P 4.4 USING A DENSE PRECIPITATION GAGE NETWORK TO ESTIMATE ANNUAL MAXIMUM DAILY PRECIPITATION

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1. INTRODUCTION

The Minnesota State Climatology Office collects, maintains, and has digitized records from a dense, statewide network of precipitation observers, spanning 1958 through present. The Twin Cities Metropolitan Area has the greatest density of these observers. For the most part, daily data from the network have been used to construct detailed maps of individual precipitation events. In this study we investigate the utility of these data in refining our knowledge of the magnitude and spatial variability of annual maximum daily precipitation values (heretofore "annual maximum precipitation," or AMP). We select this measure because of its importance in estimating precipitation design values, e.g., the 24-hour, 100-year return period precipitation value.

2. DATA & METHODS

Our study area is a 120 km east-west, by 80 km north-south rectangle centered on St. Paul and Minneapolis, divided into 100 km^2 squares (figure 1). We allocated daily precipitation data from 1958 through 2002 to appropriate 100 km^2 analysis areas based on the UTM coordinates of the observers. The number of observers per cell obviously varied both spatially and temporally. We have four cells on the far eastern side that have no observations. For the remaining 92 cells, the average annual number of observations varied from 1 to nearly 17; some cells had over 30 observers at times during the 1970s and again in the 1990s.

Quality control was extremely important for these data given the volunteer nature of most of the observers (see table 1). Possible sources of error include accumulating precipitation over multiple observation days as well as reading, transcriptional and data entry errors. We used a computer-aided data editing system that graphically displayed the largest daily precipitation value in each cell for each year (figure 2). The data editing software highlighted possibly erroneous values based on discrepancies between the station in question and surrounding observers. It then allowed us to investigate precipitation amounts on prior days within

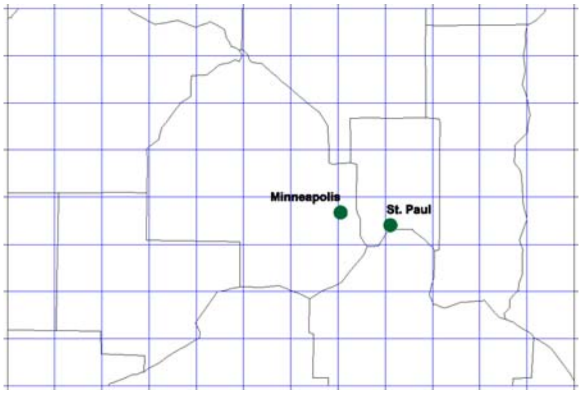
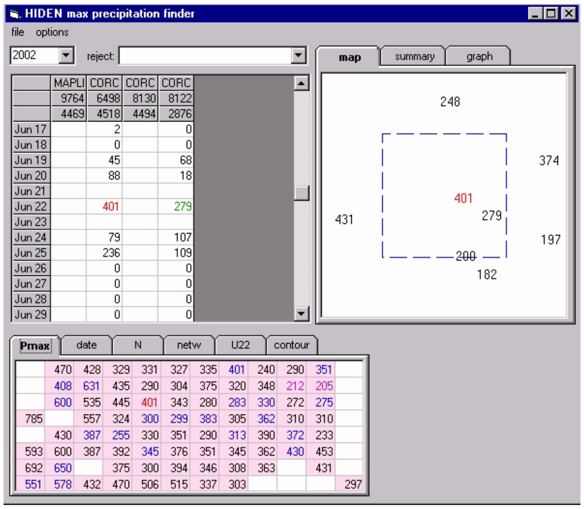


Figure 1. The study area, centered on the Twin Cities



2002

	MAPLI	CORC	CORC	CORC
	9764	6498	8130	8122
	4469	4518	4494	2876
Jun 17		2		0
Jun 18		0		0
Jun 19		45		68
Jun 20		88		18
Jun 21				
Jun 22		401		279
Jun 23				
Jun 24		79		107
Jun 25		236		109
Jun 26		0		0
Jun 27		0		0
Jun 28		0		0
Jun 29		0		0

	470	428	329	331	327	335	401	240	290	351	
	408	631	435	290	304	375	320	348	212	205	
	600	535	445	401	343	280	283	330	272	275	
785		557	324	300	299	383	305	362	310	310	
	430	387	255	330	351	290	313	390	372	233	
593	600	387	392	345	376	351	345	362	430	453	
692	650		375	300	394	346	308	363		431	
551	578	432	470	506	515	337	303				297

Figure 2. The data editing environment. Grid at bottom is the study area, with AMP values in hundredths of inches. Table at upper left shows all observations within a cell. Upper right image is map of cell in table, with amounts for given date shown.

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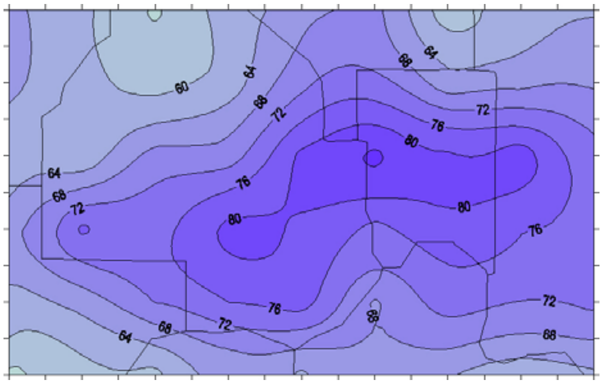

Figure 3. Mean annual daily maximum precipitation (mm).

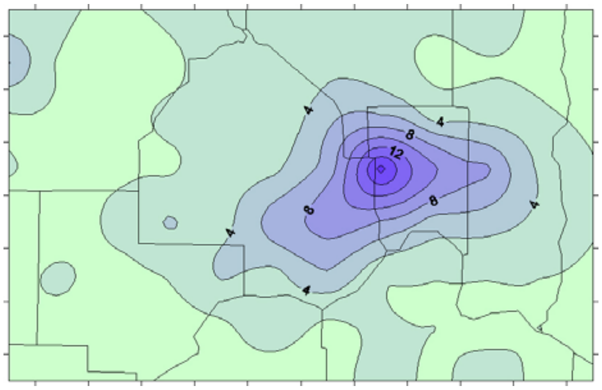

Figure 4. Average observer density per 100 km^2

the cell, and then across the entire grid. If we rejected the AMP value, we would repeat the process with the next largest precipitation value in the cell. Once we accepted an AMP value, we were finished for that cell for that year. The process often required several iterations before we found a satisfactory AMP value. The data editing resulted in a time series of annual daily maximum precipitation values for each cell within the grid. The number of years in the time series varied from cell to cell.

We calculated each cell's average AMP from our time series, excluding twelve cells that had fewer than 10 years of data. We then assigned the average values to corresponding cell centers, and then gridded the data (using Kriging), and contoured using a heavy smoothing.

3. RESULTS

The average AMP values range by about 30 mm over the study area, with the largest values in a west to east band across the most heavily urbanized parts of the Twin Cities, and the smallest values in the west, northwest, and northeast peripheral areas (figure 3). The pattern suggests the Twin Cities region has a strong bias towards urban-environment intense rainstorms, a mesoscale meteorological phenomenon that certainly would warrant further investigation. We did notice, however, that the pattern of average observer density over the study area appears to fairly closely resemble the pattern of average maximum values (figure 4).

We plotted the average annual maximum precipitation against average observer density and found a strong linear relationship up to about nine observers per cell (figure 5). For cells with nine or fewer observers, the observer density explained 94% of the variance of the mean AMP values ($r^2 = 0.94$). Beyond the ninth observer the predictive relationship fell apart. One interpretation of this finding is that nine stations per 100 km^2 is "optimal" for capturing the mesoscale variation within the event-causing thunderstorm; at this observer density the "true" maximum of the thunderstorm actually gets measured. As the observer density decreases, the likelihood increases that the most intense rain bursts are falling between observers--and therefore are not being measured. The findings also suggest that extraordinarily high observer densities (e.g., [n $\geq$ 10]/100 km^2) do not add much information, at least for the purposes of the present study.

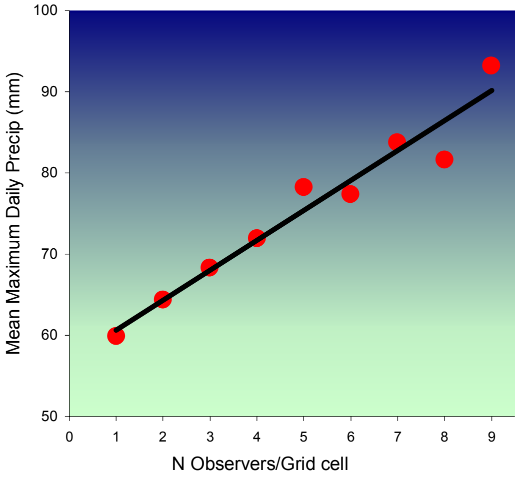

Figure 5. Regression trendline, number observers versus mean annual daily precipitation values.

We used inflation factors for each cell to correct for lower mean AMP values caused by sparse observer densities. For any cell averaging fewer than nine observers we added to its mean value the regression trend slope of 3.685mm for each missing observer. Of course, we excluded cells that had no stations from these adjustments, so as not to create artificial precipitation minima.

We created contour plots of the new adjusted mean annual maximum values using two different methods. In the first case, we essentially re-gridded (Kriging) the first map, substituting the corrected means for the old values. In the second case, we gridded the observer deviations from nine, giving cells with greater than nine observers values of zero and excluding empty cells. We then multiplied the values at each grid point by the regression coefficient and added the new grid to the grid of the uncorrected means. These two plotting methods nevertheless yielded one spatial distribution of corrected mean annual maximum values (figure 6).

The urban “bullseye” that had dominated the uncorrected map vanishes, if not reverses, once we correct for observer density. The new spatial pattern appears much flatter, and more random, with a range only about two-thirds that of the uncorrected spatial pattern. Now we find a relative minimum over the most urbanized parts of the Twin Cities; this local minimum appears to be associated with a ribbon of relatively low values stretching northwestward from Minneapolis-St. Paul. We also find a relative maximum just to the west of Minneapolis, in the southwestern part of Hennepin county near the large and potentially important Lake Minnetonka. This local maximum is connected to another local maximum in the southeast part of the study area by a band of elevated values that stretches across the southern portion of the Twin Cities area before fanning out to cover its extreme eastern reaches.

This new spatial distribution of mean AMP amounts has several implications for local climatology. First, if one believes the linear regression, then highly urbanized portions of the Twin Cities are not more prone to intense rainfalls than outlying areas; conversely, the urban areas may see lower intense rainfall amounts than surrounding locales. Second, the two different treatments of the data (the uncorrected mean values versus correcting for observer density) yield vastly different area-wide mean AMP values (67 mm for uncorrected, 90.6 mm for corrected). The large increase in the mean AMP suggests that the region’s calculated precipitation design values may indeed be underestimating the true potential for intense rainfall across the Minneapolis-St. Paul area.

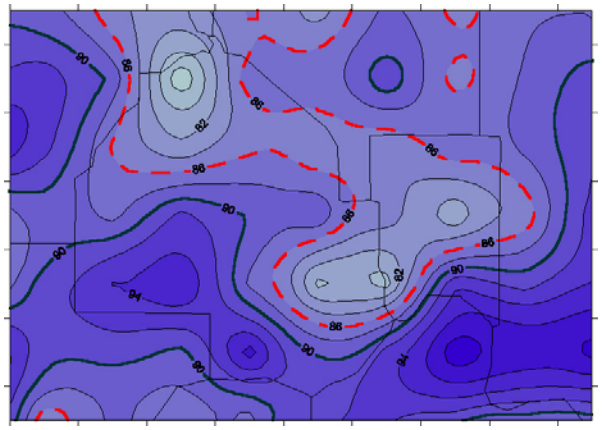

Figure 6. Mean AMP, corrected for observer density

4. CONCLUSION

In this study we investigated daily precipitation data from a dense network of observers across the Minneapolis-St. Paul metropolitan region. In particular, we were interested in the annual maximum daily precipitation, which we initially found to be highest over the heart of the study area. Linear regression analysis, however, demonstrated (with an r^2 of .94) that the pattern of inflated urban values was largely an artifact of higher observer densities, suggesting that cells with fewer observers were not capturing the mesoscale variability of each event. Conversely, the cells with nine observers or more were likely capturing values that approximated the “true” maxima in most cases. We corrected the mean annual maximum precipitation values for observer discrepancies and found first that the urban bias completely disappeared and even reversed, and second that the spatially averaged values increased significantly. Given the extreme nature of the events under investigation, our findings suggest that indices such as return-period statistics, when derived from relatively course data sets, underestimate the true potential for heavy precipitation.

We wish to acknowledge the Center for Urban and Regional Affairs (CURA), University of Minnesota for funding this project

Table 1. Observer networks available to the study. Information given is for state of Minnesota

Network	**Number of Stations**	**Quality**	**Coverage**
National Weather Service	About 150	Good	Observations 12 months per year
Department of Natural Resources	About 80	Good	Observations 12 months per year
Metropolitan Mosquito District	About 60	Good early but declining	Observations 9 months per year
State Climatologist Backyard Volunteers	About 300	Good	About 50% 12 months per year and 50% 9 months per year
Future Farmers of America	Declining from 1000 in 1970s to 10 or so at present	Poor	Variable
KSTP Network	About 30	Good	Discontinued but 12 and 9 month observations from 1980 to early 1990s
Soil and Water Conservation Districts	700 to 1000	Good	Variable with most in summer
Miscellaneous, e.g., WCCO network.	Variable	Variable	Variable