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Understanding Critical Infrastructure Failure: Examining the experience of Biloxi and Gulfport Mississippi after Hurricane Katrina.

Carrie Beth Lasley, David M. Simpson, Thomas D. Rockaway, Terry Weigel

Working Paper 07-09

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ABSTRACT

This article examines disaster recovery and resilience issues following a major hurricane. Two coastal communities were chosen for study following Hurricane Katrina in order to explore the issues in measuring and evaluating recovery and resilience. The communities were Biloxi and Gulfport, Mississippi. A mix of data sources were employed to determine effects on critical infrastructure at a community-wide scale. The data sources included key informant interviews, GIS data, and secondary data such as newspaper reports, city financial statements, and similar documents. The key findings indicate a methodological problem with the formulation of recovery and resilience curves as discussed in other literature. While information regarding a particular community can be mapped, its characteristics are unique and difficult to generalize to other communities. While this issue is not necessarily new to the area of hazards research, it adds weight to the argument that more should be done to collect post event data that can be analyzed in a cross comparative way with other communities. Recommendations include the establishment of a "data archivist" position that would be co-located in an EOC, and the development of standardized measurement sets that all disaster affected communities would gather post event. Finally, specific recommendations for further research are offered.

INTRODUCTION AND ISSUES

Methods for measuring and evaluating resilience have been developed for natural disasters. For example, Reinhorn and Bruneau (2007) evaluate resilience of hospitals to the effects of earthquakes. Recognizing that hospital operation is essential during and immediately after an earthquake to save lives and treat wounds, researchers measured how well hospitals can withstand and adapt to seismic events and their associated infrastructure failure. Resilience includes the ability of the structure to withstand the actual shaking of the ground, as well as the

ability to operate despite the loss of power and water, fires, and impacts on transportation networks. (Reinhorn 2007)

Earthquake resilience has been a focal point of researchers at the SUNY Buffalo Multidisciplinary Center for Earthquake Engineering Research (MCEER), the Mid-America Earthquake Center (MAE Center) at the University of Illinois, as well as others at Georgia Tech, the University of Central Florida and Texas A&M University. The research evaluating hurricane resilience, however, is not as developed. Hurricanes have multiple damage vectors from wind, storm surge, and flooding. Locating a facility in high elevation might mitigate flooding, but increases wind exposure. Hurricanes are the costliest and one of the deadliest natural disasters. NOAA data indicates that in the period 1980-2006 in the U.S., there have been 22 hurricanes with damages exceeding $1 billion. (National Oceanic and Atmospheric Administration 2007). Several sources indicate the rebuilding cost for Hurricane Katrina will exceed $200 billion.

While there may be limited structural mitigation that can withstand hurricanes and storm surge, advances in forecasting enable meteorologists to more accurately predict landfall and provide advance warning. Better models and improved data-tracking enable 72-hour landfall forecasts to be more accurate. On August 26, 2005, three days before landfall, the National Weather Service's National Hurricane Center forecasted landfall just east of New Orleans, predicting a 15-20ft storm surge. As landfall approached, forecast accuracy increased (White House 2006). The August 26 model gave communities three days to prepare.

Preparedness, however, is not uniform. Some communities are able to withstand hurricanes with minimal disruption, others are paralyzed for weeks. Developing a method to measure a community's vulnerability and resilience to hurricanes can provide a warning signal for communities, encouraging investment in mitigation. Cross-community comparisons can illustrate

successful preparedness examples. Additionally, identifying potential storm impacts can better communicate to residents how life will change and for how long.

This analysis focuses on critical infrastructure measurement and how that can assist communities in preparedness and planning. Critical infrastructure includes a community's ability to provide communication, water, electricity, emergency services and healthcare to residents. O'Rourke (2007) describes critical infrastructure as "lifelines," or as "systems … intimately linked with economic well-being, security and social fabric."

Critical infrastructure is dependent on other sectors within the community. If the transportation network is damaged, emergency services may be unable to reach those in need. Water pumps and treatment facilities need electricity to operate. Loss of one system of critical infrastructure often leads to failure of others. The systems are essential in minimizing loss of life and damage, and restoring quality of life. Loss of multiple systems intensifies the problems. A loss of electricity, water and communication networks, for example, could lead to the need for a boil-water advisory, but with an inability to disseminate the message, leading to an increase in water-related illnesses.

The recovery curves we identify are partially a measure of resilience. They estimate the damage and the amount of time for loss recovery. Infrastructure capability (%) is on the x axis and recovery time in on the y-axis.

Challenges in Measurement

Hurricanes pose a challenge in developing recovery curves, as they inflict three types of damage (wind, storm surge, and flooding). All pose a threat to infrastructure, and sorting out which peril does what damage is often difficult after the fact. A recovery curve aggregates damage from all three events, however, and depending on the individual storm, any one aspect

may have dominated the damage. A community may be prepared to withstand one damage type, but may suffer greatly from another. For example, Hurricane Katrina carried a great deal of rain and it is estimated that as much as half of the water that flooded New Orleans came from the sky (Christian 2007). Hurricane winds start at 74 miles per hour and can climb well above 150 mph. Katrina's winds exceeded 120 mph.

In developing curves for Katrina-affected communities, there were additional challenges. The first is fatigue. Katrina occurred in the busiest hurricane season experienced in recorded years. Reporters, aid workers and researchers came in droves. City officials and residents were asked questions repetitively. As those questions were answered numerous times, willingness to participate in research declined, and recollection of exact events began to fade.

Another issue in data collection relates to critical infrastructure itself. Loss of power meant computers were no longer collecting data, but also meant that those in the best position to collect data were busy maintaining operations. Attention to details such as time, locations of failure, and the order of problems encountered were eclipsed by needs of response—leaving critical information unrecorded, unknown, or forgotten. What data remained is incomplete, estimated, inaccurate or missing.

Methodology

Two cities were chosen as case studies to better understand how infrastructure failed during Hurricane Katrina. Fifty miles northeast of Katrina's landfall are the communities of Biloxi and Gulfport, Mississippi, both within Harrison County. These cities combine with Pascagoula to make a single Metropolitan Statistical Area on Mississippi's Gulf Coast. Gulfport (71,127 pop.) is larger (Biloxi, 50,644) and they are the second and third largest cities in Mississippi.

Three trips to the area were conducted to collect data and interview key informants. Press releases, media reports and journal articles were used to help pinpoint events. Qualitative and quantitative data were collected from multiple sources. The team conducted on-site interviews of public works administrators, government officials and emergency personnel. Photographic evidence, geographic information systems (GIS) data, and public documents were used to supplement interviews. Where data was missing, investigators turned to press releases and media reports.

Gulfport and Biloxi were selected because their size and services structure enabled larger-scale observations of systems. A total loss of electricity was experienced by Mississippi Power, the area's provider. If backup generators were not available, loss of power was followed by cascading failures of services, data collection and communication. Even where generators were available, fuel shortages led to eventual service loss. Immediately following landfall, efforts were concentrated on saving lives and solving critical problems such as the unanticipated fuel crisis and closing of leaking gas lines. Data collection was a secondary consideration.

A more complete data set might include all aspects of critical infrastructure behavior aggregated for both communities, but also available as separate sets. This was not possible. Analysis relied in many cases on data aggregated to Harrison County, while in some cases data was available in one community but not the other.

A second common issue with the data is the assumption of resident return. Evidence suggests many residents hardest hit by storm surge could not, or chose not to, return. For example, in a January 2007 newsletter from the City of Biloxi, pre-Katrina and post-Katrina school enrollment numbers were compared. Fewer than 52 percent of students enrolled in 2004 returned to classes when school opened in October of 2005. In January 2007, that number had only risen to 76

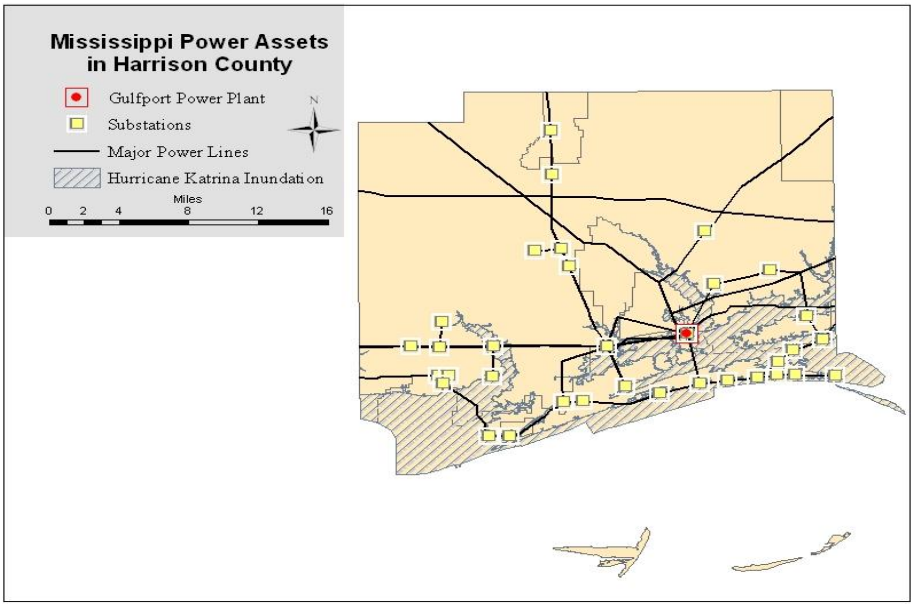
percent (Tisdale 2007). The Biloxi GIS manager acknowledged that the northern suburb of Orange Grove experienced a population boom after the storm (Cohan 2006), indicating some residents who left low-lying neighborhoods chose to move to higher elevations. Dislocation may be permanent or may continue only while residents await insurance payments, money from FEMA, or some additional level of recovery before returning.

The following sections examine the critical infrastructure elements in the two communities, developing recovery curves where possible from the available data. These sections are followed by some preliminary conclusions, and recommendations for policy and research as result.

Electricity

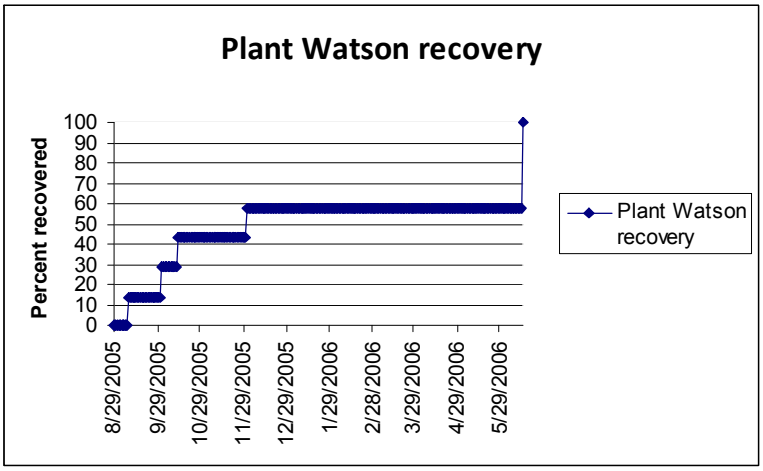
Mississippi Power is the area provider of electricity for the communities and much of Mississippi. Upon Katrina's landfall, all 195,000 Mississippi Power customers lost service, including those in the Coast division. Map 1.1 shows key electric infrastructure in Harrison County, Mississippi, as well as the inundation contours.

Map 1.1



Storm surge affected the electric infrastructure significantly, striking several substations as well as the Watson power plant in Gulfport, indicated by the red circle on Map 1.1. Plant Watson provided three important services to Mississippi Power. It was the second-largest power generator, and housed the emergency operations center and backup power generators. These services were lost upon flooding from storm surge; water filled the basement and a foot of the first floor. (Ball Spring 2006) Figure 1.1 shows the recovery curve for Plant Watson. It took about nine months to restore full power capability. (Mississippi Business Journal 2006)

Figure 1.1

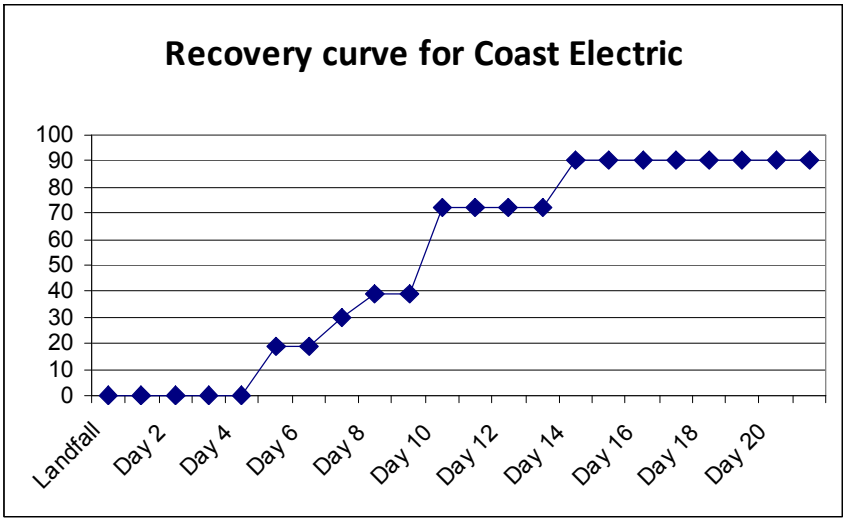


Aggregate data exists for total Mississippi Power restoration. Mississippi Power divides its service areas into divisions, and there is aggregate data for each division. Data for the coastal division was reported as percentage restored and given on a daily basis (in a press release) from Mississippi Power beginning on Day 5. The recovery curve is represented in Figure 1.2 below.

On Day 5, the first day for which data was available, 14,169 residents on the coast had power restored, 19 percent of the customers in the division. Thereafter, a steady increase, followed by a jump from 39 percent to 72 percent, between Day 8 and Day 10, occurred. By Day 13, all customers who could receive power (90 percent) on the coast had received it. (Southern

Company 2005) This data suggests that 10 percent of its households and businesses receiving power before the storm were incapable of receiving it two weeks afterward, and were unlikely to be households where people were living, and therefore were not in need of electricity.

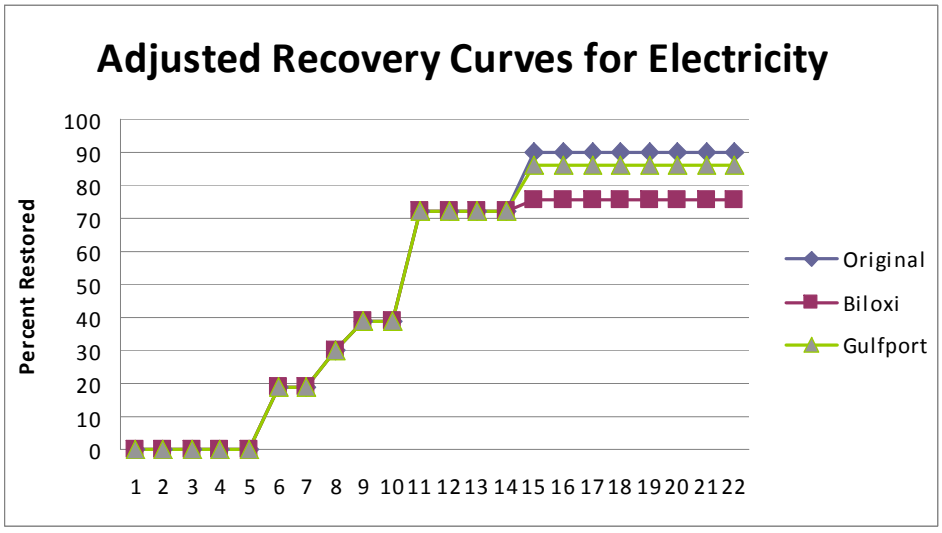
Figure 1.2: Recovery curve for the coast division of Mississippi Power, a subsidiary of the Southern Company. Data is from daily press releases from Mississippi Power.



A Southern Company-Mississippi Power Press release issued in January 2006 gave specific numbers of households not yet restored. This number was community specific. In Biloxi, there were 5,148 households without power. In Gulfport, there were 3,707 households without power. (A Southern Company 2006) Using census statistics from the 2000 Census, the final percentage in each community not restored was determined. Analysis indicated a larger percentage of the unrecovered customers were in Biloxi. With more outages (5,148) and a lower population (50,644), Biloxi residents were harder hit by electricity loss. About a quarter (24.6 percent) of households were without power in March, six months later.

Gulfport, on the other hand, had a larger population and a smaller number of residents. Just 14 percent of Gulfport households were not capable of coming back online by March. Figure 1.3 shows all three fragility curves, the aggregate or original curve, as well as the adjusted curves for each community. An additional assumption is made that Mississippi Power's final recovery statistic was the maximum it expected to restore after Katrina (U.S. Census, 2000).

Figure 1.3: Numbers are adjusted based on population, household size and number of customers not receiving electricity in March of 2006.

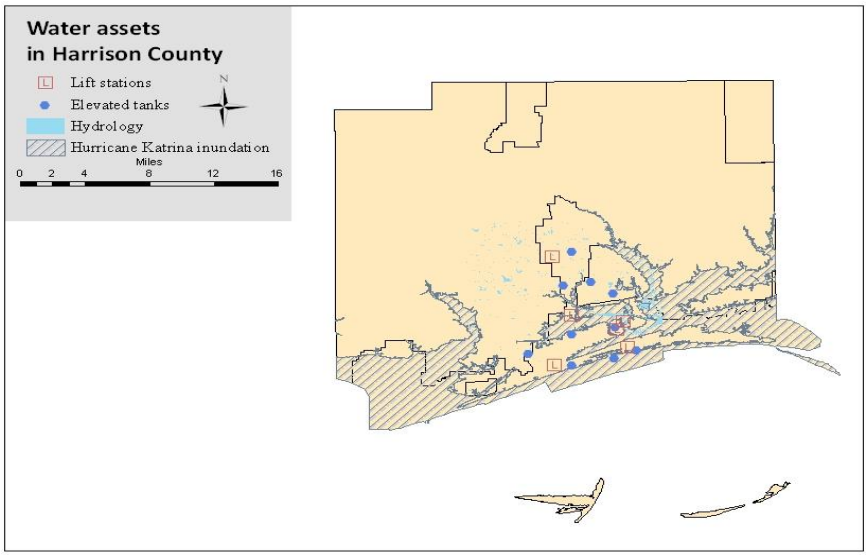


Mississippi Power expected the restoration cost to be between $245-$295 million. About two-thirds of the power infrastructure needed repairs. Among those necessary repairs, the utility's generating facility in Gulfport sustained flooding on its first floor, and additionally 1,000 miles of transmission line, 9,000 poles and 300 transmission poles needed repairs (A Southern Company 2005). These repairs would continue to disrupt Gulf coast lives on a local basis well after the storm, but Mississippi Power was able to restore power quickly due to a post-storm functioning communication system, adequate staff, a sufficient inventory of replacement parts and system redundancy.

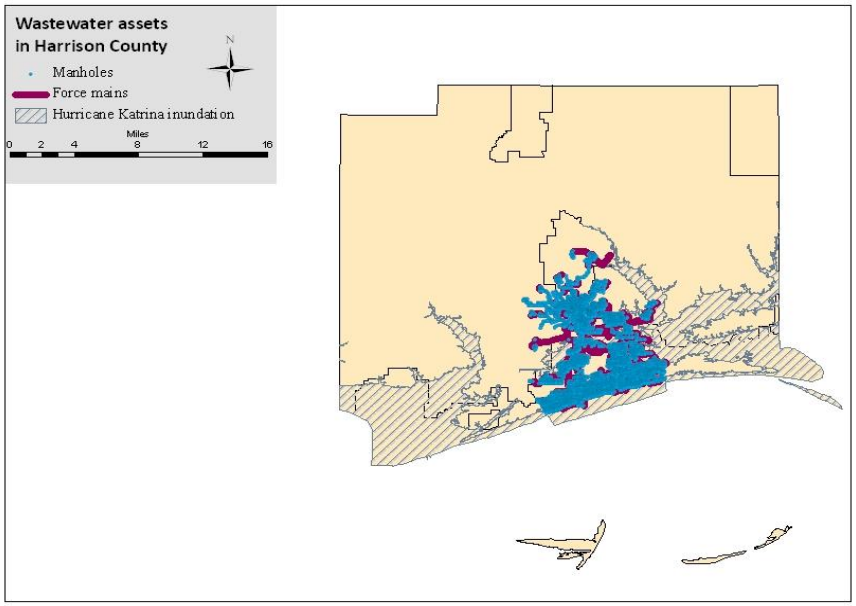
Water and Wastewater

Flooding, storm surge and high winds combined to severely impact the water and wastewater infrastructures. System damage, coupled with power loss, created a situation in which running and potable water could not be delivered to Harrison County residents. This section describes recovery efforts of the water and wastewater infrastructure. Map 2.1 shows water utility infrastructure in Gulfport of Harrison County and Katrina surge inundation limits. Map 2.2 shows wastewater assets in the same area.

Map 2.1

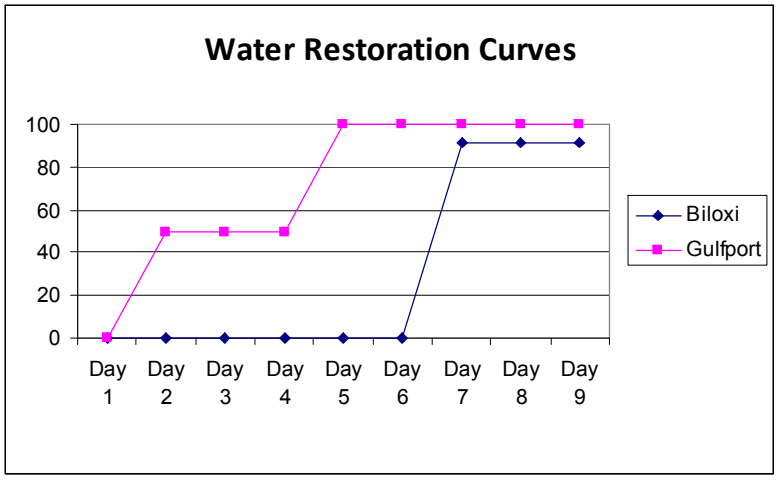


Map 2.2



Information on water utilities was unbalanced. While good data exists for Gulfport, the same cannot be said for Biloxi. Public notices have helped determine when the majority of the water system came online. Full recovery data is not available, although it is likely that all wells were either brought back online or were bypassed in the municipal water system. Figure 2.1 shows the recovery curves for each community. Biloxi is limited to 91.3 percent.

Figure 2.1

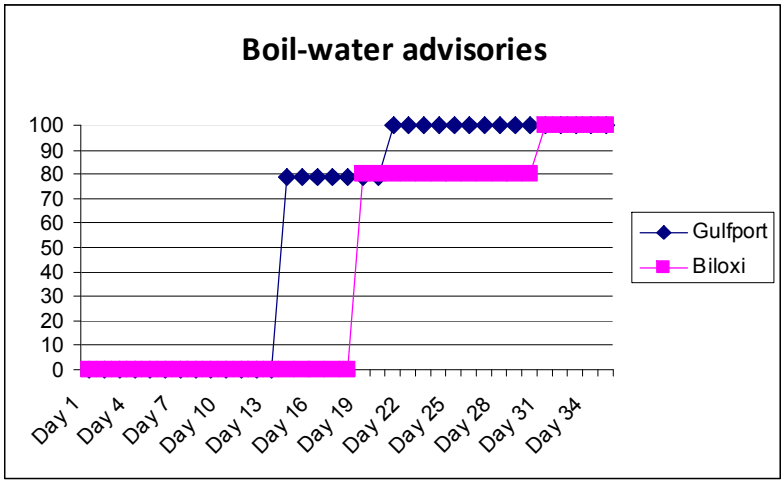


Recovery with time does not reflect the severity of damage done to the infrastructure. Although both communities were able to quickly restore service to residents, Biloxi's water restoration was problematic. Biloxi's water recovery came with a warning that the pressure was "very low" on Sept. 4. Two of 23 wells were still out of service. (City of Biloxi 2005) The city warned residents to employ strict conservation measures until the pressure was restored. Restoration of running water, however, did not mean that it was safe to drink.

Although water was not pumping through the pipes, both cities ensured water needs were met. Five locations in Biloxi were open daily to distribute bottled water, and Gulfport residents also received bottled water. United Parcel Service was among several corporations and organizations that sent water and food to Biloxi and Gulfport. (United Parcel Service 2005)

The U.S. Environmental Protection Agency had to approve water services before boil-water notices could be lifted. The systems had been exposed to debris and sewage during Hurricane Katrina. Once the system was cleared by the EPA, the boil-water notices could be lifted. Figure 2.2 shows the recovery curves for potable water, represented by the expiration of boil-water advisories.

Figure 2.2: Data showing when municipal boil-water advisories were lifted for Gulfport, Miss., and Biloxi, Miss.



Gulfport lifted the boil-water advisory to the part of the community and to the full community at a faster rate, but Biloxi restored water to 1 percent more households on Sept. 16. This is due to a slightly lower proportion of residents living south of the railroad tracks in Biloxi. Each community was able to lift boil-water advisories on north of the railroad tracks faster than the heavily damaged area south. Gulfport needed two weeks to restore service to most residents, and Biloxi required a few extra days. (Reimann 2006, Nolan 2006)

In both communities, the water infrastructure suffered severe damage-- pumping stations were flooded, debris found its way into wells. Even after running water was restored, there was still a great deal of damage from which to recover. Manhole covers were not locked down, and were easy displaced by storm surge. Nine months after Katrina, Gulfport estimated that recovery of the water system was just 30 percent complete. (Reimann 2006)

In Biloxi, generators were necessary for lift stations. One year later, the generators were still being used. In some instances when wastewater treatment plants returned to service, they were not fully functional. For two months after the storm, manual chemical treatment was still needed (Holloway 2006). In Biloxi, the Biloxi Regional Medical Center needed a mobile treatment unit from the EPA to continue operating (Grumbles 2005).

Both cities, despite crippled infrastructure, had restored water and sewage a little more than two weeks, with all those who could receive service restored. In the state of Mississippi, six weeks after the storm, there were still 30 utilities, serving 10,000 customers, not operating in any capacity, and 54 utilities, serving 43,000 households still operating under boil-water advisories. (Grumbles 2005) Both cities fared better than neighboring counties.

Discussions with Gulfport officials noted that the city successfully implemented its emergency preparedness plan, confirming the operation of backup power on the wells that were so equipped. The Public Works department deployed tire-repair kits, and sent the fleet of vehicles home with workers so the fleet would not be vulnerable at a single location. The fleet dispersion allowed workers to quickly respond to problems in their own neighborhood, thus allowing a number of sites to receive attention early. No vehicles were lost as a result of the storm. Municipal workers also removed vegetation near the drainage system to lessen the potential for contamination and clogging by debris. (Reimann 2006)

Gulfport Public Works observed that upon landfall, system pressure dropped quickly, and was completely lost within 30 minutes (at 8:30 a.m.). By 2 p.m., damage was under investigation, and the system south of Interstate 10 was purposefully cut off from the rest of the system due to heavy damage. Even in areas heavily damaged by the storm, water pumps were operational; though they were pumping into flood water. (Reimann 2006)

Telecommunications

During a disaster, the ability to communicate is critical. Communications help those working the recovery to report observed needs, progress and damage. Communication between officials and the public, and between members of the public, facilitates information distribution, such as boil-water advisories and road closings.

The loss of electricity proved to be a lethal blow to communication links, contributing to slow recovery. The House Select Committee on Hurricane Katrina stated that the Gulf Coast of Mississippi experienced total destruction of communications infrastructure. (U.S. House of Representatives 2006) One month after the storm, 22,000 households in the state were still without phone service. Cell towers suffered, with more than 2,000 towers taken off line by Katrina. A month later, a little more than half had been restored to service. The House Select Committee estimated that 20 million calls failed to go through; including 911 calls. (U.S. House of Representatives 2006)

Where communications existed, it was often cited as insufficient. Operability was an issue when lines, poles, switching centers, cellular towers and radio antennas were damaged by the storm. Lack of interoperability created problems when responders could not communicate with other organizations. In the White House report on Katrina, federal communications aid given to local and state agencies was criticized as being insufficient. The report notes that two of five

MERS (Mobile Emergency Response Support) vehicles were deployed, but in retrospect, more should have been ready to assist. In addition, the Department of Homeland Security used its National Communications System to assist, but this was still not enough to coordinate (U.S. House of Representatives 2006).

One of the clear issues was the problem interoperability. A report from the 2004 Conference of Mayors indicated that 44 percent of cities had agency interoperability issues in the previous year, and that most could not communicate effectively with state and federal agencies. (U.S. Conference of Mayors 2004). In Katrina's aftermath, most agencies could communicate internally, but interagency communications were difficult. The House Select Committee on Hurricane Katrina pointed to a lack of redundancy in planning. (U.S. House of Representatives 2006) The most successful alternate communication mode was satellite phone. High winds and heavy bandwidth traffic jammed lines and many essential messages failed to get through. Another unanticipated problem was the off-target satellite antennas caused by high wind. The Mississippi Emergency Management Agency noted there was an insufficient cache of satellite phones. (U.S. House of Representatives 2006)

Communication networks are complex. To measure the loss and subsequent recovery, a rubric was created that evaluated which communication systems were necessary, which were available, which were working, when a failure occurred and the length of the delay before service was recovered. The matrix is displayed in Appendix A.

In total, 30 possible methods of communication were considered. These include the traditional forms of communication, such as landline phones, cellular services, 911 and police radios. It includes methods of disseminating information to residents such as radio, TV and newspaper. Points were assigned based on the ease of communication with state and federal

agencies such as MEMA, FEMA and the National Guard. One point was assigned if the county had provisions in place to maintain communications. Another point was awarded if the communication system worked. For a perfectly functioning communication system, the score assigned would be 60. Harrison County scored 41.5 or had 69.2 percent of its total possible communication needs met at landfall. Table 3.1 below shows a summary of which networks were available at landfall, and which were not. Multiple media outlets of the same media are combined in the table

Table 3.1: Summary of communication networks in Harrison County and their availability or failure upon landfall of Hurricane Katrina

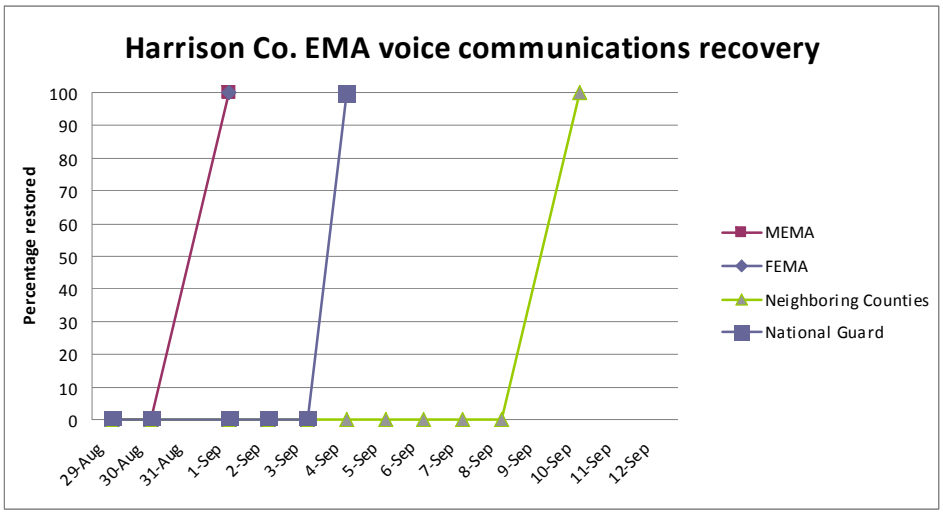
Network	Operational	Failed
Landlines		✓
Cellular Lines		✓
Internet	✓	
Satellite phones	✓	
911 Call Center	✓	
Public Works	✓	
Police and Fire	✓	
Redundant System	✓	
Radio		✓
TV	✓	
Newspaper		✓
Mail		✓
National Guard		✓
FEMA		✓
MEMA	✓	
Neighboring Communities		✓
Outside Help	✓	

There were a total of 15 networks that failed, five of them cellular. Two were landline networks – one for local calls and one for long-distance calls. The following section examines recovery curves and information about recovery and systems that did not fail.

In terms of response, Harrison County was an example for other storm-affected counties to follow. Harrison County never lost 911 services, when most communities did. In order to protect responders, calls to the service were stacked, with names and addresses taken to help guide early rescue efforts. County Sheriff's Deputies, municipal police and fire encountered few communication problems. (Kessie 2005)

Figure 3.2 shows the recovery period for voice communications between Harrison County emergency response officials and various emergency agencies.

Figure 3.2: Recovery curves for real-time voice communications between the Harrison County Emergency Management Agency and the Mississippi Emergency Management Agency, the Federal Emergency Management Agency, emergency management agencies in the neighboring counties of Hancock, Jackson, Pearl River, Stone and George and with the Mississippi National Guard.



The National Guard, MEMA and state responders and law enforcement were among those with whom Harrison County could not communicate easily. Within these agencies, memos and face-to-face meetings were the available methods. The inability for Harrison County officials to communicate up the line continued for at least 48 hours. The House Select Committee found in its report that the Mississippi National Guard had access to satellite phones but was not receiving

calls on two important lines. It was later discovered the National Guard has changed the number prior to the storm, and had failed to alert others (U.S. House of Representatives 2006).

Harrison County was cited by the House Select Committee as an example of a prepared community. Interoperability grants allowed the creation of the Enhanced Digital Access Communications Systems (EDACS). Although this system remained operable throughout the storm and its aftermath, communication with federal and state agencies was not possible due to interoperability problems. However, the system was capable of communicating with Florida agencies who aided in first response and law enforcement. Therefore, emergency response within Harrison County was possible, and within two weeks, Harrison County's Emergency Operations Center could communicate with first responders in adjoining counties.

Communications with organizations higher up, such as Mississippi Emergency Management Agency (MEMA) and the Federal Emergency Management Agency, were not as reliable. Immediate communications were possible with MEMA from the Harrison County EOC via satellite, and permanent satellite radios mounted in coastal counties should have provided 12 hours of communication. In Harrison County, the radio system suffered severe damage and was inoperable. Communication between the two emergency management organizations was established via a mobile emergency response vehicle through the internet (U.S. House of Representatives 2006).

A communications success was use of the Southern LINC system of radios deployed in eastern sections of the state, including Gulfport and Biloxi. While the 115 radio units in the system were not sufficient to connect everyone who needed them, they did operate. Alabama Public Works officials as well as some in Mississippi used the system to relay information about power, water and wastewater needs. The radios are programmed for disaster response, with

channels for various aspects of recovery and telephone capabilities. (U.S. House of Representatives 2006) Gulfport Public Works utilized the Southern LINC system, experienced no operation or communication problems. (Reimann 2006)

Harrison County has been identified as a communications success story. The Federal Communications Commission oversees 9-1-1 Magazine, and reviewed Harrison County's successes in its April 2006 issue. It noted that Harrison County had the only emergency call center to remain operational in areas directly hit by Katrina. In the article, Harrison County Emergency Communications Commission Telecommunications Manager Robert G. Bailey cited off-site redundancy, staff training, engineering forethought and service contracts as key elements that made communications more dependable. To restore most communications, the only significant post-storm task was the re-alignment of satellite dishes.

Specific actions taken by Harrison County that resulted in a functioning communication system during Hurricane Katrina include (Scott 2006):

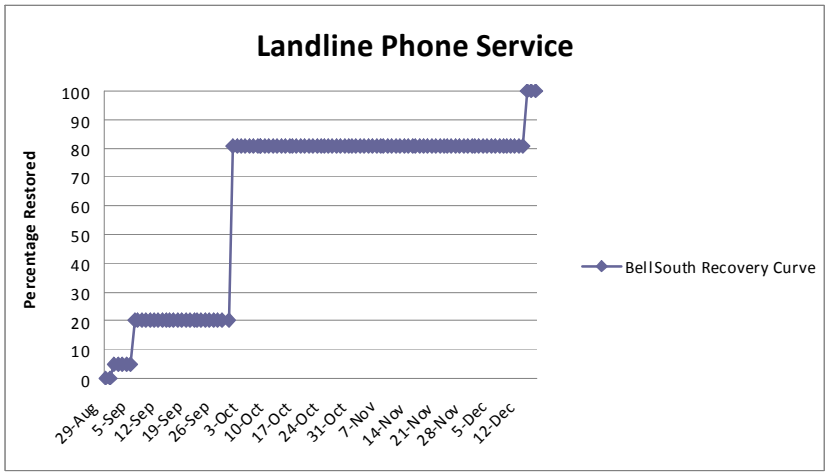
- ✓ Constructing antenna platforms 4 feet above the 500-year floodplain
- ✓ Pre-assigning radio frequencies for search and rescue agencies
- ✓ Conducting annual emergency training for all communications staff
- ✓ Conducting annual testing and backup and redundant systems
- ✓ Establishing service contracts with vendors for use in emergencies

Figure 3.3 shows the recovery curve for landline phone service. Winds snapped phone lines and downed telephone poles, creating a communications black hole in the region and further isolating survivors of the storm. The White House report states that the state of Mississippi lost 50,000 telephone poles, and more than 3 million customers lost phone service. (White House February 2006)

Bell South provides phone service in the area, and recovery was tracked by company press releases. BellSouth's first step was to provide long-distance service, completed by Aug. 31.

Long-distance service does not require the use of local switching stations which were damaged in the storm. Landline recovery was complicated by unanticipated events. First, in Gulfport, the building that housed the switching station and generator lost a wall to debris, but employees rebuilt the wall with locally available materials, including plywood, cardboard and a child's science project, to get the station back in operation (Belson 2005). BellSouth anticipated the need to restore poles and lines, but it had not expected to need heavy work underground. To complicate matters, contractors and residents accidentally cut wires as they tried to clear debris. The Mississippi Gulf Coast was an area where accidental wire cutting was common, and slowed service restoration. (BellSouth Corp. 2005)

Figure 3.3: Recovery curve for the re-establishment of landline phone service by BellSouth in Harrison County, Mississippi.



There are five cellular networks in the Gulfport-Biloxi area, and all went down. Verizon Wireless, Sprint/Nextel, T-Mobile, Cingular and Cellular South all lost the ability to connect calls due to loss of cellular towers. Figure 3.4 shows the recovery of cellular services within Harrison County. Though most service was not restored until Sept. 7, critical areas were restored more quickly through deployment of cellular on wheels (COWs). COWs were placed near Keesler Air Force Base and Red Cross relief areas. COWs permitted affected residents to communicate with relatives and loved ones (Nobel 2005).

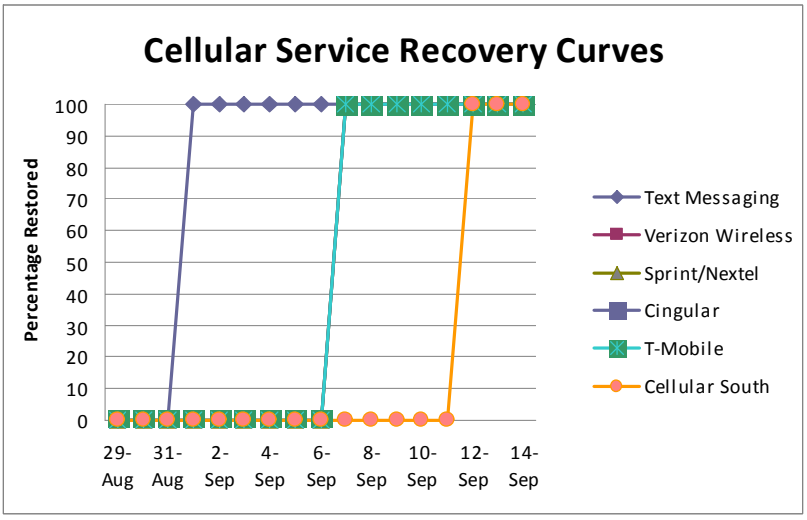
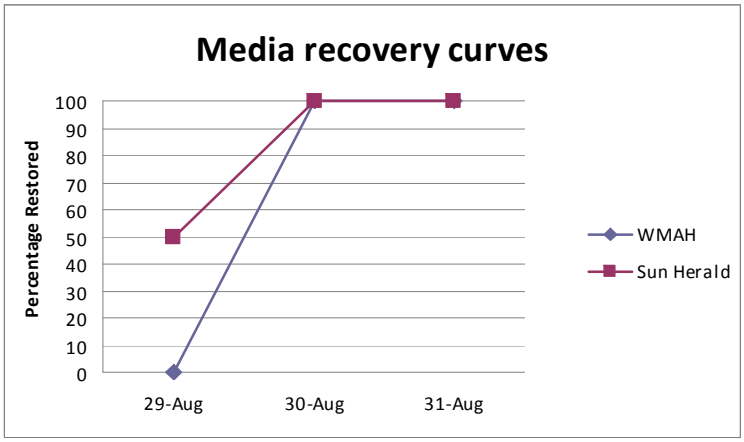


Figure 3.4: Recovery curves for cellular services.

Figure 3.4 shows recovery curves for Mississippi Public Broadcasting radio station WMAH-FM and for the Harrison County's local newspaper, The Sun Herald. The Sun Herald could not have distributed newspapers on the day of landfall even if there had not been an evacuation order in effect. Katrina landfall occurred around 8 a.m. and was preceded by severe storm conditions. By the next day, the daily newspaper had a print edition ready for distribution. There was no charge for the paper, which was distributed widely at locations where people gathered such as shelters and Red Cross centers. The paper was provided free-of-charge until October. (Editor & Publisher 2007) Unlike its radio counterpart, the starting point for the newspaper begins at 50 percent on the day of landfall. This is due to an arrangement made with local reporters, regional reporters and the Harrison County Emergency Management Agency, allowing reporters to establish an online edition called "Eyes on Katrina." The service continued beyond the recovery of the print edition, and included connections to such features as an "I'm-OK line," while serving as a community bulletin board that checked on the welfare of the newspaper staff as well as posting bulletins about damage and needs. (Hammack 2005)

Figure 3.5: Recovery curves for the first local newspaper and first local radio station to return after Hurricane Katrina. The Sun Herald posted information online on the day of the storm. TV station WLOX never went off the air.

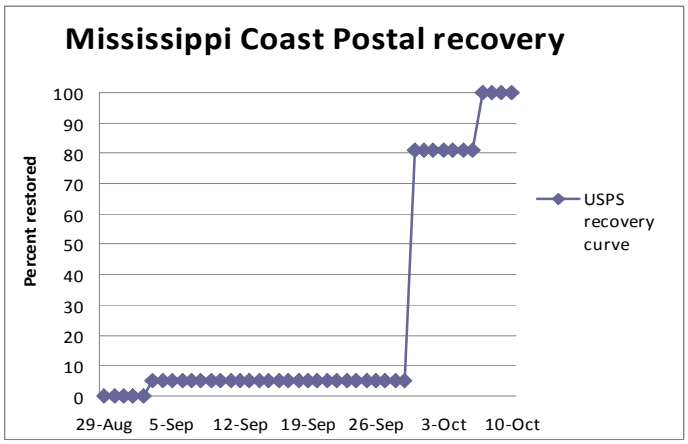


The White House report stated that about half of radio stations in the communities affected by Hurricane Katrina lost the ability to broadcast. (White House February 2006) While this number is higher in Harrison County, the first station back online was a Mississippi Public Broadcasting station, WMAH-FM, located in Biloxi. Two days prior to landfall, the station began to issue 24-hour emergency bulletins informing residents as to how to evacuate and expected conditions facing those staying. Hours after landfall, MPB engineers traveled to Harrison County to restore generators and re-establish broadcasting and continue disseminating information. (Burns 2005)

The journal, Broadcast Engineering, examined how television stations fared during the storm. WLOX-TV, headquartered in Biloxi, maintained a signal throughout the storm and recovery. Small disruptions in broadcasting were experienced when portions of the WLOX-TV building had to be evacuated as the storm hit. Despite the loss of a large portion of the roof, and collapse of a broadcast tower into the building, WLOX-TV continued to operate. The WLOX-TV transmission tower was 27 miles north of the station and survived unharmed. Fifty employees kept the station broadcasting until relieved by affiliate crews. (Kurz 2005)

The U.S. Postal Service struggled to restore mail service. Six post offices were lost in Mississippi in the storm. Loss of street signs, houses, and mailboxes led to a delay in service resumption. Full service was restored by October 7 to all households who could receive it. (U.S. Postal Service 7 October 2005) Figure 3.6 shows the recovery curve for mail service.

Figure 3.6: U.S. Postal Service recovery in the Mississippi coast region. Total recovery is 100 percent of those who can receive mail. Original improvements were some post offices open for Social Security checks only at given times.



The Internet was available for use in Harrison County's EOC when other methods failed. Two Sun Herald reporters, Hammack and Greer, wrote an instantly updated web log "Eyes on Katrina," from the EOC. It included updates from reporters around the area as well as information about road closings, damage reports, emergency operations and community needs. A by-product of the blog was an event-by-event tracking of the Internet access available to the EOC. Harrison County Emergency Management Agency maintained Internet access throughout the storm event and subsequent recovery period, with mostly minor interruptions. (Hammack 2005)

On September 7, 2005, the Los Angeles Times examined some of the surprising recovery developments in areas affected by Hurricane Katrina, including Biloxi and Gulfport. It discovered that while the old landline telephone system is the national standard for communication, an event of this magnitude exposed how much faster new high-tech

communication options could be brought online. While workers from around the nation labored to erect new telephone poles and string lines, wireless broadband Internet was the fastest way to connect storm victims with the outside world. Biloxi and Gulfport residents could visit Red Cross centers and use email and Voice-over-Internet-Protocol services, as early as 11 days after landfall. (Granelli 2005)

TRANSPORTATION

Highways

Transportation networks were used by search-and-rescue teams to reach survivors and aid in distributing relief. The need was acute "south of the railroad tracks" in Biloxi and Gulfport, where uprooted street signs and distributed debris severely complicated response. With loss of street signs, first responders were often lost trying to locate even familiar addresses. Even familiar landmarks were destroyed or relocated by the storm. (Reimann 2006)

With heavy damage to bridges, areas of the community risked being isolated. Katrina illustrated that bridges can be particularly vulnerable to storm surges, where rising water and big waves lift decks of several tons and displace them. Commercial ports, trains and airports were all used to move relief supplies into the area, and also help to right the economy of port cities such as Biloxi and Gulfport. Most roads south of the railroad tracks were either washed away or so covered with debris that they were impassable for several days. (Sullivan 2006) Map 4.1 shows the roads, bridges and airport in Gulfport. Major highways were not without damage. Figure 4.1 below shows the recovery of three U.S. Highways/Interstates. In the period just after Katrina, mostly passable roads were used for emergency purposes. This was the situation for the three roads listed in Figure 4.1. At the beginning of September, roads were cleared for public use, where possible. (Florida State Emergency Response Team 2005)

Map 4.1

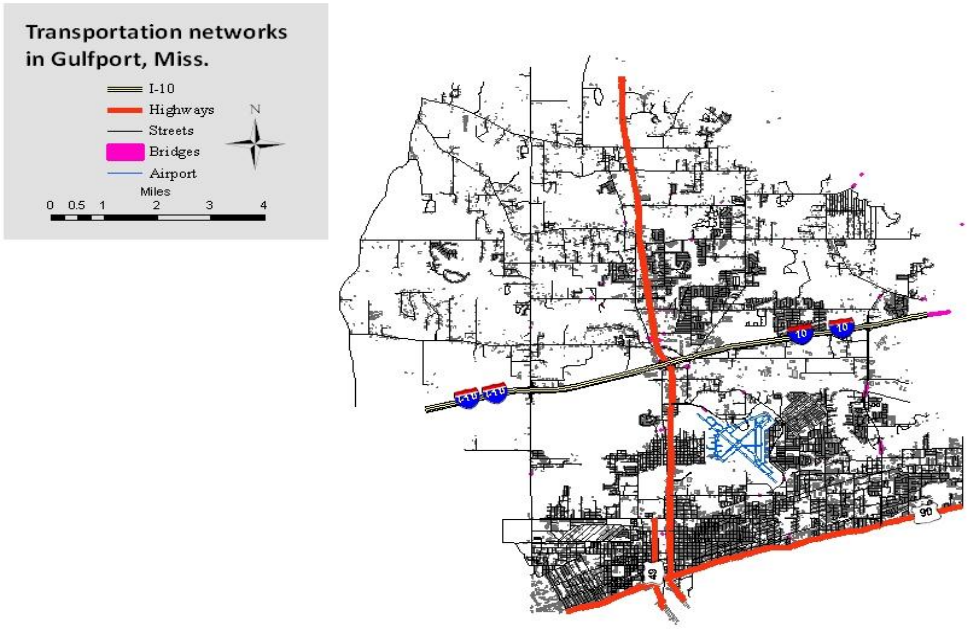


Figure 4.1: Recovery curves for three U.S. Highways or Interstates, Interstate 10, Interstate 110, which connects Biloxi to I-10, and U.S. 49 all were impassable in parts of Harrison County immediately following the storm, but were back in service within two weeks.

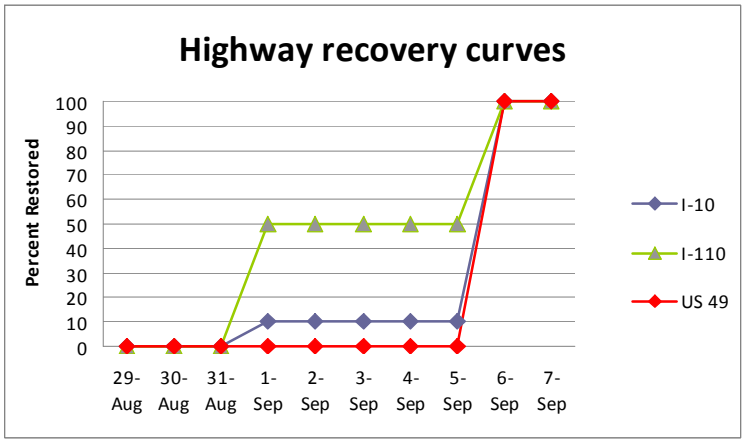
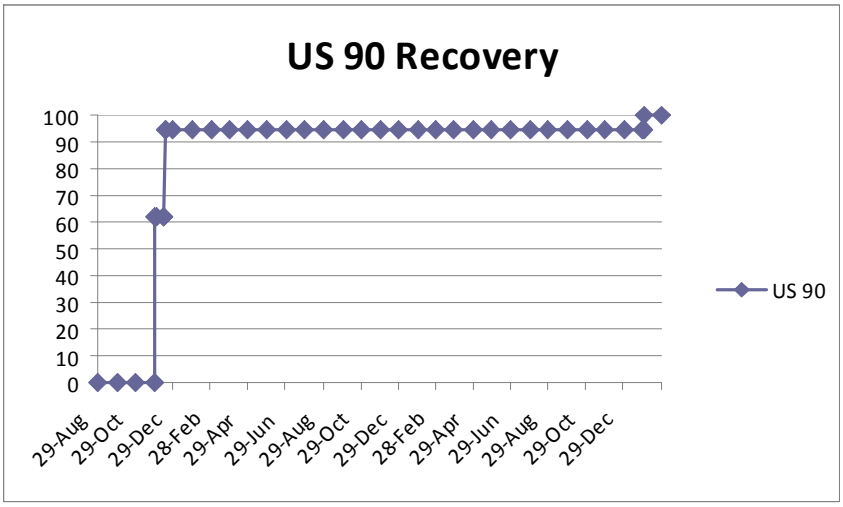


Figure 4.2: Recovery curve for U.S. Highway 90



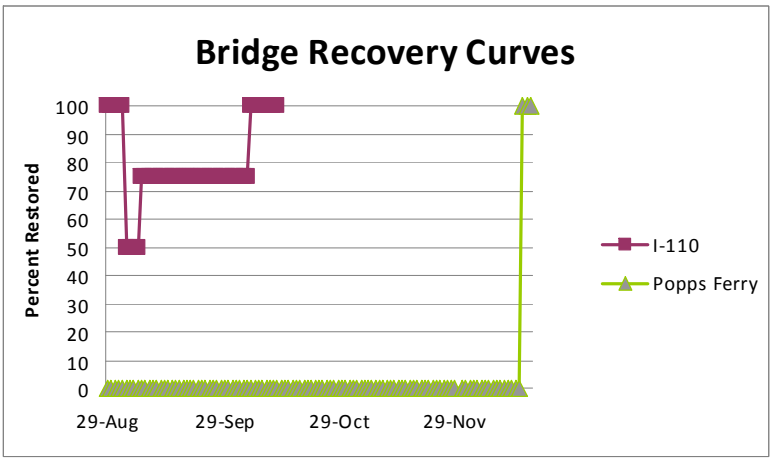
A main artery between Gulfport and Biloxi is U.S. Highway 90, along which the casinos have located (US90 shown in Map 4.1). Casino barges were driven from their moorings, sand and debris were piled high on the roadway. It took more time to restore U.S. 90 for public access than other major roads. Gulfport would open essentially all of its part of US90 on November 29, 2005. Biloxi followed on December 17. (Burton 2005) The bridge span was opened with temporary fixes. Road work is still underway in 2007, scheduled to be completed in January 2008. Street lights were in place in Biloxi when the road opened. Gulfport will install new lights in the fall of 2007. (Burton, The Tale of City Lights 2007) Figure 4.2 shows the recovery curve for U.S.90.

Bridges

The bridges connecting beach communities have been slower to return. Bridge recovery often requires large construction permits. In Biloxi and Gulfport, four bridges were heavily damaged in the storm. One of these, the Old Bridge that connected Biloxi to the town of D'Iberville was used as a pedestrian bridge and a fishing pier. It had large spans removed and

dumped into the bay. As it is not used for vehicle traffic it was not included in the analysis. The remaining three bridges are the Popps Ferry Road Bridge in the west, the Interstate-110 bridge that connects D'Iberville to Biloxi, and the Biloxi Bay Bridge, which was a span of U.S. 90 and connected Biloxi to the community of Ocean Springs in Jackson County to the east. Figure 4.3 shows the recovery of the I-110 bridge and the Popps Ferry Road Bridge.

Figure 4.3: Recovery curves for the Interstate-110 bridge and Popps Ferry bridge show two paths to recovery.



The two bridges followed distinct paths to recovery. Popps Ferry did not lose spans, but large boats and other debris crashed into it, misaligning 21 spans of the bridge and crushing safety railings. When work was completed (Dec 23, 2005), Popps Ferry bridge had 12 new and nine repaired spans (Wilson 2006). The Popps Ferry bridge carried about 20,000 cars a day prior to the storm. While the bridge was out of service, travel between the north and south sides of the bay required a drive through Gulfport or a drive over the already-busy I-110 bridge. (Burton, Popps Ferry Bridge Repair Ahead of Schedule 2005)

The I-110 Bridge survived the storm, but not unscathed. Like the Popps Ferry bridge, debris collisions damaged guard rails. In order to temporarily restore the bridge to service, access to the lane where the damage was done to the guardrail was blocked and the remainder of the bridge was left in service. For a few days another lane was closed to repair cracks. The I-110 bridge

recovery curve therefore has a discontinuity where it went from 75 percent to 50 percent operational, when the second lane was closed. (City of Biloxi 2005) Since the other bridges were not carrying traffic, work went forward quickly on the I-110 bridge. Two lanes were open on October 6, just more than a month after Katrina (Nachko 2007).

Figure 4.4 shows the projected recovery curve for the Biloxi Bay Bridge. The spans of the bridge were moved from their pilings and dropped into the bay. Figure 4.5 shows the progress on the bridge 14 months after landfall. Currently a large portion of the bridge remains much as it was after landfall. Pilings are either entirely missing, (submerged entirely in the bay) or are partially supported by a piling and partially supported by the bottom of the bay. The amount of cleanup and reconstruction necessary to restore the bridge is large, and the first cars are expected to cross mid-November 2007. The bridge is expected to be complete by April 2008. Bridge improvements were incorporated into the contract. Heavier spans with tie-downs should be more resistant to storm surge and uplift, while two additional traffic lanes and a pedestrian/bike path increase the bridge capacity. (South Central Contruction 2007)

Figure 4.4: Recovery curve for Biloxi Bay Bridge.

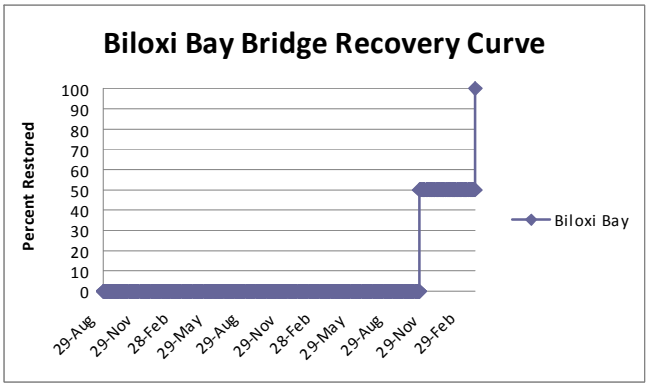
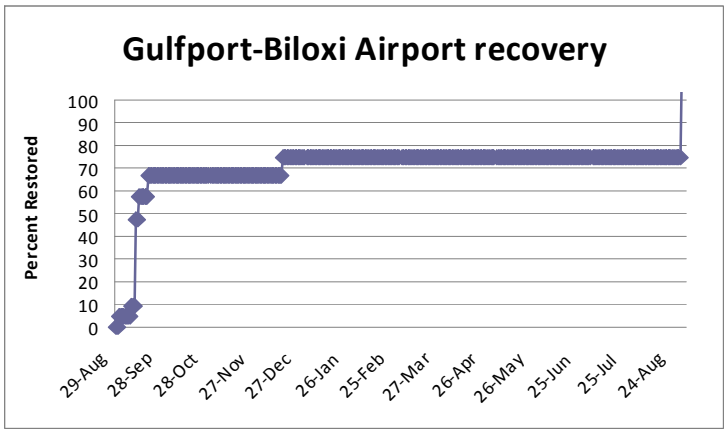


Figure 4.5: Photo of Biloxi Bay Bridge, three weeks after landfall. (Simpson 2005)

Airports

Broken windows allowed water damage to portions of the airport and control tower. (Multidisciplinary Center for Earthquake Engineering Research 2005) Once water was cleared from runways, relief missions were able to get in supplies within two days of landfall. Commercial flights began within 10 days when Northwest Airlines resumed one of its daily flights. (Administration 2005) The addition of two gates, additional flights by airlines operating pre-Katrina, and the introduction of a new airline (AirTran) has increased activity to 114 percent of that of pre-storm activity. Figure 4.6 shows the recovery curve for the Gulfport-Biloxi Airport. (Gulfport-Biloxi International Airport 2006)

Figure 4.6: Recovery curve for Gulfport-Biloxi Regional Airport. Relief missions were in by August 31, commercial flights began on September 8, and by Aug. 29, 2006, the airport was operating at full capacity.

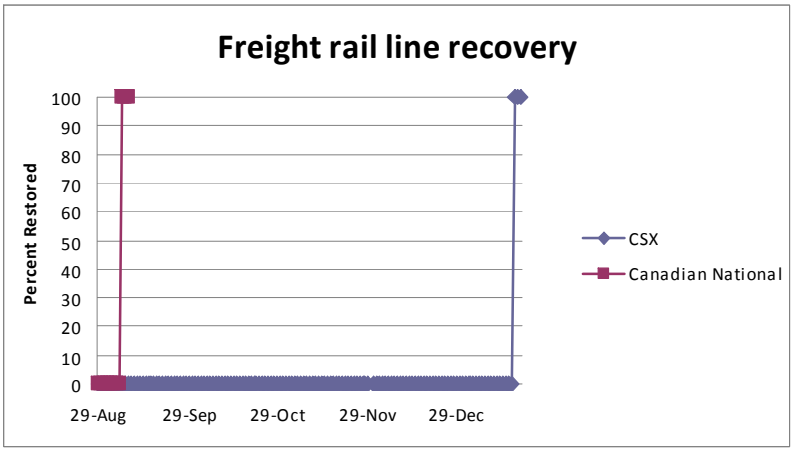


Railroad

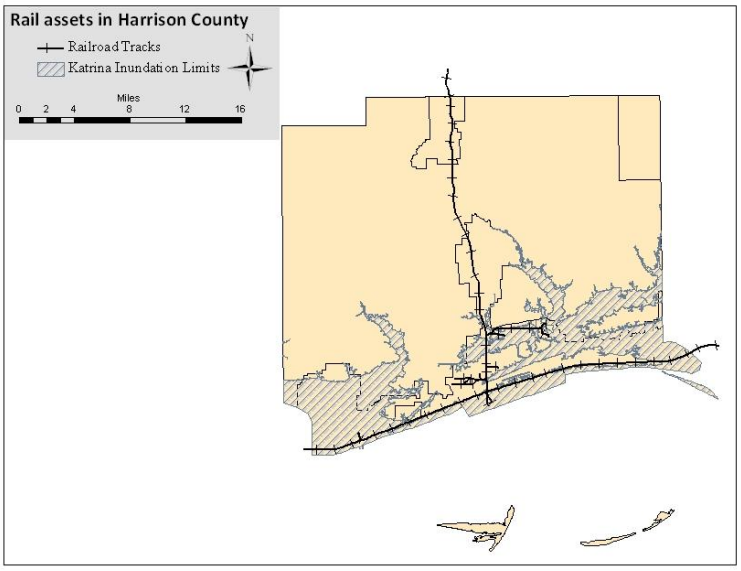
Rail lines and the Port of Gulfport are essential to both the local and national economy. The CSX tracks, which parallel the coast, helps move freight east-west across Mississippi. Canadian National, and Kansas City Southern also had lines in the Gulfport area. The CSX line lost a rail bridge as well as miles of track.

Figure 4.7 shows the track recovery in Gulfport. Map 4.2 shows the rail lines and Katrina's storm surge inundation line, illustrating heavy damage. Canadian National had restored service by September 6. (U.S. Department of Energy 2005) The first CSX Transportation train rolled over the tracks on January 18, 2006, almost five months after Katrina made landfall. (CSX Transportation 2006)

Figure 4.7: Freight rail line recovery curve for tracks in Gulfport. Kansas City Southern has a north-south line also used by Canadian National, and CSX Transportation has an east-west line that parallels the coast.



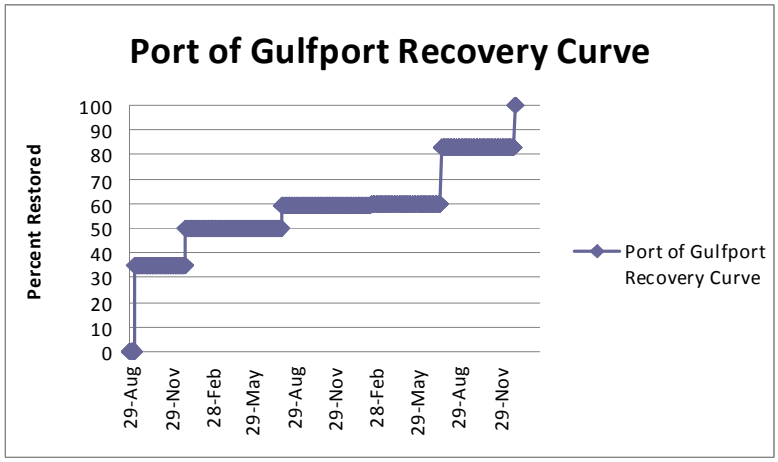
Map 4.2



Ports

As the second-busiest port for fruit imports to the United States, food prices were affected by the loss of the Port of Gulfport. Debris from the port was a cause of damage, as well as damage done to the port itself as containers were battered, scattered and emptied by the storm. Figure 4.8 shows the recovery curve for the Port of Gulfport.

Figure 4.8: The recovery curve for the Port of Gulfport shows a slow but steady progress that is scheduled to conclude by the end of 2007.



Katrina's effect on the Port of Gulfport was intense. Secretary of Transportation Norman Mineta described the situation in an October 6, 2005 appropriations hearing:

> Other Gulf ports, while much smaller, do serve important markets. Prior to Katrina, the Gulfport facility in Mississippi served as an important location for growing Central and South American trade. … Gulfport's physical damage was much more severe and will require close to total reconstruction, but the Department has offered its assistance – working along with other Federal partners – to help the port authority and state and local governments recreate a thriving port facility along the Mississippi coast. (Mineta 2005)

The Port of Gulfport recovery is ongoing. It was several weeks after landfall that electricity was available at the port. (Port of Gulfport on Fast Track to Recovery 2005) Offices, warehouses and freezers and navigational aids were lost to the storm. The seafloor was dumped on the port, and the land at the port became a pile of containers and contents spread through the harbor. On September 10, 2005 the port opened for business, after cleaning and dredging that enlisted help from the Coast Guard, Navy and other national and local agencies. (U.S. Department of Energy 2005) By the end of the year, the port was at half capacity. Currently the port is operating at 83 percent capacity, and officials anticipate full restoration by the end of 2007. (SSA Marine 2007)

EMERGENCY SERVICES

After landfall, fire police and hospitals in each community, as well as the Harrison County Sheriff's Department and the Mississippi State Highway Patrol, were capable of performing their essential functions almost immediately. They had intermittent communication with each other and with other groups working on emergency issues. Emergency services did encounter challenges in dealing with such a large-scale event.

Health Care

In the health care sector, two facilities were severely impacted by Katrina. Select Specialty Hospital in Biloxi and Gulf Coast Medical Center, also in Biloxi, each failed to operate in the days following the Katrina.

Select Specialty Hospital-Biloxi was a 42-bed, long-term acute care facility on U.S. 90 in Biloxi. As described in a previous section, U.S. 90 was severely damaged by storm surge and debris. Select Specialty fared no better. According to an analysis presented to the Mississippi State Department of Health after the storm, "As a result of Hurricane Katrina, the Biloxi facility was damaged beyond repair." The solution for Select Specialty, which had resources in Gulfport as well, was to relocate patients to their Gulfport facility and expand their operations there. This merger was completed on May 31, 2006. While Katrina did not remove Select Specialty Hospital from the Gulf Coast, its operation in Biloxi was closed due to damages. (Mississippi Division of Health Planning and Resource Development February 2005)

The day after landfall, Gulf Coast Medical Center began evacuating patients and staff. The 189-bed hospital suffered severe water damage (Tenet Health 2005). On September 12, 2005, when the hospital reopened to new patients, many services were not available, and the capacity was just 50, less than a third of pre-storm capacity. Surgeries were postponed until there was a dependable water source (Hrickiewicz and Kehoe 2005). Facility costs related to Katrina eventually resulted in the hospital being sold. In a Tenet Healthcare Corporation press release issued April 17, 2006, it states, "The company said the devastating impact of last summer's hurricanes had caused it to reevaluate its operations in Mississippi, mainly as a result of continuing uncertainty about the long-term health care needs of the area." Tenet would complete the sale of the hospital to Health Management Associates, Inc., which also runs Biloxi Regional Medical Center (Tenet Health 2006).

Biloxi Regional's parent company, HMA, sent a generator capable of running the hospital to Biloxi before the storm hit. It also prepared its facility by stockpiling more food, water, fuel and clean-up staff prior to the storm. The foresight paid off. Broken windows and roof damage failed

to significantly slow hospital operations. Eventually Biloxi Regional Hospital became, at least temporarily, not just a health care facility, but a shelter of last resort, and the new home to the large portion of its staff that lost their homes in the hurricane. Relief nurses, staff and physicians were eventually sent from affiliated hospitals to ease the workload on the permanent staff. (Health Medical Associates 2006)

Gulfport Memorial Hospital had an emergency plan, and executed it with changes made to accommodate patients. Despite suffering window breakage and flooding, the hospital remained functional and safe enough to earn the 2006 Safety Net Award from the National Association of Public Hospitals and Health Systems. The hospital had backup generators and a four-day' supply of fuel stockpiled prior to Katrina. It also had a private well, and therefore had access to water, even after the city water system failed. Based on Katrina experience, hospital staff adjusted the emergency plan, storing additional fuel and retrofitting the roof and windows. (VMA Health Foundation 2007)

First responders

For first responders, the medical and emotional toll are generally delayed, surfacing after the initial crisis has passed. This was the case with Biloxi and Gulfport Fire Departments. The Gulfport Fire Chief discussed morale in a June 2006 interview, stating many firefighters lost their homes, but even those who did not suffer at the onset of the storm would be facing long-term losses. In June 2007, Biloxi Fire Department graduated its first rookie class since Katrina. Nine new firefighters should ease the load on a department that had seen more than two dozen firefighters leave and was unable to replace them because of a 14-month hiring freeze. (Miles 2007)

Firefighters faced a daunting task in the immediate wake of Katrina. Hydrants were uprooted by the storm surge or were damaged by heavy debris. Water pressure was nonexistent. Even if these conditions had not existed, it was impossible to travel to the site of an emergency due to an impassable transportation network. Fuel and water shortages further complicated the situation. To solve the water problem, drop tanks were used in ponds, and water was borrowed from the local Naval Construction Battalion. Additionally, seven tank trucks were borrowed from FEMA, and were retained locally for several months (Sullivan 2006). Fuel was a problem throughout the area-- enough to require state law enforcement involvement in the commandeering of tanker trucks. At one point, the Gulfport FD was within an hour of running out of fuel (Sullivan 2006).

CONCLUSIONS

In the aftermath of any disaster, data collection is not high on the list of objectives for community officials. Much of the data used to analyze the recovery for Biloxi and Gulfport were pieced together from a mix of press releases, media reports and recollections of stakeholders recorded months after the storm. Due to the nature of the sources, data was often vague, incomplete or missing. The problem is evident in the lack of data about gas lines or the aggregation of electric data in this report.

Interviews gave insight regarding the extent of data issues. The Biloxi city GIS specialist recalled that gas lines were capped manually, but had no record of where it was done or how much gas escaped (Nolan 2006). The GIS coordinator for Southern Mississippi Planning and Development District said there was virtually no documented record of what they did after the storm hit (Barnes 2006). Gulfport Public Works interviews found that the city's pumps kept working when they were underwater, but pumped sewage into the open. However, they could not

determine when the water eclipsed the pump levels, when they receded, or how much sewage passed through.

While press releases offered data that could not be found in any other readily accessible form, it is important to note that these releases and media reports are inherently sub-optimal sources. Press releases are issued from corporate sources and tend to favor positive progress of the organization, while minimizing failures. Press releases also tend to summarize and aggregate data, when parsing is needed or more appropriate for analysis. Media reports also tend to the extremes, looking for the emotional and interesting issues. On the other hand, they are also unique in that as a daily source, they can correct mistakes as the situation is clarified.

Data collection in emergency events needs to be improved if research and analysis can advance to the point where community preparedness and mitigation can be meaningfully compared and improved. Utilizing new methods of data collection is essential to progress in this regard. The data issues raise several implications addressed in the recommendations for action and future research. Gulfport and Biloxi were fortunate not to encounter the severity of problems that some cities experienced. Demonstrating preparedness in some aspects of communications and public works, these cities illustrate positive examples. However, land-use decisions, transportation and fuel storage experiences in the communities illustrate a number of problems faced by coastal communities in any hurricane. Establishing recovery curves and standardized measurement methodologies for infrastructure within the community can help understand the effects and assist communities as they prepare for the next event. To reach that point, policy changes and advances in data collection are necessary to improve analytical power of post event activity.

Recommendations

Billions have been spent on recovery, and millions on research, in the wake of this disaster. It is clear that one of the weaknesses in the ability to conduct research and learn from the events is the existence of a "data gap." The gap is the natural result of the focus (entirely appropriate) of efforts on response and recovery, and not documentation. While there was a great deal of post-Katrina "lessons learned" and "what happened" style reports, none called for the improvement of process documentation, data archiving or other observational efforts that could create richer data sets for post event analysis. We argue that there are gains that would offset the cost of improving these data sets. Two specific examples are 1) creating a "data specialist" position in the Emergency Operation Center, that would co-exist sided-by-side with the communications officer, the logistics officer, and similar, and 2) creating a "Data Element" in the FEMA response plan that embeds a data specialist in the community as part of the response and recovery efforts. The individual (or individuals) would have a standardized set of data that they would be looking for, in addition to any ongoing observational data collection. These efforts have very small marginal costs, and yet would build from each disaster experience a deeper and more easily compared database of community recovery.

Research of course will be needed to determine the most appropriate sets of measurements that would make this effort successful, for example should the analysis be framed around fragility and recovery curves, or some other set of metrics. Additional research would be needed to understand exactly how an embedded data specialist would operate, and what data would be made publicly accessible. To the degree possible, funding agencies (such as NSF, NIH, EPA and others) should invest a small percentage of agency funding efforts that would look to consolidate and coordinate the data gathering efforts and the range of research that inevitably follows a

disaster. While some of these steps have been taken in individual agencies (NSF for example), there has not been funding that seeks to synthesize efforts across multiple agencies.

Just as it is true that disasters will continue to affect our communities, it is also true that we will continue to improve our understanding of the effects, and how to mitigate against the worst of them. Improved measurement and a deeper understanding of the critical elements in a community's infrastructure will enable more effective and cost efficient investment of resources in any community.

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Appendix A: Communications Rubric

	Have it	Works	Recovered		Upgraded
Land lines-LD	1	0	31-Aug		1
Landline local	1	0	20 by 9/5, 81 BY 9/30, 100 of all possible by 12/13		1
Sat Phones	1	1		1	1
Internet at EOC	1	1	Na	na	
911 Calls	1	1	Na	na	
So LINC	1	1	Na	na	
Redundant	1	1	Na	na	
WMAH	1	0	Aug. 30		1
WLOX	1	1	Na	na	
Memos	0	.5 biloxi	Na		0
Mail	1	0	Office Dist. SS by 9/3, 75 9/10, 82 9/14, 100 by 10/7. Lost 6 pos		
Sheriffs	1	1	Na		1
Police	1	1		1	1
Fire	1	1		1	1
National Guard	1	0		4-Sep	1
FEMA	1	0	Sept. 1		1
Sat to MEMA	1	0	Sept. 1		1
MEMA	1	1	Na	na	
Neighboring Counties	1	0	Sept. 10		1
Outside help	1	1	Na	na	
WiFi	1	0	Sept. 10		1
Verizon Wireless	1	0	critical areas by Sept. 7		1
Cingular	1	0	improving by Sept. 7		1
Sprint/Nextel	1	0	improving by Sept. 7		1
Tmobile	1	0	improving by Sept. 7		1
Cellular South	1	0	Sept. 12		1
Newspaper (Sun-Herald)	1	1	Online, immediately, in print: 8/30		0
Text Messaging	1	0		1-Sep	0
	29	12.5		41.5	
				69.16666667	