TORNADO OUTBREAK *of* 2011

IN ALABAMA, GEORGIA, MISSISSIPPI, TENNESSEE, AND MISSOURI

8 Observations on Infrastructure Performance

Natural hazards not only damage buildings but can also damage and disrupt a community's infrastructure. Infrastructure damaged during disaster events can have a widespread effect on a community's ability to recover and significantly delay its return to normal functioning.

While MATs have historically concentrated on the performance of buildings, this MAT also assessed the performance of some utilities that were affected by the tornadoes, including water treatment and distribution facilities and towers (communications and antennae). The MAT also visited a wastewater treatment facility that performed well during and after the event and determined that lessons applicable to similar facilities could be learned.

The MAT assessed infrastructure in Tuscaloosa, AL, and Smithville, MS. The Tuscaloosa facilities the MAT visited are shown in Figure 8-1. The Smithville facilities are shown in Figure 8-2.

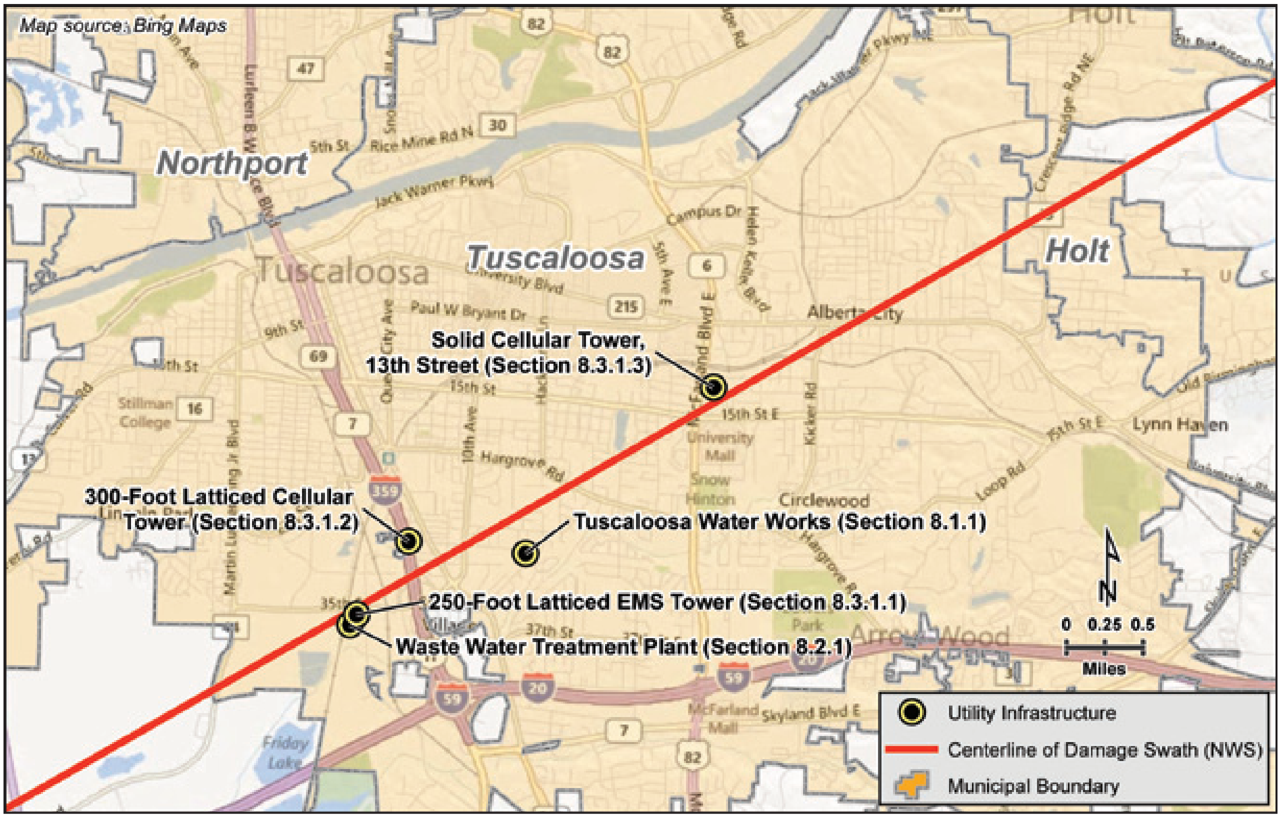

Figure 8-1: Locations of infrastructure assessed by the MAT in Tuscaloosa, AL
SOURCE FOR TORNADO TRACK: HTTP://WWW.SRH.NOAA.GOV/SRH/SSD/MAPPING

The MAT visited several infrastructure facilities and assessed tornado damage and its effects on those facilities; however, the MAT did not provide EF ratings for the structures for two reasons. First, no EF scale DIs are established for some of the infrastructure types the MAT visited, and second, the effects of high winds on the infrastructure were not always the result of direct damage to the infrastructure, but rather to the utilities that served the infrastructure. Most notably, the high winds did not damage the water treatment and distribution systems the MAT observed, but did damage the electric lines that fed those systems; therefore, the most serious consequences of the tornadoes on those facilities were not from direct damage, but from the loss of electrical power.

8.1 Water Treatment and Distribution Facilities

Water treatment and distribution facilities typically consist of a water source, a treatment facility, and a system of water distribution pipelines that deliver treated water to customers. Depending on the relative elevations between the water sources and the customers and the geographical location of those customers, water storage towers and water pumping stations may also be present. Water towers can be vulnerable to high-wind events, particularly when the amount of water stored in them is low, and water treatment facilities and water pumping stations can be vulnerable to service interruptions when electrical power is lost. Long-duration service interruptions can be devastating to a community trying to recover from a natural hazard event. Service interruptions can also lead to

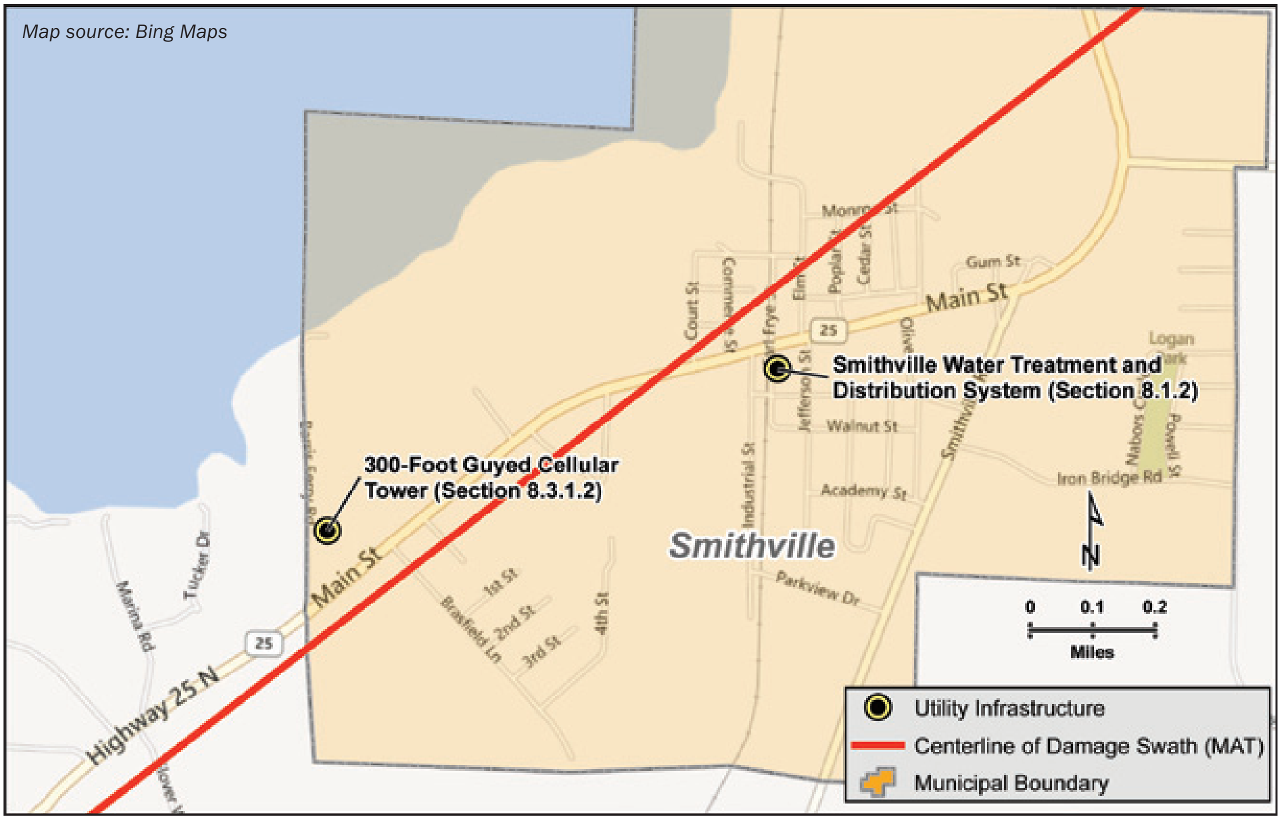

Figure 8-2: Locations of infrastructure assessed by the MAT in Smithville, MS. The NWS track is not shown since it varied greatly from MAT observations.

SOURCE FOR TORNADO TRACK: MAT-DERIVED

contamination of the treated water and create significant health hazards. Following the devastating April 2011 tornadoes, the MAT visited two water treatment facilities, one in Tuscaloosa, AL, and one in Smithville, MS.

8.1.1 Tuscaloosa Water Works (Tuscaloosa, AL)

The Tuscaloosa Water Works is part of the Tuscaloosa Water Works and Sewer Department. According to their Web site, the Tuscaloosa Water Works delivers more than 10 billion gallons of water to their customers annually. They serve over 200,000 customers in the City of Tuscaloosa and surrounding communities of Carrols Creek, Coaling, Coker, Englewood-Hulls, Foster-Ralph, Mitchell, and Peterson.

Location of Facility in Tornado Path: Figure 8-3 shows an aerial view of the tornado damage swath. NWS rated the center of the tornado circulation as EF4 in the vicinity of one of the Tuscaloosa Water Works storage towers and the DCH Regional Medical Center, a local hospital served by the Tuscaloosa Water Works that suffered reduced water pressure after the tornado.

Facility Description: The Tuscaloosa Water Works system has 575 miles of water mains that are 4 inches in diameter or larger and 3,684 public fire hydrants. The Tuscaloosa Water Works collects

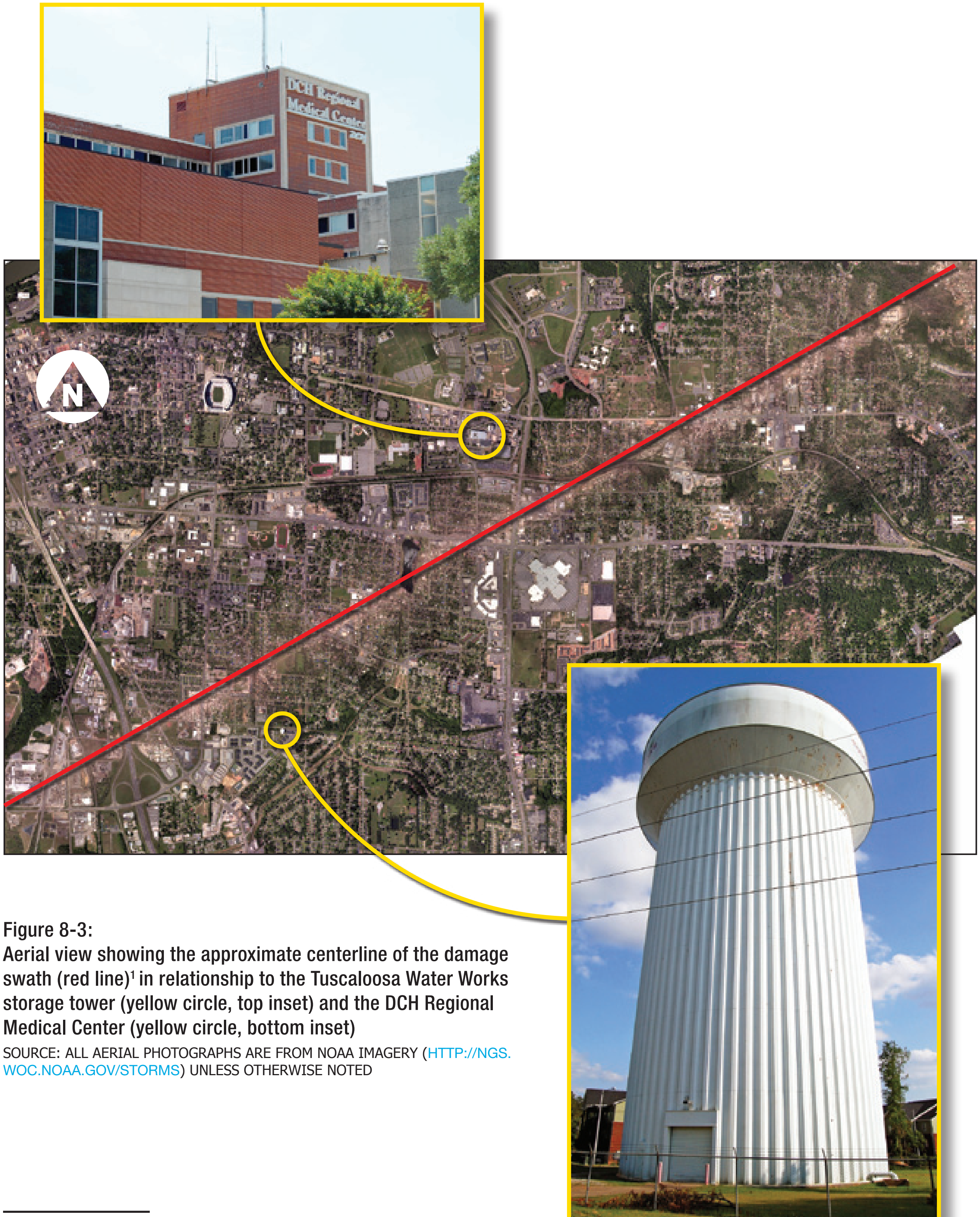

Figure 8-3:
Aerial view showing the approximate centerline of the damage swath (red line)[1] in relationship to the Tuscaloosa Water Works storage tower (yellow circle, top inset) and the DCH Regional Medical Center (yellow circle, bottom inset)

SOURCE: ALL AERIAL PHOTOGRAPHS ARE FROM NOAA IMAGERY (HTTP://NGS.WOC.NOAA.GOV/STORMS) UNLESS OTHERWISE NOTED

1 The red line in this and all similar figures represents the center of the damage swath. The track location is approximated by the MAT based on post-event aerial photographs. The actual centerline of the vortex is offset from the centerline of the damage.

water from the Ed Love Lake and the smaller Jerry Platt Lake. The Ed Love plant can treat up to 45.7 million gallons per day (MGD). The Jerry Platt plant can treat up to 14 MGD. Water is treated at two treatment plants, pumped into 13 storage towers, and fed to customers. The system can store 25.4 million gallons of treated water, 20.6 million gallons of which are stored in tanks; the remaining quantity is stored in the distribution piping.

Emergency power at the Ed Love plant consists of two 1,500-kilovolt-ampere diesel generators that allow the plant to fully function while normal power is lost. There are 23 booster pumps in 8 booster pump stations that fill the storage tanks and control system pressure. The pumps range in size from 25 to 100 horsepower. The pumps are powered by overhead electrical lines from the local electrical utility; no emergency generators are in place to provide alternate power to the pumps.

General Wind Damage and Functional Loss: The Tuscaloosa Water Works storage towers were outside of the tornado's swath and were not damaged. However, tornadic winds along the track destroyed hundreds of buildings and other structures in Tuscaloosa. The tornado winds also destroyed miles of overhead electrical transmission and distribution lines and damaged or destroyed electrical substations. Power to the area was interrupted, and several water service lines were broken when buildings were destroyed by the tornado. Figure 8-4 shows representative damage to overhead lines and substations. Shortly after the storm, line breaks contributed to large amounts of water loss, but the larger water line breaks were isolated within hours, so water losses through line breaks were quickly minimized. Smaller line breaks were isolated within 2 to 3 days.

Electrical power, however, was not restored for several days, and without power to drive the lift pumps that fill tanks and booster pumps for system pressure, the storage tanks drained and system pressures dropped. Water service was affected, including water service to critical facilities. For example, approximately 7 hours after the storm, the normal 90 pounds per square inch (psi) of water pressure normally provided to DCH Regional Medical Center (location shown in Figure 8-3) dropped to 25 psi. With the reduced water pressure, toilets on upper floors would not flush and the low water-pressure levels required the hospital to shut down a boiler supplying steam to their central sterilization equipment. Without sterilization equipment, surgical procedures were curtailed.

Figure 8-4: Representative damage to overhead electrical lines and substations along the tornado path (Tuscaloosa, AL)

8.1.2 Smithville Water Treatment and Distribution System (Smithville, MS)

Smithville, MS, is supplied by a 42 MGD water treatment and distribution system. Surrounding areas are supplied by a separate rural water treatment and distribution system. The urban and rural systems serve approximately 450 clients each. The rural system was not damaged by the tornadoes and was not inspected. Observations of the system in Smithville proper are described below.

Location of Facility in Tornado Path: A tornado touched down west to southwest of Smithville and travelled east to northeast. NWS rated the center of the this tornado circulation as EF5. The approximate centerline of the tornado damage swath is shown in Figure 2-2 (tornado #43) and below in Figure 8-5. Figure 8-5 also shows the location of the Smithville Water Treatment Plant and storage tower, as well as the location of a 300-foot-tall guyed cellular tower that collapsed (discussed in Section 8.3.2.1).

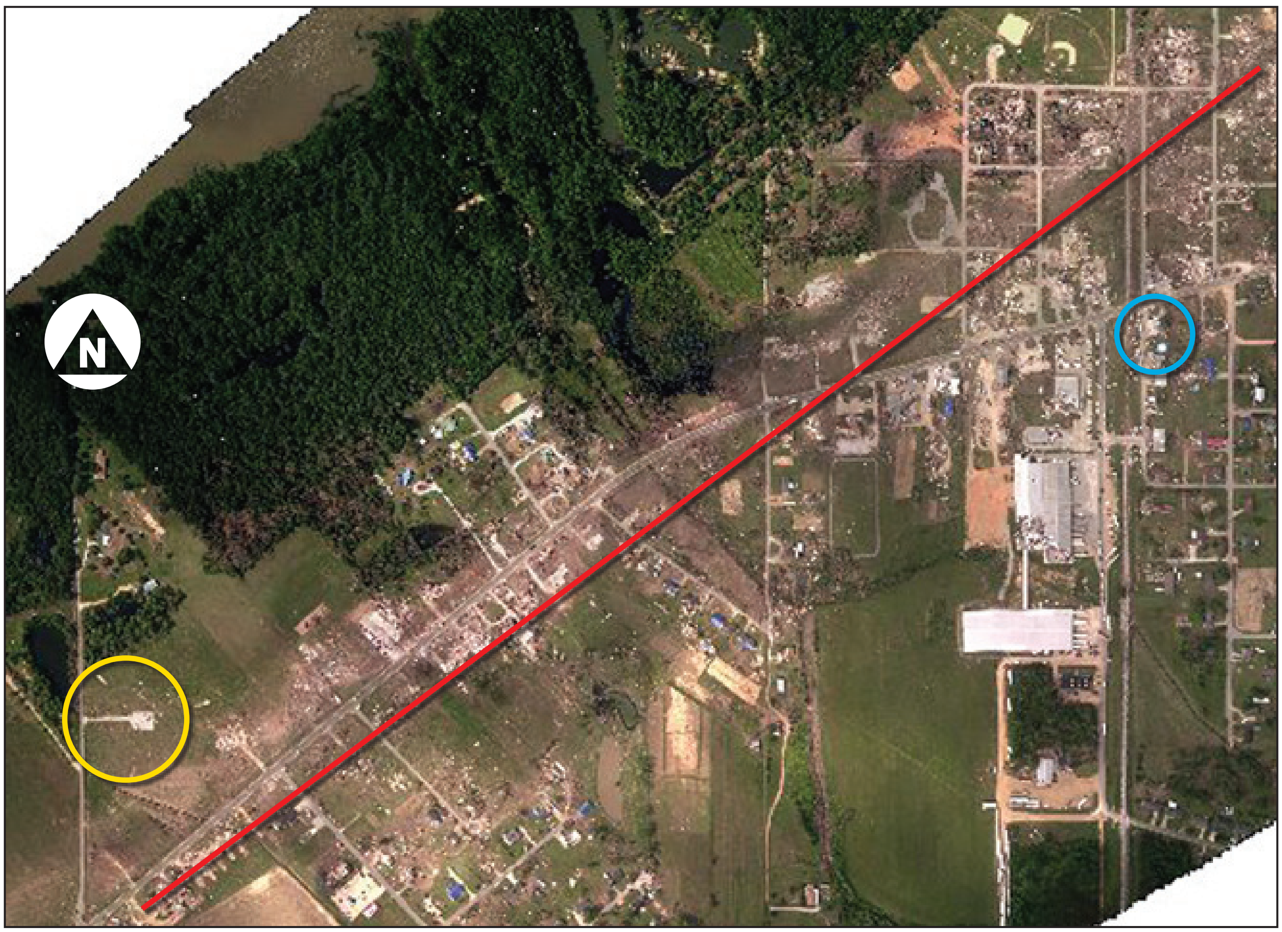

Figure 8-5: Aerial view showing the approximate centerline of the tornado damage swath in Smithville, MS (red line), the Smithville Water Treatment and Distribution System Plant (blue circle), and the 300-foot-tall cellular tower discussed in Section 8.3.2.1 (yellow circle)

Facility Description: The Smithville Water Treatment and Distribution System Plant is shown in Figure 8-6. The water for the urban system is drawn from two wells, treated, stored in an underground clear well, and then pumped into a large storage tank (Figure 8-7). From the storage tank, treated water is gravity-fed to customers. Treatment consists of aeration, sand filtration, chlorination, and pH control. Since the well water is high in dissolved iron, it is also treated for iron removal. The wells, treatment plant, lift pumps, and storage tower are all on Earl Frye Street in Smithville.

Water is pumped from the treatment facility clear well to the storage tank with two 20-horsepower lift pumps. The pumps are operated lead/lag (i.e., only one pump operates at a time). The pumps are supplied by overhead electrical lines. The facility does not have any emergency or standby generators for alternate power.

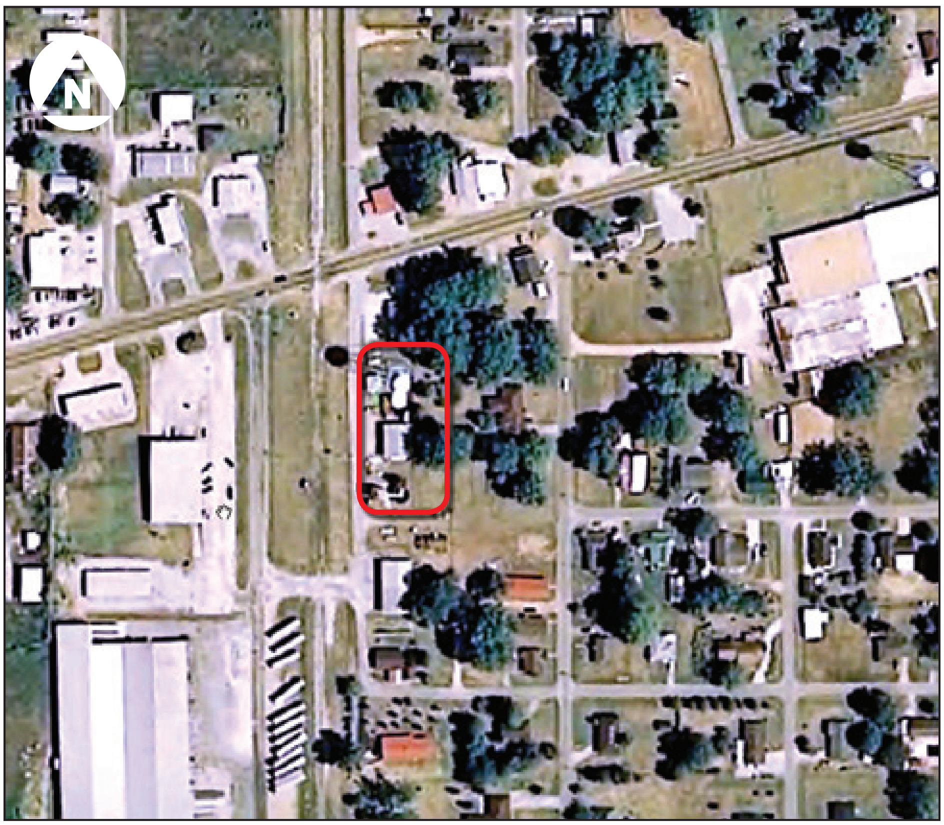

Figure 8-6:
Smithville Water Treatment Plant and storage tower (red box) aerial photograph pre-dates the tornado (Smithville, MS)
SOURCE: © GOOGLE EARTH

General Wind Damage: At the Smithville Water Treatment and Distribution System Plant, the tornado destroyed a small building constructed of unreinforced CMU and damaged a small storage building constructed of metal frames and metal wall and roof panels (Figure 8-8). The buildings were used for secondary non-critical functions like maintenance and storage, and the damage did not significantly affect operations.

Figure 8-7:
Water tower after the tornado (Smithville, MS)

Figure 8-8: Destroyed unreinforced CMU building (left) and damaged metal-framed building (right) (Smithville, MS)

The water treatment control equipment was in a building constructed of reinforced masonry (Figure 8-9). While close to the other buildings and exposed to similar winds, the stronger reinforced building was not extensively damaged.

Figure 8-9:
Reinforced CMU building housing control equipment (left) and undamaged water treatment control equipment (right) (Smithville, MS)

The storage tower was struck by large pieces of wind-borne debris (Figure 8-10). The debris impacted the tank itself and a compression strut that provides lateral bracing and support for the tower legs. At the time of the MAT visit, the impacted area of the tank was not repaired, but the damaged compression strut had been straightened and reinforced. System operators did not know whether the repairs were completed under the direction of a design professional.

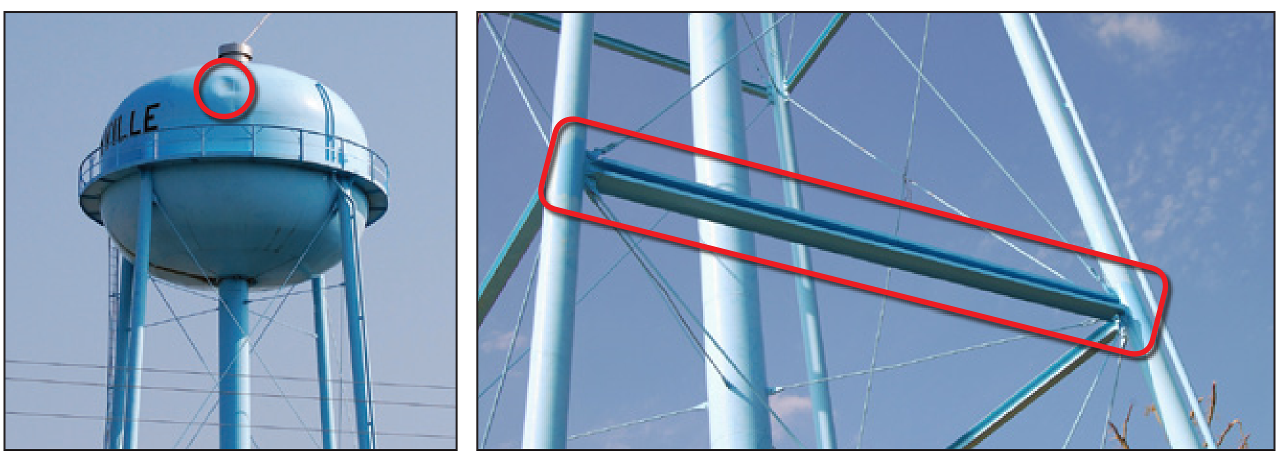

Figure 8-10: Debris impact damage to Smithville, MS, water tank: photograph on left shows where debris struck the water tank itself (red circle) and photograph on right shows the repaired compression strut that was damaged by wind-borne debris (red box)

Water pumps and pump controllers were located outside (Figure 8-11). Even though wind-borne debris was widespread in the area, they were not damaged. However, high-pressure chlorine cylinders were stored outside and only lightly secured with small-gage chain (Figure 8-12). Some cylinders were dislodged and displaced nearly 100 yards by the tornadic winds.

Figure 8-11: Lift pumps and controls of the Smithville, MS, water plant were exposed, but not damaged

Figure 8-12: Lightly secured chlorine cylinders; some were displaced by high winds (Smithville, MS)

> Chlorine is a hazardous material and 40 CFR 355.30 triggers emergency planning requirements when more than 100 pounds of chlorine is stored. Containers of chlorine should be protected from exposure to weather, extreme temperatures changes, and physical damage, and they should be stored separately from flammable gases and vapors and combustible substances.

Functional Loss: While critical equipment was not damaged (even though much of it was exposed), the tornado destroyed overhead electrical lines and disrupted power to the Smithville, Water Treatment and Distribution System Plant. The tornado also broke fire hydrants and destroyed most of the buildings in town. The destruction of buildings damaged much of the water service piping laterals that supplied individual customers.

The damage to distribution piping and water service piping laterals resulted in rapid water loss. Since there were no emergency or alternate power supplies serving the lift pumps, the storage tank drained rapidly, and there was a loss of system pressure in the distribution system. The loss of system pressure can allow groundwater to enter distribution piping and contaminate the treated water in the system. Although operators stated that they did not know if water contamination occurred after the tornado, the water treatment and distribution system plant issued “Boil water before use” orders to its customers as a precautionary measure. During the MAT’s visit 11 days after the event, distribution and service line breaks had been repaired or isolated, and system pressure was restored. Operators of the system were awaiting water test results before lifting the “Boil water before use” orders.

8.2 WasteWater Treatment Facilities

A functioning wastewater treatment facility is critical for recovery after a natural disaster. Long-term loss of a wastewater treatment facility can create significant health hazards. The MAT interviewed the director of the Tuscaloosa Waste Water Treatment Plant. The plant managed to continue running after the tornado even though the facility experienced wind damage and normal power supply to the plant was lost.

8.2.1 Tuscaloosa Waste Water Treatment Plant and Collection System (Tuscaloosa, AL)

The Tuscaloosa Waste Water Treatment Plant treats effluent from the entire city and surrounding service areas. The plant has a current capacity of 30 MGD, but plans to add an additional 15 MGD in 2013.

Location of Facility in Tornado Path: The location of the Tuscaloosa Waste Water Treatment Plant is shown in Figure 8-1. Figure 8-13 shows an aerial view of the centerline of the tornado damage swath in the vicinity of the Tuscaloosa Waste Water Treatment Plant.

Facility Description: The Tuscaloosa Waste Water Treatment Plant is a 30 MGD plant that serves Tuscaloosa and surrounding areas. Power for the water treatment facility is normally provided by the local electrical utility from overhead distribution lines. The treatment plant itself has on-site emergency diesel generators that allow the plant to operate during prolonged power outages. Also, approximately 50 of the 60 remote lift stations that pump untreated effluent to the treatment plant are equipped with emergency generators.

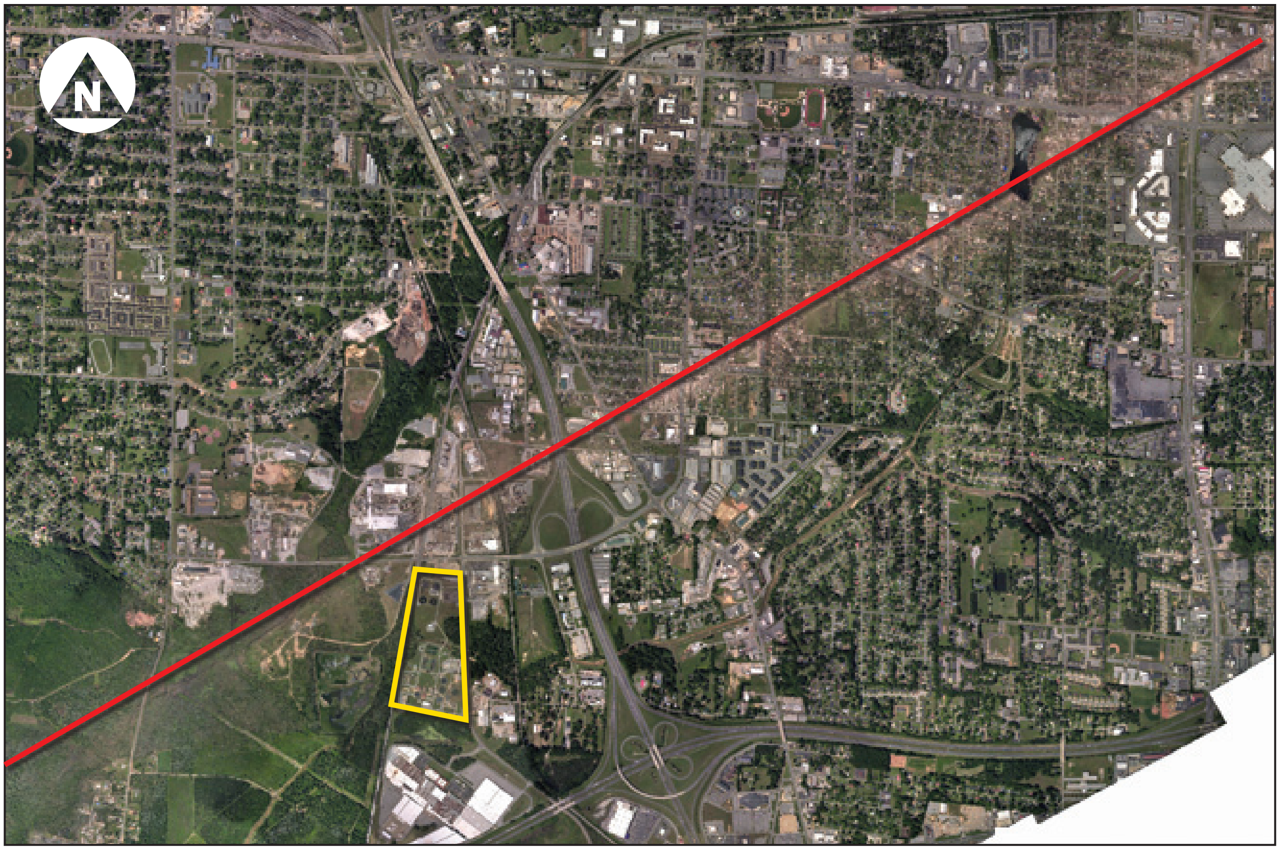

Figure 8-13: Aerial view of the Tuscaloosa Waste Water Treatment Plant (yellow rectangle) in relation to the approximate centerline of the April 27, 2011 tornado damage swath (red line)

General Wind Damage and Functional Loss: The director of the Tuscaloosa Water Works and Sewer Department stated that the tornado disrupted the normal utility power to the plant and remote lift stations, and caused damage to roof systems, doors, and windows at the treatment plant. While normal power was lost, the system continued to operate on emergency power during and after the event with no overflow or discharge of untreated effluent. Some of the remote lift stations lacked emergency power, and effluent had to be pumped into trucks for transportation to the central treatment plant. The loss of doors, windows, and roof coverings allowed water to enter the treatment plant building, but the water entry did not disrupt operations.

8.3 Towers (Communications and Antennas)

Communications towers support antennae that serve cellular phones, emergency management systems (EMSs), fire, police, and other critical functions. Since the number and type of antennae mounted on any given tower varies greatly, the functional effects of losing a tower can only be determined on a case-by-case basis.

Towers fall into two general categories: guyed towers and free-standing towers. Guyed towers use a system of steel cables that provide lateral support for a single vertical mast. One end of each cable is connected to the tower, and the other end is connected to earth anchors or concrete foundations. Guy wires are usually installed in sets of three, with each guy wire spaced 120 degrees from adjacent wires. Guy wires are tensioned so that the lateral loads on the mast are balanced, and the mast itself is exposed only to compression loads. The mast in a guyed tower is typically quite slender since the mast is primarily loaded in compression, and lateral wind loads are resisted by the guy wires.

Free-standing towers can be either latticed structures or solid structures. Solid structures are not solid through their cross-sections but rather their interiors are hollow and their outer surfaces solid. Unlike guyed towers, free-standing towers do not rely on guy wires and anchors for lateral support. For a free-standing tower to function, it must be strong enough to resist all lateral loads imposed on it from a design event. It must also be able to transfer those loads to a suitable foundation and the foundation must be large enough and strong enough to transfer all applied loads to the supporting soils below. Without guys, free-standing towers must have a wide footprint and large foundations to prevent overturning and toppling.

8.3.1 Free-Standing Towers

The MAT assessed two latticed towers: a 250-foot tower used by the Tuscaloosa EMS and a 300-foot cellular tower. It also evaluated a solid cellular tower near a retail center in Tuscaloosa, AL (see Section 5.2.3); although the MAT did not visit this tower, it evaluated to tower's performance by reviewing photographs taken from a helicopter during a flyover 3 days after the tornado struck the area.

8.3.1.1 Latticed 250-Foot EMS Communications Tower (Tuscaloosa, AL)

The Tuscaloosa EOC (described in Section 7.3.1), which was destroyed by the tornado, was served by a free-standing, latticed, 250-foot-tall communications tower. The tower supported antennae for fire, police, and the EOC. The 250-foot EMS tower was located at N33.177933° and W87.563561°.

Location of Facility in Tornado Path: The location of the EMS communications tower is shown in Figure 8-1. Figure 8-14 shows an aerial view of the centerline of the tornado damage swath near the EMS communications tower. The EMS communications tower was within 1,000 feet of the center of the tornado damage swath.

Facility Description: The EMS communications tower was relatively new, having been constructed within the last 2 years. The tower was a triangular-based latticed steel structure on concrete foundations. The tower bases were spaced 20 feet apart and constructed with six 7/8-inch-diameter anchor bolts on poured concrete foundation caps. The size and depth of the foundation could not be determined visually.

General Wind Damage and Functional Loss: The EMS communications tower collapsed during the storm and fell across the road that separates it from the EOC. By the time of the MAT's visit, the tower had been removed, and only its concrete base remained. The tower was, however, photographed by EMS staff from the ground the day of the event (Figure 8-15) and from a helicopter 3 days after the tornado struck it on April 27 (Figure 8-16).

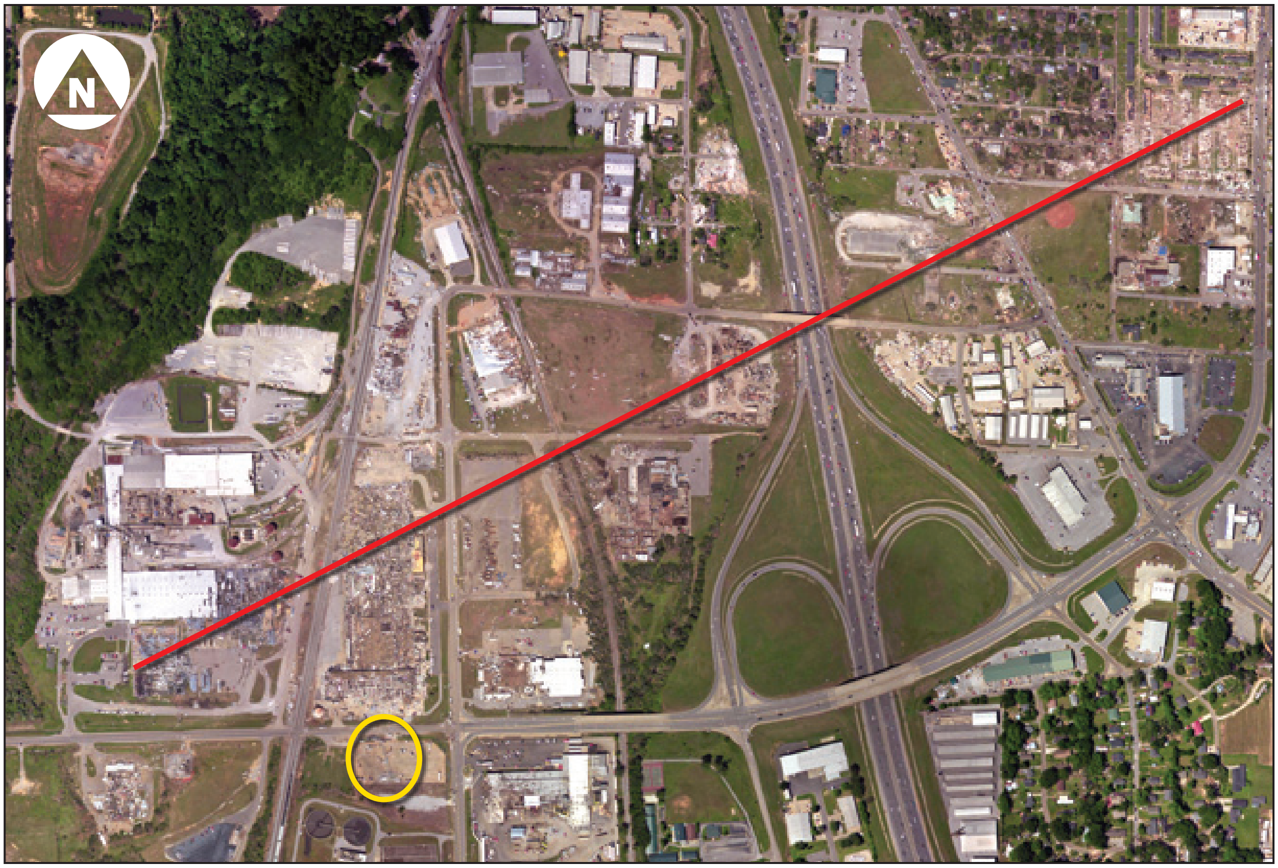

Figure 8-14: Aerial view of the approximate centerline of the tornado damage swath (red line) in the vicinity of the latticed 250-foot EMS communications tower (yellow circle) (Tuscaloosa, AL)

Figure 8-15: View of toppled EMS communications tower taken by EMS personnel after the tornado. Note the wind-displaced material (discussed in text) adhered to the tower (Tuscaloosa, AL).

PHOTOGRAPH COURTESY OF TUSCALOOSA COUNTY SHERIFF'S OFFICE

Figure 8-16: View of the collapsed EMS communications tower (yellow oval); the EOC across 35th Street is also shown (red oval) (Tuscaloosa, AL). The communications tower was cut, and the debris that was across the road was removed (yellow triangle).

PHOTOGRAPH COURTESY OF TUSCALOOSA COUNTY SHERIFF'S OFFICE

The MAT noted fresh shear cracks in the concrete foundation bases (Figure 8-17). The cracks resulted from tensile loading in the tower/base connection and suggest that bending occurred in the concrete tower base.

Figure 8-17: Photograph shows the six-bolt tower base with cracks in concrete foundation cap (red oval) (Tuscaloosa, AL)

> In this section, the MAT introduces a new term: ***wind-displaced materials***. Historically these materials have been referred to as wind-borne debris.
>
> While both wind-displaced materials and wind-borne debris are created by high-wind events, their effects on downwind structures are very different. Wind-borne debris tends to puncture building envelopes, while wind-displaced materials tend to wrap around or adhere to downwind structures and can increase wind loads on those structures.

Wind-displaced materials adhered to the latticed EMS communications tower (Figure 8-16). The adhered materials consisted of chain link fence fabric and webbing interwoven into the fabric. The adhered materials created nearly solid surface areas that increased the amount of surface area exposed to wind pressures, thereby increasing the wind loads on the tower.

The MAT could not determine if the wind-displaced materials adhered to the EMS communications tower before or after it collapsed. Since fencing is generally not an engineered structure, and communications towers are generally extensively engineered, it is highly likely that the fencing was displaced before the tower collapsed. If this was the case, any displaced fencing material that wrapped around the tower would have increased wind loads and could have contributed to the tower failure.

ASTM E1996, *Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes* (2009), which is referenced in the wind-borne debris requirements of the 2012 IBC, specifies missile types and sizes ranging from small steel balls that simulate roof surface aggregate to large 2x4 framing members that simulate debris from destroyed upwind structures. However, there is no specification for materials that do not puncture building envelopes, termed here as "wind-displaced materials" (see text box). Currently there is no consensus standard on wind-displaced materials and no guidance on how to treat their effects on wind loading of structures.

8.3.1.2 Latticed 300-Foot Cellular Tower (Tuscaloosa, AL)

A 300-foot latticed cellular tower was located approximately 0.6 mile northeast of the EMS communications tower. Like the EMS communications tower, the cellular tower was a latticed style free-standing tower. Unlike the EMS tower, the cell tower was older and appeared to have been in service for years. The 300-foot cellular tower was located at N33.184515° and W87.557541°.

Location of Facility in Tornado Path: The location of the latticed 300-foot cellular tower is shown in Figure 8-1. Figure 8-18 shows an aerial view of the centerline of the tornado damage swath in the vicinity of the 300-foot latticed cellular tower; also shown is the location of the EMS communications tower 0.6 mile to the southwest (described in Section 8.3.1.1). The 300-foot cellular tower was approximately 500 feet north of the center of the tornado damage swath.

Facility Description: The bases of the 300-foot latticed cellular tower were spaced 30 feet apart and consisted of six 1½-inch diameter anchor bolts set in cast-in-place concrete (Figure 8-19).

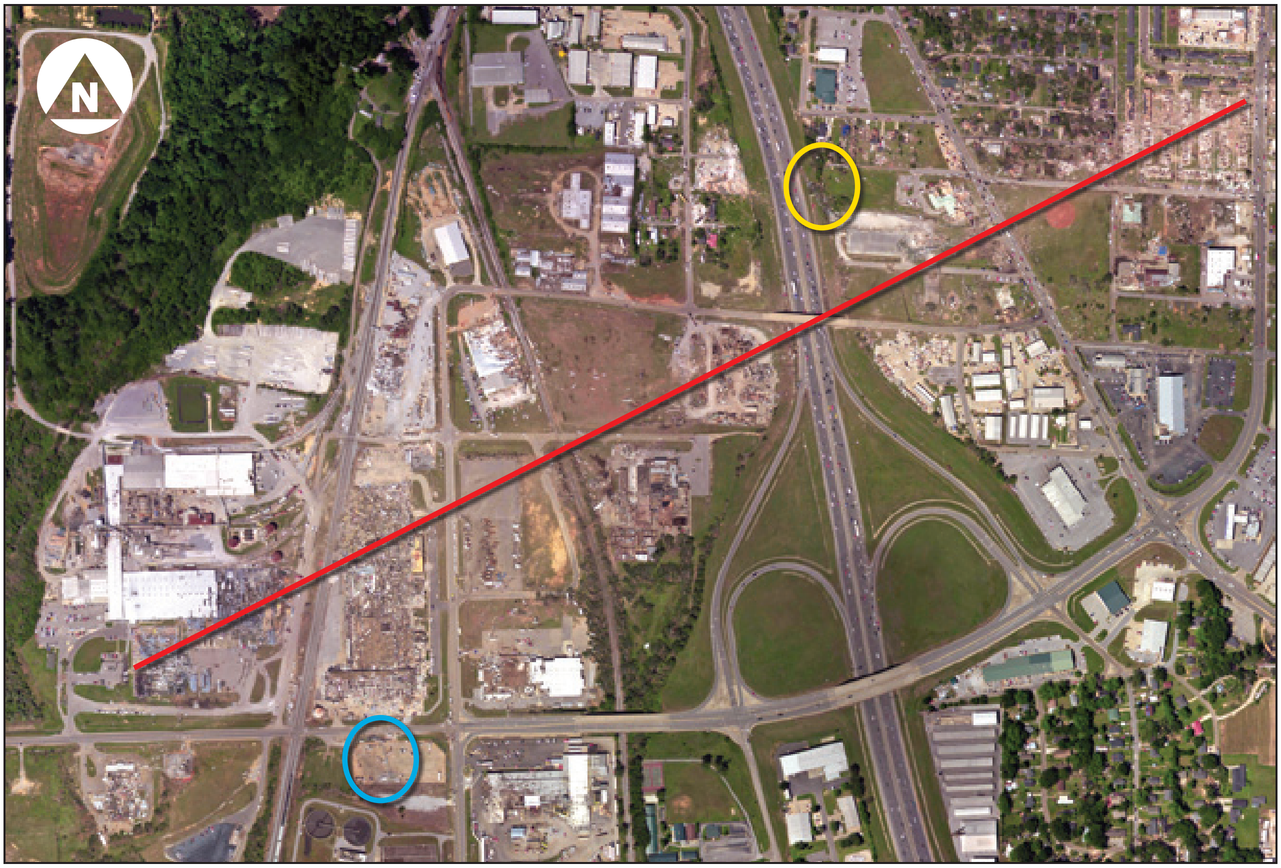

Figure 8-18: Aerial view of the approximate centerline of the tornado damage swath (red line) in the vicinity of the 300-foot latticed cellular tower (yellow oval). Also shown is the 250-foot EMS tower described in Section 8.3.1.1 (blue oval) (Tuscaloosa, AL).

Figure 8-19: Base for 300-foot latticed cellular tower (Tuscaloosa, AL)

General Wind Damage and Functional Loss: The 300-foot latticed cellular tower was completely destroyed by the April 27, 2011 tornado. Figure 8-20 shows the collapsed cellular tower.

Figure 8-20:
View of the 300-foot latticed cellular tower that collapsed during the tornado event (Tuscaloosa, AL)

No wind-displaced building materials were seen physically adhered to the fallen latticed tower. However, a large metal building southeast of the tower had been destroyed (Figures 8-21 and 8-22), and large sections of metal panels were scattered throughout the area. The MAT also observed a trailer frame leaning against the fence surrounding the cell tower base (Figure 8-23). These observations suggest that the storm created large amounts of wind-borne debris and wind-displaced sheathing in the vicinity of the tower and wind-displaced material likely struck the tower.

Figure 8-21:
Photograph of the 300-foot cellular tower (yellow oval) and the metal building to the southeast (blue box) before the April 27, 2011 tornado (Tuscaloosa, AL)
SOURCE: © GOOGLE EARTH

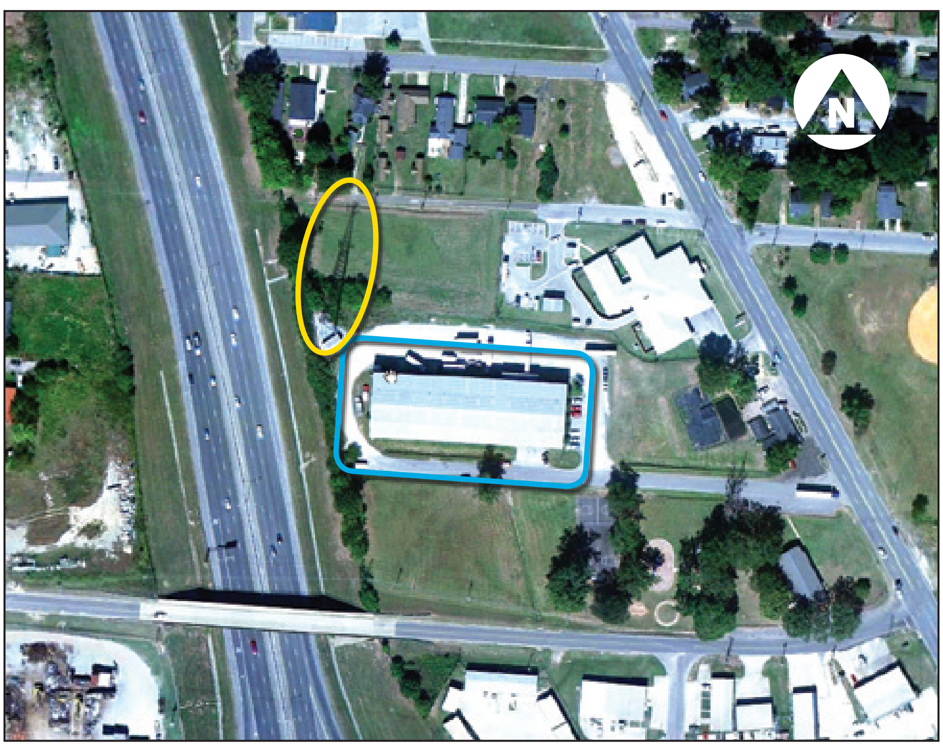

Figure 8-22:
View of the collapsed 300-foot cellular tower (yellow oval) and the destroyed metal building southeast of the tower (blue box) in relation to the approximate centerline of the tornado damage swath (red line) (Tuscaloosa, AL)
PHOTOGRAPH COURTESY OF TUSCALOOSA COUNTY SHERIFF'S OFFICE

Figure 8-23:
Remnants of a trailer that struck the fence surrounding the 300-foot cellular tower (Tuscaloosa, AL)

8.3.1.3 Solid Cellular Tower, 13th Street (Tuscaloosa, AL)

A solid cellular tower near 13th Street in Tuscaloosa, AL, was not visited during the MAT field reconnaissance, but was assessed by reviewing aerial photographs taken during a flyover 3 days after the April 27, 2011 tornado event. While this limited assessment did not provide detailed information on the performance of the tower, it allowed the MAT to make the observations described below. Web-based data from Google Earth Pro (liscensed) indicate that the tower is located at N33.201454° and W87.521943°. Although this tower was within the tornado damage swath, the cellular tower did not collapse during the event.

Location of Facility in Tornado Path: The location of the solid cellular tower is shown in Figure 8-1. Figure 8-24 shows an aerial view of the centerline of the tornado damage swath in the vicinity of the solid cellular tower. The cellular tower is within 500 feet of the centerline of the tornado damage swath in an area where the storm caused extensive damage and destruction to nearby buildings.

Facility Description: Oblique aerial photographs taken during a flyover 3 days after the event show that the tower is free-standing (i.e., not guyed) and of a solid style, tapered-steel construction (Figure 8-25). Although the aerial photographs do not allow precise measurements of tower height, the MAT estimates the tower to be approximately 300 feet tall based on its height relative to nearby buildings.

General Wind Damage and Functional Loss: The aerial photographs show that the tower withstood the event without collapsing.

Figure 8-24: Aerial view of the approximate centerline of the tornado damage swath (red line) in the vicinity of the solid cellular tower left standing after the tornado (yellow circle) (Tuscaloosa, AL)

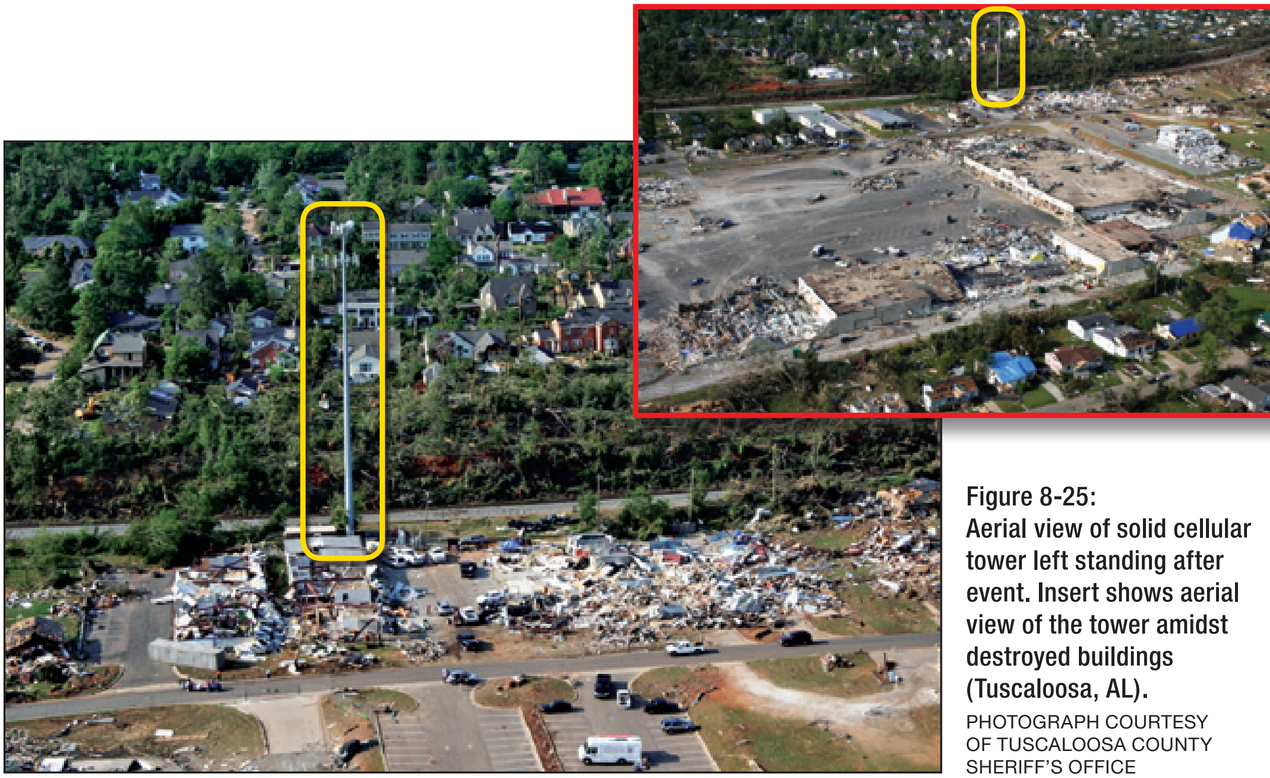

Figure 8-25:
Aerial view of solid cellular tower left standing after event. Insert shows aerial view of the tower amidst destroyed buildings (Tuscaloosa, AL).

PHOTOGRAPH COURTESY OF TUSCALOOSA COUNTY SHERIFF'S OFFICE

8.3.2 Guyed Towers

Like all towers, guyed towers can fail during high-wind events such as tornadoes. High winds can create forces that exceed a tower's strength and can create wind-borne debris that damages portions of it. High winds can also create wind-displaced materials that can adhere to a tower's mast or guys, increasing the wind loads the tower must resist to avoid failure. In addition, guyed towers are at risk because all guys and anchors must be functional for the tower to remain stable. The loss of even one guy can result in tower collapse.

8.3.2.1 300-Foot Guyed Cellular Tower (Smithville, MS)

The MAT inspected a 300-foot guyed cellular tower in Smithville, MS. The 300-foot guyed tower is located approximately three-quarters of a mile west-southwest of the Smithville water tower (described in Section 8.1.2) and 1.25 miles west-southwest of the center of town. The guyed tower is situated in an open field approximately 450 feet northwest of Highway 25.

Location of Facility in Tornado Path: The 300-foot-tall guyed cellular tower is shown in Figure 8-2 and 8-26. The centerline of the tornado damage swath is approximately 200 yards southeast of the tower. There were few buildings near the tower, but the MAT noted wind-borne debris and wind-displaced materials littering the cellular tower site.

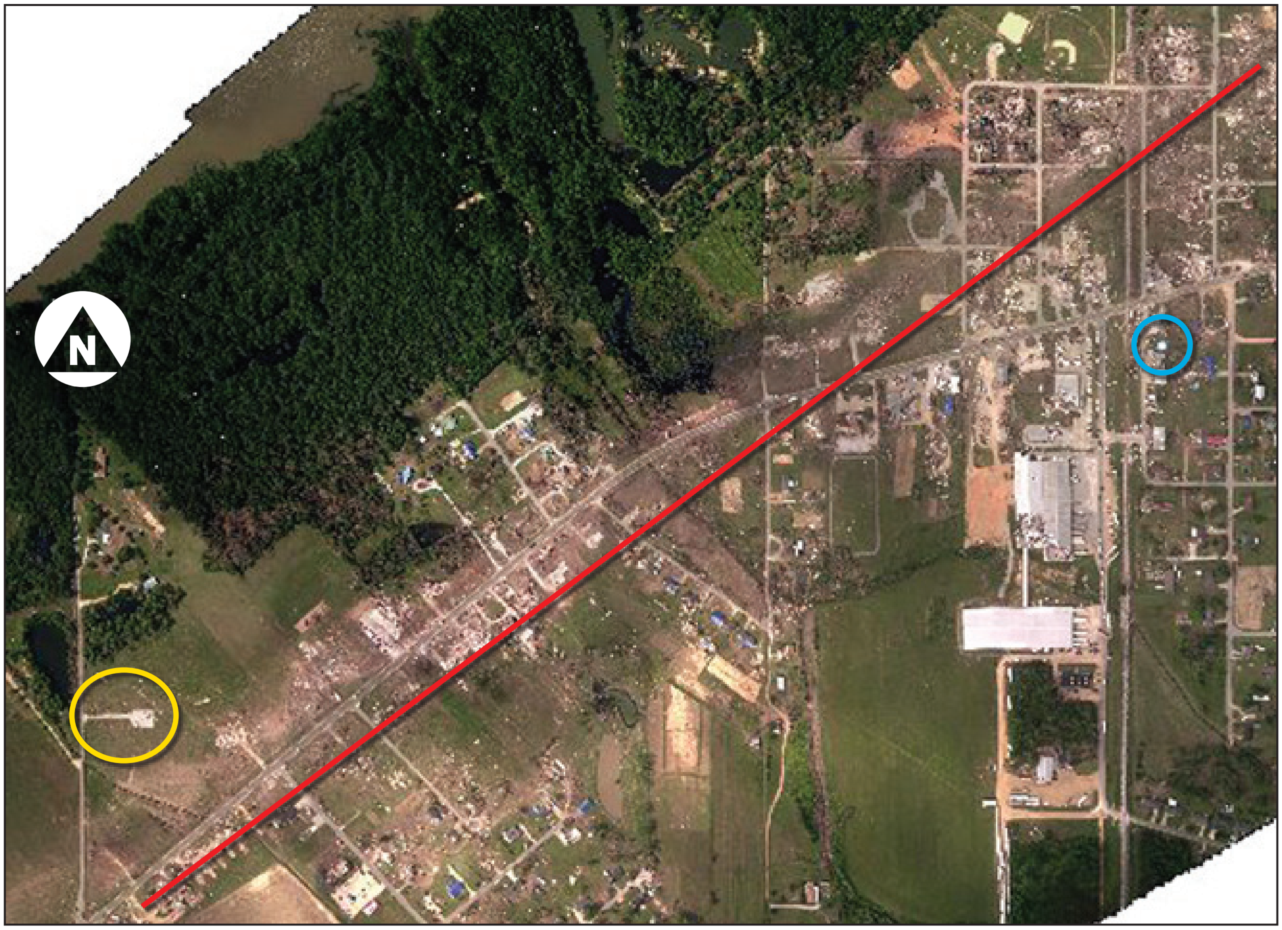

Figure 8-26: Aerial view of the 300-foot guyed cellular tower (yellow circle) in relationship to the approximate centerline of the tornado damage swath (red line) in Smithville, MS. The Smithville water tower shown in Figures 8-5 through 8-7 is northwest of the guyed tower and circled in blue for reference.

Facility Description: The guyed tower was laterally supported by three sets of earth anchors. The guys and anchors were oriented approximately at 60 degrees (east-northeast), 180 degrees (south) and 300 degrees (west-northwest), as shown in Figure 8-27.

The mast was connected to each of the guy anchors with five galvanized guys (both 5/16- and 7/16-inch-diameter guys were used) and turnbuckles (Figure 8-28). The ground anchor shafts were 2 inches in diameter. The MAT could not determine if each of the three anchor shafts terminated in an earth anchor or in a buried concrete mass.

General Wind Damage and Functional Loss: The tower collapsed during the event (Figure 8-29), and by the time the MAT visited the site 11 days after the event, preliminary clean-up activity had occurred and a temporary tower had been erected on site. The upper portion of the collapsed tower had been moved to clear the access road to the site.

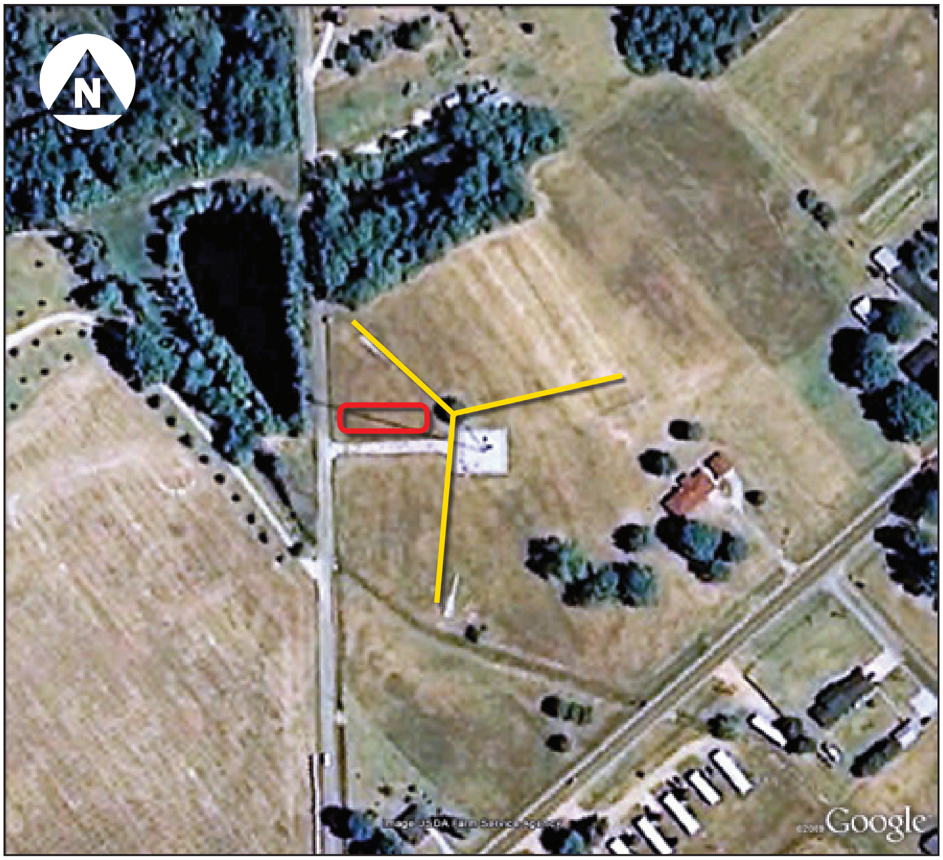

Figure 8-27:
Aerial photograph showing the 300-foot-tall guyed cellular tower after the tornado; the yellow lines show the location of the original guys, and the red box shows the position of the tower remnants observed by the MAT (Smithville, MS)
SOURCE: © GOOGLE EARTH

Figure 8-28:
Guy attachment plate, turnbuckle, and anchor shaft (Smithville, MS)

Figure 8-29: Collapsed 300-foot cellular tower (blue box). The triple guy in the foreground (red oval) is one of the three supports for the temporary tower on the site (Smithville, MS).

Wind-displaced building components struck and adhered to the south guy (Figure 8-30). The anchor that secured those guys failed and was dragged several feet though the ground (Figure 8-31).

The remnants of the tower indicate that it fell to the west. The location of the fallen tower, the presence of the wind-displaced materials adhered to the southern guy, and the failure of the guy anchor suggest that wind-displaced materials overloaded the southern anchor, and the failure of the southern anchor caused the tower to collapse.

Figure 8-30: Wind-displaced building materials wrapped around the 300-foot cellular tower guy (Smithville, MS)

Figure 8-31:
The anchor securing one guy was dragged several feet through the ground (Smithville, MS)

8.4 Summary of Conclusions and Recommendations

Table 8-1 provides a summary of the conclusions and recommendations for Chapter 8, *Observations on Infrastructure Performance*, and provides section references for supporting observations. Additional commentary on the conclusions and recommendations is presented in Chapters 10 and 11.

Table 8-1: Summary of Conclusions and Recommendations for Infrastructure Performance

Observation(s)	Conclusion	Recommendation
Failed towers due at least in part to wind-displaced materials: • Latticed 250-Foot EMS Communications Tower (Section 8.3.1.1) • Latticed 300-Foot Cellular Tower (Section 8.3.1.2) • 300-Foot Guyed Cellular Tower (Section 8.3.2.1)	**Conclusions #6 and #21** **(#6) Wind-displaced materials affected communications towers.** **(#21) Wind-displaced materials affected tower performance.**	**Recommendations #30 and #31** **(#30) Work collaboratively to better understand the risks of wind-displaced materials on communications towers.** **(#31) Work collaboratively to better understand the effects of wind-displaced materials on latticed structures.**

Table 8-1: Summary of Conclusions and Recommendations for Infrastructure Performance (concluded)

Observation(s)	Conclusion	Recommendation
Reliance of systems on utility power to operate lift or booster pump resulted in loss of system pressure when portions of electrical distribution systems were destroyed: • Tuscaloosa Water Works in Alabama (Section 8.1.1) • Smithville, MS, water treatment and distribution system (Section 8.1.2)	**Conclusion #19** **Lost utility power caused loss of system function.**	**Recommendation #32** **Provide an alternate electrical source.**
Failed communications and cellular towers: • Latticed 250-Foot EMS Communications Tower (Section 8.3.1.1) • 300-Foot Guyed Cellular Tower (Section 8.3.2.1)	**Conclusion #20** **Guy anchors failed when struck by wind-displaced materials.**	**Recommendation #33** **Work collaboratively to better understand communications tower performance.**