NIST Special Publication 1139

Progress Report, National Institute of Standards and Technology (NIST)

Technical Investigation of the May 22, 2011, Tornado in Joplin, Missouri

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U.S. Department of Commerce
Rebecca Blank, Acting Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Under Secretary of Commerce for Standards and Technology and Director

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Table of Contents

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List of Acronyms, Abbreviations, and Conversion Factors

Acronyms

ADA	Americans with Disabilities Act of 1990
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
BOCA	Building Officials and Code Administrators
BTS	box-type system
CDT	central daylight time
CF	concrete frame
CMU	concrete masonry unit
EF	Enhanced Fujita
FEMA	Federal Emergency Management Agency
GIS	geographic information system
IBC	International Building Code
ICC	International Code Council
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
NCST	National Construction Safety Team
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
SF	steel frame
SPC	Storm Prediction Center (NOAA)
UL	Underwriters Laboratories
USC	United States Code
WF	wood frame

Abbreviations and Conversion Factors

deg	wind direction in degrees	mph	mile(s) per hour
ft	foot, feet	s	second(s)
km	kilometer(s)		
m	meter(s), 1 m = 3.281 ft		
m/s	meter(s) per second, 0.447 m/s = 1 mph		

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Summary

Following a preliminary reconnaissance that began on May 24, 2011, the National Institute of Standards and Technology (NIST) announced on June 29, 2011, that it would conduct a technical investigation of the tornado that struck Joplin, MO, on May 22, 2011. In November 2011, NIST released a draft plan for the study and briefed the National Construction Safety Team (NCST) Advisory Committee on the progress of the investigation in a meeting that was open to the public. The final investigation plan, released in May 2012, can be found at http://www.nist.gov/manuscript-publication-search.cfm?pub_id=911000.

This report summarizes the progress NIST has made and the cooperation it has received from a variety of organizations in conducting the study. It includes updates on the following activities:

- Establishing the investigative Team under the NCST Act
- Briefing the NCST Advisory Committee
- Identifying and collecting materials relevant to the investigation from State and local government agencies, businesses, and other sources
- Determining the tornado hazard characteristics, including the meteorological conditions leading to and during the event, the tornadic wind field, and the tornado climatology
- Investigating the behavior and fate of individuals—both those who survived and those who did not—by collecting and analyzing information on injuries and fatalities, human behavior, situational awareness, and emergency communications before and during the tornado
- Analyzing the performance of single- and multi-family residential buildings, commercial structures, and critical buildings, including designated safe areas
- Assessing the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings

Highlights of this progress report include the following:

- A timeline of meteorological events and emergency communications preceding and during the tornado, including warnings and siren soundings
- The outline of an approach for fitting a tornadic wind field model to the observed data to create a map estimating maximum surface wind speeds in the tornado
- Information about first-person data collection efforts targeting human behavior, situational awareness, and emergency communications before and during the tornado, including a description of the data collection and analysis methodology
- Analysis of information relevant to the design, construction, and performance of buildings during the tornado

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Chapter 1. Introduction

This report summarizes the progress made by the National Institute of Standards and Technology (NIST) in its technical investigation of the tornado that struck Joplin, MO, on May 22, 2011 (referred to after this point as "the Joplin tornado").

1.1 Goals of the Joplin Tornado Investigation

NIST's study of the Joplin tornado has two major goals. The first is to investigate the wind environment and technical conditions that caused fatalities and injuries; the performance of emergency communications systems and the public response to such communications; and the performance of residential, commercial, and critical buildings, designated safe areas in buildings, and lifelines. The second goal is to develop findings and recommendations that can serve as the basis for

- potential improvements to requirements for the design and construction of buildings, designated safe areas, and lifeline facilities in tornado-prone regions;
- potential improvements to guidance for tornado warning systems and emergency response procedures;
- potential revisions to building, fire, and emergency communications codes, standards, and practices; and
- potential improvements to public safety.

1.2 Objectives of the Joplin Tornado Investigation

The primary objectives of the NIST technical investigation of the Joplin tornado are to:

1. Determine the tornado hazard characteristics and associated wind fields in the context of historical data
2. Determine the pattern, location, and cause of fatalities and injuries, and associated performance of emergency communications systems and public response
3. Determine the response of residential, commercial, and critical buildings, including the performance of designated safe areas
4. Determine the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings
5. Identify, as specifically as possible, areas in current building, fire, and emergency communications codes, standards, and practices that warrant revision

1.3 Authorities and Use of Information in Legal Proceedings

NIST is a non-regulatory agency of the U.S. Department of Commerce. NIST investigations are focused on fact finding, not fault finding. No part of any report resulting from a NIST investigation into a structural failure or from an investigation under the National Construction Safety Team (NCST) Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 U.S.C. 281a, as amended by Public Law 107–231).

1.4 Liaison with the Professional Community, the Public, and Local Authorities

NIST is maintaining ongoing liaison with the professional community, the general public, and local authorities during the investigation through briefings and presentations. NIST has established the following website to communicate information related to the investigation: http://www.nist.gov/el/disasterstudies/weather/joplin_tornado_2011.cfm. This information also is available in print; every effort will be made to ensure that those without internet access can receive the same information by mail.

Communications may be sent to NIST via electronic mail (e-mail), facsimile, or regular mail:

E-mail: disaster@nist.gov

Facsimile: (301) 975–4032

Regular mail: Disaster and Failure Studies Program
Engineering Laboratory
National Institute of Standards and Technology
100 Bureau Drive Stop 8611
Gaithersburg, MD 20899–8611

Chapter 2. Implementation of Legislative Authorities

2.1 Establishment of National Construction Safety Team

Following the May 22, 2011, tornado that devastated the city of Joplin, MO, NIST sent four engineers to Missouri from May 24 through May 28 to conduct a preliminary reconnaissance.[1] Based on analysis of the data collected and other criteria required by law and regulation, NIST Director Patrick Gallagher established a Team under the NCST Act on June 29, 2011, to proceed with a more comprehensive study of the impacts of the disaster. The establishment of the Team was announced in the Federal Register on July 19, 2011 (76 FR 42683). Additional information regarding the rationale for the technical investigation is provided in the investigation plan (http://www.nist.gov/manuscript-publication-search.cfm?pub_id=911000).

2.2 NCST Advisory Committee

The NCST Advisory Committee was provided an update on the Joplin tornado study at its November 7, 2011, meeting in Gaithersburg, MD. The committee was briefed on the draft investigation plan and the research progress to date. A copy of this presentation is available at http://www.nist.gov/el/disasterstudies/ncst/upload/NCSTACJoplin110411.pdf. Approximately one-half hour was reserved for public comments, and speaking times were assigned on a first-come, first-served basis as described in the Federal Register notice announcing the meeting (76 FR 64326, October 18, 2011).

Additional information about the NCST Act and the NCST Advisory Committee is available at http://www.nist.gov/el/disasterstudies/ncst/.

[1] See http://www.nist.gov/el/disasterstudies/upload/Joplin_Reconnaissance_Presentation061511-2.pdf for more information about the NIST preliminary reconnaissance at the site of the Joplin tornado.

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Chapter 3. Progress on Joplin Tornado Investigation

3.1 Technical Approach of Investigation and Scope of Progress Report

The technical approach of the Joplin tornado investigation, described in the final investigation plan (http://www.nist.gov/manuscript-publication-search.cfm?pub_id=911000) released in May 2012, includes the following major tasks:

- **Identify Issues Requiring Technical Study**
  Review data and information collected through the NIST preliminary reconnaissance related to the following: the performance of both the building envelope and the building's main wind force resistance system in residential (e.g., single-family and multi-family wood frame), commercial (e.g., professional office, big box retail), and critical or high occupancy (e.g., hospital, school) buildings; the wind conditions based on observed damage and available measurements; the performance of designated safe areas and lifeline facilities; the tornado warning systems and emergency procedures, and the patterns, locations, and causes of fatalities and injuries; and the locations and causes of post-tornado fires.

- **Collect Data**
  Gather the following types of data and information: building design documents, records, plans, and specifications; building construction, maintenance, and operations records; video and photographic data; field data; interviews and other oral and written accounts from building occupants, families of victims, emergency responders, building operators, and other witnesses; emergency response records, including audio communications; physical evidence; and other records. Obtain these materials from building, fire, and emergency response officials; Federal, State, and local authorities; and the public. To the extent permitted by law and policy, collected data will be stored in NIST's publicly accessible Disaster and Failure Events Data Repository.

- **Analyze and Compare Designs, Codes, and Practices for Buildings and Emergency Communications Systems**
  Analyze and compare the codes, standards, and specifications used at the time of the tornado and before for the City of Joplin; compare as-designed conditions with model code requirements and with as-built conditions observed in the NIST preliminary reconnaissance; and review and analyze practices used to design, construct, and operate buildings and emergency communications systems.

- **Prepare Technical Findings and Recommendations**
  Prepare final reports, incorporating established review processes involving the NIST Editorial Review Board; augmented reviews conducted by NIST senior management, legal counsel, and public affairs personnel; reviews of key reports by the NCST Advisory Committee; and, as necessary, reviews of key reports by individual outside experts.

- **Identify Needs for Revisions to Codes, Standards, and Practices**
  Identify specific areas of codes, standards, and practices in need of revision based on the findings of the investigation.

These main tasks encompass a number of more specific tasks that are organized around the five objectives of the study listed in Chapter 1. Descriptions of these objective-specific tasks and the overall technical approach are available in the investigation plan (see http://www.nist.gov/manuscript-publication-search.cfm?pub_id=911000, Attachment 1). Table 1 summarizes, for each objective of the investigation, the subjects that are under study and the purpose of the specific tasks that are being performed.

Table 1. Technical investigation of the Joplin tornado

Study objective[a]	Subject(s) being studied	Purpose of associated tasks
1	Tornado Hazard Characteristics	To obtain, review, and analyze information and documents relating to the specific characteristics of the Joplin tornado and how those characteristics compare to similar tornado events in a historical context at the local, regional, and national levels.
2	Emergency Communications, Public Response, Fatalities and Injuries	To investigate the behavior and fate of individuals—both those who survived and those who did not—by collecting and analyzing information on injuries and fatalities and on human behavior, situational awareness, and emergency communications before and during the Joplin tornado.
3	Response of Buildings, Including Designated Safe Areas	To obtain, review, and analyze information and documents relating to the design, construction, and performance of single- and multi-family residential structures and of commercial and critical buildings, including designated safe areas, affected by the Joplin tornado, and to identify technical issues for development and/or revisions of codes, standards, and practices pertaining to designing for tornadoes.
4	Performance of Lifelines Related to Continuity of Operations of Buildings	To obtain, review, and analyze information and documents relating to the performance of lifelines that support continuity of operations for selected buildings and facilities affected by the Joplin tornado.
5	Identification of Codes, Standards, and Practices That Warrant Revision	To make recommendations for potential improvements to model codes, standards, and practices, and/or for further research based on findings from this investigation of the Joplin tornado.

[a] Objectives 1–5 are defined in Chapter 1.

This report summarizes the progress made by NIST and the cooperation it has received from a variety of organizations. It covers the status of data collection efforts and progress toward meeting the five objectives of the investigation.

3.2 Status of Data Collection Efforts

NIST is basing its review, analysis, and modeling work for the Joplin tornado investigation on a solid foundation of technical evidence. NIST has obtained critical data such as building docu-

ments, video and photographic records, emergency response records, and oral histories. NIST has received considerable cooperation and information from a variety of businesses, organizations, professional associations, and individuals representing building designers, building owners, utilities, disaster researchers, and disaster responders. NIST has also received considerable cooperation and information from citizens in the Joplin area, as well as from Federal, State, and local authorities.

Local authorities providing information include the Joplin Public Works Department, the Joplin Police Department, the Joplin Fire Department, Joplin Schools, and the Joplin/Jasper County Emergency Management Agency. State authorities providing information include the Missouri Department of Public Safety's State Emergency Management Agency, the Missouri Department of Health and Senior Services, the Missouri State Highway Patrol, the Missouri Division of Fire Safety, the Oklahoma State Department of Health, and the Kansas Department of Health and Environment's Office of Vital Statistics. Federal authorities providing information include the U.S. Army Corps of Engineers, the Federal Emergency Management Agency (FEMA), the National Oceanic and Atmospheric Administration's National Weather Service (NWS), and the U.S. Department of Health and Human Services' Centers for Disease Control and Prevention.

NIST has also received information from the American Red Cross; Mercy (the parent organization for St. John's Regional Medical Center); architectural and engineering design firms Patterson Latimer Jones Brannon Denham (PLJBD) Inc. and Heery International, Inc.; the Structural Engineers Association of Kansas and Missouri; the Missouri Structural Assessment and Visual Evaluation (SAVE) Coalition; the Empire District Electric Company; and GeoEye, Inc.

The documents and other information obtained relate to meteorological conditions, warning communication systems, warnings issued, emergency response activities, the design and construction of buildings, the performance of buildings and lifelines, and fatalities and injuries. They include information such as the following:

- Meteorological data and records for the Joplin area on May 22, 2011
- Emergency management and hazard mitigation plans
- A tornado siren operations plan and coverage map
- Warning information provided to the public on May 22, 2011
- Audio recordings of emergency responder radio traffic
- Audio recordings of 911 calls
- Fatality and injury records and information
- Interviews with survivors and with friends and families of deceased victims
- Plans and specifications for a number of buildings in the tornado impacted area
- Local building and fire code adoptions, legislation, and ordinances
- Photographs and videos made during and after the tornado

- Pre- and post-tornado aerial imagery
- Building damage reports
- A building/property information database and associated geographic information system (GIS) files
- A building damage database and GIS files
- A sign damage database and photographs

NIST has not been able to locate the following important documents and materials:

- Design information for the original seven-story hospital building (West Tower) at St. John's Regional Medical Center, including architectural and structural plans and window product information
- Design information for renovations to the West Tower at St. John's Regional Medical Center that involved modification or replacement of windows, particularly the 1969 renovations to the Behavioral Health Unit

The Joplin Public Works Department has informed NIST that some of their records were lost to water damage. They were only able to provide drawing sets for some of the requested buildings, including some of the drawings sought for St. John's Regional Medical Center. Additional partial drawing sets for some of the buildings at St. John's Regional Medical Center were obtained from Mercy and from the architectural and engineering design firm Heery International, Inc.

NIST is working with the Missouri Department of Health and Senior Services to obtain additional information about those who were injured. NIST recently obtained a list of mutual aid fire departments that responded to the tornado from the Office of the State Fire Marshal, and has contacted these departments to request any records they may have pertaining to these fires.

NIST has also obtained and reviewed publications from other studies of various aspects of the May 22, 2011, tornado in Joplin. They include the publications cited below:

- "NWS Central Region Service Assessment: Joplin, Missouri, Tornado—May 22, 2011," National Weather Service, Central Region Headquarters, Kansas City, MO, July 2011.
- "Mitigation Assessment Team Report—Spring 2011 Tornadoes: April 25–28 and May 22, Building Performance Observations, Recommendations, and Technical Guidance," FEMA P–908, Federal Emergency Management Agency, Washington, DC, May 2012.
- Joplin Tornado Committee, "Investigations and Recommendations Based on the May 22, 2011 Joplin, Missouri Tornado," Structural Engineers Association of Kansas and Missouri, Shawnee Mission, KS, May 2012.
- Natural Disaster Task Force, "Analysis of Damage from Historic Tornado in Joplin, Missouri, U.S.A. on May 22, 2011," Report 201–12–01, Tilt-Up Concrete Association, Mount Vernon, IA, January 2012.

- D. O. Prevatt, W. Coulbourne, A. J. Graettinger, S. Pei, R. Gupta, and D. Grau, "Joplin Tornado of 2011: Damage Survey and Case for Tornado-Resilient Codes," American Society of Civil Engineers (in press).
- B. K. Paul and M. Stimers, "Tornado Warnings and Tornado Fatalities: The Case of May 22, 2011 Tornado in Joplin, Missouri," Quick Response Report QR226, University of Colorado at Boulder, Natural Hazards Center, Boulder, CO, 2011.
- K. M. Simmons and D. Sutter, "Deadly Season: Analysis of the 2011 Tornado Outbreaks," American Meteorological Society, Boston (2012).
- M. Smith, "When the Sirens Were Silent: How the Warning System Failed a Community," Mennonite Press, Newton, KS (2012).

NIST's evidence collection is nearly complete. Additional records on injuries and on fires following the tornado have been requested from the Missouri Department of Health and Senior Services and the many area fire departments providing mutual aid to Joplin, respectively. Despite significant efforts, NIST has been unable to locate the design information for the original seven-story hospital building at St. John's Regional Medical Center and later renovations to exterior windows, as identified in this section. NIST seeks information from the public identifying potential sources of these documents.

3.3 Tornado Hazard Characteristics

This section describes the progress that NIST has made in carrying out the tasks specifically related to study Objective 1 (Determine the tornado hazard characteristics and associated wind fields in the context of historical data).

Task 1.1: Collect data on meteorological conditions related to the Joplin tornado; pre-storm and post-storm conditions and damage; and historical and climatological information on tornadoes and impacts in the Joplin area.

Data collected to support Objective 1 include wind and meteorological data, photographs, videos, and GIS-based data sets. A summary of the data is shown in Table 2.

Task 1.2: Assess meteorological conditions leading to and during the tornado, including timeline.

Investigation of surface and upper-air charts in addition to large-scale environmental parameters identified a situation favorable for severe thunderstorm and tornado development. This situation was reflected by convective outlooks and tornado watches issued by the NOAA Storm Prediction Center (SPC), which has nationwide responsibility for issuing tornado and thunderstorm watches during the periods leading up to such events.

Once thunderstorms developed, tornado warnings were issued in the Joplin area by the local NWS office (NWS/Springfield, MO) based on NWS radar imagery, which showed echoes with characteristics of possible tornadic thunderstorms to the west of Joplin. Based on this information, NIST constructed a timeline of the tornado-related events on May 22, 2011. This

Table 2. Data collected in support of investigation Objective 1

Data type	Data list
Meteorological/ Wind	Joplin Airport meteorological/wind data, WSR–88D radar data, National Oceanic and Atmospheric Administration (NOAA) graphics and text, Wind Profiler and Model Sounding data, other meteorological data, NOAA tornado database
Photographs	Building and infrastructure damage, street sign damage
Videos	Surveillance and other videos made during the tornado, videos of post-tornado damage
GIS Based	Post-storm aerial photos, tornado path, local roads/boundaries, structural damage databases, tax assessor data, NIST created (e.g., tree fall), fatality locations
Miscellaneous	Street sign damage database, lifeline information

timeline, shown in Fig. 1, includes outlooks and watches issued by the SPC, warnings issued by NWS/Springfield, locations of the tornado estimated from surveillance videos, and sirens activated by the Joplin/Jasper County Emergency Management Agency.

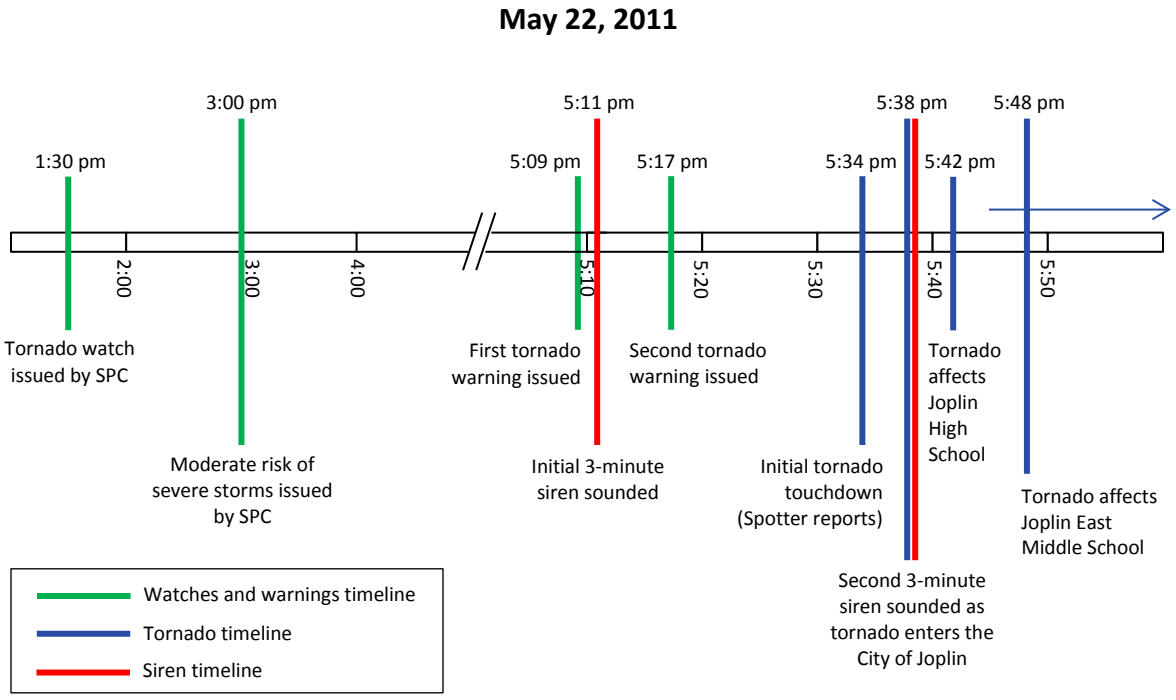

Figure 1. Timeline of meteorological events, warnings, and siren soundings (central daylight time (CDT))

Task 1.3: Develop wind speed estimates for the tornado.

As radar information did not provide details on near-surface (less than 20 m above ground) wind speeds where most damage occurred, both direct and indirect methods were used to quantify the near-surface wind environment for the Joplin tornado. Wind speeds were measured at the Joplin Airport Automated Surface Observing Station (call letters KJLN). Although the station is located 8–10 km (5–6 miles) north of the most significant tornado damage, wind speeds there appear to have been influenced by the tornado (Fig. 2). The shaded area in Fig. 2 (5:34 p.m. CDT to 5:48 p.m. CDT) represents the approximate period when the tornado was on the ground and causing damage in the Joplin area. Around this time, wind gusts increased to near 24 m/s (54 mph), 2-minute mean wind speeds approached 20 m/s (45 mph), and the mean wind direction was consistent with the position of the tornado.

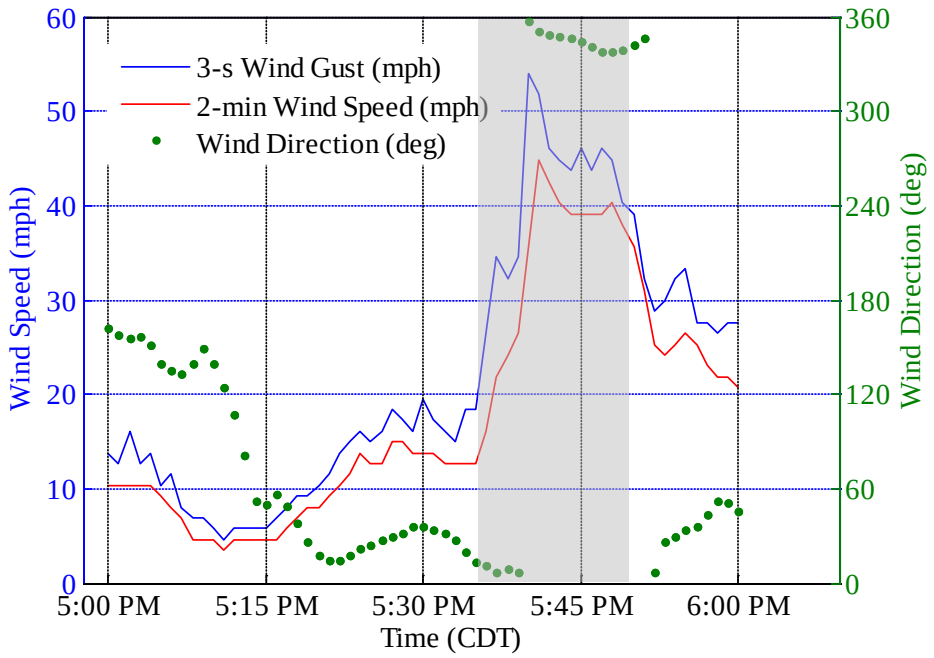

Figure 2. Joplin Airport Automated Surface Observing Station (KJLN) time history of mean and gust wind speed and mean wind direction from 5 p.m. to 6 p.m. CDT, May 22, 2011. (Data source: National Climatic Data Center)

Since the wind speeds measured at KJLN did not include those that produced significant damage, indirect methods of estimating wind speeds are also being used for this task, including inferring wind speeds based on observed damage using the Enhanced Fujita (EF) Scale and modeling the wind field using a Rankine vortex model fitted to tree fall patterns. The procedures being used for each of these methods are summarized below.

EF-Scale Estimation:

- Selected structures surveyed by NIST (for investigation Objective 3) were assigned EF-Scale ratings based on ground surveillance and post-storm aerial photographs.

- Approximately 7500 residential structures were damaged or destroyed by the Joplin tornado. A database provided by Jasper County Geographic Information Systems categorized the damage by "type" (e.g., light, medium, heavy/totaled, demolished). As part of the investigation, NIST has developed a methodology to compare these general damage types with damage and wind speed information contained in the EF Scale.

Wind Field/Tree Fall Model:

- A computer-based "grid" was developed and overlaid on a map of Joplin, marking points 32 m (106 ft) apart latitudinally and longitudinally throughout the city. The grid points represent the locations of modeled trees and where the wind velocity is calculated based on the Rankine vortex model.
- Initial parameters (i.e., initial inputs) for the Rankine vortex model were estimated using Joplin-specific information on tornado translation speed and direction from radar data and surveillance videos, the tornado's touchdown location and radius of maximum wind from post-storm aerial imagery, and critical tree fall wind speed from storm reports and tree experts. Other parameters in the model were initialized using consensus information from peer-reviewed tornado studies. Supplementary information from survivor interviews (investigation Objective 2) was also utilized.
- Given the initialization parameters, the wind field was translated through the grid system. At each time step (approximately every 1.2 s), a wind speed and direction were estimated at each grid point using the parameters of the Rankine vortex model. Once the wind speed at a grid point exceeded the critical tree fall wind speed, the tree was assumed to fall along the wind direction corresponding to that wind speed.
- The modeled tree fall output, which included information on the direction of tree fall as well as tree damage dimensions (e.g., damage width), was then compared to observed tree fall directions and dimensions estimated from post-storm aerial photographs. Parameters in the Rankine vortex model were modified until a resemblance between modeled and observed tree fall was achieved. These parameters are being used to create overall wind field (wind speed, wind direction, time) information for locations throughout Joplin, including specific structures surveyed by NIST pursuant to study Objective 3.

Task 1.4: Assess the Joplin tornado in a climatological context, including probabilistic approaches used to assess tornado hazards at local, regional, and national levels.

A literature review of previous U.S. tornado climatology studies was performed. Information on current tornado wind speed mapping and design guidance in the United States was obtained and reviewed, including the following standards and guidelines for nuclear facilities, storm shelters, and safe rooms:

- ANSI/ANS–2.3–2011, Standard for Estimating Tornado, Hurricane and Extreme Straight Line Wind Characteristics at Nuclear Facility Sites (2011)
- ASCE/SEI 7–10, Minimum Design Loads for Buildings and Other Structures (2010)
- ICC 500–2008, Standard for the Design and Construction of Storm Shelters (2008)

- FEMA 361, Design and Construction Guidance for Community Safe Rooms (2008)

The official tornado database (1950–2011) published by NOAA was used to assess a baseline U.S. tornado climatology for this investigation. Due to a number of inconsistencies in the database for the lower intensity tornadoes, a probabilistic analysis was performed on only EF2 and higher tornadoes. Figure 3 shows a density estimation of EF2 and higher tornado touchdown locations in the contiguous United States. Touchdown locations are denoted by black dots. Over 11,000 tornadoes classified as EF2 or greater have been rated and recorded in the United States since 1950. Probabilistic estimations are being developed for EF2 through EF5 tornadoes both separately and in combination. These estimations include calibrations and assessments of the tornado hazard at local, regional, and national levels and will be compared to current tornado and wind-load design guidance.

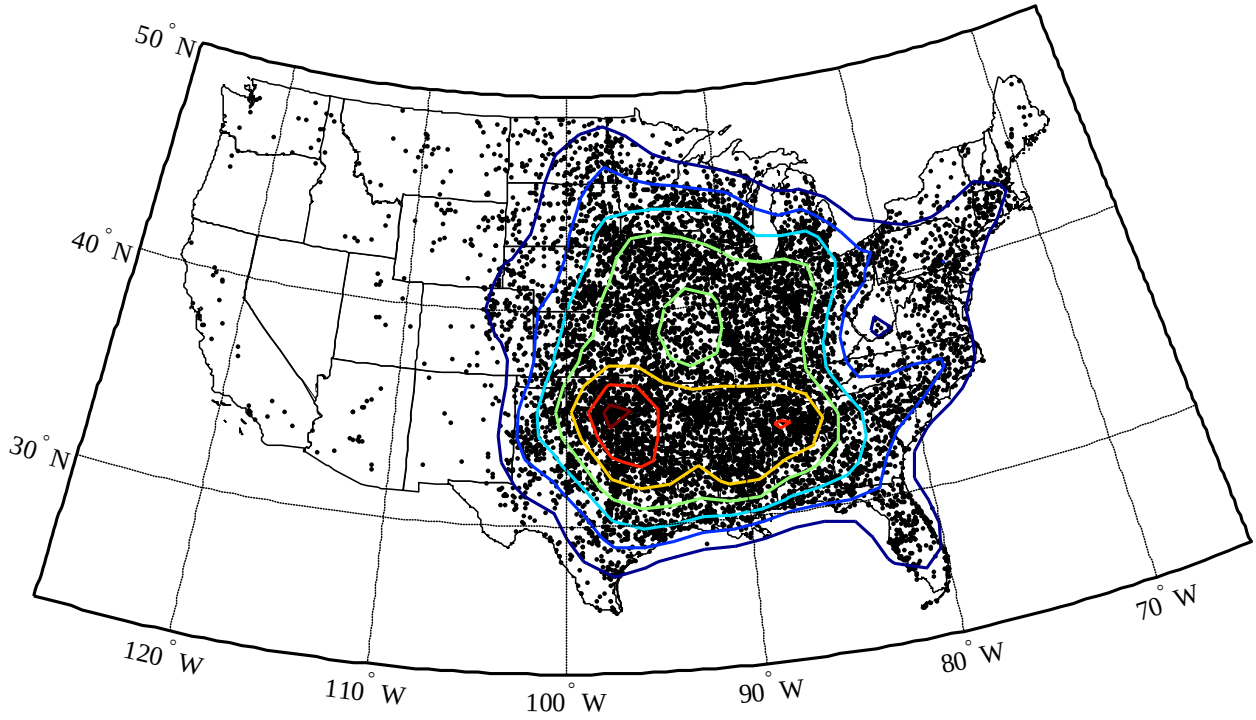

Figure 3. Density estimation of EF2+ tornadoes during the period 1950–2011. Black dots represent individual touchdown locations. The contour lines denote gradations in the density of occurrence, from higher (areas enclosed by red and orange) to lower (areas encircled by greens and blues). (Data source: NOAA/SPC)

Task 1.5: Analyze the spatial characteristics and consequences of the Joplin tornado, including the historical context.

This task involves significant input from Tasks 1.2 through 1.4, above, as well as from the work being done for investigation Objectives 2, 3, and 4. Work on this task is performed as results from the other parts of the investigation become available.

Task 1.6: Assess the practice of rating tornadoes based on observed damage, using the Enhanced Fujita (EF) Scale.

NIST has developed a brief history of the EF Scale and its predecessor, the F Scale, for this investigation. Official guidance regarding the implementation and use of the EF Scale, especially guidance concerning significant tornadoes (EF3 or greater) has been researched to determine possible methods of enhancing the rating process. To compare official guidance about the EF Scale to its use in practice, studies and findings regarding use of the scale, including those pertaining to the Joplin tornado and other recent, violent tornado events (e.g., Greensburg, KS, Tuscaloosa, AL) are being compared, and observations relating to the appropriateness and sufficiency of indicators used for damage are being explored.

3.4 Emergency Communications, Public Response, Fatalities and Injuries

In order to investigate the behavior and fate of individuals—both those who survived and those who did not—data are being collected and analyzed in the areas of human behavior, situational awareness, and emergency communications before and during the Joplin tornado, and in relation to injuries and fatalities.

Task 2.1: Gather baseline information on the response of individuals to the Joplin tornado.

NIST is collecting data on the response of individuals to the Joplin tornado from a number of sources. First, interviews were conducted via telephone or face-to-face meetings with survivors and with the friends and families of deceased victims. Interviewees were recruited by means of a NIST Tech Beat article that was posted on the NIST website,[2] flyers, and Joplin area newspaper and radio coverage. Also, the City of Joplin's public information officer and emergency manager, and members of the Joplin Area Chamber of Commerce and local faith-based organizations assisted NIST in publicizing the project. This very visible public recruitment enabled NIST to interview willing participants from a variety of geographic locations throughout the Joplin area, including some who had been displaced by the storm. Individuals interested in telling their stories were pre-interviewed to ensure that they in fact were located (or knew of someone who was located) in or near the damage path during the tornado.

After careful consideration, NIST determined that a semi-structured interviewing technique best fit the requirements of this investigation. Highly structured interviews use a fixed set of questions, often with set response options that allow for ease of data comparison from one interview to the next, while unstructured interviews are conducted more like a conversation between the interviewee and interviewer, where very little structure is provided by a question set. The semi-structured interviewing technique allows for both the collection of rich, detailed data on tornado experiences, as well as the opportunity for comparison among similar data.

Following this semi-structured approach, interviews were conducted in two phases. In phase 1, respondents were asked to describe their experiences from the time they first became aware that something was happening until the moment they responded to the tornado. Phase 2 was more

[2] http://www.nist.gov/el/disasterstudies/joplin-101311.cfm.

structured; the interviewer asked follow-up or clarifying questions about important topics from a pre-established list of probing questions. The list of questions was developed by collecting and analyzing over 100 media accounts of Joplin tornado eyewitness survivor stories and probed the following topics: awareness of the event, emergency communications received, actions taken, risk perceptions, pre-existing or event-driven injuries or impairments, previous experiences with severe storms, and familiarity with and perspectives on the emergency communications system in Joplin. At the end of the interview, interviewees were also asked to help recruit other individuals, such as friends, family members, or coworkers, who might be interested in participating in the investigation.

For 5 days immediately following the tornado and then again from October 2011 through February 2012, NIST interviewed 165 survivors of the tornado, in a combination of in-person and telephone interviews.[3] These 165 individuals represent a convenience sample of survivors, since interviews were performed with persons who volunteered to participate or were suggested to NIST by those who volunteered (known as the snowball sampling technique). NIST determined that interviewing was complete when two requirements were met. The first was that certain topics (i.e., experiences with the tornado on May 22, options for protective action, and previous experiences with and perspectives on warning systems and tornadoes) were saturated, in that very little new information was being collected as the interviews continued. The second was that the convenience sample varied by age, geographic location throughout the damage path (i.e., address), and physical location during the event (i.e., home, business, outdoors, or vehicle).

The respondents ranged in age from 19 to 88, with a mean age of 51. Gender was also distributed, with women making up 60 percent of the sample. A geographic analysis of the locations of respondents showed that the sample was well distributed across the tornado path through Joplin. Reported physical locations of the interviewees at the time of tornado touchdown were also widely distributed: approximately 68 percent were at their or someone else's home (or apartment), 13 percent were in a private business, 7 percent were driving or stopped in a vehicle, 5 percent were in St. John's Regional Medical Center, 5 percent were in a Joplin area church, and the remaining 2 percent of the sample were either located outside of buildings or did not specifically state where they were located as the storm struck. Respondents located at home took protection in various places, including tornado shelters, full or partial basements, crawl spaces, the first floors of apartment complexes or duplexes, and internal locations within homes, such as bathrooms, closets, or hallways.

A portion of the survivor interviews (8 percent) were conducted with managers and employees of local businesses and institutions, as well as individuals with authoritative roles at St. John's Regional Medical Center. These individuals often had others' safety in mind, in addition to their own, when the storm hit. Information on organization-wide tornado emergency procedures, structural damage to the facility, sheltering options, and previous experience with emergencies was obtained from these interviews. Attempts were also made to speak with managers and individuals in charge of local businesses, including the hospital, even if they were not involved in the tornado in order to understand contingency procedures and the overall response on May 22, in-

[3] The 165 participants include 11 survivors who e-mailed their stories to NIST.

cluding evacuations after the tornado hit. These individuals participated in the NIST interviews with their management's consent.

In addition to survivor interviews, NIST obtained official records from the Missouri Department of Health and Senior Services, the Oklahoma State Department of Health, and the Kansas Department of Health and Environment's Office of Vital Statistics regarding the causes and locations of the 161 fatalities caused by the tornado. NIST also collected a small number of stories about the experiences of these deceased victims via interviews with and e-mail from family and friends. Additional information on deceased victims was obtained from obituaries, Facebook, media accounts, and other websites in which lists of the deceased and information were provided. NIST has received some official records of injuries sustained during the tornado from the Missouri Department of Health and Senior Services. A limited amount of information on injuries has been collected through the survivor interviews and media accounts. Transcripts and audio recordings of emergency communications in Joplin on May 22 (911 calls and police and fire radio traffic) provided some additional data on fatalities and injuries.

Task 2.2: Collect archival records relating to prior tornado incidents and associated community responses, and document codes, standards, and practices for tornado warnings.

NIST collected data from various sources on prior tornado incidents and how communities have responded to such incidents. First, all Joplin tornado interviewees were asked about their prior experiences in tornadoes, including whether they had experienced a tornado or severe weather event, what physical damage occurred, if any, and how they had responded. In addition, NIST collected reports from previous tornado incidents, including a collection of NWS Service Assessment reports on tornado events and social science research reports on human responses to tornadoes. NIST is currently analyzing human responses to past tornadoes, including the Super Tuesday event in 2008, the Mother's Day tornado that hit Oklahoma and Missouri in 2008, and the tornado that hit Joplin in 1971, to better explain the social response to the 2011 tornado in Joplin. A review of the literature on tornado deaths and injuries is also under way to identify the main factors that influence tornado casualties and evaluate whether these played a role in Joplin in May 2011.

NIST has collected and assessed codes and standards to understand the current state of emergency communications systems for tornadoes. The following is a list of 15 codes and standards relating to emergency communications systems for tornadoes:

1. NFPA 72, National Fire Alarm and Signaling Code (Chapter 24, Emergency Communications Systems) (2013)
2. NFPA 1221, Standard for the Installation, Maintenance, and Use of Emergency Services Communication Systems (Chapter 14, Public Alerting Systems) (2010)
3. UL 2017, Standard for General-Purpose Signaling Devices and Systems (2011)
4. UL 1971, Standard for Signaling Devices for the Hearing Impaired (2008)
5. IEC 60849, Standard for Sound Systems for Emergency Purposes (1998)

6. UL 1480, Standard for Speakers for Fire Alarm, Emergency, and Commercial and Professional Use (2010)
7. UL 1989, Standard for Standby Batteries (2010)
8. ANSI S1.13, Measurement of Sound Pressure Levels in Air (2010)
9. ANSI S1.26, Method for the Calculation of Absorption of Sound by the Atmosphere (2009)
10. ANSI S12.14, Methods for the Field Measurement of the Sound Output for Audible Public Warning Devices Installed at Fixed Locations Outdoors (2007)
11. ANSI S3.2, Method for Measuring the Intelligibility of Speech over Communications Systems (2009)
12. ISO 9921, Ergonomic Assessment of Speech Communication (2003)
13. ANSI S3.5, Methods for the Calculation of the Speech Intelligibility Index (SII) (1997)
14. IEC 60268–16, Sound System Equipment—Part 16: Objective Rating of Speech Intelligibility by Speech Transmission Index (2011)
15. 2010 ADA Standards for Accessible Design (Chapter 7, Communication Elements and Features) (2010)

The first five of these codes and standards focus on the construction, performance, and testing of individual physical components of communications systems. Standards 6 and 7 on the list are devoted exclusively to specific components of communications systems; these particular standards pertain to speakers and standby batteries. Standards 8 through 15 focus primarily on the sound and intelligibility levels of communications, including how to measure each. Although FEMA does provide guidance on the use of outdoor warning systems as an alert signal for hazards, no Federal codes or standards exist on the content of emergency messages or the ways in which emergency communications systems should disseminate emergency communications before or during tornadoes. Instead, as indicated above, current codes and standards focus on the construction, performance, and testing of the physical components of such systems.

Additionally, there are no Federal laws focused on public broadcasting of tornado warnings. While the Federal Communications Commission requires broadcasters to operate in the public's best interest, and most television and radio stations provide severe weather information to varying degrees, there is no Federal law requiring local broadcasters to provide tornado warnings to the public before or during an emergency.

Possibly due to the lack of requirements and standardization, a variety of methods can be used and are currently being used to disseminate information during tornadoes. An assessment of more than 75 U.S. counties, cities, and towns has shown that emergency information for tornadoes is disseminated using a variety of methods before a tornado hits. Siren systems, for example, may sound differently from one town to the next to alert people of a tornado, or they may sound the same across towns for different types of events. In both cases, individuals can become confused as to what type of event is actually taking place as they travel from location to location,

even within the same State. As part of this task, NIST is documenting these differences in emergency communication dissemination techniques.

Task 2.3: Document pre-event archival records for Joplin in relation to tornadoes and the tornado warning system.

The purpose of this task is to understand the emergency communications system and procedures that were in place in Joplin before the tornado hit on May 22, 2011. According to the data collected, Joplin/Jasper County had emergency plans in place that specified how the siren system should operate. The Joplin "zone" consisted of 25 sirens in total that were all tied to the same system, that is, if one activated, they all activated. The Joplin sirens sounded if one of the following three conditions was met: (1) the communications operator was notified that a tornado had been sighted; (2) a tornado warning was issued by the NWS for Jasper, Newton, or Cherokee County; or (3) sustained winds of 75 miles per hour or higher were detected in any part of Joplin. The sirens were specified to sound for 3 minutes continuously, one time, and there was no requirement for an all-clear message or siren. Sirens were tested weekly on Monday mornings at 10 a.m., and sounded for 1 minute during the test. Joplin/Jasper County also had other channels for communication of emergency messages, including primary and local Emergency Alert System television and radio stations, Reverse 911 telephone calling, and NOAA Weather Radios (purchased on an individual or company-wide basis).

The "Joplin/Jasper County Local Emergency Operations Plan" (Plan) also presented guidance on protective actions in the event of a tornado. The Plan states, "The burden of heeding warnings and taking proper action, rests with individual communities and citizens."[4] It also explains that while there is no guaranteed safe place during a tornado, some locations are better than others. The Plan indicates that the interior part of a basement, preferably under something sturdy like a table, is the safest place in the home to take refuge. If a basement is not available, an inside room on the lowest floor (for example, a closet or bathroom with no windows) should be sought.

NIST has obtained census information to aid in understanding the demographics of the Joplin area, especially the area along the tornado damage path. Demographics for Joplin's damage path, at the census tract level, will be used to provide the foundation for evaluating the generalizability, if any, of the survivor interviewees and to provide the ability to compare the demographics of the deceased victims with the larger Joplin population.

Task 2.4: Collect information from third-party sources including television interviews and newspaper articles.

As mentioned previously, over 100 media accounts of survivor and deceased victim experiences were collected. These materials were organized into a database and used to develop the probing questions used in the survivor interviews (see Task 2.1). The accounts of survivors will also be combined with data from the survivor interviews for analysis in Task 2.5.

[4] Missouri Department of Public Safety State Emergency Management Agency, Joplin/Jasper County Emergency Management Agency, Jasper County Officials, and City of Joplin Officials, "Joplin/Jasper County Local Emergency Operations Plan," Joplin, MO, February 2011, page K–8.

Task 2.5: Analyze the data to study the public response to the tornado, including protective actions.

NIST is conducting a qualitative analysis of the interview transcripts, narrative e-mails, and interview notes for the purposes of survivor trend analysis and theory building. Based upon the existing probing questions (discussed earlier) and a preliminary analysis of all transcripts, NIST developed a list of codes, or categories, used to label sections of the transcript data. For example, one code is "previous experience with tornadoes," which was used to label all instances where interviewees described their previous experiences with storms, tornadoes, or sheltering in the event of a storm. During the coding process, analysts labeled sections of the transcripts with over 50 different codes. All of the coding was reviewed for consistency by the Task Leader.

Currently, NIST is in the process of identifying properties (components or attributes) and dimensions (modes of variation) of the data within each code/category to create additional categories, if necessary. Then, the data will be sorted based upon these categories, including pre-storm individual factors (e.g., prior tornado experience), environmental cues from the storm, individuals' interpretations, and actions taken, to begin to detect data patterns and trends. When trends begin to formulate, it is important to test these trends with additional data from this and other studies of the human response to tornadoes. Through these methods, a conceptual model of human response to the Joplin tornado will be created.

In parallel with the in-depth trend analysis of survivor stories, NIST is comparing the circumstances and behaviors of survivors with those of persons severely injured or killed by the Joplin tornado. Analysis of the fatality and injury data is being conducted to understand the circumstances surrounding each injury or death in as much detail as possible and to help answer questions such as the following: What protective actions (if any) were taken by those injured or killed, and how did that compare to actions taken by survivors in the same building, the same type of building, or a building nearby? What environmental hazards (e.g., wind speed of the tornado) surrounded the deceased victims versus the survivors or those injured during the storm?

Results of the work being performed for investigation Objective 1 are being used to understand the intensity and timing of the tornado hazards in the area of each fatality. Results from Objective 3 are being used to understand the effects of building design and performance for each of the fatalities as well as nearby survivors. These results, in addition to the circumstances of and actions taken by those injured and killed, will be compared to attempt to identify the factors that influenced whether and how a victim died or was injured on May 22, 2011.

3.5 Response of Buildings, Including Designated Safe Areas

Task 3.1: Collect field data on the performance of buildings, establish environmental conditions affecting these buildings, and develop failure hypotheses.

During field deployments, NIST selected approximately 25 commercial and institutional buildings and a number of residential structures, out of the approximately 8000 damaged or destroyed buildings, for on-site surveys of their performance during the tornado. The NIST-surveyed structures are representative of common construction types and functions in the affected area.

The following construction types are represented among the structures surveyed: steel moment frame, concrete moment frame, box-type system with concrete masonry unit (CMU) wall, box-type system with precast concrete tilt-up wall, light steel frame, unreinforced brick, and wood frame. By function, the surveyed structures include critical facilities such as hospital buildings, schools, and fire stations; high-occupancy facilities such as large retail stores and churches; smaller medical and commercial offices; nursing homes; and single- and multi-family residences. Table 3 shows summary information for many of the NIST-surveyed buildings and facilities.

NIST has completed the collection, review, and summarization of field performance data for all of the NIST-surveyed buildings. Field performance data collected include photographs taken by NIST during the deployments or requested by NIST from others (Structural Engineers Association of Kansas and Missouri, FEMA, St. John's Regional Medical Center), observation notes, measurements, and in the case of Joplin East Middle School, videos from security cameras. These data are being used to help understand as-built conditions (e.g., dimensions of building components or systems), connection and reinforcement details, damage conditions, and possible failure modes and sequences.

Figure 4 shows an example of the field data collected. These photographs, which show a failure observed at Joplin East Middle School's gymnasium, are being used to develop the failure hypothesis for this building. Using the results from work performed pursuant to study Objective 1, wind speed and direction time histories can be obtained at specific building locations. These estimated wind velocities are being used in combination with collected field performance data and design information to develop and refine failure hypotheses for the surveyed buildings.

Figure 4. Example of photographic field data used in developing a failure hypothesis for the gymnasium at Joplin East Middle School. (Photo source: NIST)

Table 3. Damage condition and design information for many of the NIST-surveyed structures

	Damage condition information			Design information		
	Collapse of main wind force resisting system	**Damage or loss of roof and/or wall cladding**	**Loss of functionality**	**Construction type[a]**	**Code**	**Drawings obtained by NIST**
Engineered	Wal-Mart		Complete	BTS (CMU)	BOCA 1990/ IBC 2000	Complete
	Joplin East Middle School auditorium		Complete	BTS (CMU)	IBC 2000	Complete
	St. Mary's School		Complete	BTS (CMU)	BOCA 1990	Partial
	Franklin Technology Center		Complete	BTS (CMU)	1978	Partial
	St. John's[b] generator and chiller buildings		Complete	BTS (CMU)	Not known	Partial
	Home Depot		Complete	BTS (Tilt-up)	BOCA 1996	Complete
	Joplin East Middle School gymnasium		Complete	BTS (Tilt-up)	IBC 2000	Complete
		St. John's[b] main buildings	Complete	CF, SF	Not known	Partial
		St. Paul's Church	Complete	SF	BOCA 1996	Partial
		Joplin High School buildings	Complete	CF, SF	IBC 2000	Partial
		Ramesh Shaw Center	Complete	SF	BOCA 1990	Partial
		W. Meredith Center	Complete	SF	Not known	None
		Ozark Center	Complete	CF	Not known	Partial
Non-/Marginally Engineered	Single- and multi-family homes	Single- and multi-family homes	Complete/ partial/none	WF	Various years	None
		Mercy Village	Partial	WF	IBC 2000	Partial
		Swanson Office Building	Partial	WF	IBC 2006	Complete
		Fire Station #4[c]	Complete	CMU	Not known	None

[a] BTS = Box-Type System; CF = Concrete Frame; SF = Steel Frame; WF = Wood Frame; CMU = Concrete Masonry Unit.
[b] St. John's Regional Medical Center.
[c] Confirmation of engineered or non-/marginally engineered categorization is pending receipt of design drawings.

Task 3.2: Obtain and review design drawings to refine the failure hypotheses.

NIST has obtained design drawings from the Joplin Building Department for some of the NIST-surveyed buildings. Many of the drawing sets are incomplete and provide only partial design information. NIST has obtained structural and architectural drawings for other buildings from sources that include St. John's Regional Medical Center and the architectural and engineering design firms of Patterson Latimer Jones Brannon Denham (PLJBD) Inc. and Heery International, Inc. The last column of Table 3 shows the status of design drawings obtained to date. As the table shows, only partial design information is currently available for buildings at St. John's Regional Medical Center. Despite significant efforts, NIST has been unable to locate the design information for the seven-story reinforced-concrete frame hospital building, including information on the original design and subsequent renovations to exterior windows, as described in Sec. 3.2. NIST seeks information from the public identifying potential sources of these documents.

NIST has reviewed the drawings obtained, and design information from the drawings has been compared with field observations to assess consistency between as-designed and as-constructed conditions. Design information from the drawings is also being used to support and refine the failure hypotheses developed for the different buildings.

Task 3.3: Review performance of designated safe areas, including shelters, safe rooms, and areas of buildings used for refuge.

NIST identified no community storm shelters (defined as meeting the International Code Council's ICC 500–2008 standard) or community safe rooms (defined as meeting FEMA 361 guidance) in the city of Joplin or the tornado affected areas. Some commercial and institutional facilities provided guidance and assistance to move occupants to certain parts of the buildings as the tornado approached. Through interviews of survivors, managers, and employees, along with analysis of design drawings, NIST has identified the areas within some of the commercial buildings that were used as designated safe or refuge areas during the tornado. Several residences were identified as having in-residence shelters, including a concrete room in a basement and a steel box bolted to a slab on grade. Evaluations of the performance of these designated safe and refuge areas is beginning, incorporating results from the wind field analysis undertaken for investigation Objective 1 and the fatality and injury data and analysis gathered and performed for Objective 2.

Task 3.4: Obtain, review, and evaluate appropriate model building code and standards requirements for design of building envelopes and main wind force resisting systems.

Current national codes, standards, and practices do not require conventional buildings, with the exceptions of storm shelters and safe rooms, to withstand tornadoes, and do not explicitly consider tornadoes in the design process. However, how buildings that are compliant with current building codes perform in tornadoes can indicate how adequate those codes are for designing and constructing buildings that are resistant to tornadoes. Table 3 shows that the NIST-surveyed buildings were designed to various building codes in effect at the time of their design and construction. NIST also has determined that the City of Joplin has a long history of building and fire code adoptions, with records dating back to 1877. NIST has obtained the building codes listed in

Table 3 and reviewed relevant design requirements pertaining to building envelopes and structural systems as well as requirements for building functionality.

Task 3.5: Assess building performance based on the estimated wind field and on observed damage, relative to model code requirements.

NIST is continuing to assess the performance of selected NIST-surveyed buildings. NIST is using estimated wind speed and wind direction time histories at building locations, which are being developed for investigation Objective 1, in conjunction with analyses of ground and aerial photographs to develop hypotheses regarding the damage and collapse sequences. In some instances, where sufficient structural and architectural information is available, NIST estimates of wind speeds required to fail different elements of the buildings are being used to validate the failure hypotheses, to corroborate wind speed estimates developed for Objective 1, and to compare to design wind speeds required by the model building codes. This analysis is considering the performance of both the structural systems and the building envelopes. In some instances, such as the main buildings at St. John's Regional Medical Center, there was almost no damage to the structural systems. However, the buildings were rendered completely nonfunctional by extensive nonstructural damage to the building wall and roof systems and subsequent wind and water damage to the interior of the buildings.

Due to the large number of residential structures affected by the tornado (approximately 7500 residential structures), a statistical assessment of the performance of residential structures is a more practical approach than would be detailed assessments of individual structures. NIST is employing a GIS-based analysis using building characteristics and damage information from the Joplin GIS database to correlate the performance of residential construction with estimated wind speeds (from Objective 1) and fatalities and injuries (from Objective 2), and to assess the performance of residential structures in comparison with the model code requirements and the estimated tornadic wind speeds.

3.6 Performance of Lifelines Related to Continuity of Operations of Buildings

NIST has collected field performance data and information on lifeline systems that affect the continuity of operations of residential, commercial, and critical buildings in the area impacted by the Joplin tornado. Progress on the tasks relating to lifeline performance is described below.

Task 4.1: Gather information on lifeline systems and facilities that support building operations.

NIST has gathered information on the performance of lifeline systems and facilities that support the continuity of operations of buildings in Joplin. This includes information on the following:

- Collapse of the open steel frame and transformers of Empire District Electric Company's power substation 59 at 26th Street and Pearl Avenue in Joplin, as well as damage to several transmission lines and approximately 3900 power poles
- Collapses of ancillary buildings that housed the backup generator and chiller equipment for St. John's Regional Medical Center

- High-pressure gas leak at St. John's Regional Medical Center immediately after the tornado
- Collapse of an old, unreinforced brick building that was used for storage at the Joplin water treatment facility
- Multiple water leaks resulting in reduced city water pressure

Task 4.2: Evaluate the performance and timelines from disruption to restoration of service (power, water, sewer, and gas systems) and assess the robustness of the systems during the tornado.

Electrical power was lost for an extended period of time throughout much of Joplin due to damaged power substations, transmission lines, and distribution systems. Power substation 59 was recently repaired with new transformers installed in June 2012,[5] more than a year after the May 22, 2011, Joplin tornado. Data collection and performance evaluation are continuing.

Task 4.3: Evaluate the performance of backup power systems with regard to location and protective enclosures.

St. John's Regional Medical Center's backup power supply systems were damaged as a result of the collapses of the box-type buildings that housed this mechanical equipment. The loss of both line power and backup power contributed to the total loss of functionality of this critical facility, even though the structural systems of the main buildings sustained little damage. NIST is reviewing issues related to the vulnerability of structures that house backup power systems and whether changes to standards, codes, and practices could improve the availability of power for safe emergency evacuation and ongoing building functionality.

Task 4.4: Collect data on, and assess the causes and extent of, building fires resulting from the tornado.

Interviews with Joplin fire officials[6] indicated that there were fewer than 10 fires following the tornado and that mutual aid departments from around the region handled most of the fires. According to the Joplin fire officials, the fires were caused mainly by residential gas leaks and downed power lines, and remained confined to the structures where they originated. The Joplin fire officials also indicated that although the fires were limited, the reduction in water pressure due to multiple water leaks caused by tornado damage could have contributed to reduced effectiveness in firefighting efforts. Joplin fire officials informed NIST that Joplin had no response records for these fires. The Missouri Division of Fire Safety's Office of the State Fire Marshal also had no response records for the fires following the tornado. They indicated that while no fire incidents were entered into the National Fire Incident Reporting System (NFIRS) for the Joplin area for May 22 or May 23, 2011, NFIRS reporting is not mandatory. NIST recently obtained a list of mutual aid fire departments that responded to the tornado from the Office of the

[5] R. McKinney, "Empire District Electric Co. replaces transformers damaged during 2011 tornado," The Joplin Globe, June 19, 2012; accessed July 3, 2012, at http://www.joplinglobe.com/topstories/x651523560/Empire-District-Electric-Co-replaces-transformers-damaged-during-2011-tornado.
[6] Interviews 1 and 13.

State Fire Marshal and has contacted these departments to request any records they may have pertaining to fires following the tornado.

3.7 Identification of Codes, Standards, and Practices That Warrant Revision

Task 5.1: Evaluate the results obtained for Objectives 1–4 for potential improvements needed in model codes, standards, and practices, and/or for further research needed, and make recommendations for potential changes to increase tornado resilience.

Evaluation of existing standards and guidelines related to the identification of tornado hazards has been completed as part of the work performed for investigation Objective 1. Evaluation of existing codes, standards, and practices related to emergency communications has been completed as part of the work for Objective 2. Evaluation of model building codes, standards, and practices is nearing completion under Objective 3. As the remaining tasks under Objectives 1–4 are completed, those results will feed into the analysis and recommendations for potential revisions in order to ultimately improve the tornado resilience of buildings, lifelines, and communities.

3.8 Moving Forward

As described in this report, NIST has made significant progress on the investigation. NIST's evidence collection is nearly complete. Despite significant efforts, NIST has been unable to locate the design information for the seven-story reinforced-concrete frame hospital building at St. John's Regional Medical Center, including information on the original design and subsequent renovations to exterior windows, as described in Sec. 3.2. NIST seeks information from the public identifying potential sources of these documents. In addition, NIST is working with the Missouri Department of Health and Senior Services to obtain additional information about those who were injured in the tornado and has requested response records for the fires following the tornado from mutual aid fire departments that responded to Joplin.

Strong progress has been made on most of the tasks related to the first four objectives of the investigation. NIST is now beginning to tie the results of the work performed under each of these objectives together to understand how the tornado hazard, tornado warnings, responses to warnings, protective actions, and building performance all interrelated and led to the outcomes of survival, injury, or death. Work under Objective 5 will proceed as the work under Objectives 1 through 4 nears completion.