Lessons Learned From the Evacuation of an Urban Teaching Hospital

Christine S. Cocanour, MD; Steven J. Allen, MD; Janine Mazabob; John W. Sparks, MD; Craig P. Fischer, MD; Juanita Romans; Kevin P. Lally, MD

Hypothesis: Valuable lessons can be learned from the emergent evacuation of a large urban teaching hospital because of flooding.

Design: Case report.

Setting: Four hundred fifty-bed adult and 150-bed children’s tertiary referral teaching hospital.

Case Summary: Massive rainfall from tropical storm Allison caused extensive flooding. Emergency power came on at 1:40 AM. Complete power loss occurred at 3:30 AM. The decision to begin evacuation of patients was made at approximately 10:30 AM. All 575 patients were either discharged from the hospital (169 patients) or evacuated (406 patients) to 29 other facilities by both ambulance and helicopter by 3 PM the next day. Six deaths occurred, none of which could be attributed to the conditions created by the flooding.

Conclusions: The lessons learned from this experience included the following: (1) flooding will occur in a flood plain; (2) electrical power outages are not necessarily temporary—begin evacuation; (3) appoint a triage officer from those available; (4) have a reliable in-house communication system not dependent on telephone lines or electricity; (5) have a reliable telephone system for contacting outside facilities; (6) have flashlights available on all units; (7) have battery-operated exit signs and stairway lights; (8) maximize use of volunteers when they are available and fresh; (9) maintain a paper record of all patient transfers; (10) coordinate loading of ambulances and helicopters for patient transfer; and (11) reassign staff as necessary to care for transferred patients. Emergent evacuation of a large, tertiary hospital requires extensive effort from both the hospital staff and the community.

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ON TUESDAY, June 5, 2001, tropical storm Allison formed in the northwest Gulf of Mexico, 80 miles (128 km) south of Galveston, Tex. She came ashore that evening, fewer than 12 hours after forming, and over the next 5 days produced record amounts of rainfall that led to devastating flooding across portions of southeast Texas. There were 3 distinct heavy rain events that affected the Houston area during this period. The first occurred with Allison’s landfall on the fifth; the second occurred on the seventh; and the third, which was the most devastating, occurred on the eighth and ninth. Each major freeway in the Houston area was severely flooded in at least one location during the third event. Nearly 37 in (94 cm) of rain fell during a 12-hour period, with 8.5 in (21.6 cm) falling during a 2-hour period. These rates are the highest ever recorded in this area. As a result of the flooding, 3 major hospitals were closed to new patients. Two of these hospitals transferred their most critical patients to other institutions or other parts of their campus and 1 hospital completely evacuated all patients, effectively shutting down more than 2000 hospital beds and more than 500 intensive care unit (ICU) beds for the city of Houston. This storm also forced closure of the Texas Medical Center, considered the costliest natural disaster ever to hit southeast Texas.

The Texas Medical Center was not immune. The Texas Medical Center is a consortium of health care institutions including 2 medical schools and 13 hospitals with more than 6041 licensed beds. The flooding that affected the Texas Medical Center occurred when Allison returned to Houston on June 8, 2001. Approximately 15 in (31 cm) of rain fell during a 12-hour period, with 8.5 in (21.6 cm) falling during a 2-hour period. These rates are the highest ever recorded in this area. As a result of the flooding, 3 major hospitals were closed to new patients. Two of these hospitals transferred their most critical patients to other institutions or other parts of their campus and 1 hospital completely evacuated all patients, effectively shutting down more than 2000 hospital beds and more than 500 intensive care unit (ICU) beds for the city of Houston. This storm also forced closure.
of 1 of only 2 level I trauma hospitals in Houston that serve more than 4 million people.

A hospital disaster preparation plan is usually directed toward handling an external event that creates mass casualties, not an internal event that requires complete evacuation of the institution. Evacuation of a hospital is rare, but has been reported in cases of riot, earthquake, internal flooding, and hazardous material spill. Rarer still is forced evacuation without power. This article recounts the evacuation of a tertiary teaching institution and the lessons learned from this process.

**SETTING**

Memorial Hermann Hospital (MHH) and Memorial Hermann Children's Hospital (MHCH) are, respectively, a 450-bed adult and 150-bed children's tertiary referral teaching hospitals affiliated with the University of Texas, Houston Medical School. The institutions have 199 ICU beds that include 84 level II and 113 neonatal ICU beds. Memorial Hermann Hospital and Memorial Hermann Children's Hospital are 1 of only 2 level I trauma centers serving more than 4 million people in the greater Houston area. They are part of the MHH system that includes 14 hospitals scattered throughout Southeast Texas.

Memorial Hermann Hospital and Memorial Hermann Children's Hospital are located at the northeast corner of the Texas Medical Center on Fannin and N MacGregor streets (Figure). Ross Sterling Street borders the hospital on the west and Texas Medical Center Garage 4 is to the south. The Hermann Professional Office Building, known as the Hermann Professional Office Building pedestrian and utility tunnels (construction requirement changes with each pavilion) consists of 4 pavilions (Cullen, Robertson, Jones, and Hermann) surrounding a central lobby. Each pavilion has both a basement and ground floor along with a variable number of additional floors. (Cullen Pavilion has 5 additional floors; Robertson, 6 additional floors; Jones, 9 additional floors; and Hermann, 11 additional floors.)

**THE FLOOD**

On June 8, 2001, rain began falling at approximately 6 PM. At that time, all flood prevention systems were in place and functioning. Rising water was observed in the Texas Medical Center at around 11 PM. The water in streets surrounding MHH/MHCH rose so quickly that it was unable to drain into the local bayous because the storm sewer drainage system was filled to its capacity. Electrical power from Reliant Energy was lost at 1:40 AM and the hospital went to emergency power. The electrical switchgear flooded at approximately 2 AM and an internal disaster was declared at 2:15 AM. All power to the hospital was lost by 3:30 AM.

Floodwater occurred from several sites into the lower 2 levels of the hospital and the Hermann Professional Office Building. The former primary entrance to the hospital (Figure), located on Fannin Street, which enters into the Jones pavilion had significant floodwater penetration. The vehicle lanes and landscaping on the Fannin Street side of the hospital were designed to be 2 ft (60 cm) above the 100-year flood plain, and yet these berms were overtopped by rising water of at least 2 ft (60 cm) over their height. The water collected against the glass walls and doors at the Jones pavilion's lobby entrance until the exterior glass broke, allowing the floodwater to enter the central core of the hospital.

Floodwater did not enter from the N MacGregor Street side of the hospital; nor did it breach the flood logs between the purchasing and loading dock area and Texas Medical Center Garage 4 (Figure). However, storm drain and manhole covers that were inside the flood protection zone were forced open by the pressure of the water-filled storm sewers. This allowed a tremendous amount of water to pour down the purchasing ramp and directly enter the hospital.

The water also entered through the Hermann Professional Office Building pedestrian and utility tunnels as well as tunnels entering from the Ross Sterling Street side of the hospital. The Hermann Professional Office Building, opened in 1947, had never experienced significant flooding. The lobby, which is approximately 2 ft (60 cm) above the 100-year flood plain, had 18 in (46 cm) of water that had entered through the Main and Fannin streets entrances. The water entered the lobby and emptied into the elevator shafts and stairwells, thus reaching the pedestrian tunnel. The floodwater accumulation between the Hermann Professional Office Building garage and basement forced open metal security doors, pouring water into the underground tunnels and allowing floodwater to enter MHH/MHCH. This high-pressure water destroyed the pathology laboratory and caused disbursement of medical waste and biohazardous material throughout the Jones and Hermann pavilions' basements. The tremendous water volume and pressure significantly damaged the lower 2 levels of the hospital complex. Although water levels varied slightly between pavilions (construction requirement changes with each new pavilion made basement and ground levels built at different depths), the Hermann Pavilion's ground floor was flooded to the ceiling.

The water in the lower 2 levels continued to rise and eventually submerged the hospital's electrical switchgear.
and all other mechanical, electrical, and plumbing systems located on the basement level. Although the emergency generators located on the second floor were above water and supplied with fuel, the flooding of the switchgear rendered the emergency generators unable to provide emergency power to the hospital. The hospital was then without electrical power, water, or telephone service.

PATIENT CARE ISSUES

Although ICUs are located in all 4 hospital pavilions, most patients were located in the Cullen, Jones, and Hermann pavilions. Only 1 surgical procedure was in progress at the time of the switch to emergency power. The surgical procedure was finished before the complete loss of power; no other surgical procedures were started.

In the ICUs, many of the ventilators did not have batteries and patients receiving ventilatory assistance dependent on electrical power were manually ventilated using an ambu bag. Other ventilators had battery packs, but the life of a battery pack is only about 2 hours. Once the battery pack ran out, these patients required manual ventilatory assistance. Patients were also ventilated using intermittent positive pressure breathing machines. The intermittent positive pressure breathing machines normally run off of compressed air, but owing to a lack of electricity, compressed air was not available; therefore, oxygen was used. This led to an increased use of oxygen, depleting supplies at a much quicker rate than usual. The oxygen supply was further hampered by the inability of fresh tanks of oxygen to be delivered owing to the flooding.

Hospital staff became creative in caring for patients. For example, infants in the neonatal ICU were kept warm by using chemical perineum pads and skin-to-skin contact. Suctioning was performed using a suction catheter and a 60-mL syringe. Dial-a-flow meters (Abbott Laboratories, North Chicago, Ill) controlled intravenous drips. Portable monitors were used to monitor pulse, blood pressure, and oxygen saturation. Failed battery packs were sent to a physician’s nearby home to recharge.

THE EVACUATION

Flooding in the streets surrounding the hospital rose as high as 5 ft (150 cm). Most roads into the Texas Medical Center were impassable until about 9 AM on Saturday, June 9. The decision to begin evacuating patients who were receiving ventilatory assistance was made at approximately 10:30 AM and the decision to completely evacuate all patients was made at approximately 2 PM.

A command center was initially set up in the ambulance bay of the emergency center. Medical and nursing directors of the different ICUs were asked to evaluate their patients’ conditions and to determine the order in which they should be evacuated. The medical director of the shock trauma ICU, a surgeon, assumed the role of triage officer to appropriately evacuate the adult ICU patients from the multiple ICUs. Pediatric triage and evacuation was under the supervision of the chief of pediatric surgery and chief of pediatrics.

Hospital administrators began contacting outside hospital facilities regarding bed availability. The triage officer with the help of a senior nursing director, then determined the order of evacuation, the facility, and whether the patient would go by ground or air ambulance. This information was kept manually by obtaining a patient identification sticker from each patient as they departed. Patients were brought to the ambulance bay of the emergency center which was used as a staging area. Ambulances were loaded at the emergency center ambulance bay while a helicopter landing zone was created on MacGregor Street just outside of the emergency center (Figure).

Transfer of patients had to take into consideration the type of patient and the resources available at the accepting institution, with the goal of avoiding overwhelming a facility with too many patients arriving at once. Nursing staff and equipment were sent with patients as needed. For example, one hospital had available beds but did not have staff or equipment. This made it possible to send the patients of an entire ICU, complete with nursing staff and ventilators.

Teams of physicians, nurses, ancillary staff, and volunteers transported patients to the waiting ambulances and helicopters down as many as 10 flights of stairs without benefit of elevators, overhead lights, or air conditioning. Patients were secured to backboards for transit. In the pediatric unit, as many as 5 infants were secured to 1 backboard. Adults were more difficult to maneuver and required multiple persons to carry each patient. A manual census was continuously taken to assess patient location and condition.

The lobby of the Cullen Pavilion was turned into a supply receiving area and temporary food service site. Life Flight brought in water and food, which was distributed to both patients and staff.

By 3 PM on June 10, the last patient was evacuated. Over a span of 31 hours, 169 patients were discharged from the hospital and 406 patients were successfully transferred by ground and air ambulance to 29 hospitals throughout southeast Texas. All 3 Life Flight helicopters were used along with helicopters from the Coast Guard and Texas National Army Reserve. Six patients died, but none of the deaths were attributed to the conditions caused by the flooding. This was confirmed by the Harris County coroner.

A central staffing office was established, where all hospitals communicated their needs and efforts were made to match the acuity of the patient with the skills of the nursing and medical staff. Nurses, ancillary staff, and equipment were sent with patients as needed by the accepting hospitals. Memorial Hermann Hospital and MHCH physicians were given emergency privileges at receiving hospitals to facilitate the continuity of care.

The damage to the lower 2 levels of MHH/MHCH was extensive. More than 42 million gallons of storm water was pumped from the hospital. More than 3000 fifty-gallon (209-L) barrels of medical waste were removed. The pathology laboratory, clinical pharmacy, 5 state-of-the-art heart catheterization laboratories, gamma knife, physical therapy, central supply, and biomedical supply services, and repair laboratory were completely destroyed. The estimated facility losses for MHH/MHCH are $200 to $250 million. The hospital re-
opened July 17, 2001, on a limited basis to trauma and surgical services and reopened to medical services August 8, 2001.

Medical services to the Houston area community were greatly affected. Not only had MHH/MHCH completely closed, but 3 other major hospitals, 2 in the medical center and 1 in downtown Houston, had sustained damage that severely limited their capabilities. The South East Texas Trauma Regional Area Council established a command center at a local community hospital that is part of the MHH system and is a level III trauma hospital. The MHH/MHCH trauma surgeons upgraded service at this facility to help alleviate the lack of trauma services. The upgrade included an 8-bed shock trauma ICU staffed by MHH/shock trauma ICU nurses and ancillary staff. The South East Texas Trauma Regional Area Council was successful in encouraging the distribution of trauma patients to the level III trauma facilities in the community.

LESSONS LEARNED

The lessons learned from this experience may seem mundane and obvious, but bear discussion. Flooding will occur in a flood plain. The Texas Medical Center is built in a flood plain over the Harris Gully, which is a series of underground pipes that drain the area into Brays Bayou. Memorial Hermann Hospital was opened in 1925 and since that time has experienced minor flooding only once in 1976. When the new Hermann Pavilion was opened in 1995, it was designed and built to exceed the requirements of a 100-year flood standard. However, flood experts have estimated that the June 8-9, 2001, flood was in the 300- to 500-year range and it is clear that standard preparations could not have prevented significant damage.

Electrical power outages are not necessarily temporary—begin evacuation. The common assumption when electrical service is interrupted is that it will be out for only a short time. This is not always the case as was seen during the flood. The cause of electrical disruption must be quickly assessed and the determination made whether electrical power can be restored. If it cannot, begin evacuation. The lack of electrical power necessitated increased use of oxygen to power compressed air–driven ventilators. If the oxygen supply cannot be renewed with fresh supplies, this will govern the time in which you have to evacuate oxygen-dependent patients.

Appoint a triage officer from those available to coordinate evacuation. Flooding prevented many physicians and staff from traveling to the hospital; therefore, a prearranged triage officer is impractical but should be designated from those physicians and staff who are available. The person must be knowledgeable about the hospital and patient care to triage and to evacuate multiple ICU's followed by the remaining patients. A natural separation occurred in the evacuation of adults and children. Those familiar with MHCH took charge of evacuating pediatric patients while those familiar with adults took charge of evacuating adult patients. A central command center is essential as communication between those triaging patients and those communicating with outside facilities must be kept accurate and current.

Have a reliable in-house communication system independent from telephone lines or electricity. When electricity was lost, normal communication was also lost. Runners were used to alert floors as to the next patient to be brought to the staging area. This led to occasional problems with the number of patients brought to the staging area. Therefore, a ready supply of fully charged handheld radios and cellular telephones should be available in all units to facilitate staff communications.

Have a reliable telephone system for contacting outside facilities. One national cellular telephone switching system was disabled for several days because of flooding making these cellular telephones useless. Cellular telephone service for all carriers was knocked out in parts of the city where cellular telephone towers were without power. Therefore, it is important not to depend on just 1 cellular telephone carrier.

Have flashlights with fresh batteries available on all nursing units. Flashlights for all caregivers and at least 1 for every patient or patient room should be purchased and maintained in all units. Flashlights became a precious commodity when power was lost.

Have battery-operated exit signs and stairwell lights. These would have helped in safely maneuvering through stairwells. We had Boy Scout volunteers standing in stairwells with flashlights illuminating the path for those carrying patients.

Maximize use of volunteers when they are available and fresh. Volunteers were numerous and eager at the beginning of the day. By midnight, volunteers were tired. In retrospect, it would have been prudent to bring patients from upper floors when more help was fresh and available rather than keeping patients on the upper floors until ready to evacuate. The evacuation of patients was slowed and eventually halted until morning, to decrease risk of potential injury to either patients or volunteers.

Maintain a paper record of all patients, their attending physician, accepting facility, and accepting physician (if available) as well as discharges. Because the information system (computer system) was down, and copy machines were unavailable, the patient’s medical record was sent with the patient to the accepting facility. This made it imperative to keep a list of all patients transferred, as well as the accepting facility. A sticker with the patient’s name, hospital number, and admission date was removed from the patient’s chart as the patient was loaded into either an ambulance or helicopter and the facility to which the patient was being transferred was noted. It was then placed into a log. In retrospect, it would have also been useful to track the patient’s physician as well to help physicians find their patients.

All transfers or discharges must go through those in charge. A number of patients were discharged home and because the computer system was down, the discharge could not be recorded. This led to confusion when a master list of patients prior to electrical power loss was compared with the record of patients transferred to other facilities.

Coordinate loading of ambulances and helicopters for patient transfer. No more than 1 critical patient was sent to an accepting hospital at any one time. Since the Army Blackhawk helicopters have the capacity to take
up to 3 patients at a time, and the Life Flight helicopters
could take up to 2 patients at a time, multiple patients
were sent together only if they were stable, uncomplic-
cated, or if only one was considered critical. However,
most critical patients were sent singly. The helicopters
were used for longer distance transports, while ambu-
ance transport was used for facilities within or close to
the medical center.

Do not overwhelm any one accepting facility by send-
ing multiple patients that arrive at the same time. It was
attempted to avoid having multiple patients arrive at once
at any one facility. If multiple patients went by helicop-
ter, or if 2 patients were sent by ambulance, these pa-
tients were generally uncomplicated and stable.

Reassign staff as necessary to care for patients trans-
ferred to other facilities. Many facilities had beds avail-
able but did not have the nursing staff or equipment
to care for patients. In this situation both nursing staff and
equipment went with patients. A staffing hotline was
created to allow MHH nursing staff to be reassigned
to take care of patients transferred to the community
hospitals.

Backup batteries for the ventilators may obviate or
postpone the need for hand ventilation. Most ventila-
tors did not have battery backup. In these cases, the pa-
tients required hand bagging until the patient arrived at
another facility. Oxygen-powered ventilators were also
used in select circumstances. Battery-operated moni-
tors and intravenous pumps were used until batteries
failed.

Keys to the Pyxis machines (electrically operated
medication storage system) should be kept in each crash
cart to ensure medications can be obtained if there is a loss
of all power. When electrical power was lost, access to floor
stock medications was lost. This can be averred if keys to
the medications (Pyxis machines) are kept on each unit
in the crash cart or another designated location.

Institute an equipment tracking system. Much equip-
ment was sent to other facilities; however, it was not cata-
alogued and tracked as it left. This has made it quite dif-
cult to recover equipment sent to other hospitals.

Electrical panels should be located high enough to
avoid flood damage. Although the emergency gener-
ators were located well away from the flooded areas, the
switchgear was within the flood zone, making it impos-
sible for the emergency generators to supply power to
the hospital once the switchgear was flooded.

Only services that are not critical to patient care
should be located in lower levels of the hospital. The de-
partments located in flooded areas included the pathol-
ogy laboratory, the clinical pharmacy, the catheteriza-
tion laboratories, and gamma knife, physical therapy, and
central supply services. In the future, all nonessential ser-
vi ces will be located in the lower levels of the hospital.

**SUMMARY**

It’s impossible to be fully prepared for a disaster such as
occurred at MHH on June 9, 2001, because disaster drills
can only go so far. It takes ingenuity, common sense, flex-
ibility, and most of all people working together to make
it work. The response and support of southeast Texas hos-
pitals was outstanding and made it possible to safely care
for all 406 patients who required transfer.

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Corresponding author: Christine S. Cocanour, MD, De-
partment of Surgery, University of Texas Health Sciences Cen-
ter at Houston, 6431 Fannin, MSB 4.284, Houston, TX 77030
(e-mail: Christine.S.Cocanour@uth.tmc.edu).

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