Atmospheric Sciences Section
Illinois State Water Survey

CHICAGO HYDROMETEOROLOGICAL AREA PROJECT:
A COMPREHENSIVE NEW STUDY OF URBAN HYDROMETEOROLOGY

by
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INTRODUCTION

This report is a brief summary of progress and key accomplishments in the first two years of the planned 3-year research program, plus additional contributions made during the 6-month flexibility period of the second year of the grant (1 February 1978 to 31 July 1978). All important aspects of the research during the 2-year NSF grant covering the period, 1 February 1976 to 31 January 1978, have been presented in detail in three previous research reports to NSF and will not be repeated here. Thus, detailed descriptions of the field activities and early phases of the analyses were provided in the First Interim Report (Changnon and Huff, 1976). The Annual and Interim Report dated December 1977 (Changnon and Huff, 1977) summarized all aspects of the field and analysis program for both the first year (1 February 1976 to 31 January 1977) and for the first part of the second year (1 February 1977 to 31 July 1977). The third report (Changnon, et al., 1978) described progress and achievements for the period 1 August 1977 to 31 January 1978. Since NSF funding for support of the planned third-year activities was not forthcoming, we then proceeded to complete as much of the remaining research as possible with remaining funds (State of Illinois and NSF) during the 6-month flexibility period of the grant.

Background of Research

In an effort to better describe the hydrometeorology of Chicago and environs, an investigative program was begun by the Water Survey scientists in 1974. All the historical rainfall data for the area were procured and studied. The resulting analyses were aimed primarily at providing rainfall information of various types that would be useful to urban hydrologists in the design of storm-sanitary sewer systems. This investigation culminated in the publication of a Water Survey report (Huff and Vogel, 1976) which provided much useful information on various aspects of the hydrometeorology of heavy rainstorms in Chicago and northeastern Illinois. However, these results, plus interaction with various local and regional users in the Chicago area, revealed further extensive needs for a sophisticated level of urban rainfall data and information that could not be served by the results obtained from the existing data base at Chicago or those at most other major American cities.

To this end, the Illinois State Water Survey began designing and developing a comprehensive urban hydrometeorological investigation. Thus, an extensive rainfall measurement program, which became labeled as Phase 2, was planned. The study of the historical data done in 1974-1976 was labeled as Phase 1. It aimed at developing a short-term rainfall probability forecast skill, real-time estimates of rainfall over the city, rainfall information for water quality and runoff models, and extensive rainfall distribution data for the 10,500 km² area enveloping Chicago. This was envisioned as a 5-year project, and it was launched in the fall of 1975 with funding from the State of Illinois. The National Science Foundation's Program for Research Applied to National Needs subsequently funded a portion of the program beginning in February 1976.
The major facilities of Phase 2 have included the world's largest dense raingage network of over 320 recording raingages and a new sophisticated 10-cm weather radar with state-of-the-art signal processing and an attached computer that allow for rapid digitization of rainfall data. Provisions were made for linking the radar-computer system with the Metropolitan Sanitary District (MSD) Operational Headquarters to demonstrate, both locally and nationally, the use of a sophisticated weather radar system in the real-time operations of an urban hydrologic system. The raingage network has furnished rainfall data for calibrating the radar-indicated rainfall, for testing water quality models, for developing new rainstorm intensity models, and for studying localized effects on rainfall.

Goals

Phase 2 has proceeded with the following major goals:

1. To develop a real-time prediction and monitoring system and methodology for specifying rainfall quantity over the urban area using a weather radar.
2. To provide precipitation data and information for hydrologic and water quality models and for use in the design of hydrologic systems.
3. To establish methods and techniques for transferring the Chicago area findings to other cities, so as to optimize precipitation measurement systems.

Objectives

A number of specific objectives were undertaken on the presently uncompleted Chicago Hydrometeorological Area Project (CHAP). One of these has focused on the development of better and more detailed rainfall relations for both point and areal mean rainfall so as to meet and improve design requirements for storm and sanitary sewer systems. This effort has utilized the dense raingage network data. A second objective has been to develop statistics on rainfall distributions, in time and space over urban and suburban areas of varying size, for use in various hydrologic models.

A most important objective of CHAP has been to develop an interface for a digital weather radar system and the MSD water resources operational system so the radar results can be used by MSD personnel. Radar operations and signal processing have been geared to develop data which will permit operators in the MSD water resource system to make better decisions, both about the likelihood of approaching rainfall as well as the rainfall quantity actually occurring over various basins of the urban hydrologic system.

The fourth objective of CHAP has involved analyses of the raingage and radar data so as to develop criteria for determining optimum rain measurement systems, involving either, or both, radar and raingages in other cities. The
final objective of CHAP is transferral of these pertinent results, both to the local and regional interests in the Chicago area, and to national interests in private practice or in governmental entities in urban water resources.

None of these objectives could be totally met since the project was funded for only two of the three desired years. The study area for CHAP is shown in Figure 1. The sites of the 320 recording raingages are shown, along with the site of the project's radar, labeled as HOT.

Project Organization and Personnel

The organizational diagram for CHAP during the 2-year grant period is presented in Fig. 2. The three major functions have been *Operations*, *Analysis and Research*, and *User Interactions*. Distribution of effort has involved about 45% in the operational area, 40% in the analysis area, and 15% in the user interaction area. The senior professional staff and their assignments are shown in Figure 2. Detailed lists of project support staffs, including professional, junior professional and research and student personnel, along with their titles, time devoted to project, and source of support (State or NSF), have been provided in the previous interim reports and will not be repeated here. The professional staff remained the same throughout the project period, and only minor changes occurred in the junior professional and research support staff. No key personnel were lost during the two years.

Examination of support for the research (see Annual and Interim Report dated December 1977) shows an extensive contribution of state support. During the two years of NSF funding (Phase 2), the State of Illinois provided approximately 40% of the total funds. All funds expended on Phase 1 in the previous two years were supplied by the State.
Figure 1. Study Areas and Facilities for CHAP
Figure 2. Organizational Chart for CHAP
BRIEF SUMMARY OF PROGRESS AND ACHIEVEMENTS IN CHAP DURING THE FIRST TWO YEARS OF NSF GRANT

At the time that funding of the grant terminated (31 January 1977), the work schedule and milestones outlined in the original research proposal to NSF had been met. In the following pages, a brief summary is provided of progress and achievements during the first two years of the planned 3-year research. Details are contained in the three previous reports submitted under ENV76-01447.

Scientific Achievements

The first task completed under project objectives was a background climatological study of heavy rainfall occurrences in the Chicago urban area through the use of historical data from an urban network of 17 recording gages in the 1949-1974 period. This study culminated in the publication of a major report (Huff and Vogel, 1976) that has been widely distributed. This investigation served as a prologue to the present large-scale field and analysis program, provided useful background information for planning this program, and provided pertinent data on the characteristics of heavy storms for utilization by urban hydrologists. The report was given wide distribution and has brought us many favorable comments from both governmental and private sources.

A second background study pertinent to the development of our real-time prediction and monitoring system was completed in early 1977. This study concerned determination of radar echo characteristics associated with heavy rainfall rates in the Chicago area, and was based on data collected by the National Weather Service at the Marseilles radar located 105 km SW of Chicago. Analyses were made of the frequency distributions of echo speed, direction of movement, duration, intensity, areal extent, and vertical extent in the heavier storms experienced in 1974-1975. The results are helpful in establishing the radar scanning, echo tracking, and prediction requirements for the real-time operational system.

In pursuing the Phase 2 studies, computer programs were developed for reducing and filing the raingage data on disks in a form convenient for use in the hydrologic design studies and for post-analysis in the real-time research. Other programs were developed to derive time and space distributions of rainfall in heavy storms, for making frequency analyses in these storms, and for interpolation of missing gage data which is essential to our hydrometeorological analyses. Various analyses using these programs were in progress when the research was stopped at the end of the second year. A number of other computer programs needed for various computations in accomplishing Phase 2 were written, tested, and put into use during the grant period.

In conjunction with development of the real-time prediction and monitoring system, analyses and evaluation had progressed to the point where the basic radar adjustment procedure and tracking programs for the tests and
demonstration planned for 1978 had been selected. A Water Survey modified version of the Brandes method (Brandes, 1975) was selected as most applicable to the urban hydrology problem after consideration of various techniques presented in the literature. Various computer programs necessary to incorporate this computational method into the HOT radar system (FPS-18 and associated hardware) were nearing completion.

Echo tracking methods were investigated and two were selected for the rainfall prediction scheme. System movement (squall lines, cold fronts, etc) are to be tracked by a lag correlation technique. Programs were written and preliminary testing carried out in late 1977. As a storm system closely approaches the urban area, a modified version of the FACE tracking program (Ostlund, 1974) is activated to track intense convective entities within the system across the urban region. Comprehensive testing and final adjustments remained to be completed at the end of the 2-year grant period (31 January 1977).

Initial testing of the modified FACE program for echo tracking and analysis was accomplished in late 1977 and early 1978 (see Third Interim Report, dated April 1978). Results indicated that this echo tracking program can be used for real-time operations, but some further refinement and testing of the tracking procedures would be desirable before putting it in to routine use. This additional work could not be carried out without the third-year funding. It was concluded that the radar rainfall field must be monitored at intervals of 15 minutes or less for effective utilization of radar in real-time operations.

In general, it appears from preliminary testing that the lag correlation method (see Third Interim Report) provides a good estimate of echo velocities, particularly in the relatively heavy storms which tend to move more uniformly than light storms. The heavy storms, of course, are those of major interest in the urban hydrologic applications. However, before putting this method into routine operation, it would be necessary to implement the present simple system with provisions for computing areal and rain intensity growth with time, velocity smoothing at the beginning and end times, and some form of compensation for problems that arise at the grid square edges in the present computational method. With certain additions and modifications, it is concluded that the lag correlation method could be successfully used in the manner originally planned; that is, for prediction guidance as a storm approaches the urban area. These changes remained to be made at the end of the first two years.

Two of the proposed studies to develop pertinent meteorological information for hydrologic design purposes were completed at the end of the first two years. These included 1) the orientation and shape of heavy rainstorms, and 2) the relation between point and areal mean rainfall frequencies. Also, detailed studies were made of several severe rainstorms that were flash flood producers on the CHAP Network during 1976-1977. These provided much information of hydrologic significance.

Other hydrometeorological studies were in progress as of 31 January 1977, and were scheduled to be completed in the third year of the project.
These included studies of the synoptic weather associated with heavy storms, the time distribution characteristics of storm rainfall, the spatial distribution properties of storm rainfall (area-depth relations), the frequency distribution of heavy rainstorm events, and the characteristics of storm movements in flash-flood storms. Some initial analyses had also been undertaken to define antecedent rainfall conditions associated with heavy storms and the frequency of dry periods between storm rainfall periods (pollution application).

Operational-Technical Achievements

This sizeable project has had major field efforts involving the installation, operation, and maintenance of weather equipment. Also involved has been special equipment development and testing. These major achievements are listed below.

1. Siting of 320 raingages at locations of similar exposure and arrangements with owners of each site completed.
2. Installation of 320 raingages in a 10,500 km area completed in four months.
3. Continuous operation of 320 raingages from June 1976 with 15 months data acquired. Quality control is high with only 3 to 4% data missing in any week.
4. Erection of radar facility (building constructed, cement antenna foundation poured, radome erected, trailers installed, and power lines installed) plus installation of all radar-computer equipment completed in 1976.
5. Communication system components and computer memory equipment ordered, equipment received, and interfacing with the existing radar-computer system constructed and completed in 1977.
6. Raingage data for first 15 months all edited, digitized, and processed.
7. Two periods (3- and 4 1/2 months) of radar operations completed.
8. Installation of equipment for transmission to MSD of rain estimates completed and communication system operational; radar software for use at radar site and for data display at MSD offices completed; and selected rain cases transmitted in real-time during November 1977.
The combination of radar and raingages is essential to the real-time prediction and monitoring of storm rainfall in urban areas. Radar provides the major input to the prediction of storm behavior by measuring such properties as the motion, duration, horizontal and vertical extent, changes in relative intensity, and the fine-scale structure of the rainfall distribution pattern. In the absence of a dense raingage network, radar also provides useful quantitative measurements of the rainfall in time and space. Our studies indicate that dense raingages in which telemetered raingages are spaced no more than 5 to 8 km apart will provide quantitative measurements that are superior to those obtained with radar alone and equivalent or superior to those determined with radar adjusted by widely scattered raingages.

Ideally, one would employ both radar and a dense network of telemetered raingages to optimize prediction, monitoring, and measurement of rainfall in storms as they approach and cross the urban area. However, such raingage networks are usually not employed in urban areas because of various problems, such as cost, difficulty in achieving proper gage exposures, and limited applicability in prediction (which is a most important factor in effective operation of urban hydrologic systems). From our research, we have concluded that the best and most practical solution to the urban problem is use of radar in conjunction with a moderate network of raingages to adjust the radar-indicated rainfall. This is the type of system we had planned to test and demonstrate in the third year of the CHAP project, and which our research indicates would provide an effective prediction-monitoring system for the operation of urban hydrologic systems in Chicago and other large metropolitan areas.

Measurement of Rainfall Intensity for Real-Time Prediction and Monitoring

The 1976-1977 CHAP analyses have led to certain tentative conclusions and recommendations regarding criteria for quantitative estimates of rainfall intensity within operationally acceptable limits. For prediction purposes, it is essential to have quantitative estimates of rainfall intensity in storms before they reach the urban area. For this purpose, our studies indicate in the Midwest one should have telemetered recording gages spaced approximately 16 km (10 mi) apart. The average measurement error in radar-indicated rainfall should then not exceed 30% which will be very useful for predicting rainfall expected over the urban area. These gages should be located within distances of 30-35 km (20 mi) in the directions from which most storms move. This would be from south through west to northwest in the Chicago region. Installation of the telemetered gages would be required by the city, since the raingage density of the climatic network of the National Weather Service does not meet these specifications. For initial estimates of the rainfall beyond the telemetered gages, use should be made of a climatic-derived, radar-rainfall equation for the region of interest. This would be an equation containing an average adjustment factor for the radar-observed rainfall field, based upon observed relationships between unadjusted radar and raingage measurements of rainfall.
Within the urban area, greater accuracy in the measurement of rainfall would be needed than in the periphery region where the measurements would be primarily for prediction purposes. Here, our studies indicate the telemetered raingage density should be increased to one gage every 8-11 km (5-7 mi) if possible, so as to keep the average measurement error at 20% or less. However, even a lesser density, such as recommended for the surrounding rural area, would be quite helpful in interpreting the rainfall intensity distribution within the urban area. In urban areas, a major problem is obtaining proper exposure for raingages because of the built-up areas, and measurement accuracy deteriorates quite rapidly when satisfactory exposure criteria are not met.

Another important finding from our studies to date is that with an effective radar adjustment procedure, measurement accuracies for 30-minute amounts are approximately the same that others have found for total storm or daily rainfall (Wilson, 1976). The spatial relative variability is normally greater within partial storm than in total storm periods. This results in greater sampling errors when measurements are required over short intervals, such as the 30 minutes being used in the CHAP project. Measurements over short time intervals are essential for effective operation of urban hydrologic systems.

Accuracy of Radar Measurements of Rainfall

Much debate has ensued in the meteorological community with regard to how well one can measure rainfall amounts and rates with radar in combination with raingages. Our CHAP studies have provided considerable information on this subject. Our results suggest that under real-time operational conditions, where fine tuning of the radar-indicated rainfall is not feasible, an average error of estimate of approximately 20% is about the best that can be achieved. This error is based upon 30-minute and 60-minute measurements of average rainfall intensity during 1976-1977 over areas ranging from 500 to 2000 km².

A major problem in evaluating the accuracy of radar measurements of rainfall is the comparison base to be used. Should the best estimate of the areal mean rainfall be that obtained from a dense network of raingages, and radar accuracy then evaluated against this value? Or, should we assume the radar-indicated rainfall after adjustment with data from a dense raingage network provides a more accurate spatial portrayal of the rainfall distribution than that obtained with the dense raingage network alone? This comparison base assumes that the continuous spatial distribution provided by the gage-adjusted radar is better than the interpolated pattern obtained from the raingage network.

Difference in measurement accuracy with the two methods are illustrated in Table 1, through the use of eight storms analyzed for the 1977 operational period on the CHAP Network. The upper portion of the table shows average measurement errors when the radar was adjusted with the full-density network
Table 1. Average Measurement Errors in 30-minute Rainfall Using Various Combinations of Radar and Raingages.

<table>
<thead>
<tr>
<th>Gage Spacing (km)</th>
<th>Unadjusted Radar</th>
<th>Adjusted Radar</th>
<th>Gages Only</th>
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<td>Radar Comparison Base</td>
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<td>5</td>
<td>35</td>
<td>0</td>
<td>18</td>
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<tr>
<td>Raingage Comparison Base</td>
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<td>35</td>
<td>32</td>
<td>30</td>
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(1 gage/5 km) which is assumed to be the best estimate of the "true" rainfall. The lower portion of the table shows similar tabulations when the mean obtained from the full-density gage network alone is assumed to be the best available estimate of the actual rainfall in the sampling areas. The first column shows the gage density employed in each computation. The second column shows the average error when the radar-indicated rainfall is not adjusted with raingage values. The third column shows the adjusted radar estimate with each method, and the fourth column indicates the average error with various densities of raingages. As found throughout the study, the least accurate measurements occur with the unadjusted radar. The size of the adjusted radar and the raingage errors is strongly dependent upon the comparison base.

Adjustment of Radar Rainfall Estimates by a Sequential Analysis Technique

Cain and Smith (1976, 1977) have developed a sequential analysis technique to be used with real-time raingage and radar data for adjusting radar-indicated rainfall estimates. The technique is claimed to have some advantages over other methods of adjusting radar estimates of rainfall. For example, it does not react to random, inherent variability of short duration that frequently occurs when comparisons are made between radar-indicated and raingage-indicated rainfall. The technique requires constant monitoring of the radar and raingage estimates of rainfall. Sequential tests are performed on the data and the radar estimates are adjusted only when systematic errors are indicated by the test.

During the flexibility period of the present grant, this new technique has been investigated through use of 12 storms from the 1976-1977 CHAP Network to evaluate it against the Brandes technique. However, further work needs to be completed before a final decision can be reached concerning the applicability of the Smith technique in the real-time operation of urban hydrologic systems. Early indications are that the residual error in the rainfall estimates will not be an improvement on that obtained by the Brandes method, and the operational time required for the technique to reach a decision on whether the radar-rainfall estimates are acceptable or need adjustment appears to be too long. For instance, some results indicate that as much as 2-3 hours will elapse before reaching a "reject" decision. This would mean that all estimates in the previous 2-3 hours are incorrect and need to be revised. This could present a very serious problem in real-time operations especially when one considers that many intense storms do not last more than 2-3 hours in an urban area. However, further evaluation may show that "fine tuning" of the technique will force it to render decisions more often and thereby reduce the radar-rainfall estimate errors. The modified Brandes technique used in CHAP overcomes the foregoing time correction problem.
Orientation and Shape of Heavy Rainstorms

Results of studies to define the distribution of storm orientation and shape in heavy rainstorms in the CHAP Network were presented in the Third Interim Report (Changnon, et al., 1978). It was found that the most frequent orientation of the major rain axis was from W-E and nearly 67% of the relatively heavy storms moved from SW, WSW, or W. The most common storm shape was found to be elliptical, followed closely by those storms that are multicellular in character. In general, storm orientation and shape in the CHAP storms were similar to those found for other areas of Illinois from earlier network studies (Stout and Huff, 1962; Huff, 1967; Huff and Schickedanz, 1970; Huff, 1978). The Illinois results are considered representative of the Midwest, since similar storm conditions prevail throughout this relatively large region of the country. Therefore, results can be used as a guide in hydrologic design for both urban and rural areas of the Midwest. No evidence was found for significant differences in storm shapes and orientation between urban and rural areas, based upon the CHAP results and the earlier network studies by the Water Survey.

Relation Between Point and Areal Mean Rainfall Frequencies

Results of the study of the relationship between point and areal mean rainfall frequencies were presented in the last interim report, and will only be briefly summarized here. This relationship is very useful in deriving the frequency distribution of areal mean rainfall for which a great need exists in urban hydrologic design problems. The method makes use of long-term records of point rainfall in conjunction with much shorter records of areal mean rainfall to establish the frequency distribution of areal mean rainfall in storms of various duration over areas of various sizes. In our study, the CHAP results were found to agree with earlier studies of the Water Survey on other Illinois raingage networks. Furthermore, no evidence has been found that the urban and rural relations differ significantly. Table 2 summarizes results of these studies in a general form which can be applied by the hydrologist and others for use in midwestern areas.

Use of Table 2 is illustrated by the following example. Huff and Vogel (1976) have indicated that the 6-hour heaviest rainfall to be expected on the average of once in 10 years in the center of the Chicago urban area is 81 mm (3.2 in), based on long-term point rainfall records. Assume one wishes to determine the equivalent mean rainfall over an area of 200 km² in the same region. Referring to Table 2, the 6-hour, 200-km² ratio is 0.90. Multiplying 81 x 0.90 yields the desired value of approximately 73 mm.
Table 2. Ratio of Areal Mean to Point Rainfall Frequencies in Heavy Storms.

<table>
<thead>
<tr>
<th>Storm Period (hours)</th>
<th>Ratios for Given Area (km²)</th>
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<td>25</td>
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<tr>
<td>1</td>
<td>0.92</td>
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<td>3</td>
<td>0.96</td>
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<td>6</td>
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<td>12</td>
<td>0.98</td>
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<tr>
<td>24</td>
<td>0.98</td>
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</table>
Synoptic Types Associated with Heavy Rainstorms

Huff and Vogel (1976) made a study of synoptic weather conditions associated with heavy 1-day storms in northeastern Illinois, based upon historical data on point rainfall in the 1949-1974 period. They found that cold fronts and squall lines (usually pre-cold frontal) were most frequently associated with the heavy storms. Huff and Changnon (1972) found that cold fronts were the most frequent synoptic type associated with all intensities of rainstorms. These evaluations were based upon use of daily weather maps of the National Weather Service (NWS).

As part of the CHAP program, more comprehensive analyses were made of the association of heavy rainstorms and synoptic weather conditions, through use of the much more detailed rainfall data from the 320-gage network. Furthermore, a more detailed classification of synoptic storm types was used than in the two earlier studies.

In the CHAP study, analyses were limited to those storms in which one or more raingages within the network recorded rainfall of 25 mm (1 inch) or more. The synoptic storm types were the same as those used in the METROMEX studies at St. Louis (Changnon et al., 1977). These consisted of seven major rain-producing storm types defined as follows.

Squall Line Storms. A nonfrontal group of thunderstorms accompanied by a trigger mechanism, usually a short wave trough. The convective activity associated with the storm systems was intense, well-organized, and often times was arrayed in a narrow band or line of active thunderstorms.

Squall Zone Storms. A mesoscale system of thunderstorms organized into an area or cluster and independent of a frontal zone. These storms, like squall lines, tended to move across large regions of the Midwest, and an upper-air impulse was usually discernible.

Frontal Storms. Precipitation formed within 120 km (75 mi) of a surface front (cold, static, or warm). There was no synoptic evidence that this precipitation was associated with a squall line or squall zone which, on occasion, moved 40 km (25 mi) or more ahead of the fronts.

Pre-Frontal and Post-Frontal Storms. Precipitation associated with a frontal structure but at a distance of 120 to 240 km (75 to 150 mi) ahead or behind a front (cold, static, or warm).

Air Mass Storms. A shower or thunderstorm generated within an unstable air mass. No large scale or mesoscale synoptic causes were evident. The resulting convective activity was usually widely scattered to scattered and weak.

Low Pressure Storms. A cyclonic storm situated so close to the research area that it was not possible to associate the precipitation with a frontal or mesoscale weather structure. These systems are rare during the summer months.
There were 46 storms sampled in the 2-year period. The frequency of each storm type and its percent of the total occurrences are shown in Table 3. This table shows that the relatively heavy storms during 1976-1977 were most frequently associated with squall zones, squall lines, and cold fronts. In fact, these three types accounted for 83% of the cases. Squall zones were not included in the earlier storm classifications by Huff and Vogel (1976) because of difficulty in identifying them on the NWS daily maps. It is likely that part of the squall zones were identified as air mass storms or as frontally-associated storms in the coarser classification. Allowing for this, both studies show that the combination of cold fronts and squall lines were associated with nearly 50% of the rainstorms. Heavy storms are usually associated with organized storm systems and cold fronts, and pre-frontal organized lines or zones are the most favored breeding places for these storms.

These findings also agree with those from the METROMEX program which showed that heavy convective entities were most commonly associated with cold fronts, squall lines, and squall zones (Huff, 1977). Among raincells producing rainfall of 6 mm or more in the five summers of 1971-1975, 89% occurred with cold fronts, squall lines, and squall zones. Only 3% occurred with unorganized air mass storms.

Thus, the results of the CHAP, METROMEX, and other Water Survey studies of synoptic conditions associated with heavy rainstorms leads to the conclusion that the flash-flood storms in Illinois and the Midwest are usually associated with organized convective activity which is most frequently associated with cold fronts and squall systems in advance of fronts. Except over very small areas, flash-flood storms are seldom associated with unorganized air mass activity. No evidence was found for difference between urban and rural areas with respect to synoptic weather systems that produce these storms.

Spatial Distribution of Storm Rainfall

As part of the CHAP research, the space and time distributions of rainfall in heavy storms has been investigated. Knowledge of the space and time characteristics is of paramount importance in solving certain hydrologic problems, such as the design of urban storm sewer systems and evaluating the flood potential of various types of storms. Much of this work was intended for the third year of the project when the sampling of convective season storms would have been completed.

Area-depth curves are frequently used to portray the spatial distribution properties of heavy storm rainfalls, since they provide a simple mathematical expression of the spatial distribution. Two types of area-depth curves are employed. The most frequently used type, which is referred to as the standard curve henceforth, is constructed by planimetering storm isohyetal maps and summarizing the areal mean rainfall from the storm center outward (high to low values). The y-intercept of the curve represents the maximum point rainfall and the last point on the curve is the areal mean rainfall. The slope of the standard curve provides a measure of the gradient
Table 3. Synoptic Weather Types Associated with Heavy Rainstorms on CHAP Network, 1976-1977

<table>
<thead>
<tr>
<th>Synoptic Type</th>
<th>Frequency</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Front</td>
<td>10</td>
<td>21.7</td>
</tr>
<tr>
<td>Warm Front</td>
<td>3</td>
<td>6.5</td>
</tr>
<tr>
<td>Static Front</td>
<td>5</td>
<td>10.9</td>
</tr>
<tr>
<td>Squall Line</td>
<td>13</td>
<td>28.3</td>
</tr>
<tr>
<td>Squall Zone</td>
<td>15</td>
<td>32.6</td>
</tr>
<tr>
<td>Low Pressure Center</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Air Mass</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
of near rainfall in the storm. The area-depth envelope curves display the area enveloped by point rainfall values of various magnitude from the storm center outward, rather than the mean rainfall over the enveloped area, as is done with the standard curve. The y-intercept indicates the maximum point rainfall, the last point on the curve is the minimum point rainfall, and the envelope slope is a measure of the point rainfall gradient in the storm.

For hydrologic purposes, there is little interest in light rainfalls, since structures are designed to store or divert excess water in heavy storms. Therefore, in the CHAP study, we have limited our analyses to those storms which produced mean rainfalls of 12.5 mm (0.50 in) over one or more subareas within the CHAP network. During 1976-1977 operations, 25 storms qualified for inclusion. These storms had network durations of 3 to 18 hours, and 72% lasted less than 12 hours. Area-depth relations were developed for 22 subareas within the CHAP network. Each of the 25 storms qualified on several subareas, so that a total of 242 subarea samples were obtained in the 2-year sampling period. The subareas ranged in size from 280 km$^2$ (108 mi$^2$) to 2564 km$^2$ (990 mi$^2$).

The storm area-depth relations for 1976-1977 were grouped according to area, and mean relations developed for each size of area. Further stratification according to storm mean rainfall, storm duration, and other parameters was not possible with the 2-year sample. The mean curves provide a first estimate of typical area-depth relations in the Chicago region, and are also useful for comparison with results of area-depth studies made for other areas in earlier Water Survey studies. No effort was made to separate urban, suburban, and rural subareas, since inspection did not indicate significant variation in area-depth characteristics between these regions.

Figure 3 shows a family of standard area-depth curves derived from the 2-year sample for areas of differing sizes and Figure 4 shows similar curves for envelope area-depth relations. In Figure 3, the area-depth ratio is defined as the ratio of the mean rainfall over the given partial area to the mean rainfall for the entire area. Similarly, the area-depth envelope ratio is defined as the ratio of the point rainfall enveloping the given partial area to areal mean rainfall. The ratios are used to normalize data from storms of varying rainfall intensity. The mean curves in Figures 3 and 4 are closely fitted by a square-root relation of the general form:

$$Y = a + bX^{0.5}$$

where, Y is precipitation depth, X is area, and a and b are regression constants. This equation has been found to correspond frequently to the rainfall spatial distribution in thunderstorm rainfall on small areas (Huff and Stout, 1952). Later research on other dense raingage networks in Illinois verified the foregoing general equation as providing the overall best fit, but also revealed that the spatial distribution varies with several storm factors, such as basin size, mean rainfall, rain duration, precipitation type, and synoptic storm type (Huff, 1968). Thus, the distribution equation may vary considerably between individual storms. In the very intense storms which have a recurrence interval of once in two years or longer in a given location, the best-fit equation was found to be of the form:
Figure 3. Average Area-Depth Relations for CHAP Storms Having Areal Means of 12.5 mm or More During 1976-1977.
Figure 4. Average Area-Depth Envelope Relations for CHAP Storms Having Areal Means of 12.5 mm or More During 1976-1977.
\[
\log Y = a + b x^{0.5}
\]

The above form for intense storms in the Chicago region was verified in the initial CHAP study (Huff and Vogel, 1976). The Huff and Vogel relations are recommended for hydrologic design uses in the Chicago urban area. Most of the 1976-1977 storms were not extreme events, and this accounts for the more common form of the relationship found in this period.

The area-depth relationships developed from the CHAP studies can serve as a guide for hydrologists concerned with urban design of hydrologic structures. It would be most desirable to continue this type of study on the large CHAP network, and to combine the CHAP findings with those obtained from the METROMEX Network of 1971-1975 in the St. Louis region. This had been planned as part of the third-year effort of the CHAP research.

Time Distribution of Storm Rainfall

Time distribution analyses performed to date on the 2-year sample of rainstorms on the CHAP network have not indicated any significant differences from those found with a large sample of rural storms in central Illinois (Huff, 1967), and from limited analyses of heavy storms in the Chicago region which was summarized in the first CHAP report (Huff and Vogel, 1976). Therefore, the reader is referred to the Huff and Vogel report for a summary of the time distribution characteristics of storms that is applicable to hydrologic problems in the Chicago area, and to the earlier Huff paper for a more detailed discussion and description of storm distribution characteristics in midwestern storms.

In general, no evidence has been found that the time distribution characteristics of storms vary significantly between urban and the surrounding rural areas. Also, no substantial differences are evident in the time distribution properties obtained from dense networks in various areas of the state. It is our conclusion that the basic distribution properties are essentially equivalent throughout the Midwest and other areas of similar precipitation climate. Therefore, the Illinois findings should have wide application in those areas where warm-season, convective storms are the primary cause of floods.

Gage Density Requirements

One of the objectives of the CHAP research has been to determine raingaging requirements for 1) use in combination with radar in real-time, prediction-monitoring systems, and 2) providing data for urban hydrologic design purposes. In the CHAP studies, emphasis has been placed upon gage density requirements for the measurement of 30-minute and 1-hourly rainfall amounts. These are time periods which must be used in the prediction-monitoring system which we have developed. Furthermore, there is a need for evaluating sampling errors in these periods for certain hydrologic design applications. There has been considerable work done in the past in
determining sampling errors (Linsley and Kohler, 1951; Huff and Neill, 1957; McGuinness, 1963; Huff and Schickedanz, 1970), but emphasis has been on the measurement of storm mean rainfall rather than on intervals within storms.

The gage density studies have not been completed at this time, since the analysis program was designed to utilize the 3-year data bank that would have been available at the end of the project, as originally planned. However, considerable information has been derived on sampling errors from data analyzed in development of the prediction-monitoring system. Gage density requirements for operation of this system were summarized earlier in this report in the section dealing with the prediction and measurement of storm rainfall with radar and raingages.

In the CHAP analyses, we have calculated the sampling errors by two methods. First, we computed the sampling errors for a given area, such as the Chicago urban area, in which the errors were based on using all observations in the target area, including those stations with no rainfall during a particular sampling period (Method A). The derived relations have application in some hydrological problems and in various other fields. However, for the prediction-monitoring system and other hydrologic uses, it is most important to measure the rainfall only within the region where rain is actually falling (Method B). This is where we have concentrated our attention. Computations have been made for consecutive intervals of 30 minutes and 60 minutes within storms and for total storm rainfall.

Results obtained to date with Method B are summarized in Table 4, where average sampling errors are shown for various gage spacings on areas of 500 to 1500 km$^2$ for 30-minute, 60-minute, and total storm rainfall. The results are derived from 12 storms for which 92 samples of 30-minute amounts and 51 samples of 60-minute amounts were available. Only amounts that equalled or exceeded 2.54 mm (0.10 in) were used in the analyses, since light amounts are not significant in the type of hydrologic applications being studied in this project. This, of course, limits the number of samples greatly in any given period, since most rainfall amounts during intervals of 30 to 60 minutes are less than the base used here.

Table 4 can be used by urban hydrologists as a guide in determining raingaging requirements for various applications. The sampling error that is acceptable will vary, depending upon the accuracy requirements of the particular application. For most needs, it is likely that gage spacings of 5 to 10 km would be acceptable. If interest is limited to total storm rainfall over areas of 500 to 1500 km$^2$, gage spacing of 10-15 km should be adequate.

Table 5 shows average sampling errors derived from the 12-storm sample with Method A. Sampling errors for 30-minute and 60-minute intervals were combined because differences were so small with this method. Because of the inclusion of zeroes in the averaging, the errors are smaller than with Method B for measurement intervals of 30 to 60 minutes. However, there are no significant differences in the total storm values, because zeroes are infrequent within areas of the size sampled here over a total storm period. Comparison of the total storm errors in Tables 4 and 5 with those obtained from a much larger sample of network storms in an earlier Water Survey study
Table 4. Average Sampling Errors with Method B on Areas of 500 - 1500 km$^2$ in Convective Storms.

<table>
<thead>
<tr>
<th>Gage Spacing (km)</th>
<th>Average Sampling Error (%) for Given Measurement Interval</th>
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<tbody>
<tr>
<td></td>
<td>30-Min Intervals</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
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<tr>
<td>10</td>
<td>14</td>
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<td>15</td>
<td>22</td>
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<td>20</td>
<td>29</td>
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<td>25</td>
<td>36</td>
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<tr>
<td>30</td>
<td>43</td>
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<tr>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>57</td>
</tr>
</tbody>
</table>
Table 5. Average Sampling Errors with Method A on Areas of 500 - 1500 km$^2$ in Convective Storms.

Average Sampling Error (%) for Given Measurement Interval

<table>
<thead>
<tr>
<th>Gage Spacing (km)</th>
<th>30- to 60 min Intervals</th>
<th>Total Storm</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
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<td>15</td>
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<tr>
<td>25</td>
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<td>17</td>
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<td>35</td>
<td>34</td>
<td>29</td>
</tr>
<tr>
<td>40</td>
<td>41</td>
<td>35</td>
</tr>
</tbody>
</table>
(Huff, 1970) show that the 1976-1977 CHAP values are typical of those obtained in warm-season convective storms. Where primary interest is in total storm rainfall, the above reference paper provides measurement errors under various types of conditions, and can be used as a guide by the urban hydrologist, since urban-rural differences in measurement errors should be nearly equivalent.

**Location of Heavy Rainfall Centers**

In the initial CHAP study, historical rainfall data for stations within and surrounding the Chicago urban area were used to investigate whether heavy rainstorms tended to be centered more frequently in certain areas (Huff and Vogel, 1976). The hypothesis was that the urban effect might result in more frequent storm centers in or downwind of the city, similar to the situation found at St. Louis (Changnon, et al., 1977). Results indicated a distinct trend for more centers over the metropolitan area and in the region immediately S and SW of the city.

The 2-year sample of CHAP network data was used to explore further the distribution of storm centers. However, the sample of heavy storms was relatively small. Analyses of those storms in which maximum amounts exceeded 25 mm (1 inch) provided no strong evidence of a preferred area for heavy storm centers to occur. There was slight support for an above-average frequency immediately south of the urban area where a preferred region had been identified in the historical study. An urban-induced increase in storm centers would be difficult to detect with a raingage network in the Chicago area. With most frequent storm movements from SW, W, and NW, the urban-related maximum would most likely occur very near or over the lake. At St. Louis, the urban-induced rainfall maximum occurred 25-30 km NE of the central city (Changnon, et al., 1977).

**Antecedent Rainfall Associated with Heavy Rainstorms**

The amount of rainfall preceding heavy storms is of major importance in both flood prediction on a real-time basis and in the design of hydrologic structures. For design purposes, the probability distribution of rainfall amounts for several days preceding a heavy storm event is of prime concern. Data for the CHAP network and other dense networks that have been operated by the Water Survey in Illinois in the past 25 years are being combined to provide an answer to this problem. This study has not been completed, but preliminary results are presented here as an initial guide to the urban hydrologist.

Our analyses were confined to the warm season from mid-April to mid-October when convective rainfall predominates and most of the flash-flood storms occur in Illinois and the Midwest. Probability distributions were derived for 1 to 10 days preceding all storms in which the network mean rainfall equalled or exceeded 25 mm (1 inch). At this time, distributions have been computed for areas ranging in size from 25 km² (10 mi²) to 1000 km²
(approximately 400 mi$^2$). These are areas which are of major interest in urban and small watershed hydrology.

Preliminary results are shown in Table 6 which presents probabilities for selected areas of 25, 250, and 1000 km$^2$ during antecedent periods of 1 to 10 days. These should be considered first approximations that may be modified as more analyses are completed. Amounts in the table were abstracted from probability curves derived for each specified situation.

Table 6 shows that the antecedent rainfall tends to be greater as the sampling area increases. This is related to a strong trend for heavy convective storms on the larger areas to be associated with organized convective activity of a macroscale nature and to occur during periods of relatively heavy rainfall in the general region. Whereas a single airmass shower of strong intensity could produce a 25-mm mean on 25 km$^2$, it would require a storm system of considerable areal extent to produce a mean of this magnitude over 1000 km$^2$. Intense, isolated airmass showers frequently develop in summer during periods when rainfall is not widespread.
Table 6. Probability Distributions of Antecedent Rainfall for 1 to 10 Days on Selected Areas in Storms Producing Mean Rainfall of 25 mm or More.

<table>
<thead>
<tr>
<th>Probability</th>
<th>1 Day</th>
<th>2 Days</th>
<th>3 Days</th>
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<tbody>
<tr>
<td>%</td>
<td>25</td>
<td>250</td>
<td>1000</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>21</td>
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<tr>
<td>20</td>
<td>6</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>40</td>
<td>3</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>4</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>5 Days</th>
<th>10 Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>51</td>
</tr>
<tr>
<td>10</td>
<td>38</td>
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<td>20</td>
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<td>40</td>
<td>11</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
</tr>
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</table>
UTILIZATION EFFORT

Introduction and Users

This project, as designed, was an ideal science-to-technology effort, made to order for the aims of the Foundation's RANN Program and those of the Illinois State Water Survey. The project had two main phases, each requiring a different type of information transfer and thus a differing utilization effort. The user audience differed but was largely within the water resources and engineering communities.

The phase of CHAP dealing with areal rainfall frequencies (from the raingage data) had water resource design and modeling implications for the hydrologic community. These issues were primarily concerned with 1) storm drainage and sewer designs to estimate better the time and space variations likely to be encountered in large urban areas, and 2) the use of real data in complex hydrologic models such as those being used to develop strategies required to meet EPA water quality standards under the "208 Plan." Thus, the users were design engineers (both private and governmental), modelers of urban water resource systems (private and institutional), and state and federal decision makers involved in the meeting of standards (HUD and EPA).

The other phase of CHAP dealt with the use of a weather radar in conjunction with raingaging facilities in the operation of a complex water resources system in large urban areas, such as Chicago. It was aimed at demonstrating the utility of such an approach to those who 1) operate large urban systems, and 2) the decision makers who design and plan for future operational systems. The need here was to prove, primarily to the sizeable engineering community of Chicago, the great advantages of the radar-rainfall measuring system, and to let them help us "sell the product" to engineer-operations elsewhere.

Although the audiences for the results of these two phases differed in their engineering-hydrologic specialities, they were all within the large community of water resource experts and could be reached through the literature common to all. The users of the results and developments of the project were classed into local groups, and into national and international groups.

The utility of the project and its products has already been recognized at the national level. President Carter commissioned a 1977 study of the nation's water problems, and national experts helped OSTP draft a report to the President's Policy Committee. This 1978 report is entitled Scientific and Technological Aspects of Water Resources Policy, and in its text on "Urban Water Programs" states "The space and time resolution of most of the precipitation gauge networks throughout the nation is quite inadequate to permit interfacing with the kinds of sophisticated urban runoff and water quality models needed. There are a few examples of dense hydrologic..."
networks, installed near large cities and including radar equipment as well as recording and telemetering raingauges, that meet these needs. However, these installations and their supporting organizations have begun to pay off very effectively in terms of improved urban catchment control. Notable among these is the Chicago Hydrometeorological Area Project (CHAP).

This reveals the extent of the information transfer already accomplished in two years and reflects on the vitality and value of the project and its products.

Means of Information Transfer

Certain of the information and techniques developed in the proposed project are at the forefront or "cutting edge" of urban hydrology. Pioneering information normally has a limited user application; it is usually readily accepted only by outstanding engineers and in this specific case, by cities like Chicago and San Francisco, which have sophisticated hydrologic systems ready to implement new rainfall information. Therefore, use of many project results by the engineering community will require continuing communication and time to achieve widespread acceptance.

The Illinois State Water Survey, with an 85-year history as a water resources agency of Illinois specializing in scientific research and related services to everyone in Illinois, has developed an enormous user community and the means (publications, workshops, etc.) to reach and interact with this community that includes city engineers, private consulting engineers, waste treatment plant managers, chemists in water quality laboratories, plus the local, state, and federal officials who control or operate all hydrologic facilities in Illinois. Since the Survey is also a unique organization (no other state has a comparable water resources research agency), it also has developed national prominence and its staff and accomplishments are well known to engineers and scientists beyond Illinois.

A major feature of this urban-rain project has been user interactions. The strategy called for continued and gradually increasing user involvement with time. This project actually began in 1973 when Survey atmospheric scientists and hydrologists began to plan this intensive rainfall study for the Chicago area using all available historical data. Thus, the NSF-funded project began at the culmination of two years of research and planning coupled with input from a series of interactions with users, both in Illinois and on the national scene.

User Interactions, 1973-1975. Actual involvement with local and national users of the project findings began in 1973 as Survey scientists and engineers had developed the preliminary plan for a multi-year study of precipitation in the Chicago area in 1973. The first phase was a state-supported background study of all historical rain records and close interactions with local users (Huff and Vogel, 1976). The Survey invited a
group of local users (representatives of 3 private engineering firms, the City of Chicago engineering office, MSD, and NIPC) to a meeting in Chicago during May 1974. This meeting was sought 1) to advise them of our plan, 2) to better define presentations of results by understanding their needs for rainfall information, 3) to establish a working level user interaction, and 4) to identify and obtain all available historical rain data. In this and subsequent 1974-75 meetings with MSD staff members, a new need became apparent -- means for providing real-time information about precipitation quantity, both over the city and that approaching the city. The potential for use of sophisticated weather radars became recognized.

The need for a large dense network of raingages to provide the type of rainfall data and information that could not be gleaned from the existing historical rain stations in the study area became clear as Survey research progressed. This fact, plus the newly recognized possibility of radar-rainfall measurements for urban network operations, led to further discussions with local and national water resource people. The potential for the radar-raingage network research and demonstration project was discussed with local users (Chicago city leaders, MSD staff and Northeastern Illinois Planning Commission) in a special meeting in May 1975, and with staff members of the Center for Urban Studies of the University of Chicago in April and May 1975. This potential was also discussed with national users including a key representative of the ASCE (Dr. M. B. McPherson, Director of the Urban Water Resources Research Program), the city engineers of San Francisco (they were visited in June 1975), and urban design engineers at Colorado State University, Purdue University, and the University of Illinois (April-May 1975). Thus, these user interactions became the basis for launching the large project funded by NSF/RANN and the State of Illinois.

User Interactions, 1976-1978. To a large degree, the processes of utilizing the CHAP results included the following efforts.

1) The Survey involved several major area users (MSD, city officials, and NIPC) in the siting of 315 instruments and in project information description.

2) Three meetings were held in Chicago for those concerned with the rainfall quantity information (for design purposes), for those involved in system operations, and for those concerned with developing and calibrating urban models.

3) Direct involvement of the MSD operational engineers with the radar phase was discussed frequently (about 6 times per year).

4) An advisory panel involving representatives of key user groups was established and convened at the project start. It also was asked to review project results and to assist in translation of results to users.

5) The Survey, through its many regular communication channels (staff on water planning committees, regional office interfaces, positions in ASCE, etc.), constantly translated project information to a variety of users.

6) Scientific papers were presented at a variety of regional and national conferences of appropriate societies (ASCE, AGU, AMS), and major papers
Meetings and visits were held in 1976, 1977, and 1978 with engineers and water resource operators in the Chicago area, both to inform them of the project and to secure their assistance in the siting and installation of project facilities. A particular effort has concerned development of a close working relationship with the operational staff of the Metropolitan Sanitary District of Greater Chicago, the agency with which we will demonstrate the utility of weather radar for their operation of the Chicago water resource system. This interaction included 6 meetings of key staff members of the Water Survey and MSD, 2 visits of Survey staff relating to raingage siting and historical rain data, and 3 visits by a Survey meteorologist to observe the actual operations of the MSD system during pre-rain and rain periods. Some of the direct interactions with local and regional users are listed in Table 7. Other direct interactions with local users concerned visits with those operating other water and weather projects in the Chicago area.

Information on project activity has also been handled by the release of project information through various news media. An information flyer released by NIPC to planning agencies described the initiation of CHAP. This was distributed to all governmental and planning groups throughout the Chicago area. Three major news releases about the project were made. The general public, particularly in Illinois, is also a user of the project information. To this end, six presentations, on either radio or TV, about the project were given.

Another major activity in building local-regional user interest and interaction, has been the distribution of storm rainfall maps for major rainstorms that occurred during the project. Examples of these maps appear in the project progress reports (Changnon and Huff, 1976 and 1977). Cover letters and the maps were distributed to some 75 "users" in the Chicago region within 3 weeks after the storm date. Recipients included planning agencies, city engineers, news media, University scientists, private engineering firms, and all governmental entities interested in rainfall.

Requests for rain design information and project data have correspondingly grown. In a three-month period ending 31 October 1977, we received and responded to 16 requests, largely from engineering firms.

Since several other meteorological and hydrologic research projects have developed in the Chicago region since CHAP began, and partially as a result of CHAP, we hosted a 1-day workshop in April 1977 to develop regional communication between the 25 research scientists. We also discussed joint operations and means for data exchange between the research groups.

To obtain advice and to initiate information distribution at high levels, the project established an 8-person advisory panel. It consists of users from engineering offices of two cities (Chicago and San Francisco), presidents of two large consulting firms, a national leader in urban water resources, the head of the hydrology program of the National Weather Service, and the chief engineers of MSD of Greater Chicago and the Northeastern
Illinois Planning Commission. They are listed in Table 8. We have met with this panel, had a site visit, obtained their advice, and kept them informed about the project. A second scientific advisory group was formed in 1977. It consists of three weather radar specialists. Two are from the National Weather Service, and one is from the university research community.

Nineteen project talks (Table 9) were presented at various conferences of the American Geophysical Union, American Meteorological Society, the American Water Resources Association, American Water Works Association, and American Society for Civil Engineering. These were aimed at reaching the "national" users, those throughout the nation concerned with urban water resources. Talks to non-technical audiences are listed elsewhere (Huff and Changnon, 1977). A talk at Western Michigan University helped create interest in joining in the project by that institution. They purchased twelve recording raingages ($5,000) to help enlarge the network so as to secure data in Michigan.

In addition to these direct interactions and oral presentations, considerable efforts, considering the relatively short length of the project, were extended towards the publication of project information and results (Table 10). Seventeen scientific papers and reports were published. Copies of these publications have been widely distributed. Several other Survey reports closely related to CHAP have been published, as shown in Table 10.

In an attempt to get direct user interaction, staff members visited with hydrologists and engineers of the city of Chicago and San Francisco, at MSD (many times), and with urban-regional planners of Chicago and St. Louis. A 1-day workshop, and tour of the radar facility was conducted at the HOT radar site on 16 November 1977. Leaders of MSD participated in this orientation and information exchange held after the successful 1977 radar test operations.

Summary

Extensive efforts to develop and maintain direct interaction with users and transferral of information about the project were conducted during the project. To recount, the local-regional users of Chicago and environs were reached through direct presentations at local meetings and by actual working discussions at meetings with project scientists and those involved in related projects at the University of Chicago, MSD, city engineering offices, Northeastern Illinois Planning Commission, and other agencies. On the national level, the major user interactions have concerned talks at major scientific meetings, the publication of seventeen papers and reports (widely distributed through the Water Survey's user-focused mailing system), and our advisory panel.

A key activity on this project, both for scientific-technical guidance and to secure user interactions, relates to the 8-man advisory panel established. They are leaders chosen to represent local and national interests, private and governmental interests, and varying scientific and
engineering interests in urban hydrology. They have assisted us in the transmittal of project information throughout the urban water resource field, as well as providing advice on project research.

The costs of user interactive efforts reflect the extent of the effort. The State of Illinois invested $26,000 in costs of publication, salaries, travel, mailing, and meetings; NSF funds expended totaled $17,000 for advisory costs, publications, and travel to conferences; and the MSD of Greater Chicago invested an estimated $10,000 in staff costs. Thus, the user effort totaled $53,000, or about 7 percent of the total project costs.

The question of whether the user effort succeeded has been and will continue to be answered in a variety of ways. The singular identification of CHAP in the report to President Carter is one clear indication that its results are known at the national level. Another indication is the many letters received requesting data, added information, and complimenting us on the project. Six letters, selected from among more than 50 received, are included in the following pages to reveal the interest of county, state, and city officials plus that of private industry.
Table 7. Examples of Direct Interactions with Local-Regional Users in 1976.

Meeting with Water Control Staff of Metropolitan Sanitary District (MSD) and 5 project staff members in Chicago, May.

2-day observational visits at MSD to view actual system operations in May and in June.

Meeting with leaders of Northeastern Illinois Planning Commission and representatives of Hydrocomp, Inc., concerning interaction of their work on PL 208 water quality project and CHAP research, March.

Meeting with George Tolley, University of Chicago, October, to discuss data exchange, in Chicago.

Meeting with National Weather Service personnel of Chicago Office, in March, in Chicago.

Meeting with urban planning groups of DuPage County and McHenry County in February, in Woodstock.
Table 8. User Advisory Panelists for CHAP.

Robert Clark, Associate Director of Hydrology, National Weather Service, NOAA, Silver Spring, Maryland.

Harold Coffee, Chief Engineer, Department of Public Works, San Francisco, California.

Clint Keifer, President, Keifer and Associates, Chicago.


Murray B. McPherson, Director, ASCE Water Resources Research Program, Marblehead, Massachusetts.

Forrest C. Neill, Chief Engineer, Metropolitan Sanitary District, Chicago.

Dick Pavia, Commissioner, Department of Waters and Sewers, Bureau of Engineering, City of Chicago.

Joseph A. Smedlie, Chief Engineer, Northeastern Illinois Planning Commission Chicago.
Table 9. Professional Papers and Technical Presentations.


"Impacts of Chicago Hydrometeorological Area Project on Hydrologists and Design," given by S. A. Changnon, Meeting of Illinois Section of ASCE, Chicago, April, 1977.

Table 9. (continued).


Table 10. Project Publications.


Table 10 (continued).


Closely Related Reports of Other Water Survey Research and Staff


July 8, 1976

Illinois State Water Survey  
P.O. Box 232  
Urbana, IL 61801

Attn: Stanley A. Changnon, Jr.

Re: Rainfall Patterns in Northeastern Illinois

Dear Mr. Changnon:

I am in receipt of your letter of July 2, 1976 and the rainfall pattern for the storm of June 13, 1976, which did so much damage in South Eastern DuPage County. The type of information presented in this document is of great value to engineers and local governments who are involved in storm water management. I would like to continue to receive this information and any other information that would be pertinent.

I would like to know also, if your organization is capable of determining duration of storm and the distribution of the rainfall during the storm duration. This information would be of value in developing very small basin storm sewer designs.

Sincerely yours,

H. Dale Dunteman, P.E.  
Drainage Engineer

HDD/jag  
cc  
file
Dr. Wm. C. Ackermann, Chief  
Illinois State Water Survey-  
Box 232  
Urbana, Illinois  61801

Subject: Report of Investigation 82  
Hydrometeorology of Heavy  
Rainstorms in Chicago and  
Northeastern Illinois

Dear Bill:

We would like to obtain a supply (say 50 copies) of your Report of  
Investigation 82, issued 1976 on the subject of the storm rainfall  
experience in Northeastern Illinois, with particular emphasis upon the  
Chicago metropolitan area.

We plan to use this booklet as an appendix to various Step 1 Studies  
for villages in the Chicago metropolitan area. We believe it provides  
the best presentation of a summary of rainfall experience in our area,  
and would be the most effective way to communicate to decision makers  
as to the effects of increased hydraulic capacities of sewers, if it  
should be provided by new construction.

We have found that the most severe rains, say the 10 most severe in  
the period 1949 through 1974 which you analyzed in the subject Report,  
were associated with high intensities for a short period of time. The  
increases in rates of outflow which could be achieved by increased  
hydraulic capacities of sewers have remarkably little impact on the  
problem of street storage. We make this statement based upon actual  
observations of how the water has behaved in actual storms in Western  
Springs, Illinois. We were able to derive from this data an estimate of  
the total infiltration that occurred during these storms, and have then  
arbitrarily broken this total into 1" of initial infiltration plus something  
less than 0.1" per hour thereafter as a means of making our analyses.  
This appears to agree fairly well with the data.

Taking the 10 most severe storms for the small drainage areas tributary  
to low spots in neighborhoods, we found that increasing the outlet  
capacity 9 times would achieve a 19% reduction in the depth of ponding  
during the most severe storm, and would achieve a 45% reduction in depth  
of ponding for 10 or more times during the 25-year period.
Dr. Wm. C. Ackermann, Chief
Illinois State Water Survey

Considering the worst storm in 25 years, the 19% reduction in depth of street ponding might amount to say 8". One is faced with the obvious question of whether one can more easily protect against the 8" higher depth of ponding than provide a 9-fold increase in overall hydraulic capacity of the sewer system.

This is the sort of argument that we would like to make with the aid of your Report. There are many millions of dollars at stake, dollars which could be wasted in a vain attempt to eliminate the street ponding which the public associates with "flood" problems.

Very truly yours,

William J. Bauer
President
January 13, 1978

Dr. Charles Thiel
National Science Foundation/RANN
1800 G Street, N.W.
Washington, B.C. 20550

Dear Dr. Thiel:

It has come to our attention that continued funding for the Chicago Hydrometeorological Area Project (CHAP) is in jeopardy. The Metropolitan Sanitary District of Greater Chicago would like to urge the National Science Foundation to continue funding in 1978 so that CHAP can be completed.

The long-term implications of CHAP could include a system which will help optimize the operations of the Chicago Sanitary and Ship Canal and the Tunnel and Reservoir Project (TARP) - both of which are vital to pollution control, flood control and water supply for the Chicago Metropolitan area. Other cities are considering systems similar to TARP as a solution to the combined sewer overflow problem.

We are also constructing small reservoirs as a part of the SCS PL-566 program. Similar programs are underway throughout the nation. We should like the opportunity of determining the value of the CHAP system in their operation. The operation of small reservoirs is common to most urban areas. User application of the CHAP system should be readily transferable to other cities if the final results are as promising as they now appear.

Additionally, there may be some application of the CHAP system to increase efficiency of plant operations. For this, and for the reasons cited above, we urge continued funding of the project.

Very truly yours,

Forrest C. Neil
Chief Engineer

FCN/WB/w

bcc: Mr. Stanley A. Changnon, Jr.
Messrs. Lynam/Dalton/McMillan/Carlson/Bergman/File
January 18, 1978

Dr. Charles Thiel
National Science Foundation/RANN
1800 G Street NW
Washington, D.C. 20550

Dear Dr. Thiel:

This letter solicits your continued financial support for the Chicago Hydrometeorological Area Project (CHAP) currently being executed by the Illinois State Water Survey.

This Commission is responsible for regional planning in the six counties of northeastern Illinois, an area encompassing 3,700 square miles, over seven million people, and a large and varied industrial base. There are over 260 municipalities in the region, including the city of Chicago, as well as a large number of sanitary, drainage, soil and water conservation, and surface water protection districts, all involved in matters related to stormwater runoffs and flood control planning. Experience has shown us the extreme vagaries of weather patterns, storm intensities and durations.

Given the large investment in the region, and recognizing the inherent risks and hazards associated with inadequately designed stormwater drainage and flood control protective systems, we have need for current, factual data such as can be generated by the CHAP. Similarly, we have need for information which documents the air pollutants which fall out or wash out on our region. Better knowledge of their quantitative, temporal, and spatial variations will materially assist us in water quality management studies.
Mr. Charles Thiel

January 18, 1978

Your continued support of CHAP is strongly recommended.

Sincerely yours,

Robert G. Ducharme
Consulting Executive Director

RGD:10
January 20, 1978

Dr. Charles Thiel
National Science Foundation
1800 G Street N.W.
Washington, D.C. 20550

Dear Dr. Thiel:

I have recently learned the National Science Foundation is considering not funding the Illinois State Water Survey for the third and final year in their effort to better define the spatial rainfall frequency in the Chicago Metropolitan Area. The Division of Water Resources is the State agency charged with reducing urban flood damage. As such, we believe the completion of this research will provide a tool for managing flood control works, including the stages and flows in the Sanitary and Ship Canal, to minimize flood damages.

The Division of Water Resources is also charged with allocating diversion from Lake Michigan. In order to prevent flooding in downtown Chicago, it is necessary to begin dewatering the canal system in anticipation of rainfall. If rainfall does not occur, or is less than anticipated, water must be diverted from Lake Michigan to re-establish depths in the canal sufficient for commercial navigation. A sufficient quantity of water must be held in reserve for this contingency, and is therefore, un-navigable for allocation to domestic, commercial and industrial needs. Successful completion of this research project will provide more accurate prediction of storm flow and consequently an increase in allocable water in this critically water-short area.

Operation and maintenance of the Chicago Deep Tunnel Plan for flood control and pollution abatement, through accurate storm flow predictions, will be facilitated. Technology developed here will be useful in other major urban areas. Finally, what is learned through this research project will certainly provide a better insight to the effects of urban areas on local climate.
I hope you will consider these items and act favorably on the State Water Survey request to continue this research.

Sincerely,

Frank Kudrna
Director

FK:JC:mam
cc: Stanley Chagnon
25 January 1978

Dr. Charles Thiel
National Science Foundation/RANN
1800 G St., NW
Washington, DC 20550

Dear Dr. Thiel:

As a member of the advisory panel for the Chicago Area Hydrometeorological Project (NSF ENV76-01447), it has come to my attention that the third year of the project may not be funded. Since one of my major concerns about the project was its short planned life (3 years), I am naturally disappointed that support may be terminated even earlier.

The raingage network established under CHAP is the world's largest dense network and is a valuable asset for many types of meteorological and hydrologic research. However, record length is important. In some previous research at Stanford University we used data from another dense network, but found our study severely hampered by the fact that only five years of record were available. That particular study was aimed at determining the desirable density of gages for use in modern hydrologic simulation. If the CHAP network is terminated (or greatly reduced) after only two years, much of the value of the efforts already expended will be diminished. I hope that the network can be maintained for five years before reduction in density.

In addition, the opportunity to investigate radar-rainfall relationships over this network and to attempt real-time forecasts of rain based on the radar is important, but the value of such research will also be diminished if the system cannot be operated for a sufficient time to yield results which have statistical validity.

I believe that shortening the CHAP project will greatly reduce the validity of the research proposed under CHAP and at the same time will deprive hydrologists and meteorologists of a data resource which is of potential value for a number of other research efforts. I realize that NSF may have compelling reason to terminate support of this project. If, however, the decision is not final and continued support is possible, I strongly recommend that the support be continued.

Very truly yours,

Ray R. Linsley
Chairman

RKL:ns
REFERENCES


