The July 2 and September 17, 2023, Flash Flood Events in the Chicago Metro Area

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Created: November 21, 2023

Updated: November 29, 2023

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Summary

Two extreme rainfall events occurred in the Chicago metropolitan area during the summer of 2023. The first event occurred on 2 July and was caused by heavy rainfall from multiple nearly-stationary bands of showers and thunderstorms near, and rotating around the center of, a slow-moving low pressure area. The second event occurred just over two months later on 17 September and was caused by a narrow band of very heavy rainfall also associated with a slow-moving area of low pressure. Both events caused widespread flash flood impacts to roadways and structures, with some areas experiencing significant impacts. Both events were declared state and federal disasters.

During the 2 July 2023 event, light rainfall occurred in the vicinity of Chicago from approximately 4:00 AM CDT (0900 UTC) to 4:00 PM CDT (2100 UTC), with embedded periods of heavier rainfall occurring during two waves. The first wave began around 5:30 AM CDT (1030 UTC) and ended around 12:00 PM CDT (1700 UTC), and the second wave began around 1:30 PM CDT (1830 UTC) and ended around 4:30 PM CDT (2130 UTC). During the periods of heaviest rainfall, each of which occurred in the same general area, individual showers or storms moved very little (Figure 1 and Figure 2). The highest storm total rainfall occurred near the border of Chicago, Cicero, and Oak Park, with a peak rainfall value estimated at 9.1 inches.

For the 17 September 2023 event, light rainfall occurred in the vicinity of Chicago from approximately 2:00 AM CDT (0700 UTC) to 5:00 PM CDT (2200 UTC), also with heavier rainfall occurring during two waves. The first wave began around 6:00 AM CDT (1100 UTC) and ended around 9:00 AM CDT (1400 UTC), and the second wave began around 9:30 AM CDT (1430 UTC) and ended around 2:00 PM CDT (1900 UTC). During the periods of heavy rainfall, individual showers and storms moved very little (Figure 3 and Figure 4), but each wave occurred in a different part of the Chicago area, and the second wave of rainfall was more significant. The highest storm total rainfall occurred at Calumet City, with a peak rainfall value estimated at 8.7 inches

For both events, maximum rainfall amounts were estimated to have about a 0.2% chance of occurring annually for a given location. Although very rare for a single location, multiple extreme rainfall events of a similar magnitude have occurred since 1950 somewhere in the vicinity of Chicago. It can be expected that an event of this magnitude will occur once or twice per decade, on average, in the Chicago area.

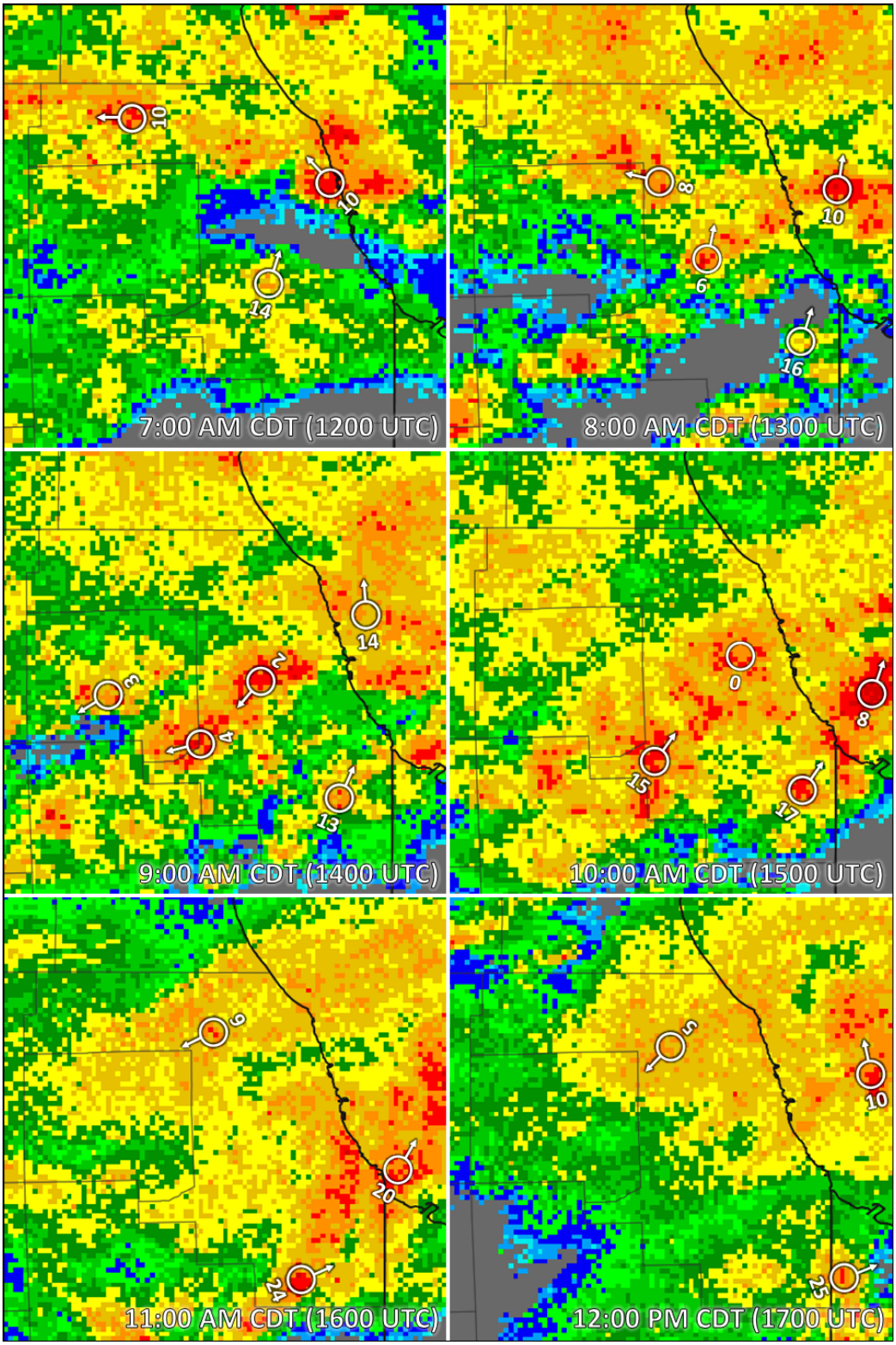


Figure 1. Radar imagery during the first wave of heavy rainfall impacting the central Chicago metro on July 2, 2023. Images are one hour apart, in left-to-right, top-to-bottom order, beginning at 7:00 AM CDT (1200 UTC) and ending at 12:00 PM CDT (1700 UTC). Imagery from the Iowa Environmental Mesonet. Storm motion of major echoes are indicated in miles per hour.

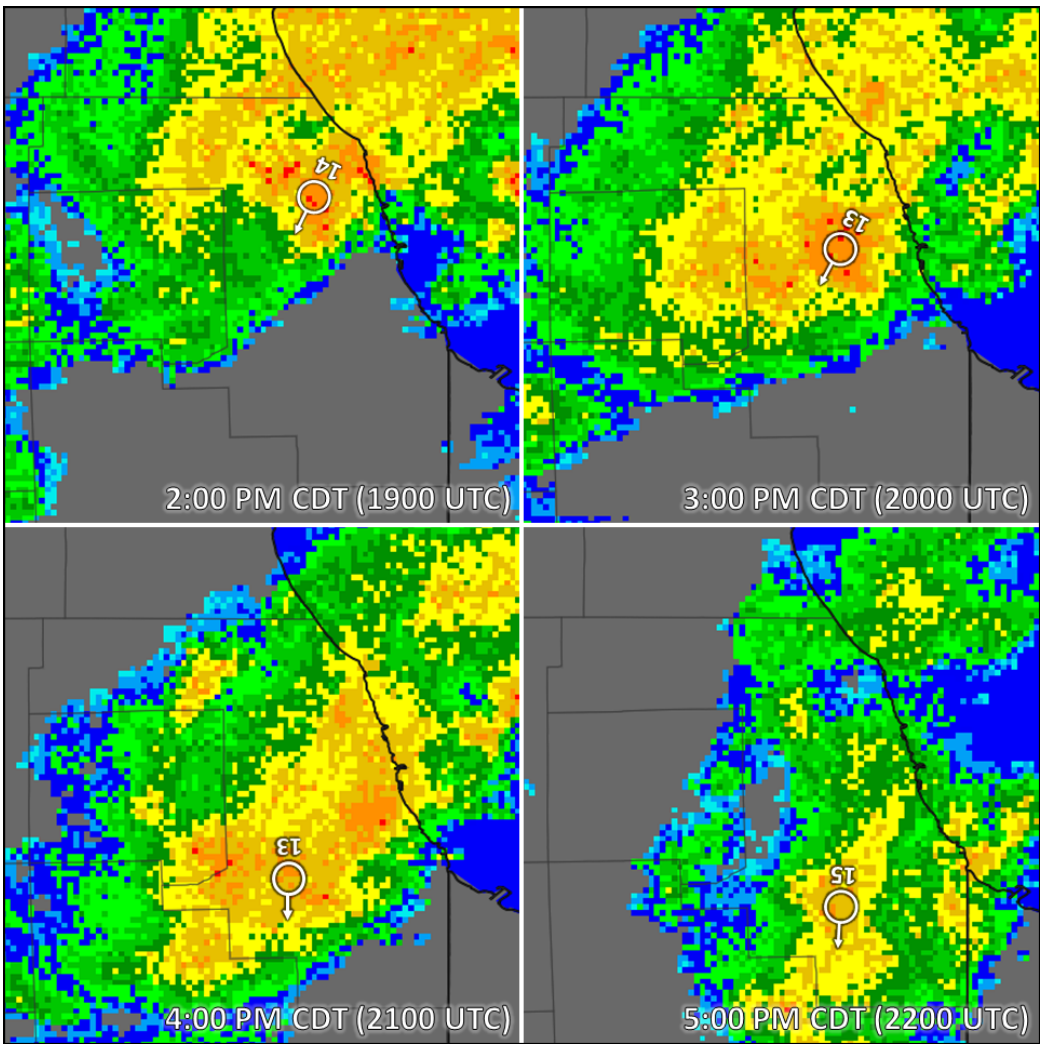


Figure 2. Radar imagery during the second wave of heavy rainfall impacting the central Chicago metro on July 2, 2023. Images are one hour apart, in left-to-right, top-to-bottom order, beginning at 2:00 PM CDT (1900 UTC) and ending at 5:00 PM CDT (2200 UTC). Imagery from the Iowa Environmental Mesonet. Storm motion of major echoes are indicated in miles per hour.

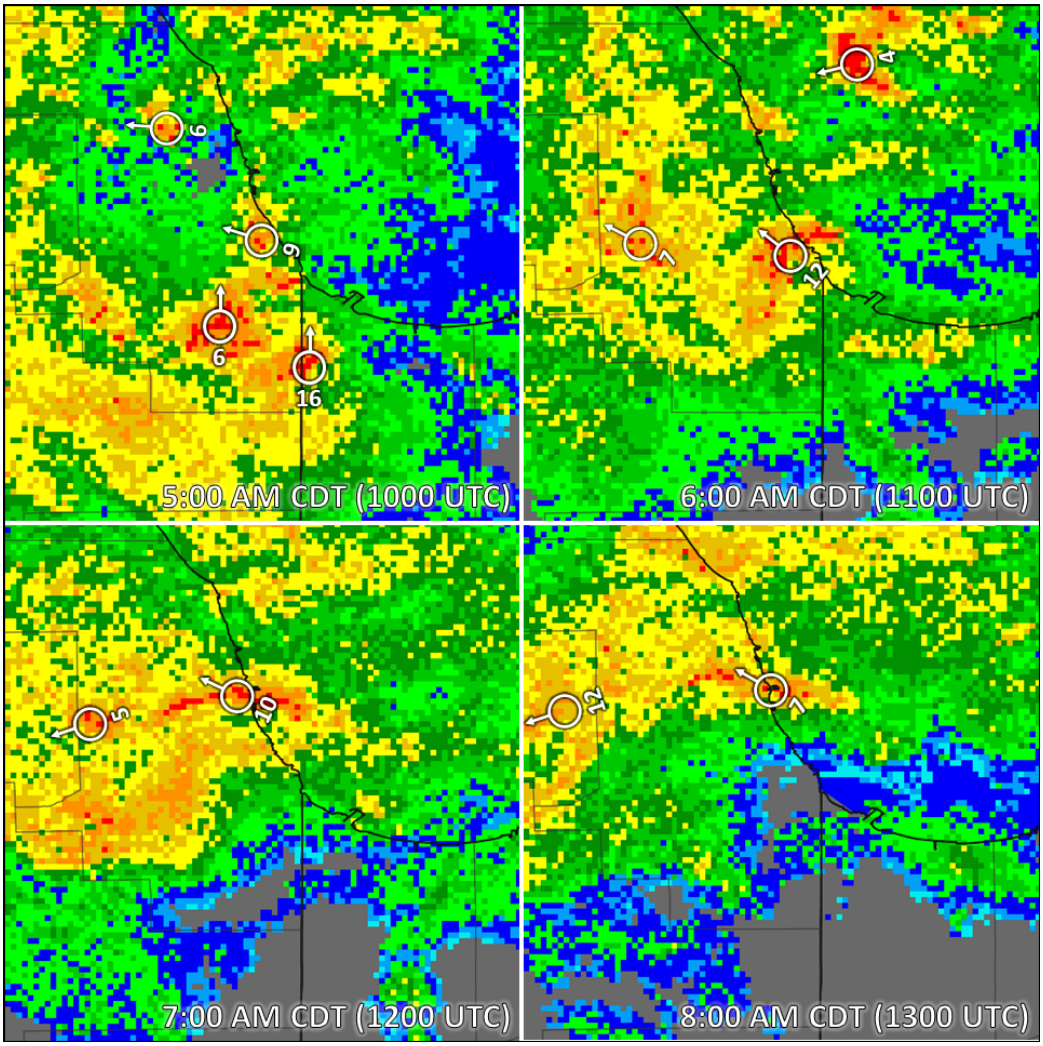


Figure 3. Radar imagery during the first wave of heavy rainfall impacting the central Chicago metro on 17 September 2023. Images are one hour apart, in left-to-right, top-to-bottom order, beginning at 5:00 AM CDT (1000 UTC) and ending at 8:00 AM CDT (1300 UTC). Imagery from the Iowa Environmental Mesonet. Storm motion of major echoes are indicated in miles per hour.

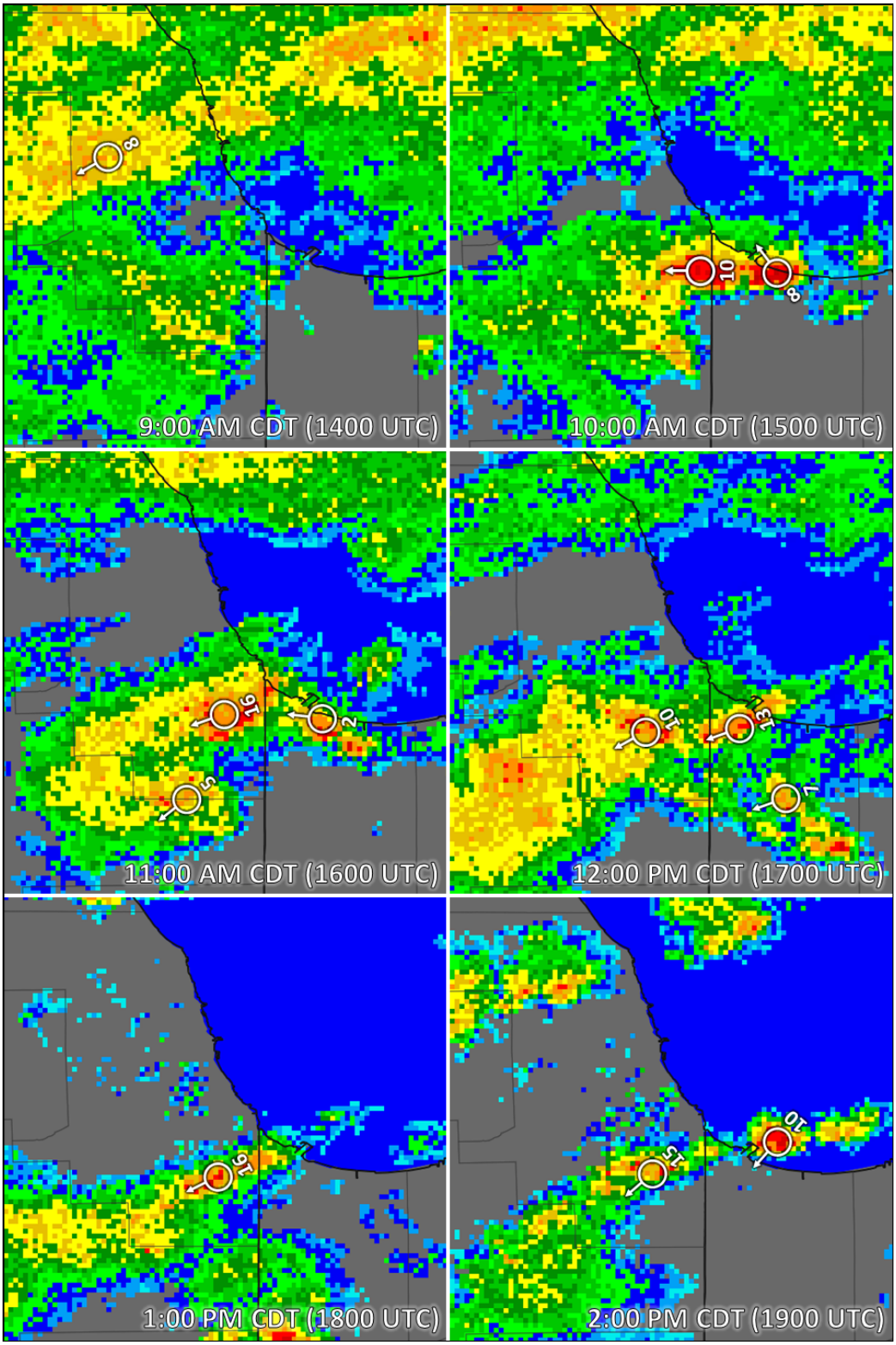


Figure 4. Radar imagery during the second wave of heavy rainfall impacting the southern Chicago metro on 17 September 2023. Images are one hour apart, in left-to-right, top-to-bottom order, beginning at 9:00 AM CDT (1400 UTC) and ending at 12:00 PM CDT (1700 UTC). Imagery from the Iowa Environmental Mesonet. Storm motion of major echoes are indicated in miles per hour.

Meteorology & Forecastability

2 July

During the overnight hours of 1 July into 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. In west central Illinois, a weak area of surface low pressure was drifting slowly to the northeast. These surface features were mostly evident based upon changes in wind direction as temperatures and dewpoints were relatively similar across the area. On both sides of the warm front, dewpoints ranged from the upper 60s to near 70. At 850 mb, winds were light in 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. This shortwave was almost completely cut off from the large-scale flow. Over the next several hours, the surface warm front drifted slowly to the north with the surface low pressure area drifting to the east (Figure 5). The upper air features remained largely unchanged.

At 0900 UTC on 2 July, a second surface low was identified along the warm front just to the west of the Chicago metro area. This area of low pressure was likely a remnant mesoscale convective vortex (MCV) from earlier convection. Scattered light to moderate rainfall was ongoing along and north of the warm front. Rainfall intensity increased significantly between 1100 UTC and 1200 UTC, with the heaviest band of rain located across portions of the Chicago metro area just to the northeast of the new surface low. The 1200 UTC sounding from DVN (Davenport, IA) indicated a nearly saturated profile with only light winds up to approximately 200 mb and a precipitable water value of 1.8 inches. Storm Prediction Center (SPC) mesoanalysis derived from the RAP model indicated a corridor of 1.8 inches roughly following the warm front from west to east across northern Illinois. Over the next 4 hours, the surface low pressure moved very slowly to the east toward Lake Michigan, with the heavy rain band remaining over the Chicago metro, shifting just a few miles to the north or south, owing to the very slow storm motions.

At 1800 UTC, the surface low was located just off the shore of Lake Michigan with the heaviest rainfall also east of Chicago. Shortly after, a band of heavy rainfall formed to the north of the low and moved slowly onshore to the west. This band remained nearly stationary for the next 3-4 hours, adding more rain to the same areas impacted earlier in the morning.

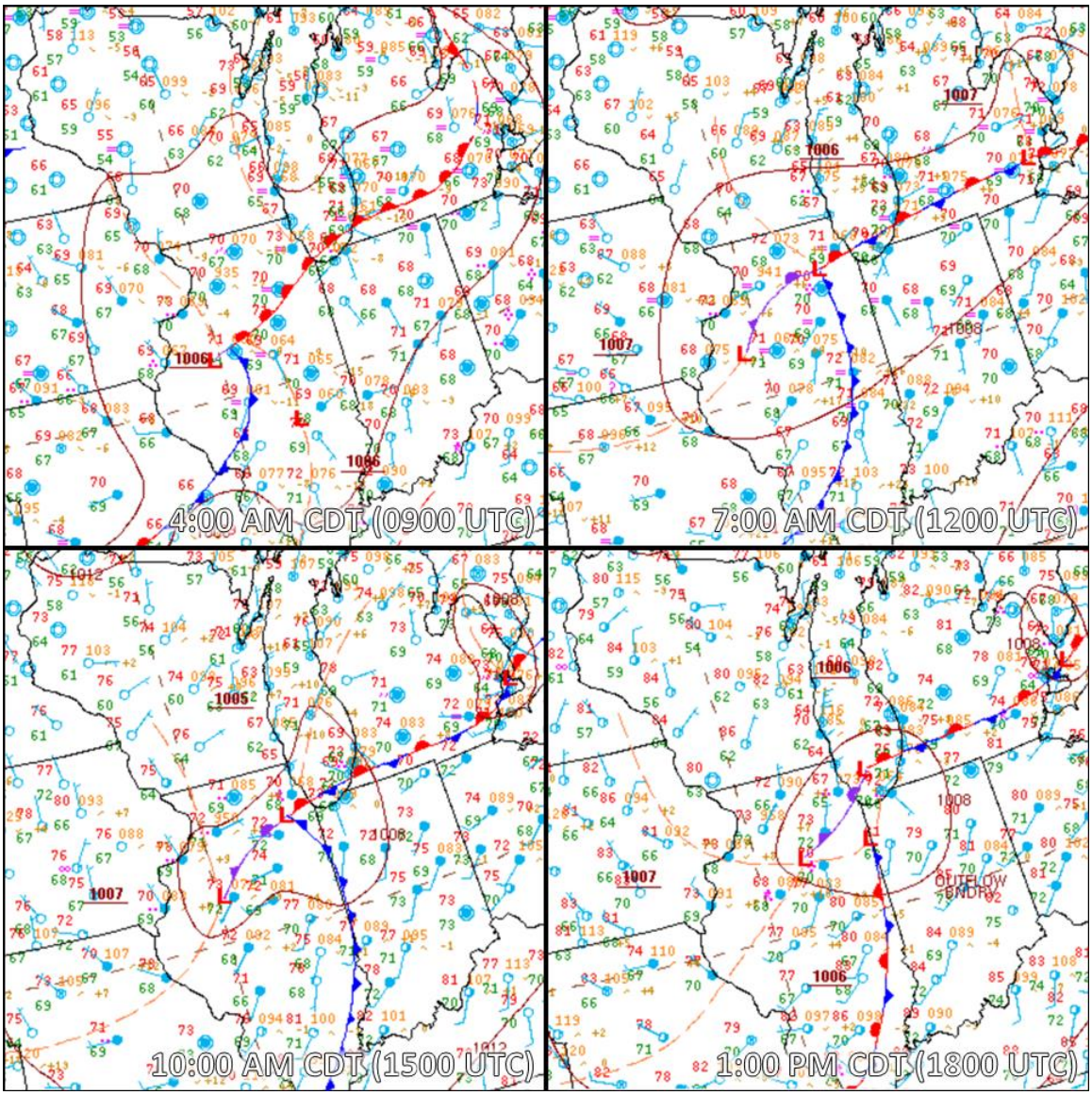


Figure 5. Surface analysis for 2 July 2023. Images are 3 hours apart, in left-to-right, top-to-bottom order, beginning at 4:00 AM CDT (0900 UTC) and ending at 1:00 PM CDT (1800 UTC). Imagery from the Weather Prediction Center.

As early as the morning of June 30, some weather forecast model runs indicated the possibility of isolated heavy rainfall in northern Illinois. The 0000 UTC run of the High Resolution Ensemble Forecast (HREF) system indicated numerous isolated areas of 1-2 inches of rainfall, with one notable area of 3-4 inches, across northern Illinois when using the Localized Probability-Matched Mean (LPMM) product. Subsequent runs of HREF continued to indicate a similar pattern and similar peak rainfall amounts, although in different locations with each run. As the event neared, peak rainfall amounts forecasted by HREF increased, with isolated values peaking at 5-7 inches. Although forecasters recognized the

potential for isolated heavy rainfall, the likelihood of flooding was deemed low due to the ongoing severe drought across most of northern Illinois and the unlikely chance that one of these small areas of heavy rainfall would line up exactly with an urban area like the Chicago metro. A previous heavy rainfall event several weeks prior occurred outside of the heavily-urbanized part of the Chicago metro and, despite rainfall amounts exceeding 4 inches, caused no known flash flood impacts due to the drought. The July 2 event thus presented a forecasting challenge – had the area of heaviest rainfall occurred in a rural area just 20 miles away, flood impacts would likely have been much less severe.

17 September

During the overnight hours of 16 September into 17 September 2023, a weak cold front was located from southern Iowa eastward into far northern Illinois. Surface winds and radar-indicated motion of showers and thunderstorms suggested a possible low pressure area, or MCV, along this front in northern Illinois. This MCV was likely a remnant of convection from the previous evening, but was more subtle than the one that occurred on 2 July and was not initially indicated on surface weather analysis maps. Similar to the 2 July event, surface features were mostly evident based upon changes in wind direction due to the generally uniform temperature and dewpoint values across the area. On both sides of the cold front, dewpoints were in the upper 50s. 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. A jet streak was located on the western and southern edge of this trough, extending from Iowa south to Missouri and southeast into Arkansas and Tennessee. Over the next several hours, the surface cold front drifted slowly southward (Figure 6). The upper air features drifted slowly to the southeast during this time period.

At 0900 UTC, radar data and surface winds suggested the MCV was located in far northeast Illinois, north of Chicago and just onshore from Lake Michigan. An area of light to moderate rainfall was beginning to increase in coverage and intensity across the Chicago metro. By 1200 UTC, the MCV was located just east of Chicago over western Lake Michigan, with the weak cold front having passed to the southeast. Rainfall intensity increased significantly at this time, 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 sounding from ILX (Lincoln, IL) indicated a saturated profile only in the lowest 100 mb (approximately 1000 meters), with a precipitable water value of only 0.78 inches (Plymouth State University 2023). At DVN

(Davenport, IA), the sounding was relatively similar, with a precipitable water value of 0.81 inches. 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. Over the next couple hours, the MCV appeared to drift slowly southward with the narrow band of heavy rainfall remaining near Chicago, with very slow storm motions.

At 1500 UTC, the cold front had moved farther to the southeast, extending from southeast Michigan southward through Indiana. The MCV had drifted southward and was located along 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, quickly accumulating a significant storm total.

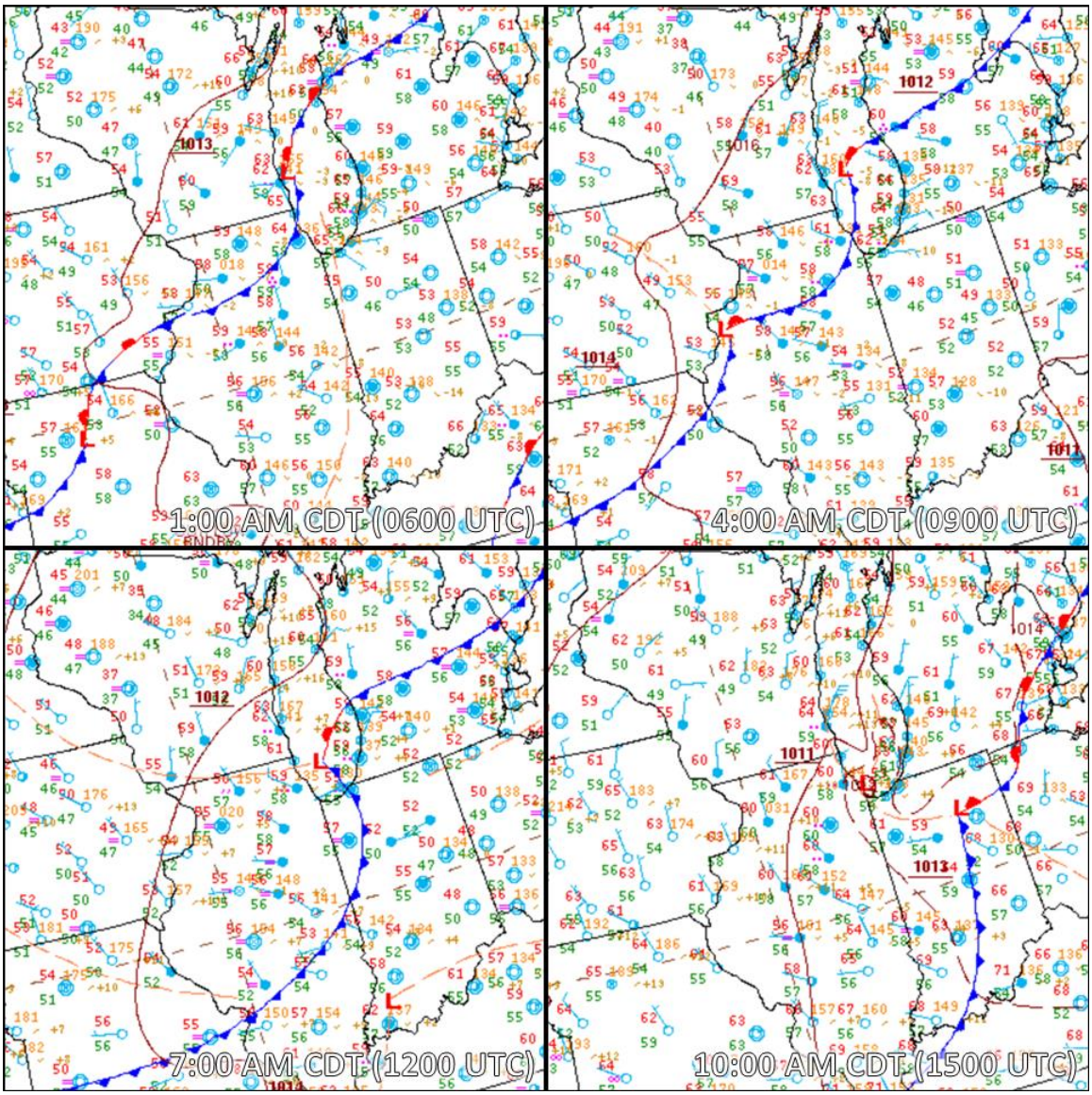


Figure 6. Surface analysis for 17 September 2023. Images are 3 hours apart, in left-to-right, top-to-bottom order, beginning at 1:00 AM CDT (0600 UTC) and ending at 10:00 AM CDT (1500 UTC). Imagery from the Weather Prediction Center.

On the evening of 15 September, some weather forecast model runs indicated the possibility of showers and thunderstorms occurring across northeast Illinois two days later. The 0000 UTC run of the HREF system indicated many areas of rainfall up to 1 inch, with a few isolated areas up to 2 inches, when using the LPMM product. On the following day, the 1200 UTC run of the HREF indicated a similar pattern of rainfall for 17 September, but introduced a very isolated area of up to 4 inches of rainfall with the LPMM near the Lake Michigan shore north of Chicago. Several individual models used by the HREF even

depicted a slow-moving surface low in northeast Illinois or over southern Lake Michigan, somewhat similar to the eventual MCV track. With the 0000 UTC 17 September run of the HREF, the final run available prior to the onset of rainfall, an isolated area of rainfall up to 4 inches just north of Chicago was again depicted. Forecasters recognized the potential for isolated heavy rainfall with this event, but the likelihood of flooding was again deemed low because the probability of such a small area of heavy rainfall hitting an urban location was small, and overall weather pattern was not particularly favorable for significant rainfall. The 17 September event presented another forecasting and messaging challenge, just as the 2 July event did about two months prior.

Data Sources and Data Collection

Rainfall Data

Multiple sources of rainfall data are available to NWS forecasters during real-time operations. Single-site radar-derived rainfall estimates were available from KLOT radar site located at the NWS Chicago office in Romeoville. Radar mosaic derived rainfall estimates were also available from the Multi-Radar Multi-Sensor (MRMS) system. Bias corrected radar estimates are available each hour from the NWS River Forecast Centers (RFCs), but they only become available 30-60 minutes after the top of the hour. Several automated rain gauges are also located in the Chicago metro area, including sites at area airports and several operated by the United States Geological Survey (USGS). NWS warning forecasters also monitor rainfall data from privately-owned weather stations.

Real-time gauges typically monitored by the NWS include those operated by the FAA (ASOS and AWOS) and the USGS. A large amount of additional rainfall information was collected to analyze the rainfall of 2 July and 17 September. Once per day, rainfall information becomes available from manual observations including the NWS Cooperative Observer Program (COOP) and the Community Collaborative Rain Hail and Snow (CoCoRaHS) network. These observations cover a meteorological observation day (24-hour period ending at 7:00 AM CDT or 6:00 AM CST). For a comparison between meteorological days, calendar days, and the time periods of heaviest rainfall on 2 July and 17 September, see Figure 7 and Figure 8, respectively. Data was also collected from private weather stations across the area, although these stations often have varying quality and usefulness. Sources of private weather station data include the Metropolitan Water Reclamation District (MWRD), the Citizens Weather Observation Program (CWOP), Davis Instruments (Davis), and the Weather Underground Personal Weather Station network (WU PWS). A count of observations collected from each of these networks is shown by Table 1. A different number of gauge observations were collected for each event because the location and spatial extent of each event varied. A large number of the collected gauges are for areas away from the Chicago metro area and were added to the analysis to assist with bias correction, but the primary focus was to collect as much data as possible in and near the area of highest rainfall amounts. Limited quality control was used to filter out bad observations. Observations of 0.0 inches in areas of obvious heavy rainfall, or observations below 50% or above 200% of radar estimates, were removed from the analysis.

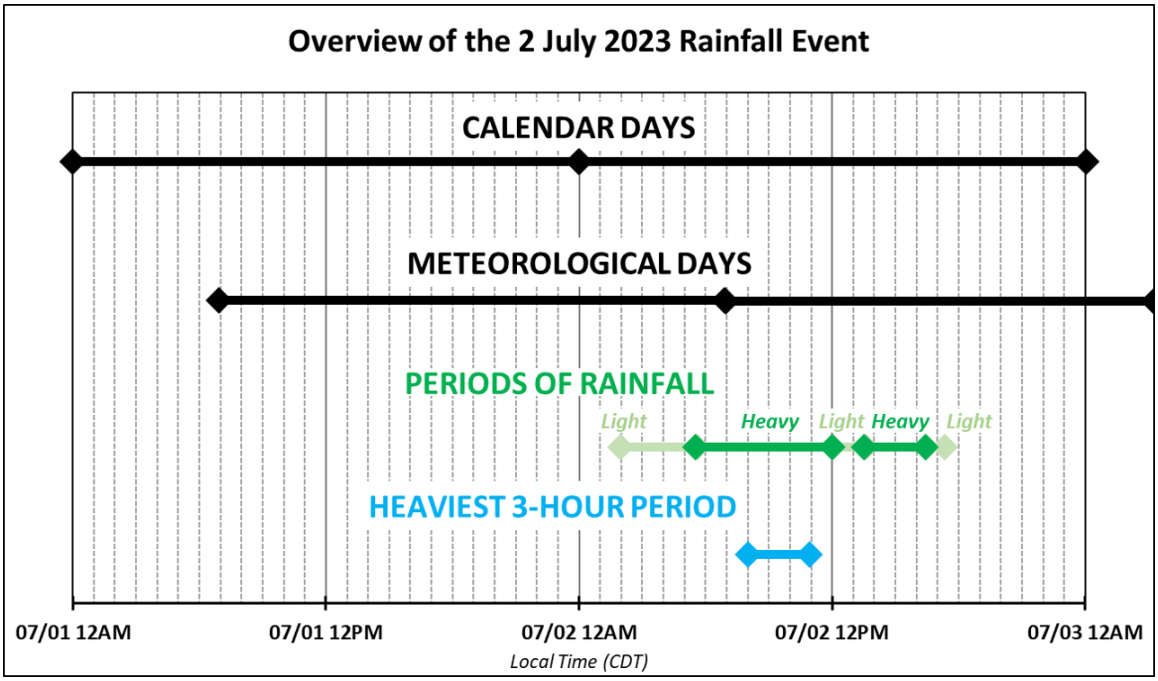


Figure 7. Timeline of rainfall associated with the 2 July 2023 flood event compared to calendar days and meteorological observation days.

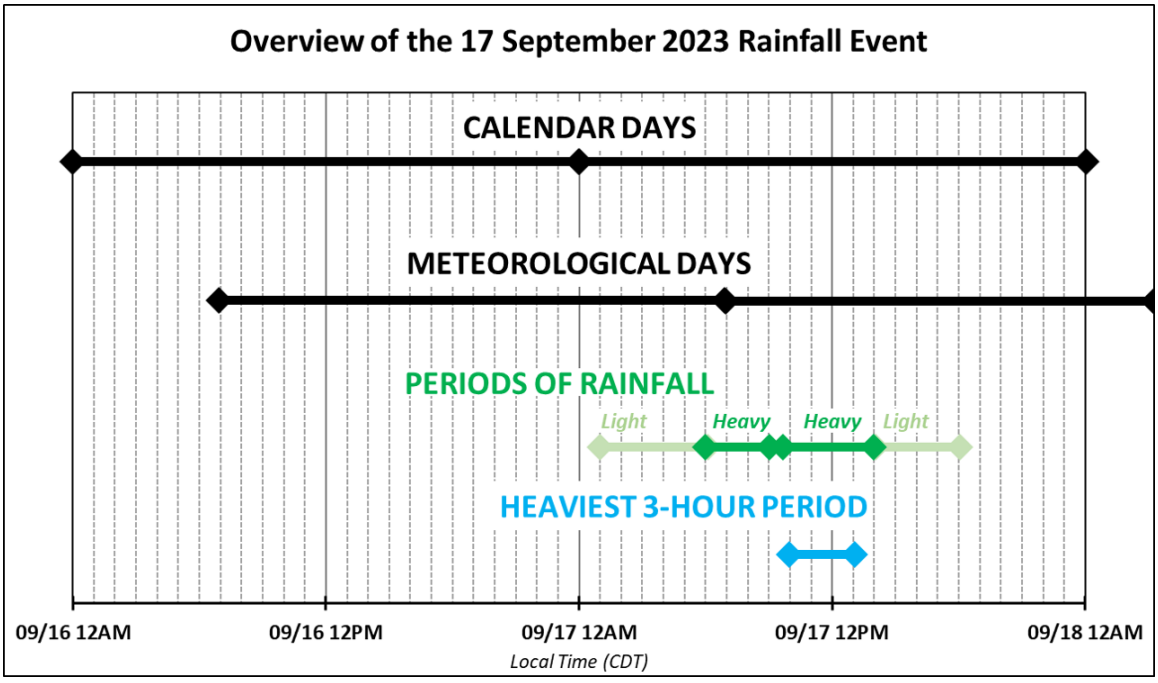


Figure 8.Timeline of rainfall associated with the 17 September 2023 flood event compared to calendar days and meteorological observation days.

Table 1. Number of observations collected for each event by source.

Rainfall Observation Source	Number of Observations	
	2 July 2023	17 September 2023
ASOS/AWOS	3	0
USGS	30	29
CoCoRaHS	364	433
COOP	9	32
Davis	4	0
CWOP	7	0
WU PWS	2,054	10
Manual/Other	0	4
Total	2,471	508

Flood Impacts

Generally, reports of flash flood impacts come from many sources, including law enforcement, local emergency management officials, trained weather spotters, media sources, departments of transportation, and sometimes the public. As a flash flood event is occurring, local broadcast media, roadway departments, and the public often report roadway flooding and basement flooding, which can be collected and stored as preliminary local storm reports (LSRs). In the days that follow an event, images and videos shared via broadcast media and social media can be used to fill in gaps and refine the documented severity. An export of calls made to the Chicago 311 system can also be used to find areas with basement and street flooding, although this would only be available for areas within the city limits. Weeks to months after an event, information from local and state emergency management agencies can be used to estimate total damage costs.

Rainfall Amounts

2 July

A review of all available rainfall data indicated that portions of Lake, Cook, DuPage, and Will counties in Illinois and Lake County in Indiana received heavy rainfall (> 1.0 inches) between 1:00 AM (0600 UTC) and 7:00 PM on 2 July (0000 UTC on 3 July). Rainfall near Chicago was confined to a shorter duration of time, from approximately 5:00 AM (1000 UTC) to 5:00 PM (2200 UTC). The heaviest rainfall occurred in two periods, the first from approximately 5:30 AM (1030 UTC) to approximately 12:00 PM (1700 UTC), and the second from approximately 1:30 PM (1830 UTC) to approximately 4:30 PM (2130 UTC). The first period of rainfall alone was significant enough to cause significant flash flood impacts in central Cook County. This was followed by a brief period of subsiding impacts, only for significant impacts to return during the second period of heavy rainfall. The highest rainfall amounts are estimated to have occurred near Cicero, Berwyn, Oak Park, and the Austin community area of Chicago. In this area, up to 7.9 inches was estimated by the bias-corrected rainfall estimate from the NWS RFCs, up to 7.5 inches was estimated by the radar-only product from MRMS, and up to 9.0 inches was observed by a rain gauge.

Showers and thunderstorms occurring from about 5:00 AM (1000 UTC) to 9:00 AM (1400 UTC) generally moved from east to west, but movement was slow and cells continuously redeveloped over the same areas. As the surface low pressure center moved across the Chicago metro area, the movement of individual shower and thunderstorm cells changed to a generally southwest to northeast direction and then to a generally north to south direction. The slow cell movement continued through both periods of heavy rainfall, leading to multiple hours of rainfall in the same locations.

Because of the earlier mentioned differences in rainfall durations between various types of gauges, the relative contribution of rainfall from each of the meteorological observation days was analyzed. For the purposes of this analysis, the 2-day rainfall accumulation ending at 7:00 AM (1200 UTC) on July 3 was used because it included all the various rainfall measurement durations of the various observations. In the area with the heaviest storm total accumulation, the overwhelming majority of the rainfall occurred during the single meteorological day ending at 7:00 AM (1200 UTC) on 3 July.

Rainfall observations collected from the various rain gauge networks were in general agreement with gridded radar-rainfall estimates. Although a few gauge observations were slightly lower than gridded radar estimates in the Chicago metro area, a majority of gauges were higher than the gridded radar estimates. The rainfall observations received from private weather station sources were further

evaluated, especially reports of rainfall that significantly deviated from radar estimates. Only two observations were removed because of the simple QC procedure, due to reporting values below 50% of radar estimates. Appendix A provides a table that lists the collected rain gauge observations.

Using the available gauge observations, gridded rainfall estimates were bias corrected to further improve the gridded estimates. In the vicinity of Cicero and the Austin community area of Chicago, bias-corrected, gridded rainfall peaked near 9.1 inches for the 2-day period ending at 7:00 AM (1200 UTC) on 3 July 2023 (Figure 9). For comparison, the highest observed point observations in the vicinity include a private weather station that recorded 8.96 inches in far northeastern Berwyn, a private weather station that recorded 8.49 inches in the Austin community area of Chicago, a private weather station that recorded 8.47 inches in southeastern Oak Park, and a USGS rain gauge that recorded 8.5 inches in northern Cicero.

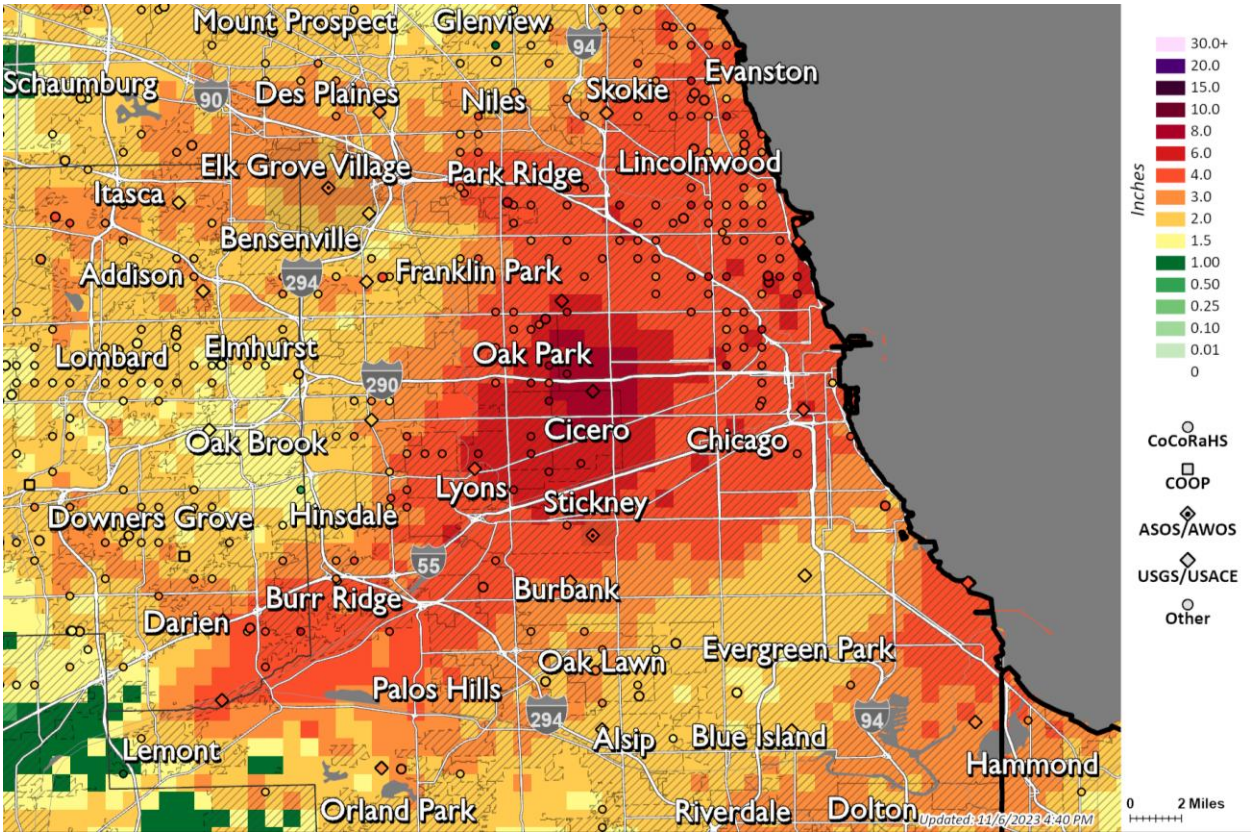


Figure 9. Bias-corrected rainfall estimate for the 18-hour period ending at 7:00 PM on 2 July 2023 (0000 UTC on 3 July) with observed rainfall as an overlay. For a given location, especially central Cook County and Chicago, rainfall generally occurred over a shorter duration. Point rainfall observations are broken up by source network.

17 September

A review of all available rainfall data indicated that portions of Cook, DuPage, and Will counties in Illinois and Lake County in Indiana received heavy rainfall (>1.0 inches) between 4:00 AM (0900 UTC) and 4:00 PM (2100 UTC) on 17 September. The heaviest rainfall near Chicago occurred in two periods, the first occurring near central portions of the city, generally away from the highest storm total rainfall amounts, from 6:00 AM (1100 UTC) to 9:00 AM (1400 UTC). The first wave of rainfall caused just isolated, nuisance flooding in central Cook County while the second wave of rainfall caused significant flash flood impacts in southern Cook County. For the area of heaviest rainfall in southern Cook County, Illinois, and northern Lake County, Indiana, the second wave of heavy rainfall occurred from 9:30 AM (1430 UTC) to 2:00 PM (1900 UTC). The highest rainfall amounts are estimated to have occurred near Calumet City, Burnham, Dolton, Hammond, and the Hegewisch community area of Chicago. In this area, up to 7.3 inches was estimated by the bias-corrected rainfall estimate from the NWS RFCs, up to 7.5 inches was estimated by the radar-only product from MRMS, up to 5.7 inches was observed by a rain gauge, and up to 8.8 inches was observed by in an empty container left outdoors.

Showers and thunderstorms generally moved from east to west during the event, but movement was slow and cells continuously redeveloped over the same areas. As the cold front and MCV moved to the southeast of the Chicago area, the movement of individual cells changed slightly, with a slight north-to-south component. The slow movement and very high rain rates, especially during the second wave of rainfall centered over southern Cook County, lead to the high rainfall accumulations.

Because of differences in rainfall durations between various types of gauges, the relative contribution of rainfall from each of the meteorological observation days was analyzed. For the purposes of this analysis, the 2-day rainfall accumulation ending at 7:00 AM (1200 UTC) on 18 September was used because it included all the various rainfall measurement durations of the various observations. In the area with the heaviest storm total accumulation, the overwhelming majority of the rainfall occurred during the single meteorological day ending at 7:00 AM (1200 UTC) on 18 September.

Rainfall observations collected from the various rain gauge networks were in general agreement with gridded radar-rainfall estimates. Some rain gauge observations were lower higher than gridded estimates, but many rain gauge observations were higher than gridded estimates. Near the area of heaviest storm total accumulation, rain gauge observations were generally higher than gridded estimates. No observations had to be removed because of the simple QC procedure. Appendix A provides a table that lists the collected rain gauge observations.

Using the available gauge observations, gridded rainfall estimates were bias corrected to further improve the gridded estimates. Near Calumet City, bias-corrected, gridded rainfall peaked near 8.7 inches for the 2-day period ending at 7:00 AM (1200 UTC) on 18 September 2023 (Figure 10). For comparison, the highest observed point observations in the vicinity include a USGS rain gauge (about 3.5 miles to the west) that recorded 5.69 inches and a measurement of water collected in an empty container to a depth of approximately 8.75 inches.

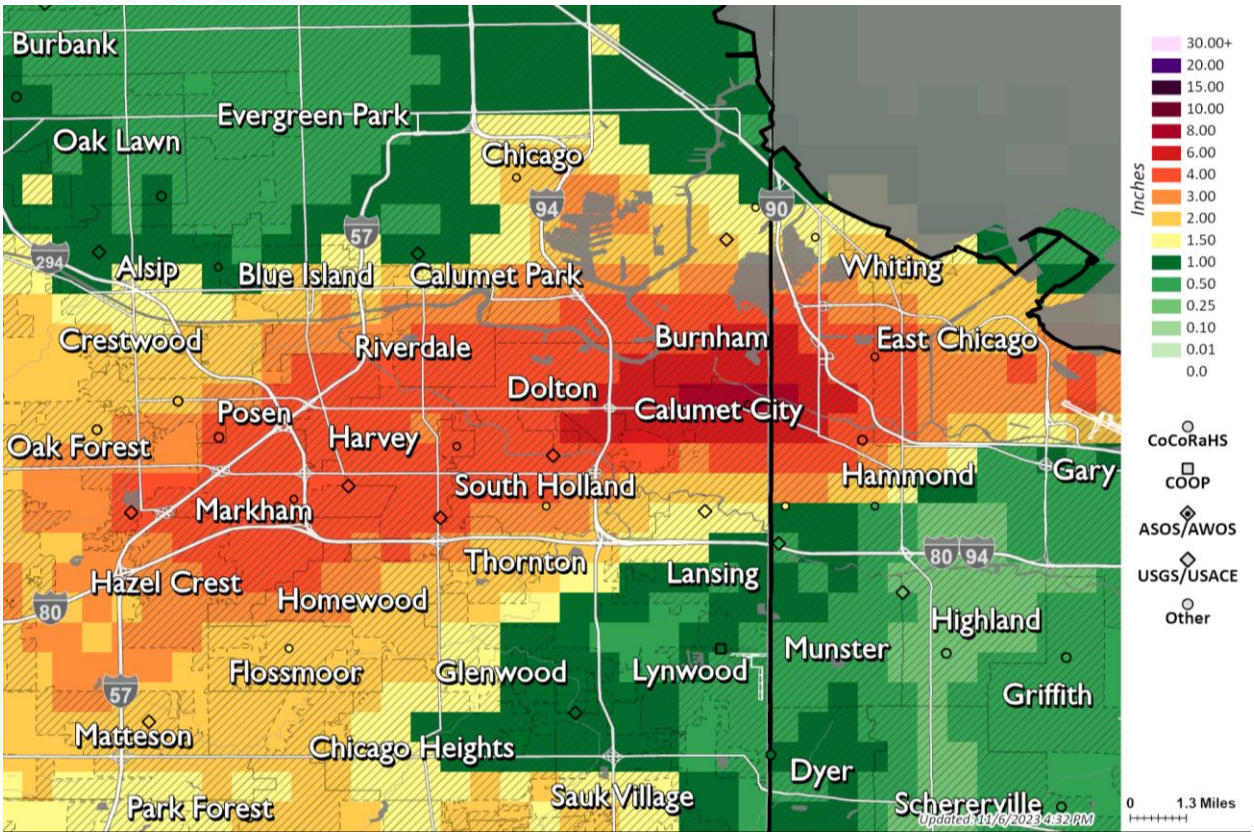


Figure 10. Bias-corrected rainfall estimate for the 12-hour period ending at 4:00 PM (2100 UTC) on 17 September 2023 with observed rainfall as an overlay. Point rainfall observations are broken up by source network.

Climatological Context of Rainfall

The bias-corrected, gridded rainfall estimates for each event were compared to NOAA Atlas 14 to calculate the annual exceedance probability (AEP) which represents the annual chance of occurrence for a given rainfall amount. For the purposes of this analysis, rainfall with a 1% or less chance of occurring in a given year (also sometimes referred to as a 100-year ARI) was considered an extreme event.

2 July

Across the central Chicago metropolitan area, observed for 2 July 2023 rainfall ranged from typical to extreme (Figure 11). During the 12-hour period from 7:00 AM (1200 UTC) to 7:00 PM (0000 UTC on 3 July), portions of northeast DuPage County, southeast DuPage County, and most of central Cook County received rainfall with less than a 50% chance of occurring in a given year covering an area of approximately 700 square miles. Rainfall amounts became more rare toward the center of central Cook County. A small area within central Cook County including at least a part of Chicago, Oak Park, Cicero, Stickney, Berwyn, Forest View, Lyons, Riverside, North Riverside, Forest Park, and River Forest received rainfall amounts with less than a 1% chance of occurring in a given year, covering an area of approximately 33 square miles. In the northern half of Cicero, far eastern Oak Park, and most of the Chicago community area of Austin, covering an area of approximately 5 square miles, rainfall with an AEP of 0.2% or less occurred. Rainfall at the 1% AEP level and greater (lower value) is almost always associated with significant flood impacts. Also notable was the gradient between extreme rainfall and more typical rainfall; for example, typical (approximately 50% AEP) rainfall occurred in Oak Brook and Hillside, just four (4) miles to the west of the area of extreme rainfall.

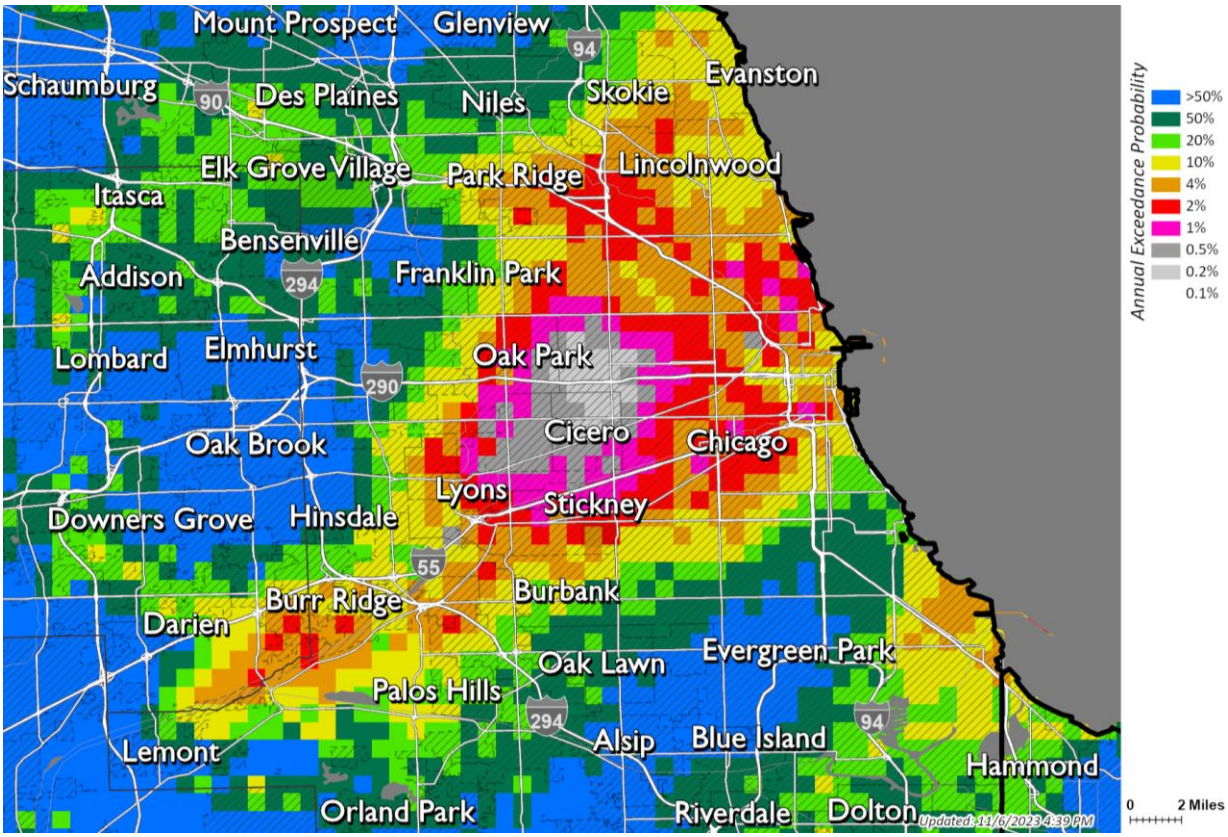


Figure 11. Annual exceedance probability for the 12-hour bias-corrected rainfall ending at 7:00 PM on 2 July 2023 (0000 UTC on 3 July).

Due to the extreme rainfall observed, automated recording rain gauges in the vicinity of Cicero, Oak Park, and Austin community area of Chicago were analyzed more closely. Automated rain gauges with the highest storm totals included WUPWS site KILCICER16 with 8.96 inches, WUPWS site KILOAKPA31 with 8.47 inches, and USGS site BERI2 with 8.50 inches. After just four (4) hours of rainfall, these locations accumulated enough rainfall to exceed the 1% AEP before rain rates briefly subsided for 1-2 hours (Figure 12). After the brief lull, the second wave of rainfall cause accumulations to near the 0.1% AEP. The highest rainfall rates and the longest duration of rainfall occurred with the first wave. For both waves of rainfall, observed rainfall rates often exceeded estimated rainfall rates from MRMS, leading to a low bias in the radar-derived estimates (Figure 13). This low bias was most evident during the second wave of rainfall during periods with the highest rainfall rates.

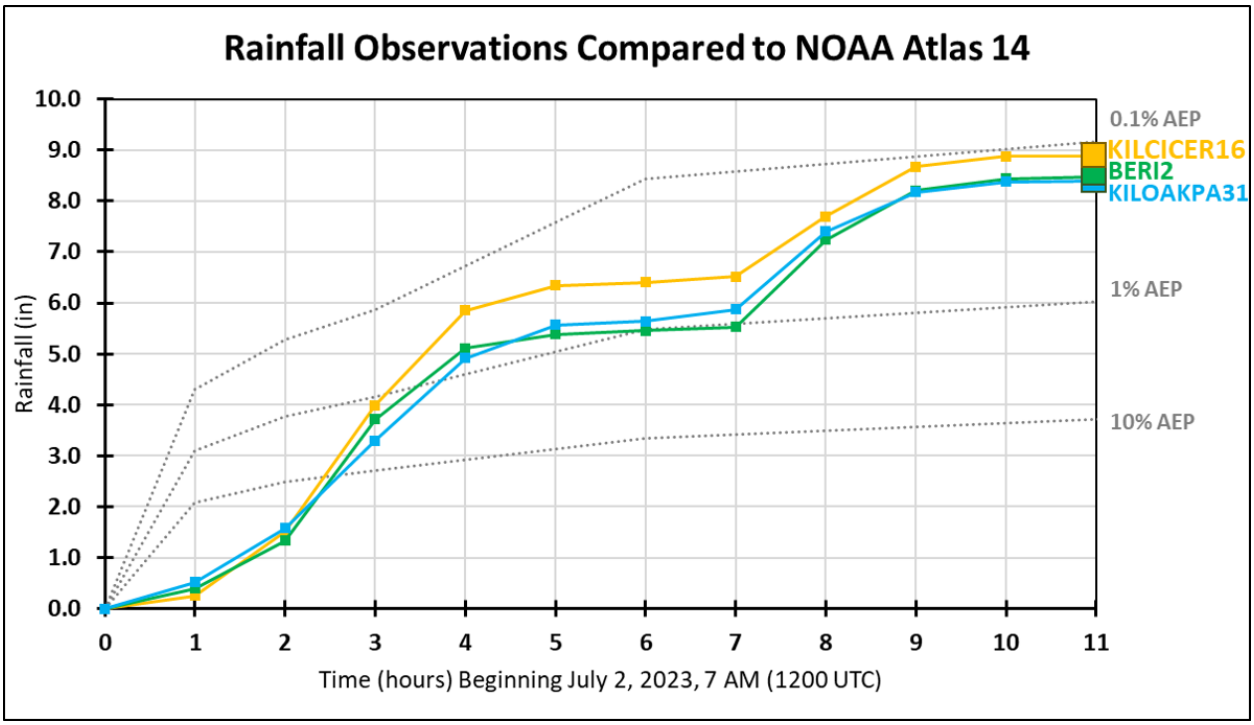


Figure 12. Total accumulated rainfall for three (3) observation locations in the vicinity of the peak rainfall on 2 July 2023. NOAA Atlas 14 rainfall duration frequency are shown by dotted lines.

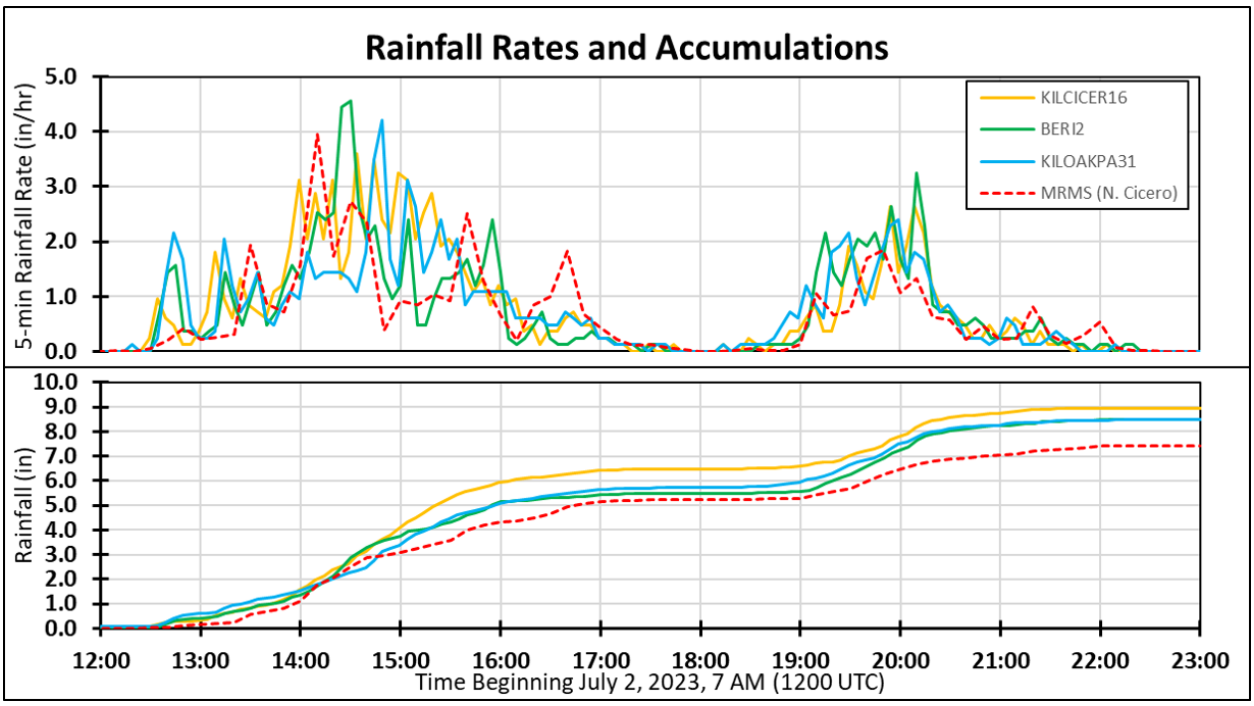


Figure 13. Rain rates for three (3) observation locations in the vicinity of the peak rainfall on 2 July 2023 with radar-only rainfall estimated by MRMS (top), and total accumulated rainfall from the same sources (bottom).

17 September

Across the southern Chicago metropolitan area, observed rainfall for 17 September 2023 ranged from typical to extreme (Figure 14). During the 12-hour period from 4:00 AM (0900 UTC) to 4:00 PM (2100 UTC), portions of southern Cook County and northern Lake County received rainfall with less than a 50% chance of occurring in a given year, covering an area of approximately 150 square miles. Rainfall amounts became more rare toward the isolated portion of Cook County centered on Calumet City. A very small area in southern Cook County and northern Lake County including at least part of the communities of Calumet City, Burnham, Dolton, Hammond, and the Hegewisch community area of Chicago received rainfall amounts with a less than 1% chance of occurring in a given year, covering an area of approximately 8 square miles. In far northeastern Calumet City and far western Hammond, covering an area of approximately 1 square mile, rainfall with an AEP of 0.2% or less occurred. Rainfall at the 1% AEP level and greater (lower value) is almost always associated with significant flood impacts. Notable was the very isolated nature of the heavy rainfall amounts; the corridor of rainfall exceeding the 50% AEP was approximately 23 miles wide and at most 7 miles wide. The majority of the Chicago metro area did not experience unusual or extreme rainfall from this event.

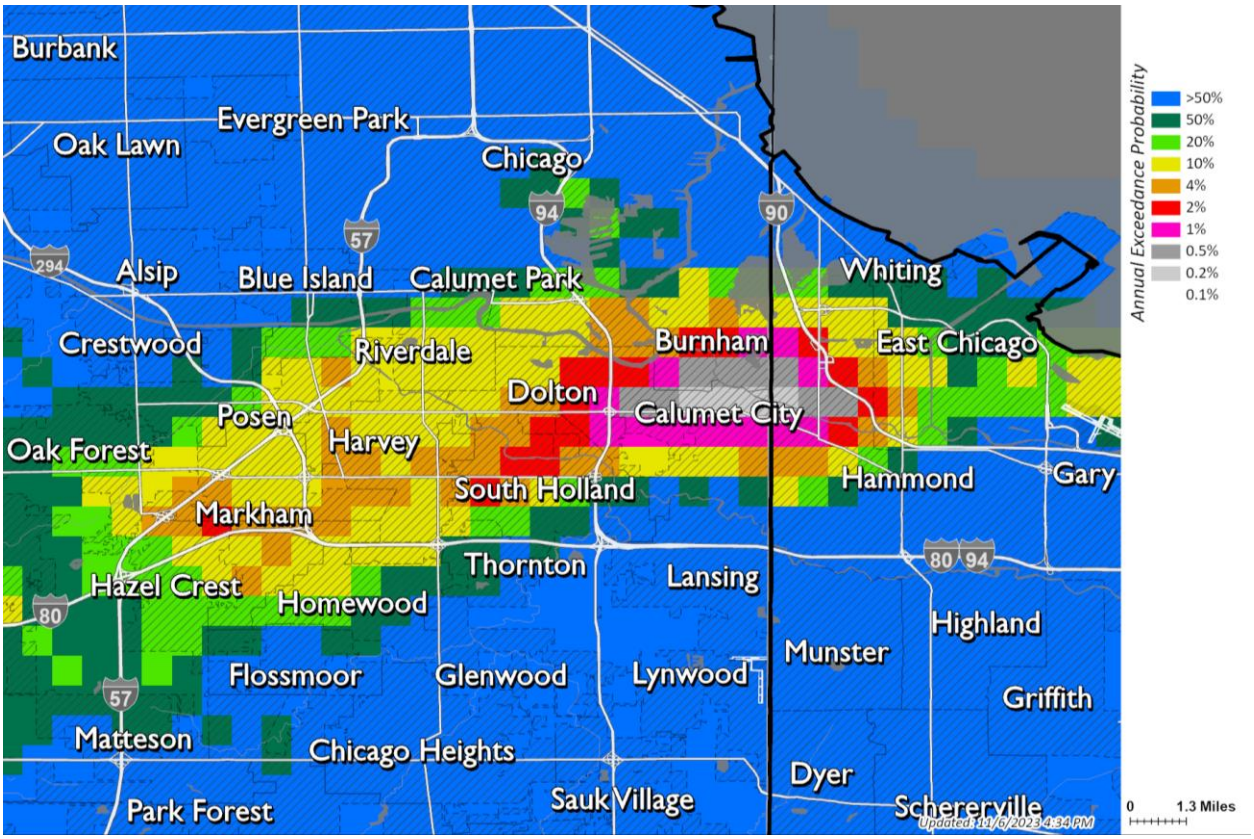


Figure 14. Annual exceedance probability for the 12-hour bias-corrected rainfall ending at 5:00 PM (2200 UTC) on 17 September 2023.

Automated recording rain gauges near Calumet City, Burnham, Dolton, and Hammond were analyzed more closely. Automated rain gauges with the highest storm totals included USGS sites SHLI2 and MKHI2 with 5.69 inches and 5.04 inches, respectively, and WU PWS site KINEASTC16 with 4.53 inches. The rainfall observed at these locations was significantly less than the bias-corrected, peak rainfall value because the heaviest rainfall generally occurred in between gauges. A report was received of an empty container filled to approximately 8.75 inches by rainfall in Calumet City, which was very similar to the bias-corrected rainfall estimate for that location. In southern Cook County, the first wave of rainfall was much lighter than the second wave. Bias-corrected rainfall estimates indicate that after just two (2) hours of rainfall, what was a common event quickly became an extreme event, exceeding the 1% AEP (Figure 15). Although peak rainfall values for the entire event reached the 0.2% AEP, the most intense 2-hour period from approximately 9:00 AM to 11:00 AM (1400 to 1600 UTC), as estimated by radar data, likely exceeded the 0.1% AEP. Even without bias correction, the raw radar-only MRMS estimates exceeded nearby gauge estimates due to the isolated nature of this event (Figure 16).

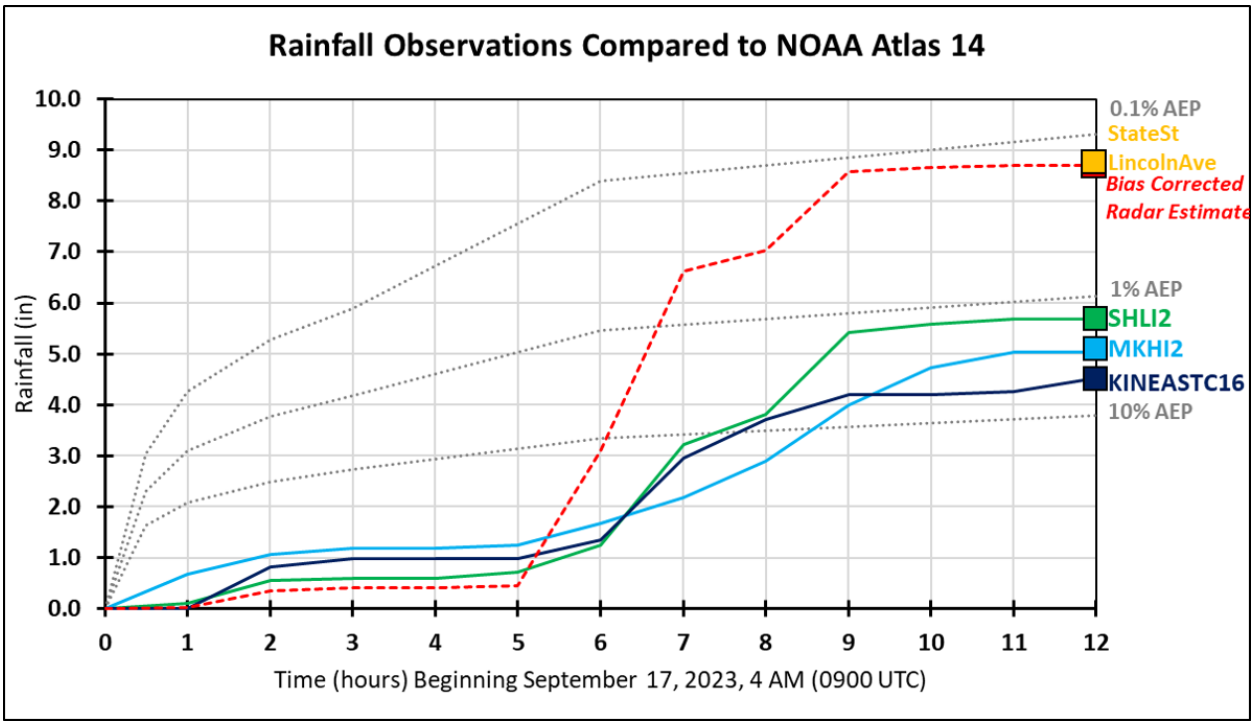


Figure 15. Total accumulated rainfall for three (3) observation locations near the peak rainfall on 17 September 2023. NOAA Atlas 14 rainfall duration frequency are shown by dotted lines. Because no rain gauges were located in the area of peak rainfall, bias-corrected radar estimates from MRMS are shown for reference.

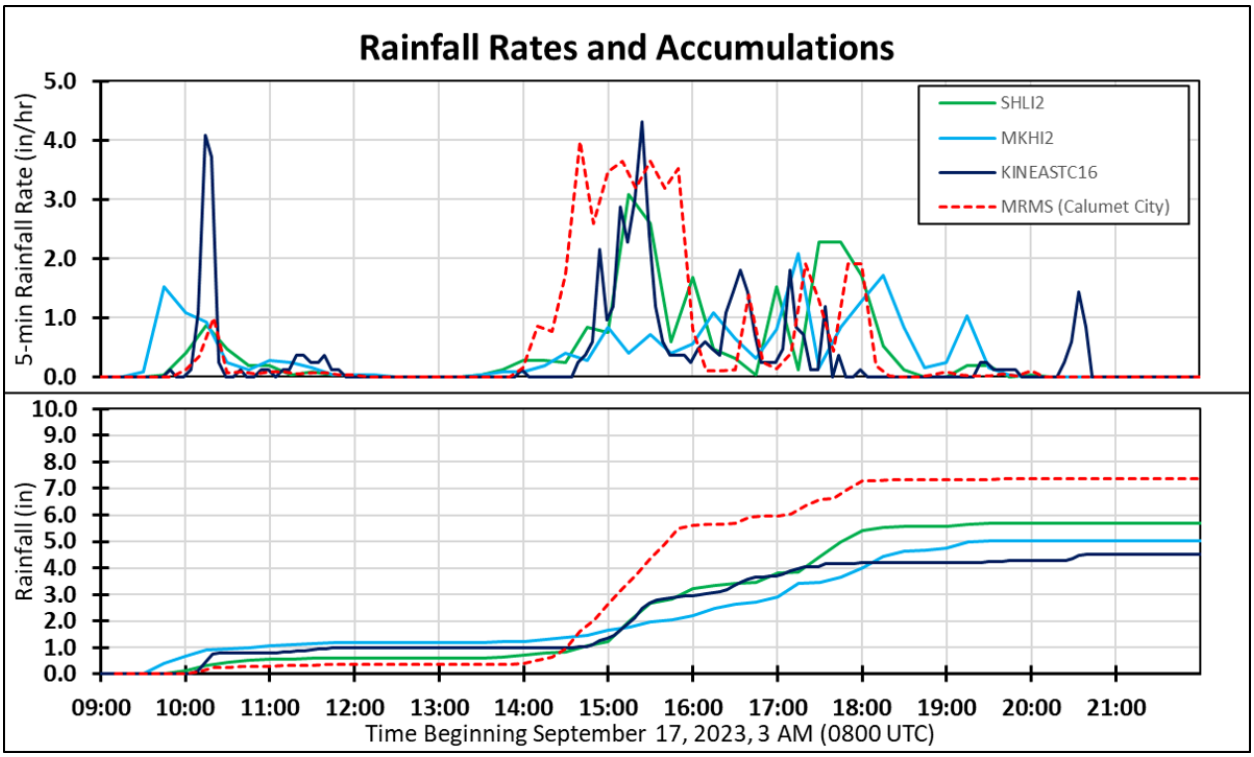


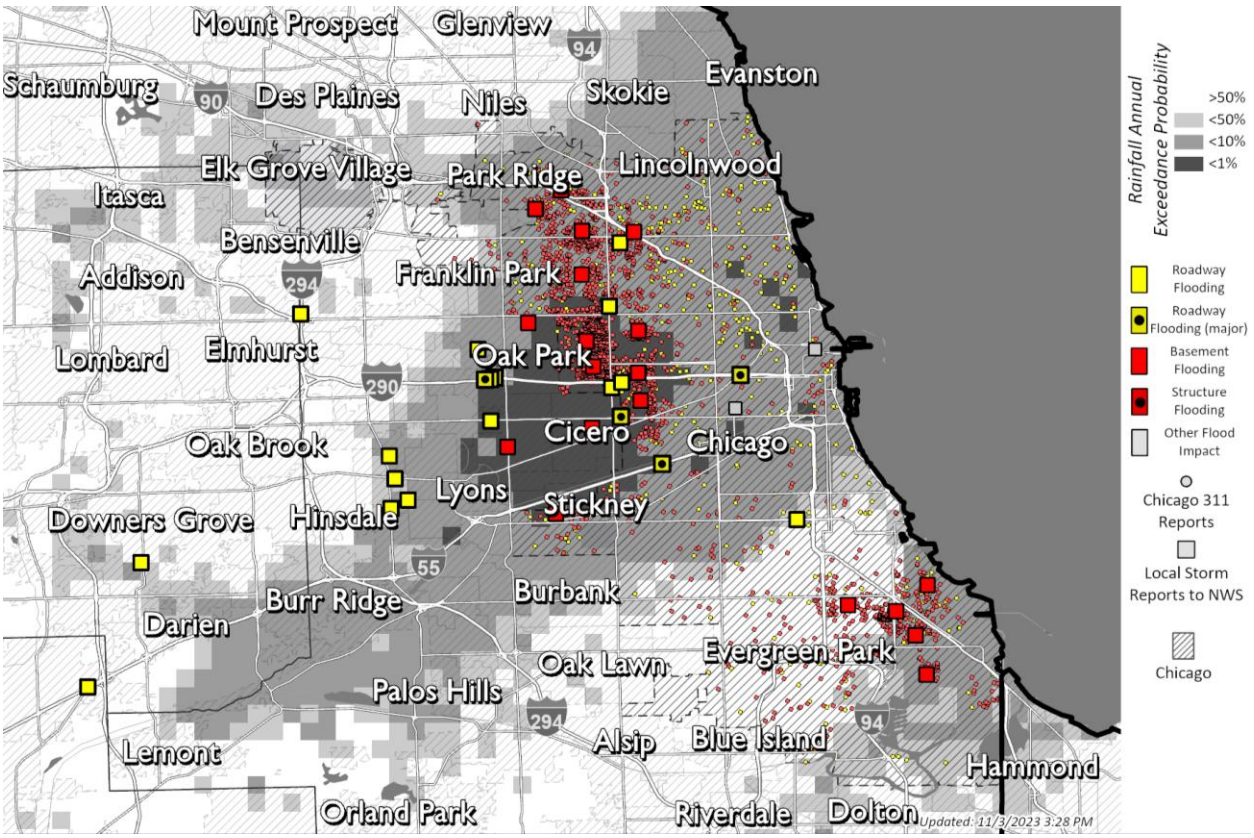
Figure 16. Rain rates for three (3) observation locations in the vicinity of the peak rainfall on 17 September 2023 with radar-only rainfall estimated by MRMS (top), and total accumulated rainfall from the same sources (bottom).

Flash Flood Impacts

2 July

According to news reports and estimates from local emergency management, more than 10,000 homes experienced flood-related damage in portions of Cicero, Oak Park, and Chicago. Although most flooding was confined to roadways and basements of structures, flood damage was likely at least $500 million. As of 21 November 2023, FEMA had approved 74,876 applications for individual assistance, totaling $285.0 million, and $1.7 million in public assistance for the affected municipalities (https://www.fema.gov/disaster/4728). A FEMA press release on 16 November indicated that the Small Business Administration had provided $96.5 million in low-interest disaster loans for homeowners and businesses (FEMA 2023). A review of FEMA's National Flood Insurance Program claims indicated $782,000 paid through 8 November (FEMA 2023).

Areas of known flash flood impacts are illustrated by Figure 17. In addition to neighborhood-scale flash flooding, rainfall was heavy enough to completely fill the deep tunnel and McCook Reservoir, leading to a combined sewer overflow event on the Chicago River and a significant river rise. The Chicago River flooded the Chicago Riverwalk in the Loop, and triggered the opening of Chicago Lock which reversed the flow of the river. Flood impacts and damage amounts are considered preliminary and are subject to change as information becomes available, which is likely to occur after the completion of this report.



406

407 Figure 17. Known flash flood impacts reported to, and collected by, the National Weather Service for the 2 July
408 2023 heavy rainfall event (large squares). Small dots indicate street flooding and basement flooding reports
409 reported to the city of Chicago's 311 system. Reports are generally intended to represent the worst impact from a
410 given area and do not include all areas impacted. Bias-corrected rainfall annual exceedance probability is shown as
411 an underlay in grayscale.

412

17 September

According to news reports and aerial documentation of the event, potentially hundreds of homes experienced flood-related damage in the Calumet City, Burnham, Dolton, and Hammond areas. Some imagery showed entire neighborhoods with all roads flooded and most homes surrounded by water. Damage costs were still being tabulated at the time of this report, but the impacted area was declared a federal disaster on 20 November, suggesting that flood damage estimates exceeded the approximately $23 million threshold for Cook County (https://www.fema.gov/assistance/public/tools-resources/per-capita-impact-indicator). A review of FEMA's National Flood Insurance Program claims indicated $42,000 paid through 8 November (FEMA 2023).

Areas of known flash flood impacts are illustrated by Figure 18. Flood impacts and damage amounts are considered preliminary and are subject to change as information becomes available, which is likely to occur after the completion of this report.

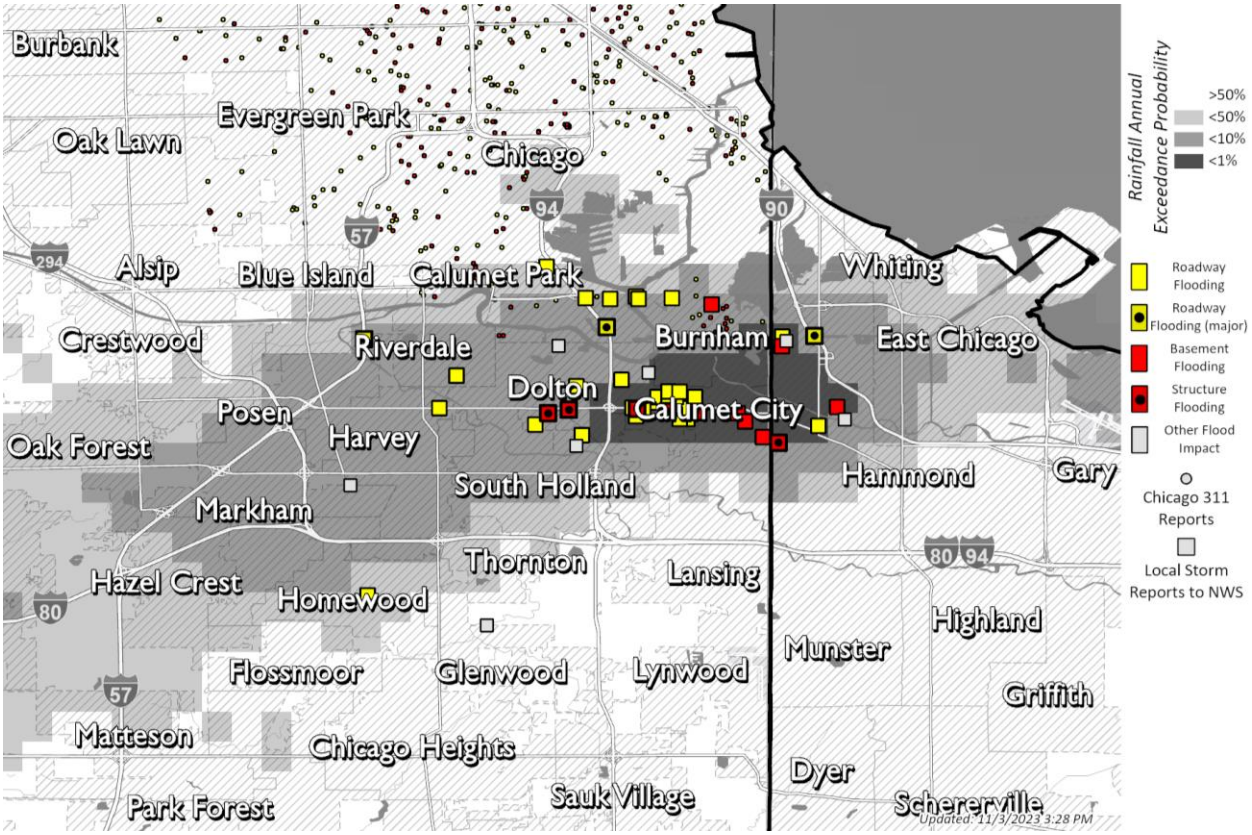


Figure 18. Known flash flood impacts reported to, and collected by, the National Weather Service for the 17 September 2023 heavy rainfall event (large squares). Small dots indicate street flooding and basement flooding reports reported to the city of Chicago's 311 system. Reports are generally intended to represent the worst impact from a given area and do not include all areas impacted. Bias-corrected rainfall annual exceedance probability is shown as an underlay in grayscale.

National Weather Service Products

National Weather Service forecasters typically use a combination of products to assess flash flood potential, including radar reflectivity, rainfall rates, accumulated rainfall compared to gridded flash flood guidance (GFFG), accumulated rainfall compared to depth duration frequency (DDF/ARI) information, and modeled unit streamflow from the Flooded Locations and Simulated Hydrographs (FLASH) project. Four (4) of these indicators – rainfall rate, rainfall to GFFG, rainfall ARI, and unit streamflow – are used at NWS Chicago as part of the 4-Panel Technique (Lincoln and Marquardt 2023) to assist with flash flood warnings. Three (3) of the four (4) products showing the same potential flood hazard is considered a recommendation to issue that product. The output from these products is considered guidance and usefulness may vary from event to event. Warning forecasters use professional judgement in real time as to the usefulness of each product, including any potential biases with the estimates.

2 July

For the 2 July event, the first flood hazard product issued by the NWS Chicago office was a Flood Advisory issued at 6:55 AM (1155 UTC), approximately 2.5 hours prior to a recommendation for the same product by the 4-Panel Technique. A Flash Flood Warning (base impact level) was issued at 9:16 AM (1416 UTC), 24 minutes prior to a recommendation by the 4-Panel Technique. The Flash Flood Warning was upgraded to the "considerable" impact level at 10:15 AM (1515 UTC), with no recommendation by the 4-Panel Technique. It should be noted that two (2) of the four (4) products suggested considerable level impacts at 10:40 AM (1540 UTC), 25 minutes after the warning was issued by NWS Chicago, which suggested higher-level impacts were possible but didn't specifically qualify for a recommendation. The late recommendations by the 4-Panel Technique are directly attributable to the rainfall underestimate by MRMS products. NWS warning forecasters recognized this bias in real-time during the event by monitoring observed rainfall at numerous rain gauges. Flash Flood Warnings were issued prior to recommendations by the 4-Panel Technique and in advance of the known times of reported flood impacts. A timeline of NWS flood hazard products, flood hazard recommendations from the 4-Panel Technique, and a summary of known flood impacts are illustrated by Figure 19.

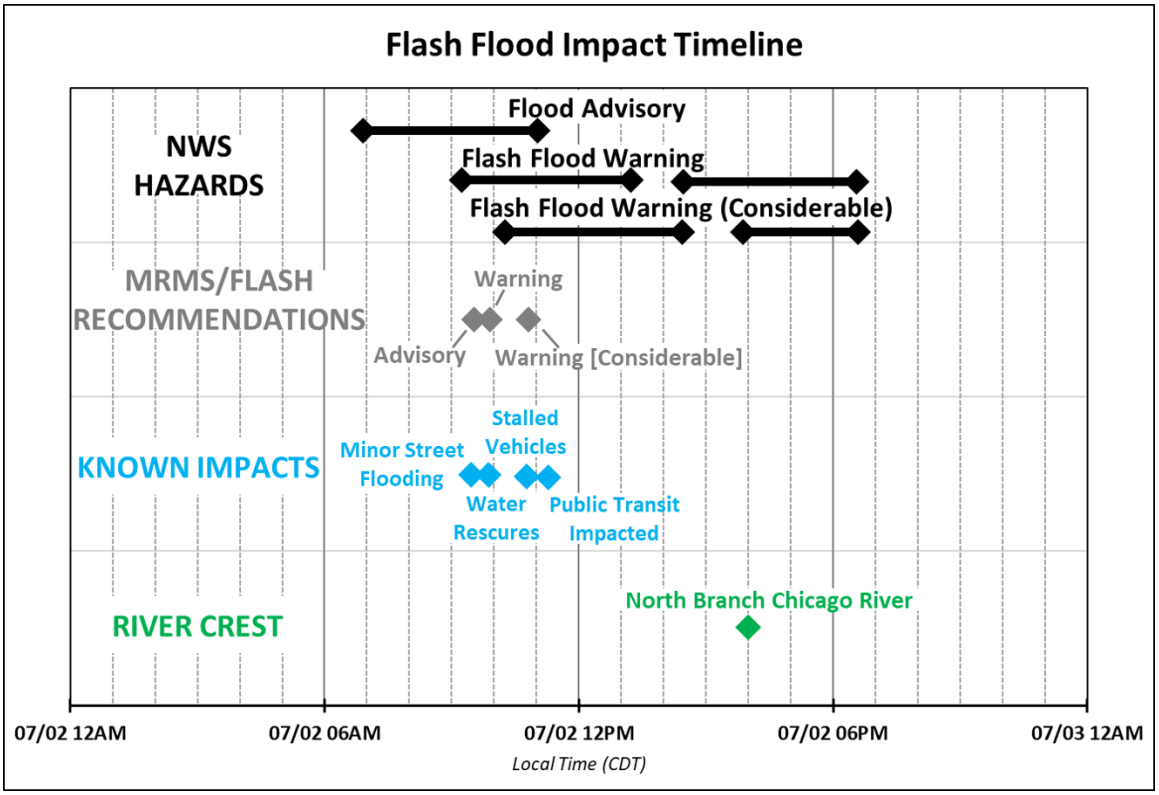


Figure 19. Timeline of National Weather Service hazard products, hazard recommendations from MRMS/FLASH products, known impacts, and observed river crests for the 2 July 2023 flash flood event.

17 September

For the 17 September event, the first flood hazard product issued by the NWS Chicago office was a Flood Advisory issued at 6:02 AM (1102 UTC), over an hour after a recommendation for the same product by the 4-Panel Technique, but prior to any reports of flooding. This Flood Advisory was allowed to expire at 8:56 AM (1356 UTC), with no reports of flooding received from southern Cook County. At 9:30 AM (1430 UTC) the 4-Panel Technique again recommended a Flood Advisory, followed by a recommendation for a Flash Flood Warning at 9:50 AM (1450 UTC). A Flash Flood Warning was issued 17 minutes after the recommendation, but still prior to any reports of flooding. The 4-Panel Technique quickly followed with a recommendation for a Flash Flood Warning (considerable) and a Flash Flood Warning (catastrophic) at 10:10 AM (1510 UTC) and 10:20 AM (1520 UTC), respectively. This quick ramp up in recommendations was likely due to the very intense rainfall rates estimated by radar, which were likely triggering very high sub-hourly ARI and GFFG ratio values, prior to actual rainfall accumulation climbing to significant values. A Flash Flood Warning (considerable impact level) was issued at 10:50 AM (1550 UTC), at least 30 minutes after the recommendation by the 4-Panel Technique, but prior to

reports being received of water rescues and widespread flooding. Although Flash Flood Warnings were not issued prior to recommendations by the 4-Panel Technique, they were issued in advance of the known times of reported flood impacts. The rapid-onset nature of this significant rainfall event possibly reduced the maximum possible lead time because extreme values presented by radar-only products needed to be evaluated. The limited number of automated rain gauges available due to the isolated nature of the heavy rainfall band also made gauge confirmation of rainfall estimates more difficult in real-time. A timeline of NWS flood hazard products, flood hazard recommendations from the 4-Panel Technique, and a summary of known flood impacts are illustrated byFigure 20.

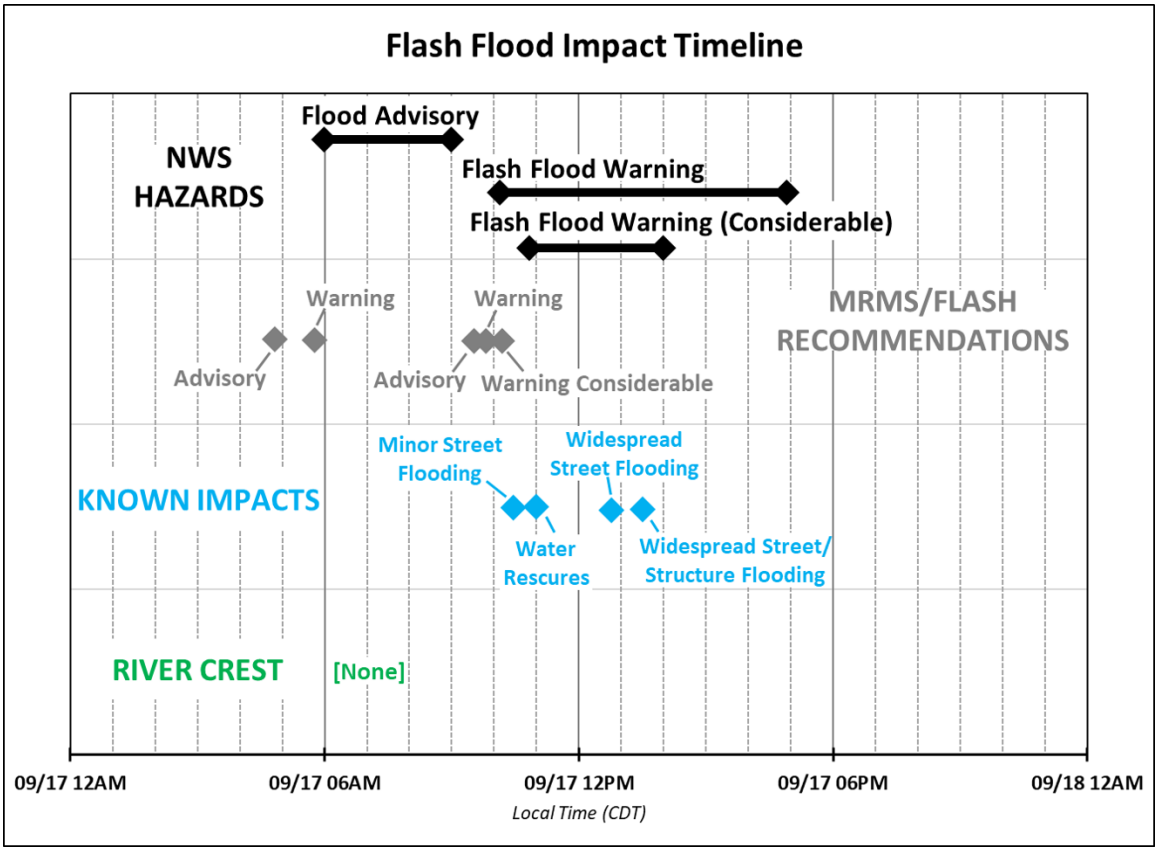


Figure 20. Timeline of National Weather Service hazard products, hazard recommendations from MRMS/FLASH products, known impacts, and observed river crests for the 17 September 2023 flash flood event.

Conclusions

Two significant flash flood events occurred in the Chicago area during the summer of 2023, the first on 2 July 2023 and the second on 17 September 2023. Both events were due to slow-moving low pressure areas, known as MCVs. Gridded rainfall estimates and rain gauges indicate that peak rainfall amounts were near 9.1 inches for 2 July and near 8.7 inches for 17 September. Rainfall of the magnitude seen during each of these events has approximately a 0.2% chance or less of occurring in a given year. During each of these events, flood impacts included widespread roadway flooding and basement flooding. Potentially 10,000 or more structures were impacted on 2 July, causing damages estimated at nearly $500 million (as of the time of this report). Hundreds of structures were potentially impacted on 17 September, but no estimate of damage cost is yet available. Fortunately, no reports of injuries or fatalities were received by the NWS.

The NWS provided lead time for each event, including for the significant flood impacts. The amount of lead time that could be provided was limited by the urban topography of the impacted area. Warning forecasters provided warnings in advance of recommendations by the 4-Panel Technique on 2 July, but after these recommendations on 17 September.

Although very rare for any given location, the heavy rainfall that occurred on 2 July 2023 and 17 September 2023 was not unprecedented for Chicago and vicinity. Preliminary research currently underway at NWS Chicago indicates that multiple events of a similar magnitude have occurred in Chicago and central Cook County since 1950. These events have been caused by a range of synoptic weather patterns.

Acknowledgements

The author would like to acknowledge the comments and suggestions provided by colleagues at the National Weather Service Chicago Weather Forecast Office, which improved this technical report.

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Appendix A

To review the heavy rainfall that occurred in the Chicago metro on 2 July 2023 and 17 September 2023, rainfall observations were collected from 2471 and 508 locations, respectively. These observations were of varying types and of different quality. A few observations were removed from further analysis if 0.0 inches of rainfall was reported in an area of obvious heavy rainfall, or if values were below 50% or above 200% of radar estimates. A list of rainfall observations used in this analysis (filtered to values greater than or equal to 2.0 inches storm total) are indicated by Table A1 and Table A2.

Table A1. List of rain gauge observations collected for analysis of the 2 July 2023 event, filtered to only storm total observations greater than or equal to 2.0 inches.

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILCICER16	WU PWS	2.49	5.60	6.40	8.96	y
BERI2	USGS	2.39	4.72	5.91	8.50	y
ColumbusPark_Davis	Other				8.49	y
KILOAKPA31	WU PWS	1.72	4.40	5.82	8.47	y
KILCHICA498	WU PWS	1.29	3.64	5.77	8.12	y
IL-CK-32	CoCoRaHS				7.92	y
KILCHICA677	WU PWS	1.46	3.16	5.78	7.89	y
KILCHICA974	WU PWS	2.12	3.46	6.27	7.72	y
KILOAKPA38	WU PWS	1.88	4.65	5.30	7.56	y
KILSTICK6	WU PWS	2.38	4.86	5.91	7.47	y
KILOAKPA32	WU PWS	1.90	4.98	6.16	7.42	y
IL-CK-74	CoCoRaHS				7.41	y
KILCHICA790	WU PWS	1.51	3.21	5.36	7.36	y
KILCHICA955	WU PWS	1.81	3.24	5.24	7.34	y
IL-CK-384	CoCoRaHS				7.30	y
KILBERWY3	WU PWS	1.92	4.85	5.63	7.21	y
KILEVANS41	WU PWS	3.90	5.88	5.95	7.10	y
KILCHICA742	WU PWS	2.03	3.12	3.82	7.09	y
KILBERWY5	WU PWS	1.82	4.22	5.05	6.67	y
KILOAKPA18	WU PWS	1.70	3.48	4.91	6.53	y
KILCHICA916	WU PWS	1.59	3.01	4.80	6.52	y
KILCHICA900	WU PWS	1.78	2.84	4.25	6.50	y
KILCHICA956	WU PWS	1.32	2.61	4.16	6.40	y
KILCHICA1024	WU PWS	1.28	2.67	3.38	6.37	y
KILCHICA656	WU PWS	1.95	3.44	4.71	6.34	y
F4705	Other	1.95	3.44	4.71	6.34	y
VittumPark_Davis	Other				6.34	y
KILCHICA679	WU PWS	1.66	2.89	4.83	6.29	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILCHICA733	WU PWS	0.94	2.54	4.38	6.28	y
KILEVANS65	WU PWS	1.97	2.69	3.78	6.26	y
KILCHICA711	WU PWS	2.03	3.39	4.50	6.25	y
KILBERWY12	WU PWS	1.68	3.24	4.36	6.25	y
IL-CK-285	CoCoRaHS				6.20	y
KILWILLO25	WU PWS	2.47	5.36	5.65	6.20	y
KILCHICA843	WU PWS	0.93	2.54	4.14	6.20	y
KILRIVER29	WU PWS	2.02	3.91	4.64	6.12	y
MortonCollege_Davis	Other				6.09	y
KILFORES13	WU PWS	1.37	3.50	4.19	6.07	y
KILCHICA1007	WU PWS	0.78	2.13	3.70	6.06	y
CBLI2	USGS	1.88	2.70	4.92	6.04	y
KILCHICA1049	WU PWS	1.00	2.20	4.00	6.04	y
KWIFITCH6	WU PWS	1.80	2.96	3.59	5.99	y
RVRI2	USGS	1.86	4.35	4.94	5.97	y
F4219	Other	1.37	3.00	4.24	5.95	y
KILOAKPA11	WU PWS	1.27	2.93	4.33	5.95	y
KILCHICA800	WU PWS	1.08	2.21	3.35	5.95	y
KILOAKPA26	WU PWS	1.19	3.01	4.23	5.94	y
IL-CK-323	CoCoRaHS				5.94	y
KILCHICA920	WU PWS	1.72	3.55	4.50	5.90	y
KILCHICA673	WU PWS	0.87	2.51	4.01	5.90	y
Pilsen_Davis	Other				5.90	y
KILCHICA862	WU PWS	1.67	2.69	3.17	5.89	y
KILOAKPA35	WU PWS	1.54	3.70	4.18	5.82	y
KILCHICA985	WU PWS	1.18	2.44	3.80	5.82	y
KILCHICA428	WU PWS	1.38	2.48	4.01	5.79	y
KILCHICA861	WU PWS	0.97	2.74	4.18	5.76	y
KILCHICA569	WU PWS	0.91	2.57	3.77	5.75	y
KILCHICA821	WU PWS	1.32	2.21	2.88	5.74	y
KILCHICA1022	WU PWS	1.52	2.42	3.08	5.74	y
KILCHICA892	WU PWS	1.38	2.12	3.10	5.73	y
KILCHICA865	WU PWS	1.44	2.52	3.86	5.73	y
KILCHICA971	WU PWS	2.01	3.02	4.26	5.68	y
KILCHICA1067	WU PWS	1.89	2.57	3.17	5.68	y
KILCHICA952	WU PWS	1.22	2.40	3.37	5.64	y
CBBI2	USGS	1.46	2.43	3.76	5.63	y
KILCHICA850	WU PWS	0.91	2.43	3.73	5.62	y
KILCHICA1000	WU PWS	1.83	3.05	4.02	5.60	y
KILCHICA823	WU PWS	1.54	2.40	3.02	5.56	y
KILCHICA1036	WU PWS	0.91	2.45	3.69	5.55	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILCHICA883	WU PWS	1.22	2.52	3.72	5.54	y
KILCHICA659	WU PWS	1.42	2.77	3.67	5.54	y
KILCHICA747	WU PWS	1.04	2.20	3.33	5.53	y
KILCHICA1004	WU PWS	1.81	2.71	4.86	5.50	y
KILCHICA631	WU PWS	1.35	2.22	2.96	5.50	y
KILBURRR7	WU PWS	2.70	4.80	4.99	5.48	y
KILCHICA775	WU PWS	0.89	2.17	3.49	5.46	y
KILBROOK18	WU PWS	1.71	3.97	4.52	5.45	y
KILCHICA798	WU PWS	1.16	2.32	3.33	5.45	y
KILCHICA984	WU PWS	1.11	2.04	2.75	5.44	y
KILCHICA173	WU PWS	1.25	2.36	3.80	5.42	y
KILCHICA832	WU PWS	1.01	2.04	2.82	5.41	y
KILCHICA1009	WU PWS	1.55	2.28	3.11	5.38	y
KILBROOK19	WU PWS	1.63	3.87	4.46	5.35	y
KILCHICA979	WU PWS	1.07	2.08	2.96	5.33	y
KILWILLO40	WU PWS	1.49	3.89	4.42	5.29	y
KILCHICA1001	WU PWS	1.49	2.28	3.06	5.29	y
KILCHICA1082	WU PWS	0.74	1.92	3.21	5.26	y
KILCHICA681	WU PWS	1.49	2.17	2.79	5.24	y
KILCHICA625	WU PWS	1.20	2.38	3.46	5.21	y
KILCHICA1018	WU PWS	0.83	1.95	3.35	5.20	y
KILCHICA989	WU PWS	1.10	2.27	3.20	5.20	y
KILCHICA700	WU PWS	0.76	2.08	3.41	5.18	y
KILYATES5	WU PWS	3.24	4.86	5.13	5.17	y
KILCHICA1068	WU PWS	1.91	3.05	4.16	5.16	y
CHJI2	USGS	1.56	4.16	4.32	5.15	y
IL-CK-371	CoCoRaHS				5.13	y
KILCHICA820	WU PWS	1.67	2.15	2.97	5.11	y
IL-CK-94	CoCoRaHS				5.11	y
MWRD_Stickney	MWRD				5.08	y
KILCHICA736	WU PWS	1.36	2.11	2.87	5.08	y
KILFORES12	WU PWS	1.36	3.32	3.78	5.07	y
KILEVANS64	WU PWS	1.51	2.11	3.02	5.07	y
KILEVANS71	WU PWS	1.29	2.07	2.80	5.07	y
KILCHICA600	WU PWS	1.33	2.35	3.56	5.05	y
KILCHICA844	WU PWS	1.38	2.21	3.06	5.05	y
KILCHICA951	WU PWS	0.79	2.11	3.40	5.03	y
KILOAKPA33	WU PWS	1.06	2.64	3.46	5.02	y
KILWILLO36	WU PWS	2.14	4.40	4.62	5.01	y
KILBROOK16	WU PWS	1.78	3.77	4.20	4.99	y
KILCHICA1041	WU PWS	1.51	2.14	2.79	4.99	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILCHICA868	WU PWS	0.98	1.85	2.77	4.99	y
IL-CK-232	CoCoRaHS				4.97	y
MWRD_MOB	MWRD				4.96	y
KILWILLO18	WU PWS	2.11	4.59	4.83	4.94	y
KILCHICA911	WU PWS	2.01	3.03	4.01	4.94	y
KILEVANS48	WU PWS	1.74	2.52	3.22	4.94	y
MWRD_NorthBranchPS	MWRD				4.92	y
KILCHICA487	WU PWS	1.99	2.84	3.75	4.91	y
KILCHICA931	WU PWS	1.20	2.25	3.71	4.91	y
KILEVANS51	WU PWS	1.07	1.94	2.69	4.89	y
KILBRIDG5	WU PWS	1.25	2.54	3.47	4.88	y
KILCHICA796	WU PWS	0.93	1.86	2.75	4.87	y
KILCHICA129	WU PWS	1.01	2.15	2.96	4.83	y
KILCHICA867	WU PWS	0.91	2.18	2.89	4.79	y
KILCHICA714	WU PWS	1.17	1.90	2.65	4.77	y
KILCHICA1040	WU PWS	1.54	2.29	2.91	4.77	y
KILCHICA891	WU PWS	1.00	1.97	2.74	4.76	y
KILCHICA914	WU PWS	0.91	1.76	3.25	4.72	y
KILCHICA1048	WU PWS	1.00	2.00	2.77	4.72	y
KILCHICA939	WU PWS	1.79	2.58	3.71	4.71	y
KILCHICA898	WU PWS	0.82	1.76	2.69	4.71	y
KILRIVER35	WU PWS	1.07	2.34	3.19	4.70	y
KILLAGRA32	WU PWS	1.78	3.34	3.92	4.69	y
KILCHICA996	WU PWS	0.58	1.53	2.78	4.69	y
IL-DP-79	CoCoRaHS				4.69	y
CCHI2	USGS	0.96	2.44	3.24	4.69	y
KILEVANS83	WU PWS	1.48	2.29	3.21	4.65	y
MWRD_Obrien	MWRD				4.63	y
MWRD_Springfield	MWRD				4.62	y
KILCHICA577	WU PWS	0.93	1.70	2.71	4.61	y
KILCHICA934	WU PWS	0.96	1.76	2.50	4.59	y
KMDW	ASOS	1.60	2.48	3.44	4.57	y
IL-CK-345	CoCoRaHS				4.54	y
KILSKOKI38	WU PWS	0.88	1.60	2.56	4.54	y
KILCHICA1042	WU PWS	1.21	1.97	3.07	4.53	y
C8740	Other	1.72	3.27	3.82	4.50	y
KILCHICA1035	WU PWS	1.06	1.98	2.56	4.50	y
KILLAGRA2	WU PWS	1.73	3.28	3.82	4.49	y
KILCHICA591	WU PWS	0.90	1.89	2.61	4.46	y
IL-CK-12	CoCoRaHS				4.46	y
KILWILLO41	WU PWS	1.15	3.37	3.84	4.45	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
IL-DP-186	CoCoRaHS				4.44	y
KILCHICA1025	WU PWS	0.80	2.01	2.73	4.42	y
KILCHICA1017	WU PWS	0.81	2.22	2.89	4.41	y
KILCHICA1077	WU PWS	1.04	1.85	2.84	4.41	y
KILCHICA950	WU PWS	1.24	2.25	3.36	4.40	y
KILCHICA530	WU PWS	0.88	1.62	2.72	4.39	y
IL-CK-214	CoCoRaHS				4.37	y
IL-CK-321	CoCoRaHS				4.36	y
LAGI2	USGS	1.72	3.67	3.95	4.35	y
KILNILES18	WU PWS	1.56	2.22	3.02	4.34	y
KILEVANS76	WU PWS	1.20	1.85	2.58	4.30	y
IL-KN-119	CoCoRaHS				4.30	y
KILRIVER36	WU PWS	0.88	1.95	2.78	4.26	y
KILCHICA1033	WU PWS	1.02	1.78	2.44	4.26	y
KILEVANS52	WU PWS	0.77	1.64	2.44	4.26	y
KILPLAIN154	WU PWS	3.39	3.75	3.86	4.25	y
KILCHICA1010	WU PWS	0.92	1.97	2.92	4.24	y
KILITASC7	WU PWS	1.41	2.86	3.42	4.22	y
IL-CK-14	CoCoRaHS				4.21	y
KILHARWO17	WU PWS	1.33	1.85	2.59	4.18	y
KILCHICA999	WU PWS	0.95	1.68	2.44	4.17	y
KILEVANS67	WU PWS	1.02	1.57	2.40	4.17	y
KILLAGRA27	WU PWS	1.32	3.10	3.54	4.15	y
LMNI2	USGS	2.07	3.53	3.80	4.12	y
KILCHICA109	WU PWS	0.94	1.71	2.32	4.11	y
KILPARKR11	WU PWS	1.19	1.78	2.41	4.11	y
E0592	Other	0.94	1.71	2.32	4.11	y
KILCHICA882	WU PWS	0.70	1.68	2.90	4.08	y
KILCHICA855	WU PWS	0.99	1.84	2.46	4.08	y
IL-CK-229	CoCoRaHS				4.07	y
E5858	Other	0.75	1.62	2.46	4.06	y
KILCHICA847	WU PWS	1.15	2.25	2.75	4.06	y
KILSKOKI34	WU PWS	0.62	1.39	2.33	4.06	y
KILWILME45	WU PWS	0.83	1.34	2.29	4.06	y
KILMILAN9	WU PWS	2.19	3.71	4.00	4.05	y
KILALGON65	WU PWS	1.95	3.32	3.89	4.05	y
KILCHICA716	WU PWS	0.68	1.54	2.60	4.00	y
KILCHICA1078	WU PWS	0.69	1.95	2.90	4.00	y
KILBURRR9	WU PWS	1.58	3.45	3.65	3.99	y
KINWHITI8	WU PWS	1.56	2.42	2.84	3.98	y
MWRD_RacinePS	MWRD				3.98	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILCHICA972	WU PWS	0.94	1.67	2.56	3.95	y
KILSKOKI19	WU PWS	0.64	1.37	2.35	3.94	y
KILCHICA1003	WU PWS	1.01	1.61	2.27	3.92	y
KILHOPEW1	WU PWS	2.60	3.13	3.46	3.90	y
KILDOWNE22	WU PWS	2.63	3.09	3.17	3.90	y
KILCOUNT1	WU PWS	1.28	2.77	3.26	3.90	y
KILSKOKI32	WU PWS	0.94	1.58	2.45	3.90	y
KILDARIE13	WU PWS	2.17	3.24	3.34	3.89	y
KILCHICA329	WU PWS	0.63	1.76	2.61	3.87	y
KILLISLE37	WU PWS	2.27	3.20	3.47	3.86	y
IL-CK-63	CoCoRaHS				3.85	y
KILCHICA452	WU PWS	1.15	1.61	2.22	3.85	y
KILALGON67	WU PWS	2.33	3.19	3.73	3.85	y
KILITASC17	WU PWS	1.12	2.36	2.94	3.85	y
KILSKOKI39	WU PWS	0.71	1.42	2.23	3.84	y
KILCHICA1013	WU PWS	1.13	1.84	2.42	3.80	y
KILWILME47	WU PWS	0.73	1.44	2.15	3.80	y
KILCHICA975	WU PWS	0.86	1.28	2.24	3.79	y
KILCHICA256	WU PWS	0.92	1.66	2.15	3.78	y
KWISOUTH57	WU PWS	2.15	3.12	3.77	3.77	y
KILPARKR12	WU PWS	0.72	1.40	2.06	3.74	y
BPRI2	USGS	1.08	1.93	2.59	3.73	y
KILBROOK22	WU PWS	1.27	2.62	3.00	3.72	y
KILPALAT74	WU PWS	2.23	3.18	3.52	3.71	y
KILINDIA2	WU PWS	1.37	2.88	3.17	3.69	y
KILELMHU31	WU PWS	0.79	1.23	2.15	3.69	y
KILELKGR8	WU PWS	0.93	1.97	2.52	3.69	y
KILMUNDE23	WU PWS	2.09	2.11	3.09	3.69	y
KILCHICA734	WU PWS	1.45	1.57	1.80	3.68	y
KILDARIE17	WU PWS	1.52	2.88	3.09	3.68	y
KILCHICA693	WU PWS	0.81	1.65	2.38	3.68	y
F5674	Other	0.81	1.65	2.38	3.68	y
KILDESPL47	WU PWS	0.73	1.54	2.29	3.66	y
KILDESPL17	WU PWS	0.69	1.29	2.30	3.64	y
DARI2	USGS	1.37	3.06	3.21	3.60	y
SKOI2	USGS	0.61	1.25	2.18	3.60	y
KILARLIN70	WU PWS	1.43	2.38	2.79	3.60	y
KILCHICA997	WU PWS	1.41	2.82	3.01	3.59	y
C7543	Other	0.55	1.43	2.52	3.58	y
KILWILLO11	WU PWS	1.32	2.74	3.02	3.57	y
KILBURRR1	WU PWS	0.49	1.38	2.50	3.56	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILDEKAL49	WU PWS	1.90	2.92	3.48	3.56	y
IL-FL-7	CoCoRaHS				3.55	y
KILGOLF2	WU PWS	0.86	1.52	2.46	3.55	y
KILMARKH1	WU PWS	0.86	2.12	2.25	3.55	y
KILALGON5	WU PWS	1.78	2.97	3.43	3.54	y
KILPALAT92	WU PWS	1.85	2.81	3.05	3.53	y
KILPLAIN41	WU PWS	1.74	3.14	3.28	3.52	y
KILDESPL67	WU PWS	0.78	1.46	2.15	3.51	y
KILSMITH10	WU PWS	1.23	2.67	3.49	3.50	y
KILDARIE14	WU PWS	1.55	2.76	2.91	3.50	y
KILALGON70	WU PWS	1.81	3.24	3.44	3.50	y
KILDESPL29	WU PWS	0.67	1.32	1.97	3.48	y
KILBRIDG4	WU PWS	0.93	1.71	2.14	3.47	y
KILEVANS68	WU PWS	0.75	1.62	2.33	3.46	y
KILALGON56	WU PWS	2.07	2.80	3.34	3.45	y
KILOAKLA55	WU PWS	1.01	1.47	2.17	3.43	y
KILADDIS17	WU PWS	0.78	1.78	2.43	3.43	y
KILCHICA511	WU PWS	0.81	1.52	1.98	3.41	y
KILMINOO8	WU PWS	1.82	3.09	3.19	3.40	y
KILORLAN75	WU PWS	1.32	2.34	2.49	3.40	y
KILADDIS10	WU PWS	0.87	1.34	2.04	3.40	y
KILCHICA912	WU PWS	0.79	1.44	2.06	3.40	y
KILLOCKP34	WU PWS	1.33	1.99	3.25	3.38	y
IL-PR-20	CoCoRaHS				3.38	y
KILWILME39	WU PWS	0.72	1.47	2.29	3.35	y
MKHI2	USGS	1.06	2.13	2.27	3.34	y
KILWATER5	WU PWS	1.16	2.22	3.19	3.34	y
KILELKGR37	WU PWS	0.73	1.69	2.28	3.34	y
IL-CK-382	CoCoRaHS				3.33	y
KORD	ASOS	0.76	1.08	1.81	3.33	y
KILLASAL6	WU PWS	2.59	3.19	3.22	3.33	y
KILWHEAT73	WU PWS	1.09	2.44	2.77	3.32	y
KILPONTI9	WU PWS	1.96	3.28	3.30	3.31	y
KILARLIN48	WU PWS	1.16	2.00	2.39	3.31	y
KILLOCKP46	WU PWS	1.91	2.61	3.02	3.30	y
KWIWATER14	WU PWS	0.98	1.74	2.92	3.30	y
KILDOWNE58	WU PWS	1.48	2.47	2.57	3.29	y
KILWESTC59	WU PWS	1.37	2.26	2.60	3.29	y
KILGLEND8	WU PWS	1.19	2.15	2.87	3.29	y
KILCHICA776	WU PWS	0.56	1.31	1.95	3.28	y
KILROMEO18	WU PWS	1.19	2.61	2.98	3.28	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILWILME36	WU PWS	0.87	1.46	2.19	3.28	y
KILCHICA1019	WU PWS	1.09	1.61	2.30	3.27	y
KILOAKLA7	WU PWS	0.96	1.44	2.03	3.23	y
KILHOMER11	WU PWS	1.74	2.56	2.87	3.22	y
KILDOWNE61	WU PWS	1.73	2.44	2.52	3.22	y
KILDESPL16	WU PWS	0.82	1.56	2.17	3.21	y
KILGLENV11	WU PWS	0.66	1.32	2.16	3.20	y
KILWILME28	WU PWS	0.65	1.40	2.22	3.20	y
KILGLENC28	WU PWS	0.61	1.39	2.07	3.19	y
KILARLIN58	WU PWS	0.52	1.20	1.86	3.18	y
KILLAGRA14	WU PWS	1.00	2.25	2.52	3.16	y
KILGLENV44	WU PWS	0.61	1.53	2.26	3.16	y
KINHAMMO38	WU PWS	0.93	1.36	1.57	3.15	y
MWRD_Kirie	MWRD				3.15	y
KILMORTO39	WU PWS	0.83	1.42	2.11	3.14	y
DSCI2	USGS	0.78	1.42	2.05	3.14	y
KILDOWNE60	WU PWS	1.40	2.34	2.44	3.13	y
KILCHICA936	WU PWS	0.66	1.35	1.62	3.12	y
IL-CK-149	CoCoRaHS				3.11	y
KILWYOMI8	WU PWS	2.25	2.81	2.81	3.11	y
KILPLAIN162	WU PWS	2.51	2.71	2.83	3.11	y
KILOAKLA23	WU PWS	0.98	1.43	1.92	3.11	y
KILWILME43	WU PWS	0.60	1.26	2.00	3.11	y
CHWI2	USGS	1.28	2.22	2.58	3.10	y
KILOAKLA52	WU PWS	0.79	1.33	1.83	3.09	y
KILCHICA945	WU PWS	0.61	1.33	1.82	3.09	y
IL-CK-64	CoCoRaHS				3.08	y
KILSKOKI10	WU PWS	0.67	1.19	1.89	3.07	y
IL-DP-150	CoCoRaHS				3.06	y
IL-MCH-110	CoCoRaHS				3.05	y
KILELMHU61	WU PWS	0.57	0.94	1.78	3.05	y
IL-CK-50	CoCoRaHS				3.04	y
KILMORTO35	WU PWS	0.46	1.01	1.76	3.03	y
KILPALAT12	WU PWS	1.93	2.63	2.93	3.03	y
KILDOWNE69	WU PWS	1.63	2.35	2.43	3.02	y
PPKI2	USGS	1.34	2.37	2.68	3.01	y
IL-WL-182	CoCoRaHS				3.01	y
KILCHICA980	WU PWS	0.51	1.07	1.81	3.01	y
KILALGON73	WU PWS	1.98	2.48	2.95	3.01	y
KILWESTC35	WU PWS	1.36	2.16	2.85	3.00	y
KILPLAIN124	WU PWS	1.31	2.61	2.80	2.99	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILLAGRA39	WU PWS	0.94	1.89	2.33	2.99	y
IL-DP-98	CoCoRaHS				2.99	y
KILFRANK74	WU PWS	0.57	1.00	1.75	2.98	y
KILDESPL46	WU PWS	0.65	1.29	1.80	2.97	y
IL-DP-85	CoCoRaHS				2.97	y
KILPLAIN169	WU PWS	1.77	2.41	2.52	2.96	y
KILSHABB10	WU PWS	1.79	2.35	2.76	2.96	y
KILWILLO33	WU PWS	1.32	2.19	2.39	2.96	y
IL-CK-326	CoCoRaHS				2.96	y
KILTAYLO14	WU PWS	1.19	1.81	2.87	2.95	y
WBRI2	USGS	1.34	2.05	2.40	2.95	y
KILLOCKP44	WU PWS	0.80	2.13	2.70	2.92	y
KILLISLE35	WU PWS	2.06	2.53	2.66	2.92	y
IL-MH-5	CoCoRaHS				2.92	y
KILITASC14	WU PWS	0.83	1.60	2.07	2.91	y
KILDESPL48	WU PWS	0.65	1.14	1.66	2.91	y
KILSPEER3	WU PWS	2.30	2.50	2.74	2.90	y
KILHOMEW30	WU PWS	0.63	1.43	1.62	2.90	y
KINEASTC16	WU PWS	0.69	1.48	1.79	2.90	y
KILGLENV36	WU PWS	0.63	1.21	1.99	2.88	y
KILWHEAT44	WU PWS	1.24	2.22	2.53	2.87	y
KILMELRO2	WU PWS	0.55	1.07	1.70	2.87	y
KILLOCKP74	WU PWS	0.72	1.91	2.69	2.85	y
KILROSEM2	WU PWS	0.98	1.37	1.77	2.84	y
IL-WL-51	CoCoRaHS				2.82	y
KILWILME41	WU PWS	0.57	1.20	1.91	2.81	y
KILMOUNT107	WU PWS	0.43	1.06	1.73	2.80	y
KILPEORI7	WU PWS	1.51	2.35	2.72	2.80	y
KINFORTW58	WU PWS	2.00	2.40	2.41	2.80	y
KILCLARE20	WU PWS	1.14	1.95	2.13	2.80	y
KILLAGRA42	WU PWS	0.92	1.72	2.15	2.80	y
KILHOFFM19	WU PWS	1.09	2.33	2.67	2.80	y
IL-CK-152	CoCoRaHS				2.79	y
KILBUFFA36	WU PWS	1.02	1.62	2.03	2.79	y
CFKI2	USGS	0.51	1.02	1.70	2.78	y
KILBIGRO6	WU PWS	1.57	2.11	2.48	2.78	y
KILPAWPA15	WU PWS	1.25	2.22	2.72	2.77	y
KILDOWNE40	WU PWS	1.55	2.11	2.26	2.77	y
WHTI2	COOP				2.76	y
KILHIGHL91	WU PWS	0.57	1.33	1.85	2.75	y
CHUI2	USGS	1.01	2.02	2.11	2.74	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILPEORI34	WU PWS	1.54	2.26	2.65	2.73	y
KILLOCKP69	WU PWS	0.82	1.83	2.58	2.73	y
KILALGON53	WU PWS	0.93	2.06	2.64	2.73	y
HRVI2	USGS	0.61	1.62	1.95	2.73	y
KILOAKLA12	WU PWS	0.66	1.11	1.57	2.70	y
KILSUGAR26	WU PWS	1.29	1.91	2.29	2.70	y
KILWESTE7	WU PWS	0.80	1.58	1.90	2.70	y
KILWOODD9	WU PWS	0.29	0.78	1.38	2.70	y
KILPALAT47	WU PWS	1.90	2.16	2.46	2.70	y
KILWHEAT36	WU PWS	0.51	1.29	2.14	2.70	y
KILPLAIN119	WU PWS	1.37	2.37	2.48	2.69	y
KILROMEO26	WU PWS	0.92	2.13	2.44	2.69	y
KILCHICA851	WU PWS	0.85	1.50	2.22	2.69	y
IL-WL-131	CoCoRaHS				2.69	y
IL-CK-163	CoCoRaHS				2.69	y
KILHIGHL112	WU PWS	0.62	1.31	1.71	2.68	y
KILFLOSS6	WU PWS	0.60	1.28	1.95	2.68	y
ADSI2	USGS	0.53	0.85	1.46	2.68	y
KILTHORN1	WU PWS	0.65	1.02	1.24	2.67	y
KILDARIE22	WU PWS	1.15	1.85	2.09	2.67	y
KILWESTM21	WU PWS	0.90	1.68	1.81	2.67	y
KILADDIS16	WU PWS	0.33	0.86	1.39	2.66	y
IL-KN-134	CoCoRaHS				2.65	y
KILHINCK13	WU PWS	1.22	1.96	2.52	2.64	y
KILLOMBA31	WU PWS	0.43	0.95	1.44	2.64	y
TPKI2	USGS	1.21	1.36	1.36	2.64	y
KILPEORI26	WU PWS	1.36	2.35	2.51	2.63	y
KILMONEE31	WU PWS	0.71	0.97	1.56	2.63	y
KILVILLA28	WU PWS	0.40	0.85	1.57	2.62	y
KILMOUNT119	WU PWS	0.42	1.10	1.75	2.62	y
IL-FL-24	CoCoRaHS				2.61	y
KILHOFFM46	WU PWS	1.07	2.19	2.52	2.61	y
KILWYOMI9	WU PWS	1.95	2.32	2.47	2.60	y
KINFORTW208	WU PWS	2.09	2.42	2.45	2.60	y
KILBOLIN43	WU PWS	1.66	2.14	2.29	2.60	y
KILDOWNE65	WU PWS	1.21	1.89	2.04	2.60	y
KILMOUNT88	WU PWS	0.64	1.16	1.81	2.60	y
KILARLIN55	WU PWS	0.87	1.57	1.88	2.60	y
KILMONEE10	WU PWS	0.92	1.02	1.39	2.59	y
KILDEERF5	WU PWS	0.72	1.07	1.50	2.59	y
KILGLENE43	WU PWS	1.11	1.72	2.01	2.58	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILYATES4	WU PWS	1.75	2.23	2.38	2.57	y
KILDOWNE68	WU PWS	1.67	2.01	2.09	2.57	y
KILPARKR7	WU PWS	0.64	0.93	1.54	2.57	y
KILSTREA21	WU PWS	2.43	2.50	2.50	2.56	y
KILSUGAR30	WU PWS	1.27	1.90	2.22	2.56	y
KILNORTH63	WU PWS	0.48	1.23	1.72	2.56	y
KILOAKPA9	WU PWS	1.43	2.29	2.50	2.55	n
KILGLENE31	WU PWS	1.01	1.34	1.99	2.55	y
KILGLENE40	WU PWS	0.99	1.34	1.99	2.55	y
IL-KN-142	CoCoRaHS				2.54	y
KILHOMER4	WU PWS	1.13	2.00	2.23	2.54	y
WJWI2	COOP				2.53	y
KILHIGHL94	WU PWS	0.57	1.25	1.67	2.53	y
KILWESTM9	WU PWS	0.92	1.62	1.75	2.53	y
KILLOMBA42	WU PWS	0.44	1.08	1.49	2.53	y
IL-DP-38	CoCoRaHS				2.52	y
KILGLENW1	WU PWS	1.06	1.59	1.68	2.52	y
KILLISLE43	WU PWS	1.00	1.99	2.15	2.52	y
IL-DP-32	CoCoRaHS				2.51	y
KILWATER61	WU PWS	1.52	2.19	2.41	2.51	y
KILWOODR22	WU PWS	1.79	1.97	2.09	2.51	y
KILNEWLE66	WU PWS	1.18	1.63	2.01	2.50	y
KILMAPLE17	WU PWS	1.38	1.89	2.40	2.50	y
KILOAKPA37	WU PWS	0.66	1.63	1.92	2.50	n
KILGLENC26	WU PWS	0.46	1.21	1.81	2.50	y
LNSI2	COOP				2.50	y
KILLOCKP54	WU PWS	0.63	1.69	2.35	2.49	y
KILMELRO15	WU PWS	0.62	0.92	1.51	2.49	y
KILMOUNT129	WU PWS	0.43	1.03	1.62	2.49	y
KILALGON30	WU PWS	0.89	1.82	2.34	2.49	y
KILHIGHL95	WU PWS	0.48	1.03	1.41	2.49	y
IL-WF-24	CoCoRaHS				2.48	y
LSGI2	USGS	0.89	1.29	1.44	2.48	y
KILFLOSS13	WU PWS	0.63	1.04	1.47	2.47	y
KILWATER48	WU PWS	1.43	2.12	2.36	2.47	y
KILCLARE22	WU PWS	1.07	1.69	1.88	2.47	y
KILPROSP3	WU PWS	0.48	1.05	1.58	2.47	y
KILLAKEF43	WU PWS	1.29	2.01	2.19	2.47	y
IL-DP-40	CoCoRaHS				2.47	y
KILPRINC57	WU PWS	1.28	2.05	2.32	2.46	y
KILDOWNE38	WU PWS	1.09	1.80	1.97	2.46	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILADDIS21	WU PWS	0.45	0.80	1.39	2.46	y
KILELKGR4	WU PWS	0.64	1.29	1.73	2.46	y
KILROLLI14	WU PWS	0.87	1.60	1.88	2.46	y
KILALGON61	WU PWS	1.32	2.04	2.39	2.46	y
IL-IR-14	CoCoRaHS				2.46	y
IL-CK-260	CoCoRaHS				2.46	y
KILSOUTH38	WU PWS	0.66	1.48	1.68	2.45	y
KILWESTC57	WU PWS	0.49	1.29	1.76	2.45	y
KILGLENE38	WU PWS	0.48	0.87	1.58	2.45	y
IN-CR-9	CoCoRaHS				2.45	y
KILOAKFO24	WU PWS	0.72	0.90	1.00	2.44	y
IL-CK-75	CoCoRaHS				2.44	y
KILLOMBA33	WU PWS	0.52	1.04	1.41	2.42	y
IL-LK-74	CoCoRaHS				2.42	y
KILGLENE36	WU PWS	0.38	0.88	1.33	2.41	y
KINROANO33	WU PWS	1.19	2.09	2.40	2.40	y
KILFLOSS10	WU PWS	0.52	1.35	1.67	2.40	y
KILNEWLE49	WU PWS	0.95	1.41	2.26	2.40	y
KILHAMPS37	WU PWS	1.09	2.03	2.33	2.40	y
KILELGIN30	WU PWS	1.38	2.15	2.30	2.40	y
IL-LV-7	CoCoRaHS				2.40	y
KILPLAIN164	WU PWS	1.36	1.86	2.00	2.39	y
KILCREST12	WU PWS	1.54	2.05	2.38	2.39	y
KILBLOOM123	WU PWS	0.99	1.43	2.02	2.39	y
KILBENSE12	WU PWS	0.45	0.73	1.38	2.39	y
IL-CK-364	CoCoRaHS				2.39	y
IL-WF-28	CoCoRaHS				2.39	y
KILWESTM8	WU PWS	0.74	1.56	1.67	2.38	y
KILMOUNT33	WU PWS	0.64	1.22	1.71	2.38	y
KILPALAT13	WU PWS	1.22	1.93	2.25	2.38	y
KILPALAT100	WU PWS	1.13	1.64	2.03	2.38	y
KILWINNE16	WU PWS	0.42	1.03	1.60	2.38	y
IL-DP-109	CoCoRaHS				2.37	y
KILMIDLO4	WU PWS	0.77	1.02	1.21	2.37	y
KILEVANS3	WU PWS	0.38	0.91	1.48	2.37	y
KILCARPE29	WU PWS	1.02	1.83	2.19	2.37	y
IL-CK-367	CoCoRaHS				2.36	y
KILPLANO11	WU PWS	1.00	1.45	1.59	2.36	y
KILWATER26	WU PWS	1.30	1.95	2.24	2.36	y
KILLOMBA41	WU PWS	0.37	0.76	1.30	2.36	y
KILALGON64	WU PWS	0.66	1.57	2.04	2.36	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
KILLEMON32	WU PWS	0.74	1.70	2.06	2.35	y
KILDOWNE57	WU PWS	1.17	1.65	1.76	2.35	y
KILDOWNE33	WU PWS	1.00	1.54	1.69	2.35	y
KILGENEV60	WU PWS	1.27	1.87	2.14	2.35	y
KILFRANK63	WU PWS	0.48	0.82	1.38	2.35	y
KILGILBE7	WU PWS	1.29	2.10	2.25	2.35	y
KILPALAT87	WU PWS	1.17	1.96	2.18	2.35	y
KINFORTW281	WU PWS	1.87	2.23	2.26	2.34	y
KILELKGR24	WU PWS	0.49	1.18	1.74	2.34	y
ORDI2	USGS	0.51	0.85	1.44	2.33	y
KILPLAIN148	WU PWS	1.20	1.94	2.12	2.33	y
KILVILLA37	WU PWS	0.45	1.04	1.61	2.33	y
KILVIRGI13	WU PWS	1.18	1.90	2.16	2.33	y
KILEVANS79	WU PWS	0.56	0.97	1.47	2.33	y
KILMOUNT160	WU PWS	0.49	0.85	1.37	2.33	y
KILARLIN32	WU PWS	0.85	1.27	1.55	2.33	y
KILGLENC36	WU PWS	0.44	1.09	1.62	2.33	y
KILHIGHL104	WU PWS	0.55	1.13	1.47	2.33	y
KILCHICA51	WU PWS	0.78	1.47	1.60	2.32	y
KILHIGHL82	WU PWS	0.42	0.94	1.24	2.32	y
KILHIGHL50	WU PWS	0.43	0.80	1.22	2.32	y
KILORLAN34	WU PWS	0.89	1.12	1.23	2.31	y
KILPALAT79	WU PWS	1.24	1.80	2.13	2.31	y
MUNI2	COOP				2.30	y
KINSPENC13	WU PWS	1.96	2.30	2.30	2.30	y
KILMONEE21	WU PWS	0.57	0.89	1.59	2.30	y
KILHOMEW31	WU PWS	0.66	1.04	1.37	2.30	y
KILHOMEW40	WU PWS	0.62	1.01	1.32	2.30	y
KILALGON59	WU PWS	1.32	1.75	2.21	2.30	y
IN-MM-8	CoCoRaHS				2.29	y
KILDOWNE44	WU PWS	1.07	1.43	1.61	2.29	y
KINMUNST29	WU PWS	0.92	0.99	1.11	2.29	y
KILELKGR47	WU PWS	0.46	1.14	1.55	2.29	y
KILMOUNT78	WU PWS	0.41	0.96	1.50	2.29	y
IL-CK-148	CoCoRaHS				2.28	y
KILDOWNE46	WU PWS	0.80	1.38	1.55	2.28	y
KILWHEEL20	WU PWS	0.52	0.98	1.37	2.28	y
KILWHEEL7	WU PWS	0.82	1.31	1.61	2.28	y
KINMUNST21	WU PWS	0.74	1.12	1.18	2.27	y
KILBOLIN75	WU PWS	1.30	1.79	1.97	2.27	y
KILARLIN50	WU PWS	0.69	1.20	1.54	2.27	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
IL-CK-331	CoCoRaHS				2.26	y
KILORLAN40	WU PWS	0.80	1.29	1.38	2.26	y
KILWESTD4	WU PWS	1.23	1.97	2.14	2.26	y
KILSOUTH12	WU PWS	0.50	1.04	1.23	2.25	y
KILOAKFO29	WU PWS	0.81	0.97	1.06	2.25	y
KILPLAIN83	WU PWS	1.03	1.80	2.00	2.25	y
KILPARKR19	WU PWS	0.75	1.37	2.03	2.25	y
KILROLLI10	WU PWS	0.91	1.45	1.70	2.25	y
KILWESTC53	WU PWS	0.95	1.41	1.70	2.24	y
KILELMHU20	WU PWS	0.39	0.76	1.45	2.24	y
KILLOMBA40	WU PWS	0.36	0.69	1.12	2.24	y
KILWESTE2	WU PWS	0.84	1.57	1.77	2.23	y
KILWARRE25	WU PWS	1.22	1.83	1.95	2.23	y
IL-CK-294	CoCoRaHS				2.23	y
IL-DP-187	CoCoRaHS				2.22	y
KILARLIN73	WU PWS	0.40	1.00	1.39	2.21	y
KILORLAN44	WU PWS	0.78	1.20	1.28	2.20	y
IL-CK-131	CoCoRaHS				2.20	y
KILWOODR16	WU PWS	0.91	1.66	1.84	2.19	y
KILDEERF17	WU PWS	0.68	1.01	1.34	2.19	y
ALSI2	USGS	0.62	1.02	1.25	2.19	y
IL-DP-102	CoCoRaHS				2.19	y
KILNAPER113	WU PWS	1.37	1.94	2.05	2.18	y
KILGLENE9	WU PWS	0.86	1.56	1.79	2.18	y
KILELMHU46	WU PWS	0.40	0.66	1.29	2.18	y
KILGENEV59	WU PWS	1.12	1.56	1.89	2.17	y
IL-DP-117	CoCoRaHS				2.17	y
MI-CS-12	CoCoRaHS				2.17	y
KILFLOSS8	WU PWS	0.51	1.28	1.61	2.16	y
KILPLAIN129	WU PWS	1.67	1.80	1.91	2.16	y
KILLOMBA63	WU PWS	0.55	0.98	1.34	2.16	y
KILWINNE43	WU PWS	0.32	0.92	1.48	2.16	y
KILGLENV49	WU PWS	0.42	1.02	1.43	2.15	y
KILPALAT95	WU PWS	0.76	1.73	2.06	2.15	y
KILPEORI177	WU PWS	1.12	1.82	2.03	2.14	y
KILLOWPO10	WU PWS	1.36	1.87	1.88	2.13	y
KINSYRAC21	WU PWS	1.17	1.29	1.29	2.13	y
KILLOMBA20	WU PWS	0.43	0.97	1.32	2.13	y
KILHOFFM53	WU PWS	0.93	1.81	2.07	2.13	y
NBKI2	USGS	0.53	1.12	1.49	2.13	y
IL-WL-121	CoCoRaHS				2.12	y

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
IL-CK-53	CoCoRaHS				2.12	y
KILWINNE45	WU PWS	0.37	0.94	1.48	2.12	y
KINMUNST28	WU PWS	0.84	0.91	1.00	2.11	y
KILHOFFM51	WU PWS	0.92	1.77	2.04	2.11	y
KILMETAM9	WU PWS	1.25	1.39	1.81	2.10	y
KINFORTW181	WU PWS	1.00	2.02	2.05	2.10	y
KILOAKFO13	WU PWS	0.70	0.86	1.00	2.10	y
KILTOULO17	WU PWS	1.06	1.90	1.95	2.09	y
KILGLENE46	WU PWS	0.54	1.09	1.37	2.09	y
KILGLENE34	WU PWS	0.39	0.83	1.47	2.09	y
KILLAKEF3	WU PWS	1.22	1.67	1.82	2.09	y
WDLI2	USGS	0.40	1.16	1.52	2.08	y
KILSTCHA61	WU PWS	1.05	1.71	1.94	2.08	y
KILARLIN61	WU PWS	0.41	0.85	1.21	2.08	y
KILCARPE28	WU PWS	0.75	1.73	1.94	2.07	y
KILTOULO15	WU PWS	0.79	1.65	1.84	2.06	y
KILTAYLO36	WU PWS	1.04	1.28	1.99	2.06	y
KILELBUR46	WU PWS	0.79	1.53	1.80	2.06	y
IN-LK-15	CoCoRaHS				2.05	y
KINBLOOM263	WU PWS	0.26	0.49	0.49	2.05	y
KILPALOS2	WU PWS	0.44	1.06	1.22	2.05	y
KILBOLIN73	WU PWS	0.81	1.36	1.60	2.05	y
KILGLENE28	WU PWS	0.53	1.07	1.39	2.05	y
IN-LK-85	CoCoRaHS				2.04	y
IL-KD-24	CoCoRaHS				2.04	y
CHFI2	USGS	0.66	1.16	1.34	2.04	y
KILPEORI43	WU PWS	0.97	1.72	1.95	2.04	y
KILPALAT64	WU PWS	1.15	1.58	1.83	2.04	y
KILCHICA676	WU PWS	0.69	1.15	1.46	2.03	y
KILNORTH60	WU PWS	0.43	0.99	1.34	2.03	y
KILLAKEI30	WU PWS	1.19	1.67	1.93	2.03	y
KILGOODH6	WU PWS	0.75	1.60	1.78	2.02	y
KILHOMER22	WU PWS	0.82	1.58	1.83	2.02	y
KILLEMON19	WU PWS	0.78	1.46	1.72	2.02	y
KILVILLA33	WU PWS	0.41	0.77	1.34	2.02	y
KILLOMBA68	WU PWS	0.51	0.64	1.03	2.01	y
KINMUNST8	WU PWS	0.70	0.90	0.94	2.00	y
KINHAMMO40	WU PWS	0.82	1.21	1.24	2.00	y
KILWOODR30	WU PWS	0.92	1.31	1.41	2.00	y
KILWESTM19	WU PWS	0.64	1.28	1.38	2.00	y

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Table A2. List of rain gauge observations collected for analysis of the 17 September 2023 event, filtered to only storm total observations greater than or equal to 2.0 inches.

ID	Network	Max 1-hr Rain	Max 3-hr Rain	Max 6-hr Rain	Storm Total	Used in Analysis?
StateSt_LincolnAve_CalumetCity	Other				8.75	y
SHLI2	USGS	1.99	4.18	4.98	5.69	y
MKHI2	USGS	1.09	2.54	3.80	5.04	y
IN-LK-89	CoCoRaHS				4.79	y
163rd_TriState	Other				4.72	y
KILMARKH1	WU PWS	1.00	2.14	3.13	4.72	y
KINEASTC16	WU PWS	1.60	2.84	3.28	4.53	y
IL-CK-260	CoCoRaHS				4.47	y
HRVI2	USGS	1.07	2.44	3.32	4.35	y
OBII2	Other	2.21	3.45	3.93	4.32	y
TPKI2	USGS	1.29	1.92	2.46	4.27	y
KILSOUTH38	WU PWS	0.92	2.58	3.56	4.14	y
KILSOUTH12	WU PWS	0.68	1.45	2.03	2.99	y
IL-CK-64	CoCoRaHS				2.96	y
IL-CK-306	CoCoRaHS				2.87	y
IL-CK-253	CoCoRaHS				2.78	y
MTTI2	USGS	1.09	1.25	1.69	2.78	y
IL-CK-229	CoCoRaHS				2.76	y
HoodAve_183rd_Homewood	Other				2.76	y
OBKI2	USGS	1.21	2.20	2.60	2.71	y
KILCHICA997	WU PWS	2.00	2.41	2.45	2.66	y
IL-CR-20	CoCoRaHS				2.41	y
IL-BN-14	CoCoRaHS				2.38	y
IL-DP-117	CoCoRaHS				2.33	y
IL-CK-74	CoCoRaHS				2.29	y
IL-CK-407	CoCoRaHS				2.25	y
IL-HY-4	CoCoRaHS				2.24	y
CHWI2	USGS	1.08	1.16	1.65	2.11	y
IL-CK-150	CoCoRaHS				2.09	y
IL-CK-63	CoCoRaHS				2.07	y
IL-CK-294	CoCoRaHS				2.06	y
WBRI2	USGS	0.83	1.79	2.00	2.06	y
IL-LK-128	CoCoRaHS				2.04	y