, and away from trees and other objects that may become wind-borne debris. This geographic distancing of vehicles from the coastline (and the area affected most by the storm and its surge) will protect key equipment and reduce the impact of a future storm by allowing the first responders to be mobile shortly after the event. It should be noted, however, that many jurisdictions in low-lying areas do not have safe staging sites at higher elevations or away from the coastline.

Based on conversations with many emergency response crews that were affected by Katrina, the protection of their equipment and vehicles was a main consideration prior to the storm. Many jurisdictions throughout Mississippi and Louisiana decided to spread their vehicles out to many locations thought to be safe, in order to be certain that at least some of them would remain operational. This practice proved prudent and enhanced their abilities to respond in the immediate aftermath of the disaster. The vehicles should be sheltered in an area that is safe from flooding hazard and easily accessible after the event.

4.4.12 SUMMARY

Emergency response services are at the backbone of a community's ability to protect and save the lives and property of its citizens in any crisis. The provision of these services depends on the uninterrupted operation of emergency response facilities during and after a hazard event. This means not only that the buildings that house the crews and equipment must survive the onslaught of flooding and high winds with minimal damage, but that all the equipment and systems necessary for emergency operations must remain fully functional.

Hurricane Katrina showed that emergency response facilities have a better chance of protecting their operations if they occupy solidly constructed buildings with sufficient reserve structural capacity that cannot be easily overwhelmed by a storm of this magnitude. It also showed that facilities with functional generators were better equipped to respond after the storm than those that were left completely without power. Since the facilities cannot operate without adequate emergency power supply, all electrical systems should be connected to power back-ups, and emergency generators should be elevated and protected against floodwaters and wind-borne debris.

Mechanical systems need to be located in a sheltered area, where they will not be damaged by wind and flooding. Plumbing systems should be equipped with backflow inhibitors to prevent sewage from entering the structure during a flood. Provisions should also be made to allow the isolation of the building's water supply, so that it is possible to feed water directly into the building's water lines until municipal water supplies are restored.

Finally, the lines of communication between community command centers and individual facilities must remain functional at all times. The basic communications systems need to be protected against the effects of flooding and high-winds as much as possible, but as this storm showed, system redundancy is still the best policy. In the event of damage, the facilities should have alternative means of communication that do not depend on local systems and networks that could be damaged in the storm.