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An Analysis of Extreme Rainfall Events in Chicago and Vicinity Since 1950

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Table of Contents

Executive Summary

Main Research Questions

Flash flooding has long been one of the most impactful and costly weather hazards impacting the Chicago metropolitan area. A significant flash flood event occurring on 2 July 2023, among the most expensive weather-related disasters in Cook County history, was part of a cluster of extreme rainfall events which occurred over a 1-year period from fall 2022 through fall 2023. These events brought increased attention to the threat of flooding, and raised many questions. How often do extreme rainfall events impact Chicago? What weather patterns are associated with these events? Is the frequency of extreme rainfall events changing?

Research Methodology

To provide proper climatological context for rainfall events impacting the Chicago area, a detailed study of extreme rainfall was conducted for the 1950-2023 period. All known records of extreme rainfall events were collected and summarized, including rain gauge observations, flood damage, surface weather observations and radar data. A threshold was set to determine what should be classified as an extreme event - at least 7.5 inches for peak storm total rainfall, or sub-daily rainfall intensities exceeding the 1% annual exceedance probability according to *NOAA Atlas 14*. Daily rainfall records for the official Chicago climate site were also analyzed for trends.

Major Findings

Research indicates that at least 13 extreme rainfall events impacted Chicago and the immediate vicinity since 1950. The character of these events varies, with some events occurring over a one- to two-day period, and some events occurring over just a few hours. Weather patterns associated with Chicago extreme rainfall events include a wide range of situations. Flood impacts and damage costs also vary widely between events. Although approximately 1-2 extreme rainfall events have occurred in the Chicago area per decade, the frequency of these events has been increasing, and the interval of time between events has generally been decreasing. The distribution of 1-day rain events in the Chicago climate record also shows significant increases in recent decades when compared to the late 1800s and early 1900s, especially with higher rainfall values. These trends in extreme rainfall are generally consistent with other research and have potentially significant implications for flash flood impacts and stormwater infrastructure design in the Chicago area.

1.0 Introduction

On both 2 July 2023 and 17 September 2023, extreme rainfall occurred in and near Chicago, Illinois, causing widespread flooding of roadways and basements. These events became the second and third urban flood events, respectively, to occur in an approximately 1-year period after a separate event on 11 September 2022. Flood damage in 2023 was significant enough to trigger a federal disaster declaration for each event, with the July event among the costliest recorded weather disasters in the history of Cook County, Illinois (at least back to 1950, according to NOAA *Storm Data*; Table 1). This cluster of flood-producing rain events led to the question of how these events fit into the larger context of Chicago rainfall and flooding. While it is relatively easy to compare single-day and multi-day rainfall totals for the official Chicago climate station (varied locations since 1871, O'Hare International Airport since 1980), these values represent only a single point location in a large urbanized area. The small footprint of many extreme rainfall events means that the official climate station is unlikely to sample the area of heaviest rainfall, and in some situations may observe only light rainfall totals while a different portion of the city experiences extreme rainfall and flooding. To put the rainfall events of summer 2023 into climatological context requires a more detailed study of past extreme rainfall events impacting Chicago and its immediate vicinity.

The only known detailed analysis of extreme rainfall impacting the Chicago area was completed by Huff and Vogel (1976). The Huff and Vogel study reviewed rainfall data on timescales of 5 minutes to 1 day occurring from 1949 to 1974. Over the 47 years that have passed since this study was published (49 years since the analyzed period of record ended), multiple extreme rainfall and flash flood events are known to have occurred in Chicago. A study from decades prior may also not be applicable to modern rainfall events if they are being impacted by climatic changes. This study presents an effort to use multiple sources of information to collect extreme rainfall events impacting Chicago and the immediate vicinity since 1950, filling in the gap after publication of Huff and Vogel (1976). Rainfall data will be digitized, converted, and bias corrected, as needed, to make consistent maps for each event. Information about the synoptic weather pattern, upper-air pattern, and character of rainfall will also be summarized for each event to evaluate differences and commonalities. The distribution of rainfall at the Chicago climate site will also be evaluated for potential changes over the last century.

Table 1. Weather events in Cook County, Illinois, causing at least $5 million in damages (inflation adjusted), as documented in *Storm Data*. Inflation-adjusted values based upon the Bureau of Labor Statistics CPI Inflation Calculator (https://data.bls.gov/cgi-bin/cpicalc.pl), with April 2024 selected as the current date. Estimates noted with "*" indicate damage costs that likely include areas outside of Cook County. More details about the sources used for the "damage cost other sources" entries are provided in later sections of this report.

Event	Type	Damage Cost (*Storm Data*, Nominal)	Damage Cost (*Storm Data*, Inflation Adjusted)	Damage Cost (Other Sources, Inflation Adjusted)
July 2023	Flood	$500.0 million	$512.8 million	
July 2010	Flood	$253.7 million	$364.9 million	
March 1961	Tornado	$25.0 million	$263.0 million	
November 1965	Tornado	$25.0 million	$247.3 million	
April 1967	Tornado	$25.0 million	$236.8 million	
July 1996	Flood	$44.7 million	$89.3 million	$0.16-1.3 billion*
September 2008	Flood	$60.0 million	$86.0 million	
August 2014	Flood	$50.1 million	$66.0 million	
August 2001	Flood	$37.0 million	$65.4 million	
March 1991	Tornado	$25.0 million	$58.0 million	
September 2017	Flood	$50.0 million	$63.5 million	
July 2011	Flood	$30.0 million	$41.6 million	
January 2020	Lakeshore Flood	$25.0 million	$30.4 million	
June 2011	Hail	$17.8 million	$24.7 million	
April 2013	Flood	$18.0 million	$24.2 million	$275.7 million
July 1972	Tornado	$2.5 million	$18.7 million	
August 1972	Tornado	$2.5 million	$18.6 million	
March 1976	Tornado	$2.5 million	$14.0 million	
June 1976	Tornado	$2.5 million	$13.8 million	
July 2003	Straight-Line Wind	$5.0 million	$8.5 million	
June 2008	Tornado	$5.0 million	$7.2 million	
July 2011	Lightning	$4.5 million	$6.2 million	
June 1967	Flood	$0.5 million	$4.7 million	$5-10 million
October 1954	Flood	NA	NA	$117 million
July 1957	Flood	NA	NA	$66 million
August 1987	Flood	NA	NA	$170 million*

2.0 Methodology

2.1 Collecting Candidate Heavy Rainfall Events

Heavy rainfall events were collected through multiple methods, including National Oceanic and Atmospheric Administration (NOAA) *Storm Data* records, retrospective newspaper articles, technical reports detailing past heavy rain and flood events in the Chicago area, online searches for past flood events, and general forecaster knowledge at National Weather Service (NWS) Chicago. The goal was to collect information about historical events with an extreme storm total rainfall. For the purposes of this study, an extreme storm total is defined as 7.5 inches or higher - approximately equivalent to the 1-day, 1% AEP (1-in-100 annual chance) rain event as defined by *NOAA Atlas 14* - impacting Chicago and the immediate vicinity (Figure 1) back to 1950. Some events also occurred during this time period which had storm total rainfall amounts less than 7.5 inches, but sub-daily (1-hr, 3-hr, 6-hr, etc.) rainfall amounts which exceeded the 1% AEP. Although it was difficult to ensure that every such event could be found with the available rainfall data, these events were also included and analyzed further to the extent possible.

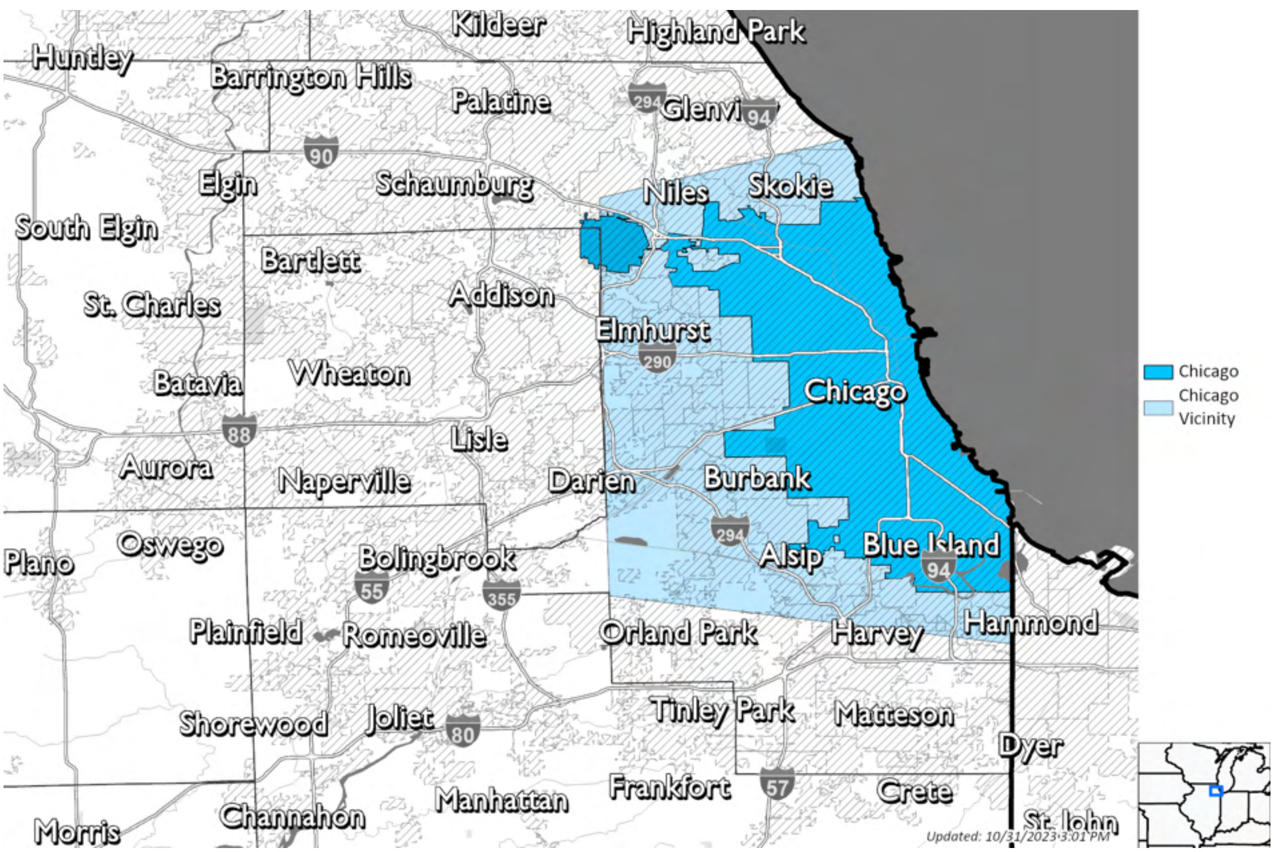

Figure 1. Map showing Chicago and the immediate vicinity. Heavy rainfall events exceeding the 7.5-inch threshold were collected for the indicated area.

Huff and Vogel (1976) provided a significant amount of detail about multiple heavy rainfall events, including locations of peak rainfall, rainfall accumulations over numerous time durations, and average rainfall over varying surface areas. Their analysis indicated candidate extreme rainfall events in 1954, 1957, and 1967. Multiple sources were used to append to this list. Local NWS technical reports were found that documented candidate rainfall events in 1987, 1996, 2022, and 2023. Technical reports from the US Geological Survey (USGS), Illinois State Water Survey (ILSWS), and the University of Chicago indicated candidate rainfall events in 1976, 2001, 2008, 2010. Local forecaster knowledge at NWS Chicago indicated potential candidate events in 2001 and 2011.

2.1.1 Collecting Rain Gauge Data

Rainfall data were collected from the Iowa Environmental Mesonet COOP data plotter application (https://mesonet.agron.iastate.edu/GIS/apps/coop/plot.phtml) in text CSV format. When available, additional rain gauge data were collected from relevant journal articles or technical reports covering a particular candidate heavy rainfall event. These additional rainfall reports might include observations from private weather observers or from bucket surveys conducted by the state of Illinois, local municipalities, or the NWS. The rainfall CSV was converted to a GIS shapefile for later analysis.

2.1.2 Digitizing Rainfall Contour Maps

A majority of the candidate heavy rainfall events had at least one published rainfall contour map available. These maps were most frequently found in technical reports from the ILSWS, USGS, or NWS. These maps were loaded into GIS software and geo-referenced using geographical features such as county boundaries, city locations, and roadway locations. A GIS shapefile of rainfall contours was then created by tracing contours from these maps; when multiple maps existed with rainfall amounts in conflict for a given location, an attempt was made to blend the data sources. The shapefile of rain gauge observations was also used as a guide to assist with creating rainfall contours. Rainfall contours were then interpolated into a storm total rainfall grid.

2.1.3 Utilizing Radar-Derived Rainfall Estimates

Candidate rainfall events in 1996, 2001, 2008, 2010, 2011, 2022, and 2023, also had digital radar data available, which could be used to provide gridded rainfall estimates. For the 1996 and 2001 candidate events, radar reflectivity data was collected from the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/archive/data/). Rainfall rates were estimated by applying a single reflectivity-rainfall (ZR) relationship, summer deep convection ($300R^{1.4}$), to the entire domain for each timestep. Rainfall rates were then totaled into a storm total accumulation, and bias-corrected to match available rain gauge data. The resulting gridded rainfall data were used in place of data derived by digitized contours.

For the 2008, 2010, and 2011 candidate events, some bias-corrected rainfall data were available with limited human quality control. Only minor adjustments to these data were made in isolated areas where additional rainfall observations conflicted with the gridded data. For the 2022 and 2023 events, detailed bias correction and analysis was already available, and no additional data review was needed. Gridded rainfall data from these events were used in place of data derived from digitizing contours.

2.2 Collecting Meteorological Conditions

Synoptic conditions associated with each of the candidate heavy rainfall events were collected and summarized. For some events, information about the surface weather pattern and upper-air conditions were already published in relevant technical reports. When available, surface weather information was collected from these reports and then compared to information published elsewhere, including the NOAA Central Library daily weather map collection (https://library.noaa.gov/Collections/Digital-Collections/US-Daily-Weather-Maps), Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php), the Iowa Environmental Mesonet Midwest mesoplot (https://mesonet.agron.iastate.edu/timemachine/), and the ERA5 reanalysis from the Copernicus Climate Change Service (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels). Upper air information was also collected from relevant technical reports, when available, and was supplemented by the NOAA Central Library daily weather map collection (https://library.noaa.gov/Collections/Digital-Collections/US-Daily-Weather-Maps) and Plymouth State Weather Center's upper air archive (https://vortex.plymouth.edu/myowxp/upa/).

2.3 Collecting Reports of Flood Impacts

When available, flood impacts were collected for each of the candidate heavy rainfall events. Information about particular buildings that were flooded, or particular sections of roadway that were flooded, were added to an event-specific shapefile. When technical reports covering an event did not provide detailed flood impacts, or when such a report was not available, historical newspaper articles were reviewed for mention of flood impacts. Damage costs associated with each flooding event were collected from *Storm Data* and from any technical reports detailing the event. Damage costs in 2024 dollars were also calculated using the Bureau of Labor Statistics CPI Inflation Calculator (https://data.bls.gov/cgi-bin/cpicalc.pl), with April 2024 selected as the current date.

2.4 Analysis of Changes in Chicago Rainfall

According to the 2023 National Climate Assessment, heavy precipitation events (above the 99th percentile) have increased by 45% since 1950s (U.S. Global Change Research Program 2023) in the Midwestern United States. Annual precipitation for the northeast Illinois climate division has increased by approximately 18% over that same period (National Centers for Environmental Information 2023). To look for evidence of changes to the distribution of rainfall accumulation over time, 1-day and 2-day rainfall accumulations were collected for the official Chicago observation site. The rainfall data were then split into two 60-year periods, 1871-1930 and 1961-2020. Using the HEC-DSSvue software, annual peak values were calculated for the 1-day and 2-day accumulations, and a Log Pearson Type III distribution was fit to the data to estimate rainfall amounts at various annual exceedance probabilities (AEPs). Because the maximum 24-hour rainfall value for a given year was not determined using a moving time window with an hourly timestep, it is possible that rainfall can cover two calendar days, introducing a bias to the precipitation frequency distribution (Lincoln, Landry-Guyton and Schlotzhauer 2016, Asquith 1998). Fixed-interval bias correction factors of 1.13 and 1.067 were applied to the calculated 1-day and 2-day precipitation frequency distributions, respectively, to reduce this bias. From the calculated precipitation frequency values, an AEP or average recurrence interval (ARI) can be determined for a selected rainfall amount, which allows for an approximate comparison of how the probability of a set rain amount has changed over time.

Precipitation frequency values were compared to those published by *NOAA Atlas 14* (Bonnin, et al. 2004) and Illinois State Water Survey (ILSWS) Bulletin 75 (Angel and Markus 2020), two widely used, definitive sources for precipitation frequency information. The information published by these studies is widely used across the engineering, stormwater, and hydrometeorology fields, but they do not include information about changes to precipitation frequency and instead provide statistics for a single, assumed climatically stable period of time. The comparison presented in this study, while subject to uncertainty, may provide some insights into the way rainfall is changing at different severity levels in the Chicago area. To supplement the rainfall frequency analyses, the number of 1-day and 2-day rainfall events exceeding set thresholds each decade from 1870 to 2023 were also collected.

3.0 Results

3.1 Extreme Rainfall Events in the Chicago Vicinity (1950-2023)

The Chicago metropolitan area has experienced many extreme rainfall events since 1950. Although the chances of an extreme rainfall event occurring at a single location within the area during a given year is very low, the chance is significantly higher that *somewhere* within the Chicago metro area will experience an extreme rainfall event. For the 2 July 2023 event, in particular, numerous media articles represented it as a “record rainfall” or one that produced “unprecedented flooding,” but a review of climatological records and studies found that at least eight (8) events with similar storm total rainfall impacted the study area (central Cook County) since 1950. Several additional events were found with lower storm total rainfall values (less than 7.5 inches) but extreme (<=1% AEP) rainfall amounts over sub-daily durations. A detailed review of the known extreme rainfall events impacting the study area is provided in the following sections.

October 9-11, 1954

From 9 October to 11 October 1954, heavy rainfall occurred across the Great Lakes region with some of the heaviest rainfall occurring in northern Illinois. Rainfall up to 11.1 inches occurred over a 48-hour period (Figure 2), the majority of which occurred from 0200 UTC on 10 October through 0200 UTC on 11 October. Peak storm total rainfall in the study area was analyzed as a 0.2% AEP (1-in-500 annual chance) event (Figure 3). This event previously held the state record for a 24-hour rainfall at an official climate station with 10.58 inches recorded at Aurora, Illinois. Widespread flooding of structures and roadways were reported across the Chicago metropolitan area (Figure 4). In Chicago, flooding caused an estimated $10 million (approximately $117 million in 2024 dollars) in damage, while $25 million (approximately $292 million in 2024 dollars) in damage was caused across the Chicago metro area (Nash and Chamberlain 1954).

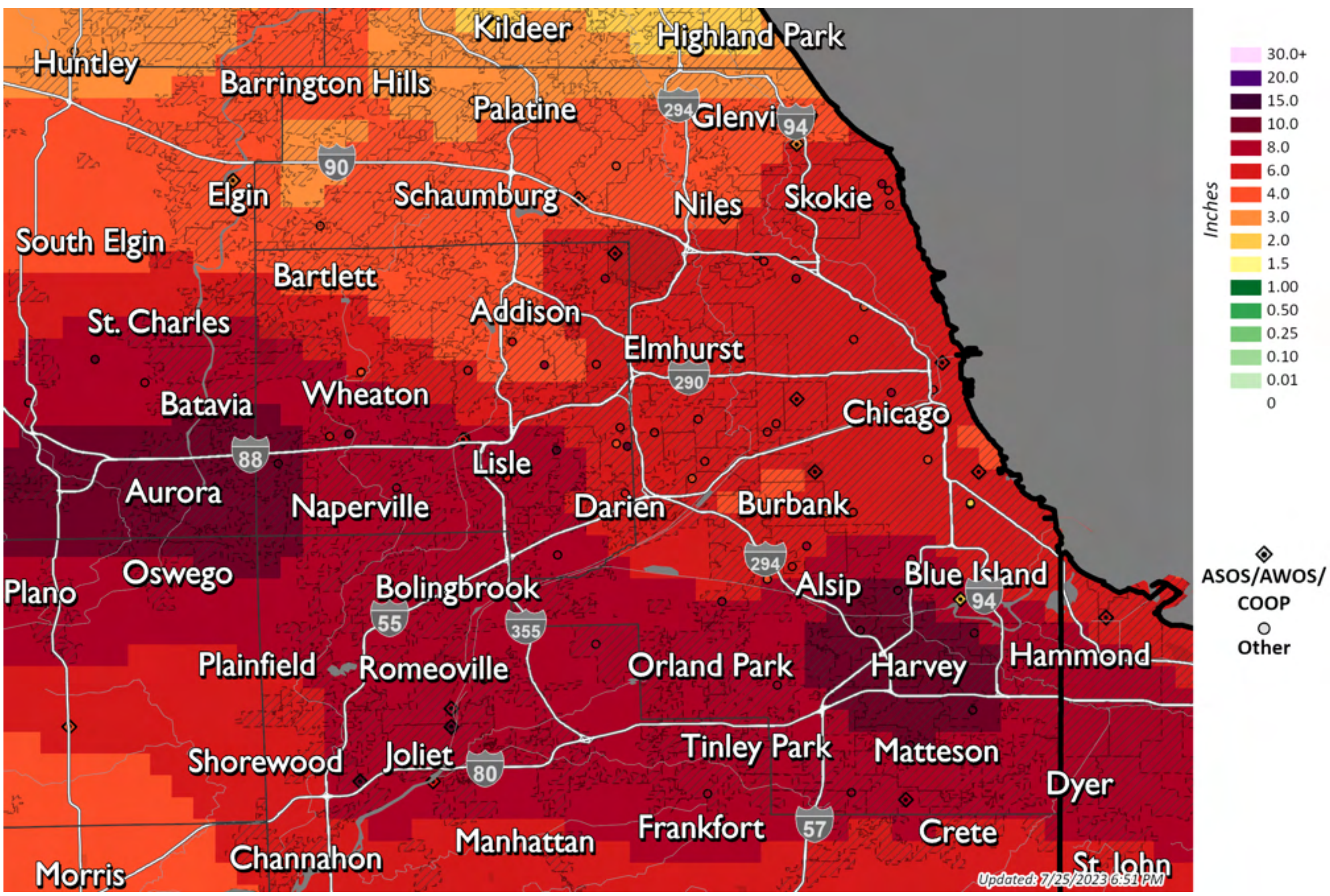

Figure 2. Storm total rainfall from 1200 UTC on 9 October 1954 to 1200 UTC on 11 October 1954.

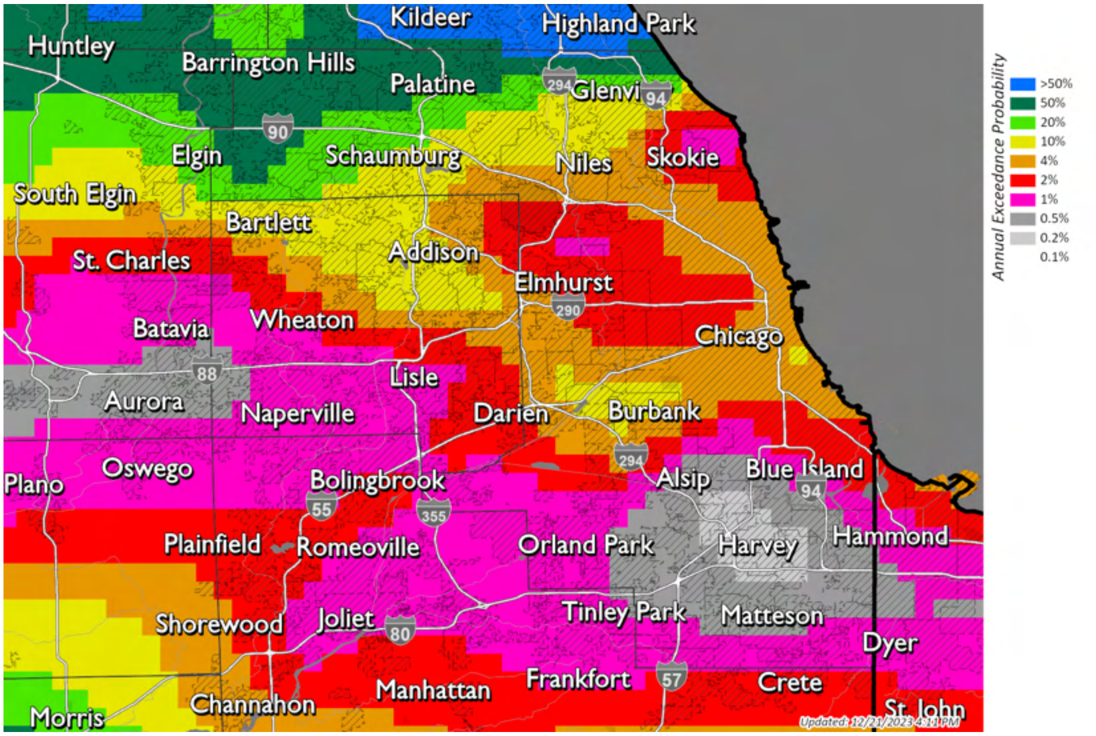

Figure 3. Annual exceedance probability for the storm total rainfall from 1200 UTC on 9 October 1954 to 1200 UTC on 11 October 1954.

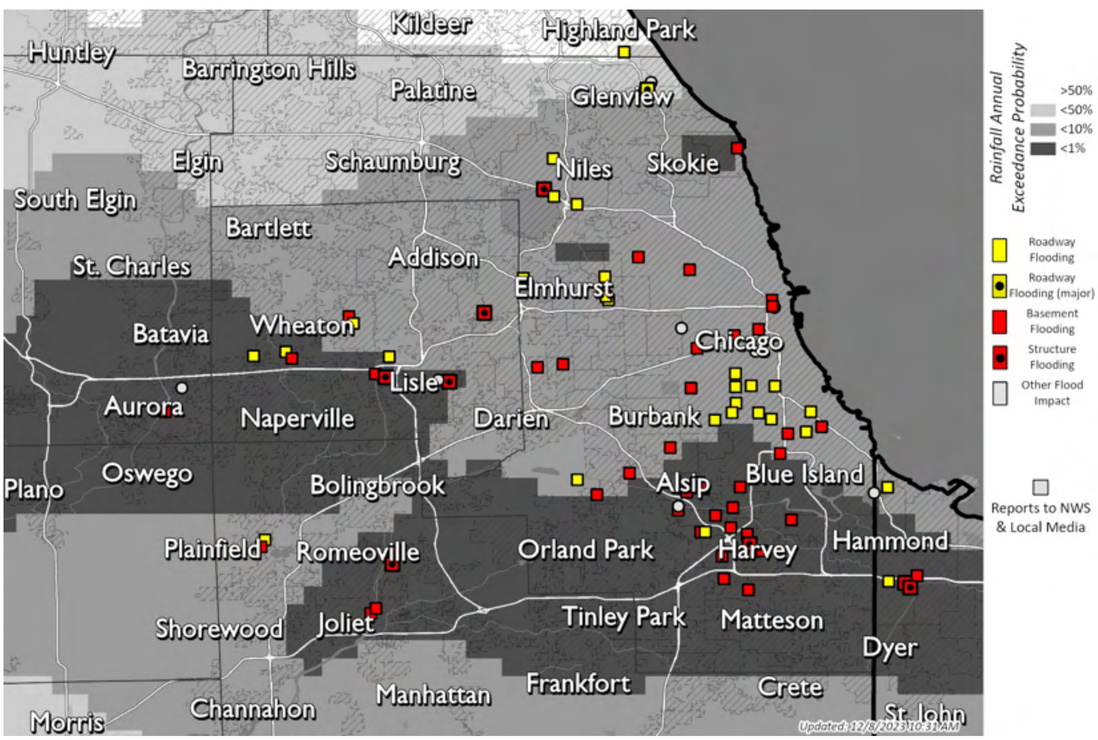

Figure 4. Known flash flood impacts for the 9-11 October 1954 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

Late in the evening of 9 October, a low pressure area was situated in northwest Kansas and a stationary boundary extended eastward toward far southern Iowa, northern Illinois, into far southern Michigan (NOAA Central Library 2023, Nash and Chamberlain 1954, Hersbach, et al. 2023). At 850 mb, a strong low-level jet was oriented from the southwest to the northeast, nearing the stationary boundary and then curving to the east along it (Plymouth State University 2023). At 500 mb, a ridge was located over the central U.S., centered near Iowa. Over the next 48 hours, the area of low pressure moved to the east along the front, with the front drifting slowly north (Figure 5). Multiple waves of thunderstorms then occurred ahead of the low pressure area near the front and in the warm sector leading to widespread heavy rainfall and significant flash flooding and river flooding. The general synoptic setup had strong similarities to the Maddox Frontal pattern (Maddox, Chappell and Hoxit 1979).

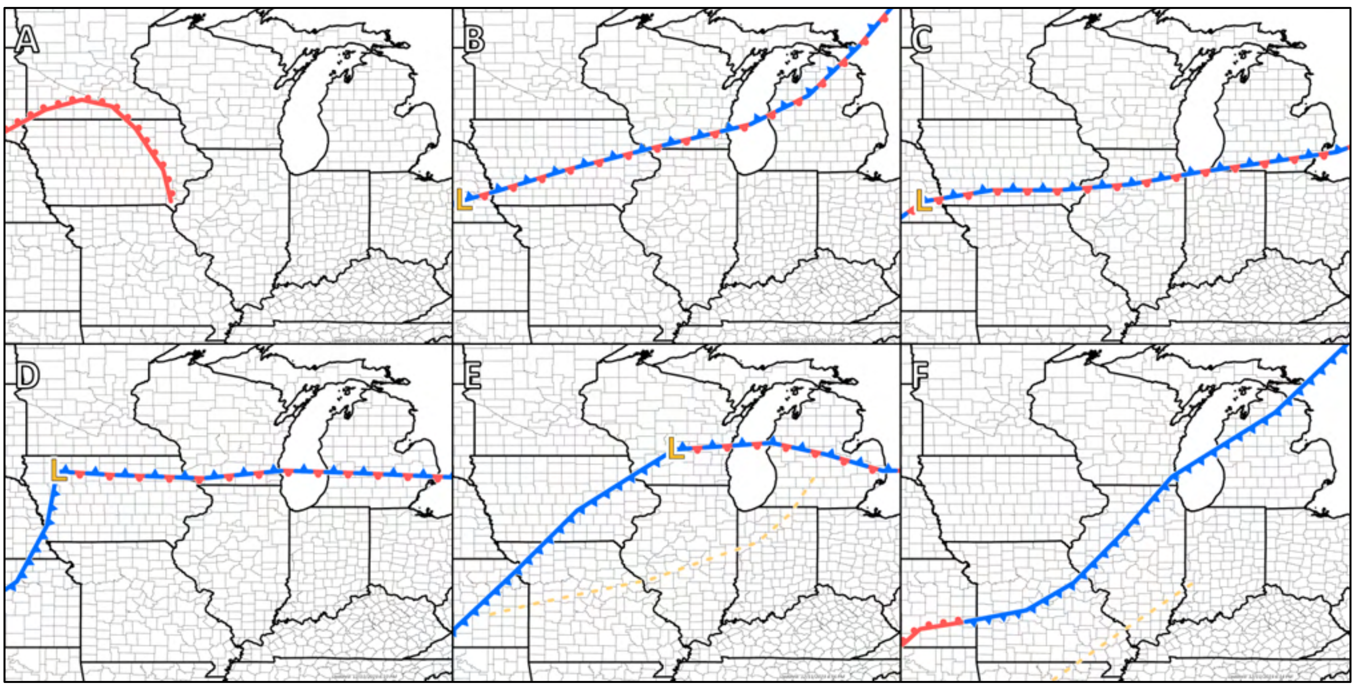

Figure 5. Surface weather maps for the 9-11 October 1954 rainfall event. Images are valid at 0330 UTC on 9 October (A), 1530 UTC on 9 October (B), 0330 UTC on 10 October (C), 1530 UTC on 10 October (D), 0330 UTC on 11 October (E), and 1530 UTC on 11 October (F). Surface maps created based upon data found in Nash & Chamberlain (1954), NOAA Central Library's daily weather map archive (2023), and the ERA5 reanalysis from the Copernicus Climate Change Service (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels); when sources conflict, an attempt was made to review archived weather data and create a consensus of surface feature locations.

Radar imagery from a research radar in place at Champaign, Illinois (CMI) indicated multiple significant echoes extending from the west-northwest to the east-southeast across northern Illinois, including southern portions of the Chicago metro area, at 2230 UTC on 9 October 1954 (Huff, Hiser and Stout 1955). These cells moved to the northeast, likely following the northward-drifting front, exited the area by approximately 0100 UTC 10 October

(Figure 6), and caused only light totals for most of the study area. Just a few hours later, at approximately 0200 UTC 10 October, an east-west oriented line of significant echoes appeared on radar from near the Quad Cities, Iowa/Illinois, to near Chicago. These cells were oriented along and just south of the stationary front, and moved generally to the east. The movement of these cells over the same areas, referred to as “training,” allowed for the accumulation of several inches of rainfall by about 1200 UTC when the echoes began to diminish. Light rainfall again occurred in northern Illinois from approximately 1400 UTC to 2000 UTC 10 October. At 2000 UTC, CMI radar imagery showed a rapid increase in significant echoes along an east-west oriented line in almost the same location as thunderstorms from the prior evening. This line of storms evolved over the next few hours into several segments which moved generally east southeast. By 2300 UTC on 10 October, the echoes had formed a squall line oriented from northeast to southwest, which was moving to the southeast. By 11 October, many locations in northern Illinois had experienced multiple periods of rainfall of varying intensity, with periods of heaviest thunderstorm activity totaling a few inches in just 1-2 hours (Figure 7).

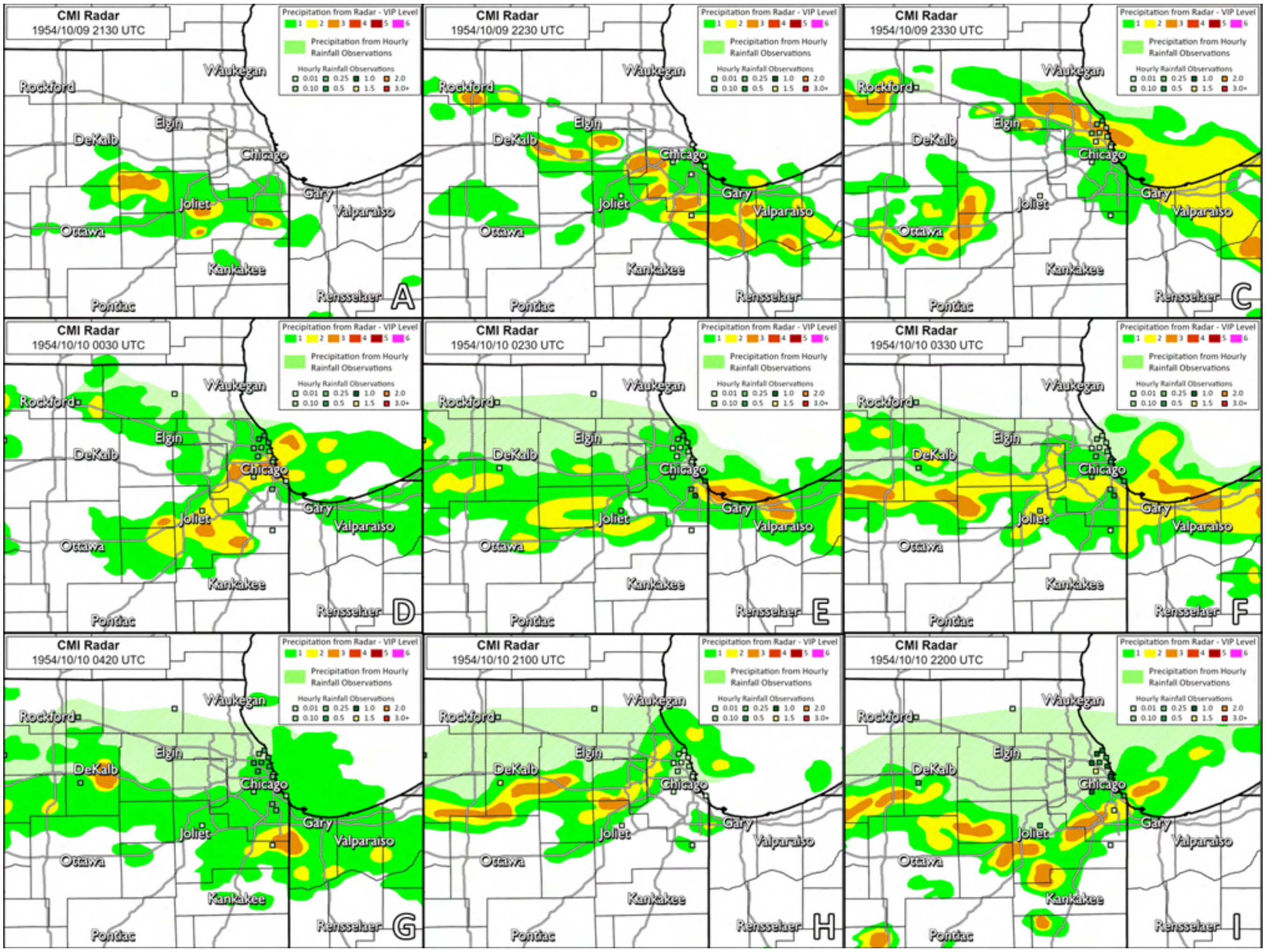

Figure 6. Digitized radar data for the 9-11 October 1954 rainfall event. Images are valid at 2130 UTC on 9 October (A), 2230 UTC on 9 October (B), 2330 UTC on 9 October (C), 0030 UTC on 10 October (D), 0230 UTC on 10 October (E), 0330 UTC on 10 October (F), 0420 UTC on 10 October (G), 2100 UTC on 10 October (H), and 2200 UTC on 10 October (I). Radar maps were digitized based upon data published by Huff et al. (1955). A review of hourly rainfall observations (color-filled boxes) suggested that attenuation occurred north of the bands of heavy rainfall; these observations were used to estimate precipitation areas that were not depicted by radar (green hatching).

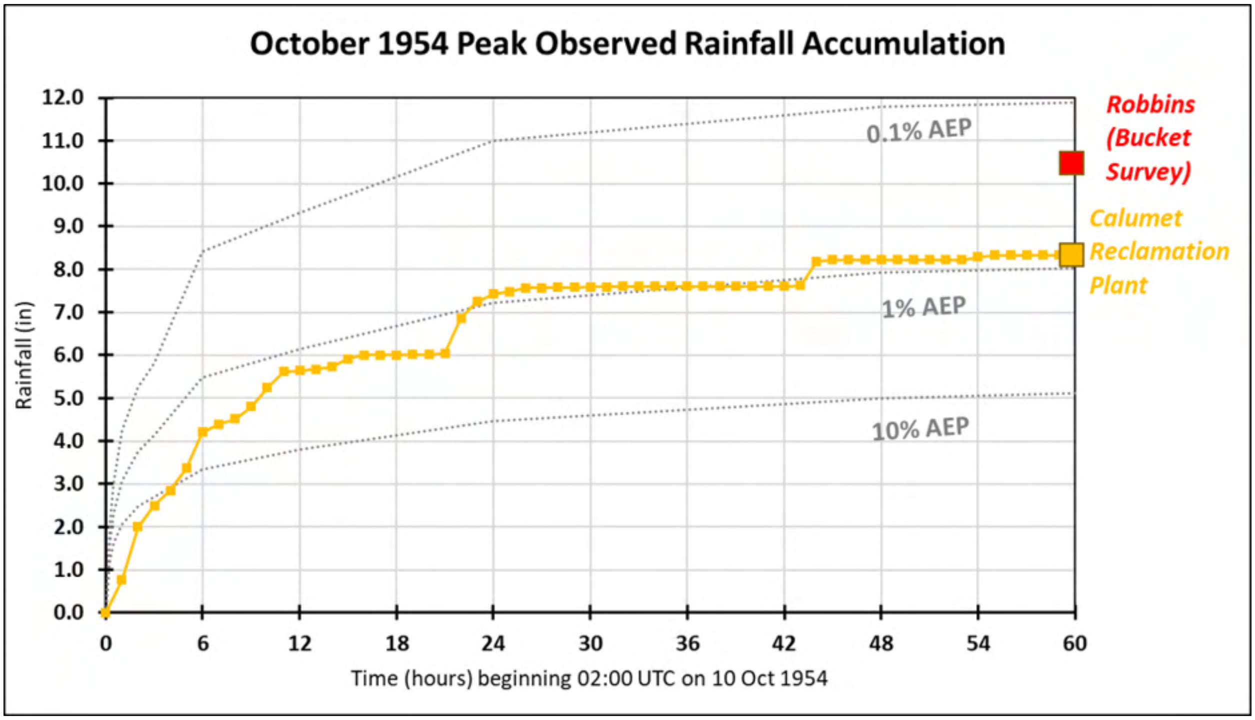

Figure 7. Running storm total rainfall for the 9-11 October 1954 rainfall event. The recording rain gauge with the highest storm total, MWRD's gauge at the Calumet Reclamation Plant, is indicated with a yellow-orange line and square. The peak rainfall observation at Robbins from the post-event bucket survey is indicated with a red square. Time on this chart begins with the first hour of measured rainfall.

July 12-13, 1957

From 12 July to 13 July 1957, heavy rainfall occurred across northeast Illinois and northwest Indiana. Rainfall up to 9 inches occurred over an 18-hour period (Figure 8), the majority of which occurred in 6-9 hours (depending on the location) from approximately 0000 UTC to 0600-0900 UTC 13 July. Peak storm total rainfall in the study area was analyzed as a 0.2% AEP (1-in-500 annual chance) event (Figure 9). This rainfall caused widespread flooding across the Chicago metro area (Figure 10) which resulted in an estimated $6 million (approximately $66 million in 2024 dollars) in damages (US Geological Survey 1964). This same event caused record flooding to the south of the Chicago metro due to observed rainfall up to 11.1 inches near Kankakee.

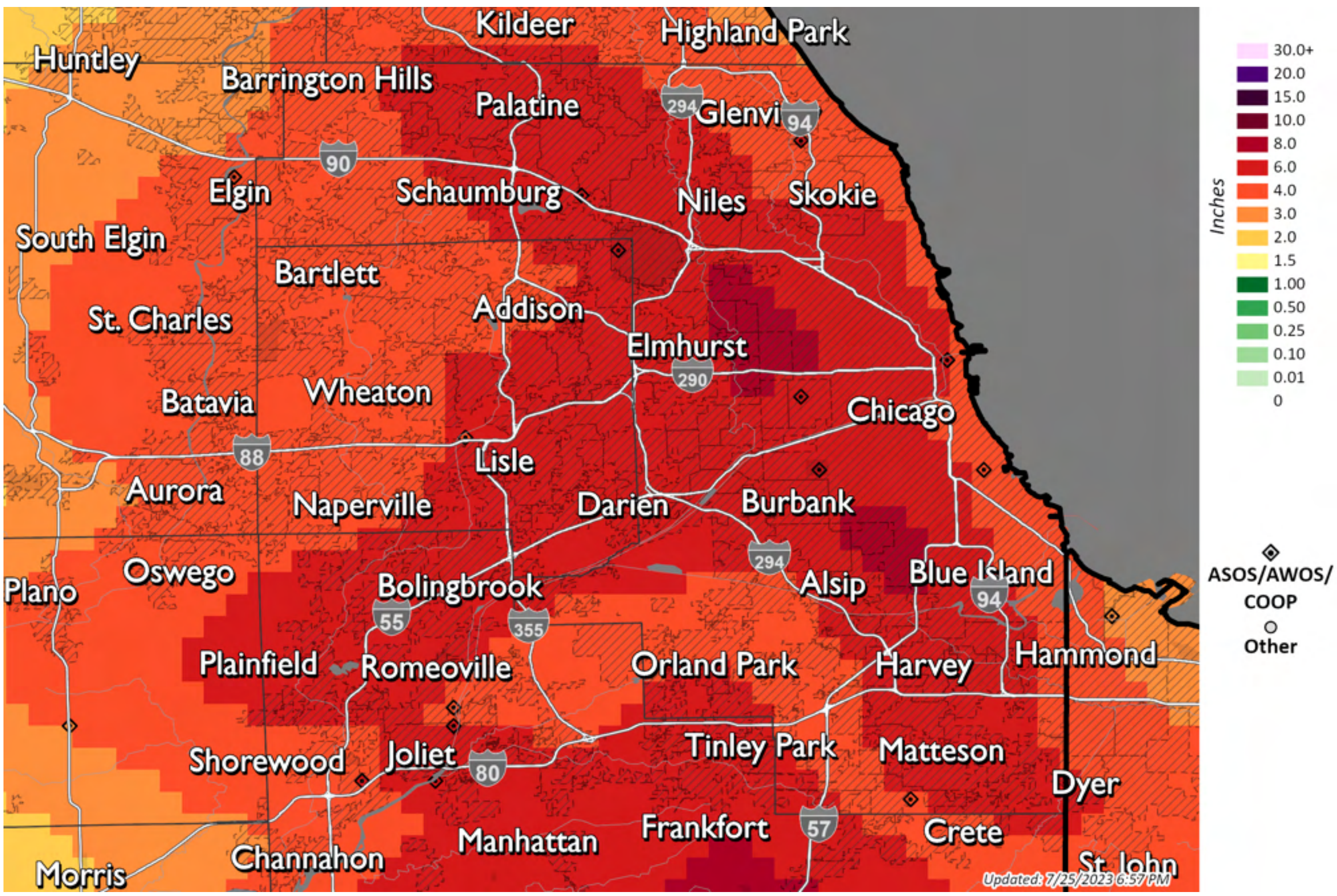

Figure 8. Storm total rainfall from 1800 UTC on 12 July 1957 to 1200 UTC on 13 July 1957.

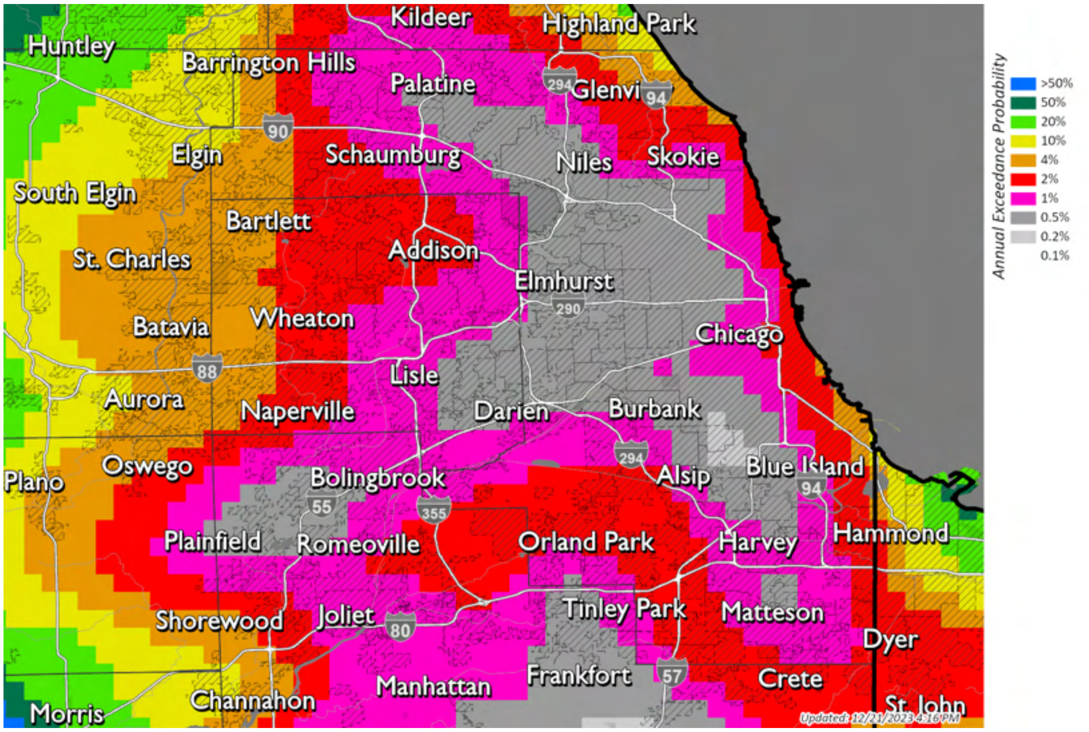

Figure 9. Annual exceedance probability for the storm total rainfall from 1800 UTC on 12 July 1957 to 1200 UTC on 13 July 1957.

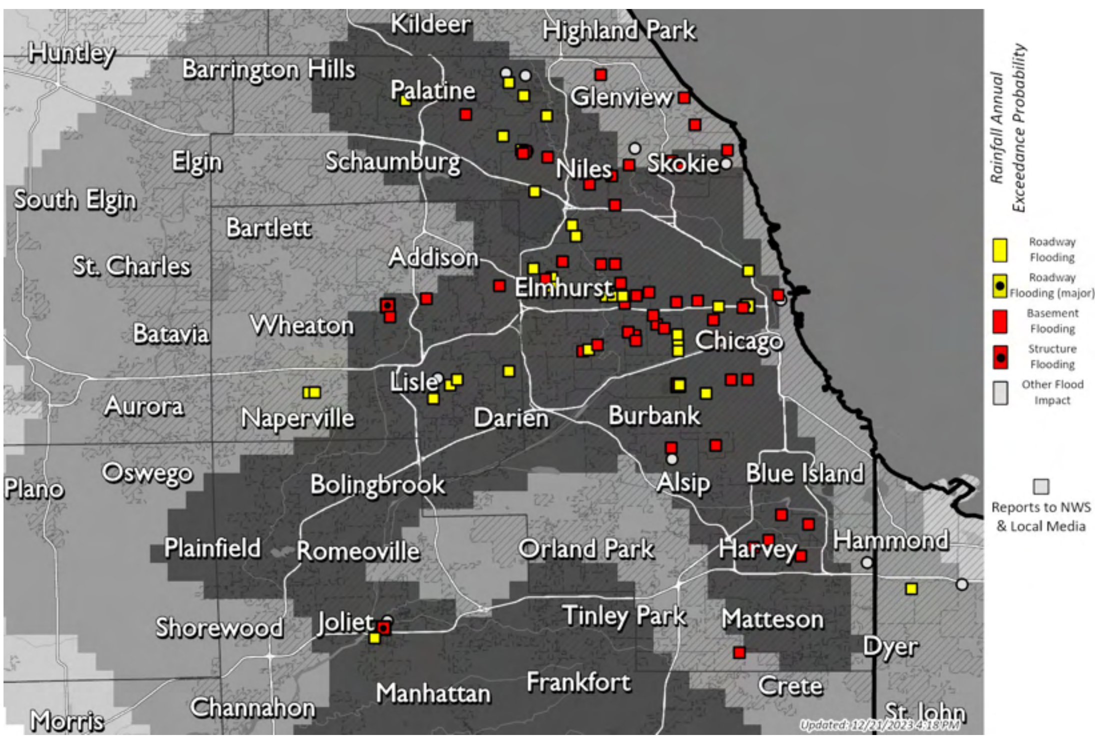

Figure 10. Known flash flood impacts for the 12-13 July 1957 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

Early in the afternoon of 12 July 1957, a low pressure area was located near the Iowa, Nebraska, and South Dakota border and a stationary front extended east toward southern Minnesota and western Wisconsin (Huff, Semonin, et al. 1958, NOAA Central Library 2023, Hersbach, et al. 2023). At 850 mb, a strong low-level jet was oriented from the southwest to the northeast, intersecting the stationary boundary in northeastern Illinois (Plymouth State University 2023). At 500 mb, a ridge was evident across the western and central U.S., centered near the Great Plaines, with northeast Illinois near the eastern edge in northwesterly flow. A cluster of thunderstorms formed in southern Wisconsin and northern Illinois, which likely generated an outflow boundary extending from southwest Wisconsin into northeast Illinois. Over the next 24 hours, the area of low pressure moved eastward into Iowa, with the front drifting slowly south and decaying. The outflow boundary was the focusing mechanism for multiple clusters of thunderstorms that caused heavy rainfall and significant flooding. The general synoptic setup had strong similarities to the Maddox Mesohigh pattern (Maddox, Chappell and Hoxit 1979).

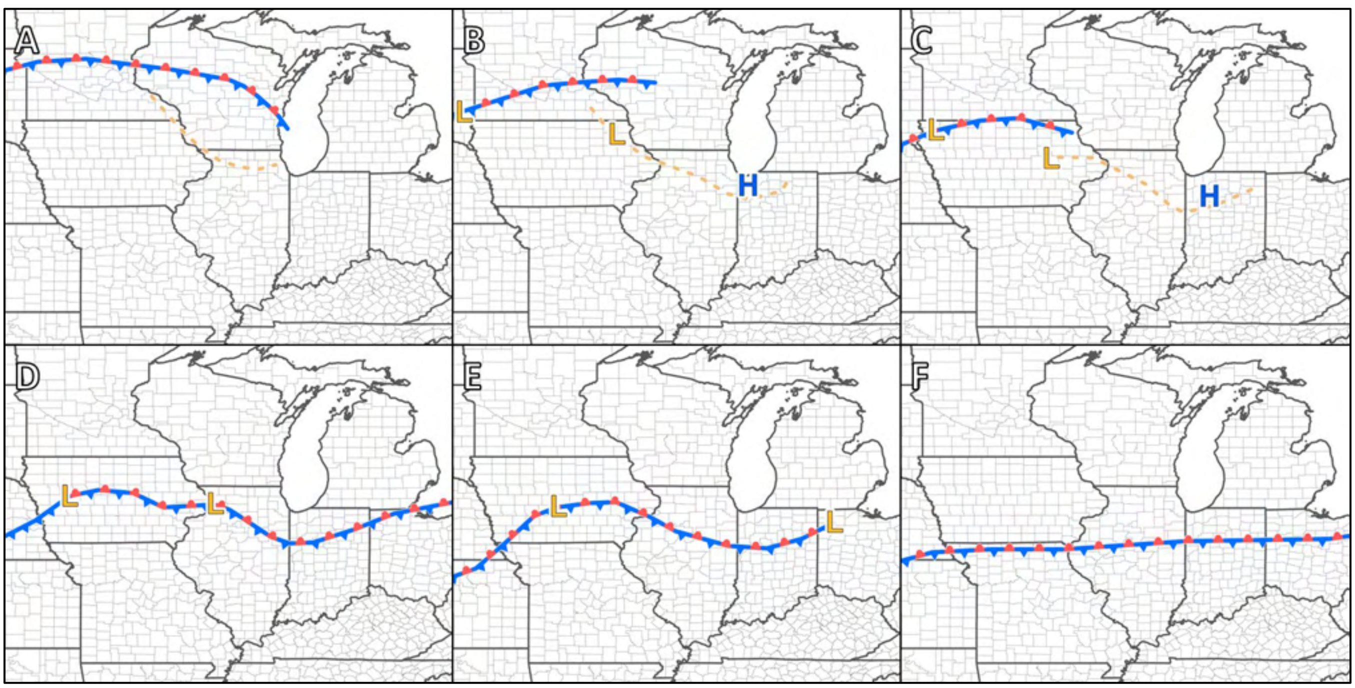

Figure 11. Surface weather maps for the 12-13 July 1957 rainfall event. Images are valid at 1200 UTC on 12 July (A), 1800 UTC on 12 July (B), 0000 UTC on 13 July (C), 0600 UTC on 13 July (D), 1200 UTC on 13 July (E), and 1800 UTC on 13 July (F). Surface maps created based upon data found in Huff et al. (1958), NOAA Central Library's daily weather map archive (2023), and the ERA5 reanalysis from the Copernicus Climate Change Service (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels). At many time steps, sources conflict; archived weather data was reviewed and a consensus of surface feature locations was created by numerous forecasters at NWS Chicago.

Radar imagery from CMI indicated a line of echoes extending from southwest to northeast moving to the southeast across northern Illinois at 1830 UTC on 12 July 1957 (Huff, Semonin, et al. 1958). These cells moved to the southeast, partially following the stationary front or a possibly a lake breeze, with additional development of echoes evident to the northwest. By 2315 UTC, radar imagery indicated a train of multiple echoes oriented northwest to southeast extended from just north of Rockford, Illinois, through Chicago, to just north of Lafayette, Indiana. These cells were generally moving to the east-southeast, with the line of echoes drifting slowly southward at about 25 mph. By 0300 UTC 13 July, a new corridor of rainfall was evident across the same northwest to southeast axis from Rockford to Chicago. At this time, the radar operator noted the attenuation of radar data on the far (northeast side) of the heavy rainfall bands, partially masking some precipitation (Huff, Semonin, et al. 1958). Radar imagery indicated that the training echoes had dissipated by 0700 UTC, but the radar operator noted that heavy precipitation near the radar site (to the south of the presented area in Figure 12) had greatly attenuated ongoing rainfall just south of the Chicago area, which was evidenced by hourly rainfall data. By the afternoon of 13 July, portions of northeast Illinois had experienced three or four rounds of rainfall, with the later rounds of rainfall orienting nearly parallel to the slow-moving frontal boundary. Rainfall intensity from individual cells increased as the cells neared the Chicago area and Lake Michigan, with this area of intensification drifting south with the line from Chicago to Kankakee, through the early morning hours of 13 July. These training storms caused peak observed rainfall rates of 2-3 inches per hour.

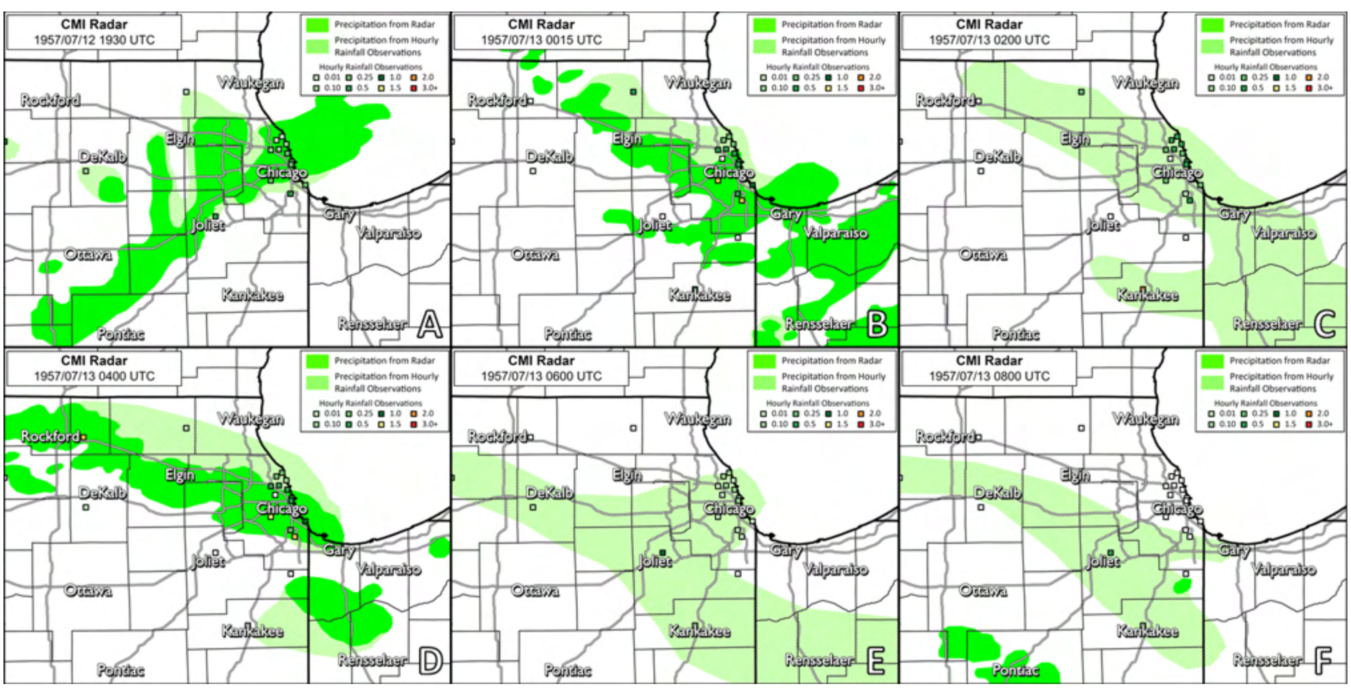

Figure 12. Digitized radar data for the 12-13 July 1957 rainfall event. Images are valid at 1930 UTC on 12 July (A), 0015 UTC on 13 July (B), 0400 UTC on 13 July (C), and 0800 UTC on 13 July (D). Radar maps were digitized based upon data published

by Huff et al. (1958) which did not include reflectivity or intensity levels. Descriptions associated with the radar data indicated that significant attenuation occurred when multiple bands of heavy rainfall were ongoing across northeast Illinois. Hourly rainfall observations (color-filled boxes) were used to estimate precipitation areas that were not depicted due to radar attenuation (green hatching).

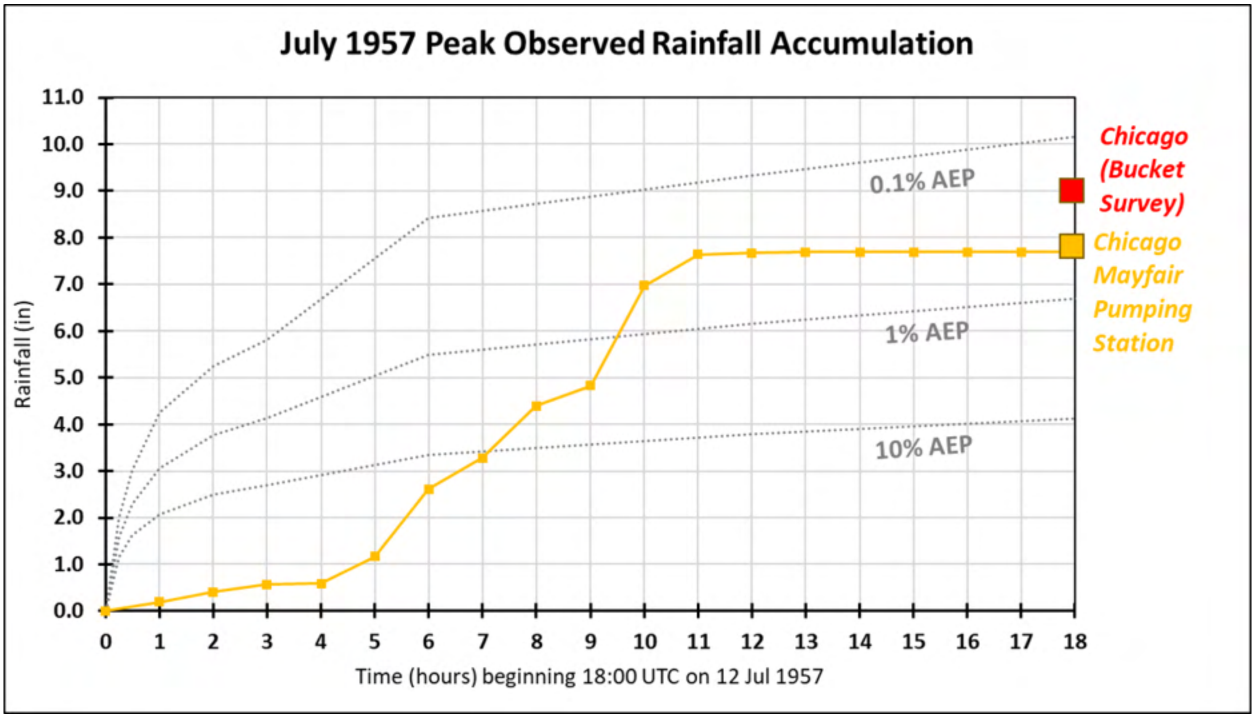

Figure 13. Running storm total rainfall for the 12-13 July 1957 rainfall event. The recording rain gauge with the highest storm total, MWRD's gauge at the Calumet Reclamation Plant, is indicated with a yellow-orange line and square. The peak rainfall observation at Robbins from the post-event bucket survey is indicated with a red square. Time on this chart begins with the first hour of measured rainfall.

June 10, 1967

On 10 June 1967, heavy rainfall occurred across northern Illinois, including the northern half of the Chicago metropolitan area. Rainfall up to 6.1 inches occurred over an 11-hour period (Figure 14) in the study area, the majority of which occurred in 3 hours (over varying time ranges depending on the location) from approximately 1700 UTC on 10 June to 0400 UTC on 11 June. Although storm total rainfall amounts were less than the 7.5-inch storm total threshold used for selection of historical rainfall events, rainfall rates were very intense over a short period of time; near the area of peak rainfall in the Chicago Loop, 3.5 inches occurred in one (1) hour, 5.2 inches occurred in two (2) hours, and 5.4 inches occurred in three (3) hours (Huff, Semonin, et al. 1958), each exceeding the 1% AEP (1-in-100 annual chance) event according to *NOAA Atlas 14*. Most notably, peak 2-hr rainfall in the study area was analyzed as a 0.2% AEP (1-in-500 annual chance) event (Figure 15). Significant flooding was noted in some areas, including on I-94 and I-90 near the Chicago Loop and to the northwest (Figure 16). News accounts indicated water in numerous basements from the northwest suburbs into the Chicago Loop, as well as minor flooding at the Art Institute of Chicago and the Studebaker Theater. Official flood damage estimates indicated amounts up to $0.5 million (up to $4.7 million in 2024 dollars), and a review of *Chicago Tribune* articles written after the event indicate damages of at least $1.4 million ($13.1 million in 2024 dollars) in the Arlington Heights, Deerfield, Des Plaines, and Deerfield areas alone (Chicago Tribune 1967, Chicago Tribune 1967). Multiple Chicago Tribune articles indicate an estimate of “millions” in damages without providing additional specific numbers, locations, or sources. Based upon the extent of the damage, the lack of inclusion of Chicago damages, and a comparison with similar events, the higher estimates provided by the *Chicago Tribune* are more likely.

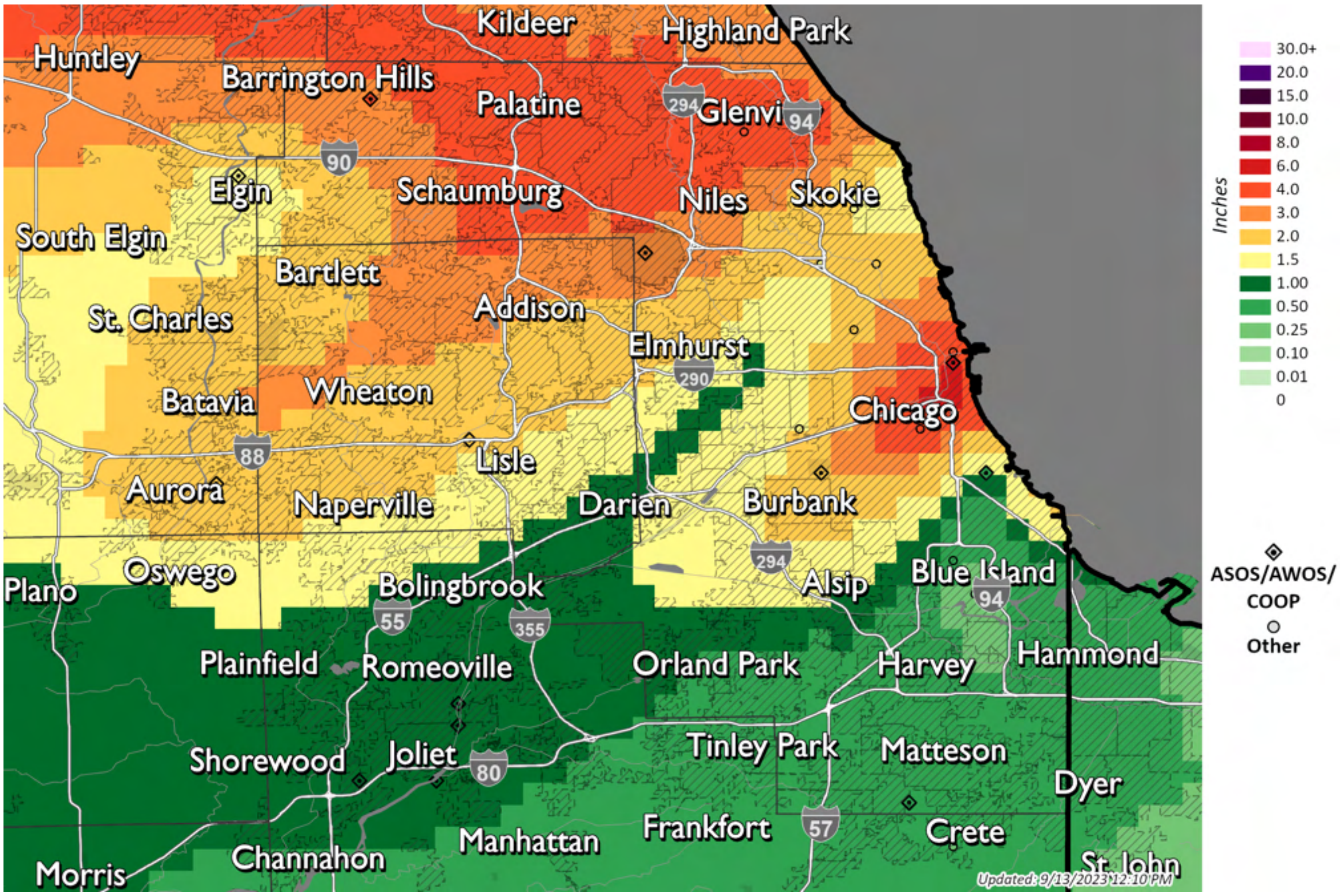

Figure 14. Storm total rainfall from 1700 UTC on 10 June 1967 to 0400 UTC on 11 June 1967.

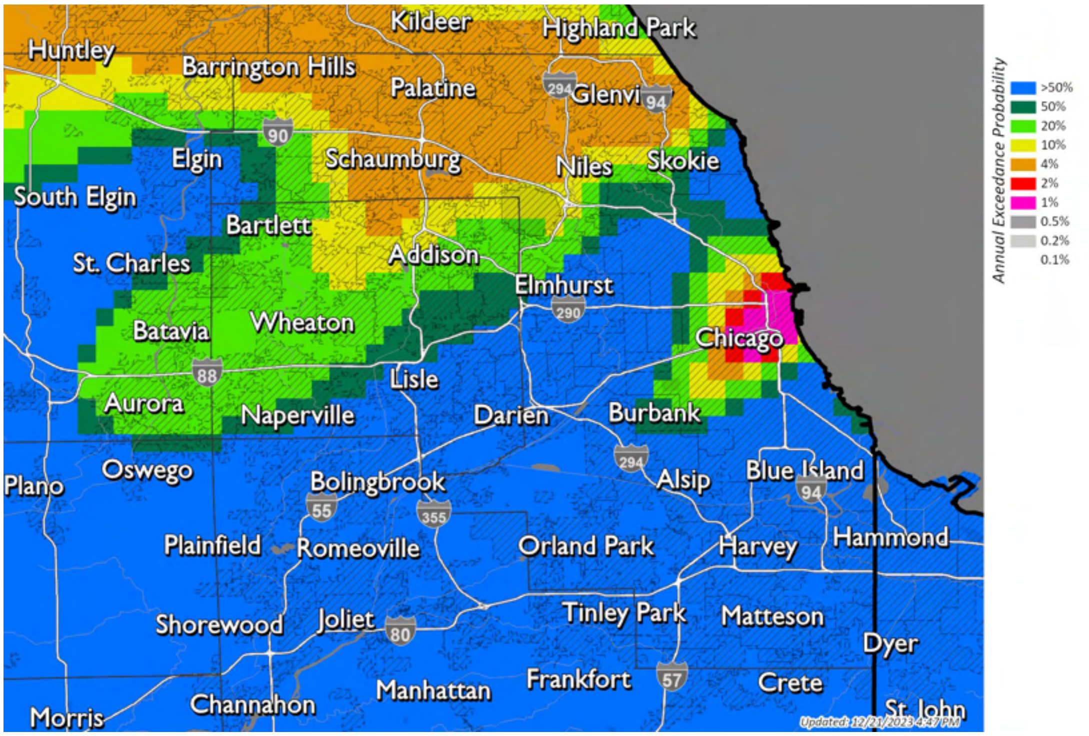

Figure 15. Annual exceedance probability for the storm total rainfall from 1700 UTC on 10 June 1967 to 0400 UTC on 11 June 1967.

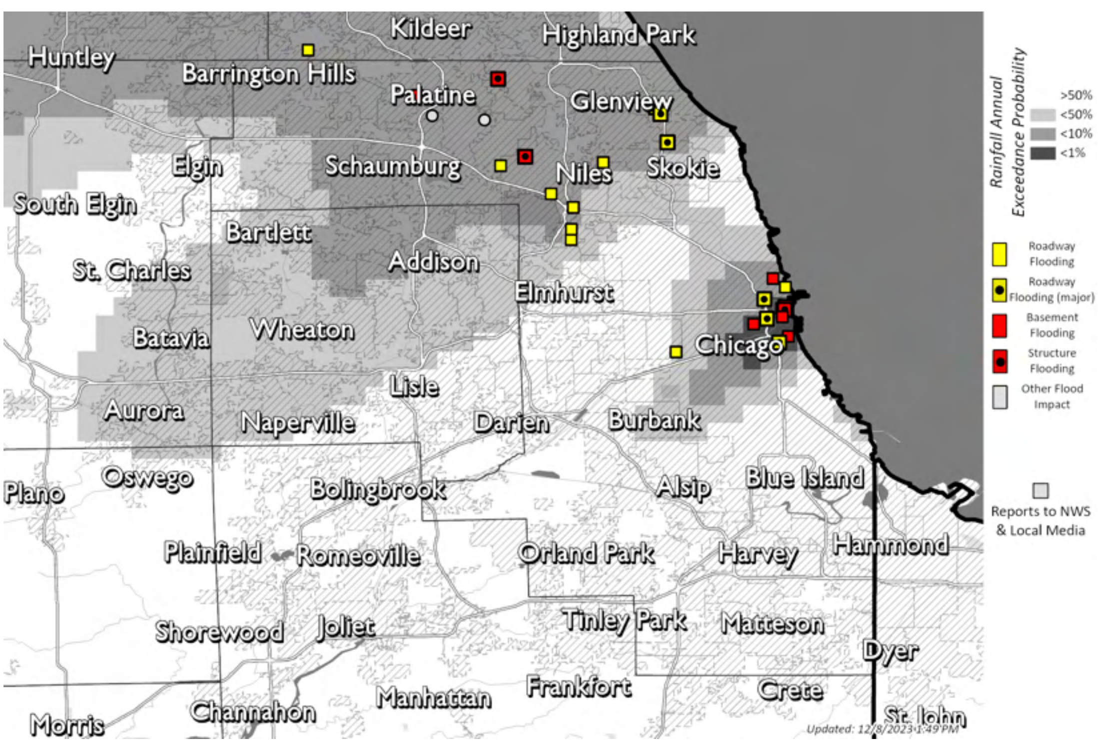

Figure 16. Known flash flood impacts for the 10 June 1967 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

Early in the morning of 10 June 1967, a low pressure area was situated in southwest Kansas and a stationary boundary extended east northeastward through Iowa and southern Wisconsin (NOAA Central Library 2023, Hersbach, et al. 2023). By 1800 UTC on 10 June, the stationary boundary had moved very little to just north of the Illinois-Wisconsin border (Figure 17). At 850 mb, a low-level jet was oriented from the southwest to the northeast, intersecting the stationary boundary in the vicinity of northeastern Illinois (Plymouth State University 2023). At 500 mb, a ridge was located across the southeast U.S., centered near North Carolina, and a trough was located across the northwest U.S., centered near Idaho. South of this boundary in the warm sector, the 1200 UTC 10 June sounding from Peoria indicated a nearly saturated profile from near the surface up to the 600-mb level, yielding a precipitable water value of 1.5 inches (Plymouth State University 2023). Over the next 12 hours, the identified upper-air features would remain generally in the same location, with only a slight shift to the east. By 0000 UTC on 11 June, the sounding from Peoria indicated a nearly saturated profile up to the 300-mb level and a precipitable water value that had increased to 1.7 inches.

Waves of thunderstorm activity formed to the southeast of the low pressure area and stationary front in the warm sector. Multiple bands of storms occurred through the afternoon, with relatively slow storm motions. The general synoptic setup had strong similarities to the Maddox Synoptic pattern (Maddox, Chappell and Hoxit 1979), and a few similarities to the Maddox Mesohigh pattern, although the lack of detailed surface observations precluded the ability to discern small-scale outflow boundaries near the Chicago metro area.

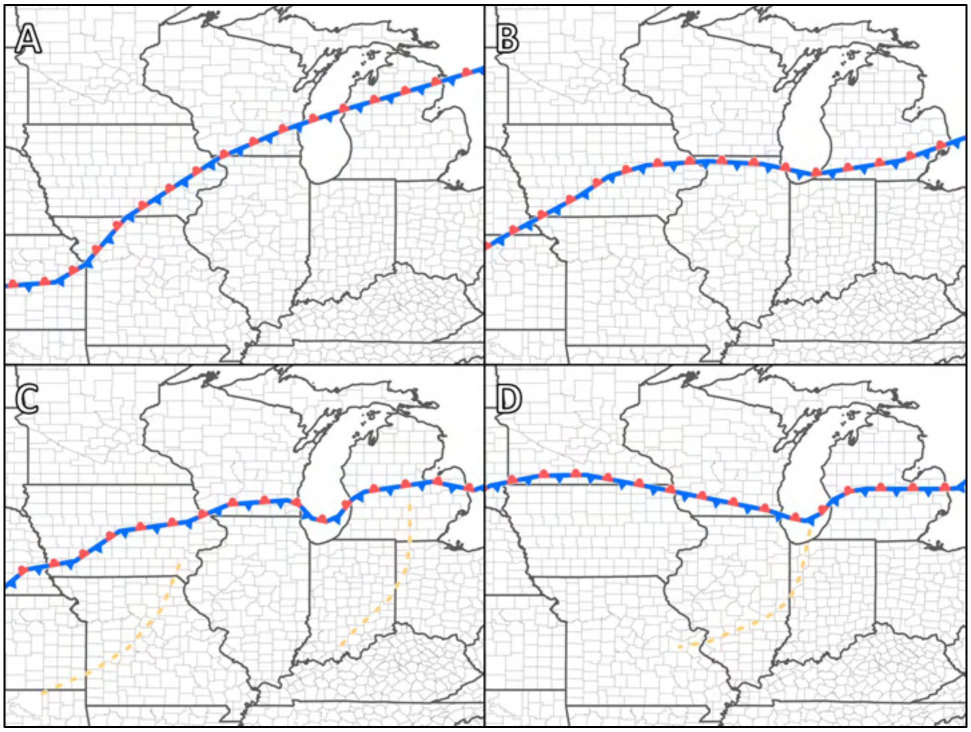

Figure 17. Surface weather maps for the 10 June 1967 rainfall event. Images are valid at 0600 UTC on 10 June (A), 1200 UTC on 10 June (B), 1800 UTC on 10 June (C), and 0000 UTC on 11 June (D). Surface maps created based upon NOAA Central Library's daily weather map archive (2023) and the ERA5 reanalysis from the Copernicus Climate Change Service (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels).

No detailed radar imagery was available for the 10 June 1967 flash flood event to help discern the character and movement of individual storm cells, although hourly rain gauge data and hourly radar observer notes were retrieved from the National Center for Environmental Information. Hourly rain gauge data indicated that storms developed over central Cook County just prior to 1800 UTC on 10 June. Manual radar observations indicated a general area of developing radar echoes in northern Illinois at 1745 UTC, with a line of echoes extending from southwest to northeast across far northwestern Illinois and a concentrated area of storms in the western suburbs of Chicago. By 1900 UTC, 1-hour rainfall accumulations had increased significantly over a small portion of Chicago extending from near Midway Airport northeast toward the Chicago Loop. This rainfall was likely associated with a line of storms noted by the radar observer extending west to east across southern Lake Michigan and into southern Michigan. The line of thunderstorms in northwestern Illinois was slowly approaching the Rockford area at this time. At 2000 UTC, rain gauges indicated that the thunderstorm over central Cook County was moving offshore over Lake Michigan, with the radar operator no longer noting a line of storms in the Chicago area. To the northwest, near Rockford, the radar operator again noted a line of thunderstorms in northern Illinois moving slowly eastward. This line became oriented in a southwest to northeast direction, with general storm motions to the north northeast, possibly causing training of echoes over the same areas. By 2200 UTC, the manual radar observations indicated that the line of storms had drifted to the southeast into the northwest suburbs of Chicago. Hourly rain gauges indicated a significant increase in 1-hour rainfall accumulations near this line. At 2300 UTC, the line of storms was located almost directly over the Chicago metro area, but hourly rainfall rates were lower than when this line was to the northwest. Gauge data indicated diminishing rainfall rates across most of northeast Illinois by 0000 UTC to 0100 UTC on 11 June, and the radar operator indicated the line of storms moving to the southeast at a faster speed. By the early morning of 11 June, portions of northeast Illinois, including the Chicago area, had experienced multiple rounds of slow-moving showers and thunderstorms with peak rainfall rates of 2-4 inches per hour (Figure 19).

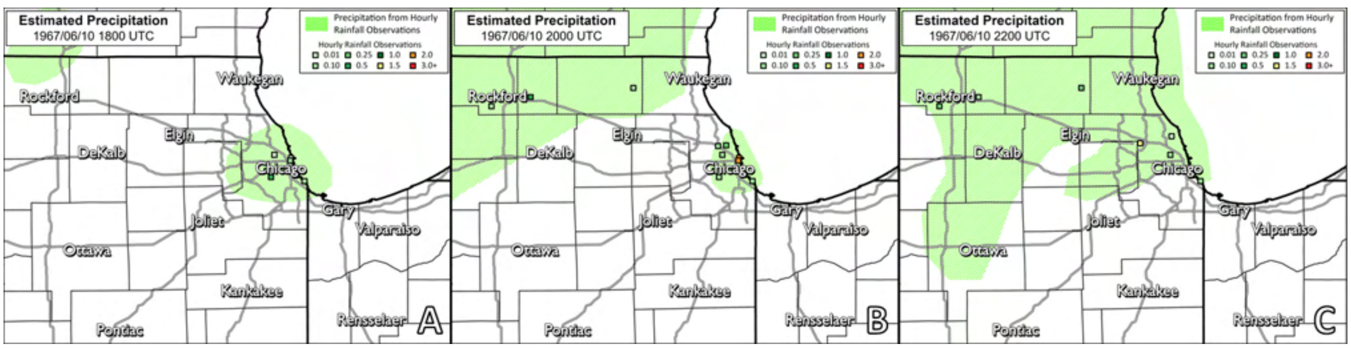

Figure 18. Estimated areas of precipitation for the 10 June 1967 rainfall event. Images are valid at 1800 UTC (A), 2000 UTC (B), and 2200 UTC on 10 June (C). No radar data were available from NCEI or the Illinois State Water Survey for this event, so hourly rainfall observations (color-filled boxes) were used to estimate precipitation areas (green hatching).

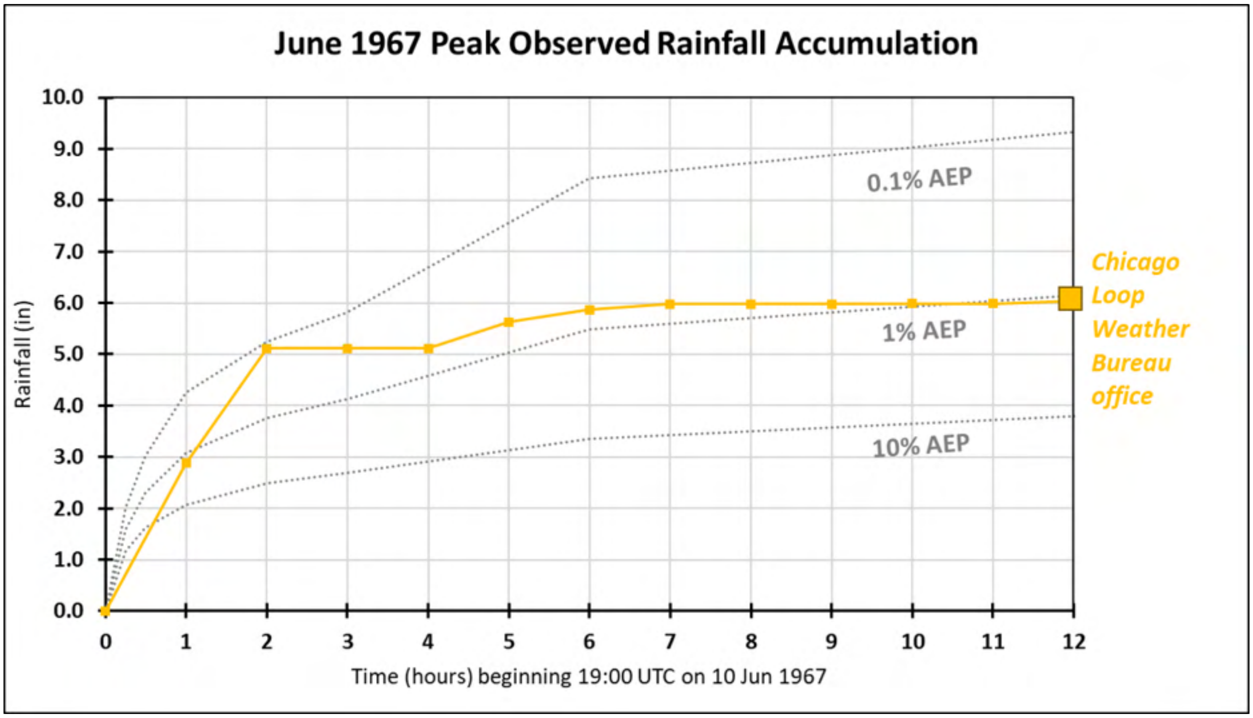

Figure 19. Running storm total rainfall for the 10 June 1967 rainfall event. The recording rain gauge with the highest storm total, NWS's gauge at Chicago Loop, is indicated with a yellow-orange line and square. Time on this chart begins with the first hour of measured rainfall.

June 13, 1976

From approximately 2200 UTC 13 June 1976 to 0100 UTC 14 June 1976, a nearly stationary supercell thunderstorm produced up to 7 inches of rainfall in portions of southwest Chicago and nearby suburbs (Figure 20). Although storm total rainfall amounts were less than the 7.5-inch storm total threshold used for selection of historical rainfall events, rainfall was very intense over a few-hour period; the peak 3-hr rainfall in the study area was analyzed as a 0.1% AEP (1-in-1000 annual chance) event (Figure 21). Significant flooding was noted in some areas, including on I-294 and I-94/I-90 (Figure 22). News accounts indicate water surrounding multiple homes in the hardest hit areas from Burbank through southern Chicago, and possible interior flooding of a few structures, although no information indicating a damage cost has been found. This was the same storm responsible for a significant tornado in the Lemont, Darien, and Downers Grove areas.

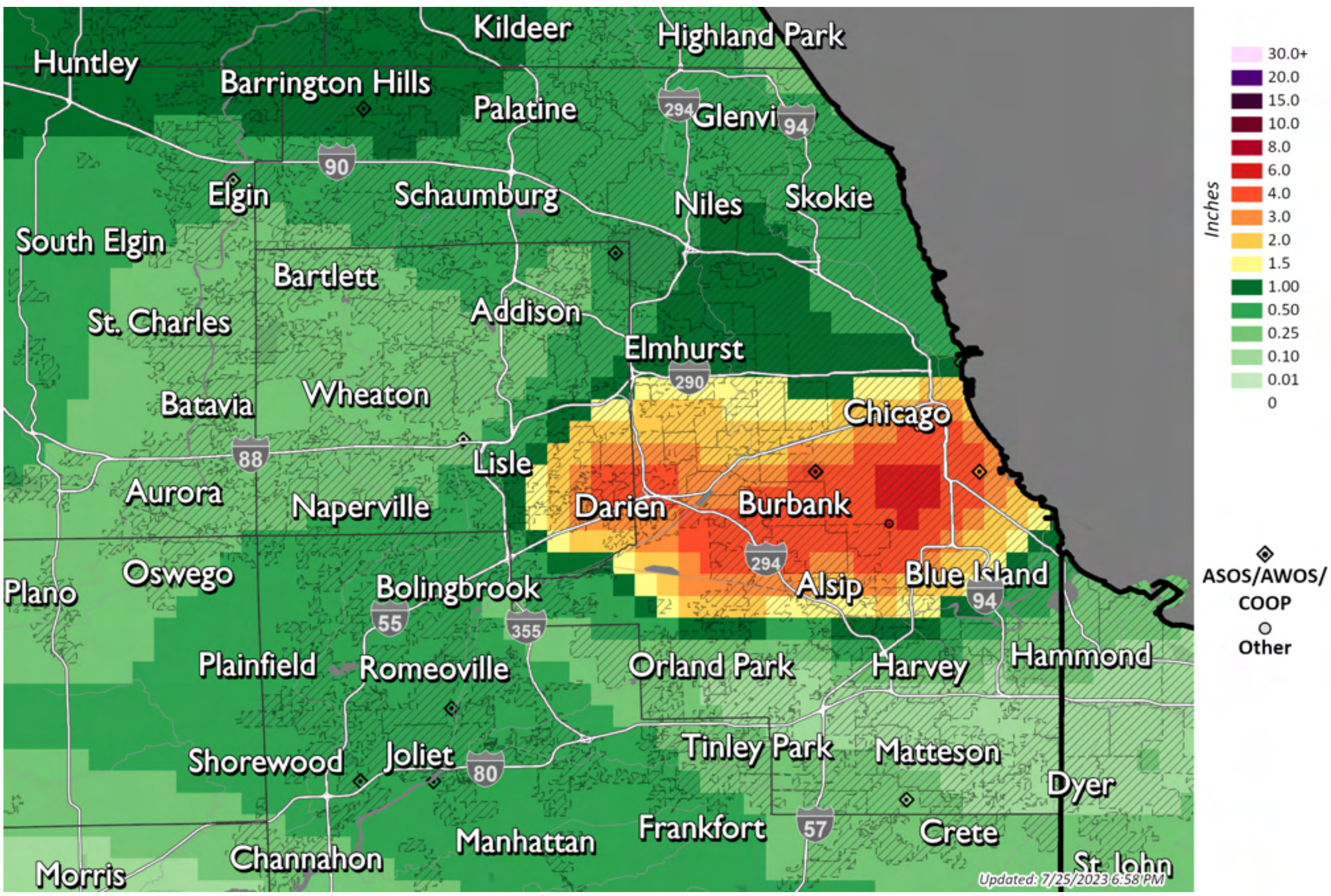

Figure 20. Storm total rainfall from 2200 UTC on 13 June 1976 to 0100 UTC on 14 June 1976.

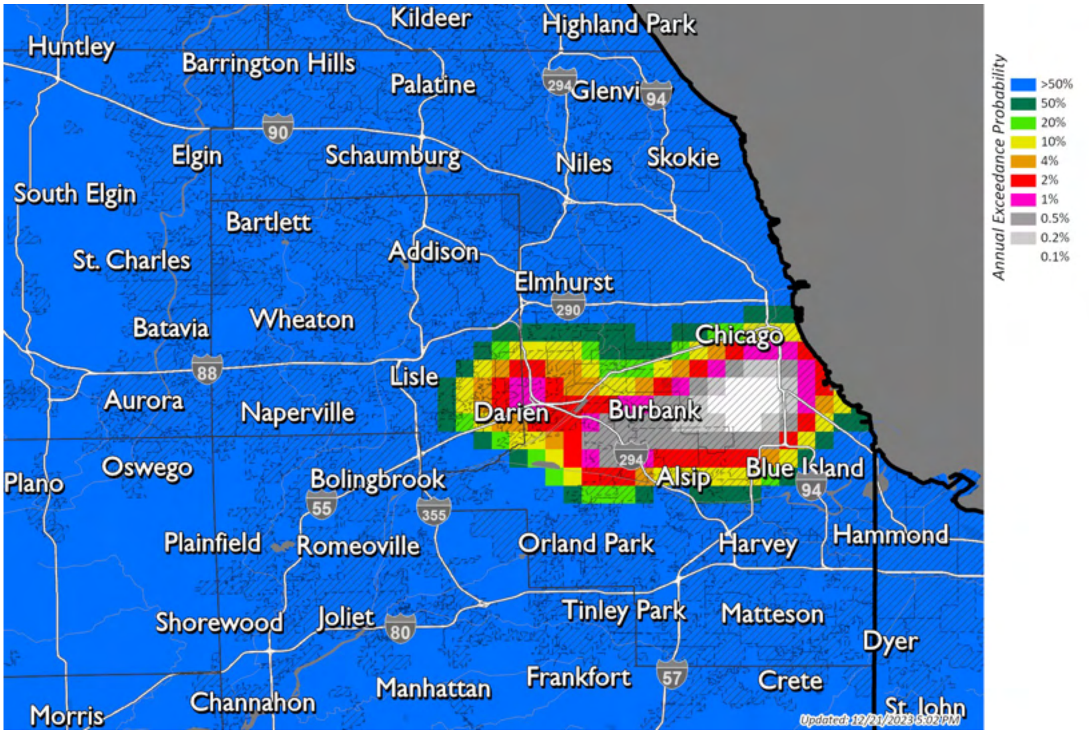

Figure 21. Annual exceedance probability for the storm total rainfall from 2200 UTC on 13 June 1976 to 0100 UTC on 14 June 1976.

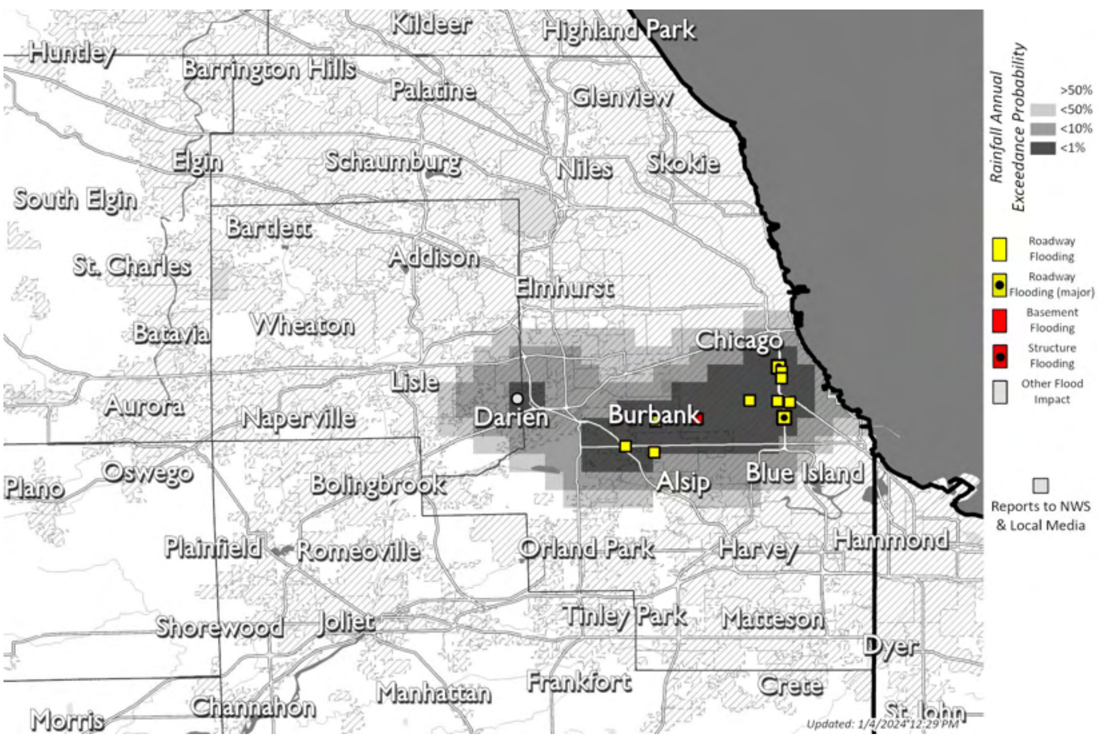

Figure 22. Known flash flood impacts for the 13 June 1976 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

At 1200 UTC 13 June 1976, a strong area of low pressure was located far to the north of the Chicago metropolitan area in southern Manitoba, Canada, with an associated warm front extending to the southeast through Michigan toward Ohio and a stationary boundary extending to the south through Minnesota and Iowa then southwest toward Kansas (NOAA Central Library 2023, Hersbach, et al. 2023). Multiple outflow boundaries were also noted in the warm section extending through portions of Iowa and Illinois (Figure 23). Throughout the morning and early afternoon, the frontal boundaries moved little and northeast Illinois remained in the middle of a broad warm sector with temperatures climbing to 80-90°F with dewpoints of 60-70°F. Surface winds across most of Illinois were out of the south or south-southwest at 10-20 mph. At 500 mb, a ridge was located in the eastern U.S. with a trough in the west, leading to southwest flow across the central part of the country (NOAA Central Library 2023, Plymouth State University 2023). A jet streak with winds of 40-50 kts was located to the southwest of northeast Illinois, leading to upper-level diffluence. A weak lake breeze moved inland from Lake Michigan by about 2100 UTC, lowering temperatures by a few degrees and shifting winds to the south southeast. Just to the west, the remnants of an outflow boundary or weak warm front extended from far southwest Wisconsin into north-central Illinois. A subtle area of converging surface winds just west of the Chicago metro area may have been the focusing mechanism for isolated, slow-moving thunderstorms.

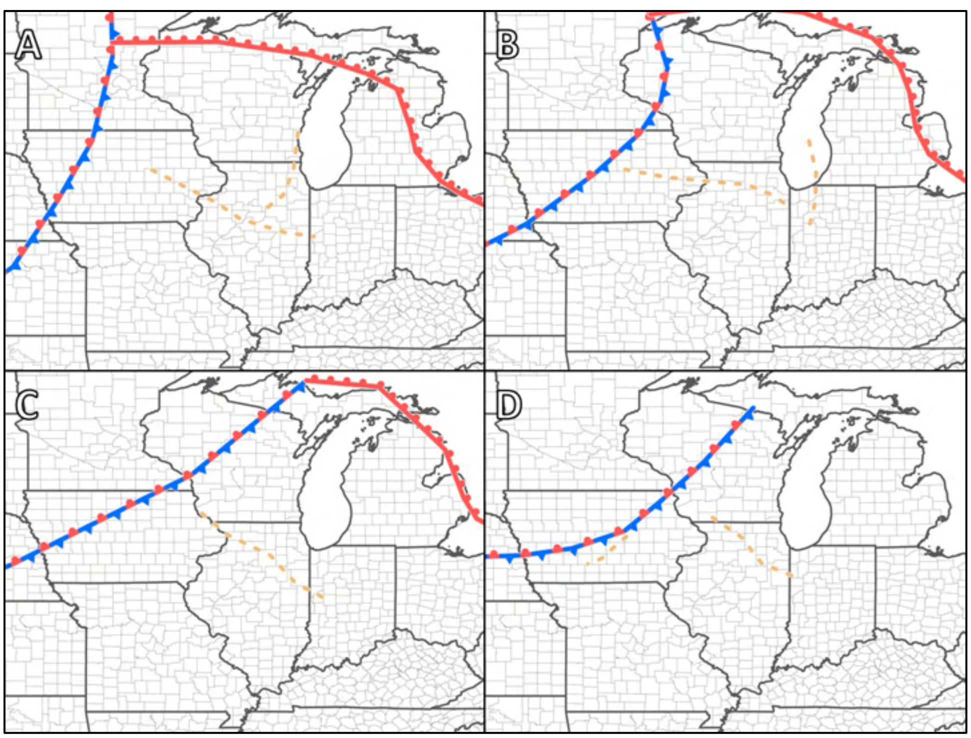

Figure 23. Surface weather maps for the 13 June 1967 rainfall event. Images are valid at 0600 UTC on 13 June (A), 1200 UTC on 13 June (B), 1800 UTC on 13 June (C), and 0000 UTC on 14 June (D). Surface maps created based upon data found in NOAA Central Library's daily weather map archive (2023), the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), and ERA5 reanalysis from the Copernicus Climate Change Service

(https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels); when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from the NWS Marseilles, Illinois, radar site (MMO) indicated a developing thunderstorm near the DuPage-Cook County line at approximately 2100 UTC on 13 June 1976 (Figure 24). This storm evolved into an intense supercell thunderstorm by 2230 UTC, producing a long-track, slow-moving tornado near Lemont, Darien, and Downers Grove. To the northeast of the tornado, the heaviest rainfall from the storm occurred near Clarendon Hills and La Grange. Over the next few hours, the area of heaviest rainfall drifted slowly to the east southeast. At 2300 UTC, MMO radar indicated the heaviest rainfall occurring near Burbank and Midway Airport. At 2330 UTC, the heaviest rainfall extended from near Clarendon Hills east through the southern portion of Chicago. At 0000 UTC on 14 June, the heaviest rainfall had moved no more than a couple miles north or south of the location from 30 minutes prior. At 0030 UTC, the storm had begun to drift to the southeast, with heaviest rainfall occurring over the central, western, and southern portions of the city. The storm began to dissipate approximately 30 minutes later. By the early morning hours of 14 June, a small portion of Cook and DuPage counties underneath this supercell thunderstorm had received off and on hail for up to one (1) hour and rainfall rates up to three (3) inches per hour (Figure 25).

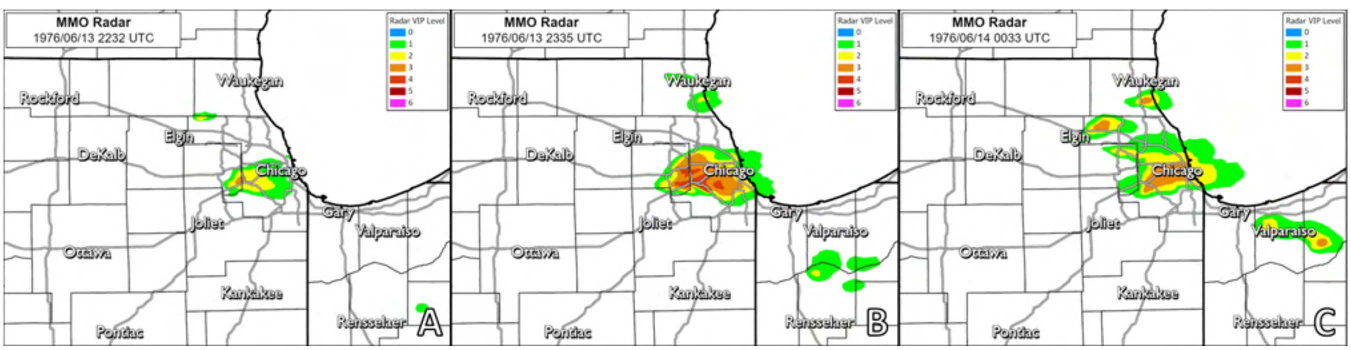

Figure 24. Digitized radar data for the 13 June 1976 rainfall event. Images are valid at 2232 UTC on 13 June (A), 2335 UTC on 13 June (B), and 0033 UTC on 14 June (C). Radar maps were digitized based upon data published by Fujita et al. (1977).

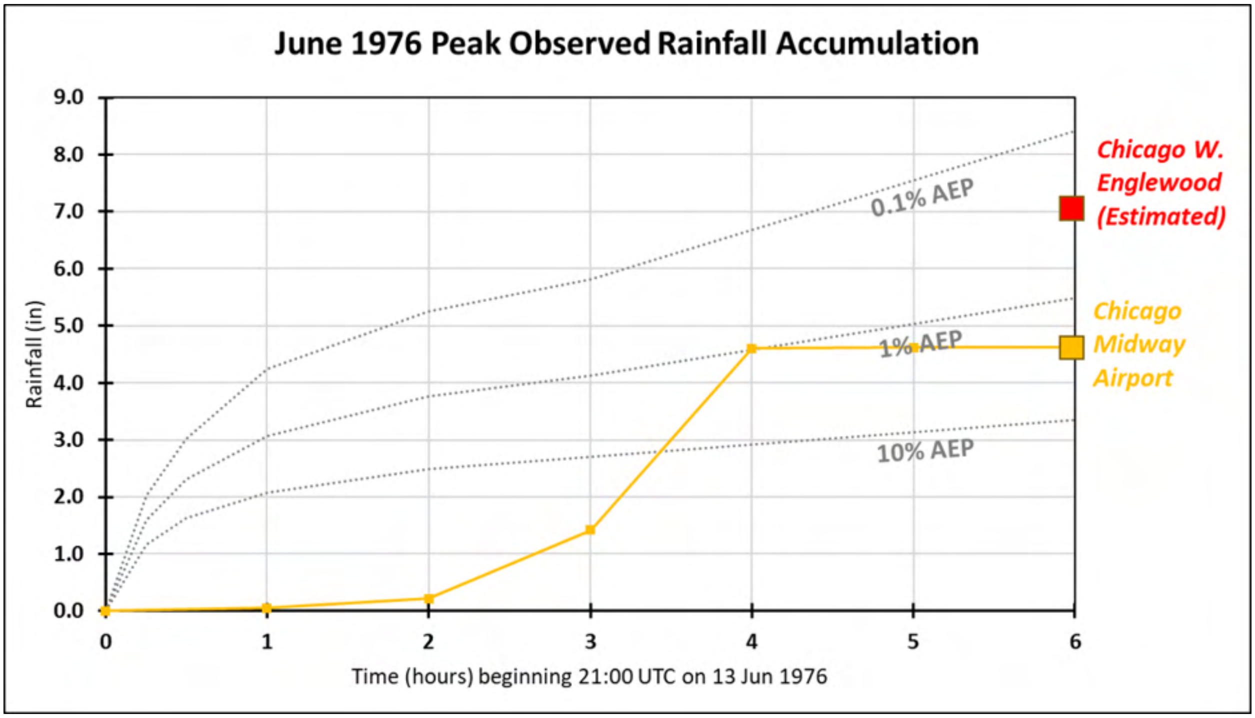

Figure 25. Running storm total rainfall for the 13 June 1976 rainfall event. The recording rain gauge with the highest storm total, the ASOS gauge at Chicago Midway Airport, is indicated with a yellow-orange line and square. The peak rainfall estimated in the West Englewood Community Area of Chicago (Fujita, Hjelmfelt and Changnon 1977) is indicated with a red square. Time on this chart begins with the first hour of measured rainfall.

August 13-14, 1987

From late evening 13 August to the morning of 14 August 1987, heavy rainfall occurred across portions of northeast Illinois. Rainfall up to 9.4 inches occurred over an 18-hour period (Figure 26). The majority of the rainfall occurred in three distinct periods within a 12-hour period: the first from approximately 0200 UTC to 0400 UTC, the second from 0600 UTC to 0800 UTC, and the third from 1200 to 1500 UTC on 14 August. Peak storm total rainfall in the study area was analyzed as a 0.2% AEP (1-in-500 annual chance) event (Figure 27). The rainfall resulted in significant flooding across about the northern half of the Chicago metro area (Figure 28) which set numerous river stage records, flooded multiple interstate highways, and caused an estimated $62 million (approximately $170 million in 2024 dollars) in damages (Balding and Ishii 1993). This event remains one of the biggest precipitation events measured at an official Chicago observing station since records began in the late 1800s.

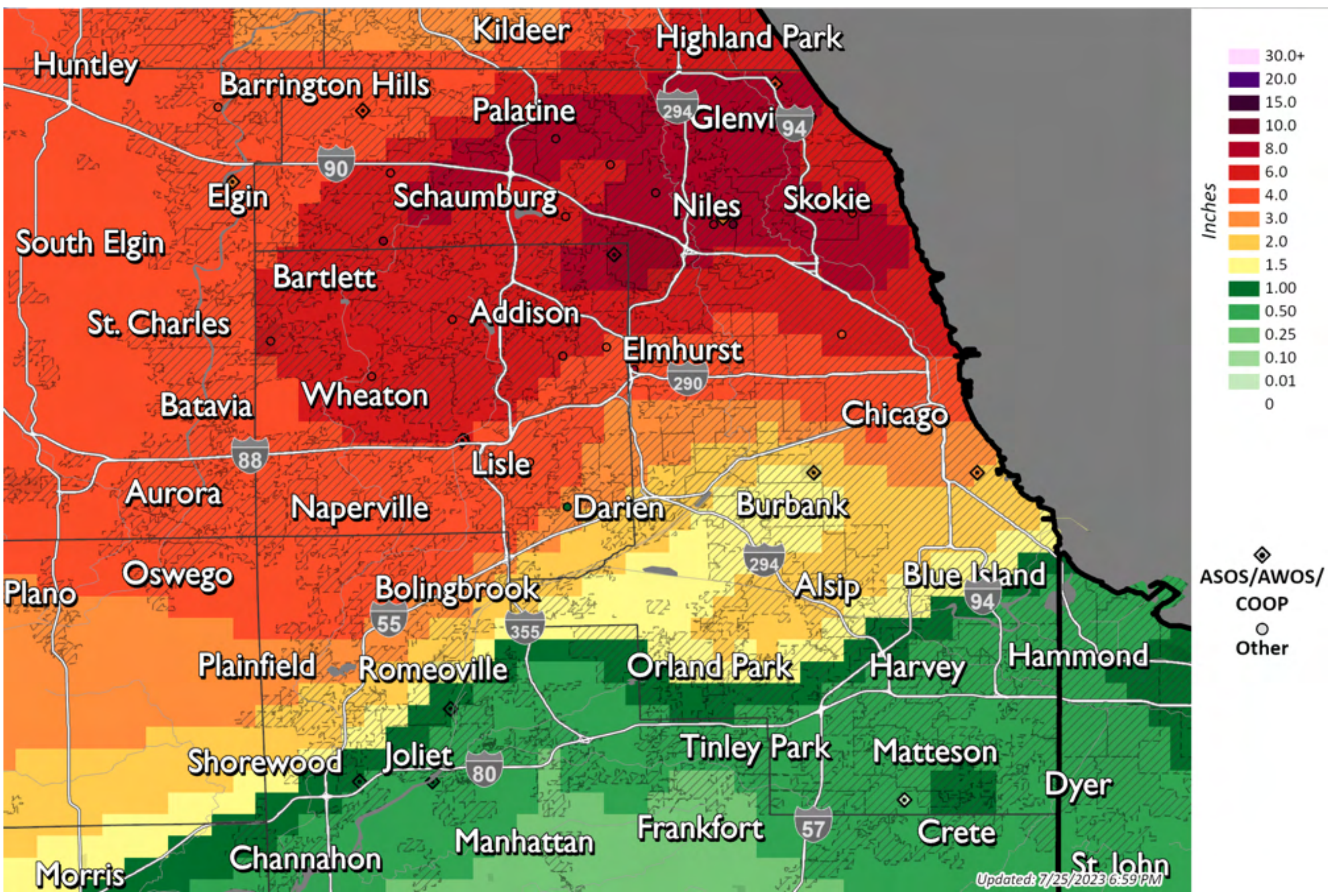

Figure 26. Storm total rainfall from 0000 UTC to 1800 UTC on 14 August 1987.

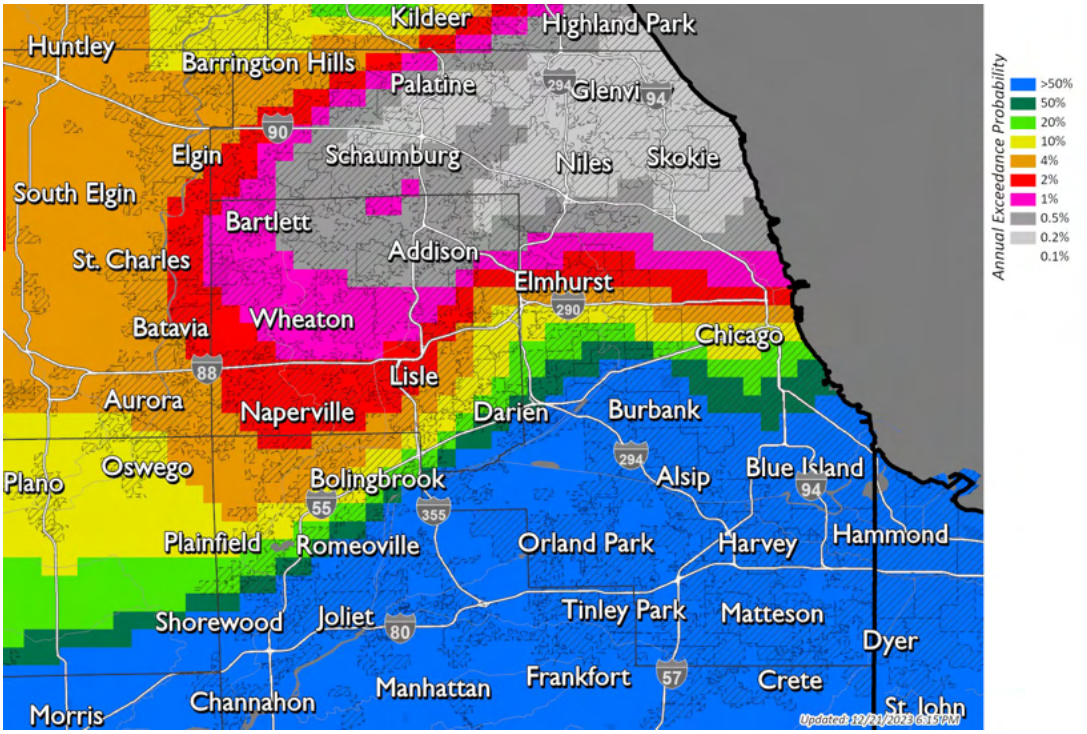

Figure 27. Annual exceedance probability for the storm total rainfall from 0000 UTC to 1800 UTC on 14 August 1987.

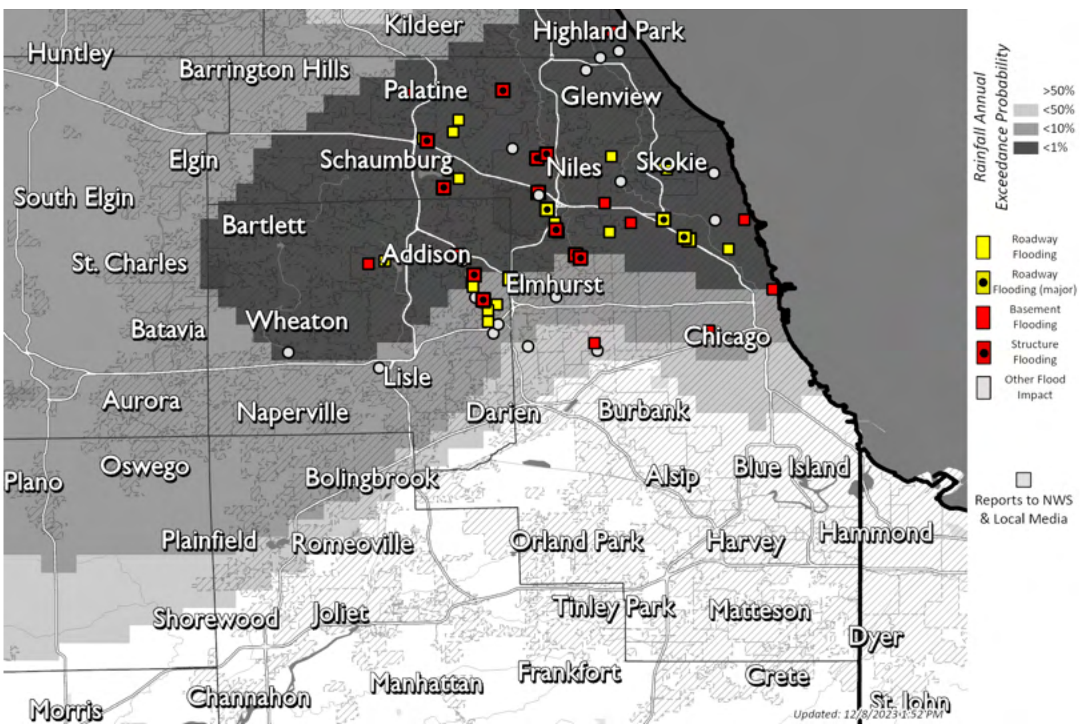

Figure 28. Known flash flood impacts for the 13-14 August 1987 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

The morning of 13 August 1987, a weak stationary boundary extended across the Midwest from Kansas northeast through Iowa and Wisconsin (Balding and Ishii 1993, Merzlock 1989, NOAA Central Library 2023). At 850 mb, generally weak flow was present across most of the of the U.S., with flow from the southwest across Illinois and neighboring states (Merzlock 1989, Plymouth State University 2023). At 500 mb, a ridge was located over the eastern U.S. centered near Maine. Across the Midwest, generally light southwest flow (20-30 kts or less) was present with the highest 500-mb wind speeds to the north near the US-Canada border. By 1800 UTC on 13 August, the weak stationary front to the west of Illinois began to dissipate while a new weak stationary front began to develop from northern Illinois east to southern Michigan, evidenced by differences in temperature, dewpoint temperature, and wind direction (Figure 29). Over the next several hours, this new stationary front drifted slowly to the north. South of this boundary in the warm sector, the 0000 UTC 14 August sounding from Peoria indicated a nearly saturated profile from near the surface up to the 400-500-mb level (Merzlock 1989), yielding a precipitable water value of 2.4 inches (Plymouth State University 2023). A precipitable water value this high in central Illinois remains near the all-time record value for the combined measurements of the Peoria and Lincoln upper-air sites. Around 2300 UTC on 13 August, a cluster of thunderstorms moved into northern Illinois, followed by multiple additional waves of storms over the following several hours, each with durations of 1-2 hours or less but very high rain rates. The general synoptic pattern had strong similarities to the Maddox Synoptic pattern (Maddox, Chappell and Hoxit 1979).

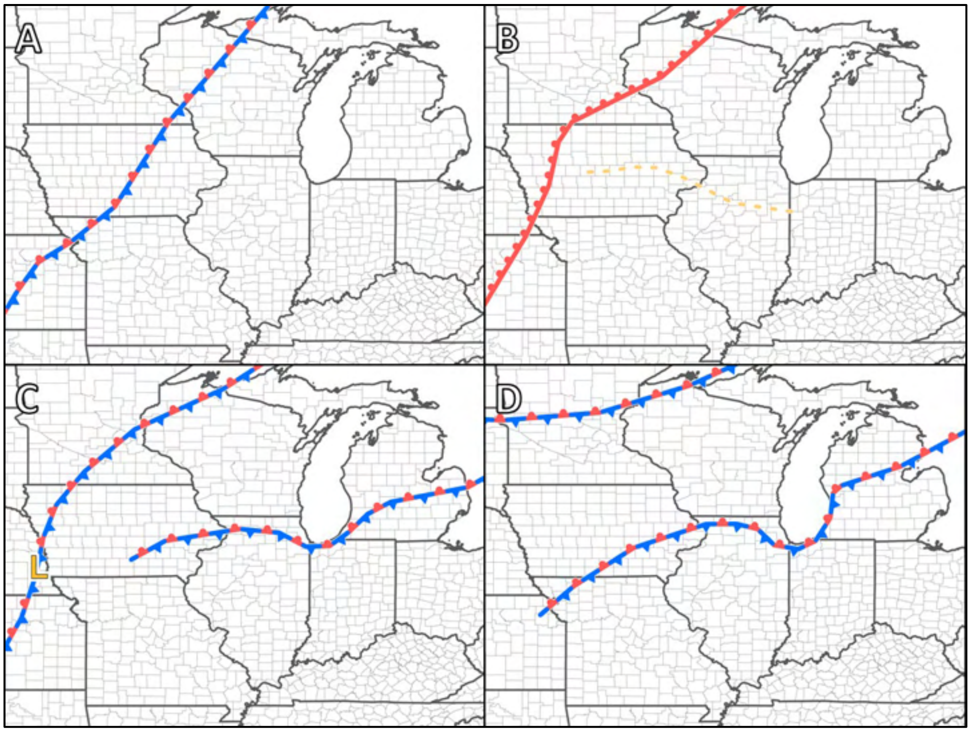

Figure 29. Surface weather maps for the 13-14 August 1987 rainfall event. Images are valid at 1200 UTC on 13 August (A), 1800 UTC on 13 August (B), 0000 UTC on 14 August (C), and 0600 UTC on 14 August (D). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php), the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), Balding and Ishii (1993), and Merzlock (1989); when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from MMO indicated a line of echoes extending from northwest to southeast moving northeast into the Chicago metro (Figure 30) around 0130 UTC 14 August 1987 (Merzlock 1989). By 0230 UTC, one of the heaviest echoes on radar moved across the northwest portion of Chicago near O'Hare Airport, with developing echoes evident in west central and northwest Illinois. This first wave of rainfall moved out over Lake Michigan by about 0400 UTC which was followed by a lull in the rainfall. At 0545 UTC, radar imagery indicated the next cluster of echoes moving into the Chicago metro area, with several thunderstorms oriented in a southwest to northeast direction. From approximately 0600 to 0730 UTC, this line of echoes moved generally to the northeast, with trailing echoes training over generally the same areas. By 0945 UTC, radar imagery indicated that rainfall had moved to the northeast of the Chicago metro. Another lull occurred from approximately 0900 to 1200 UTC, followed by the third and final wave of heavy rainfall. Radar data were not available spanning the third wave of heavy rainfall impacting the Chicago area. Radar data indicated that at 0844 UTC, a corridor of moderate to heavy rainfall was oriented from the west-southwest to the east-northeast, west of the area, and was moving slowly to the east. Hourly rainfall observations suggest that this corridor of rainfall reached the

Chicago area about two hours later, with potentially training echoes impacting the area from approximately 1100 to 1300 UTC. By late morning on 14 August, the Chicago metro area had experienced three distinct waves of rainfall, each producing approximately 2.5 to 3.0 inches of accumulation (Figure 32).

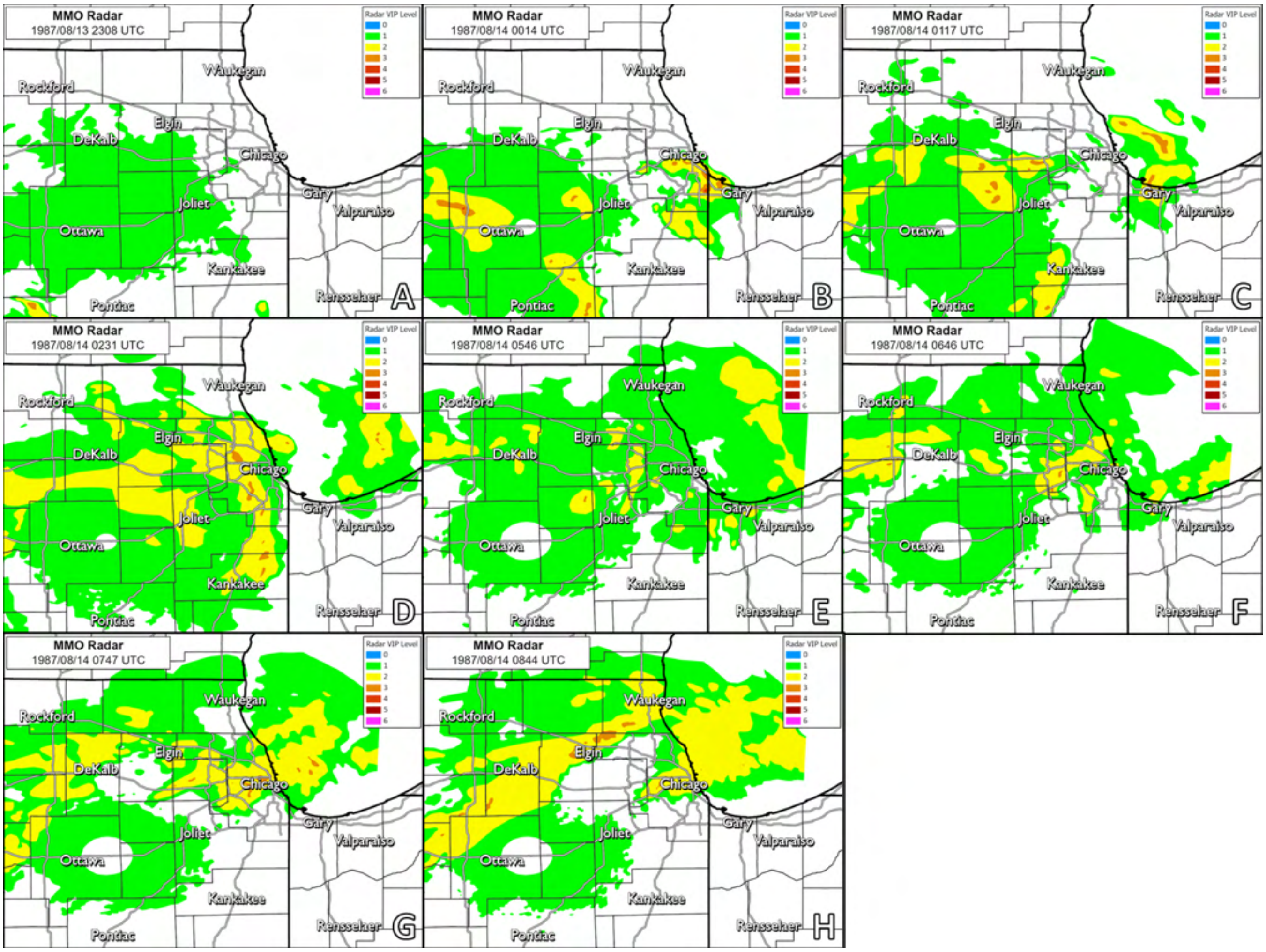

Figure 30. Digitized radar data for the 13-14 August 1987 rainfall event. Images are valid at 2308 UTC on 13 August (A), 0014 UTC on 14 August (B), 0117 UTC on 14 August (C), 0231 UTC on 14 August (D), 0546 UTC on 14 August (E), 0646 UTC on 14 August (F), 0747 UTC on 14 August (G), and 0844 UTC on 14 August (H). Radar maps were digitized based upon data published by Merzlock (1989).

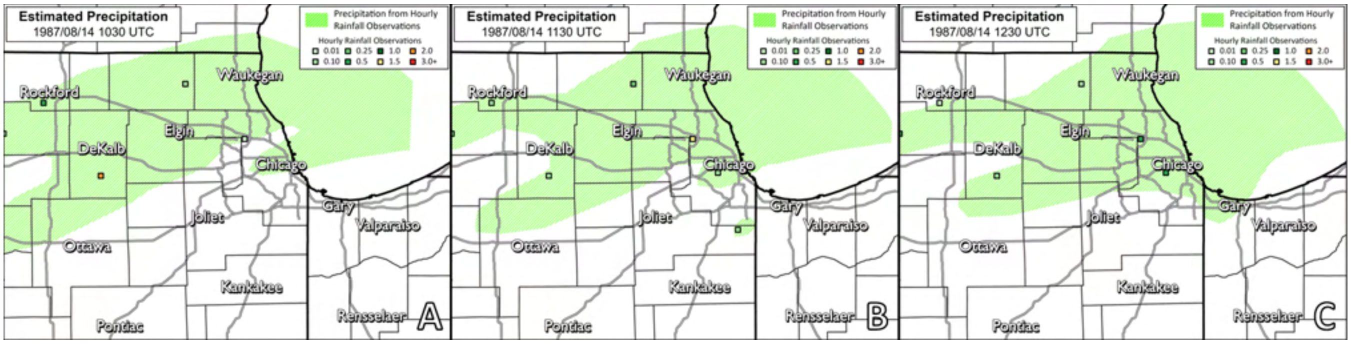

Figure 31. Estimated areas of precipitation for the 13-14 August 1987 rainfall event, for the period of time after radar data became unavailable. Images are valid at 1030 UTC (A), 1130 UTC (B), and 1230 UTC on 14 August (C). No radar data were available after approximately 0930 UTC likely due to a flood-related power outage at the building housing the Chicago National Weather Service office (Paul Merzlock, personal communication, January 2024). Hourly rainfall observations (color-filled boxes) were used to estimate precipitation areas (green hatching).

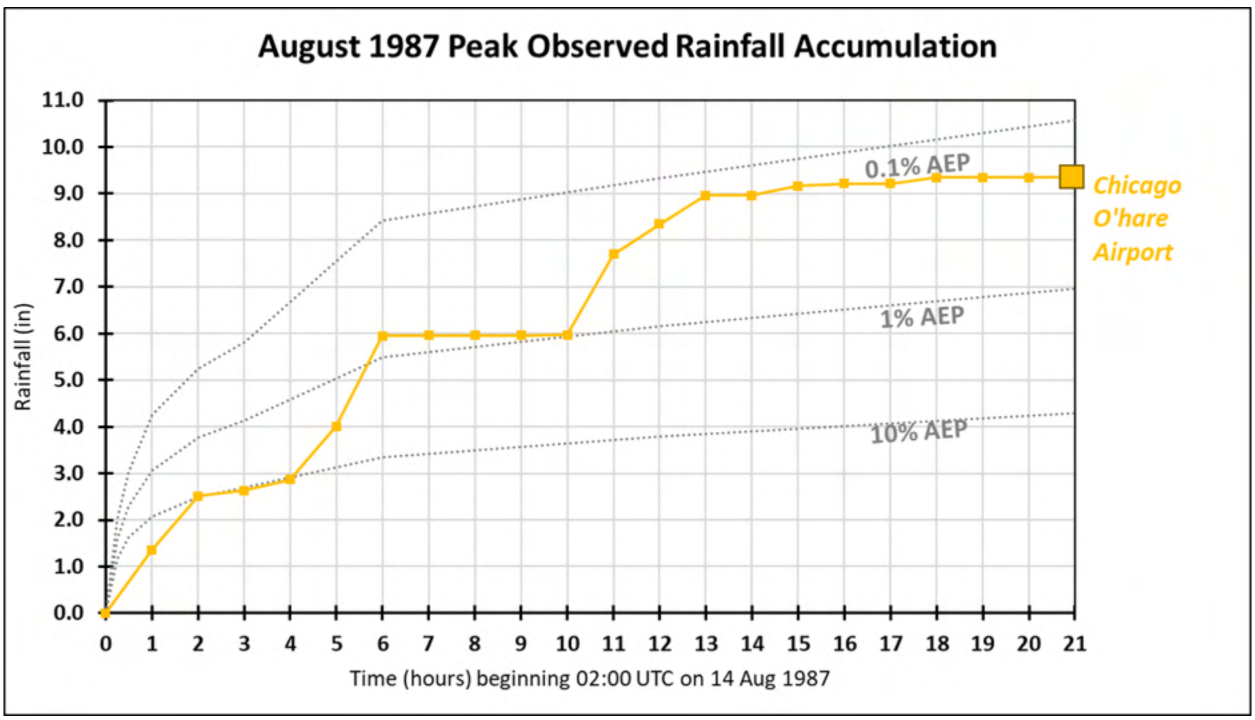

Figure 32. Running storm total rainfall for the 13-14 August 1987 rainfall event. The recording rain gauge with the highest storm total, the ASOS gauge at Chicago O'Hare Airport, is indicated with a yellow-orange line and square. Time on this chart begins with the first hour of measured rainfall.

July 17-18, 1996

From 17 July to 18 July 1996, heavy rainfall occurred across northeast Illinois and northwest Indiana. Rainfall up to 10.9 inches occurred over a 24-hour period (Figure 33) in the central Cook County study area. The rainfall occurred in two distinct periods, the first from approximately 1400 UTC to 2300 UTC on 17 July and the second from approximately 0600 UTC to 1300 UTC on 18 July. This same event caused significant flooding westward through the west suburbs of Chicago due to observed rainfall up to 16.9 inches in 24 hours near Aurora (Holmes and Kupka 1997), which remains the 24-hour rainfall record for the state of Illinois. Peak storm total rainfall in the study area was analyzed as a 0.5% AEP (1-in-200 annual chance) event (Figure 34). Widespread flooding was observed across many areas of northeast Illinois, including parts of the Chicago metropolitan area (Figure 35), with damage estimates ranging from $82 million to $640 million ($164 million to $1.3 billion in 2024 dollars), depending on the source (NOAA 1996, Changnon 1999).

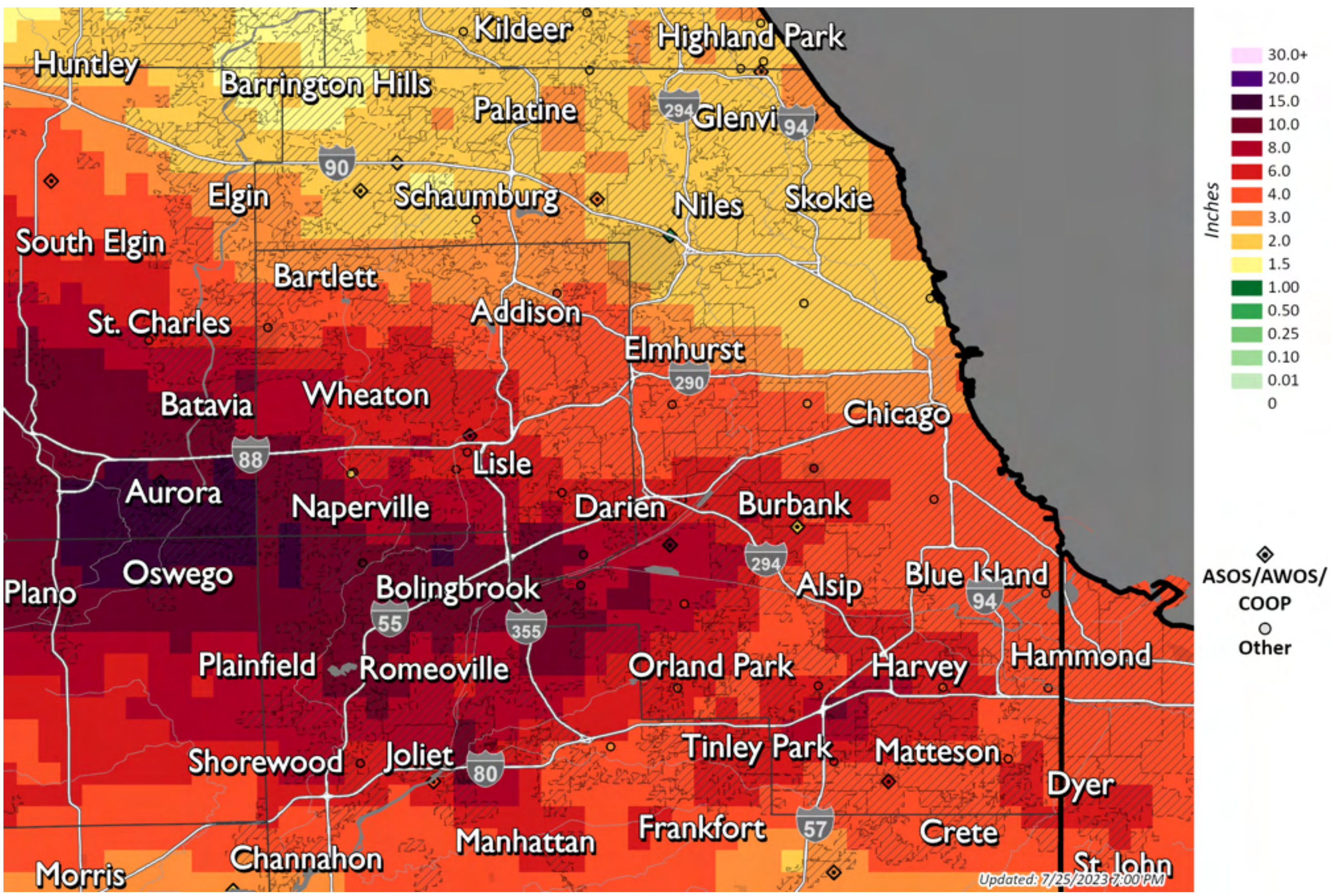

Figure 33. Storm total rainfall from 1300 UTC on 17 July 2023 to 1300 UTC on 18 July 1996.

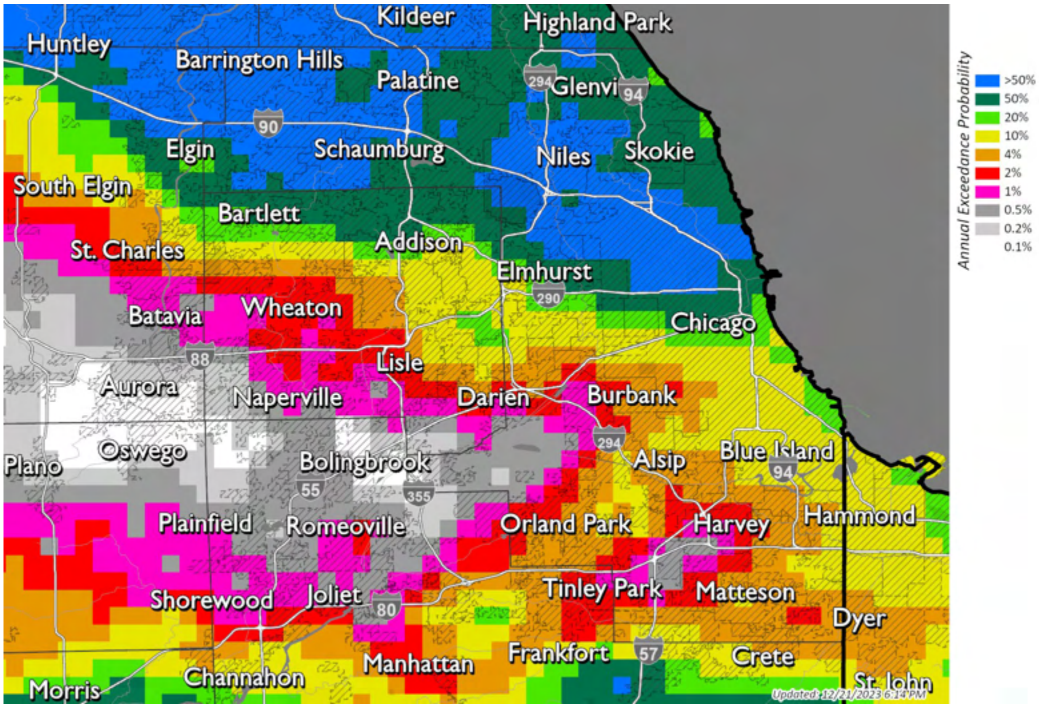

Figure 34. Annual exceedance probability for the storm total rainfall from 1300 UTC on 17 July 2023 to 1300 UTC on 18 July 1996.

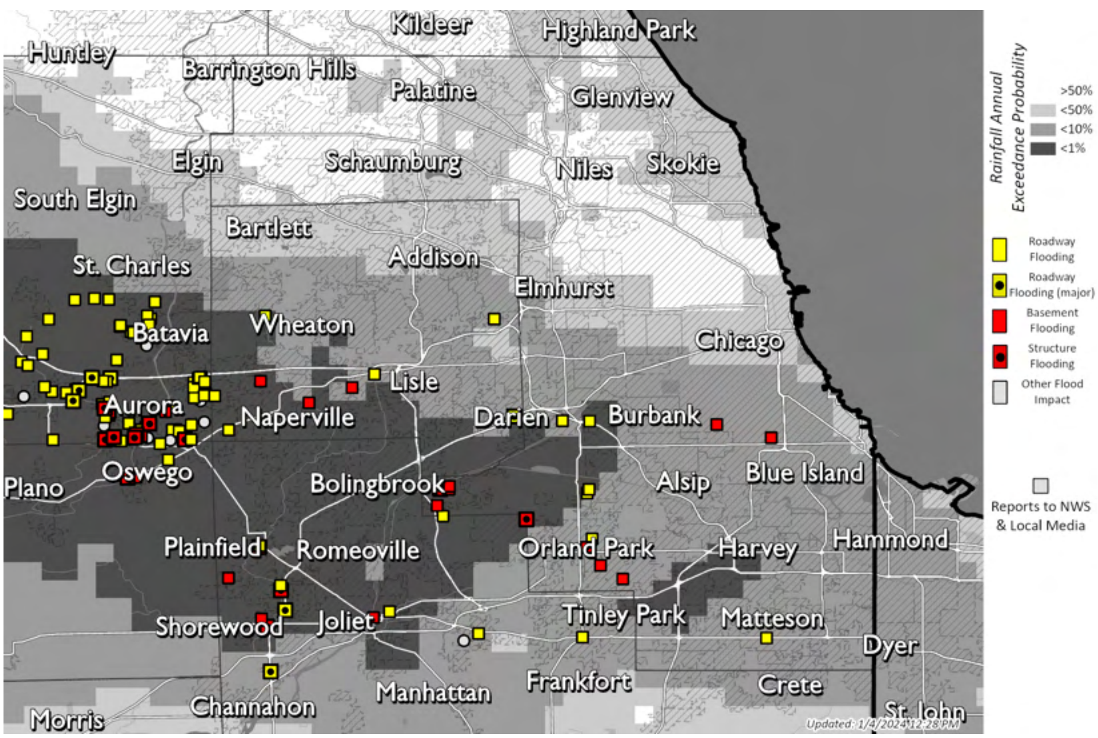

Figure 35. Known flash flood impacts for the 17-18 July 1996 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

On the morning of 17 July 1996, an area of low pressure was located in north-central Nebraska with a surface trough extending northward to North Dakota and south to western Kansas (Figure 36). To the east of the surface low extended a warm front through southwest Iowa and into southern Illinois (Changnon and Kunkel 1999). At 850 mb, a jet streak stretched from the panhandle of Texas northeast to far northwest Missouri, with wind speeds decreasing in the vicinity of the surface warm front but continuing to the northeast across Illinois. At 500 mb, a ridge was located across the southeast US, centered on the Appalachian states. An area of showers and thunderstorms developed along and northeast of the surface warm front, moving generally to the southeast across northern Illinois during the day. By 0000 UTC on 18 July 1996, the surface low had moved slightly to the northeast into central South Dakota with the surface warm front moving north, from southern Minnesota through far northeast Iowa and into north-central Illinois. The warm front orientation had changed from generally east-west in the morning to northwest-southeast by the evening. Flow at 850 mb continued to be from the southwest over Illinois and most of the Midwest, with minor ridging noted at 500 mb, centered near Iowa. South of this boundary in the warm sector, the 0000 UTC 18 July soundings from Lincoln and Davenport indicated a very moist profile from near the surface up to about 600-mb level, yielding precipitable water values of about 1.9 and 2.2 inches, respectively (Plymouth State University 2023). By 0200 UTC on 18 July, another wave of thunderstorm activity formed near and just to the northeast of the warm front, with general movement to the southeast. The general synoptic pattern had strong similarities to the Maddox Frontal pattern (Maddox, Chappell and Hoxit 1979).

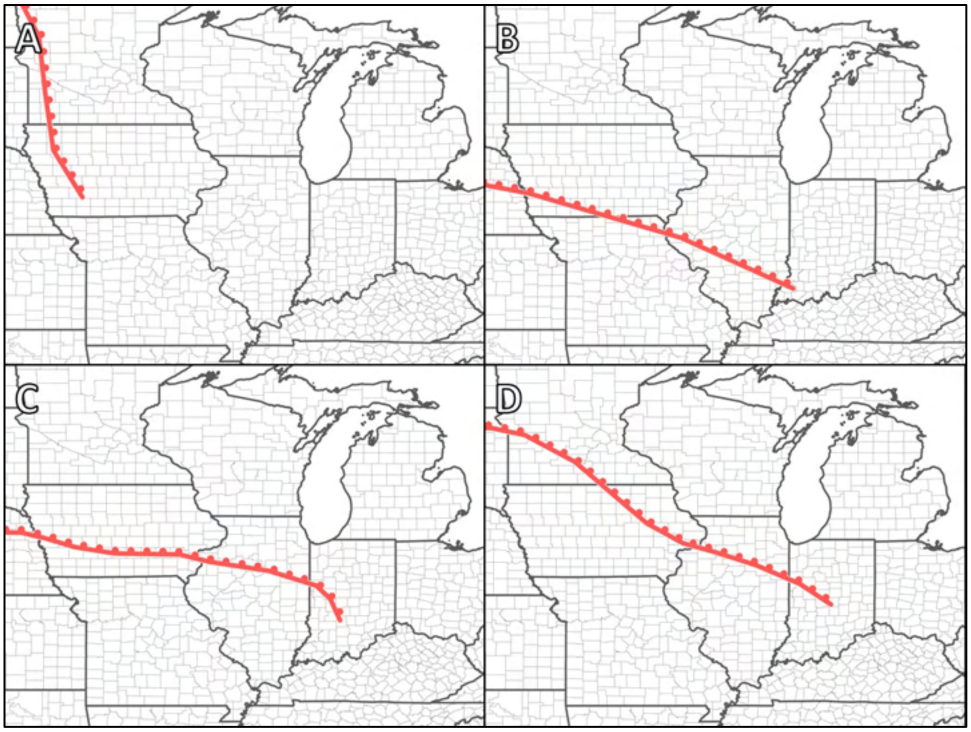

Figure 36. Surface weather maps for the 17-18 July 1996 rainfall event. Images are valid at 0600 UTC on 17 July (A), 1200 UTC on 17 July (B), 1800 UTC on 17 July (C), and 0000 UTC on 18 July (D). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php), the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), and Changnon and Kunkel (1999); when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from the NWS Romeoville radar site (LOT) indicated a cluster of thunderstorms moving into northern Illinois from Iowa at approximately 1200 UTC on 17 July 1996. These thunderstorms reached the Chicago metro area around 1500 UTC, with additional thunderstorms forming near the warm front to the west (Figure 37). This was the start of an 11-hour period of nearly continuous showers and thunderstorms in and near the Chicago metro area, from approximately 1500 UTC 17 July to 0200 UTC 18 July. The heaviest rain rates of this first wave of rainfall in central Cook County were evident from approximately 1830 UTC to 2130 UTC. While the Chicago metro area experienced a brief break in the rainfall for about one hour, a new cluster of showers and thunderstorms was developing in southwest Wisconsin and northwest Illinois. This second wave of rainfall quickly became oriented along the northward-drifting, northwest-to-southeast oriented warm front, with echoes training across generally the same areas for the next several hours (Figure 38). By 0300 UTC, a nearly continuous period of shower and thunderstorm activity had again reached the Chicago metro area, lasting for approximately 9 hours from 0300 UTC to 1200 UTC on July 18. The heaviest rain rates of the second wave of rainfall in central Cook County were evident from 0630 UTC to 0900 UTC. By 1300 UTC, radar indicated that heavy rainfall was moving southeast out of the Chicago metro area. By late morning on 18 July, the Chicago metro area had experienced two distinct waves of rainfall, each producing approximately 2 to 5 inches of accumulation, with the highest amounts in southern Cook County and the southern part of central Cook County (Figure 39).

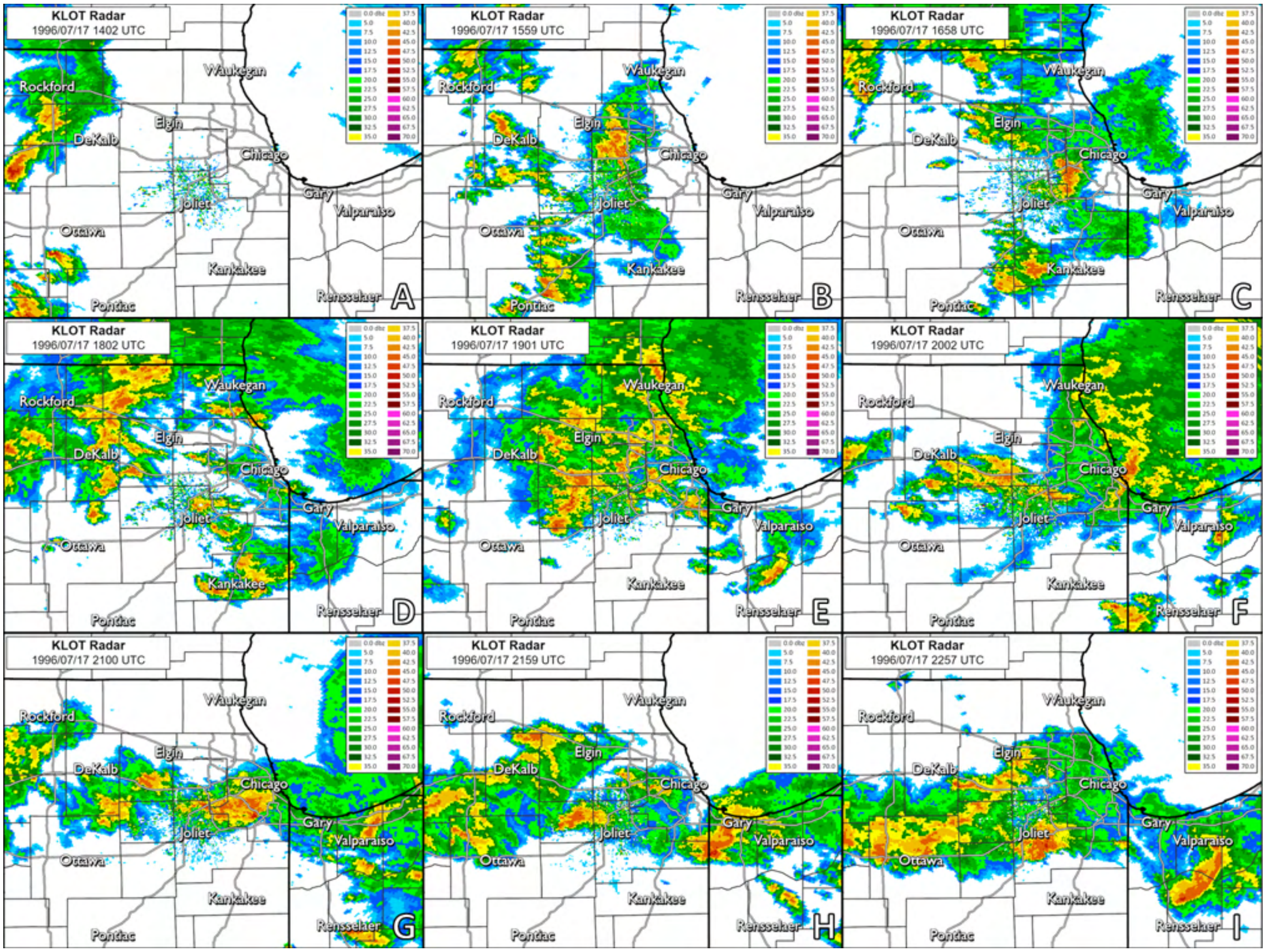

Figure 37. Radar data for the 17-18 July 1996 rainfall event. Images are valid at 1402 UTC on 17 July (A), 1559 UTC on 17 July (B), 1658 UTC on 17 July (C), 1802 UTC on 17 July (D), 1901 UTC on 17 July (E), 2002 UTC on 17 July (F), 2100 UTC on 17 July (G), 2159 UTC on 17 July (H), and 2257 UTC on 17 July. Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

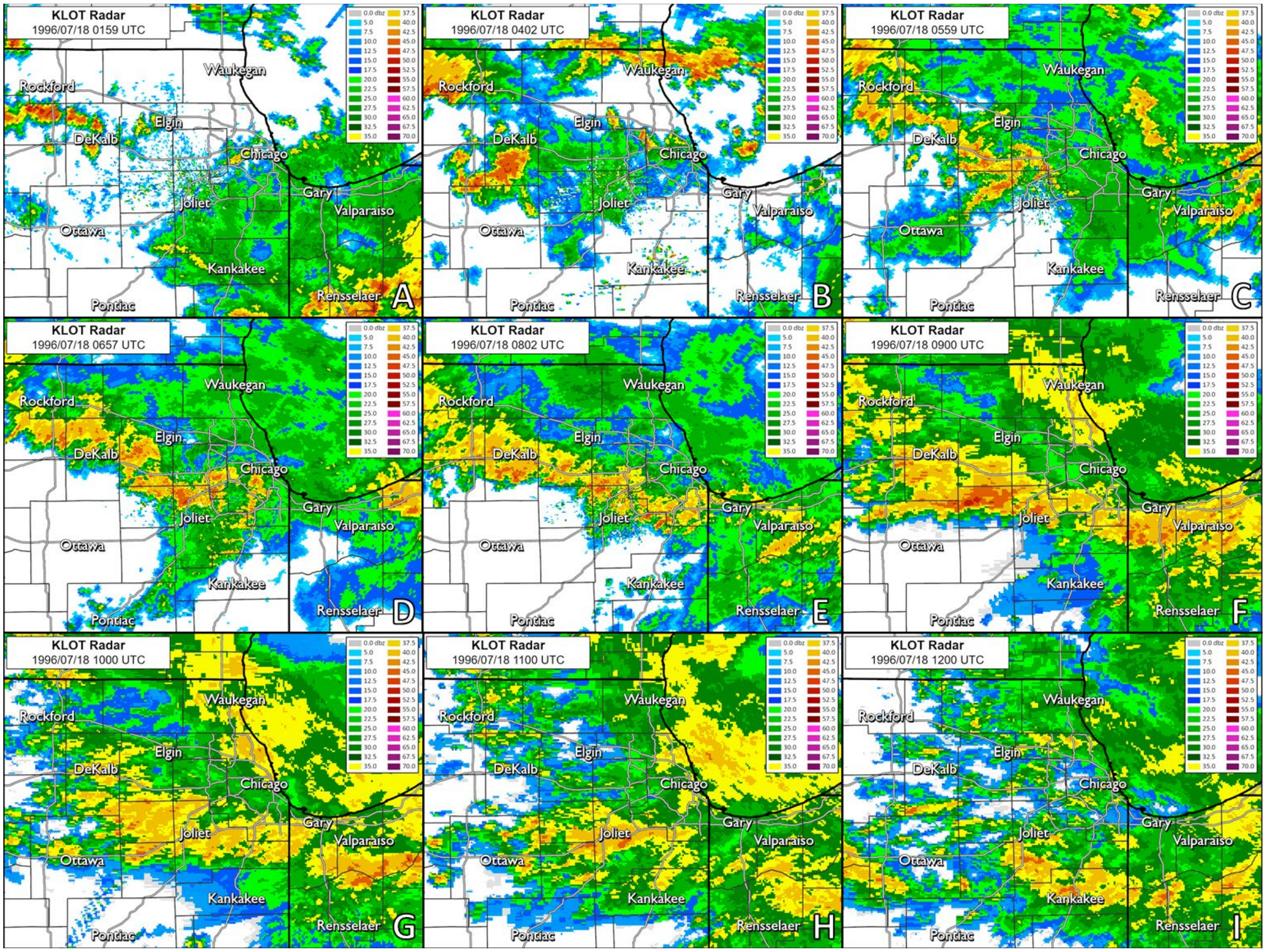

Figure 38. Radar data for the 17-18 July 1996 rainfall event. Images are valid at 0159 UTC on 18 July (A), 0402 UTC on 18 July (B), 0559 UTC on 18 July (C), 0657 UTC on 18 July (D), 0802 UTC on 18 July (E), 0900 UTC on 18 July (F), 1000 UTC on 18 July (G), 1100 UTC on 18 July (H), and 1200 UTC on 18 July. Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

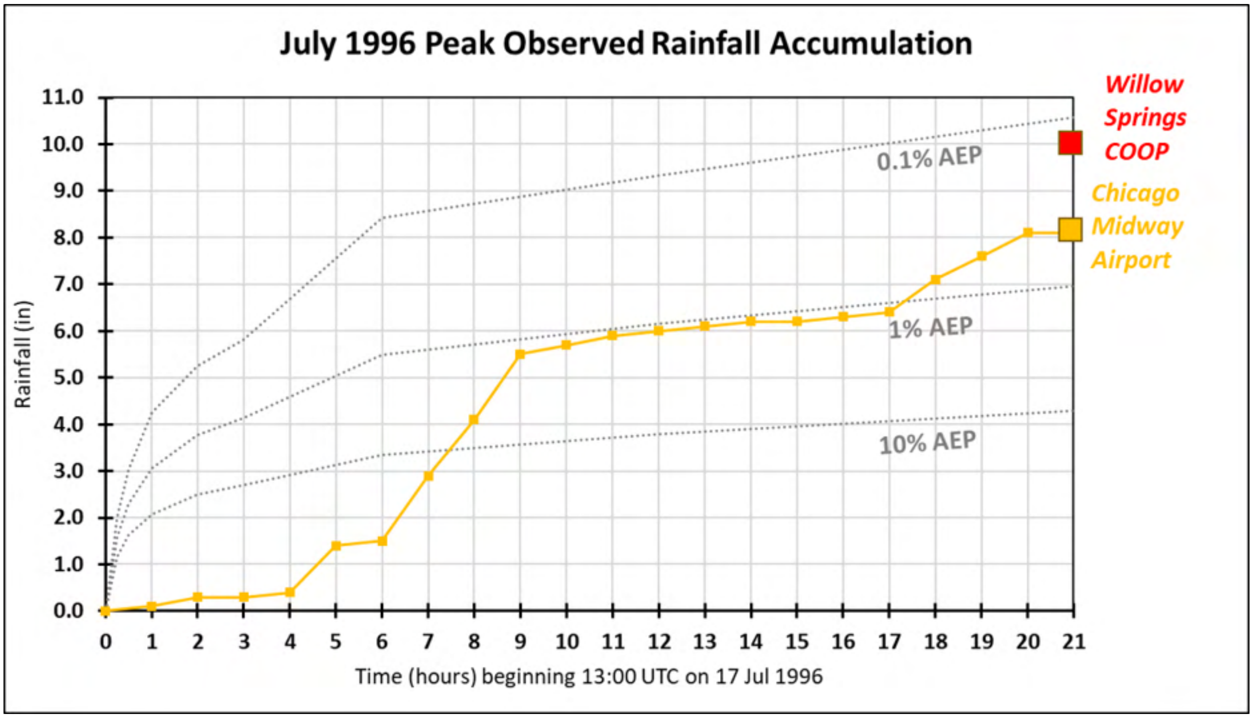

Figure 39. Running storm total rainfall for the 17-18 July 1996 rainfall event. The recording rain gauge with the highest storm total (in the study area), the ASOS gauge at Chicago Midway Airport, is indicated with a yellow-orange line and square. The peak rainfall observation near Willow Springs from a volunteer cooperative observer is indicated with a red square. Time on this chart begins with the first hour of measured rainfall.

August 2, 2001

On 2 August 2001, heavy rainfall occurred across parts of the Chicago metro area closest to the Lake Michigan shore. Rainfall up to 4.8 inches occurred over a 4-hour period from 1100 to 1500 UTC (Figure 40), the majority of which occurred in less than two (2) hours for any one location. Although storm total rainfall amounts were less than the 7.5-inch storm total threshold, rainfall rates were very intense over a short period of time; near the area of peak rainfall southwest of the Chicago Loop, 3.2 inches occurred in one (1) hour, 4.6 inches occurred in two (2) hours, and 4.8 inches occurred in three (3) hours, each exceeding the 1% AEP (1-in-100 annual chance) event according to *NOAA Atlas 14*. Peak 3-hr rainfall in the study area was analyzed as a 0.5% AEP (1-in-500 annual chance) event (Figure 41). This rainfall resulted in significant flooding in portions of the Chicago metro area (Figure 42), including the flooding of tens of thousands of basements and significant travel disruptions (Changnon and Westcott 2001). The resulting flash flooding caused an estimated $37 million (approximately $65 million in 2024 dollars) in damages (NOAA 2001).

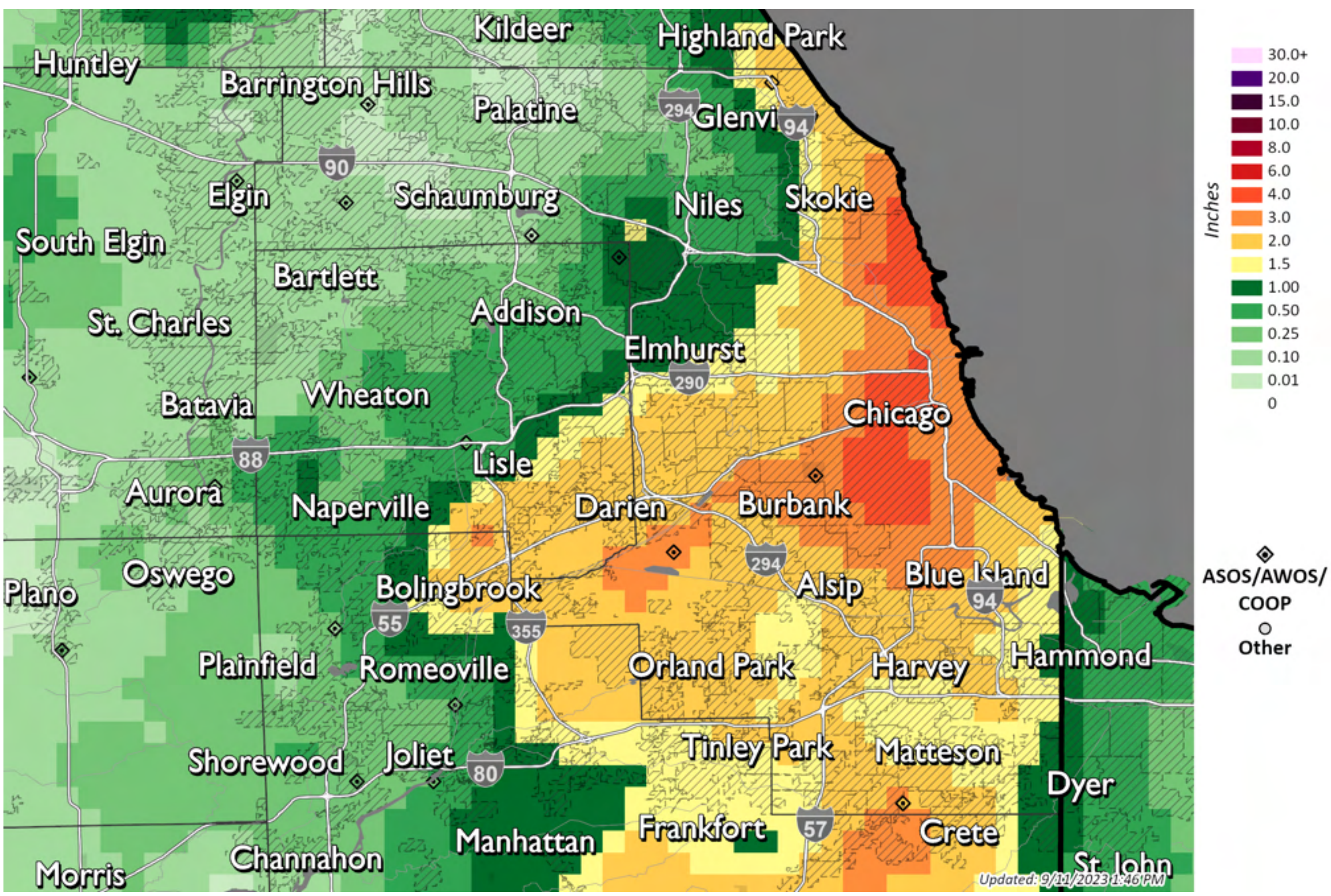

Figure 40. Storm total rainfall from 1100 UTC to 1500 UTC on 2 August 2001.

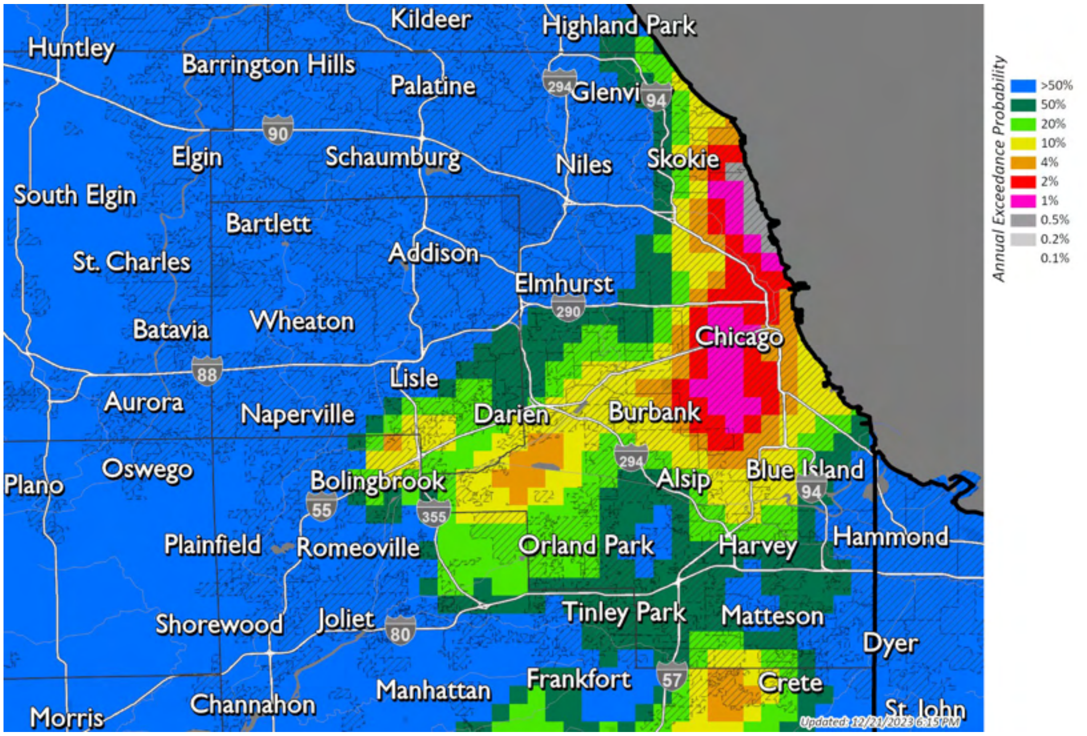

Figure 41. Annual exceedance probability for the storm total rainfall from 1100 UTC to 1500 UTC on 2 August 2001.

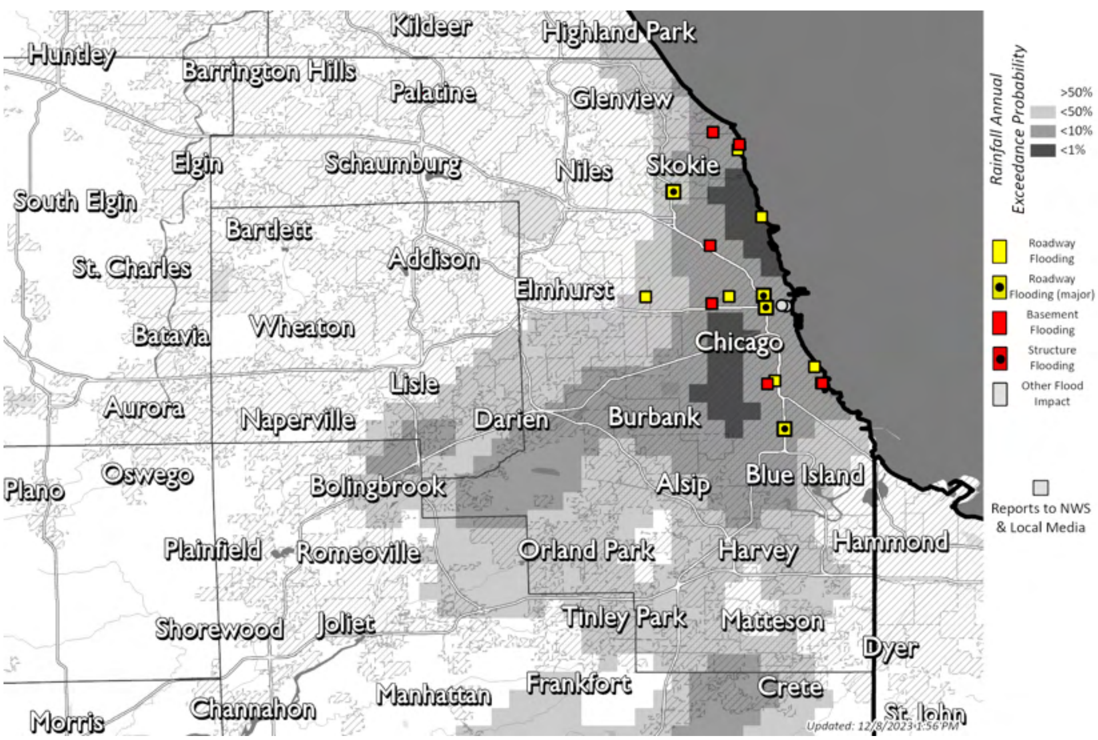

Figure 42. Known flash flood impacts for the 2 August 2001 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

At 0900 UTC on 2 August, a subtle stationary front was located from southern Nebraska northeast through central Iowa into northern Wisconsin (Figure 43). A developing outflow boundary was oriented generally east-west near the Illinois-Wisconsin border (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php), which was produced by a cluster of storms stretching from southern Wisconsin into Lake Michigan. Over the next few hours, the outflow boundary drifted very slowly to the south while an additional cluster of storms formed in southwestern Wisconsin. At 1200 UTC, 850-mb flow was generally from the west, parallel to the outflow boundary, across northern Illinois. Flow at 500 mb was also generally from the west, with a ridge evident across the south-central US. A sounding at Davenport, Iowa, indicated relatively light winds of 20 knots or less up to the 300-mb level and a precipitable water value of about 2.2 inches. Around the same time, a small cluster of thunderstorms formed along and north of the outflow boundary, just north of Chicago. Over the next few hours, this cluster of storms continued to develop along and just west of the Lake Michigan lakefront, north of the outflow boundary. The general synoptic setup had strong similarities to the Maddox Mesohigh pattern (Maddox, Chappell and Hoxit 1979).

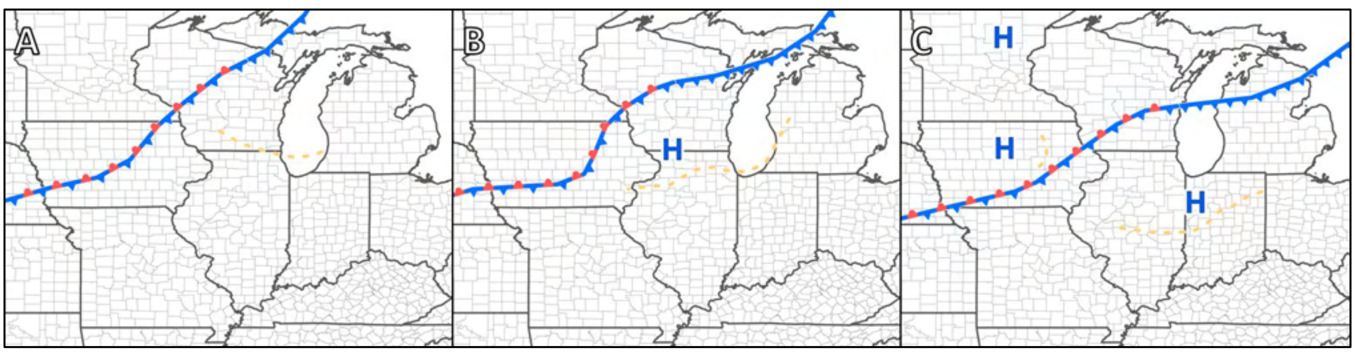

Figure 43. Surface weather maps for the 2 August 2001 rainfall event. Images are valid at 0900 UTC on 2 August (A), 1200 UTC on 2 August (B), and 1800 UTC on 2 August (C). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php), the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), and radar data; when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from LOT indicated generally light showers across northeast Illinois and the Chicago metro area from approximately 0900 UTC to 1100 UTC on 2 August 2023 associated with the passage of a southward-drifting outflow boundary. Starting about 1130 UTC, a significant increase in thunderstorm activity was noted near the Lake-Cook county line (Figure 44). Individual cells moved to the southeast at 20-30 mph, but the cluster continually redeveloped to the northwest, causing the overall movement of the cluster to be approximately southward at 10 mph. Around 1230 UTC, the cluster of storms was located over central Cook County, with the strongest echoes, producing rainfall rates up to 3 inches per hour, occurring between 1230 UTC and 1400 UTC.

Rainfall intensities quickly diminished after 1400 UTC, and, by 1600 UTC, the storms had mostly moved south of the Chicago area (Figure 45).

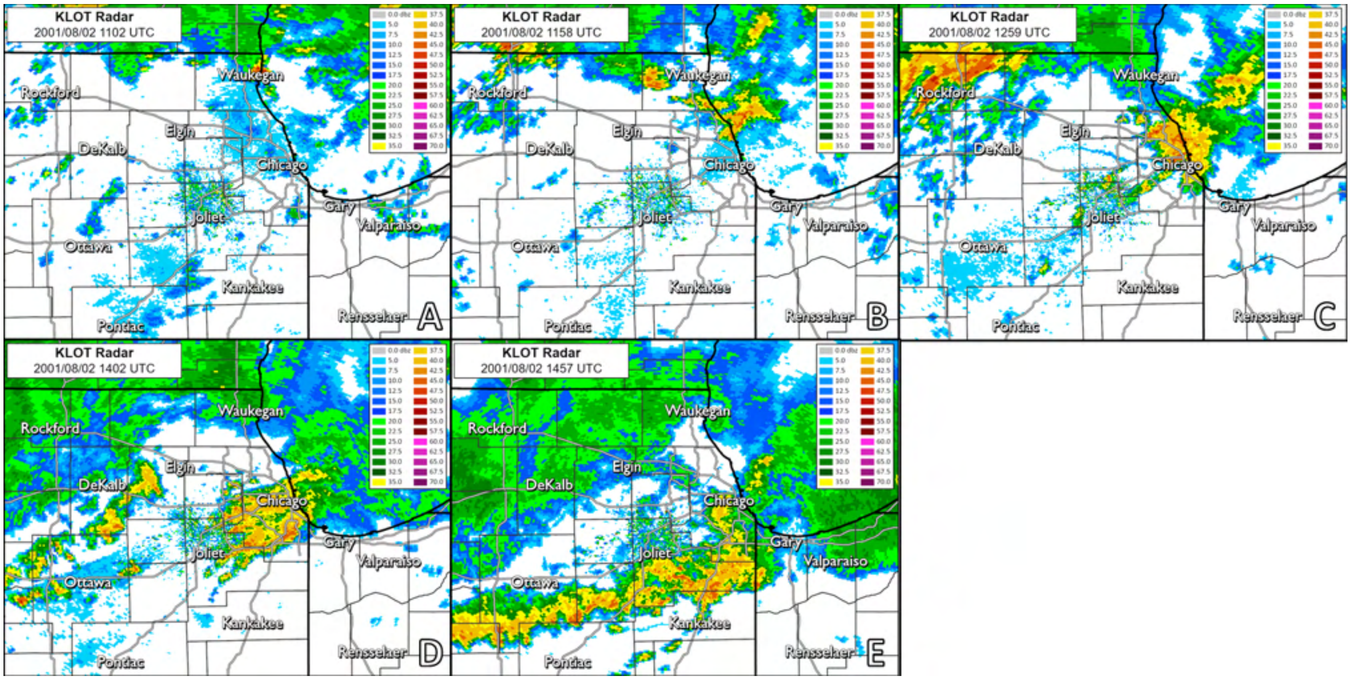

Figure 44. Radar data for the 2 August 2001 rainfall event. Images are valid at 1102 UTC on 2 August (A), 1158 UTC on 2 August (B), 1259 UTC on 2 August (C), 1402 UTC on 2 August (D), and 1457 UTC on 2 August (E). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

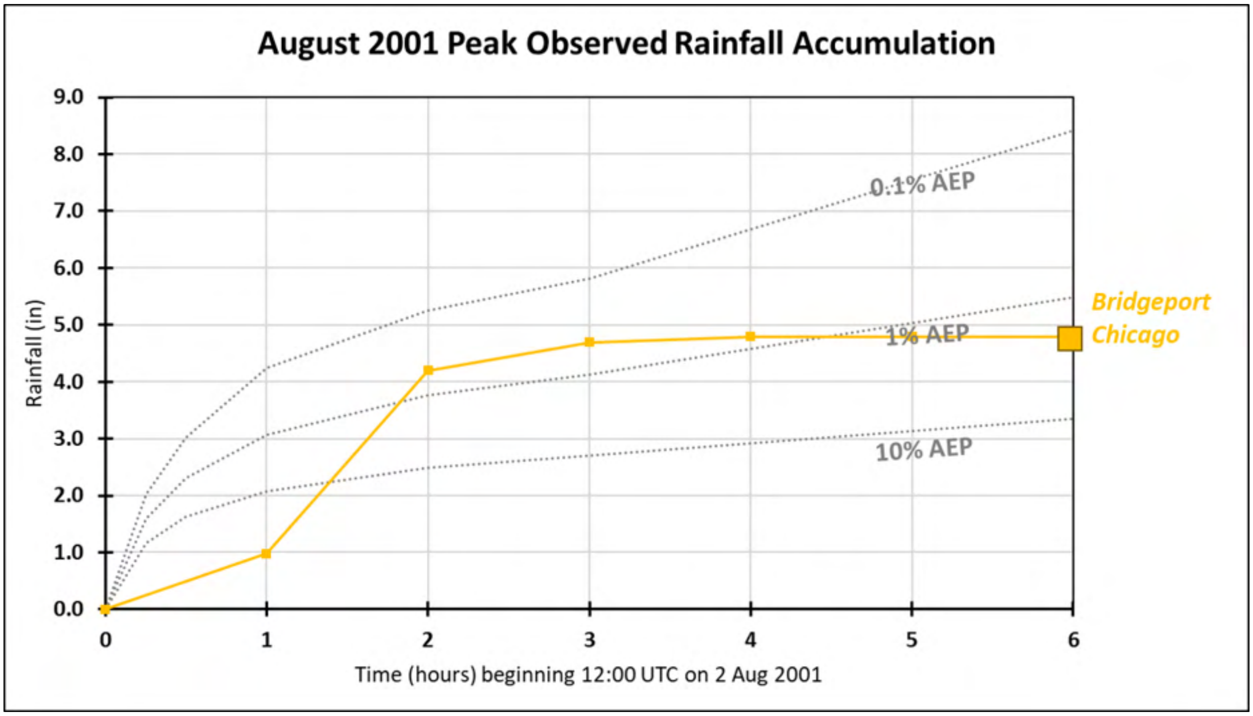

Figure 45. Running storm total rainfall for the 2 August 2001 rainfall event. The recording rain gauge with the highest storm total, the Illinois State Water Survey gauge in the Bridgeport community area of Chicago, is indicated with a yellow-orange line and square. Time on this chart begins with the first hour of measured rainfall.

September 13-15, 2008

From 13 September to 15 September 2008, heavy rainfall occurred across a large portion of central Illinois, northern Illinois, and northern Indiana. This rainfall was associated with the remnants of Hurricane Ike which made landfall in Texas early in the morning of 13 September. Rainfall up to 9.2 inches occurred over a 60-hour period (Figure 46) in the central Cook County study area. This same event caused observed rainfall up to 12.8 inches near St Charles, west of Chicago. Peak storm total rainfall in the study area was analyzed as a 0.5% AEP (1-in-200 annual chance) event (Figure 47). Just over half of the rainfall in the Chicago metro area occurred over a 6-hour period from 0900 UTC to 1500 UTC on 13 September. This rainfall resulted in widespread flooding across many areas in northeast Illinois and northwest Indiana (Figure 48), with flood damage estimates of approximately $135 million ($193 million in 2024 dollars) indicated by NOAA *Storm Data* for Illinois and Indiana (NOAA 2008), of which $120 million ($171 million in 2024 dollars) occurred in the Chicago metro area. Flood impacts may have been worsened due to antecedent conditions; rainfall of 2-3 inches occurred across the Chicago area approximately one week prior due to the remnants of Hurricane Gustav.

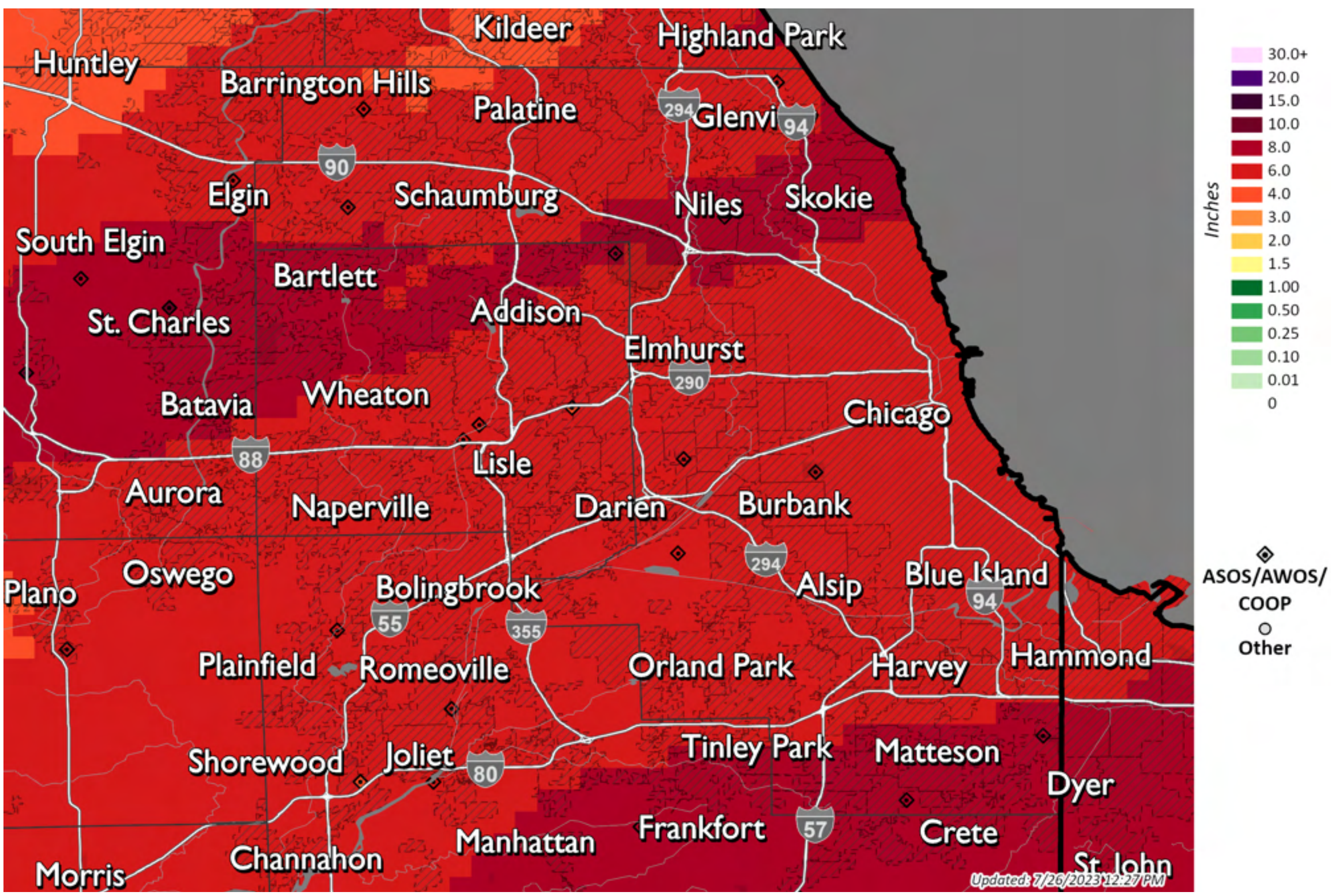

Figure 46. Storm total rainfall from 0800 UTC on 12 September 2008 to 2000 UTC on 14 September 2008.

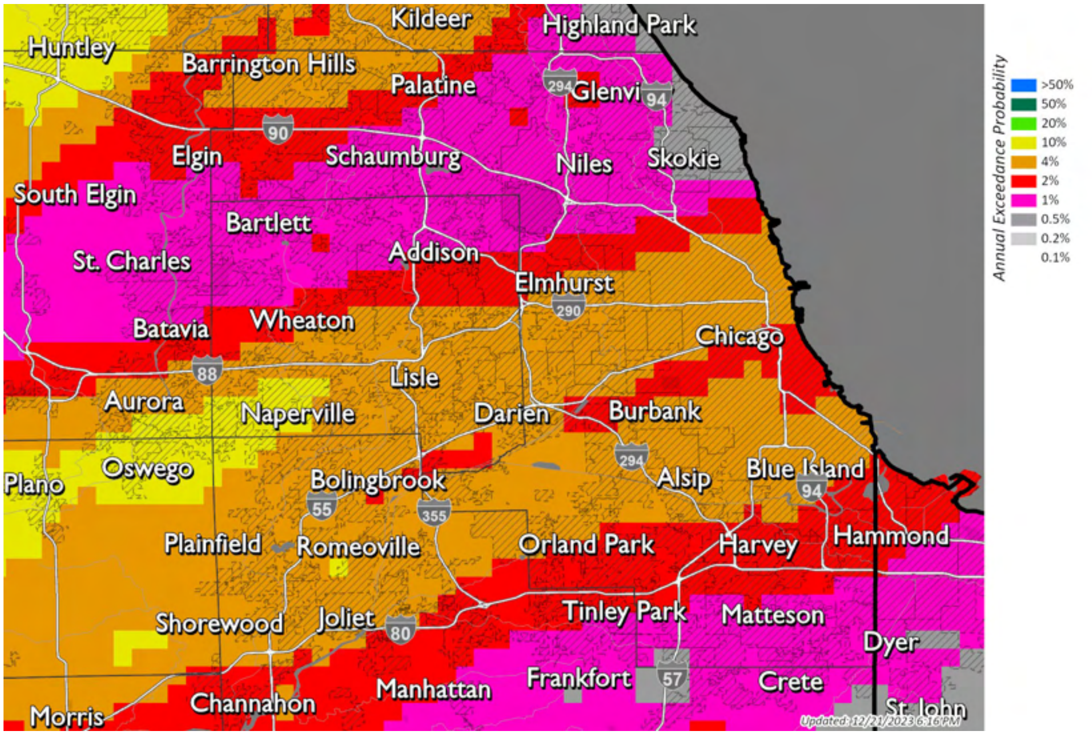

Figure 47. Annual exceedance probability for the storm total rainfall from 0800 UTC on 12 September 2008 to 2000 UTC on 14 September 2008.

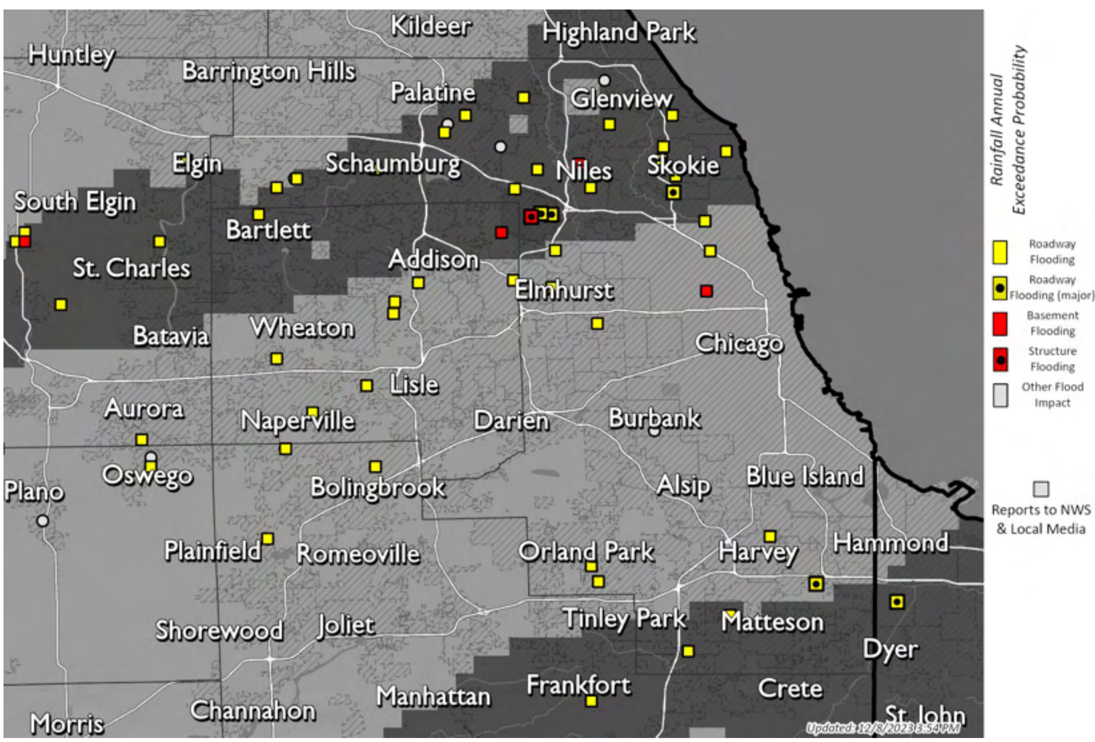

Figure 48. Known flash flood impacts for the 13-15 September 2008 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

On the evening of 12 September 2008, a stationary front was located from the southern Great Plains northeast through Kansas, Iowa, and Wisconsin (Figure 49). Along and south of the front, an area of showers was moving eastward generally parallel to the front, causing a period of light, but nearly continuous, rainfall across northeast Illinois. At approximately the same time, Hurricane Ike was making landfall along the coast of southeast Texas. By the early morning hours of 13 September, the stationary front had moved very little, but rainfall intensities began to increase as moisture from now-onshore Hurricane Ike streamed northward along the frontal boundary in the Midwest. What followed was a nearly continuous period of rainfall along the frontal boundary caused by moisture from Hurricane Ike, but not directly associated the core of the storm itself, now known as a predecessor rain event (Cote 2007). From early morning to late evening 13 September, the stationary boundary in the Midwest and southern Great Plains slowly evolved into a cold front moving to the east, and the remnants of Hurricane Ike moved northward toward the front.

At 0000 UTC September 14, a sounding from Lincoln, Illinois, indicated a nearly saturated profile up to about 600 mb and a precipitable water value of about 2.1 inches. Flow was out of the southwest at both the 850-mb and 500-mb levels, nearly parallel with the surface cold front. By 0900 UTC, the remnants of Ike merged into the cold front near the Arkansas-Missouri border, while the northern portion of the cold front passed the Chicago metropolitan area. Showers and embedded thunderstorms continued along a wide swath near the cold front across northern Illinois and northwest Indiana. By 1200 UTC, rainfall directly associated with the low pressure area that was once Hurricane Ike finally reached northeast Illinois and northwest Indiana, but the majority of the storm total rainfall had already occurred. The low pressure area and cold front moved to the east by the afternoon of 14 September, ending the rainfall.

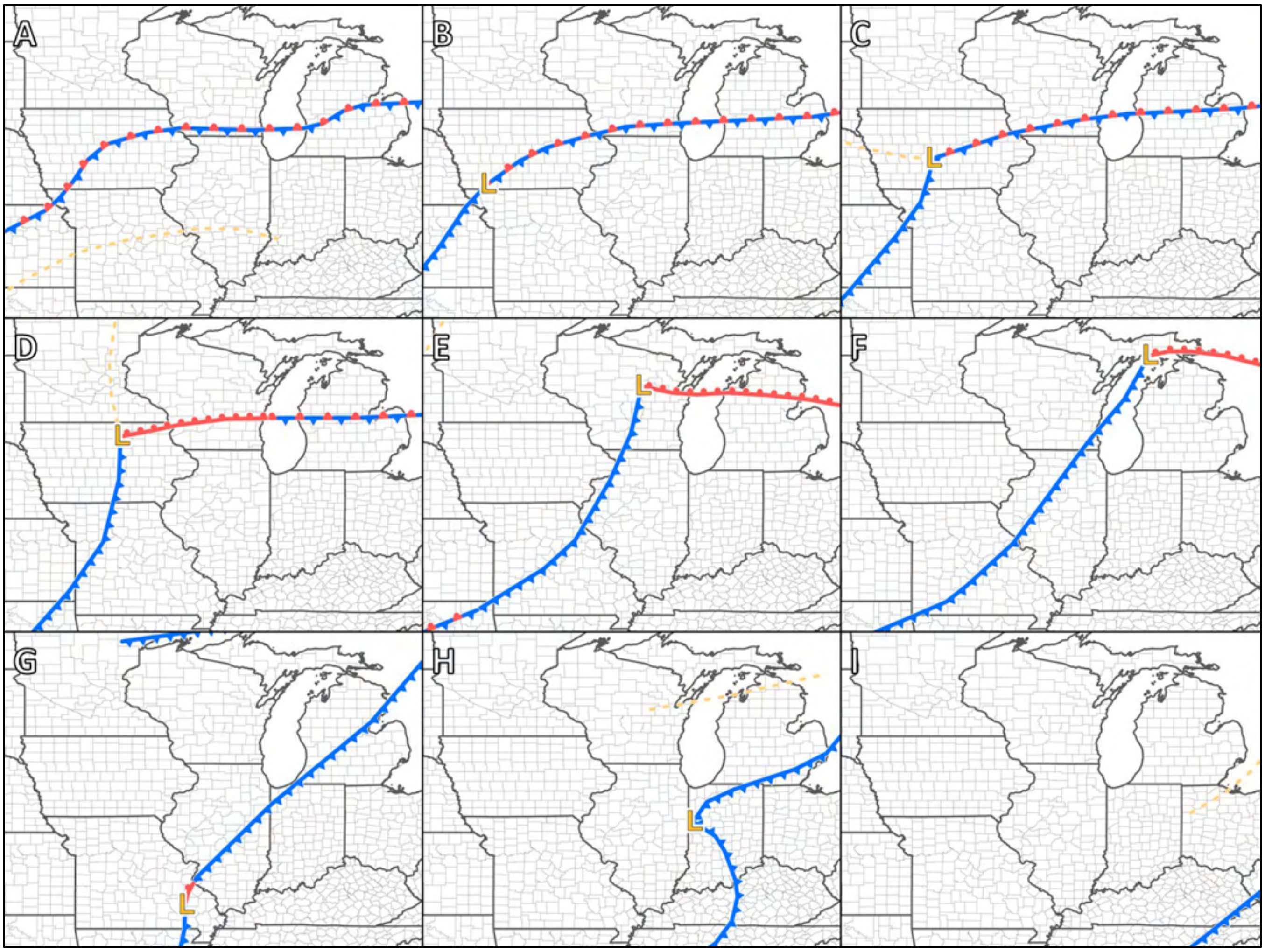

Figure 49. Surface weather maps for the 13-15 September 2008 rainfall event. Images are valid at 0000 UTC on 13 September (A), 0600 UTC on 13 September (B), 1200 UTC on 13 September (C), 1800 UTC on 13 September (D), 0000 UTC on 14 September (E), 0600 UTC on 14 September (F), 1200 UTC on 14 September (G), 1800 UTC on 14 September (H), and 0000 UTC on 15 September (I). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php) and the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4); when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from LOT indicated a nearly continuous period of rainfall of varying intensity across northeast Illinois from approximately 1900 UTC 12 September to 2100 UTC 14 September (Figure 50). The character of the echoes over the first 18-24 hours was that of eastward-moving showers with embedded thunderstorms, training over the same general areas (Figure 50). The highest rainfall rates in the Chicago metro area occurred as embedded thunderstorms moved overhead, which generally occurred from 0900 to 1800 UTC on 13 September. As the remnants of Hurricane Ike neared northern Illinois after approximately 0600 UTC on 14 September, echoes were generally moving to the northeast, parallel to the surface front. Rainfall intensity again increased for a few hours (Figure 51). Outside of these periods, rainfall intensities were generally light, with rates of approximately 0.5 inches per hour or less (Figure 52).

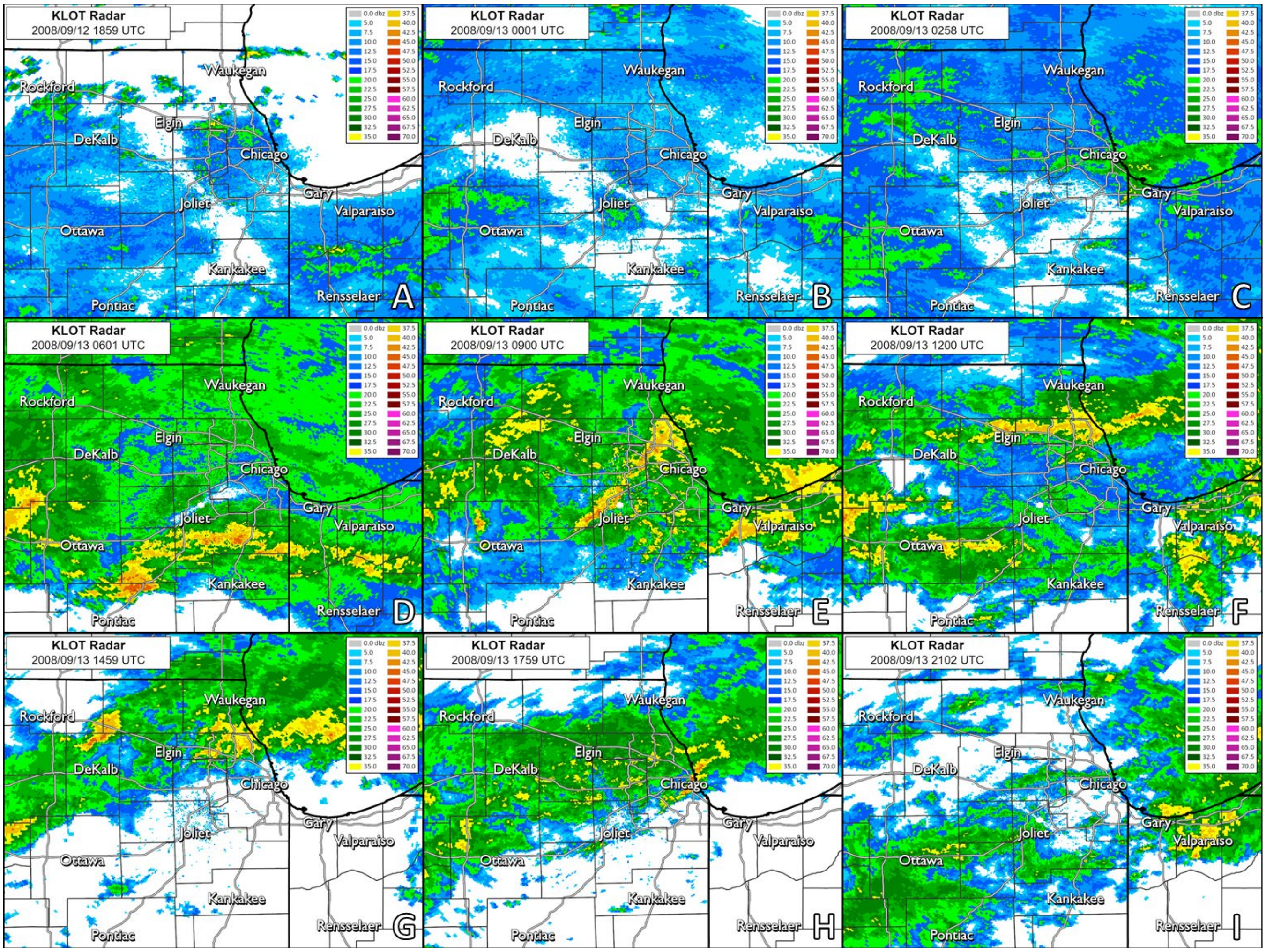

Figure 50. Radar data for the 13-15 September 2008 rainfall event. Images are valid at 1859 UTC on 12 September (A), 0001 UTC on 13 September (B), 0258 UTC on 13 September (C), 0601 UTC on 13 September (D), 0900 UTC on 13 September (E), 1200 UTC on 13 September (F), 1459 UTC on 13 September (G), 1759 UTC on 13 September (H), and 2102 UTC on 13 September (I). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

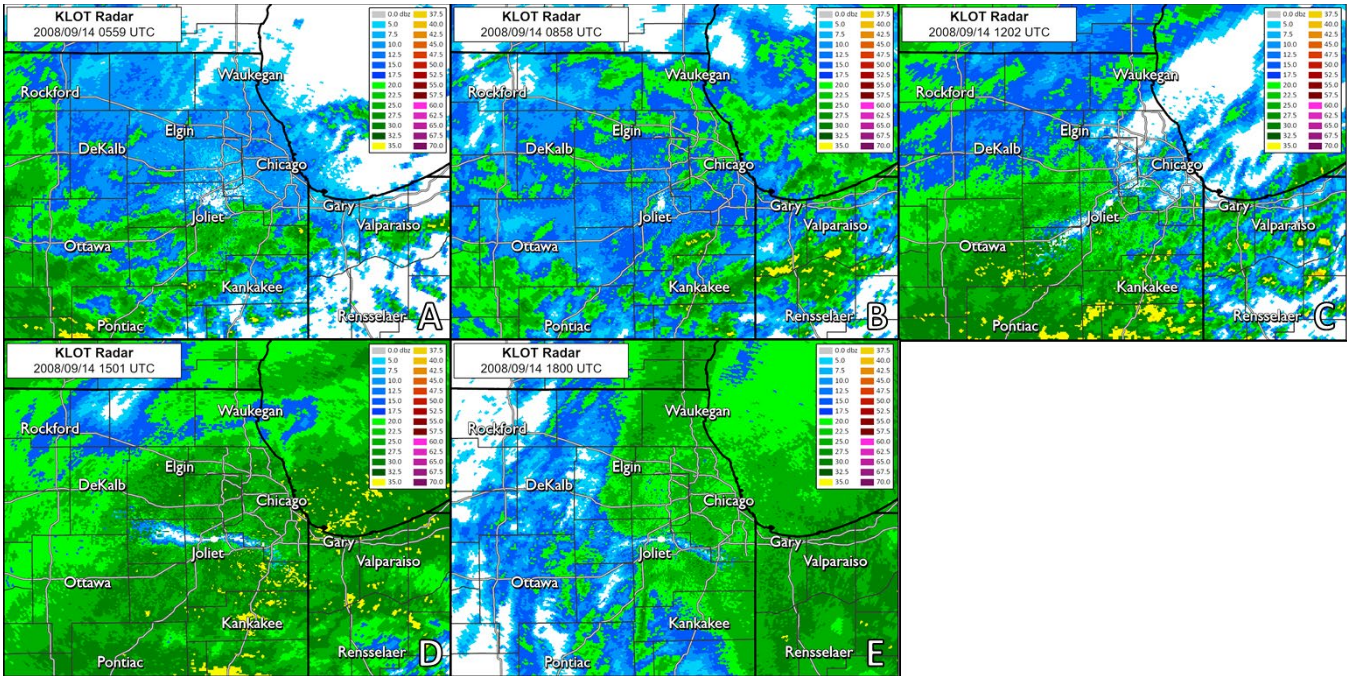

Figure 51. Radar data for the 13-15 September 2008 rainfall event. Images are valid at 0559 UTC on 14 September (A), 0858 UTC on 14 September (B), 1202 UTC on 14 September (C), 1501 UTC on 14 September (D), and 1800 UTC on 14 September (E). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

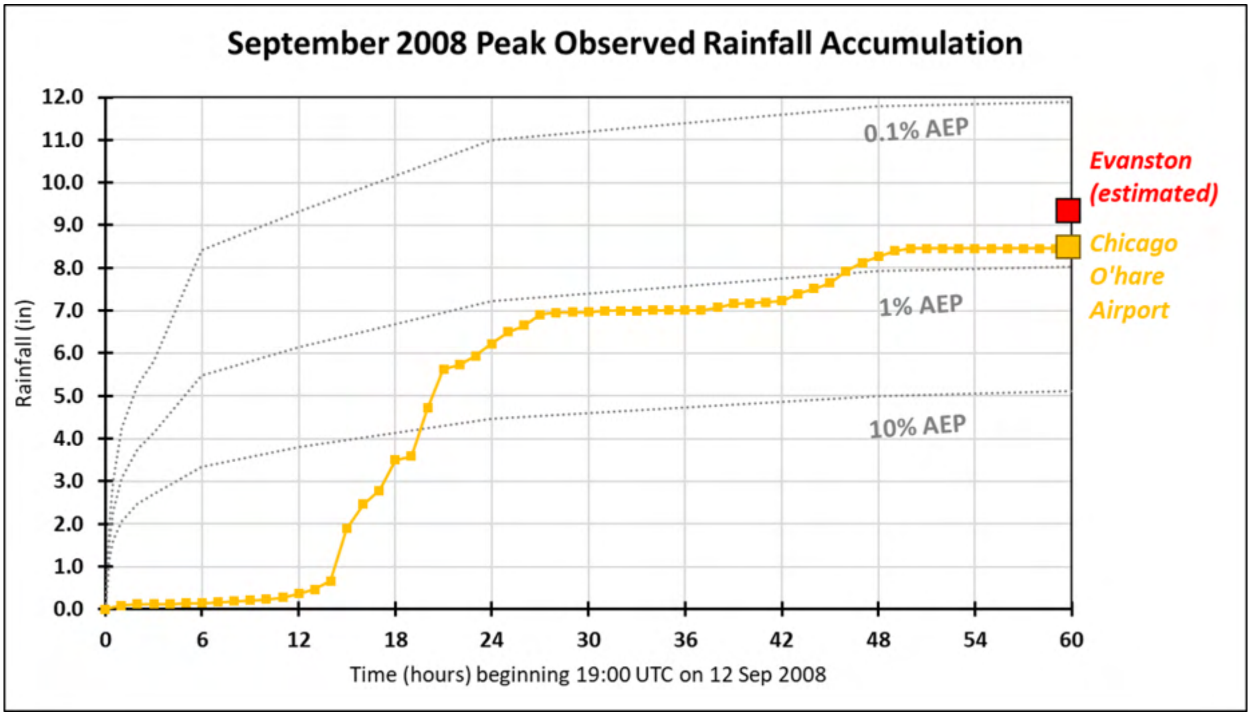

Figure 52. Running storm total rainfall for the 13-15 September 2008 rainfall event. The recording rain gauge with the highest storm total, the ASOS gauge at Chicago O'Hare Airport, is indicated with a yellow-orange line and square. The peak rainfall estimated near Evanston is indicated with a red square. Time on this chart begins with the first hour of measured rainfall.

July 23-24, 2010

From the evening of 23 July to the morning of 24 July 2010, heavy rainfall occurred across northern Illinois. Rainfall up to 10.1 inches occurred over an 18-hour period (Figure 53), the majority of which occurred in a 9-hour period during the overnight hours from 23 July into 24 July. Peak storm total rainfall in the study area was analyzed as a 0.5% AEP (1-in-200 annual chance) event with the peak 12-hr rainfall analyzed as a 0.2% AEP (1-in-500 annual chance) event (Figure 54). Flooding of roadways and structures generally occurred in a corridor through central Cook County (Figure 55). Flood-related damages were estimated at approximately $277 million ($398 million in 2024 dollars), of which $259 million ($372 million in 2024 dollars) occurred in the Chicago metro area (NOAA 2010).

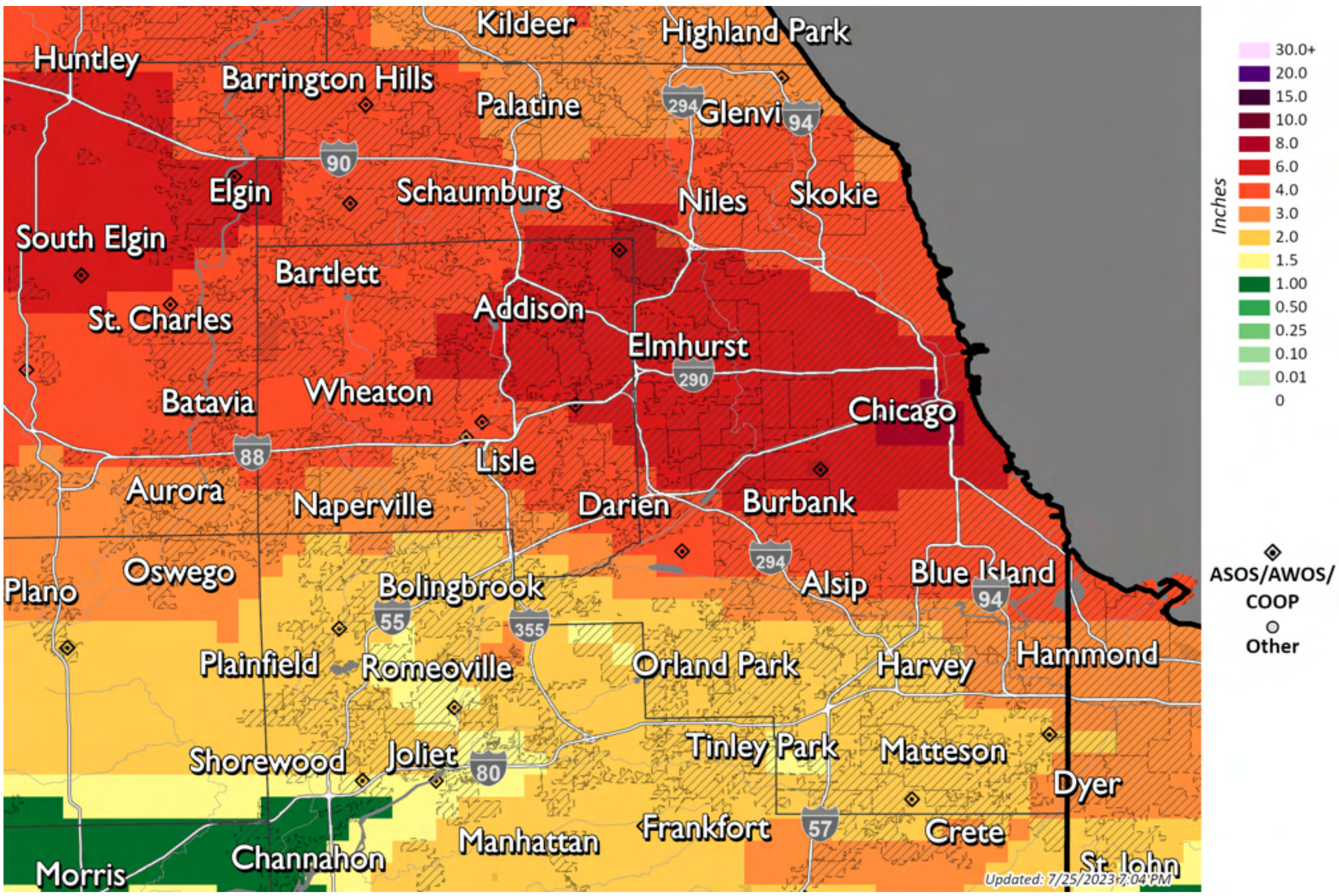

Figure 53. Storm total rainfall from 2100 UTC on 23 July 2010 to 1500 UTC on 24 July 2010.

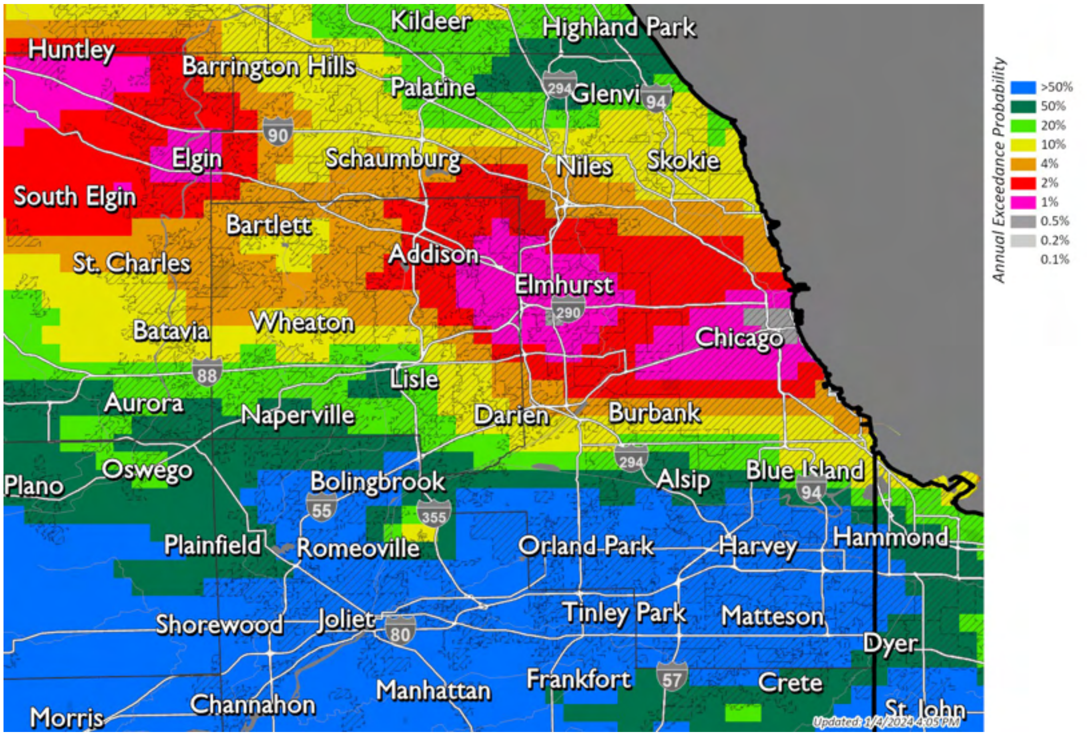

Figure 54. Annual exceedance probability for the storm total rainfall from 2100 UTC on 23 July 2010 to 1500 UTC on 24 July 2010.

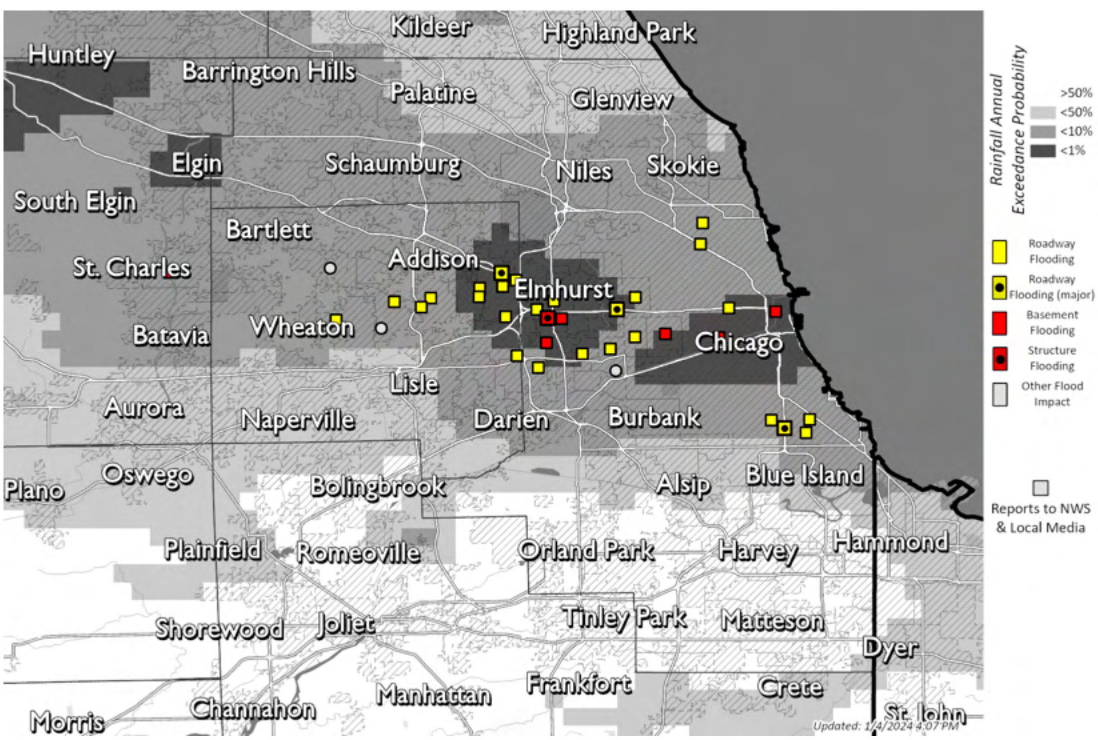

Figure 55. Known flash flood impacts for the 23-24 July 2010 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

At 1800 UTC on 23 July, a surface low was located in southwestern South Dakota, with a stationary boundary extending east into northern Iowa, central Wisconsin, and northern lower Michigan (Figure 56; https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php). An outflow boundary was oriented generally east-west near the Illinois-Wisconsin border. Over the next several hours, a line of thunderstorms moved quickly eastward across northerly Illinois south of the stationary front. This line of storms generated a new outflow boundary and a small area of high pressure in north-central Illinois. By 0000 UTC on 24 July, a strong low-level jet was located at 850 mb extending from Texas northward through Oklahoma and Kansas, then turning east northeast into the surface front and outflow boundary. Flow in northern Illinois was generally parallel to both boundaries (Plymouth State University 2023). At 500 mb, a ridge was located across the southeast US, with an east-west-oriented jet streak along the north side of the ridge extending from the central Great Plains eastward toward the Great Lakes. A sounding at Lincoln, Illinois, indicated a nearly saturated profile up to 800 mb and a precipitable water value of about 2.1 inches. Between 0000 UTC and 0600 UTC on 24 July, the outflow boundary began to drift to the northeast, and thunderstorms developed along and to the northeast of this boundary. The general synoptic setup had strong similarities to the Maddox Mesohigh pattern (Maddox, Chappell and Hoxit 1979).

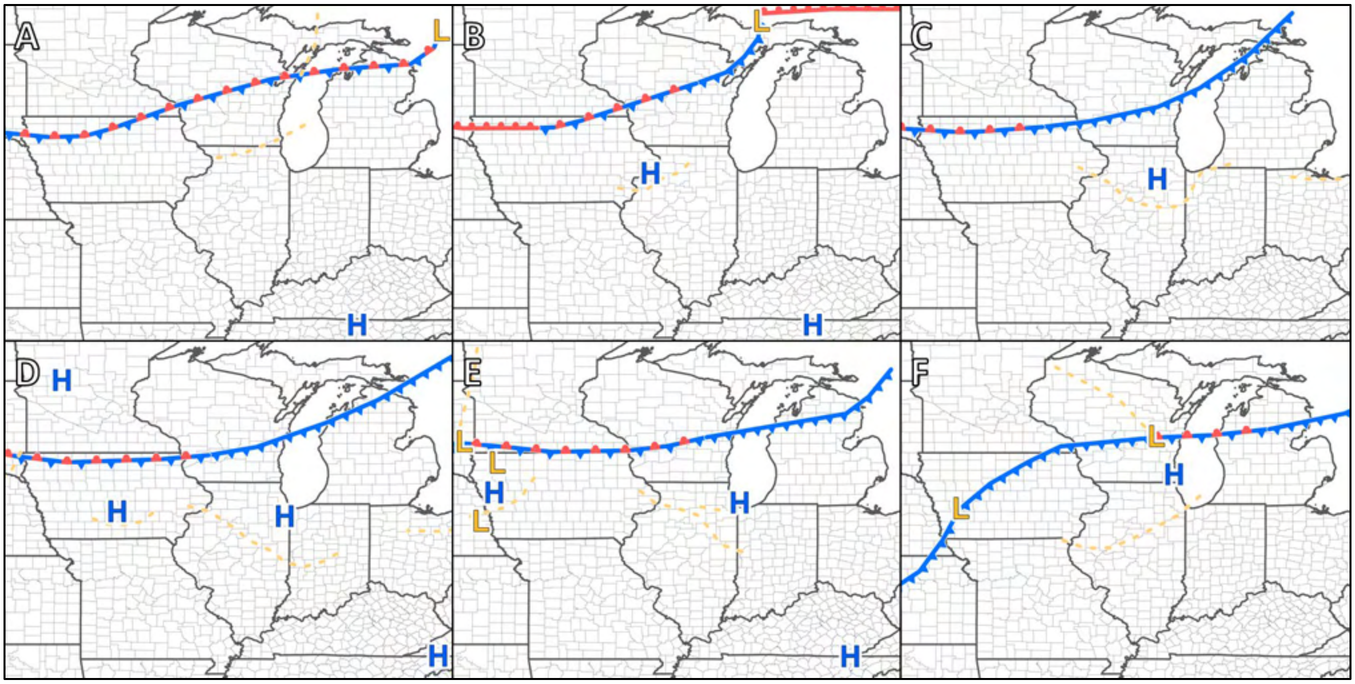

Figure 56. Surface weather maps for the 23-24 July 2010 rainfall event. Images are valid at 1800 UTC on 23 July (A), 2100 UTC on 23 July (B), 0000 UTC on 24 July (C), 0300 UTC on 24 July (D), 0600 UTC on 24 July (E), and 1200 UTC on 24 July (F). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php) the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), and radar data; when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from LOT indicated a cluster of thunderstorms moving quickly eastward across northern Illinois from 2100 UTC 23 July to 0000 UTC 24 July, south of a warm front and near an existing outflow boundary, which caused the outflow boundary to push southward from near the Illinois-Wisconsin border to central Illinois (Figure 57). By 0100 UTC 24 July, rain had ended in northeast Illinois as storms moved east into Indiana, but new storms were beginning to develop near and just north of the outflow boundary in Iowa. At 0400 UTC, radar indicated a nearly continuous line of echoes from northeast Iowa through northwest Illinois and northeast Illinois. The line of storms was oriented east-west, with individual storm motion generally to the east, leading to training of echoes over the same areas. At 0800 UTC, LOT radar imagery indicated echoes had evolved from a nearly continuous line into multiple clusters. The Chicago metro area was impacted by several of these thunderstorms, each producing rain rates of 1-2 inches per hour. By 1200 UTC, radar imagery indicated that the echoes had drifted to the south and begun to diminish. By the morning of 24 July, a swath of northern Illinois had received several hours of nearly continuous rainfall (Figure 58).

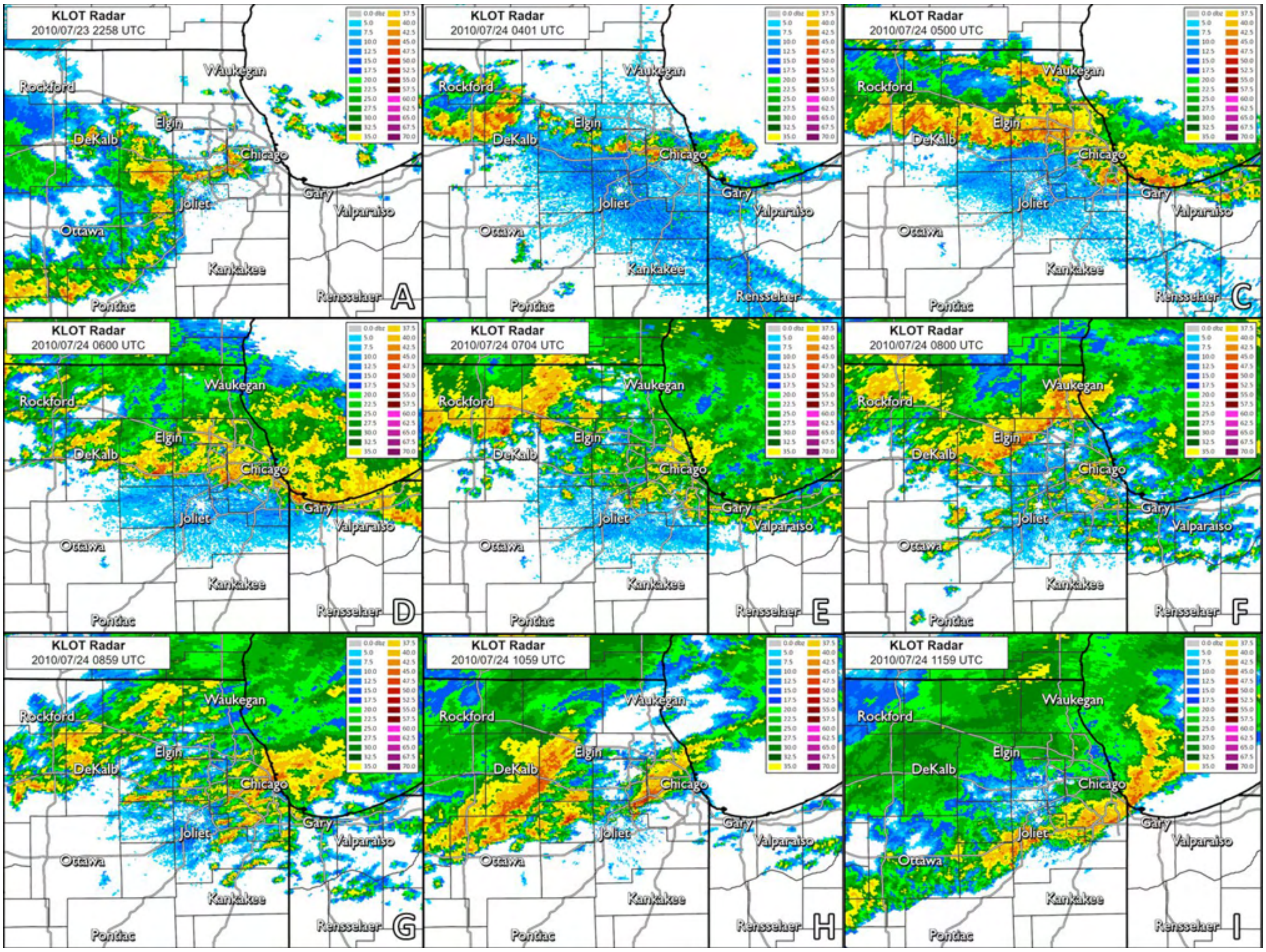

Figure 57. Radar data for the 23-24 July 2010 rainfall event. Images are valid at 2258 UTC on 23 July (A), 0401 UTC on 24 July (B), 0500 UTC on 24 July (C), 0600 UTC on 24 July (D), 0704 UTC on 24 July (E), 0800 UTC on 24 July (F), 0859 UTC on 24 July (G), 1059 UTC on 24 July (H), and 1159 UTC on 24 July (I). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

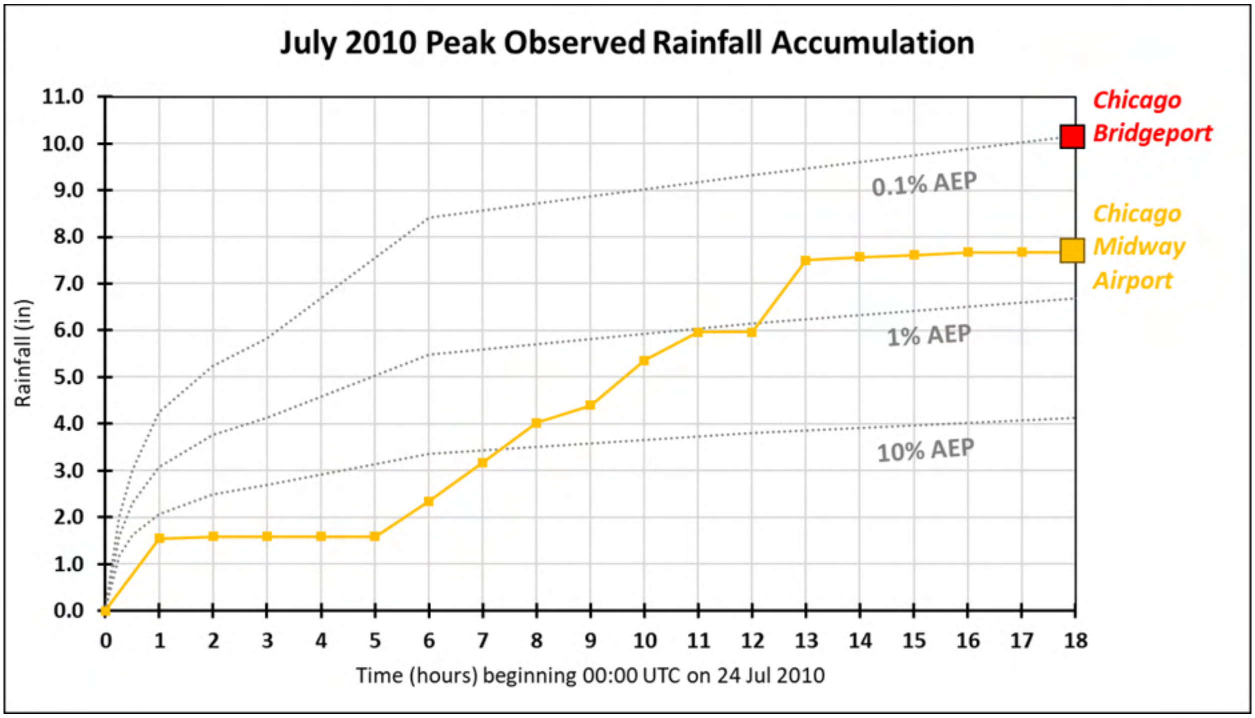

Figure 58. Running storm total rainfall for the 23-24 July 2010 rainfall event. The recording rain gauge with the highest storm total, the ASOS gauge at Chicago Midway Airport, is indicated with a yellow-orange line and square. No hourly rainfall data was available for the peak rainfall measured by the Illinois State Water Survey gauge in the Bridgeport community area of Chicago, indicated with a red square. Time on this chart begins with the first hour of measured rainfall.

July 23, 2011

During the early morning hours of 23 July 2011, heavy rainfall occurred in northeast Illinois with the heaviest rainfall occurring in the Chicago metropolitan area. Up to 6.8 inches of rainfall occurred over a 4-hour period (Figure 59) from 0600 UTC to 1000 UTC on 23 July. Although storm total rainfall amounts were less than the 7.5-inch storm total threshold, rainfall of about 3.2 inches occurred in one hour, 5.7 inches occurred in two hours, 6.7 inches occurred in three hours, and 6.8 inches occurred in four hours, each exceeding the 1% AEP (1-in-100 annual chance) event, according to *NOAA Atlas 14*. The peak 3-hour rainfall exceeded the 0.1% AEP (1-in-1000 annual chance) event (Figure 60). The rainfall caused $38 million ($53 million in 2024 dollars) in flood-related damages in Illinois, of which $30 million ($42 million in 2024 dollars) occurred in the Chicago metro area (NOAA 2011). The most significant flood-related impacts occurred in the northwestern sections of Chicago and the immediate northwest suburbs, but significant roadway flooding occurred across the city (Figure 61).

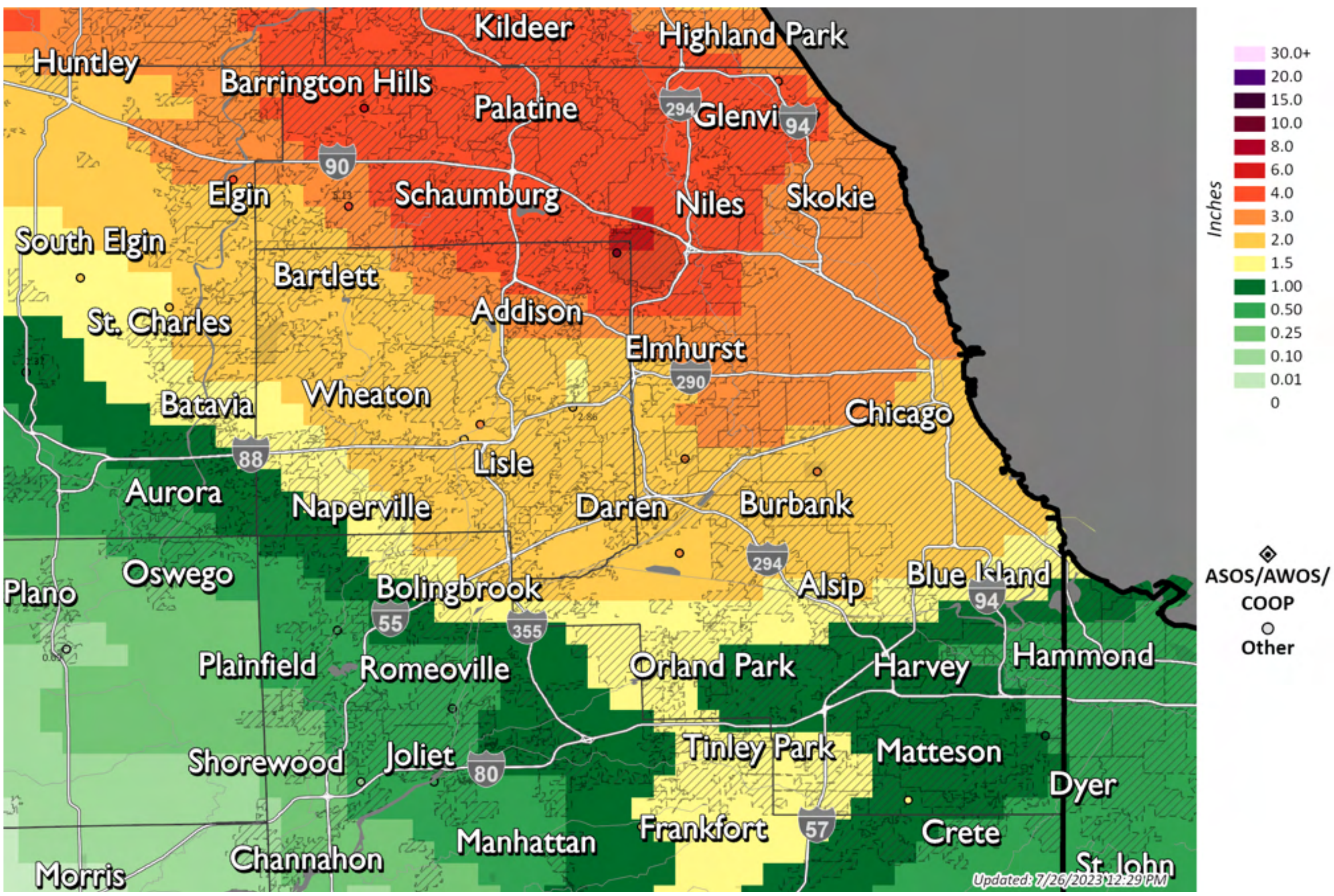

Figure 59. Storm total rainfall from 0400 UTC to 1200 UTC on 23 July 2011. Although this map depicts a longer duration, storm total rainfall from a given location in the central Chicago metro occurred over an approximately 4-hour period.

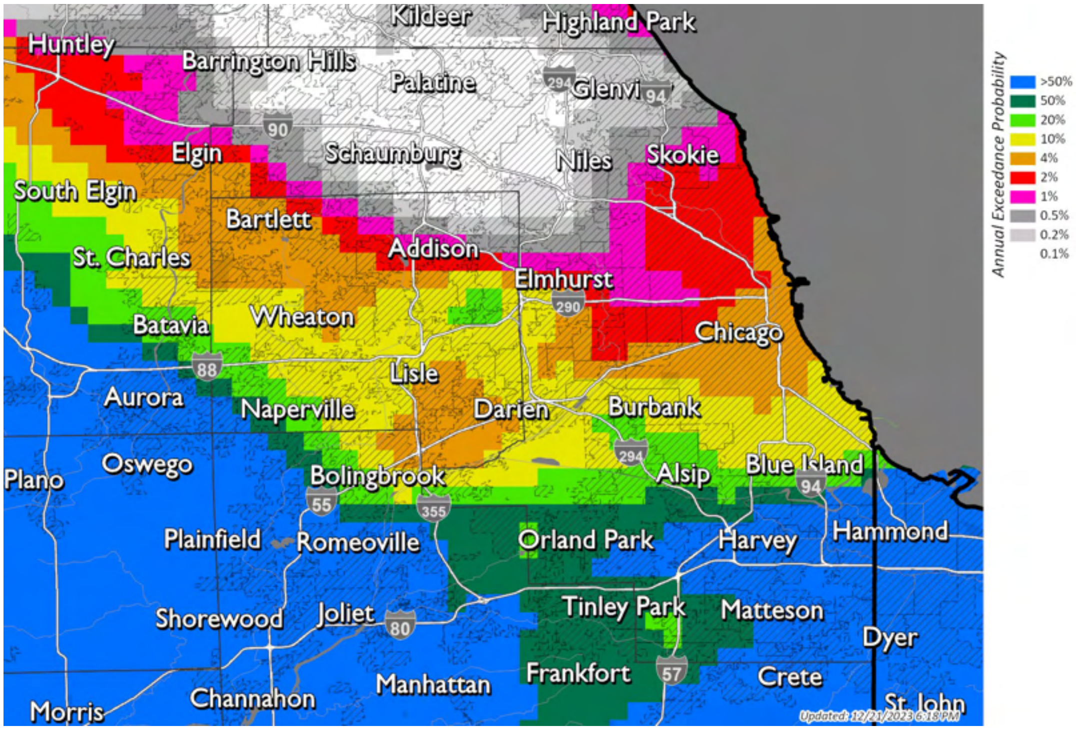

Figure 60. Annual exceedance probability for the storm total rainfall from 0400 UTC to 1200 UTC on 23 July 2011.

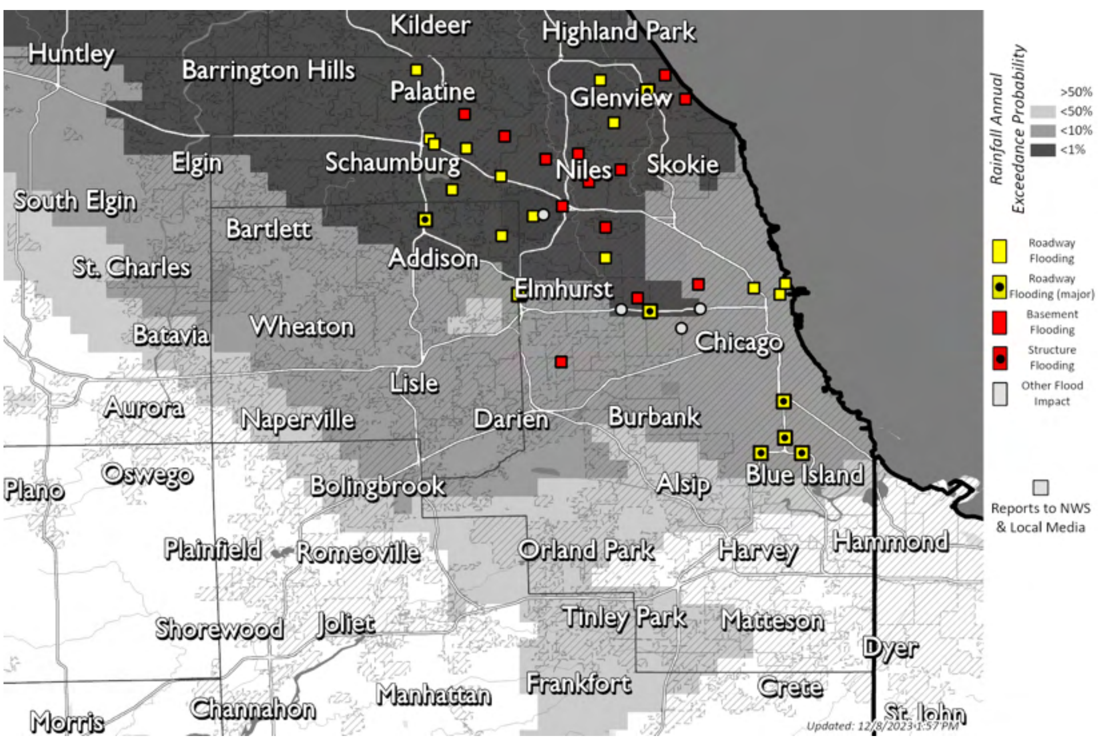

Figure 61. Known flash flood impacts for the 23 July 2011 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

At 0000 UTC on July 23 2011, a developing warm front was located from southern Iowa through northern Illinois and northern Indiana (NOAA Central Library 2023). A cluster of thunderstorms was ongoing north of the front in eastern Iowa, moving eastward into northern Illinois. At 850 mb, a strong low-level jet was located from Texas northeast into Kansas and Missouri, and turned east over Illinois (Plymouth State University 2023). At 500 mb, a ridge was located over the eastern US, with flow generally from the west-southwest across the Midwest. In the warm sector south of the developing warm front, a sounding at Lincoln indicated a precipitable water value of 1.9 inches. Over the next several hours, this warm front strengthened and drifted to the north, nearing the Chicago metro by 0600 UTC (Figure 62). Before the front reached the Chicago area, thunderstorms rapidly developed along and north of the front, oriented from west to east, ahead of the cluster of storms approaching from Iowa. Until approximately 1000 UTC July 23, multiple thunderstorms with rain rates exceeding 3 inches per hour would impact the Chicago metro area. The general synoptic setup had strong similarities to the Maddox Frontal pattern (Maddox, Chappell and Hoxit 1979).

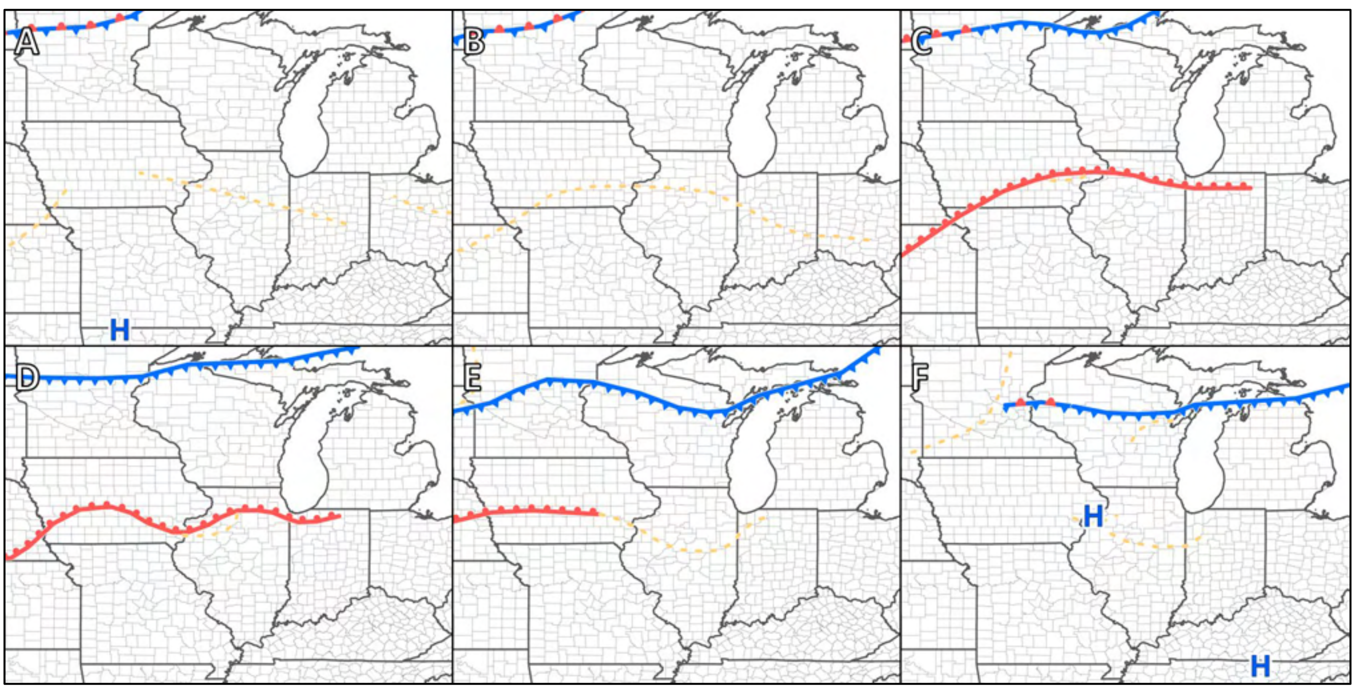

Figure 62. Surface weather maps for the 23 July 2011 rainfall event. Images are valid at 2100 UTC on 22 July (A), 0000 UTC on 23 July (B), 0300 UTC on 23 July (C), 0600 UTC on 23 July (D), 0900 on 23 July (E), and 1200 UTC on 23 July (F). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php) the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), and radar data; when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from LOT indicated a cluster of thunderstorms moving into northwest Illinois at 0400 UTC 23 July 2011 (Figure 63). Just 30 minutes later, radar imagery indicated rapid development of thunderstorms along an east-west axis from the northern half of the Chicago metro, just north of a warm front. By 0600 UTC, the cluster of thunderstorms from the west and the new thunderstorms along the front had merged into one continuous line of storms. The movement and orientation of these cells caused several hours of thunderstorm activity over the Chicago metro with rain rates up to 3 inches per hour between 0500 UTC and 0900 UTC. Radar imagery indicated that rainfall intensity diminished to on and off light showers after 0900 UTC, and then ended around 1800 UTC. Although radar imagery only indicated thunderstorms over the Chicago metro for a few hours, the rainfall intensities from individual storm cells were very heavy (Figure 64).

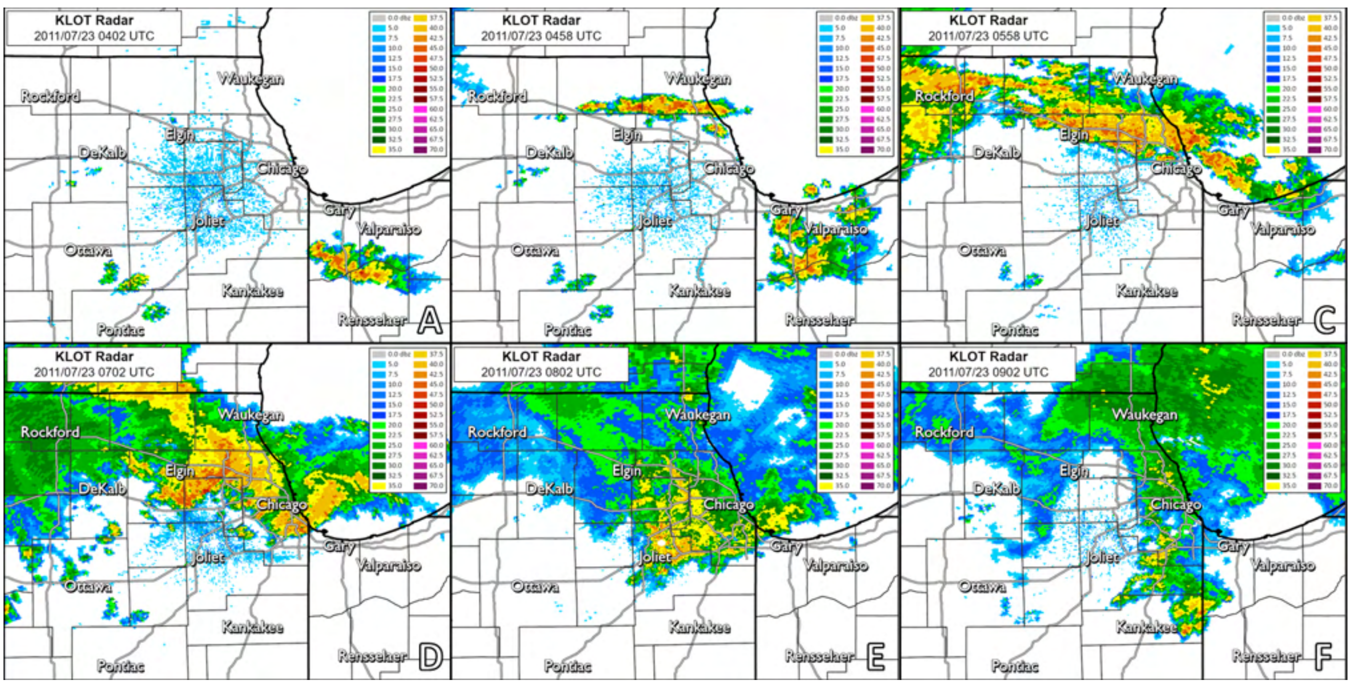

Figure 63. Radar data for the 23 July 2011 rainfall event. Images are valid at 0402 UTC on 23 July (A), 0458 UTC on 23 July (B), 0558 UTC on 23 July (C), 0702 UTC on 23 July (D), 0802 UTC on 23 July (E), and 0902 UTC on 23 July (F). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

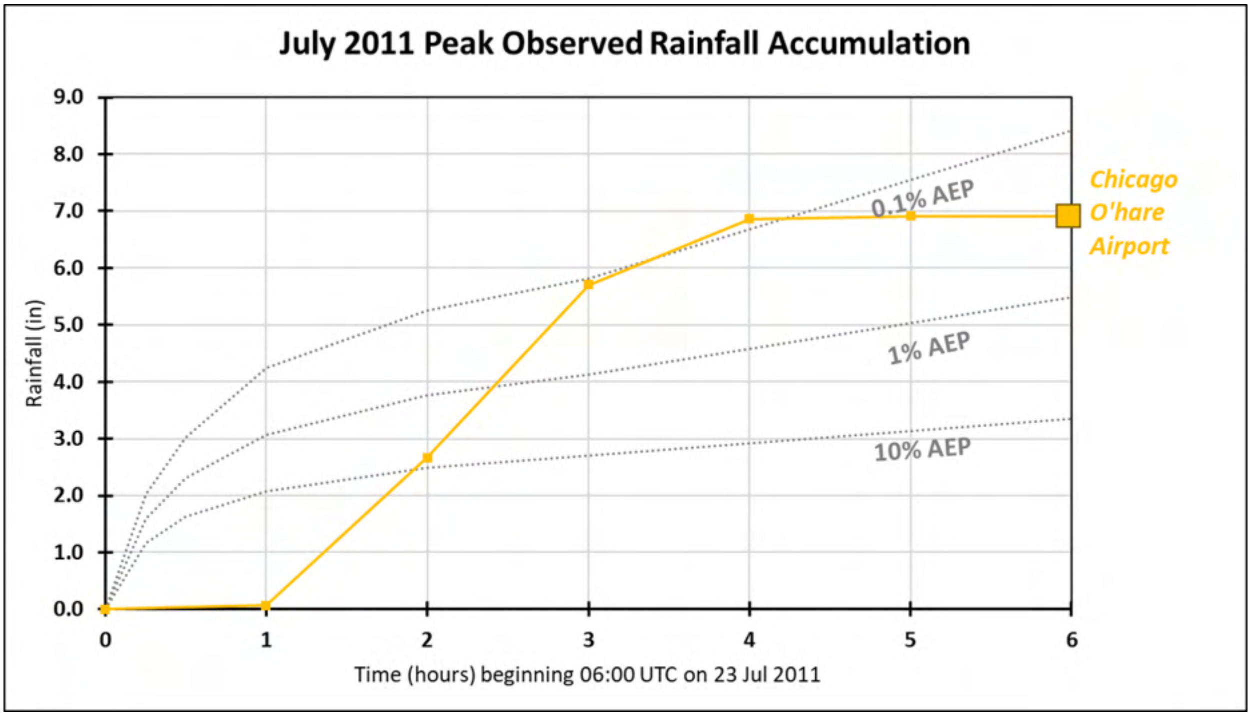

Figure 64. Running storm total rainfall for the 23 July 2011 rainfall event. The recording rain gauge with the highest storm total, the ASOS gauge at Chicago O'Hare Airport, is indicated with a yellow-orange line and square. Time on this chart begins with the first hour of measured rainfall.

September 11, 2022

During the day on 11 September 2022, a slow-moving supercell thunderstorm moved through the central portion of the Chicago metro area, causing a narrow corridor of very heavy rainfall rates. This thunderstorm was associated with a slow-moving area of low pressure moving across the region. Rainfall up to 6.4 inches occurred over a 12-hour period (Figure 65), with the majority of this occurring over approximately two hours or less (with varying start and end times depending on the location) from approximately 1300 UTC to 1600 UTC on 11 September. Although storm total rainfall amounts were less than the 7.5-inch storm total threshold, rainfall rates were very intense over a short period of time; near the area of peak rainfall in the northwestern and northern sections of Chicago, up to 2.1 inches occurred in 15 minutes, 3.6 inches occurred in one hour, and 5.1 inches occurred in three hours, each exceeding the 1% AEP (1-in-100 annual chance) event. Peak storm total rainfall in the study area was analyzed as a 2% AEP (1-in-50 annual chance) event (Figure 66) although these peak rainfall rates occurred only in isolated areas that would have been difficult to sample without the dense network of private weather stations in the Chicago metropolitan area, and didn’t show up in the gridded analysis. Significant flooding occurred in some areas, including the Portage Park, Albany Park, Ravenswood, Uptown, and Rogers Park community areas of Chicago (Figure 67). Impacts included widespread roadway flooding, flooding of I-290 in Oak Park, flooding of numerous underpasses, and isolated flooding of structures. Flood damage was estimated at $3.1 million ($3.3 million in 2024 dollars) in the Chicago metro area (NOAA 2011).

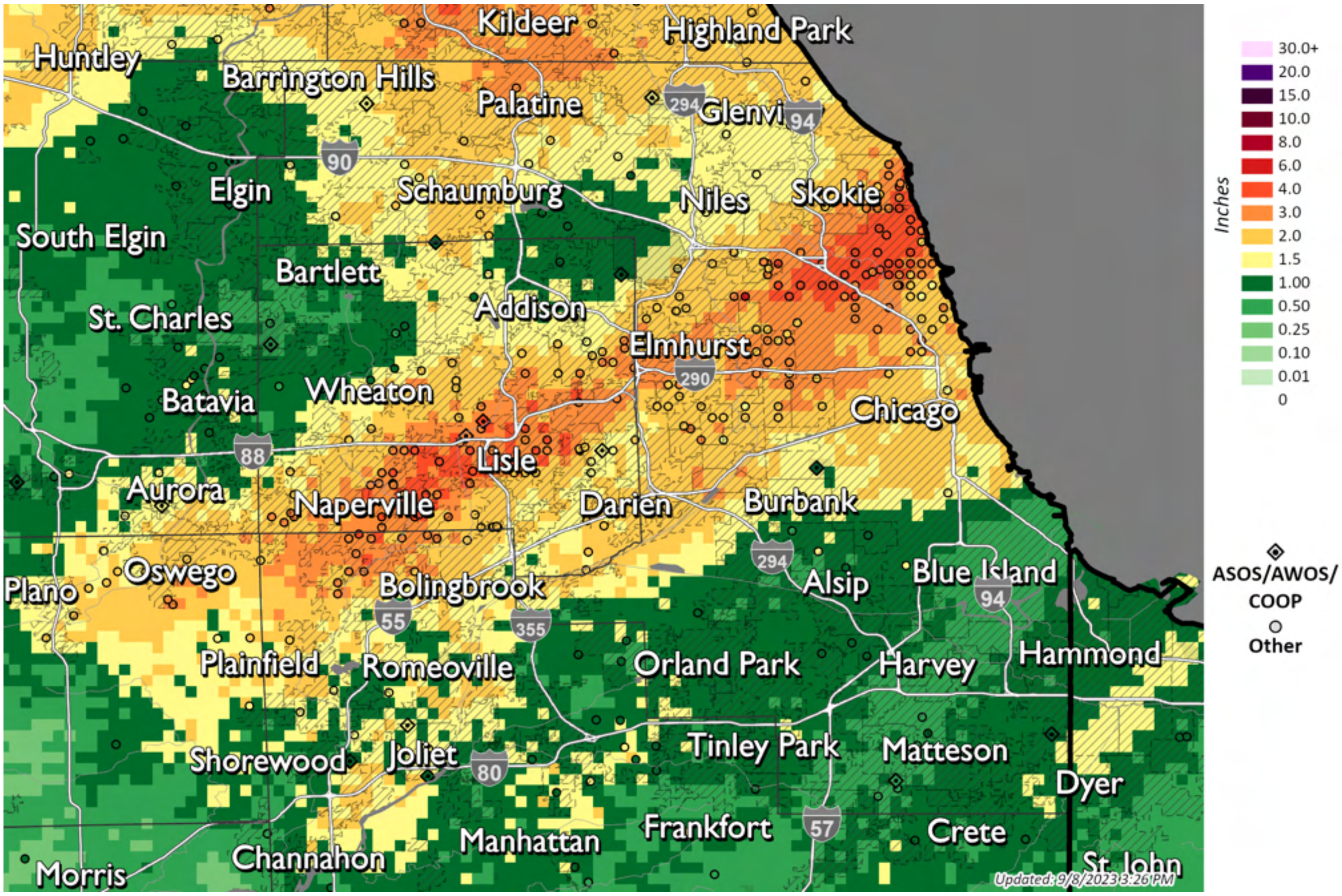

Figure 65. Storm total rainfall from 1200 UTC 11 September to 0000 UTC on 12 September 2022.

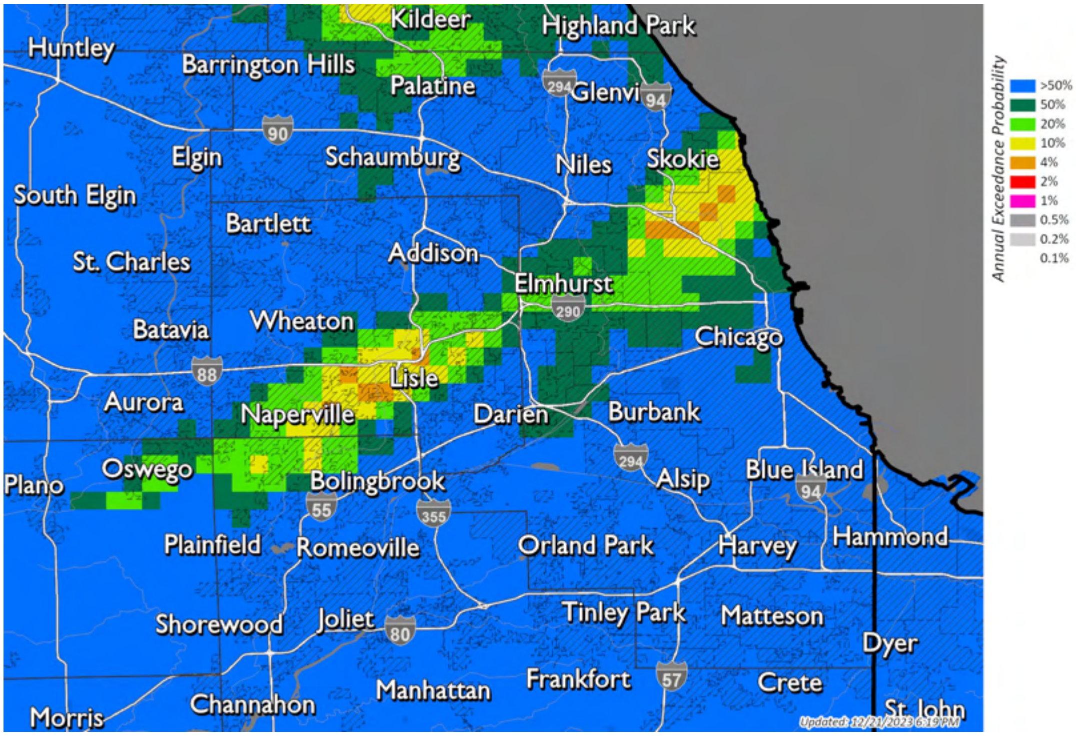

Figure 66. Annual exceedance probability for the storm total rainfall from 0400 UTC to 1200 UTC on 23 July 2011.

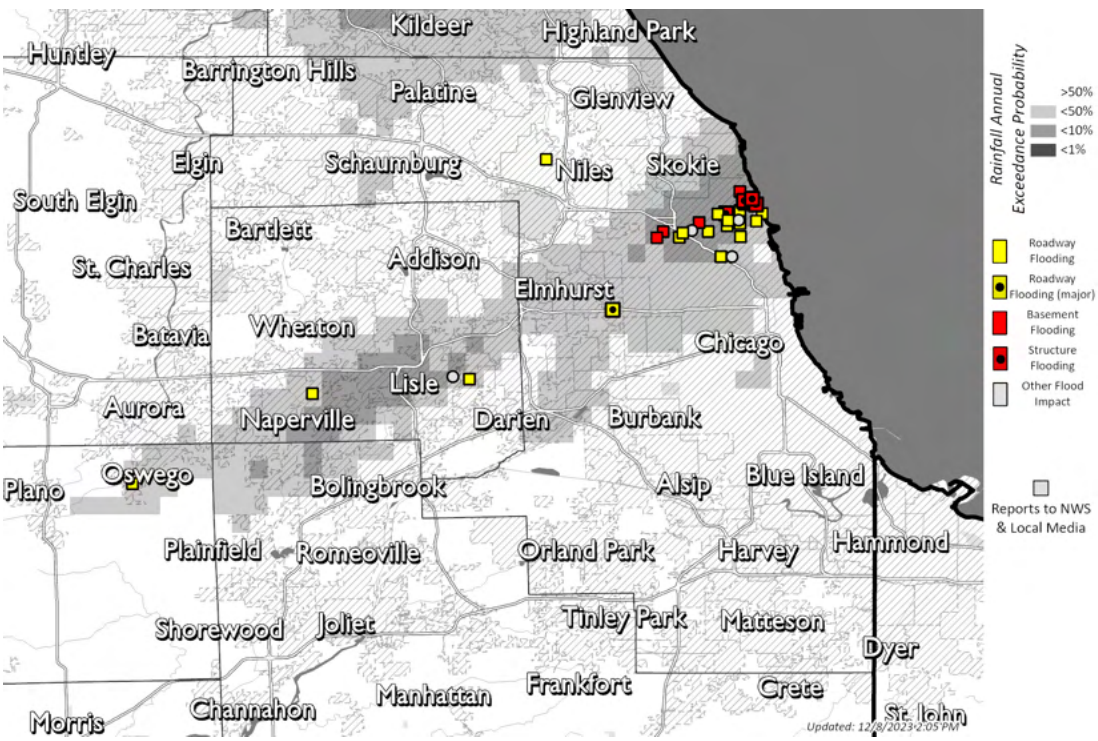

Figure 67. Known flash flood impacts for the 23 July 2011 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

At 0900 UTC on 11 September 2022, a slow-moving area of low pressure was located in north-central Illinois, southwest of the Chicago metro (Figure 68). A cold front extended from the surface low to the southwest into southern Missouri and a stationary front extended east northeast from the surface low through the Chicago metro area into southern Michigan. A line of showers and thunderstorms was ongoing across northwestern and northern Illinois, to the west of the frontal boundaries, with widely scattered showers to the east in the warm sector. By 1200 UTC, the surface low had moved to the northeast and was located over the western suburbs of Chicago. At 850 mb, an area of low pressure was located over Illinois with relatively light winds. At 500 mb, a trough was located over the central U.S., centered near the Iowa and Minnesota border, with a ridge in the eastern U.S. and another ridge in the western U.S. A jet streak was located around the central U.S. trough. Just to the south of the low pressure area, a sounding from Lincoln indicated a saturated profile up to about 600 mb, generally light, unidirectional winds in the lower atmosphere, and a precipitable water value near 1.7 inches. Showers and thunderstorms increased in coverage and intensity near the surface low in the hour leading up to 1200 UTC, with one of these thunderstorms almost co-located with the area of surface low pressure. Over the next few hours, the storm moved east-northeast across the center of the Chicago metro area and into Lake Michigan, and additional storms formed in the vicinity of the low pressure area. By 1600 UTC, the low pressure area and supercell thunderstorm had moved offshore and rainfall rates were generally diminishing across the Chicago area. As the low pressure area moved slowly to the east, bands of generally light rainfall continued to wrap around and into northeast Illinois from the east. Although additional rainfall occurred for several hours from these bands, rainfall rates were light enough to not cause additional flooding.

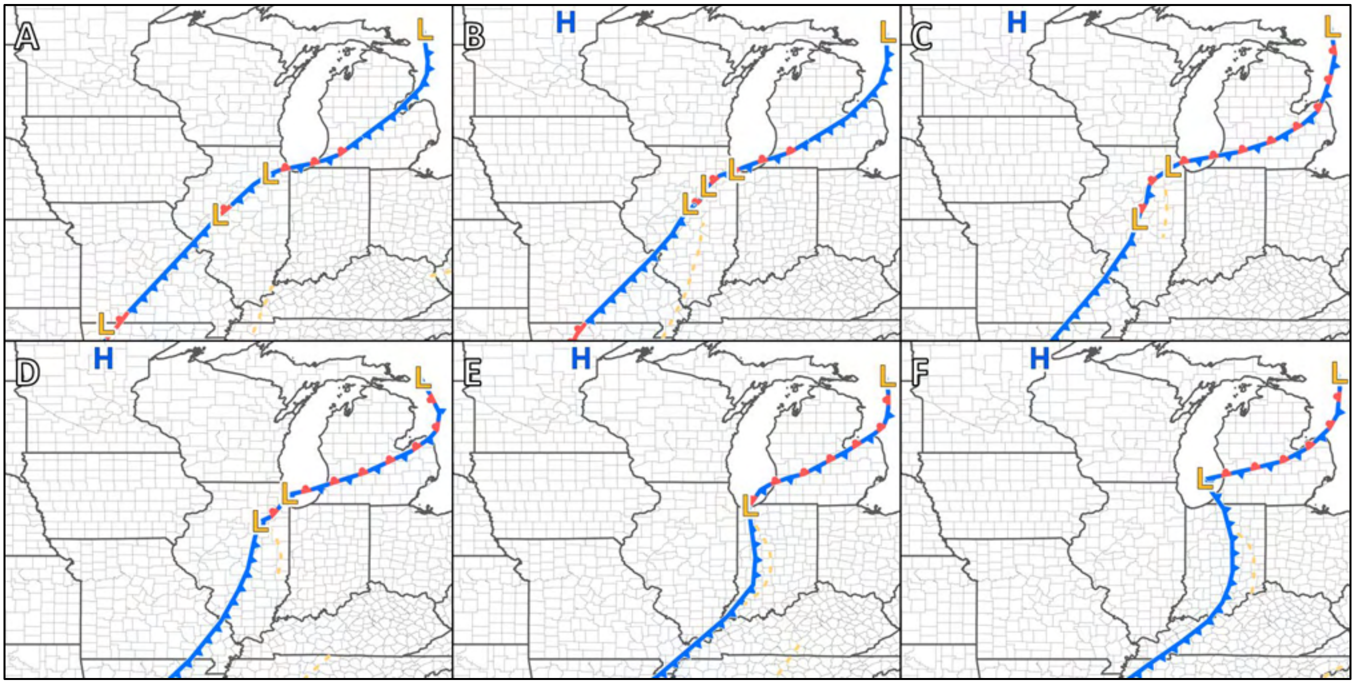

Figure 68. Surface weather maps for the 11 September 2022 rainfall event. Images are valid at 0900 UTC on 11 September (A), 1200 UTC on 11 September (B), 1500 UTC on 11 September (C), 1800 UTC on 11 September (D), 2100 on 11 September (E), and 0000 UTC on 12 September (F). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php) the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), and radar data; when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from LOT indicated generally light showers and thunderstorms across northwest Illinois from approximately 0800 UTC to 1000 UTC on 11 September 2022 associated with the approaching area of low pressure and cold front. Shortly after 1000 UTC, radar echoes increased in coverage and intensity near the surface low, then located to the west-southwest of the Chicago metro (Figure 69). The strongest cell was almost exactly co-located with the area of low pressure, and generally moved to the east-northeast toward Chicago. By 1200 UTC, this cell was entering the western Chicago metro area and had begun to develop supercellular characteristics, including mid-level rotation and an arcing shape on reflectivity. Observed rainfall rates with this cell steadily increased as it neared central Cook County and Chicago, with multiple gauges indicating accumulations of more than an inch in a 15-minute period. The supercell reached central Cook County by 1330 UTC and traversed the county over the next hour. A narrow corridor of very high rain rates occurred across the northwestern portion of central Cook County, from roughly Hillside to the Uptown community area. Although the corridor of rainfall exceeding the 50% AEP (1-in-2 annual chance) event was only 5-10 miles wide, areas near the center with the highest rainfall rates had significant flash flood impacts. From this single supercell thunderstorm alone, a narrow corridor received 2.5-4.5 inches of rainfall in just 2 hours. By 1430 UTC, this cell had moved offshore over Lake Michigan, but additional showers and thunderstorms had formed just to the west of the low pressure area and moved toward central Cook County. Rainfall intensity significantly decreased after 1430 UTC, although bands of showers wrapping around the low continued to impact far northeastern Illinois until approximately 0100 UTC on September 12 (Figure 70).

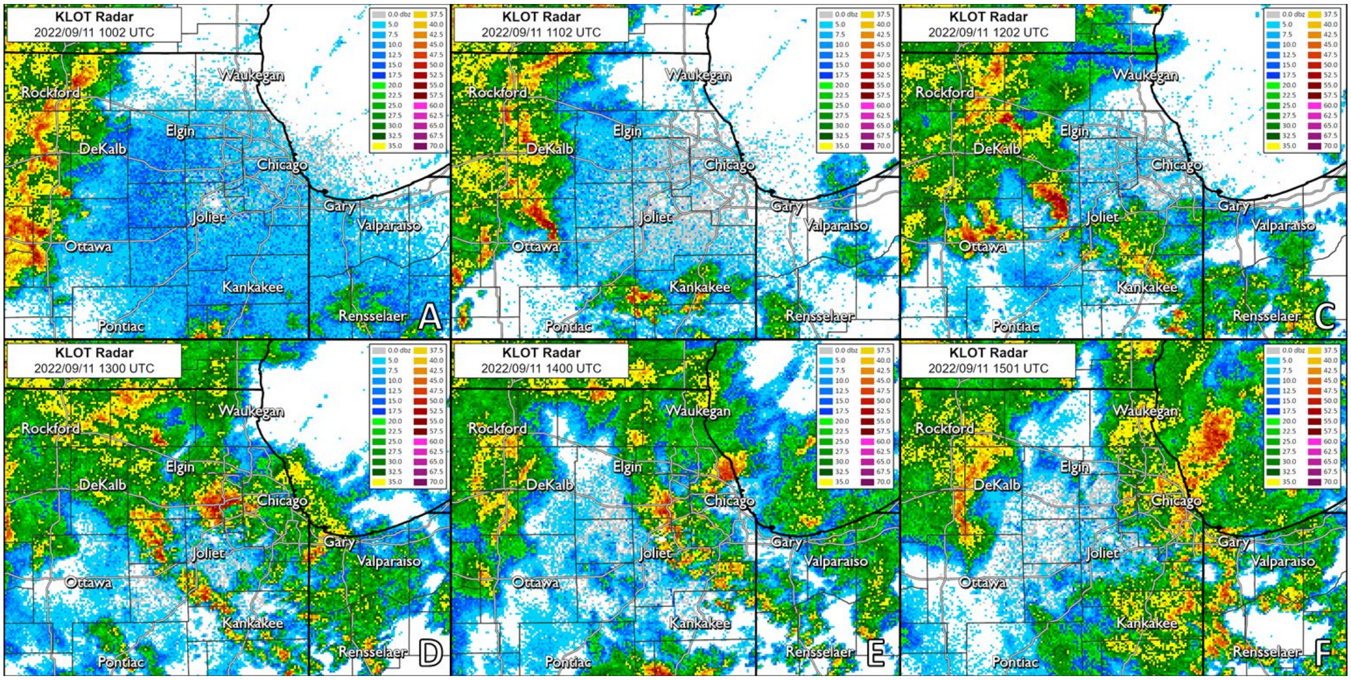

Figure 69. Radar data for the 11 September 2022 rainfall event. Images are valid at 1002 UTC on 11 September (A), 1102 UTC on 11 September (B), 1202 UTC on 11 September (C), 1300 UTC on 11 September (D), 1400 UTC on 11 September (E), and 1501 UTC on 11 September (F). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

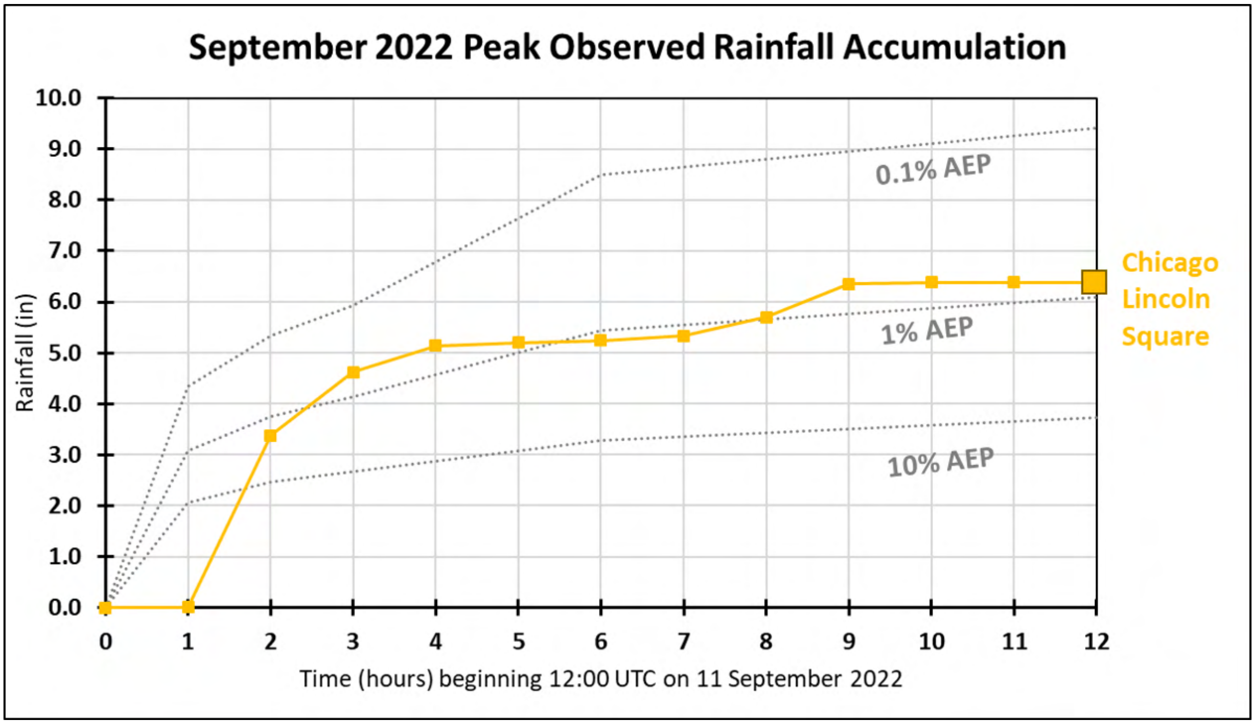

Figure 70. Running storm total rainfall for the 11 September 2022 rainfall event. The recording rain gauge with the highest storm total, a privately-owned weather station located in the Dunning community area of Chicago, is indicated with a yellow-orange line and square. Time on this chart begins with the first hour of measured rainfall.

July 2, 2023

On 2 July 2023, a small, slow-moving area of low pressure (an MCV) drifted across the Chicago metropolitan area. Around this MCV were multiple bands of heavy rainfall slowly rotating around the center and sometimes remaining relatively stationary. Rainfall up to 9.0 inches occurred over an 18-hour period (Figure 71) in central Cook County, with two distinct periods. The first period of rainfall occurred from approximately 1030 UTC to 1700 UTC on 2 July, and the second period of rainfall occurred from approximately 1830 UTC to 2130 UTC. Peak storm total rainfall in the study area was analyzed as a 0.2% AEP (1-in-500 annual chance) event (Figure 72). Significant flooding was noted in many areas, including the Berwyn, Cicero, Oak Park, and the Austin community area of Chicago (Figure 73). Impacts included widespread roadway flooding, flooding of I-290 near Oak Park, flooding of numerous underpasses, and flooding of at least 70,000 basements. At the time of this report, flood damage estimates were still being tabulated, but were roughly estimated to be at least $500 million (Lincoln 2023).

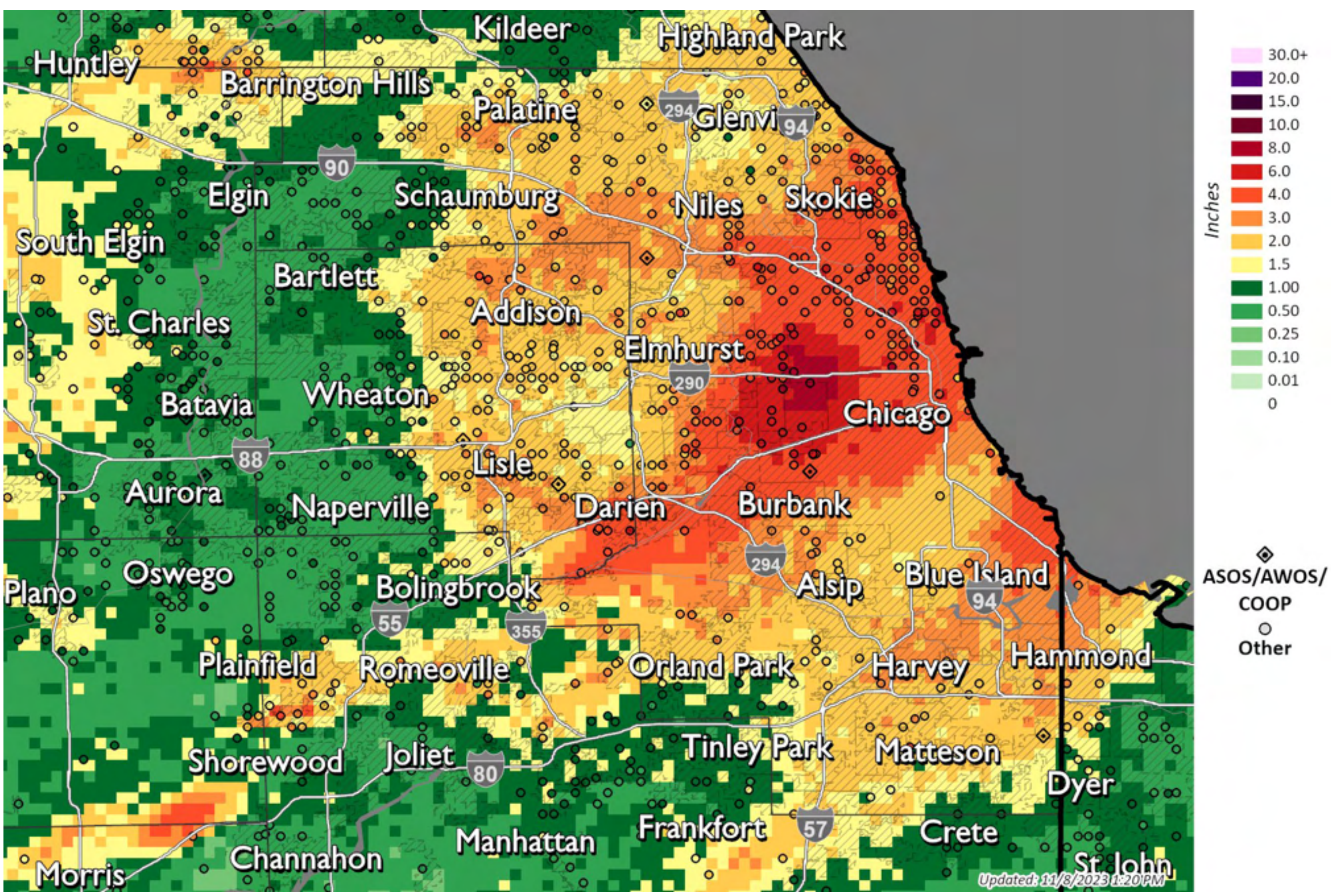

Figure 71. Storm total rainfall from 0600 UTC on 2 July to 0000 UTC on 3 July 2023.

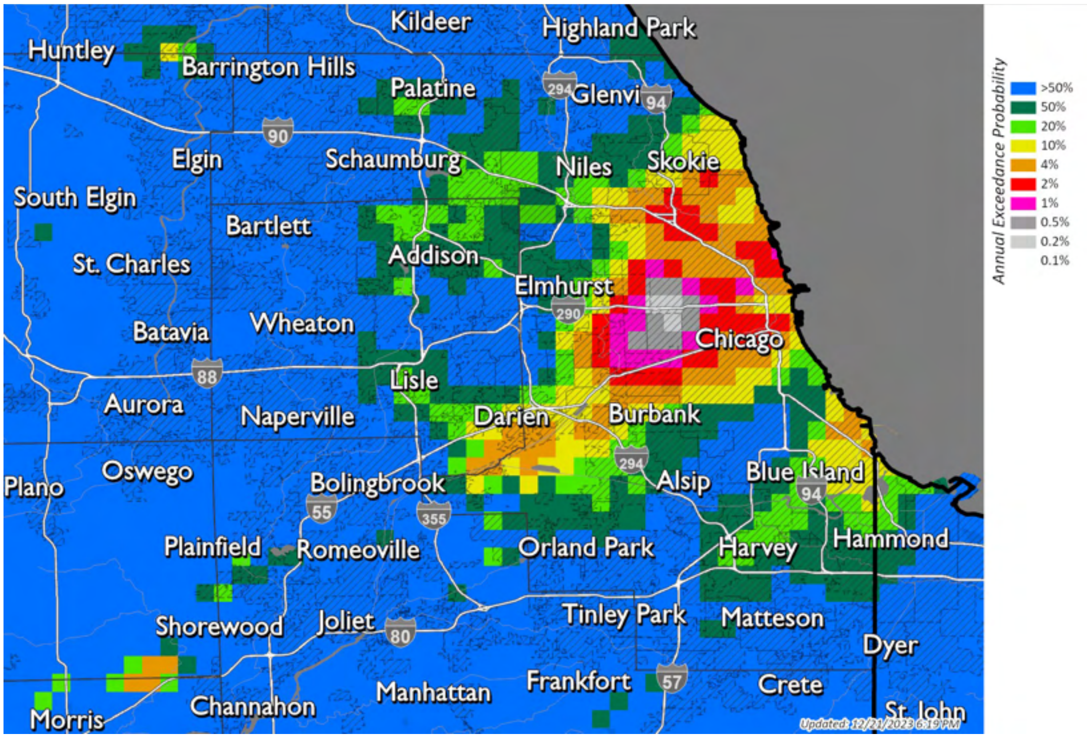

Figure 72. Annual exceedance probability for the storm total rainfall from 0600 UTC on 2 July to 0000 UTC on 3 July 2023.

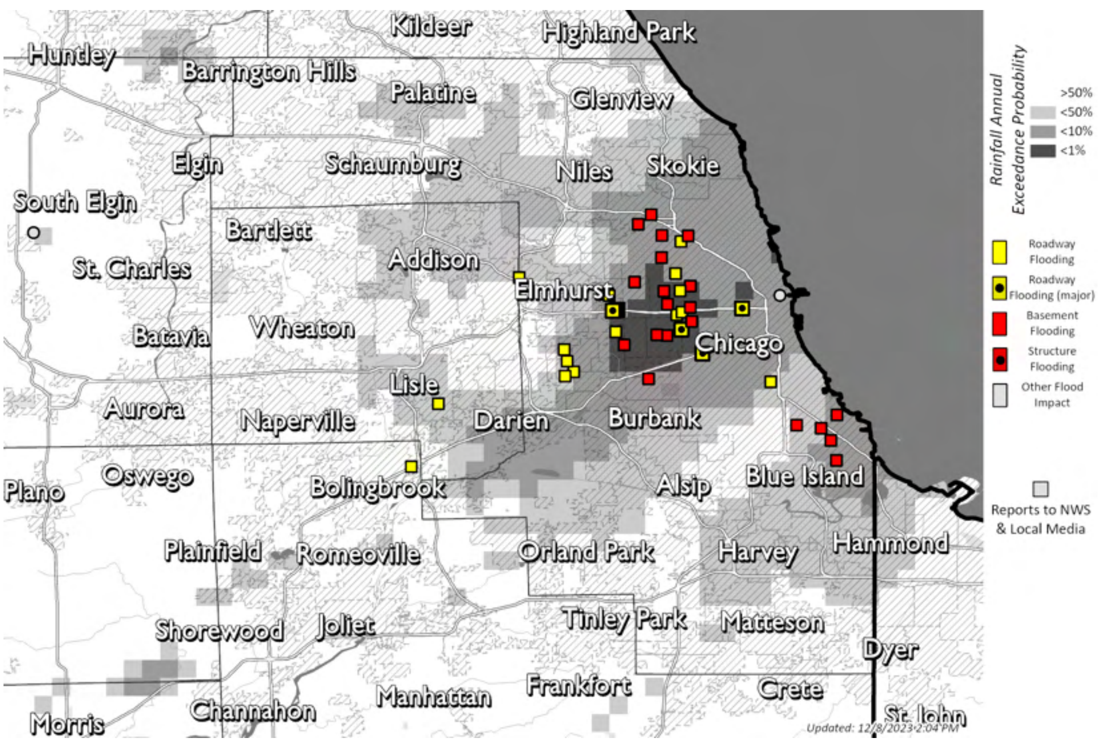

Figure 73. Known flash flood impacts for the 2 July 2023 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

During the overnight and early morning hours of 2 July 2023, a nearly stationary, weak warm front was draped across parts of northern Illinois from roughly Peoria east-northeast toward the southern Chicago metro area (Figure 74). In west-central Illinois, a weak area of surface low pressure was drifting slowly to the northeast. This area of low pressure was likely a remnant mesoscale convective vortex (MCV) from earlier convection (Lincoln 2023). At 850 mb, winds were light across northern Illinois with a weak low-level jet extending from the Mid-South eastward into the Ohio River Valley. At 500 mb, winds were also light over northern Illinois, with a shortwave over northwest Illinois near the Mississippi River. Scattered showers and isolated thunderstorms were ongoing along the warm front and near the MCV. By 1200 UTC on 2 July, the MCV had neared the far western suburbs of Chicago and the warm front and drifted slightly to the north. Heavier shower and thunderstorm activity had begun to develop along the warm front, just ahead of the MCV. The large-scale pattern at 850 mb and 500 mb had changed little. South of the warm front and MCV, the 1200 UTC 2 July sounding from Lincoln indicated a moist profile and generally light winds up to about the 300-mb level, yielding a precipitable water value of 1.57 inches. To the northwest of the warm front and MCV, at Davenport, a sounding indicated a nearly saturated profile and light winds up to about the 250-mb level, yielding a precipitable water value of 1.8 inches. Storm Prediction Center mesoanalysis derived from the RAP model indicated a corridor of precipitable water values near 1.8 inches roughly following the warm front from west to east across northern Illinois. Through the day on 2 July, multiple bands of showers and thunderstorms formed near the slow-moving MCV and generally along and north of the associated warm front as they drifted slowly eastward. By 0000 UTC on 3 July, the 500-mb shortwave had moved little, and was centered near Chicago and the southern shore of Lake Michigan.

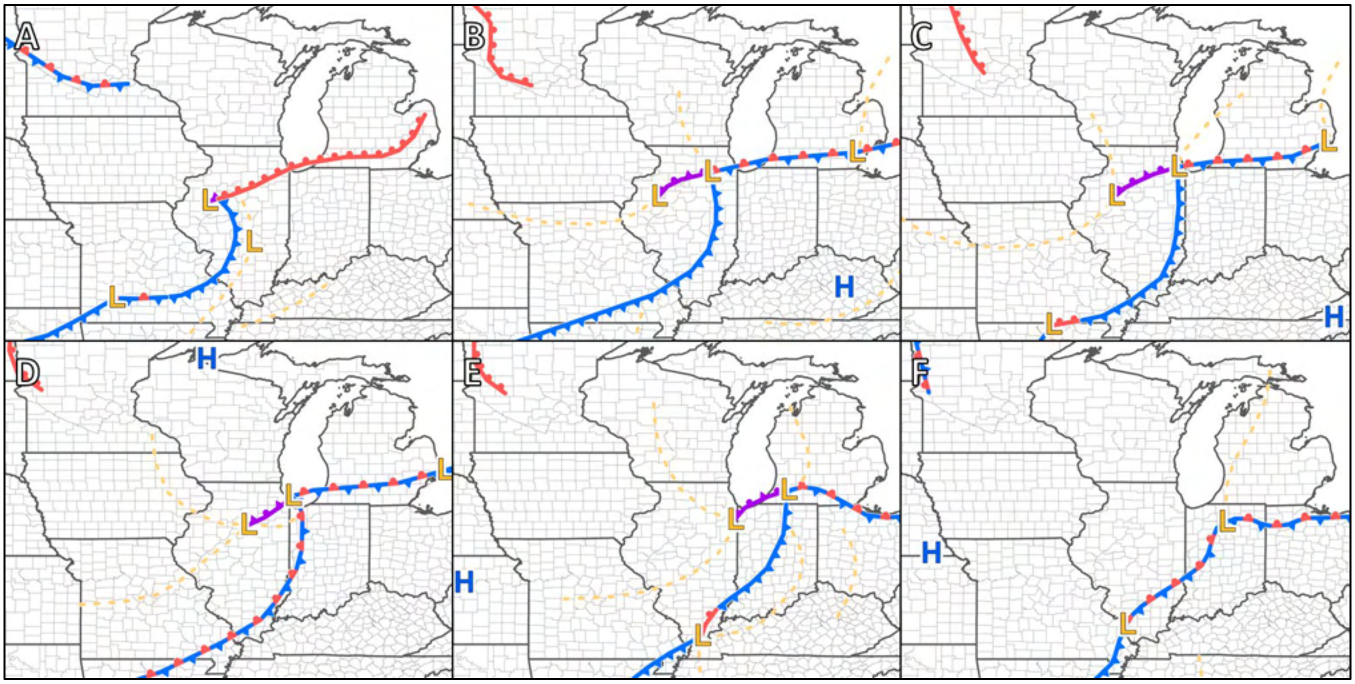

Figure 74. Surface weather maps for the 2 July 2023 rainfall event. Images are valid at 0900 UTC on 2 July (A), 1200 UTC on 2 July (B), 1500 UTC on 2 July (C), 1800 UTC on 2 July (D), 2100 on 2 July (E), and 0000 UTC on 3 July (F). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php) the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), and radar data; when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from LOT indicated an area of showers and thunderstorms forming on the north and northeast side of the MCV from approximately 1000 UTC to 1200 UTC on 2 July (Figure 75). By 1200 UTC, a line of thunderstorms was located from northern Cook County westward to northern Kane County, with slow movement to the west-southwest around the MCV as it drifted slowly toward the Chicago metro. By 1300 UTC, the line had drifted into central Cook County, impacting Chicago and suburbs to the immediate west. This was the start of a nearly 4-hour period of nearly continuous heavy rainfall across Chicago and central Cook County, until approximately 1700 UTC, with the band of rain remaining in the same general location north of the MCV as it drifted toward the Lake Michigan shore (Figure 76). From 1700 to 1900 UTC, Chicago and the immediate western suburbs experienced a brief break in the rainfall, while a new cluster of heavy showers and thunderstorms formed on the northwest side of the MCV north of Chicago. This second wave of rainfall became oriented from southwest to northeast, with slow movement to the southwest. By 1900 UTC, a nearly continuous period heavy rainfall had again reached central Cook County, continuing for approximately three hours until 2200 UTC (Figure 77). Just after 2200 UTC, radar indicated that the band of rainfall was weakening in intensity and was moving to the south of Chicago. By the evening of 2 July, the central Chicago metro area had experienced almost 18 hours of on and off rainfall from two distinct waves, more than half of which occurred during the first wave (Figure 78).

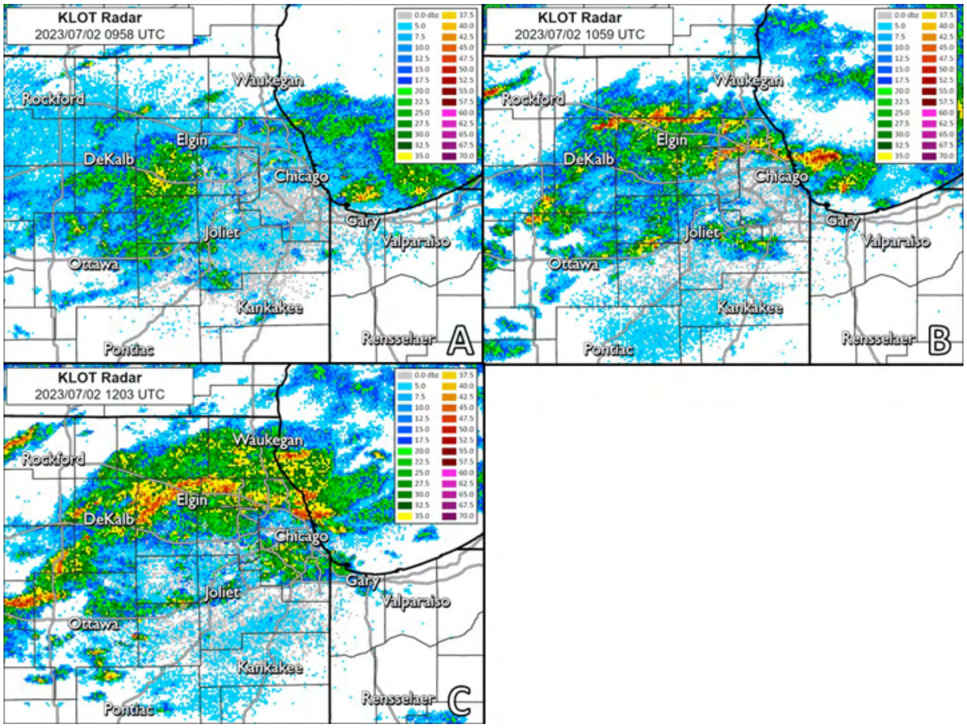

Figure 75. Radar data for the 2 July 2023 rainfall event. Images are valid at 0958 UTC on 2 July (A), 1059 UTC on 2 July (B), and 1203 UTC on 2 July (C). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

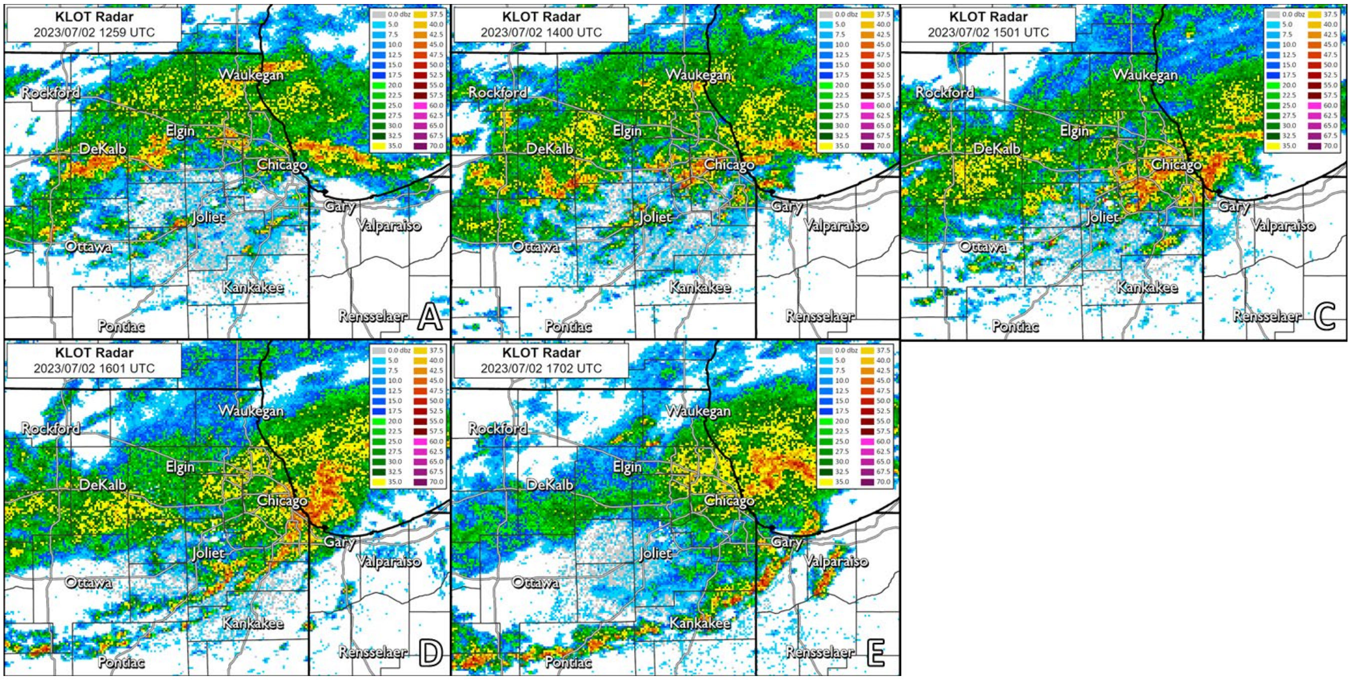

Figure 76. Radar data for the 2 July 2023 rainfall event. Images are valid at 1259 UTC on 2 July (A), 1400 UTC on 2 July (B), 1501 UTC on 2 July (C), 1601 UTC on 2 July (D), and 1702 UTC on 2 July (E). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

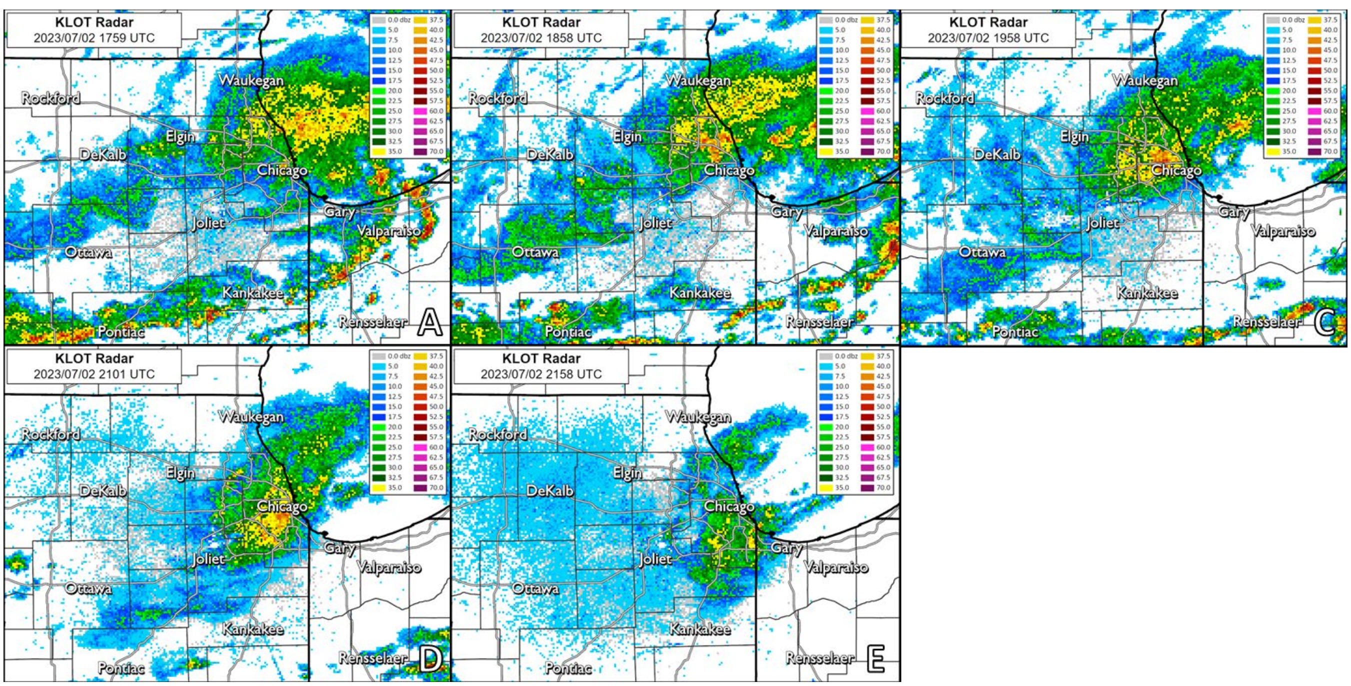

Figure 77. Radar data for the 2 July 2023 rainfall event. Images are valid at 1759 UTC on 2 July (A), 1858 UTC on 2 July (B), 1958 UTC on 2 July (C), 2101 UTC on 2 July (D), and 2158 UTC on 2 July (E). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

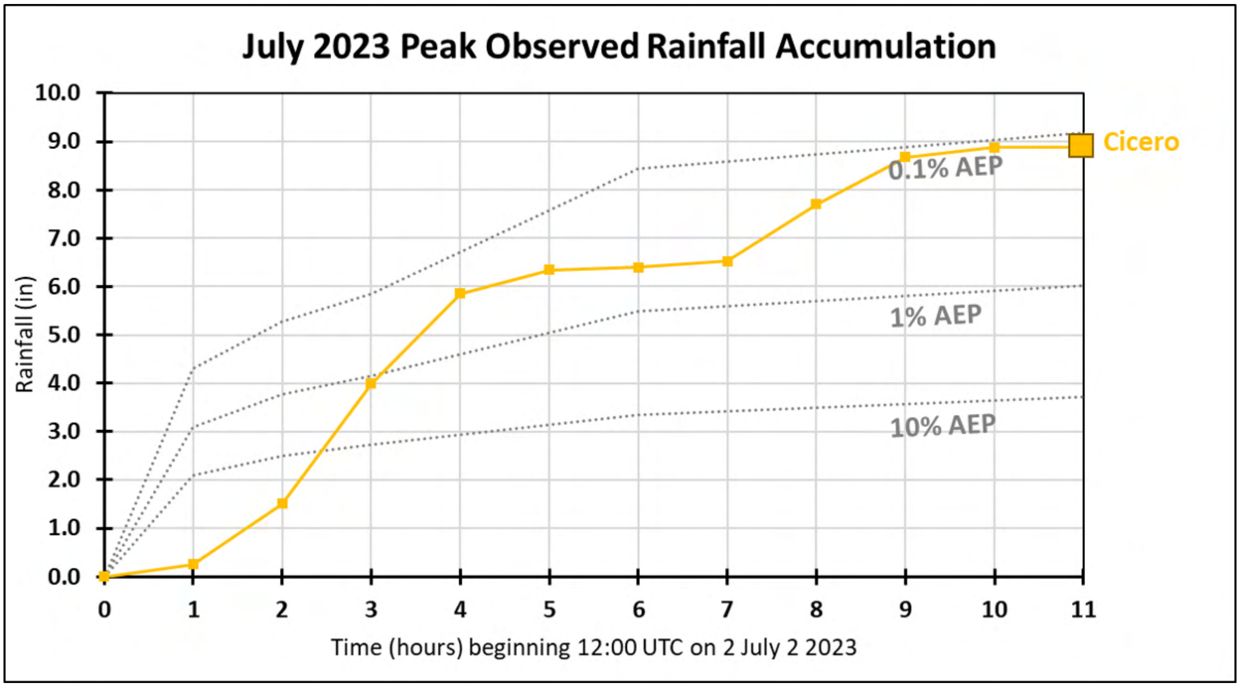

Figure 78. Running storm total rainfall for the 2 July 2023 rainfall event. The recording rain gauge with the highest storm total, a privately owned weather station in Cicero, is indicated with a yellow-orange line and square. Time on this chart begins with the first hour of measured rainfall.

September 17, 2023

On 17 September, another small, slow-moving MCV and associated cold front drifted across the Chicago metropolitan area during the morning hours into the early afternoon. At times, bands of heavy rainfall formed near this MCV, with nearly stationary storm motion. Rainfall up to 8.7 inches occurred over a 12-hour period at the southern edge of the study area in southern Cook County, Illinois, and northern Lake County, Indiana, with two distinct periods (Figure 79). The first period of rainfall occurred from approximately 1100 UTC to 1400 UTC, although the heaviest rainfall was just to the north, in central Cook County. The second period of rainfall occurred from approximately 1430 UTC to 1900 UTC. Peak storm total rainfall in the study area was analyzed as a 0.2% AEP (1-in-500 annual chance) event (Figure 80). The first period of rainfall caused generally isolated, nuisance flood impacts, while the second period of rainfall caused significant flooding, including flooding of numerous roadways and basements in the Calumet City, Burnham, Dolton, and Hammond areas (Figure 81). At the time of this report, flood damage estimates were still being tabulated, but were roughly estimated to be at least $60 million (Lincoln 2023).

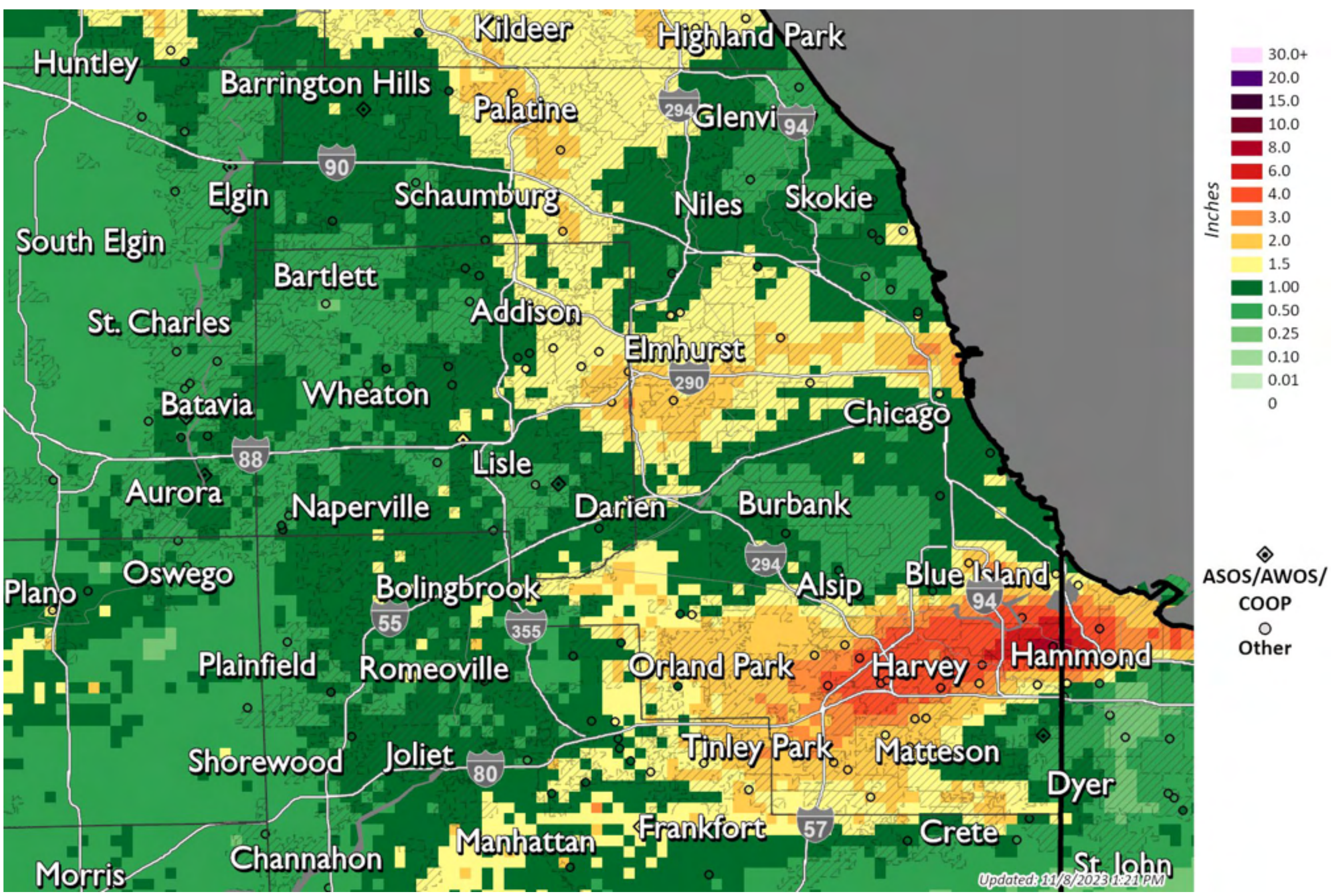

Figure 79. Storm total rainfall from 0900 UTC on 17 September to 2100 UTC on 18 September 2023.

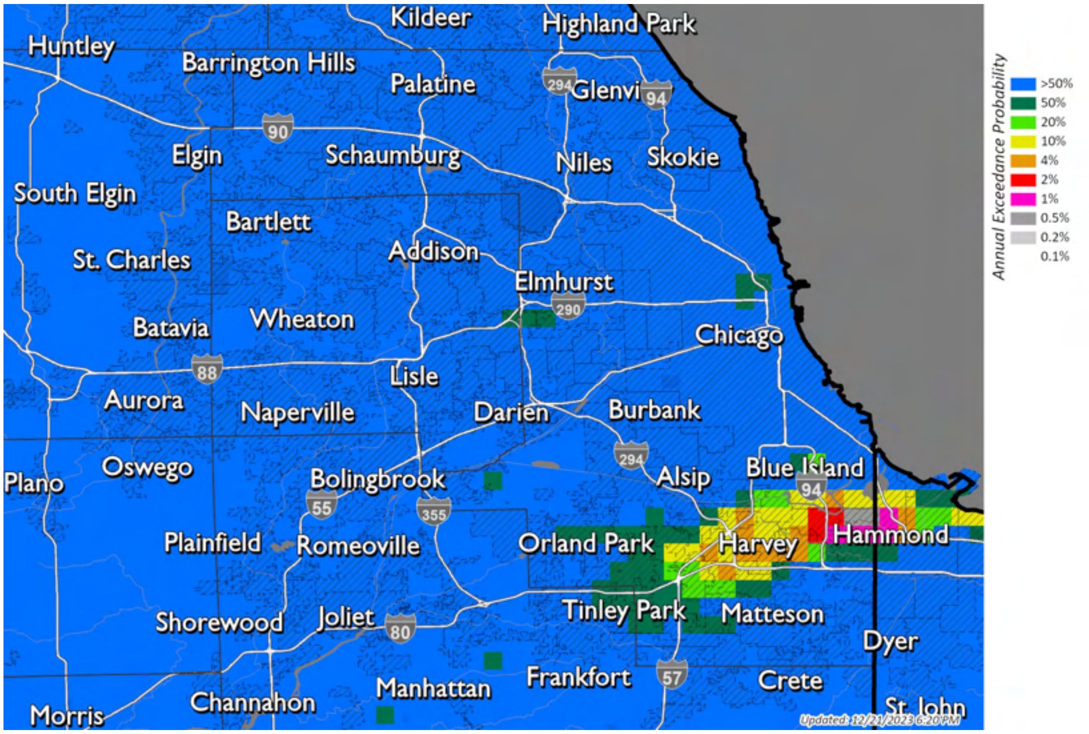

Figure 80. Annual exceedance probability for the storm total rainfall from 0900 UTC on 17 September to 2100 UTC on 18 September 2023.

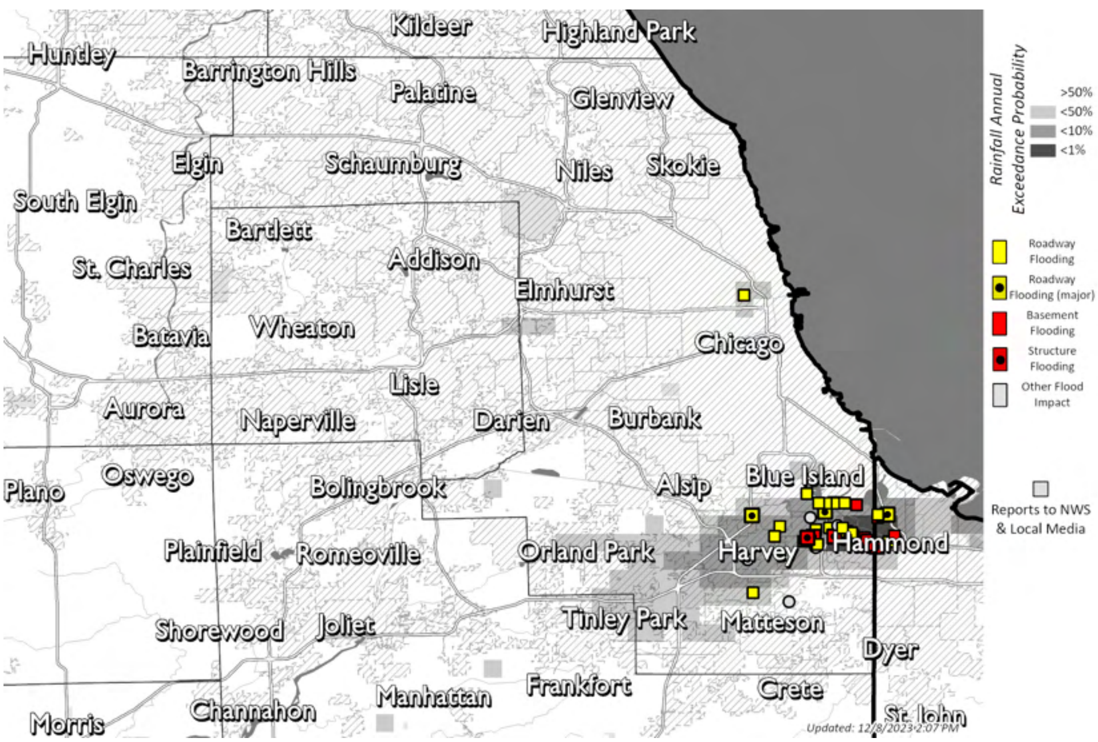

Figure 81. Known flash flood impacts for the 17 September 2023 rainfall event. Reports are generally meant to represent the worst impact from a given area and should not be assumed to include all locations impacted. Annual exceedance probability of the storm total rainfall is shown as an underlay in grayscale.

During the overnight hours of 16 September into 17 September, a weak cold front was located from southern Iowa eastward into far northern Illinois (Figure 82). Surface winds and radar-indicated motion of showers and thunderstorms suggested a possible MCV located along this front in northern Illinois, similar to the 2 July 2023 event. At 850 mb, winds were light in northern Illinois with no significant low-level jets in the region. A subtle circulation was depicted by the SPC mesoanalysis, possibly related to the surface MCV. At 500 mb, winds were also light over northern Illinois. A large ridge was evident across the western contiguous US, with a trough over the Great Lakes, near the Chicago area. From 0900 to 1200 UTC, radar data and surface winds suggested that the MCV drifted southward along the Lake Michigan shore from far northeast Illinois to just east of Chicago over western Lake Michigan, with the weak cold front passing to the southeast. Rainfall intensity increased significantly after 1200 UTC, with the heaviest band of rain located across Chicago and central Cook County, near and just to the west of the MCV. The 1200 UTC soundings from Lincoln and Davenport indicated a saturated profile only in the lowest 100 mb (approximately 1000 meters), with precipitable water values of only 0.78 inches and 0.81, respectively (Plymouth State University 2023). SPC mesoanalysis indicated a small area with slightly higher precipitable water values near 1.1 inches centered on the Chicago area, near the MCV, away from sounding locations. The MCV continued to drift slowly southward with the narrow band of heavy rainfall remaining near Chicago. At 1500 UTC, the MCV had drifted to the southern shore of Lake Michigan. The band of rainfall near the central part of Chicago had weakened, while a new, narrow band of very heavy rainfall had formed along the lake shore near the MCV. This band remained nearly stationary for the next 3-4 hours, producing significant rainfall accumulations in an isolated corridor (Figure 85).

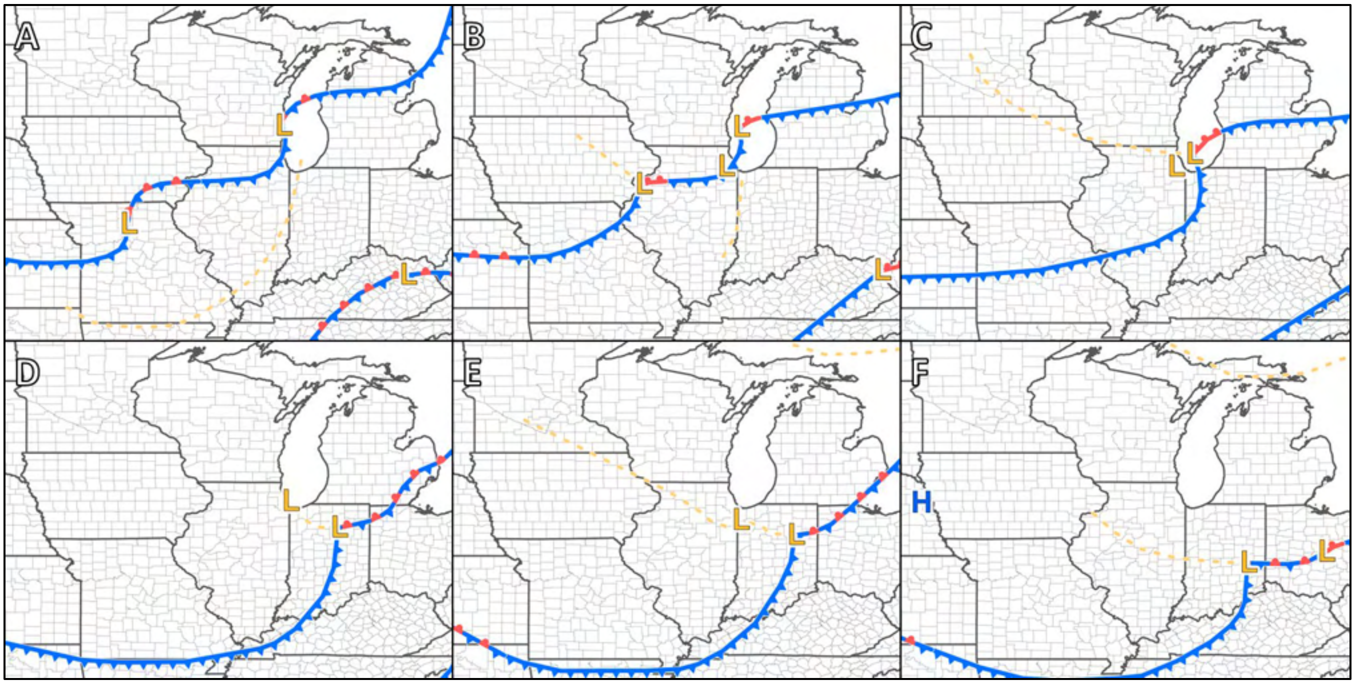

Figure 82. Surface weather maps for the 17 September 2023 rainfall event. Images are valid at 0600 UTC on 17 September (A), 0900 UTC on 17 September (B), 1200 UTC on 17 September (C), 1500 UTC on 17 September (D), 1800 UTC on 17 September (E), and 2100 UTC on 17 September (F). Surface maps created based upon data found in the Weather Prediction Center's weather map archive (https://www.wpc.ncep.noaa.gov/archives/web_pages/sfc/sfc_archive.php) the Iowa Environmental Mesonet's Midwest Mesoplot (https://mesonet.agron.iastate.edu/timemachine/#4), and radar data; when sources conflict, an attempt was made to create a consensus of surface feature locations.

Radar imagery from LOT indicated a decaying cluster of showers and thunderstorms moving into the Chicago metropolitan area overnight from 16 September to 17 September. Rainfall intensities decayed significantly by the time this activity reached Cook County. Shower and thunderstorm activity began to redevelop at approximately 0700 UTC, reaching Cook County around 0830 UTC (Figure 83). Generally light to moderate activity continued over the area for the next few hours. At 1130 UTC, radar imagery indicated a slow-moving band of showers and thunderstorms centered over central Chicago, near the MCV (Figure 84). Individual cells were moving slowly to the west, but the band was almost stationary, through 1400 UTC. At 1430 UTC, a new, narrow band of very heavy rainfall formed along the Lake Michigan shore from southern Cook County eastward into Lake County. These cells also moved slowly westward, but the band was again nearly stationary, this time for approximately 2-3 hours. Rainfall became more isolated by 1800 UTC as the MCV drifted to the southeast, with rainfall rates decreasing significantly (Figure 85).

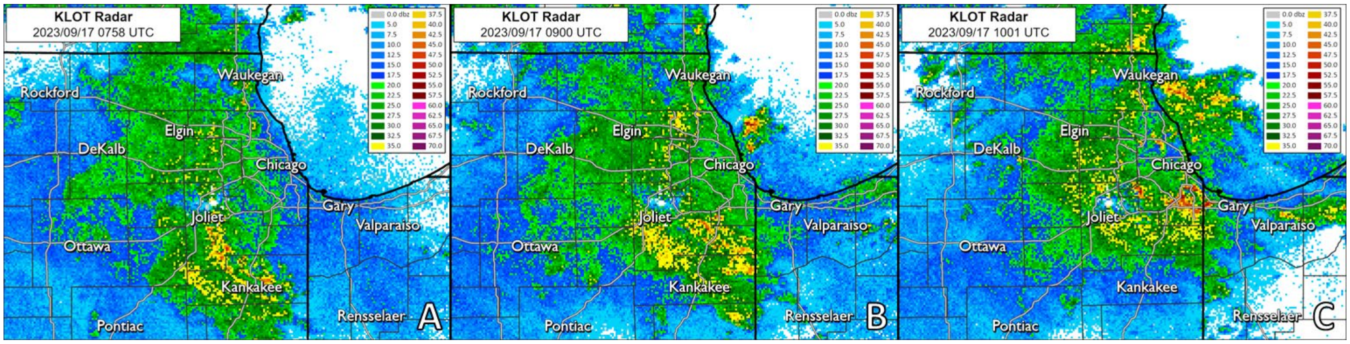

Figure 83. Radar data for the 17 September 2023 rainfall event. Images are valid at 0758 UTC on 17 September (A), 0900 UTC on 17 September (B), and 1001 UTC on 17 September (C). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

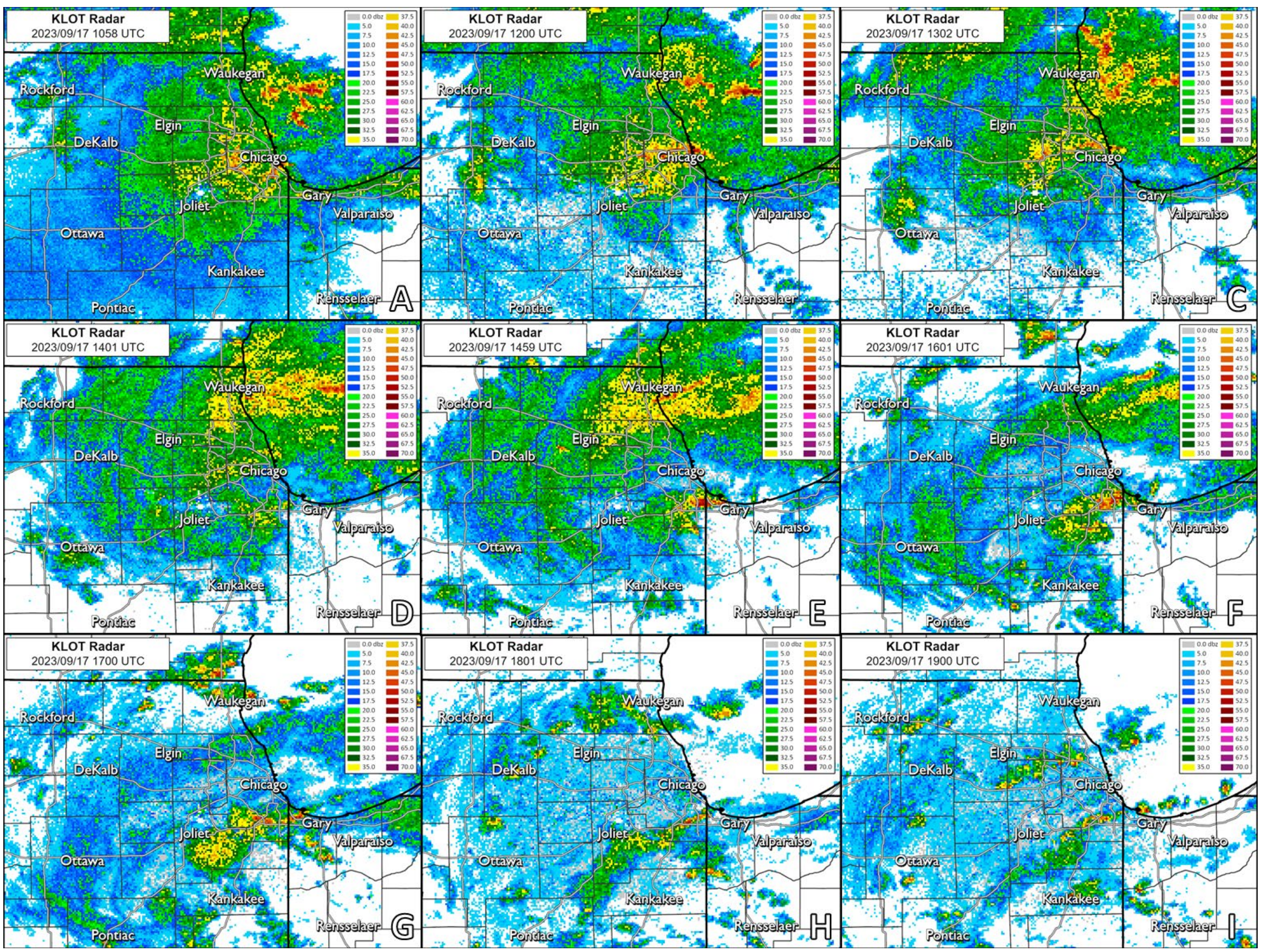

Figure 84. Radar data for the 17 September 2023 rainfall event. Images are valid at 1058 UTC on 17 September (A), 1200 UTC on 17 September (B), 1302 UTC on 17 September (C), 1401 UTC on 17 September (D), 1459 UTC on 17 September (E), 1601 UTC on 17 September (F), 1700 UTC on 17 September (G), 1801 UTC on 17 September (H), and 1900 UTC on 17 September (I). Maps were created from GIS datasets provided by the Iowa Environmental Mesonet (https://mesonet.agron.iastate.edu/GIS/radview.phtml).

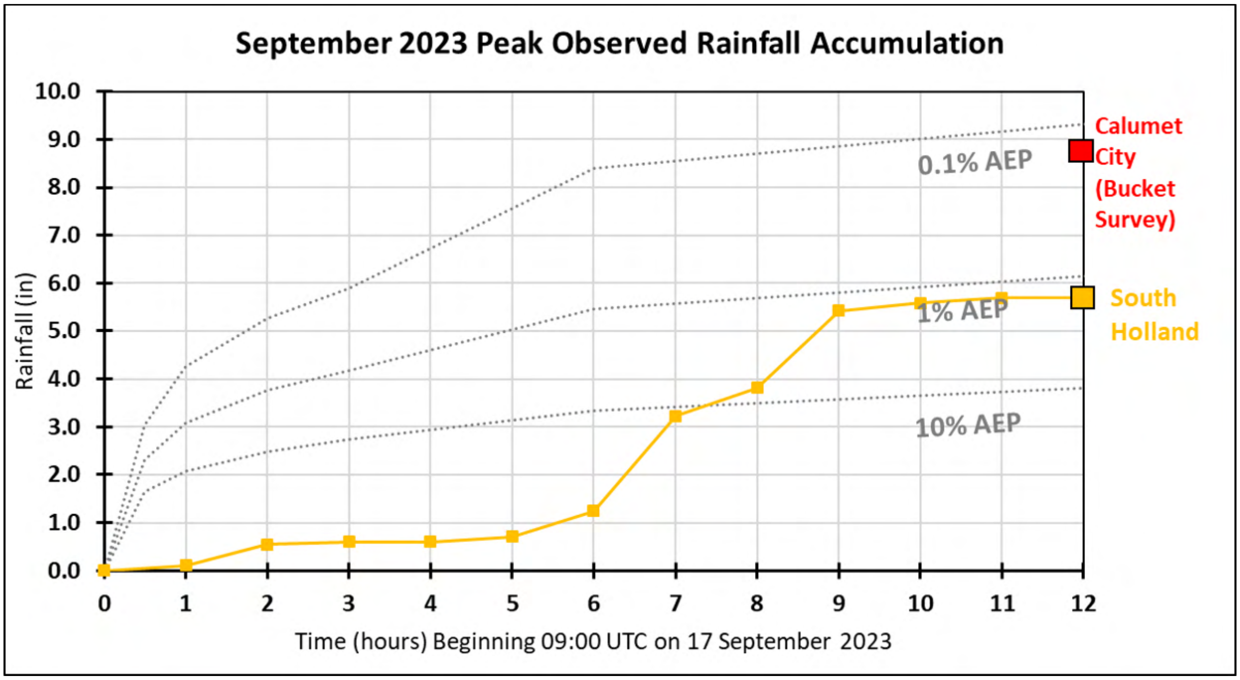

Figure 85. Running storm total rainfall for the 17 September 2023 rainfall event. The recording rain gauge with the highest storm total, the USGS rain gauge at the Little Calumet River near South Holland, is indicated with a yellow-orange line and square. The peak rainfall observation at Calumet City from the post-event bucket survey is indicated with a red square. Time on this chart begins with the first hour of measured rainfall.

Other Events

Additional extreme rainfall events may have occurred in the Chicago area since 1950, with more possible events back into the 1800s, but information is too limited for a full analysis and for preparation of detailed rainfall maps. Some of these events are known only because they caused flood impacts in and near the city, but without rainfall information from the hardest-hit areas. The source for some of these events include a review of books on Chicago area climate, such as *The Climate of Chicago* (Hazen 1893) and *The Weather and Climate of Chicago* (Cox and Armington 1914). Other events were found based upon a review of Chicago area newspaper articles. Although it is beyond the scope of this study to provide a detailed review of these events, the known information was collected summarized in the appendix.

Summary

The Chicago metropolitan area has experienced multiple extreme rainfall events since 1950, including at least eight events with storm total rainfall exceeding 7.5 inches in the study area of central Cook County. Based strictly upon the collected events with storm total rainfall greater than 7.5 inches, such an event has historically occurred in central Cook County every 2-30 years, with an average of 11 years between events. Five additional heavy rainfall events were reviewed which did not meet the storm total 7.5-inch threshold, but were classified as extreme due to AEPs <=1% over shorter durations. Including these events in the analysis would increase the rate of occurrence of extreme rain events to 1-2 per decade, or a long-term average of 6 years between events (range 0 to 11 years). The number of documented events occurring each decade has increased since the 1950s (Figure 86), and the time interval between documented events has generally decreased over that time (Figure 87). Several additional possibly extreme rainfall events occurred in the vicinity of Chicago dating back to the late 1800s, but only limited data were available to analyze these events. Not enough information is available to provide a reasonable estimate of the number of extreme rainfall events per decade prior to 1950.

Since 1950, the most common synoptic pattern associated with extreme rainfall events affecting central Cook County were the Maddox Frontal and Maddox Mesohigh patterns each with three events, followed by the Maddox Synoptic pattern, slow-moving supercell thunderstorm, and slow-moving MCV each with two events, and the remaining one event was a Predecessor Rainfall Event with tropical remnants. A summary of extreme rainfall events impacting central Cook County since 1950 is shown by Table 2. The general synoptic pattern associated with extreme rainfall events occurring prior to 1950 was not determined. Although each of the extreme rainfall events had a period of rainfall (ranging from 1 to 24 hours) which exceeded the 1% AEP defined by *NOAA Atlas 14*, other characteristics, such as sub-daily rain rate and peak rainfall location, varied widely (Table 3).

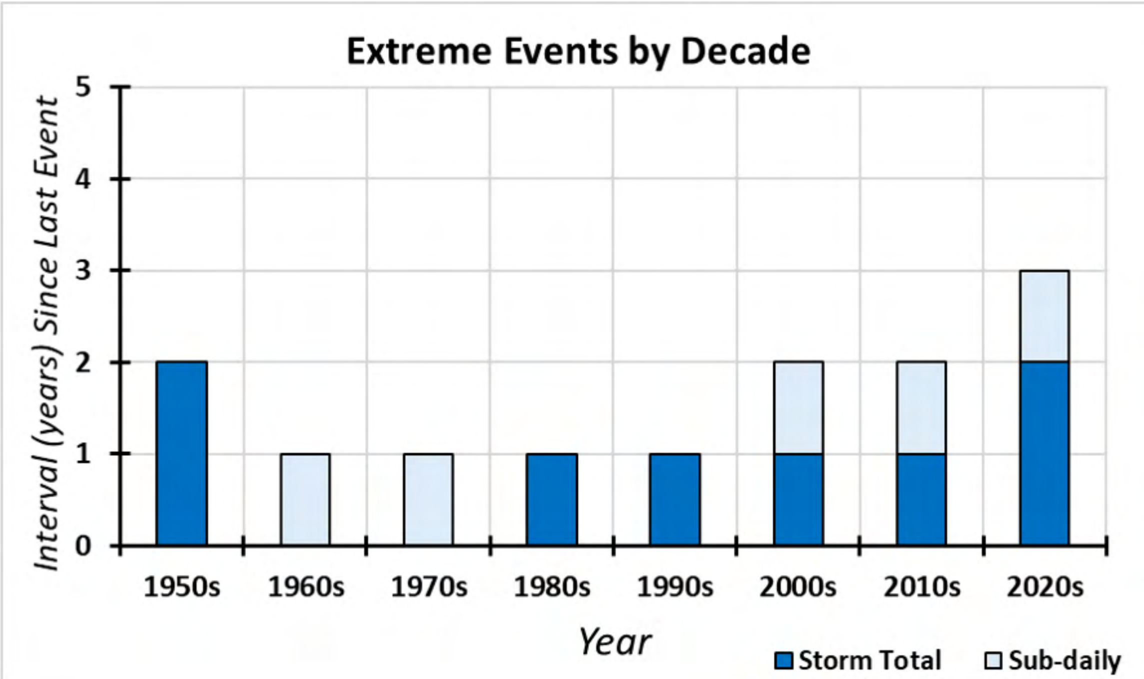

Figure 86. Count of extreme events occurring each decade, as defined by a storm total rainfall of at least 7.5 inches or by a sub-daily rainfall exceeding the 1% AEP (NOAA Atlas 14). Note that the count for “2020s” is for a partial decade.

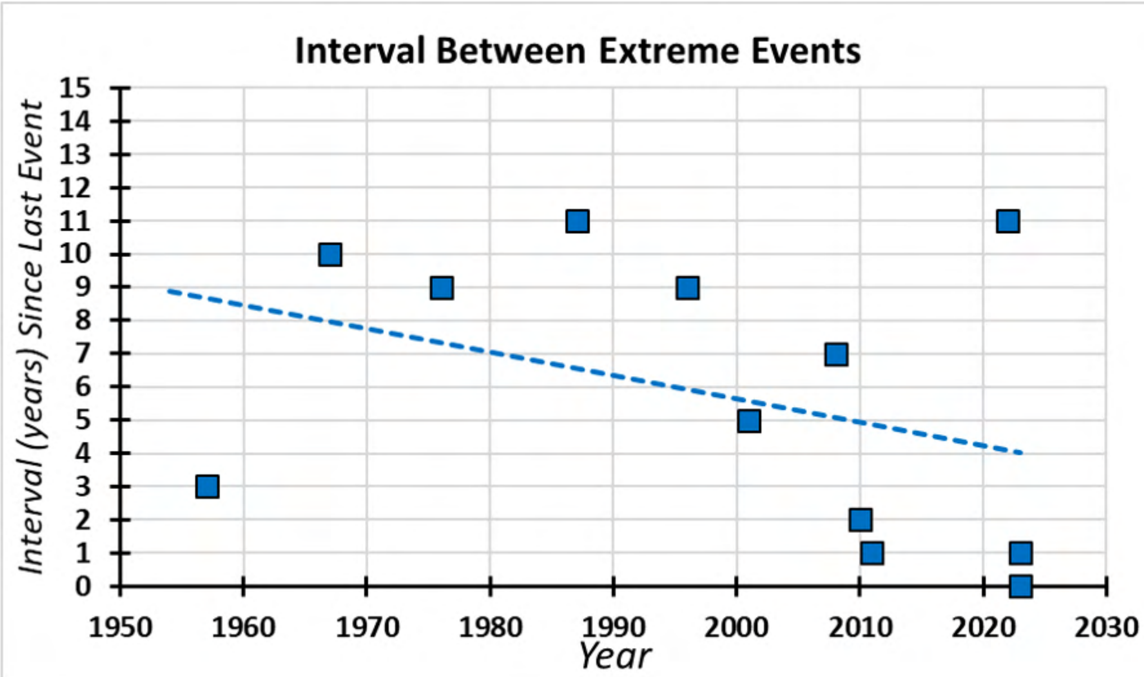

Figure 87. Interval between extreme events, as defined by a storm total rainfall of at least 7.5 inches or a shorter duration of time exceeding the 1% AEP (NOAA Atlas 14). Calculated as the number of years since the extreme event prior to the one indicated by a symbol. Dashed line indicates a simple linear regression applied to the data.

Table 2. Summary of likely synoptic weather patterns associated with extreme rainfall events impacting Chicago and vicinity since 1950. Average rainfall was calculated using the storm total gridded rainfall averaged over the study area (Figure 1). The rainfall duration includes not just the periods of highest rain rates but also light rainfall occurring both before and after. The average rainfall rate is determined by the storm total, study area average rainfall divided by the duration.

Rain Event	Type	Study Area Average Rainfall (in)	Rainfall Duration (hrs)	Average Rainfall Rate (in/hr)
October 9-11, 1954	Maddox Frontal	7.4	48	0.15
July 12-13, 1957	Maddox Mesohigh	6.9	18	0.38
June 10, 1967	Maddox Synoptic	2.1	11	0.19
June 13, 1976	Supercell thunderstorm	2.2	5	0.44
August 13-14, 1987	Maddox Synoptic	4.1	18	0.23
July 17-18, 1996	Maddox Frontal	4.8	24	0.20
August 2, 2001	Maddox Mesohigh	2.6	5	0.52
September 13-15, 2008	Predecessor Rain Event, Tropical Remnants	7.1	60	0.12
July 23-24, 2010	Maddox Mesohigh	5.6	16	0.35
July 23, 2011	Maddox Frontal	3.4	4	0.85
September 11, 2022	Supercell associated with slow-moving upper low	2.2	4	0.55
July 2, 2023	MCV	4.0	12	0.33
September 17, 2023	MCV	1.7	12	0.14

Table 3. Summary of rainfall amounts occurring over various durations from extreme rainfall events impacting Chicago and vicinity since 1950. Rainfall values are for the study area (Figure 1) only; for some events, storm total rainfall was higher outside of the study area. Peak storm total rainfall values may come from recording rain gauges, a bucket survey, or bias-corrected radar estimates. Peak 1-hr, 3-hr, 6-hr, and 12-hr rainfall amounts are valid at recording rain gauge locations only. The peak AEP values are for the entire storm duration; if a lower AEP (rarer rainfall) value occurred over a shorter time duration, it is indicated in parenthesis. Annotations in italics indicate the location and source of the indicated rainfall value. Values marked with (*) are approximate based upon limitations in source data.

Rain Event	Study Area Peak Storm Total Rainfall (in)	Peak 1-hr Rainfall (in)	Peak 2-hr Rainfall (in)	Peak 3-hr Rainfall (in)	Peak 6-hr Rainfall (in)	Peak 12-hr Rainfall (in)	Peak AEP
October 9-11, 1954	11.1 *Blue Island (Bucket survey)*	1.70 *University of Chicago (NWS gauge)*	2.25 *University of Chicago (NWS gauge)*	2.62 *Chicago Sawyer Water Plant* (MWRD gauge)	4.21 *Calumet Reclamation Plant* (MWRD gauge)	5.64 *Calumet Reclamation Plant (MWRD gauge)*	0.2%
July 12-13, 1957	9.0 *Near Evergreen Park (ILSWS analysis, source Unknown)*	2.50 *Chicago MWRD Office (MWRD gauge)*	3.33 *Chicago MWRD Office (MWRD gauge)*	4.01 *Chicago MWRD Office (MWRD gauge)*	6.47 *Chicago Mayfair Pumping Station (MWRD gauge)*	7.67 *Chicago Mayfair Pumping Station (MWRD gauge)*	0.2%
June 10, 1967	6.5 *Chicago Loop NWS Office (NWS gauge)*	3.89 *Chicago Racine Avenue Pumping Station* (MWRD gauge)	5.11 *Chicago Loop NWS Office (NWS gauge)*	5.21 *Chicago Loop NWS Office (NWS gauge)*	5.87 *Chicago Loop NWS Office (NWS gauge)*	6.09 *Chicago Loop NWS Office (NWS gauge)*	1% (Storm Total) 0.2% (2-hr)
June 13, 1976	7.0 *Near Chicago West Englewood (Fujita analysis, source unknown)*	3.18 *Chicago Midway Airport (ASOS gauge)*	4.38 *Chicago Midway Airport (ASOS gauge*	6.1 *Chicago 87th & Western* (*MWRD Gauge)*	6.1 *Chicago 87th & Western* (*MWRD Gauge)*	6.1 *Chicago 87th & Western* (*MWRD Gauge)*	0.1%
August 13-14, 1987	9.4 *Chicago O'Hare Airport (ASOS gauge)*	1.94 *Chicago O'Hare Airport (ASOS gauge)*	3.09 *Chicago O'Hare Airport (ASOS gauge)*	3.32 *Chicago O'Hare Airport (ASOS gauge)*	5.95 *Chicago O'Hare Airport (ASOS gauge)*	8.35 *Chicago O'Hare Airport (ASOS gauge)*	0.2%
July 17-18, 1996	10.9 *Near Willow Springs (Bias-corrected radar)*	1.40 *Chicago Midway Airport (ASOS gauge)*	2.60 *Chicago Midway Airport (ASOS gauge)*	4.00 *Chicago Midway Airport (ASOS gauge)*	5.30 *Chicago Midway Airport (ASOS gauge)*	6.00 *Chicago Midway Airport (ASOS gauge)*	0.5%
August 2, 2001	4.8 *Chicago Bridgeport (ILSWS gauge)*	3.22 *Chicago Bridgeport (ILSWS gauge)*	4.20 *Chicago Bridgeport (ILSWS gauge)*	4.69 *Chicago Bridgeport (ILSWS gauge)*	4.80 *Chicago Bridgeport (ILSWS gauge)*	4.80 *Chicago Bridgeport (ILSWS gauge)*	0.5%

Rain Event	Study Area Peak Storm Total Rainfall (in)	Peak 1-hr Rainfall (in)	Peak 2-hr Rainfall (in)	Peak 3-hr Rainfall (in)	Peak 6-hr Rainfall (in)	Peak 12-hr Rainfall (in)	Peak AEP
September 13-15, 2008	9.2 *Evanston* *(Bias-corrected radar)*	1.22 *Chicago O'Hare Airport* *(ASOS gauge)*	2.04 *Chicago O'Hare Airport* *(ASOS gauge)*	2.14 *Chicago O'Hare Airport* *(ASOS gauge)*	4.04 *Chicago O'Hare Airport* *(ASOS gauge)*	6.03 *Chicago O'Hare Airport* *(ASOS gauge)*	0.5%
July 23-24, 2010	10.1 *Chicago Bridgeport* *(ILSWS gauge)*	1.66 *Chicago O'Hare Airport* *(ASOS gauge)*	2.54 *Chicago O'Hare Airport* *(ASOS gauge)*	5.0* *Westchester Brezina Woods* *(ILSWS gauge)*	7.0* *Chicago Bridgeport* *(ILSWS gauge)*	9.0* *Chicago Bridgeport* *(ILSWS gauge)*	0.5% (Storm Total) 0.2% (12-hr)
July 23, 2011	7.6 *Near Chicago O'Hare Airport* *(Bias-corrected radar)*	3.03 *Chicago O'Hare Airport* *(ASOS gauge)*	5.63 *Chicago O'Hare Airport* *(ASOS gauge)*	6.79 *Chicago O'Hare Airport* *(ASOS gauge)*	6.91 *Chicago O'Hare Airport* *(ASOS gauge)*	6.92 *Chicago O'Hare Airport* *(ASOS gauge)*	0.1%
September 11, 2022	6.4 *Chicago Lincoln Square* *(Privately-owned gauge)*	3.64 *Chicago Dunning* *(Privately-owned gauge)*	4.72 *Chicago Dunning* *(Privately-owned gauge)*	5.11 *Chicago Dunning* *(Privately-owned gauge)*	5.32 *Chicago Dunning* *(Privately-owned gauge)*	6.38 *Chicago Dunning* *(Privately-owned gauge)*	2% (Storm Total) 0.5% (3-hr)
July 2, 2023	9.0 *Cicero* *(Privately-owned gauge)*	2.57 *Cicero* *(Privately-owned gauge)*	4.60 *Cicero* *(Privately-owned gauge)*	5.60 *Cicero* *(Privately-owned gauge)*	6.40 *Cicero* *(Privately-owned gauge)*	8.89 *Cicero* *(Privately-owned gauge)*	0.2%
September 17, 2023	8.8 *Calumet City* *(Bucket survey)*	2.21 *O'Brien Lock & Dam* *(USACE gauge)*	3.20 *O'Brien Lock & Dam* *(USACE gauge)*	4.18 *South Holland* *(USGS gauge)*	4.98 *South Holland* *(USGS gauge)*	5.69 *South Holland* *(USGS gauge)*	0.2%

3.2 Changes to the Rainfall Distribution at Chicago

Although not enough data were available to perform detailed analysis of individual heavy rainfall events prior to 1950, a continuous record of daily weather observations from a single point location allows for comparison of precipitation frequency for different periods of time. Significant changes were noted between the precipitation distribution occurring during the 1871-1930 period and the 1960-2020 period (Figure 88). These changes were most notable at the extreme end of the rainfall distribution (highest ARIs or lowest AEPs). The calculated precipitation frequency information was generally similar to values published in *NOAA Atlas 14* and ILSWS Bulletin 75, despite higher uncertainty and several limitations with the simple calculation provided for this study. The significant difference between the 1871-1930 and 1960-2020 periods suggests that changes have occurred to Chicago's rainfall over approximately the last century and are consistent with other studies that suggest rainfall will increase in the Midwest states due to a warming climate, as well as studies indicated that changes have already occurred[1]. These changes could have serious implications for infrastructure and the built environment of Chicago. For example, if the 1% AEP (100-year ARI) 1-day rainfall was used as an engineering threshold for stormwater projects in Chicago, it can be estimated that this has changed from 5.2 inches to 7.4 inches over about the last century, and stormwater infrastructure that has not been improved over that period will no longer provide the same level of service.

The calculated rainfall frequency distributions were also used to estimate the changes in AEP/ARI for set 1-day and 2-day rainfall amounts (Table 4 and Table 5). Information collected from recent heavy rainfall events in Chicago, for example, has indicated that approximately 3.0 inches of rainfall in 24 hours generally causes the Chicago River to reach flood stage during situations where no additional stormwater storage is available. Such an event previously had approximately a 17% chance of occurring in a given year but now has approximately a 40% chance of occurring in a given year. For a 5.2-inch rainfall, a 1-day rainfall with a 1% chance of occurring in a given year during the 1871-1930 period, the AEP increased to 7% for the 1961-2020 period. A review of 1-day and 2-day rainfall accumulations exceeding certain thresholds appears consistent with the noted climatic changes to the rainfall distribution (Table 6 and Table 7). For example, after a single 2-day rainfall event exceeding 5.0 inches in the 1870s, no such event occurred for seven decades until the 1950s, after which these events began to occur at least every other decade.

[1] NOAA Technical Paper 40 (Hershfield 1961), using data from the early 1900s to 1958, indicated a 24-hour, 1% AEP precipitation event as 6.0 inches in Chicago, ILSWS Bulletin 70 (Angel and Huff 1989), using data from 1901 to 1983, indicated 7.6 inches, and ILSWS Bulletin 75 (Angel and Markus 2020), using data from 1948 to 2017, indicated 8.5 inches.

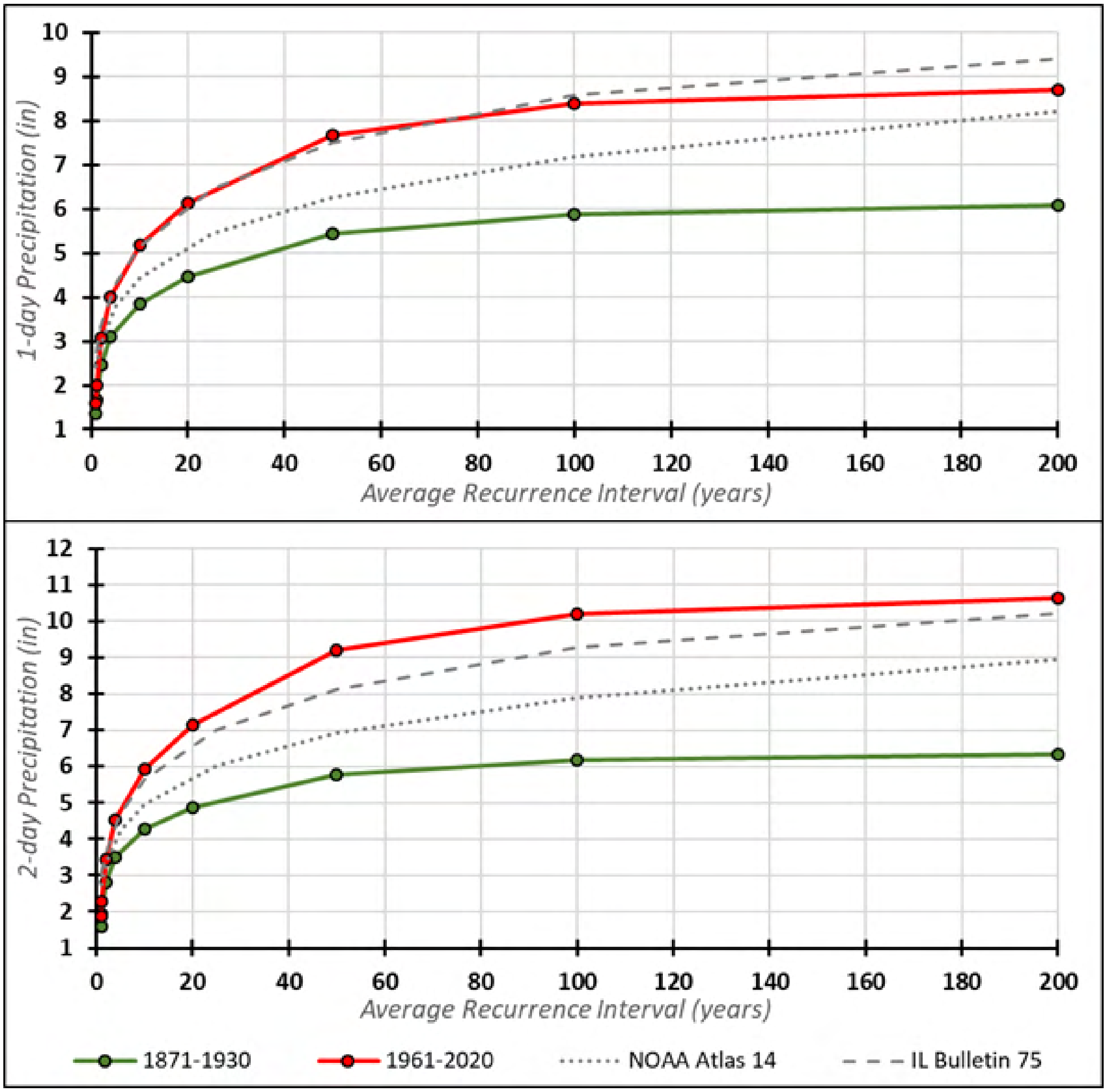

Figure 88. Rainfall frequency curves for the 1871-1930 and 1961-2020 periods calculated from 1-day (top) and 2-day (bottom) precipitation records at the official Chicago observing stations. For comparison, rainfall frequency data from *NOAA Atlas 14* added as a dotted gray line.

Table 4. Comparison of AEPs and ARIs for a given 1-day precipitation value between the 1871-1930 period and the 1961-2020 period.

1-Day Rainfall (inches)	1871-1930 ARI (years) / AEP (%)	1961-2020 ARI (years) / AEP (%)
1.0	1.0 / 100%	1.0 / 100%
2.0	1.5 / 67%	1.0 / 100%
3.0	3.5 / 29%	2.0 / 50%
4.0	12 / 8%	4.0 / 25%
6.0	160 / 0.6%	19 / 5%
8.0	>500 / <0.2%	71 / 1.4%
10.0	>500 / <0.2%	500 / 0.2%

Table 5. Comparison of AEPs and ARIs for a given 2-day precipitation value between the 1871-1930 period and the 1961-2020 period.

2-Day Rainfall (inches)	1871-1930 ARI (years) / AEP (%)	1961-2020 ARI (years) / AEP (%)
2.0	1.1 / 91%	1 / 100%
3.0	1.5 / 67%	2.1 / 48%
4.0	8 / 13%	3.0 / 33%
5.0	25 / 4%	6 / 17%
6.0	80 / 1.3%	11 / 9%
8.0	>500 / <0.2%	32 / 3%
10.0	>500 / <0.2%	90 / 1.1%
12.0	>500 / <0.2%	500 / 0.2%

Table 6. Count of 1-day rainfall accumulations exceeding the indicated threshold at the official Chicago climate site. Counts are based upon the 24-hr period corresponding with the calendar day (midnight to midnight) and not a moving observation window. Values for the incomplete decade beginning in 2020 are provided for general comparison.

Decade	>= 2.0 inches	>= 3.0 inches	>= 4.0 inches	>= 5.0 inches	>= 6.0 inches
1870	13	2	1	0	0
1880	9	4	1	1	0
1890	7	1	0	0	0
1900	7	1	0	0	0
1910	3	0	0	0	0
1920	12	3	0	0	0
1930	7	0	0	0	0
1940	19	4	2	1	1
1950	19	4	2	1	1
1960	14	4	1	0	0
1970	17	4	1	0	0
1980	18	5	2	1	1
1990	12	2	0	0	0
2000	17	5	3	1	1
2010	16	4	2	1	1
2020	*3*	*3*	*0*	*0*	*0*

Table 7. Count of 2-day rainfall accumulations exceeding the indicated threshold at the official Chicago climate site. Counts are based upon two consecutive 24-hr periods corresponding with the calendar day (midnight to midnight) and not a moving observation window. Values for the incomplete decade beginning in 2020 are provided for general comparison.

Decade	>= 3.0 inches	>= 4.0 inches	>= 5.0 inches	>= 6.0 inches	>= 7.0 inches
1870	4	2	1	1	0
1880	8	1	0	0	0
1890	5	1	0	0	0
1900	1	1	0	0	0
1910	1	0	0	0	0
1920	6	1	0	0	0
1930	2	0	0	0	0
1940	2	2	0	0	0
1950	8	3	2	2	0
1960	7	3	1	0	0
1970	6	2	0	0	0
1980	7	3	1	1	0
1990	6	1	0	0	0
2000	8	5	1	1	1
2010	8	4	3	2	1
2020	*3*	*1*	*0*	*0*	*0*

There are a few sources of uncertainty associated with the simple precipitation frequency calculation performed for this study. The 1-day and 2-day precipitation amounts were calculated from daily data rather than accumulated hourly data, which introduces a fixed-interval bias. Although a correction factor was applied to both the calculated 1-day and 2-day precipitation frequency distributions, such correction factors have limitations and theoretically may vary based upon the data time step end points (for example, 1200 UTC or local midnight) as well as a region's temporal characteristics of rainfall. Uncertainty may also be introduced because the official Chicago observation location has not remained stationary. The observing location was in the Chicago Loop from 1871-1926, at the University of Chicago from 1926-1942, at Midway airport from 1942-1980, and at O'Hare Airport from 1980 to present. It is not expected that these site moves contributed significantly to trends in rainfall, but quantifying possible impacts is beyond the scope of this study. Equipment used for measuring rainfall has also changed through the period of record. The possible contributions of changing equipment to the differences noted in the rainfall distribution are also beyond the scope of this study.

4.0 Conclusions

Although very rare for any given location, extreme rainfall events such as what occurred on 2 July and 17 September 2023 are not unprecedented for Chicago and vicinity. Using a 7.5-inch storm total accumulation as a threshold, the 1% AEP for a 1-day event according to *NOAA Atlas 14*, eight extreme rainfall events were identified back to 1950. Five events were identified with a lower storm total rainfall amount, but shorter-duration rainfall intensities nearing the 1% AEP. Of these 13 events which have impacted the Chicago area, three events were similar to the Maddox Frontal and Maddox Mesohigh patterns, followed by the Maddox Synoptic pattern, slow-moving supercell thunderstorm, and slow-moving MCV each with two events, and the remaining one event a Predecessor Rainfall Event with tropical remnants. Prior to 1950, numerous impactful flood events occurred in and near Chicago, with rainfall amounts that were potentially extreme. Based upon past events, extreme rainfall events are estimated to occur in the vicinity of Chicago about 1-2 times per decade. An analysis of the precipitation record for the city of Chicago also indicates potentially significant changes in the distribution of rainfall amounts, with the biggest changes occurring with larger values. For a 5.2-inch rainfall, the estimated 1% AEP for a 1-day event during the 1871-1930 period, the AEP was estimated to be 7% for the 1961-2020 period, a significant increase. While these calculations are subject to uncertainty, the significant difference in rainfall frequency over the last century has multiple potential implications for flash flood impacts and stormwater infrastructure design in the Chicago area.

Acknowledgements

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Appendix A

Additional potentially extreme rainfall events have occurred in the Chicago area, but were not included in this study either because they occurred prior to 1950 or because available data was too limited for detailed analysis. The known information for these events is summarized in Table 1. Note that some historical flood events make reference to "Mud Lake"; Mud Lake was once located in southwestern portions of modern-day Chicago between the Des Plaines and Chicago rivers and allowed for a hydrologic path for water to move between watersheds during floods, but no longer exists.

Table 1. A summary of notable heavy rainfall and flooding events occurring in Chicago. Events either occurred prior to 1950 or had only limited available information, which precluded their usage in this study.

Date	Description of Event
2-3 April 1877	Portions of southwestern Chicago flooded, the Chicago River was elevated, and flooding occurred along the Des Plaines River and Mud Lake (Hazen 1893).
25-26 July 1878	Storm total rainfall of 4.1 inches, most fell in 3 hours from 11:30 PM to 2:30 AM. Multiple roads washed out and multiple basements flooded (Hazen 1893).
September 25 1878	Very intense, short-duration storm occurred over about 10-15 minutes with 0.97 inches storm total and 0.92 inches in the 8 minutes ending at 11:38 AM. A few streets flooded and sewers at capacity (Hazen 1893).
25 May 1879	Heavy rainfall occurred from 1:00 AM to 6:30 AM, with 2.52 inches storm total. Hundreds of basements flooded in southern and western portions of Chicago (Hazen 1893).
21 April 1881	Portions of southwestern Chicago flooded, Chicago River became elevated, and flooding occurred along the Des Plaines River and Mud Lake (Hazen 1893).
11 November 1881	Heavy rainfall occurred from 5:15 AM to 10:15 PM, with storm total of 3.2 inches. Some minor flooding occurred in low-lying portions of Chicago (Hazen 1893).
2-3 August 1885	Rainfall of 5.63 inches occurred over 19 hours from approximately 2:00 AM to 7:00 PM, and 6.36 inches occurred over the entire 2-day period. Numerous structures were flooded, including the Chicago Opera House, and there was widespread flooding of roadways across Chicago and vicinity (Chicago Daily Tribune 1885). This event was a major contributor to the monthly record rainfall of 11.28 inches for August of 1885 (Cox and Armington 1914). Record stood until October 1954, and as of 2023 is 6th highest monthly total.
18-19 July 1889	Intense short-duration storm from 11:43 PM to 12:50 AM on 19 July caused 1.65 inches storm total, with 0.8 inches of rainfall in 10 minutes ending at 11:58 PM (Hazen 1893). Flooding of a few streets and basements occurred (Chicago Daily Tribune 1889).
27-28 July 1889	Heavy rainfall occurred over approximately 3.5 hours ending at 10:40 PM with at least 4.0 inches storm total (observer indicated that the gauge overflowed). The most intense rainfall occurred around two intense periods with 0.4 inches between 7:25 PM and 7:33 PM, and 0.3 inches between 7:44 PM and 7:49 PM. Widespread flooding of roadways and basements was reported across the city (Chicago Daily Tribune 1889), and combined damage costs from rainfall, hail, and wind estimated at $1 million (approx. $33 million today), with multiple fatalities due to building collapses (Hazen 1893).

19-20 December 1895	Rainfall of 2.7 inches occurred in 1 day, 4.3 inches was observed in 2 days, and 5.4 inches was observed in 3 days. Widespread flooding of roadways, railroads, and structures in Chicago and neighboring towns was reported (Chicago Daily Tribune 1895). Widespread flooding of nearby prairies and streams also occurred. Due to pollution in the Chicago River being diverted into Lake Michigan, the city's water supply was threatened (Chicago Daily Tribune 1895).
11-12 August 1908	Multiple waves of heavy rainfall were recorded, with notably heavy period occurring from 9:40 PM to 10:05 PM on 11 August, where approximately 1 inch was recorded (Chicago Daily Tribune 1908). By 7:00 AM, 3.3 inches was recorded. The storm total rainfall occurred over an approximately 21-hour period ending at 6:00 PM on 12 August, with 4.35 inches observed (Chicago Daily Tribune 1908). Numerous basements were flooded across the city. Newspaper accounts of the time reported that this was the heaviest rain event in 23 years.
14 August 1909	A heavy thunderstorm caused 3.46 inches of rainfall over a 4-hour period ending at 9:00 AM (Chicago Daily Tribune 1909). Additional rainfall later in the day on 14 August brought the 2-day accumulation to 3.9 inches. Two flood fatalities were reported, and hundreds of basements flooded across Chicago.
5 August 1924	A heavy thunderstorm impacted Chicago from approximately 5:00 PM to 8:00 PM, with 1.4 inches of rainfall observed at the Chicago Loop (Chicago Daily Tribune 1924). Widespread flooding of roadways and basements was reported, with the worst impacts in the north and northwest portions of the city. Anecdotal reports suggest an additional "several inches" occurred in the hardest hit areas away from the Chicago Loop. Chicago was impacted by additional on and off waves of storms over the following two days (Chicago Daily Tribune 1924), with a 1-day rainfall of 2.7 inches, 2-day rainfall of 4.1 inches, and a 3-day rainfall of 5.1 inches.
11-13 June 1926	Multiple waves of heavy rainfall occurred over an approximately 3-day period. At the University of Chicago, 1-day rainfall was 3.0 inches, and the 3-day rainfall was 5.3 inches. Rainfall was potentially much higher just to the southwest of the city, as Joliet reported 9.0 inches over the same 3-day period (Chicago Daily Tribune 1926).
20-21 June 1928	Heavy rainfall occurred during the evening rush hour on 20 June, with 2.71 inches observed in less than one hour at the University of Chicago. Hundreds of basements were flooded and numerous underpasses were inundated throughout the city (Chicago Daily Tribune 1928). Newspaper accounts suggest that the southwest part of Chicago experienced the worst flooding. Multiple waves of additional rainfall occurred over the next several days. Another heavy thunderstorm occurred on 24 June, with 1.42 inches in 2 hours ending at 8:00 PM. 1500 basements flooded, numerous underpasses flooded, and impacts to transit services were noted (Chicago Daily Tribune 1928).
31 March 1929	Rainfall of 3.1 inches was recorded at the University of Chicago and 2.5 inches at Midway Airport, most of which may have occurred during an afternoon thunderstorm (Chicago Daily Tribune 1929). Several roadway underpasses were flooded and some basements were flooded.
2 August 1929	Rainfall of 1.7 inches was recorded at the University of Chicago and 1.1 inches at Midway Airport, with unofficial estimates of rainfall up to 3.5 inches, during the afternoon through late evening hours. Basements and underpasses were flooded in parts of the city (Chicago Tribune 1929). Unofficial reports of rainfall estimated up to 3.5 inches.

11 August 1931	Rainfall of 3.9 inches was recorded at the University of Chicago in approximately 10 hours ending at 8:00 AM, with 2.5 inches observed at Midway Airport. At the time, the storm was the 3rd heaviest on record for Chicago and the heaviest since 1885. Reported flood impacts were relatively minor, with a few basements flooded and several cars stalled along flooded roadways (Chicago Daily Tribune 1931).
12 May 1935	Rainfall of 2.7 inches was recorded at the University of Chicago over a 1-day period ending at 10:00 AM, with 2.0 inches of rainfall at Midway Airport. Most of this rainfall occurred during the overnight hours. Approximately 0.5 inches fell later in the day from an additional round of rainfall, bringing the 2-day total to 3.36 inches (Chicago Daily Tribune 1935). At the time, this was the second highest daily rainfall and the highest 2-day rainfall occurring during the month of May. Almost all underpasses were flooded in the city, and at least 4500 basements were flooded (Chicago Daily Tribune 1935). A rise of water level on the Chicago River was also reported.
1 July 1938	Very heavy, localized rainfall occurred in far northern Chicago and northern suburbs. At the University of Chicago, only 0.68 inches was observed during the 1-day period ending at 7:00 AM, while 4.01 inches was recorded over the same period of time in Evanston (Chicago Daily Tribune 1938). Multiple roadways and railroads were flooded, some damaged, and damage to agriculture in just northern Cook County was estimated at approximately $1 million (approximately $23 million in 2023). A few buildings were also flooded just north of the Chicago city limits.
6 July 1943	An intense, short-duration storm impacted Chicago from 12:03 PM to 5:32 PM, with 3.92 inches of rainfall observed at Midway Airport (official observation station), 2.8 inches observed at the University of Chicago, 4.7 inches observed at the Howard Street Plant (today's MWRD O'Brien Water Reclamation Plant), 3.7 inches observed at the West Side Plant (today's Stickney), and 2.5 inches observed at the Calumet Plant. A peak rainfall rate of about 2 inches per hour was observed, with Midway Airport recording 1.5 hours, 3.33 inches in 2 hours, and 3.82 inches in 3 hours. The Howard Street Plant recorded 4.7 inches in 2 hours. Widespread flooding of roadways and underpasses was reported, including disruption of transit services (Chicago Daily Tribune 1943). A significant rise of water level on the Chicago River was also reported.
4-5 April 1947	Widespread heavy rainfall occurred across the central and southern Chicago metro area. Storm total rainfall ranged from 2.5 inches just to the northwest of Chicago to 5.1 inches just to the south of Chicago. The band of heaviest rainfall likely occurred from the western suburbs through the southern suburbs and the southern half of Chicago, where 4-5 inches was widespread. Little information is available about the rainfall duration or intensity, but 1.0 inch of rainfall was observed at Midway Airport between 11:14 PM and 12:30 AM on 5 April, 3.55 inches occurred over a 13-hour period, and the remainder of the rainfall likely occurred prior to 6:00 PM (Chicago Daily Tribune 1947). Almost 9000 basements were flooded, a few highways were flooded, a few railroad lines were flooded, and numerous underpasses were flooded. Some flooding continued for at least 2 days (Chicago Daily Tribune 1947). A rise of water level on the Chicago River was also reported.
6 July 1947	Heavy, localized rainfall occurred over western and southwestern portions of Chicago. At Midway Airport, 2.6 inches was observed over a 3-hour period, while just 0.7 inches was observed at the University of Chicago. Rainfall observations from across the Chicago metro area were highly variable and ranged from 0.0 inches to 2.6 inches. Only a few underpasses

	were reported to be flooded, with flood impacts possibly mitigated by previous dry weather (Chicago Daily Tribune 1947).
16 July 1950	Rainfall of 1.5-5.4 inches observed across the city, but almost all sites recorded less than 4 inches. Only 2.5 inches recorded at the official observing station (Midway Airport) and only 1.9 inches were recorded at the Chicago Loop. Most rainfall occurred over a 6-hour period (Huff and Vogel 1976). Highest rainfall generally occurred across southern portion of Chicago where several underpasses flooded and minor impacts to mass transit services were reported (Chicago Daily Tribune 1950).
25-26 June 1959	Rainfall ranged from just under 1 inch to 4.7 inches. Highest rainfall occurred near the southwest side of Chicago. Midway Airport recorded 0.66 inches in 15 minutes ending at 9:30 PM, 3.9 inches in 2 hours ending at approximately 12:00 AM on 26 June, and 4.55 inches in 3 hours (Chicago Daily Tribune 1959). It was also reported that 5.0 inches were observed over a 6-hour period and 5.4 inches were observed over a 12-hour period (Huff and Vogel 1976), which may have occurred elsewhere in the city. Thousands of basements flooded, widespread roadway flooding occurred, a communications office at Midway Airport flooded which shut down flights, flooding occurred at the Chicago traffic courts building, and impacts to transit services occurred.
14 September 1961	Rainfall ranged from 5.0 to 6.7 inches across Chicago and central Cook County, occurring over multiple waves of rainfall during a 3-day period as the remnants of Hurricane Carla moved across the region. The final wave of rainfall occurred overnight from 13 September into 14 September, with 2.4 to 3.5 inches occurring over an 8-hour period ending at 3:00 AM. This rainfall, combined with elevated soil moisture from previous rainfall, caused flooding in the Chicago area. Multiple homes experienced basement flooding in Chicago, with multiple reports of roadways, expressways, and underpasses flooding (Chicago Tribune 1961). A significant rise on the Chicago River was reported, which rose high enough to necessitate the opening of the Chicago Lock, sending mixed rain water and untreated sewage into Lake Michigan. September 1961 remains the wettest September on record for Chicago as of 2023.
24-25 December 1965	Rainfall of 2.0 to 3.5 inches occurred prior to a changeover to snowfall. Newspaper accounts suggest that the Weather Bureau reported isolated rainfall up to 6.6 inches in the south suburbs of Chicago (Chicago Tribune 1965), but a review of available data does not appear to support values this high. Flooding of multiple streets and a few residences led to evacuations and water rescues, especially in Harvey and Markham near Calumet-Union Drainage Canal.
26-27 July 1966	Rainfall ranged from about 1 inch to 5.4 inches across the Chicago area from the evening of 26 July to the evening of 27 July. Almost all of this rainfall occurred in a 12-hour period (Huff and Vogel 1976). Peak storm total rainfall occurred near the Chicago Loop and Midway Airport, with rainfall rates briefly reaching 1-2 inches per hour. Widespread roadway flooding occurred in Chicago and areas just to the north and west. Flooding impacts were possibly reduced because of drought conditions. (Chicago Tribune 1966).
16 August 1968	Rainfall ranged from 2.9 to 4.8 inches across Chicago and central Cook County, with the highest values occurring in isolated areas due to thunderstorms occurring over an approximately 9-hour period ending about 2:00 AM on 17 August. At least 2000 homes experienced flooding in Chicago, with numerous roadways and underpasses also flooded (Chicago Tribune 1968). A significant rise on the Chicago River was reported, which rose high enough to necessitate the opening of the Chicago Lock, sending mixed rain water and untreated sewage into Lake Michigan.

25-26 August 1972	Rainfall ranged from 1.5 to 3.0 inches across Chicago and central Cook County, with a sharp gradient toward much higher values just to the west in DuPage County and northwestern Cook County, where a swath of 7-8 inches were observed. Most of this rainfall occurred in just 1-3 hours for a given location, with rain rates of 1-3 inches per hour. Widespread flash flood occurred in the western suburbs (Chicago Tribune 1972). Flood damages were estimated at more than $7.5 million ($56 million in 2024 dollars).
30 June 1977	Flooding of roadways and a few structures occurred after 1.2-2.9 inches of rainfall occurred across the city during an approximately 10-hour period ending at 3:00 PM (Chicago Tribune 1977). Peak rainfall rates were about 1 inch in one hour and 2.5 inches in 3 hours. A significant rise of water level on the Chicago River was also reported.
7-8 June 1993	Multiple waves of heavy rainfall moved across the Chicago metropolitan area from 7-8 June 1993. Up to 6.9 inches was observed over a 38-hour period which included multiple, separate rounds of rainfall. The heaviest individual rainfall event was a 2-hour storm on the morning of 7 June with up to 3.5 inches of rainfall observed in the southern Chicago (Peppier 1994). Flood impacts included closure of I-57 near 124th St and portions of I-55 and I-94. Multiple underpasses flooded, and a several basements flooded. (Chicago Tribune 1993)
17-18 April 2013	A very heavy rainfall event occurred in the Chicago metro area over a multi-day period in April 2013 with peak rainfall occurring on the west side of the study area along the DuPage and Cook county line. Peak observed rainfall was just over 7 inches in 3 days and about 6.7 inches in 1 day near Franklin Park, recorded by an Illinois State Water Survey gauge (U.S Army Corps of Engineers 2017). Just to the northwest at Chicago O'Hare Airport, the city's official observing location recorded just over 5 inches. Widespread flooding of roadways and basements occurred across the region, with at least 2500 basements flooded in the city of Chicago alone. In addition to urban flash flooding, significant river flooding also occurred along the Des Plaines River. Flood damages in Cook County included $127.5 million in FEMA individual assistance, $77 million in Housing and Urban Development grants, and an unknown amount of loans from the Small Business Administration, totaling at least $204.5 million ($270.5 million in 2023). This event was just under the threshold to be included in the list of extreme rainfall events impacting the study area.
21-22 August 2014	Heavy rainfall occurred in the southwest parts of Chicago from a short, intense thunderstorm. Chicago Midway Airport recorded up to 2 inches in 1 hour and 4.2 inches over a 1-day period. An NWS cooperative observer in Burbank, just southwest of the airport, recorded 1.8 inches in 17 minutes, 2.75 inches in 27 minutes, and 3.6 inches in 40 minutes. Just to the west of the Chicago city limits, multiple rainfall observations up to 5 inches were reported by CoCoRaHS. Numerous streets in southwest parts of Chicago and immediate suburbs were flooded, I-294 was closed due to flooding near IL-171, and numerous basements flooded. Flood damages were estimated at $50 million ($66 million in 2024 dollars) in *Storm Data*.
14 October 2017	Multiple waves of heavy rainfall moved across northeast Illinois and the Chicago metro area over an approximately 30-hour period from the early morning hours of 14 October to the morning of 15 October. Rainfall across central Cook County ranged from 4 to 7 inches, with peak rainfall of 7.3 inches reported by a USACE/USGS rain gauge in Riverside. Numerous roadways were flooded across the Chicago metro area and the Chicago River rose to flood stage.

17 May 2020	Heavy rainfall up to 4 inches was observed in a swath from the southwest suburbs northward through Chicago and the central part of Cook County. This event followed a particularly wet period with 3-5 inches of rainfall occurring the week prior in central Cook County. These earlier rainfall events had filled the deep tunnels and McCook Reservoir to near capacity, significantly reducing the ability to store combined sewer runoff. At the same time, Lake Michigan was a few feet above the long-term average, limiting the ability to discharge floodwater into the lake during significant flood events. Widespread flooding of roadways was reported, and the Chicago River rose to one of the highest crests on record.

Appendix B

The hourly rain gauge data collected for this report allowed for updates to be made to the rankings of sub-daily Chicago rainfall records. The top 1-hour, 2-hour, 3-hour, 6-hour, and 12-hour, rainfall accumulations are indicated by Table 8, Table 9, Table 10, Table 11, and Table 12. Note that these records are based upon a combination of rain gauge data sources, including data collected by ASOS/AWOS, USGS, MWRD, and private weather stations. Chicago rainfall records listed elsewhere may be based solely on the official Chicago climate site (Chicago O'Hare Airport since 1980) or based upon only the ASOS/AWOS locations in the city (Chicago O'Hare Airport, Chicago Midway Airport, and the supplemental Chicago Midway Airport COOP station).

Table 8. Maximum 1-hour rainfall accumulation known to have occurred within present-day boundaries of Chicago. Gauge data was reviewed from multiple sources ranging from official observations to private weather stations.

	Observed 1-hour Rainfall (in)	Date	Location	Rain Gauge Source	Remarks
1	3.89	1967/06/10	Chicago Racine Avenue Pumping Station	MWRD	*Based upon hourly timestep.*
2	3.64	2022/09/11	Chicago Dunning Community Area	Privately-owned gauge	
3	3.22	2001/08/02	Chicago Bridgeport Community Area	ILSWS	
4	3.18	1976/06/13	Chicago Midway Airport	ASOS	*Based upon hourly timestep. Other Chicago rainfall records indicate 3.34 inches in 1 hour on this day. This observation occurred in Burbank, at the 3SW Chicago Midway Airport COOP site.*
5	3.03	2011/07/23	Chicago O'Hare Airport	ASOS	

Table 9. Maximum 2-hour rainfall accumulation known to have occurred within present-day boundaries of Chicago. Gauge data was reviewed from multiple sources ranging from official observations to private weather stations.

	Observed 2-hour Rainfall (in)	Date	Location	Rain Gauge Source	Remarks
1	5.63	2011/07/23	Chicago O'Hare Airport	ASOS	
2	5.11	1967/06/10	Chicago Loop NWS Office	NWS	*Based upon hourly timestep.*
3	4.72	2022/09/11	Chicago Dunning Community Area	Privately-owned gauge	
4	4.38	1976/06/13	Chicago Midway Airport	ASOS	*Based upon hourly timestep.*
5	4.20	2001/08/02	Chicago Bridgeport Community Area	ILSWS	

Table 10. Maximum 3-hour rainfall accumulation known to have occurred within present-day boundaries of Chicago. Gauge data was reviewed from multiple sources ranging from official observations to private weather stations.

	Observed 3-hour Rainfall (in)	Date	Location	Rain Gauge Source	Remarks
1	6.79	2011/07/23	Chicago O'Hare Airport	ASOS	
2	6.10	1976/06/13	Chicago 85th St and Western Ave	MWRD	*Based upon hourly timestep.*
3	5.21	1967/06/10	Chicago Loop NWS Office	NWS	*Based upon hourly timestep.*
4	5.11	2022/09/11	Chicago Dunning Community Area	Privately-owned gauge	
5	4.16	2023/07/02	Chicago South Shore Community Area	USGS	

Table 11. Maximum 6-hour rainfall accumulation known to have occurred within present-day boundaries of Chicago. Gauge data was reviewed from multiple sources ranging from official observations to private weather stations.

	Observed 6-hour Rainfall (in)	Date	Location	Rain Gauge Source	Remarks
1	6.91	2011/07/23	Chicago O'Hare Airport	ASOS	
2	6.47	1957/07/12	Chicago Mayfair Pumping Station	MWRD	*Based upon hourly timestep.*
3	6.27	2023/07/02	Chicago Austin Community Area	Privately-owned gauge	
4	6.10	1976/06/13	Chicago 87th St and Western Ave	MWRD	*Based upon hourly timestep. Rainfall ended after approximately 3 hours.*
5	5.95	1987/08/13	Chicago O'Hare Airport	ASOS	*Based upon hourly timestep.*

Table 12. Maximum 12-hour rainfall accumulation known to have occurred within present-day boundaries of Chicago. Gauge data was reviewed from multiple sources ranging from official observations to private weather stations.

	Observed 12-hour Rainfall (in)	Date	Location	Rain Gauge Source	Remarks
1	8.35	1987/08/13	Chicago O'Hare Airport	ASOS	*Based upon hourly timestep.*
2	8.03	2023/07/02	Chicago Near West Side Community Area	Privately-owned gauge	
3	7.67	1957/07/12	Chicago Mayfair Pumping Station	MWRD	*Based upon hourly timestep.*
4	6.92	2011/07/23	Chicago O'Hare Airport	ASOS	
5	6.38	1976/06/13	Chicago Dunning Community Area	Privately-owned gauge	*Based upon hourly timestep. Rainfall ended after approximately 8 hours.*

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