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A Record Number of Heavy Rainstorms in Chicago in 2001

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ABSTRACT

Operations of a dense recording raingage network across the Chicago metropolitan region revealed that Water Year 2001 had the highest number of heavy rainstorms since network observations began in 1948. The eight record-setting storms were analyzed to assess their temporal patterns, the impacts they created, and the possible effect of urban and lake influences on storm intensities. The storms occurred in a 2-month period, mid-July to mid-September, creating record high rainfall totals of 54 cm for the July-September period. Two storms created excessive short-duration rainfalls that equated to once in a 100-year events. Both storms created sizable flooding and much damage to transportation systems and property, and the excess flood waters led to overflows of polluted flood waters into Lake Michigan. The other six storms produced lesser heavy rains, typically with rain amounts rated as once in 2- to 10-year frequencies, and only minor flooding occurred, indicating that the new deep tunnel system and rain blocker system have managed to reduce flooding from storms of this magnitude. Climate studies have also shown an increase in heavy rain events across the Midwest since the 1940s, and the number in 2001 appears to reflect this trend. Three storms maximized over the city suggesting that urban influences on the atmosphere may have acted to enhance storm rainfall, as has been noted in prior studies.

INTRODUCTION

Heavy rainstorms over major urban areas create sizable problems from resulting flooding including disruption of transportation and damage to business and residential property. Due to the nearly uniform impervious surfaces in major urban areas, a 15-centimeter (cm) rainstorm causes more problems than the same rainfall amount in a rural area away from the city where large amounts of the water soak into the soil and much less property damage occurs.

During Water Year 2001 (October 2000-September 2001), Chicago experienced a record number of heavy rainstorms for the years since 1948. The record setting series of eight storms raised questions about their causation and types of impacts. This study employed hourly rainfall data from a dense raingage network operated by the State Water Survey that covers Chicago and most of Cook County. Answers to questions about causation and

impacts should provide useful guidance to those who must plan for and manage the waters generated from storm rainfall in Chicago.

Four exceptional rainstorms that struck the Chicago area since 1950 have been investigated, and these studies included field surveys to collect spatially detailed rainfall data. On October 9-10, 1954 an 18-hour series of storms produced a peak of 27 cm at Aurora and 16 cm of rain over north Chicago (Huff and Vogel, 1976). On July 12-13, 1957 a 10-hour rainstorm produced a maximum of 23 cm in the city's center with more than 12 cm of rain falling over 8,300 km^2 (Huff et al., 1958). The third major storm of the past 50 years in the Chicago area occurred on July 20-21, 1976, with a peak of 24.2 cm in Chicago during an 9-hour storm period (Changnon and Vogel, 1980). The fourth major storm produced a statewide record 1-day rainfall of 45 cm on July 17-18, 1996 in Aurora (Changnon and Kunkel, 1999). Amounts over the city's south side were as high as 22 cm in 18 hours.

Impacts resulting from heavy rainstorms in Chicago have also been assessed (Changnon, 1982). These studies showed that moderate to heavy rainfall severely impacts surface and air transportation in Chicago (Changnon, 1996). The record rainstorm in July 1996 created massive flash floods and caused losses amounting to $0.65 billion, the state's second highest weather loss of the century (Changnon, 1999).

The eight heavy storms in 2001 occurred during the July-September period, and resulted in much above normal total rainfall. The 3-month rain totals at the official raingage of the National Weather Service amounted to 54 cm and ranked as the highest in the city during the past 130 years.

ISSUES RELATED TO HEAVY RAINSTORMS IN CHICAGO

Past studies have defined the variety of problems heavy rainstorms cause in Chicago (Changnon 1980b). Flooding has been a common problem in all large cities, and a typical problem found in Chicago has been flooding of viaducts and basements of businesses and residences. Chicago is a national hub for commercial air traffic, the nation's railroads, and trucking. Consequently, heavy rains disrupt and slow or stop traffic flow, and flood waters disrupt movement of surface traffic including the city's bus and rail systems for commuters. Further, floods create extensive damage to property and businesses. Many conditions causing heavy rainstorms are related to strong thunderstorm activity, and the resulting lightning and high winds often knock out power systems, causing sizable power outages.

Chicago has a unique storm-water management problem related to the diversion of waters from Lake Michigan and the reversal of its in-lake drainage system (Changnon and Changnon, 1996). River drainage outlets to the lake are blocked by gates, and the water taken in from the lake, or falling as rain over the city, flows down the Illinois River. The annual amount of water diverted by Chicago for various purposes (local water supplies and flow down the Illinois River to dilute pollution and to maintain levels for barge traffic) is under federal control and must not be exceeded. To handle storm water, the city either must lower the waters in the local rivers and divert it down the Illinois River, or storm rainwaters must be allowed to flow into Lake Michigan to reduce city flooding.

However, this brings sewage-polluted waters into the lake, limiting intake of water for public water supplies, leading to beach closures in the warm season, and creating other environmental problems. Overflows, or events when flood waters are released into Lake Michigan, occurred 34 times during 1948-1981, and most of these occurred when rains exceeding 5.1 cm fell in 3 to 9 hours (Changnon, 1982). Thus, the problems of heavy rainfall over Chicago are greater than exist at most cities, and have led to the construction of the "deep tunnel" system. This has been a costly program that involved excavation of large underground chambers beneath portions of the city's rivers. When storms occur, storm waters are directed into these tunnels and later pumped out when river levels return to normal. It also led to the installation of the "rain blocker" system, devices installed at street drains that act to slow the intake of storm rainwater from the streets.

Causation of such heavy urban rainstorms is a key question—are there local conditions that lead to more than normal numbers of heavy rainstorms? Past research has examined the possibility that urban influences on the atmosphere lead to more rainfall over the city and beyond (Huff and Changnon, 1973) and additional heavy storms (Dettwiller and Changnon, 1976). A climatological study of historical precipitation data for the region showed that the city and areas downwind of Chicago (east) averaged 10 to 30 percent more rain than areas to the west (Changnon, 1968). A 3-year meteorological study of rains in the Chicago area using weather radars and a large raingage network, showed that urban effects on the atmosphere, sometimes interacting with lake effects, acted to increase warm season rains and occasionally lead to heavier rainfalls (Changnon, 1980a). For example, the city averages 5 more days a year with thunderstorms than do areas just west and south of the city (Changnon, 2001) and has notably more lighting (Westcott, 1995). The city is warmer than rural areas providing a source of rising air. It also provides a vast array of atmospheric particles that affect cloud droplet and raindrop formation, and the city also acts as a block to the low-level wind flow creating convergence and vertical motions of the air over and just beyond the city. All these urban conditions are important factors in rain formation and the intensification of existing rain systems (Changnon et al., 1981).

A third rainstorm issue relates to climate fluctuations that can lead to changes in the number of heavy rain events. Studies of floods and flood-producing rains over river basins in Illinois during 1930-1980 revealed an increase in floods and heavy rain events (Changnon, 1983; Kunkel et al., 1993). A case study involving two Chicago area basins, the Des Plaines and Du Page Rivers, revealed both had undergone sizable increases in annual peak flows from 1941 to 1990, and that peak daily rain amounts each year over these basins had increased by 65% (Changnon and Demissie, 1996). Part of the flood increase was also due to urban growth that enhances runoff. Studies of possible effects of global warming in the Midwest concluded that rainfall and heavier rain events would continue to increase into the 21st century (National Assessment Synthesis Team 2000).

These issues were assessed by analyzing the record number of rainstorms in 2001, as defined by the dense raingage network that is operated in Chicago (Westcott, 2000). Questions addressed included was there further evidence of local increases in rainstorms due to urban and lake effects? Has the on-going temporal increase in heavy rains across the Midwest resulted in more heavy rains than history-based statistics would predict for the city? Have the local impacts of heavy rains changed over time?

DATA AND ANALYSIS

The Water Survey installed a uniform network of 25 recording raingages across Cook County during 1989. The collection of rainfall data began on October 1, 1989. The gages were spaced approximately 10 kilometers apart and sampled rain over an area of 2,500 km^2. Each gage was a weighing-bucket recording raingage, and were serviced by trained technicians. Recording charts were analyzed to ascertain 1-hour amounts, and totals were derived for each rain event and each month. Installation of data loggers in the gages in January 2001 allowed calculation of 10-minute amounts for rain events during 2001. The study used the data from October 1, 2000, through September 30, 2001 (Water Year 2001), to assess heavy rain events as to their frequency in space and time, and the rainfall produced.

A heavy rain event was defined as one where one or more of the raingages had sufficient rainfall in one hour or a longer duration (up to 24 hours) to qualify as 2-year or greater recurrence interval rain amount. Rainfall frequency values for various durations (1-, 2-, 3-, 6- 12- and 24-hours) and various recurrence intervals (2-, 5-, 10-, 25-, 50-, and 100-years) were defined using the published updated values for the Chicago area (Huff and Angel, 1992). Information on impacts from the storms was obtained from local print media.

THE SEVERE RAINSTORMS IN 2001

The eight heavy rain events in WY 2001 were a uniquely large number, breaking all prior 1-year records. The recent occurrence of this record number is in keeping with prior findings showing that the number of heavy rain occurrences has increased over the past six decades across the Midwest.

The total rainfall produced by the eight heavy rainstorms in 2001 is depicted in figure 1. Amounts ranged from 14.7 cm (gage 23) to a high of 30.2 cm (gage 4) and the network average was 23.1 cm. The isohyetal pattern reveals that the highest values extended from the city's north side (gage 4) southward to a second maximum on the south side (gage 18). The lowest storm totals were to the north, west, and south, suggesting the potential for local enhancement due to urban and lake effects on storm intensities. The storm totals represented between 27 and 56 percent of the total rainfall for July-September 2001.

Figure 2 presents the pattern based on the number of times each raingage had a storm with amounts equaling or exceeding the 2-year return values. The peak value was 3 such occurrences in the south, and all 25 gages had at least 1 high frequency event. The pattern generally matches that for total rain (fig. 1).

July 21 Storm

The year's first rainstorm occurred on July 21, beginning at 1500 CST with point durations of 1.5 to 2 hours. (fig. 3a). The first rainfall occurred at gages 18, 19, and 23, and the storm enlarged and moved to the west, intensifying at gage 20 beginning at 1700 CST. Shown on the storm map are the seven gages that achieved rains rated as 2-year or greater events for 1 to 2-hour durations, all in the network's extreme south. The 12.5 cm

rainfall in 1-hour at gage 20 was in excess of the 100-year value of 9.1 cm (Huff and Angel, 1992). The only impacts were street flooding in the heavy rain area which was a mix of suburbs and rural countryside.

July 22 Storm
The season's second storm occurred on the next day, July 22, as thunderstorms moved from the west across the city over a 3-hour period beginning at 1500 CST. The only 2-year amount was 5.1 cm in one hour at gage 5, located in the core of a narrow storm (fig. 3b). Much of the network received light rain. There were no impacts other than an interruption of a golf tournament west of Chicago (Chicago Tribune, July 23).

July 23 Storm
The season's third storm came on the next day, making three straight days with heavy rains somewhere in the Chicago area. Rains on July 23 began at 1300 CST in the area (gages 5, 8, and 11) where rains became heaviest (fig. 3c). The heaviest rainfall was in the extreme southeast where 1-hour rain amounts at gages 22 and 25 attained 5-year values. There were no reported impacts from this storm.

July 24-25 Storm
The fourth storm was nocturnal and occurred on July 24-25, the fourth and fifth days in the sequence of locally heavy rains (fig. 3d). Rain began in the network's north (gages 4 and 5) at 2200 CST on July 24, and moved south, intensifying over the city's center. The heaviest rains fell between 0500 CST and 0800 CST on July 25 at gages 15 and 19. Point durations ranged from 4 to 8 hours. Gages 15 and 19 had 3-hour amounts qualifying as 2-year values. Minor street flooding occurred, but no other impacts were reported.

August 2 Storm
The most intense of the eight 2001 storms came on August 2 (fig. 4a). Nineteen of the 25 raingages had rainfall amounts that ranked as 2-year or greater values, and gage 10 had 11.6 cm in 2 hours, a 100-year event. Gages 7, 12, and 13 had 2- to 3- hour values rated as greater than once in 25-year values. Many raingages reached or exceeded 2-year values for 30-minutes and for durations of 1-, 2-, 3- and 4- hours. The heaviest rainfall was 12.2 cm (4.8 inches) in 3 hours at gage 10 in downtown Chicago. This value was evaluated by comparing it with highest 3-hour amounts from all Chicago area storms during 1949-1975 (Huff and Vogel, 1976). The top three values in that 27-year period were 13.7 cm on June 10, 1967; 11.7 cm on June 25, 1959; and 10.9 cm on October 3, 1954. Hence, the August 2, 2001, storm maximum of 12.2 cm ranked as the second highest on record for the 1948-1981 and 1989-2001 periods.

Rainfall occurred in the morning hours as a south-moving storm brought rain beginning at 0500 CST at northern gages 1, 2, and 3. Figure 5 presents the 1-hour rainfall maps for the August 2 storm. For the beginning hour of 0500 CST, the peak was 12.5 mm at gage 3, and in the next hour, the highest rainfall had moved south and increased to 79 mm at gage 7. The storm's third hour (fig. 5c) had a peak rain of 82 mm and it was located farther south at gage 10. For the hour beginning at 0800 CST (fig. 5d), the heaviest rainfall and core of the storm continued its southward movement. However, the maximum rainfall had diminished to 51 mm (gage 21). The storm's final hour (0900 to 1000CST) saw the ending of the rain over much of the city with heaviest rain being only 14.5 mm at

gage 25. This series of hourly rainfall patterns show the storm's southerly movement, and also shows that the rainfall intensified considerably while over the city. This storm pattern suggests that local urban and lake effects acted to enhance the rainfall over Chicago.

Major impacts occurred. The city's seven sewage treatment plants which hold 2 billion gallons of water, were filled by 0800 CST, and then the deep tunnel system filled with 1.6 billion gallons by 0900 CST. Thereafter, polluted storm waters had to be released into Lake Michigan. After the first hour of heavy rain, flooding of major expressways and streets had begun, blocking commuter travel. Commuter trains were also halted and transportation experts cited this as one of the most difficult commutes in Chicago's history (Chicago Tribune, August 2). More than 300,000 basements were flooded (Chicago Tribune, August 3). The associated thunderstorm's intense lightning and high winds led to power outages to 56,000 residents, and flights at O'Hare were delayed by several hours. Governor Ryan declared Cook County a disaster area, making it eligible for federal assistance.

August 25 Storm

Storm number six in 2001 began at 0600 CST on August 25 and rain lasted 4 hours at most gages. The resulting isohyetal pattern (fig. 4b) shows two WSW-ENE oriented paths of heavier rainfall, areas where gages had 2-year or heavier amounts. Rain began in both areas at 0600 CST and moved to the east-northeast. Gages 18 and 21 had 5-year values for 4-hour durations, but no major flooding resulted.

August 30-31 Storm

On August 30-31 a seventh heavy rainstorm occurred. Rain began at 1800 CST in the south (gages 23 and 24), and at 1900 CST in the north (gages 1 and 3) where heavy rain fell between 2000 and 2200 CST. As shown on figure 4c, gage 3 had nearly 8 cm , a once in 10-year value, and a recording raingage at O'Hare Airport had 10.9 cm, a 25-year value. Storm point rainfall durations ranged from 4 to 6 hours, with all rain ending by 0400 CST on the 31st.

Extreme street and expressway flooding occurred on the city's north side with 12,000 basements flooded. Flood waters had to be released into Lake Michigan at the Wilmette intake site. Chicago's $75 million "rain blocker" system, installed to slow inflow to the sewer system, was identified by some as a likely cause for the extensive flooding, and underwent considerable debate (Chicago Tribune , September 6). O'Hare Airport had 100 flights canceled by the storm, which also caused power outages to 15,000 customers.

September 18-19 Storm

The eighth and final heavy rainstorm of 2001 was another nocturnal storm. Rain on the network began at 2000 CST on September 18, and all rain ended by 0600 CST on September 19. A major storm cell moved from the southwest and produced heavy rainfall in the network's northwest corner (fig. 4d). Gage 1 experienced 5-year 6-hour amount during the 2100-0300 CST period. There was minor flooding in certain northwest suburbs.

CONCLUSIONS

The operation of a large and uniform dense raingage network across Chicago allowed a detailed assessment of the heavy rain events in WY2001, including their distribution in time and space. A heavy storm was defined as one that produced amounts equaling or exceeding 2-year recurrence interval values for durations of 1 to 24 hours. There were eight heavy rain storms in WY2001, a record number for a single year, and two storms produced 1-hour amounts that rated as once in 100-year events. This recent peak in storm occurrences may reflect the longer-term trend across the Midwest toward more heavy rain events.

The eight storms all produced some form of flooding, but only the August 2 and August 30-31 storms created extensive flooding leading to water reversals into Lake Michigan. These two storms both had rains achieving 25-year or greater return frequencies, whereas the other six storms had rains rated as only 2- or 10-year events and of short, 1- to 6-hour durations. Efforts to reduce flooding through the construction of the deep tunnel system and the installation the rain blocker system have clearly reduced flooding in the short duration rainstorms that do not produce rainfall values of high frequency (>25-year amounts). However, the two larger more intense storms of WY2001 still resulted in extensive flooding of basements and streets, and the need to release polluted flood waters into Lake Michigan. None of the eight storms produced heavy rains over 6 hour or longer periods. Furthermore, none of the 2001 storms produced rainfall amounts as large as four massive, longer duration storms that occurred between 1950 and the present.

The storm rainfall patterns and the rainfall movements indicated that urban effects on storm rainfall amounts and intensities were likely present on July 23, July 24-25, and August 2. In all cases the storm rainfall was greatest over the city center and intensified as the storm moved across the city. Assessment of the total rainfall generated by the eight heavy rainstorms revealed a distinct in-city maximum that had 22% more rainfall than surrounding areas, suggesting that urban and lake influences on the atmosphere acted to increase heavy rainfall.

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Figure 1. The total rainfall (cm) produced by the eight heavy rainstorms in WY2001.

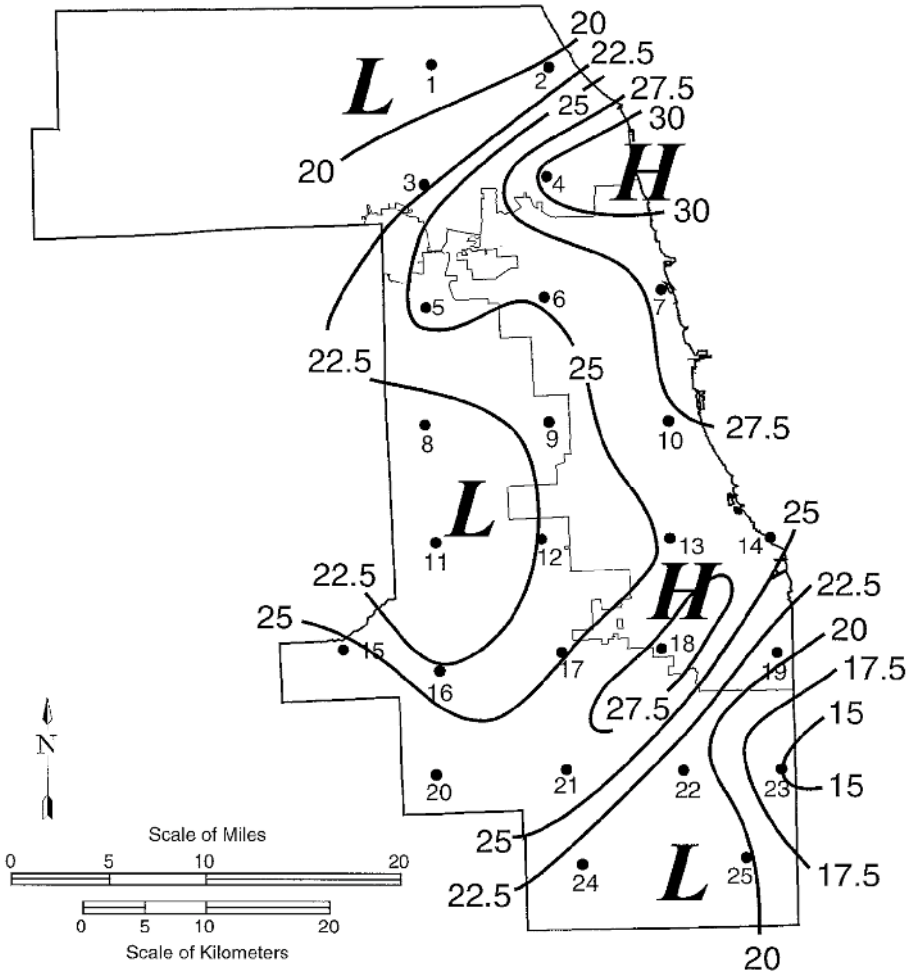

Figure 2. The number of times each raingage experienced a storm with rainfall amounts equaling or exceeding 2-year recurrence interval levels during WY2001.

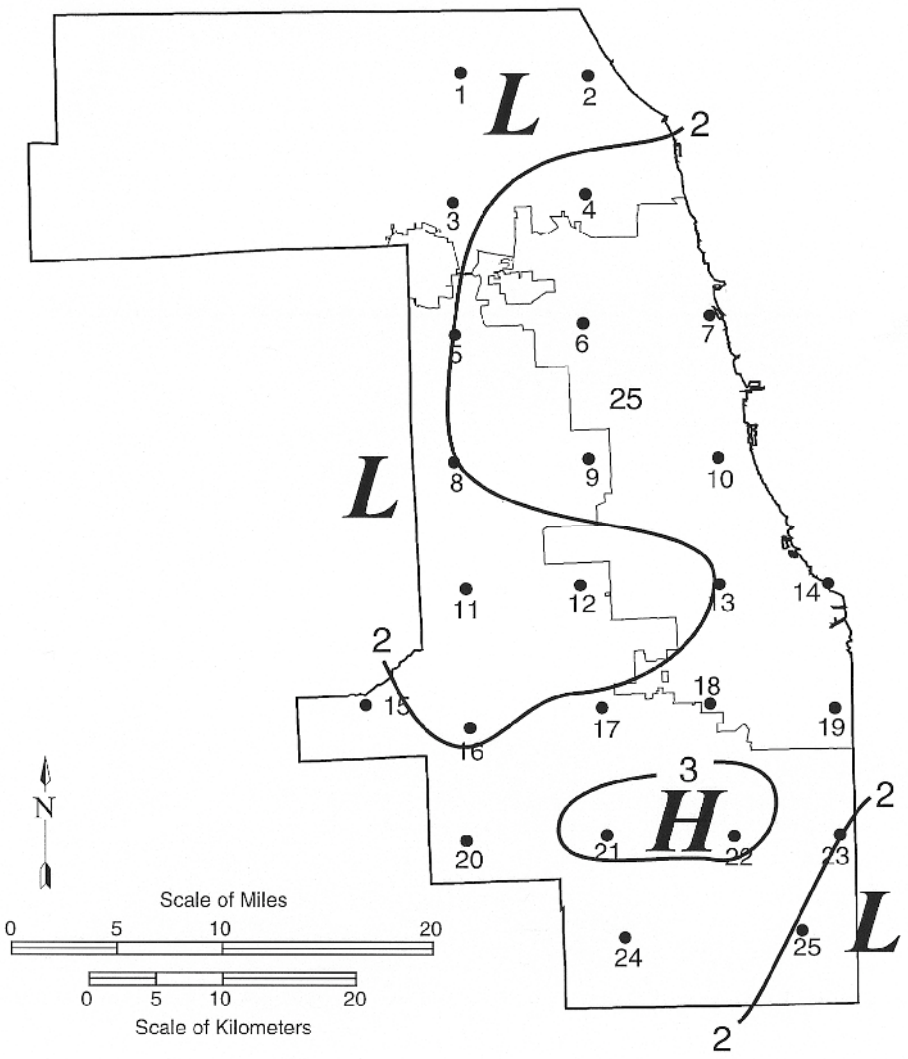

Figure 3. Patterns of the first four heavy rainstorms in WY2001, storm totals are in cm.

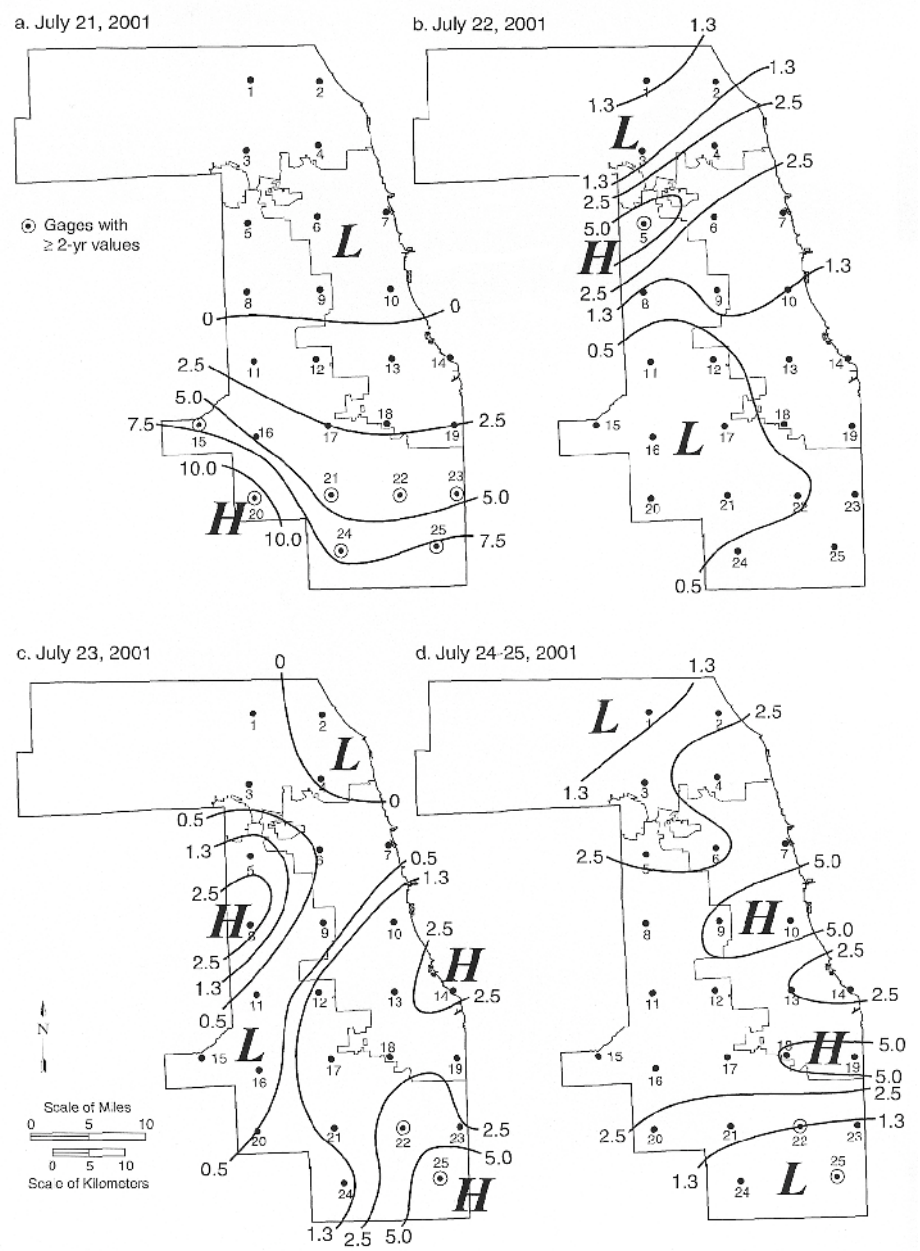

Figure 4. Patterns of the last four heavy rainstorms in WY2001, storm totals are in cm.

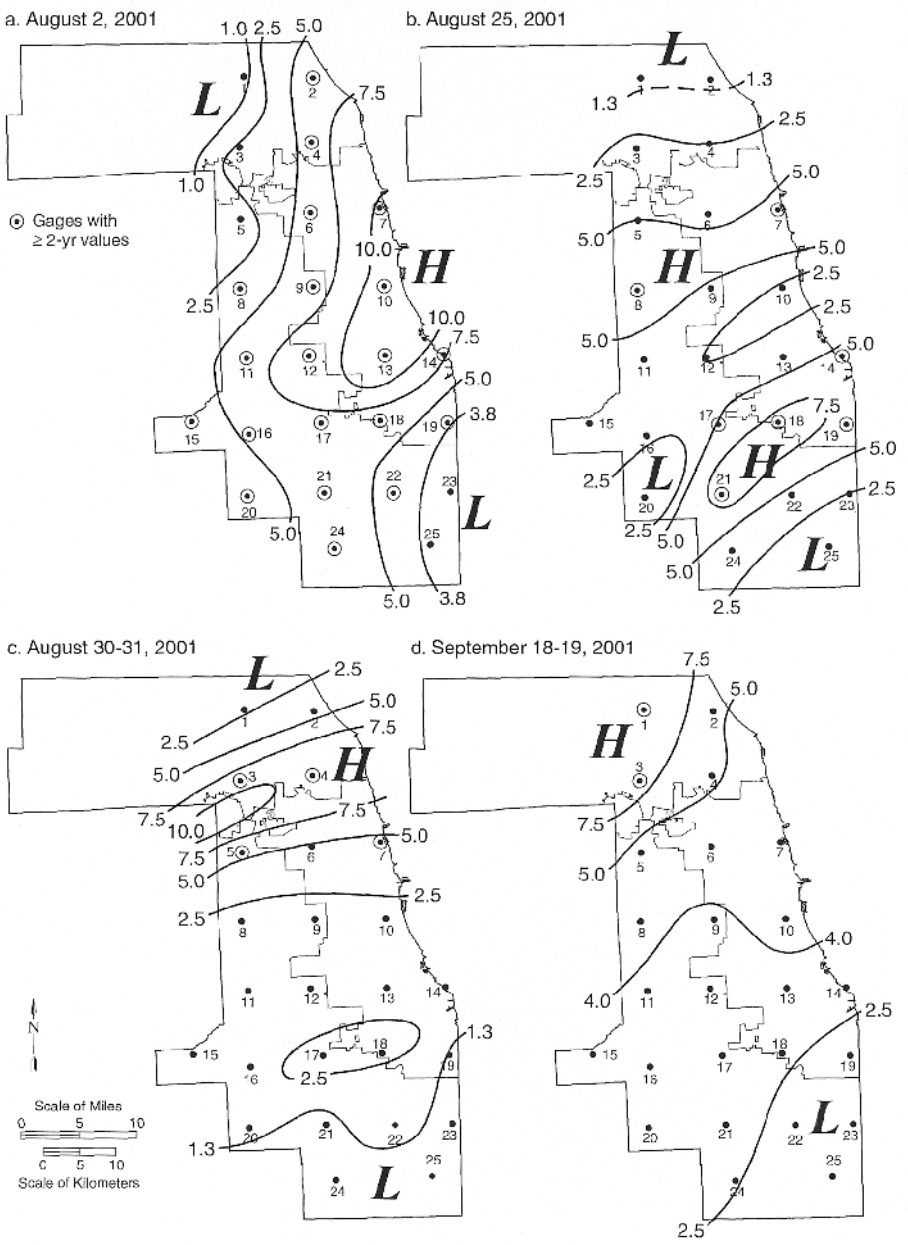

Figure 5. The hourly rainfall amounts (in mm) for the storm on August 2, 2001.