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ANNUAL REPORT
1 March 1971 - 29 February 1972 Period

FIELD STUDY OF URBAN EFFECTS ON PRECIPITATION AND SEVERE WEATHER AT ST. LOUIS

NSF Grant GA-28189X
Illinois State Water Survey-
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Principal Investigator

Introduction

The first year of this 2-year grant, 1 March 1971 - 29 February 1972, involved a massive effort 1) to design and build various electronic weather and radar equipment; 2) to install these and more than 500 other weather instruments in a 2000-mi^2 area; 3) to convert an abandoned 10-acre Air Force radar site into an operational headquarters that included housing for 12 students, 2 weather radars, and construction of a custodian's home; 4) to train 9 summer students and 2 new staff members; 5) to operate most of this equipment continuously for 92 days; and 6) to initiate the processing and analysis of the diversified data. Analytical processing completed has included 3200 raingage charts, 47 hail-dented hailpads, 105 hygrothermograph charts, 800 ft of cloud camera film, 4900 feet of wind record charts, 350 hours of radar film data all containing echoes, and 78 magnetic tapes of digitized radar data. Much of the autographic data has been digitized onto IBM cards and/or tapes.

Goal 1 Activities

The first major goal of this project is to study the surface precipitation in the St. Louis area so as to discern any types of urban-related changes on both an individual storm and on a statistical basis and in relation to detailed analyses of synoptic weather conditions associated with these precipitation events.

Primary analytical emphasis to date has been placed on the 1971 summer rainfall data involving that from 1) the 222 recording raingages (forming the largest dense raingage network in the world), and 2) the 10-cm FPS-18 radar operated continuously from 26 June through 31 August (various frequency-interference problems plus extensive modification of the NCAR antenna loaned to us resulted in the delayed June initiation of the radar). The rainfall data from each raingage has been digitized into 5-minute amounts and recombined to form hourly, rain period, and monthly amounts.

Individual rain cells (convective entities) on all rain days are being identified to study each cell's initiation, motion, maximization, total rain yield, and dissipation as a function of time and location. Cloud camera data are being used to define, where possible, cloud formation and development associated with cells. Each rain cell is being classified as to occurrence in the urban heat and nuclei plumes for the time of its existence. This will allow comparison of characteristics of "effected" rain cells and those not effected by the urban-industrial complex. The circular network design was chosen largely for this purpose. The isohyetal patterns of several rain cells on 11, 14, and 18 June 1971, as well as their related urban plumes (surface to cloud base levels) are shown in Fig. la-c. PPI radar echoes are being studied in a similar fashion with regard to echo formation, motion, and dissipation.

Available Results

There were 62 distinct summer rain periods in 1971, each related to a specific synoptic weather condition and with a time separation of 1 hour or more within the research circle. The areal distribution of maximum point rainfall values in each of these 62 rain periods, sorted according to their location

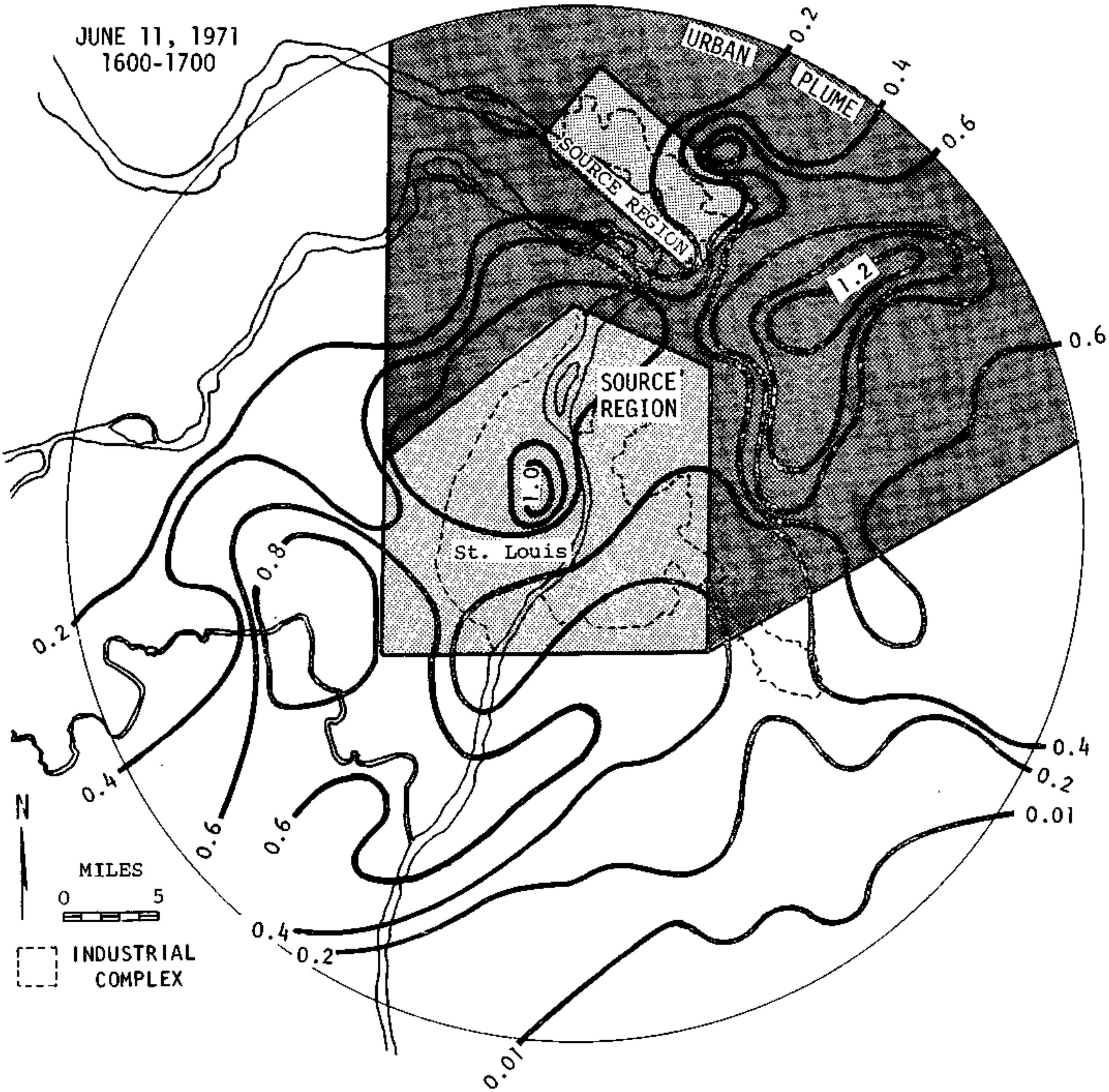

Figure la. Urban plume area and rain cells for 11 June 1971

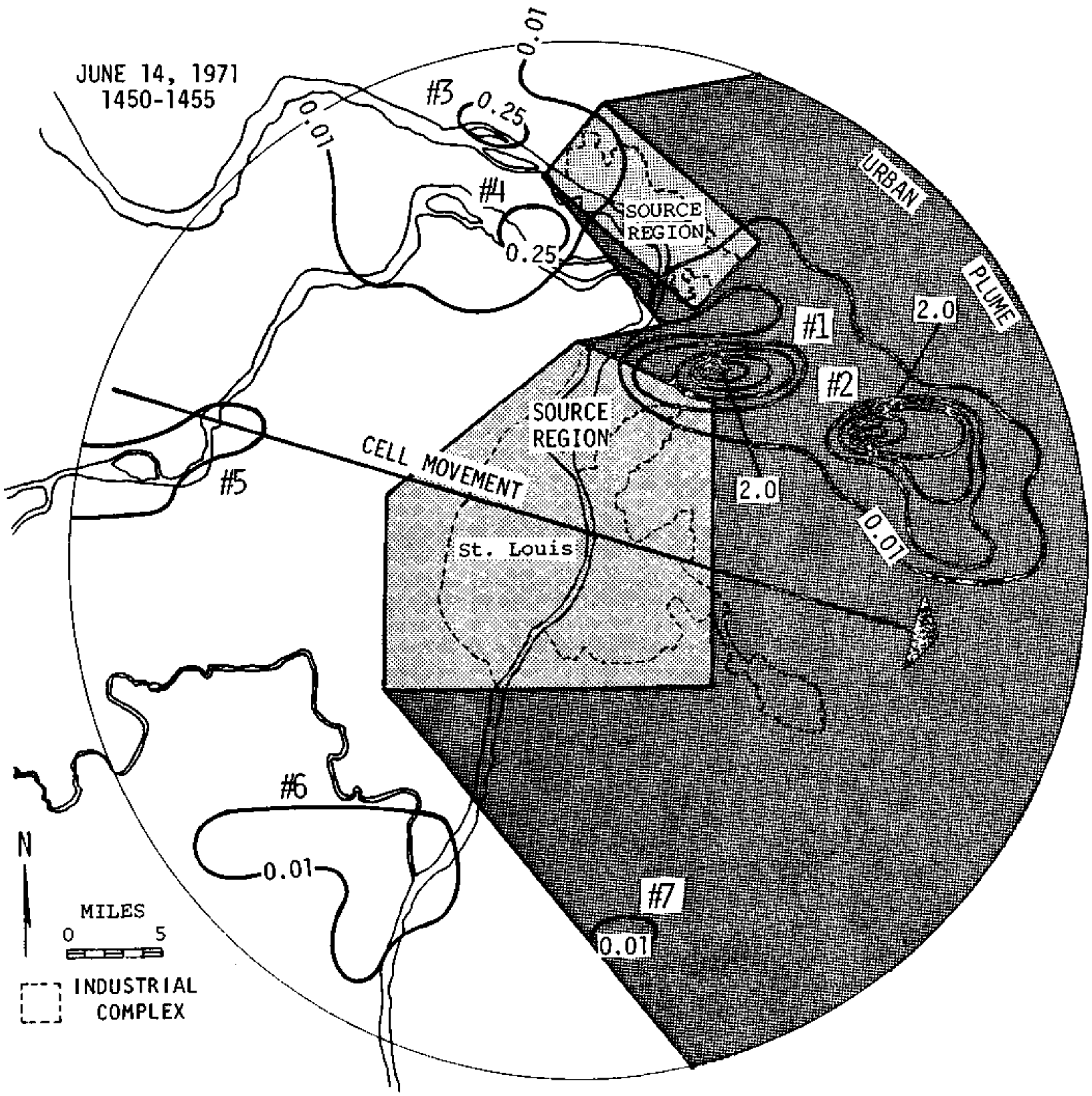

Figure lb. Urban plume area and rain cells for 14 June 1971

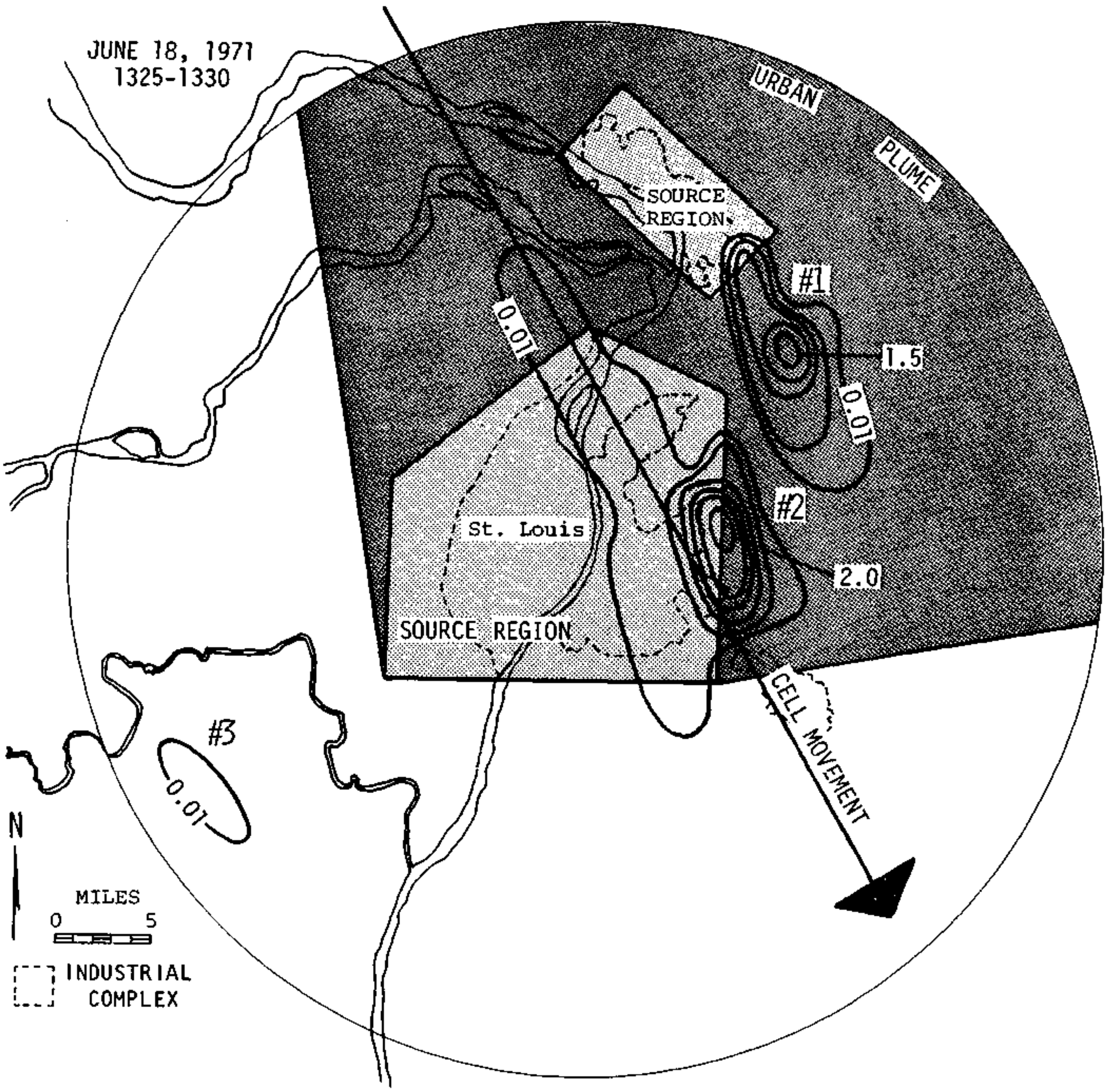

Figure lc. Urban plume area and rain cells for 18 June 1971 in three objectively defined areas, is shown in Fig. 2. The marked tendency in all months toward maximization in the Major Effect Area (where 90% of the convective storms passing over St. Louis normally move and dissipate) is indicative of a marked urban effect in 1971.

The June-August 1971 total rainfall pattern (Fig. 3) also reveals that tha area's greatest rainfall existed in two regions downwind (northeast and south-southeast) of St. Louis. This rainfall pattern is typical of that found in prior dry summers of the last 30 years. The eastern half of the research circle averaged 7.4 inches, as compared to 7.0 inches in the western half. The normal summer rainfall is 11.3 inches, and these data plus the pattern on Fig. 3 reveal the generally below normal character of the 1971 summer rainfall.

Prior climatic analyses of the St. Louis daily rainfall data from long-term stations have shown the preference for warm season (April-October) precipitation to occur in the St. Louis area on weekdays, as opposed to week-ends. This important finding, strongly indicative of man-made effects on precipitation processes, was substantiated in June-August 1971. Rain fell in the network on 45 calendar days (Table 1), and 76% of these rain days occurred on weekdays (Monday-Friday). The expected frequencies of rain days on weekdays, if rainfall is evenly distributed on all days of the week, is 71% for the five weekdays. The 76% preference for rainfall on weekdays found in 1971 is identical to that found in the studies of the past rainfall data for 1949-1968.

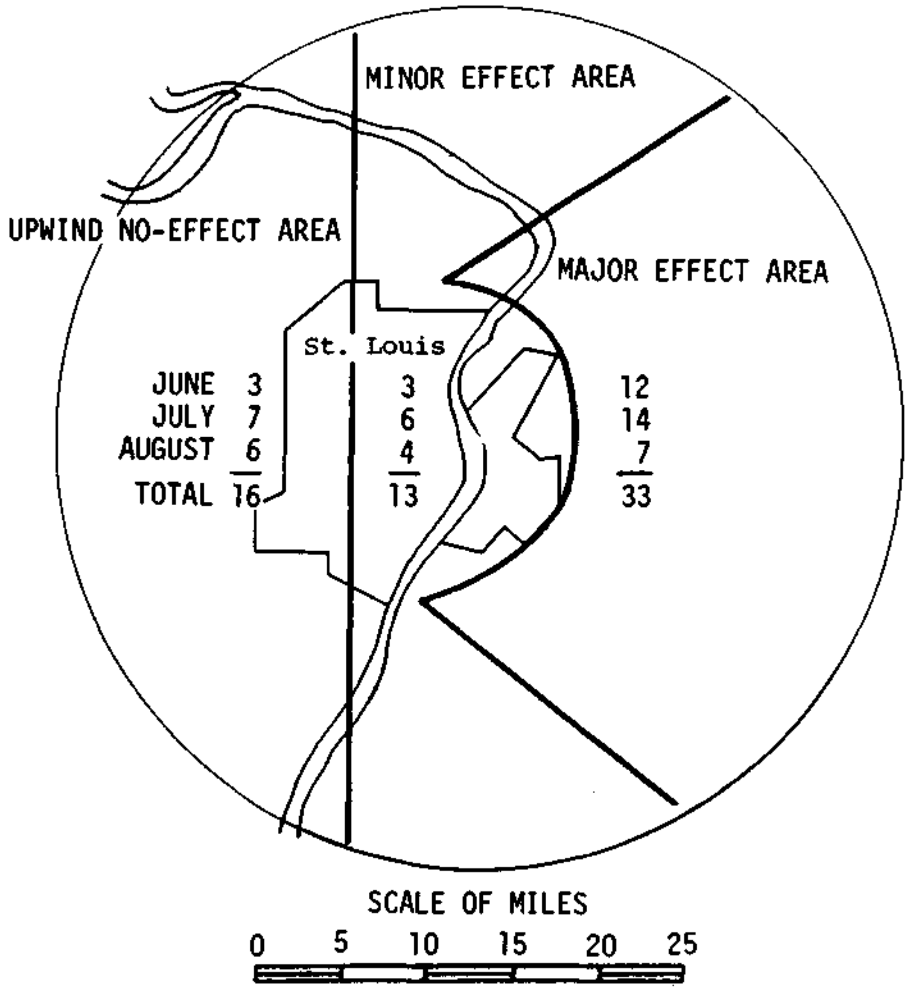

Figure 2. Location-frequency of maximum point rainfalls produced in the 62 rain periods in summer months of 1971 at St. Louis

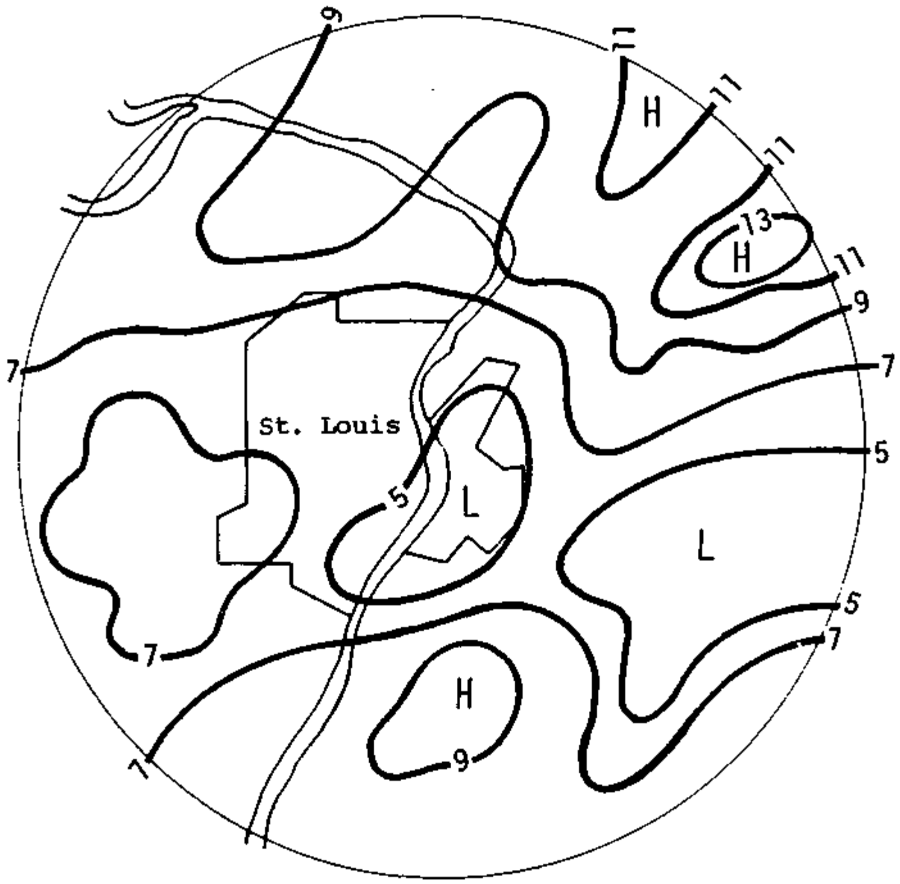

Figure 3. Total summer (June - August) 1971 rainfall pattern in the research circle at St. Louis

Goal 2 Activities

The other major goal of this research project involves study of possible urban effects on severe weather (primarily thunderstorms, hailstorms, and heavy rainstorms).

Thunder observations were available from two standard 24–hour manned observation sites plus the station established and operated at the Water Survey's Pere Marquette Radar Base northwest of the research circle. Three audio thunder detectors were designed and built as part of the thunderstorm studies of this project. These instruments were desired to obtain objective directional thunder frequency data at three unmanned sites: one upwind of the city, one in St. Louis, and one downwind of the city. The thunder detector was a graduate student design project, and they were completed, installed, and operational by 11 July 1971.

The June-August frequency of thunderstorm days at the three observation sites, and that during the 11 July-31 August period at these 3 observation sites, the three thunder detector sites, and another observer site in the south both appear in Fig. 4. Both patterns reveal an increase in the immediate downwind area, a condition found to exist in the more limited historical thunder records for dry summers during the past 30 years. Table 1 shows the dates with thunder in the study area during 1971.

Table 2 shows that 41 of the 62 rain periods had associated thunderstorm activity. Ten of these thunder-rain periods were instances of thunderstorms only downwind of St. Louis and thus represented potential urban effect situations. Six of these thunder-rain events had thunderstorms only on the west (upwind) side of the research area and would represent no positive

Table 1. 1971 Summer Rain, Thunder, and Hail Days in Water Survey's Metromex Network, (based on midnight to midnight definition)

	Rain	Thunder	Hail	Rain	Thunder	Hail	Rain	Thunder	Hail
	6/2	yes	yes	7/4(WE)	yes	yes	8/3	yes	
	6/7	yes	-	7/5	yes	-	8/4	yes	
	6/8	yes	-	7/8	yes	-	8/5	yes	
	6/10	yes	-	7/9	yes	-	8/6	no	
	6/11	yes	yes	7/10(WE)	yes	-	8/8(WE)	yes	
	6/12(WE)*	yes	-	7/ll(WE)	yes	-	8/9	yes	
	6/13(WE)	yes	-	7/13	yes	-	8/10	yes	
	6/14	yes	yes	7/14	yes	yes	8/11	yes	
	6/15	yes	yes	7/15	yes	-	8/14(WE)	yes	
	6/18	yes	-	7/18(WE)	yes	yes	8/15(WE)	no	
	6/21	yes	-	7/19	yes	-	8/21(WE)	yes	yes
	6/23	yes	-	7/23	yes	yes	8/23	yes	yes
	6/29	yes	-	7/24(WE)	no	-	8/25	yes	
	6/30	yes	-	7/27	no	-	8/26	yes	
				7/28	yes				
				7/29	no				
				7/30	no				
Total Days	14	14	4	17	13	4	14	12	2

*WE = weekend days

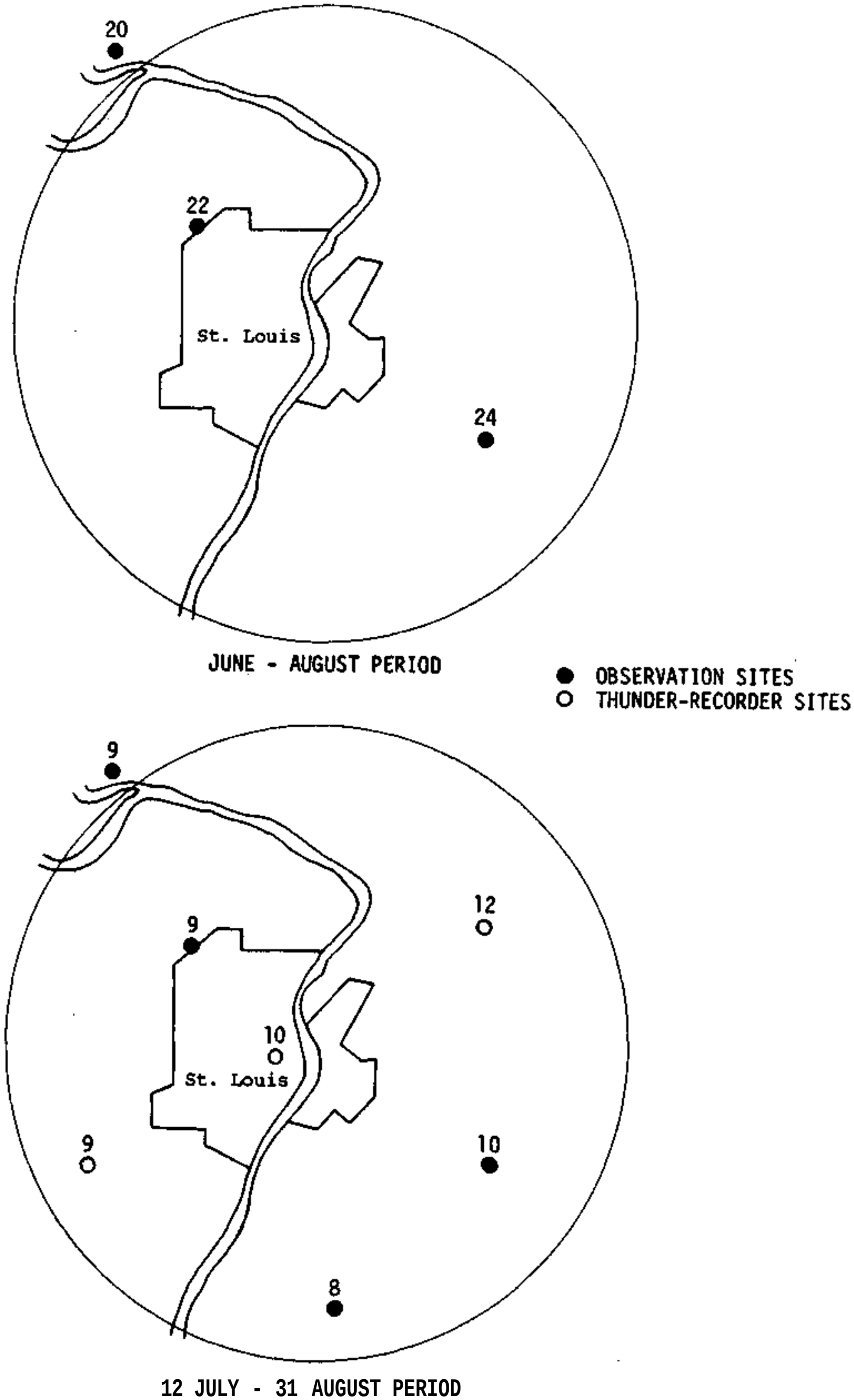

Figure 4. Thunderstorm-day point frequencies at St. Louis in 1971

urban effects. Their difference, 4 days, suggests that a 66% enhancement possibly due to urban effects existed in these days of regionally isolated thunderstorms.

Hail data were primarily from 222 hail pads (one located at each raingage) using the hail-produced spikes on the raingage charts to indicate time of hail occurrence. There were 10 hail days in the network during the June-August 1971 period. Analysis of the 48 hail pads with hail and their related raingage hail spikes reveal that on 7 hailstorm days, all the hail fell downwind of the St. Louis urban complex and from storms that had passed over the source areas and plumes (Fig. 1) relevant to that day. On the 3 days with hailfalls west of St. Louis, hail also fell downwind of St. Louis. The regional hail-day frequency differences found in 1971 with a 300% greater frequency downwind of St. Louis is comparable to that found in the prior climatic studies. However, the dense hailpad network that existed allowed a more detailed definition of all hail days, as well as a better delineation of the location of the hailstorms and the changes of hailfall intensity throughout the research area.

The prior St. Louis climatic studies had indicated a significant downwind enhancement of rainstorms producing point amounts of 2 inches or more in 24 hours. Only 6 such heavy rain periods of the 62 periods in 1971 produced 2 inches or more in 24 hours. Four of these 2-inch rainstorms occurred in the downwind Major Effect Area (as depicted in Fig. 2), and 2 storms (rain events) occurred in the no-effect area west of St. Louis. Study of the duration, intensity, and areal extent of the 2-inch or greater values reveal that when such values occurred, those in the area downwind of St. Louis had an average

Table 2. Summer 1971 Rain Periods with Thunderstorms

Synoptic Class	Location of thunderstorms in Network Circle in each rain period			
	Throughout Network	West-side only, no urban effect	East-side only, urban effect	Total
Frontal Zone	7	1	6	14
Prefrontal Zone	2	1	0	3
Squall	13	3	0	16
Air Mass	3	1	4	8
Total	25	6	10	41

duration of 4.2 hours, an average rainfall of 2.58 inches and covered an area of 18 square miles. Conversely, the averages from the 2 rain periods with 2-inch amounts on the west side (no-effect) showed an average duration of 6.1 hours, an average rainfall of 2.28 inches, and an average areal extent of 9 square miles. Comparison of these averages, eventhough they are not based on a large sample of data, indicates that not only were there more rain periods with 2-inch amounts downwind of St. Louis, but when these occurred downwind they yielded more rainfall in a shorter period (greater intensity), and extended over a larger area than did the 2-inch rainfalls in the no-effect area.

Synoptic Weather Studies Relating to Goals 1 and 2

An integral part of the research activities of this project involves study, on a rain period and on an individual rain cell basis, of the synoptic weather conditions. The goal is to ascertain those conditions under which urban effects on rain and severe weather may have occurred and thus those that are conducive to the realization of urban modification of precipitation processes. Very extensive and detailed meso-synoptic analyses are being performed on 4 dates when interesting storm development and maximization occurred over and downwind of St. Louis.

Semi-detailed meso-synoptic analyses of the 62 rain periods (that include the thunderstorm and hailstorm periods) have effectively utilized the data from 7 weather stations (recorded temperature, winds, humidity) that were installed in June 1971 and are being operated as a part of this project. These surface data coupled with the hourly observations obtained as part of the project effort at the Observational Headquarters, plus those at Lambert Field and at Scott Air Force Base have been utilized along with all available National Weather Service synoptic data including the St. Louis Arch radiosonde in performing these synoptic analyses.

Another phase of this synoptic analytical activity is an effort to define, on a rain period and a rain cell basis, the urban plumes (thermal and aerosol) that extend from the surface to cloud base. Those defined for a few June storms are illustrated on Fig. 1a-c. These were developed in the context of adequate available surface and limited low-level wind flow data. This plume definition task is very difficult and is also being investigated in detail utilizing more extensive atmospheric data on certain August operational dates when there was: 1) successive pibal release operations performed by the AWS theodolite teams working for Argonne and Wyoming, and 2) multiple aircraft flights of the four basic project aircraft (Water Survey-Atmospherics Inc., Argonne-NCAR Queenaire, University of Chicago-Lodestar, and Wyoming-C-45 Beachcraft.

Available Results

The preliminary, moderately comprehensive analysis of the synoptic weather conditions on the 62 rain periods has been completed. Essentially, this analysis showed that 4 basic summer classes were identifiable. Essentially, these are: 1) air mass when no large-scale mechanism for triggering convection is discernable and convection is typically disorganized and/or weak; 2) squall lines or zones when the trigger mechanism exists (such as dry air and/or an organized mesosystem at the surface) and the convection is organized and frequently intense; 3) frontal zone when the convective or stratiform precipitation is occurring within 50 miles on either side of a frontal line and sometimes this line is essentially only a convergence zone;

and 4) pre-frontal when weak disorganized convective activity and precipitation existed in an area between 50 and 150 miles ahead of a surface front.

The synoptic type distributions for the 62 rain periods are shown in Table 3, further sorted according to a preliminary and certainly somewhat subjective classification of the 62 rain-period patterns. Rain periods defined as urban effect were those in which either 1) one or more isolated rain cells occurred in the downwind areas (based on storm motions and existing plumes), or 2) a multicellular rain pattern existed with distinct maximization of one or more rainfall cores in the similarly defined downwind area for that rain period. The third classification of patterns was labeled "indeterminant", and were those with widespread rainfall throughout the network which usually contained rain cores distributed at random. The fourth and fifth classes were those labeled as "no effect" with either 1) the occurrence of one or more isolated cells west of the city and beyond the plumes, or 2) the maximization of rainfall in rain cores west of the city plume and in a multicellular pattern.

Examination of results in Table 3 reveals several interesting facts. Comparison of the values from the two urban effect "patterns" with those for the 2 classes of no effect reveals totals of 24 and.15, respectively. Synoptic classification comparisons reveal that 8 of the 11 air mass cases which were defined as either effect or no-effect were urban effect cases. The urban effect pattern also was preferred in the pre-frontal class with 4 of the 6 effect or no-effect cases in the urban effect class. However, the distribution of effect and no-effect cases in the frontal zone and the squall zone classes did not show any regional-effect preferences. These results certainly tend to suggest that urban effects to initiate and/or intensify precipitation in the summer of 1971 were active in disorganized localized convective situations and were much less effective in the more organized convective situations.

Results presented in Table 2 regarding the synoptic situations with thunderstorms are of interest also. Here the cases with urban effect (thunderstorms east of the city) show a distinct preference for occurrence in air mass and frontal zone conditions, as compared to results found for no effect (west-side only) frequencies. The preference for downwind thunderstorm activity with frontal zone conditions is not in agreement with the rain period analyses (Table 3), and this difference may be a result of thunder sampling inadequacies, or be due to the fact that many of the frontal zone periods included in the indeterminant class (Table 3) may indeed represent urban enhancement of precipitation that can not be easily interpreted.

Conclusions

A major conclusion from the partially analyzed data from the summer of 1971 indicates that available results totally substantiate all the earlier climatic findings for St. Louis: 1) a downwind summer rain increase occurred within 25 miles of St. Louis; 2) the higher rain was displaced into two maximums, one to the northeast and one to the southeast of St. Louis (typical of dry summers); 3) the rainfall showed a preference for occurrence on weekdays at a frequency exactly matching climatic findings; 4) a west-to-east increase in thunder-days existed and was not over but downwind of St. Louis

Table 3. Preliminary Analysis of Synoptic Weather Conditions Associated with Various Classifications of Isohyetal Patterns for Rain Periods in the June - August 1971.

Classification of Rain Period Patterns	Number of rain periods per synoptic type				
	Frontal Zone	Pre-Frontal	Squall Zone	Air Mass	Total
Urban Effect (downwind max., isolated cell/s)	5	1	0	7	13
Urban Effect (downwind max., multicellular)	2	3	5	1	11
Indeterminant (rain cells or widespread rain throughout network)	9	1	8	5	23
No Effect (West-side max., isolated cell/s)	2	1	3	3	9
No Effect (West-side max., multicellular)	3	1	2	0	6
Totals	21	7	18	16	62

(typical of past dry summers); 4) hail days were much more frequent, 2 to 3 times as great downwind of St. Louis; 5) and the 2-inch or heavier rainstorms were much more frequent downwind of the city and were more intense and widespread than those upwind of the city.

In general, the 1971 project effort was quite satisfying in that most project operations were initiated by the end of the first 3 weeks of June, only 3 months after this grant was received.

Other more preliminary results apparent from the 1971 data (that similar data in the future will clarify) include the fact that: 1) there appears to be an initiation and intensification of hailfalls 5 to 10 miles downwind of the urban-industrial sources; 2) the choice of a circular network design was excellent; 3) definition of the thermal and aerosol plumes from these urban sources that interact with individual convective storms is the most difficult analytical problem with the existing project data; 4) the urban area apparently leads to the initiation of small isolated rain cells as well as to the intensification of rainfall; and 5) no single synoptic weather condition appears to relate soley to rain periods and thunderstorms when urban related initiation-enhancement existed. The results for 1971 do not eliminate many of the initial hypotheses for urban effects on precipitation.. Two of the other groups involved in Metromex suggested in the 1971 Metromex Operational Report that their preliminary findings indicated that the urban effect on precipitation was one of dynamic influence. However, certain of the Water Survey results such as the weekday preference for precipitation (which is also substantiated in the area's historical data) do not indicate an elimination of the possibility of the effect of urban aerosols on microphysical processes.

Recommendations

Based on the analyses performed to date, it would appear that the present project would benefit considerably from two additions.

The FPS-18 radar system used in 1971 employed an antenna on a 3-year loan from NCAR. This antenna and particularly its drive system was generally inadequate for the purposes desired in this research project. The necessity to return this antenna to NCAR in 1973, and its questionable operational configuration, both indicate that another, narrower beam width 10-centimeter antenna with RHI capability will be needed in the immediate future.

The other major need relates to the existing analytical problem of defining the urban thermal and aerosol plumes prior to and during convective storms in the study area. Although atmospheric measurements of thermal and aerosol plumes were not a basic facet of this project, better definition of these plumes must be sought on convective days. These can only be obtained with data from more aircraft operations, more pibals and/or use of remote sensors (lidar and thermosondes) employed in a more frequent systematic operational basis in the summer periods of future years. The 1972 budget for this project does not contain proposed funding for either a better radar antenna or systems for more atmospheric plume delineation, but these items would be desirable for the project in 1973.

Related Project Activities

The Principal Investigator was elected by the principal scientists of Metromex as Project Coordinator for 1971. The Coordinator's duties included: 1) serving as a focal point for communications between the participating research groups, between other interested but uninvolved research groups and the 4 Metromex groups, and between the program and federal agencies; 2) coordinating the release of program information to the news media and the general public; and 3) attempting to insure collaboration between the four or more research groups including the field operations and the exchange of data. In the performance of these duties, in 1971, a large number of telephone calls were handled and about 150 letters were prepared.

Trips related to Metromex were made to St. Louis in February and May for the specific purpose of 1) talking with individual scientists and groups at Washington University and St. Louis University; 2) presenting project seminars to University groups, the local AMS chapter, and to local industrial groups. Metromex program scientists and principal investigators were called to meetings at Argonne on December 1970, at St. Louis on April 14-15, 1971, at St. Louis on August 16, 1971, and in St. Louis on November 8-9, 1971. Other coordinating activities included the organization of project tours for numerous visiting scientists in July and August and for federal project monitors on August 25-27, 1971.

Many interviews and conversations, both in person and via telephone, with members of the news media in St. Louis occurred in 1971. A news conference, arranged for us by the St. Louis Research Council, occurred on June 23, 1971 with members of all the local newspapers, radio, and T.V. present. Another project T.V. presentation was made on November 9, and 6 project news releases were issued by or funneled through the Coordinator in May, June, July, and August 1971.

As a part of project coordination, and within the defined duties of the coordinator, another effort was made to keep a record of ongoing operational activities of all 4 Metromex groups at the Water Survey's Pere Marquette Headquarters during 1971. The assistance of the Water Survey-staff to other groups is described in the 1971 Operational Report for Metromex.

Any success in project coordination in 1971 was largely achieved because of the Principal Scientists who were all willing to plan together, to exchange information and data, and to suppress some personal project desires for the good of joint operations. Certainly coordination was not as perfect as one would get with a project manager having control of the funding of all projects. Nevertheless, given the constraints and realities that existed, reasonable operational coordination was achieved. These coordinating activities during 1971 required an estimated 5% of the Principal Investigator's time.

Publications and Papers

Several papers that involved a partial or total description of Metromex and this specific project supported by the National Science Foundation were presented at scientific meetings during the first year of this project. The scientific papers presented included:

1. "Lessons from the La Porte Anomaly", given at the International Conference on Weather Modification in Australia during September 1971.
2. "Project Metromex-A Lesson From Controversy", a banquet talk presented at the 7th National Conference on Severe Local Storms in Kansas City in October 1971.
3. "Inadvertent Precipitation Modification and the Need for Field Programs", given at the ASCE - AMS workshop in Boulder, Colorado, in October 1971.

4. "Project Metromex-the Answer to Inadvertent Weather Modification Controversy", a paper presented at a staff seminar at the University of Minnesota in October 1971.
5. "Inadvertent Weather Modification and Implications for Hydrology", a paper given at the National ASCE meetings on Water Resources in Atlanta, Georgia in January 1972.

Three publications which are totally or partially devoted to Metromex and the NSF supported project GA-28189X were authored in the reporting period. These include:

1. "Lessons from the La Porte Anomaly", by Stanley A. Changnon, Proceedings of International Conference on Weather Modification, 1971, pp. 193-198.
2. "Metromex: An Investigation of Inadvertent Weather Modification", by Changnon, Floyd Huff, and Richard G. Semonin, Bulletin of the American Meteorological Society, Vol. 52, pp. 958-967, 1971.
3. 1971 Operational Report for Metromex. Partially written, edited, and organized by Stanley A. Changnon, and issued by the Illinois State Water Survey, November 1971, 94 pp. It contains project reports during 1971 written by all groups involved directly or indirectly with project Metromex.

Personnel

Supported by Grant Funds
Full-time staff, 100% or less on GA-28189X

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Supported by State Funds
Full-time staff, 100% or less

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D. W. Staggs	- Radar Engineer Supervisor
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E. Brieschke	- Network Technician and Site Custodian
D. Watson	- Network Technician

Future plans

The operation of the raingage network and the 7 surface weather stations has continued after the summer of 1971 with total support from Water Survey technicians. It is planned to keep this network in operation 12 months a year for the next several years.

The project operations envisioned for the summer of 1972 are largely identical to those performed during the summer of 1971 with no major changes in the operational and equipment procedures.

The basic scientific approach to the Metromex projects of the State Water Survey, which is concerned with the study of urban-industrial effects on precipitation is revealed in the time table below which shows the major tasks and the time table for these.

Time Period	Task
1969-71	1. Use of climatic data to define a) existence of urban effects on rainfall and choice of a city to study, b) suggest causes and develop crude hypotheses for these effects.
1970-71	2. Further development of preliminary hypotheses that encompass the possibility that surface (urban-industrial) changes in atmospheric aerosols, temperature, moisture, and mechanical turbulence act individually or in combination to develop perturbations that result in changes to clouds and precipitation on the mesoscale.
1970-71	3. Ensure that measurement and modeling programs are adequate to evaluate these Preliminary Hypotheses.
1971-72	4. Analyze initial data to evaluate and revise hypotheses and to develop new hypotheses.
1972	5. Redesign or alter field measurement program to meet these new hypotheses.
1973-74	6. Develop or acquire sufficient results to define likely causative factors for atmospheric and surface rain changes observed in 1971-73.
1974—75	7. Focus field activities to measure, in detail, the apparent causative factors.
1975	8. End of field study.
1976-77	9. Completion of modeling for translation of findings to other urban-industrial centers; and preparation of final report covering results of all projects.

Obviously, to proceed logically through this approach with the time table shown indicates a need for federal and state support beyond 1972. In fact, support through 1973-76 calendar years is envisioned as necessary to complete the project in the sense of adequate data sample, thorough analyses, and the summation of all findings into a final report, either authored by the Water Survey and/or other principal scientists involved in Project Metromex.