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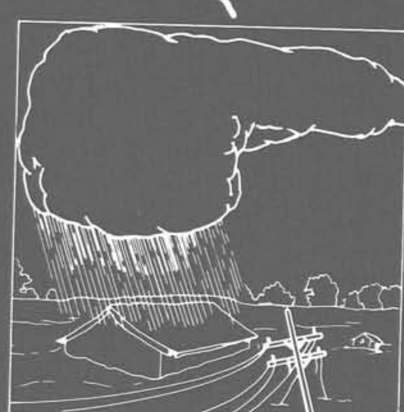
REPORT OF INVESTIGATION 105
STATE OF ILLINOIS
ILLINOIS DEPARTMENT OF ENERGY AND NATURAL RESOURCES

Floods of Winter-Spring 1982 in Illinois

by STANLEY A. CHANGNON, JR., JOHN P. LARDNER, JOHN L. VOGEL, and PETER G. VINZANI



ILLINOIS STATE WATER SURVEY
CHAMPAIGN
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Indexing Terms: Climatology, flooding, floods, heavy rain, ice jams, Illinois, meteorology, rainfall, snow, soil moisture, spring, streamflow, winter.

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ABSTRACT

A series of moderate floods, some locally severe, occurred in Illinois in the winter and spring of 1982. Flooding existed in parts of Illinois from late January to mid April and included three major flooding events: a late January flood in southern Illinois caused by a record winter rainstorm; late February floods in central and southern Illinois caused by melting of excessive snow cover, moderate rains, and ice jams; and mid March floods in central and northern Illinois caused by melting snow accompanied by heavy rains. The report describes the climatological and meteorological aspects of the flood-producing conditions, the hydrologic aspects, the impacts of the floods on broad sectors of society, and the implications for planning for future responses to floods.

The four factors combining to produce the winter-spring flooding of 1982 were: 1) above normal antecedent precipitation and heavy snowfall in January, 2) record-breaking snow cover caused by heavy snows and the much below normal temperatures, 3) soil moisture at or in excess of saturation, and 4) ice jams on larger rivers. Though no lives were lost, total losses were estimated at between $20 and $25 million. The greatest impacts were to local, state, and federal government entities and ranged from damage to local sewage and water treatment plants to damages to public bridges, buildings, and roads. Also impacted were transportation facilities and families which had to be evacuated from their homes, nearly 400 in all. The need for a state flood contingency plan was indicated.

INTRODUCTION

A series of floods occurred in various parts of Illinois during the winter and spring of 1982. These floods were not exceptionally severe nor widespread, but fell within the moderate class of winter-spring floods. Nevertheless, their occurrence and physical dimensions, the weather events and human factors causing them, and their impacts on humans and the environment have been analyzed as a first-time effort to describe in detail winter-spring flooding in Illinois. Prior Water Survey studies of flooding have focused entirely on warm season (May-October) heavy rains and ensuing flash floods (Huff, et al., 1958; Huff and Changnon, 1961; Huff, 1981; Singh and Snorrason, 1982). Monitoring and study of the water and atmospheric resources of Illinois represent the basic charge by the State of Illinois to the Water Survey. As such, this charge leads to studies of climate anomalies and ensuing water-related extremes such as droughts and floods (Changnon, 1980).

Information on flood causes and losses and on institutional reactions to flooding is needed to better understand their physical causes, to enable a better prediction of their onsets (and endings), and to assess what may be needed both to plan and then to react more effectively in future winter-spring floods. The changing climate of Illinois toward snowier and much colder winters suggests a likely shift in winter-spring flooding which could include changes in their frequency, duration, and severity. This particular climatic shift is another reason for studying the winter-spring floods of 1982. They may be the precursor to more frequent future flood conditions.

Overview of the Floods

Flooding existed in parts of Illinois from late January through mid April 1982. Flooding consisted of overbank flow with both urban and rural flooding in several locales. Most flooding occurred in the floodplains immediately adjacent to river courses and was classed as minor; that is, slightly above flood crest levels. However, localized flooding was more severe (classed as moderate) in certain locales. No widespread severe flooding occurred in Illinois. On most rivers the peak flood discharge value ranked as a once in 2- to 5-year event, but the durations of the above flood stage periods were near record on many rivers.

Flooding began in southern Illinois with very heavy rains (up to 6.3 inches in 24 hours) on 29-30 January which brought all southern Illinois rivers rapidly to flood stage. This rainfall preceded a series of 3 winter storms which brought heavy snow across southern and central Illinois during early February. Flood stage conditions were sustained during the first three weeks of February in the southern third of Illinois and in the southern half of the Illinois River.

Then, sudden warming during the last two weeks of February (temperatures averaging 4° F above normal) brought relatively rapid melting of the deep snow cover in the central and southern parts of the state. This, in turn, brought heavy runoff into all rivers south of a line from Quincy to Joliet. Most rivers in the southern three-fourths of Illinois were at or above flood stage during the last two weeks of February. This was further compounded by ice conditions in the larger rivers brought on by the extremely low temperatures that had lasted from mid December through mid February (temperatures averaged —9° F below normal). Warming brought some breakup of the thick ice, and then ice jams occurred at river bends and bridges to bring local flooding along the Kankakee River in late February.

Although the levels of the rivers in flood stage had largely fallen by the end of February, many Illinois rivers still were at or above flood stage. Their status appears in figure 1. Rivers not at flood stage were all in the northern and western portions of the state where the winter precipitation was well below normal, and at this time the melting of the snow cover in Wisconsin had not yet begun.

Cold temperatures during early March, along with a return of snow cover to northern Illinois, set the stage for the high river levels experienced in northern and central Illinois later in the month. Locally heavy rains (1 to 3 inches) across central and northern Illinois in late March coupled with the melt of the snow cover in northern Illinois brought the Vermilion and Illinois Rivers above flood levels from mid March to mid April. The continued presence of thick river ice on the Illinois River also was a major factor in bringing near record high river levels at Peoria in late March.

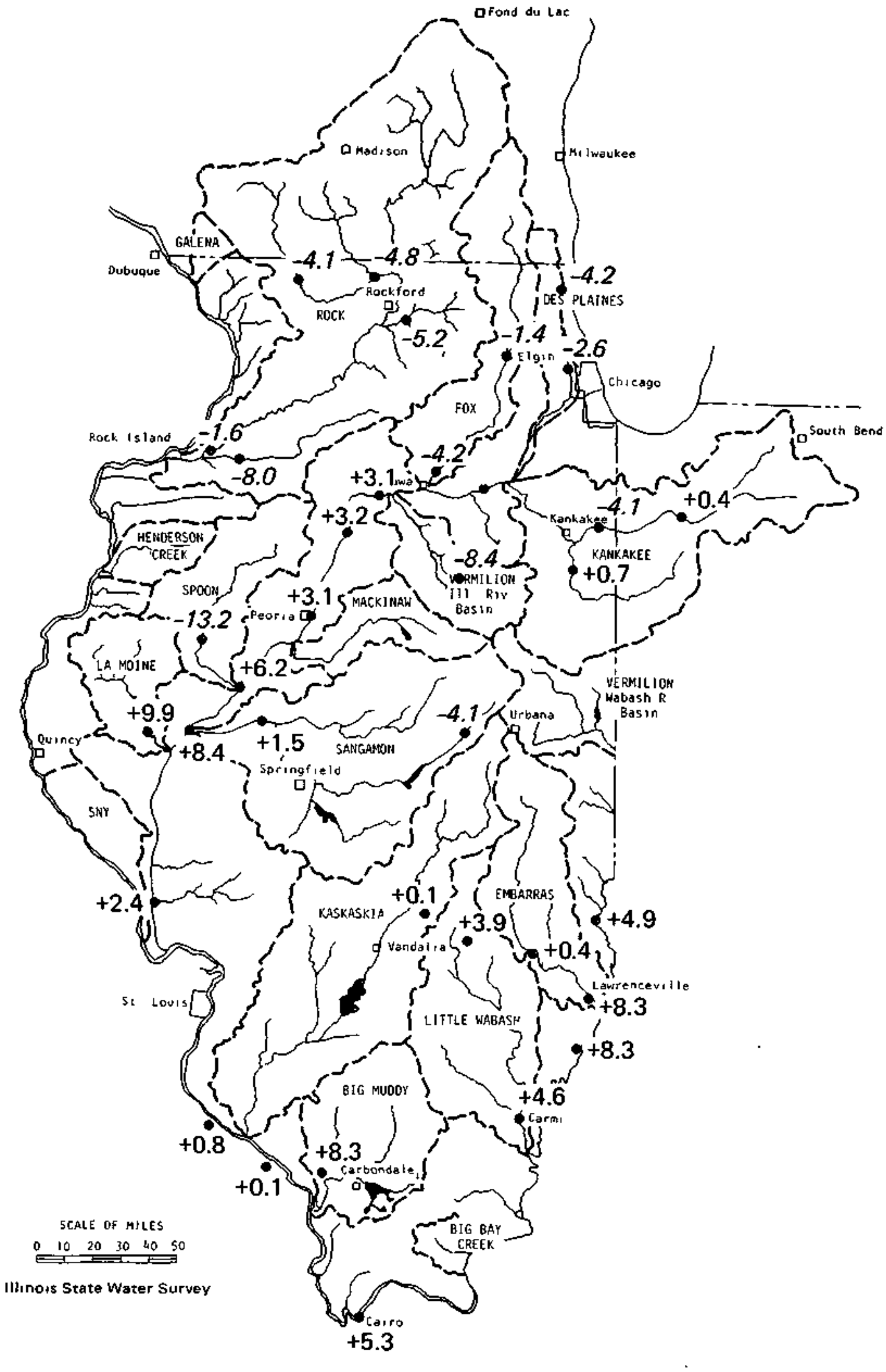


Figure 1. Departure of river levels, in feet, from flood stages on 28 February 1982

The minor flood stages of many Illinois rivers existing in early March gradually subsided during March and April with near normal March precipitation in many areas and below normal April rains statewide. The normalcy of the spring rains was a key factor in minimizing the flood severity in the late spring. The below normal spring temperatures in the Midwest were also providential because the snow cover in Wisconsin and Minnesota melted relatively slowly, and only minor flooding occurred along the northern Illinois rivers and along the Mississippi River.

Activities of the State Water Survey

The Illinois State Water Survey serves as the Floodplain Information Repository for Illinois. We possess a complete computerized library reference system for all known engineering studies of Illinois rivers (Illinois State Water Survey, 1979). As the Floodplain Information Repository, we respond to requests related to flooding and floodplains including floodplain dimensions, as part of the National Flood Insurance Program. The number of requests handled by the Water Survey relating to floods and floodplains during January-April 1982 was 382, more than three times the usual frequency for this time period.

The Water Survey serves as the state's major agency for monitoring and studying Illinois water resources. As such, we issued month-end water status reports throughout the flood period. A special detailed report was produced at the end of February to focus on the dimension of the flooding at that time. These month-end reports also presented predictions of future monthly and seasonal precipitation based on our research. Importantly, in the critical January-February period, these predictions pointed to near to below normal precipitation in the remaining spring season. This information helped the planning of state assistance and reduced concern.

As part of our information presentation role, the Water Survey also prepared several news releases and made presentations on radio and TV about the status of the floods. These helped put the floods into proper historical perspective.

Scope of the Study and This Report

This interdisciplinary study involved climatologists, meteorologists, and hydrologists on the Survey staff who focused on three aspects of the floods. The first major section of this report describes the climatological and meteorological aspects of the flood-producing conditions. The reasons for the heavy snows and prolonged deep snow cover are discussed, and the abnormality of the winter conditions in relation to average and record extremes is presented. Also addressed in this section are the predictions of future precipitation conditions and their utility for flood planning and reactions.

The next section of the report examines the hydrologic aspects of the floods. The streamflow data are analyzed statistically to assess the magnitude of the floods, and analyses are presented of the ice flows and snowmelt influences and the associated groundwater situation.

The next major section of the report describes the impacts of the floods on broad sectors of society including government institutions, transportation, households, individuals, and others.

In the summary section, the four flood-producing conditions are reviewed. Some of the implications of the floods and the related precipitation predictions and governmental adjustments are also addressed in the summary. Potentially important lessons for future planning and institutional responses to floods are offered.

CLIMATOLOGICAL AND METEOROLOGICAL CONDITIONS

Antecedent Climate Conditions

The summer and fall of 1981 (June-November) was a generally wet and cool period in Illinois. The greatest departure of precipitation from the 30-year normal occurred in the central crop district with an above normal departure of 7.47 inches, while the greatest below normal departure occurred in the southeast district with a negative departure of 1.55 inches. The wettest months of this six-month period were July and August, with the driest months occurring in the fall season. Eight of the nine crop districts had above normal precipitation during the 3-month (June-August) summer season, while eight of the nine crop districts had below normal precipitation during the 3-month (September-November) fall season.

During the summer of 1981 soil moisture did not suffer the depletion that usually occurs in that season. The much above normal precipitation amounts statewide, combined with generally below normal temperatures, kept the near surface (0- to 20-inch depth) soil moisture deficit lower than would be expected. The moderately dry fall did not significantly increase the soil moisture deficit, though the soil did not experience the recharge that would be incurred at that time with normal or above normal precipitation. As soil moisture loss due to plants using the available moisture is not occurring in the fall, below normal precipitation during this season does not have a great impact in reducing soil moisture.

Temperatures in the 6-month period prior to the winter and spring period of flooding were generally below normal. The northwest crop district experienced a 6-month (June-November) below normal departure of 1.5°F, which was the largest negative departure in the state. The southeast crop district experienced a departure of—0.3°F, the smallest departure from normal. Within this 6-month period, June and November experienced generally above average temperatures statewide, whereas the other four months had below average temperatures. The coldest month during this period was October with temperatures averaging 3 to 5° F below normal across the state.

Climatic Assessment of Winter and Spring Conditions

The winter and spring seasons (December-May 1981-1982) were generally colder and wetter than normal. Record-breaking low monthly temperatures were experienced in both January and April of 1982 in Illinois. Near or above normal temperatures were experienced only in March and May during this 6-month period. Record-breaking above normal precipitation occurred in January contributing to large snow depths across much of Illinois. A detailed study of winter temperatures and snowfall during the 1981-1982 winter season is available (Hilberg et al., 1983). Above normal precipitation was experienced over many sections of Illinois in March and May. The driest month of this six-month period was February, when below normal precipitation was experienced in eight of the state's nine crop districts.

The flooding that occurred during the winter and spring seasons was directly related to climatological factors that increased the flood threat in Illinois. Three major flooding events during the winter and spring seasons in Illinois were identified and associated with climatological factors influencing soil moisture and runoff. The three flooding events are briefly described in this text, along with the accompanying climatic conditions.

The late January flooding that occurred in southern Illinois occurred in conjunction with a record-breaking winter rainstorm that deposited over 5 inches of precipitation in 48 hours over a large area of southern Illinois. The heaviest precipitation fell to the south of a heavy snow band that produced up to 20 inches of snow across south-central Illinois. The flooding that occurred was the result of a single event, although partially frozen soils in that area helped to increase runoff. As the flooding was the result of a single storm, it falls into the category of flash flooding, rather than spring flooding. Unlike flash flooding, however, the rivers did not recede, but remained at high levels for several weeks after the storm.

The flooding that occurred in mid to late February in central and southern Illinois was the result of snowmelt, the factor which normally causes spring flooding in Illinois. A climatic factor that reduced the severity of this flooding was the absence of extremely large amounts of precipitation during the period of snowmelt. The rapid warming that began in mid February melted much of the ice pack in many Illinois rivers and created ice jams that contributed to flood damage.

The last period of flooding that occurred in central and northern Illinois during mid March was again the result of those two factors which normally cause spring flooding. Although the snow pack that melted was much less than the snow pack that was present in February, large amounts of rainfall accompanied the melting of the snow during this period. Snow cover returned to Illinois in early April, but the rapid melting that followed was not accompanied by further precipitation.

Temperature Conditions

Temperature directly influences the rate of the melting of ice and snow cover. The rate and amount of melting of the deep snow cover in 1981-1982 were major influences on the flood intensity. Table 1 presents the winter and spring season mean temperatures for crop districts in Illinois. These reveal the widespread cold temperatures in the winter (ranked as the 6th coldest of the 20th Century). Spring temperatures were slightly below normal in most of Illinois.

After the arrival of the first significant snow cover in mid December of 1981 (Hilberg et al., 1983), four thawing periods occurred during the next generally cold four months. Two of these thawing periods resulted in the melting of near record winter snow pack and river ice, leading to the creation of ice jams. The snowmelt and ice floes played a major role in the subsequent flooding.

The first thawing period occurred during the first week in January across central Illinois, where a significant snow cover existed by the end of December (Hilberg et al., 1983). Temperatures in the upper 30's and low 40's (°F), combined with heavy January rainfall, diminished the snow cover substantially in that area. An extremely cold period followed, and no significant flooding resulted in central Illinois in mid January.

Table 1. Seasonal Temperatures and Precipitation Values with Departures from 30-Year Normals, for Illinois Crop Districts

	Winter precipitation (Dec — Feb), in inches		*Winter temperatures (Dec — Feb), F*	
NW	2.94	(-1.68)	18.2	(-6.4)
NE	4.20	(-1.09)	19.7	(-6.1)
W	4.78	(-0.22)	22.2	(-5.9)
C	6.41	(+0.86)	22.1	(-6.5)
E	6.95	(+1.25)	20.8	(-6.4)
WSW	8.32	(+2.55)	24.1	(-7.2)
ESE	10.04	(+2 44)	29.3	(-6.2)
SW	12.20	(+3 20)	25.3	(-6.4)
SE	1195	(+2.18)	30.5	(-5.0)

	Spring precipitation (March — May), in inches		*Spring temperatures (March — May), °F*	
NW	10.55	(+0 54)	47.4	(-1.4)
NE	11.36	(+1.46)	47.6	(-0.7)
W	12.66	(+1.86)	50.7	(-0.9)
C	13.60	(+2.46)	50.7	(-0.8)
E	12.08	(+1.07)	49.8	(-1.0)
WSW	10.61	(-0.55)	53.3	(-0.1)
ESE	11.23	(-0.59)	53.8	(+0.2)
SW	9.49	(-3.42)	56.4	(+0.1)
SE	9.20	(-4.18)	56.7	(+0.4)

March 1981 - February 1982 precipitation

District	*Amount, inches*	*% Normal**	*Return interval, years*
NW	38.8	111%	6
NE	37.0	109%	5
W	45.0	121%	21
C	46.8	130%	35
E	45.8	128%	31
WSW	47.8	128%	23
ESE	42.5	107%	12
SW	50.6	118%	5
SE	48.1	109%	2

** Normal based on 1941 - 1970*

The second period of thawing occurred statewide during the last two weeks in February. A deep (5 to 20 inches) snow cover was present in mid February in south central, eastern and northeastern Illinois, with measurable snow cover reported at nearly every station in the state. Thawing temperatures began on 14 February and continued through the end of the month. The warmest days were 23-24 February, when temperatures reached 70° F across the southern third of Illinois. The thaw was accompanied by rains across southern and central Illinois on 16-17 February. The rain helped increase the rate of melting and the amount of runoff. The deep snow cover in southern Illinois and most parts of central Illinois was gone by 22 February. Flooding due to snowmelt occurred along the Embarras River in February, and flooding due mainly to ice jams occurred along the Kankakee River during that same period.

The third major thawing period occurred during the second week in March in northern and central Illinois. A significant snow cover existed in northern Illinois and southern Wisconsin when temperatures reached the mid 50's to low 60's by 11-12 March. Rainfall occurred on most days between 13-16 March. This water combined with the snowmelt greatly enhanced runoff during this period. Flooding occurred along the Illinois River from Chillicothe to Beardstown from mid March to mid April.

The fourth and final major thaw occurred following several late-season snowstorms that fell mainly in northern and central Illinois in early April. Thawing temperatures followed on 11-12 April when temperatures reached the low 50's to low 70's statewide. The snow cover was gone by 11 April and the heavy rains that occurred on 15-17 April were not associated with the snowmelt.

Precipitation Conditions

The winter precipitation in Illinois was slightly below normal in the northern fourth of the state, and above normal elsewhere (table 1). Much of the winter precipitation in the northern half of Illinois fell as snow, leading to record heavy snowfalls in December and January for parts of central Illinois (Hilberg et al., 1983). All but extreme western and northwestern Illinois had above normal winter snowfall with 40 or more inches in the remaining portions of the northern two-thirds of Illinois. The winter of 1981-1982 was classed as the second worst of this century. Heavy rains in late January in southern Illinois helped produce the above normal winter totals (table 1).

Spring (March-May) experienced above normal precipitation in the northern half of the state (table 1). This was largely a result of a) heavy rains in March, and b) two record heavy snowstorms in April. These two events prolonged and intensified the flooding in northern and central Illinois.

Soil moisture values for 26 January-20 April at several locales are displayed in figure 2. Basically, one notes a surplus everywhere (0 to 6 inch level) from late January throughout the spring. Hence, soils were unable to store much of the melting snow or rains in February and April.

Snow Cover

Snow during the winter months can collect on the ground, providing a vast reservoir of water waiting to be released with the first warm temperatures. This accumulated water can then melt rapidly and fill rivers with large quantities of water. One measure of this reservoir is snow cover; i.e., the amount of snow accumulated on the ground. The following section shows how snow accumulated and melted during the winter of 1981-1982.

Snow cover was plotted for four stations to represent the accumulation and melting of snow cover across Illinois. Galena in northwest Illinois and Antioch in northeast Illinois were selected to show the snow cover in northern and western Illinois. Eastern Illinois received more snow than western Illinois and these two stations help show this difference. Piper City represents central Illinois, and Nashville southern Illinois. All four stations

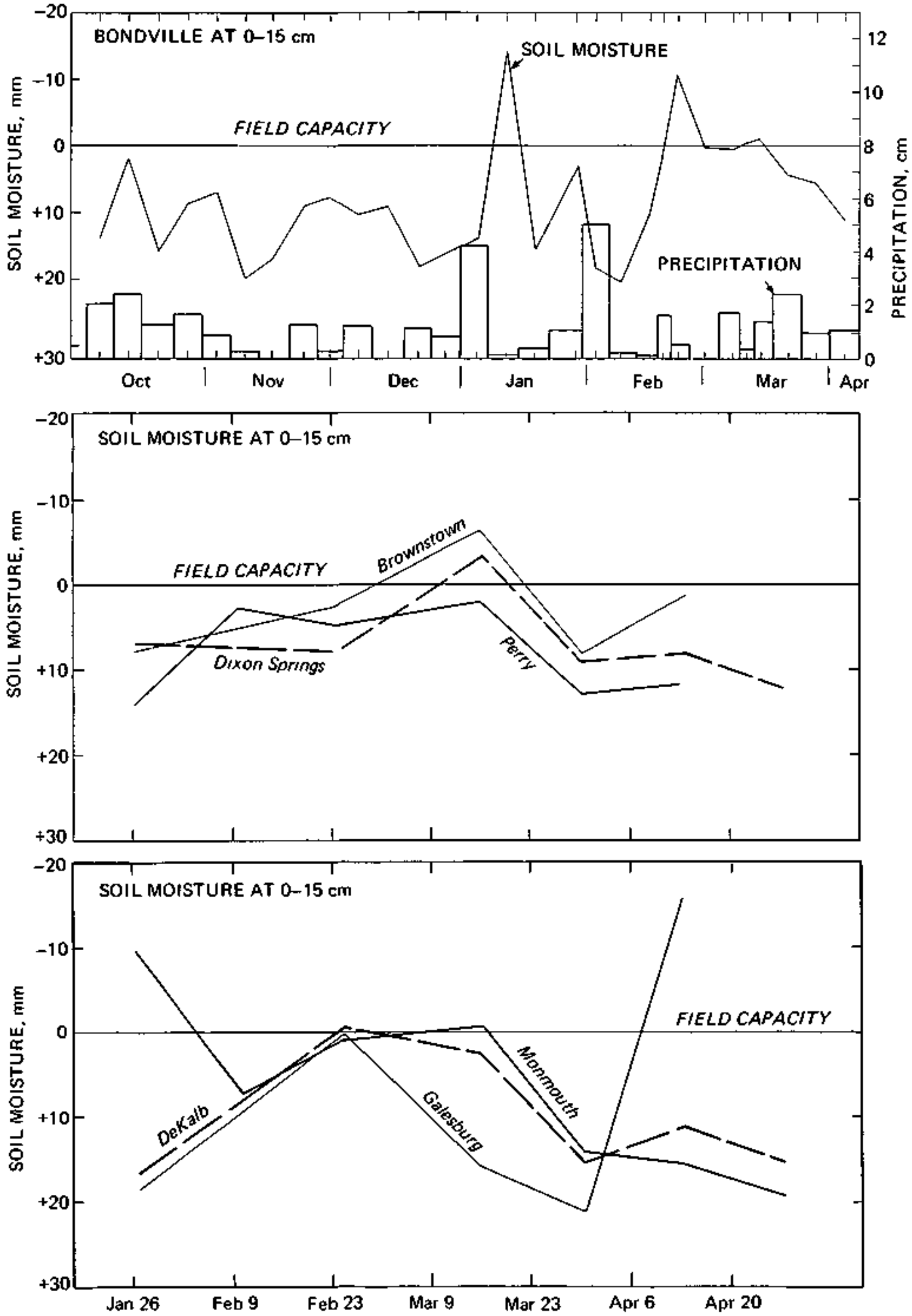


Figure 2. Soil moisture at selected stations for winter-spring 1982

represent maximum snow cover amounts for the selected areas. The accumulation of snow cover during the winter of 1981-1982 can be followed in figures 3a-h and figures 4a-d, which depict the accumulation of snow cover and its subsequent melting.

The first extended snow cover of the winter of 1981-1982 began with the snowstorm of 16-17 December. Prior to this, the only measurable snow cover was associated with the storms of 23 November and 4 December, after which the snow remained on the ground only for a day or two. On the morning of 16 December no snow was reported on the ground, but by the morning of 17 December up to 9 inches of fresh snow was on the ground (figure 3a). The maximum snowband was aligned in an east-west direction centered on Decatur. One inch or more of snow fell across most of Illinois except for the extreme southern and northern portions.

During the next 2-week period three storms moved across Illinois. The first storm (20-21 December) dropped moderate snow across northern Illinois, and the snowfall in the second and third storms (22 and 27-28 December) was centered in central Illinois. The increased snow cover in northern Illinois can be seen in figures 4a and b. A slight increase in snow cover was observed with the storm at Piper City on 21 December; however, the snow cover increased 5 inches from the 22nd to 23rd, and a 4-inch increase was recorded from 27 to 29 December.

These heavy snows across central Illinois dominated the snow cover map of 30 December. Thirteen inches of snow was on the ground at Farmer City. Over the southern third of Illinois, mostly rain fell with little or no snow, as seen by the 30 December map (figure 3b). Along the extreme northern tier of Illinois 1 inch of snow was reported at most stations.

Between 30 December and 4 January, 8 inches of snow melted at Piper City (figure 4c) associated with above freezing temperatures and rains. At the same time rain was occurring in central and southern Illinois, snow was falling in northern Illinois with 8 more inches of snow at Galena and 7 more inches at Antioch between 2 and 4 January. The storms of 6-7, 9, and 12-13 January were generally light and the snow cover increased 1 to 3 inches at most stations in northern and central Illinois. However, in southern Illinois the storm of 12-13 January dropped 3 to 5 inches of new snow (figure 4d). The snow cover on 13 January (figure 3 c) had maximums in northeast and northwest Illinois and again over east-central Illinois. The snow cover over northern Illinois increased 8 to 9 inches, and there was some reduction in snow cover over east central Illinois, but the major change was 2 to 5 inches of new snow cover across the southern third of Illinois.

The snow cover in northwest Illinois between 13 and 27 January remained relatively unchanged, while in northeast Illinois there was a gradual increase from about 8 inches to 16 inches (figure 4b). In central Illinois snow cover increased from storms on 15 and 17 January. In southern Illinois the snow cover melted due to warmer temperatures (maximum temperatures in the mid 30's to the low 50's during the period of 18-23 January). Some heavy rains were also recorded on 22 January. However, most melting was associated with the warmer temperatures beginning on 18 January as the winds shifted and brought in warm air from the south. The snow cover map for 27 January shows 1) erosion of the snow cover in west central Illinois, 2) some slight increase (1-3 inches) in the snow cover in east central Illinois, and 3) 3 to 6 inches of additional snow in extreme northeast and north central Illinois (figure 4b).

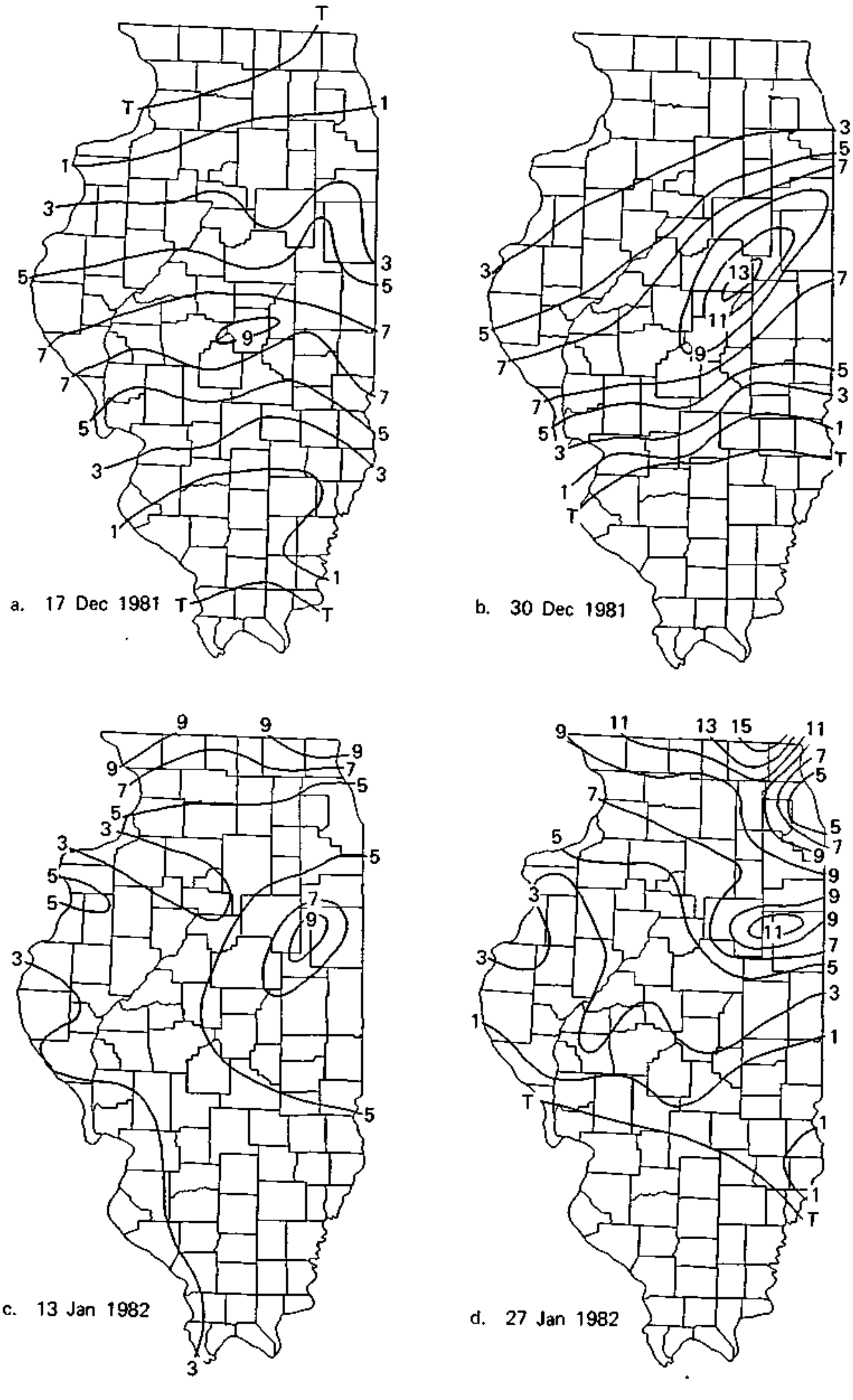


Figure 3. Snow cover over Illinois during winter and spring 1982

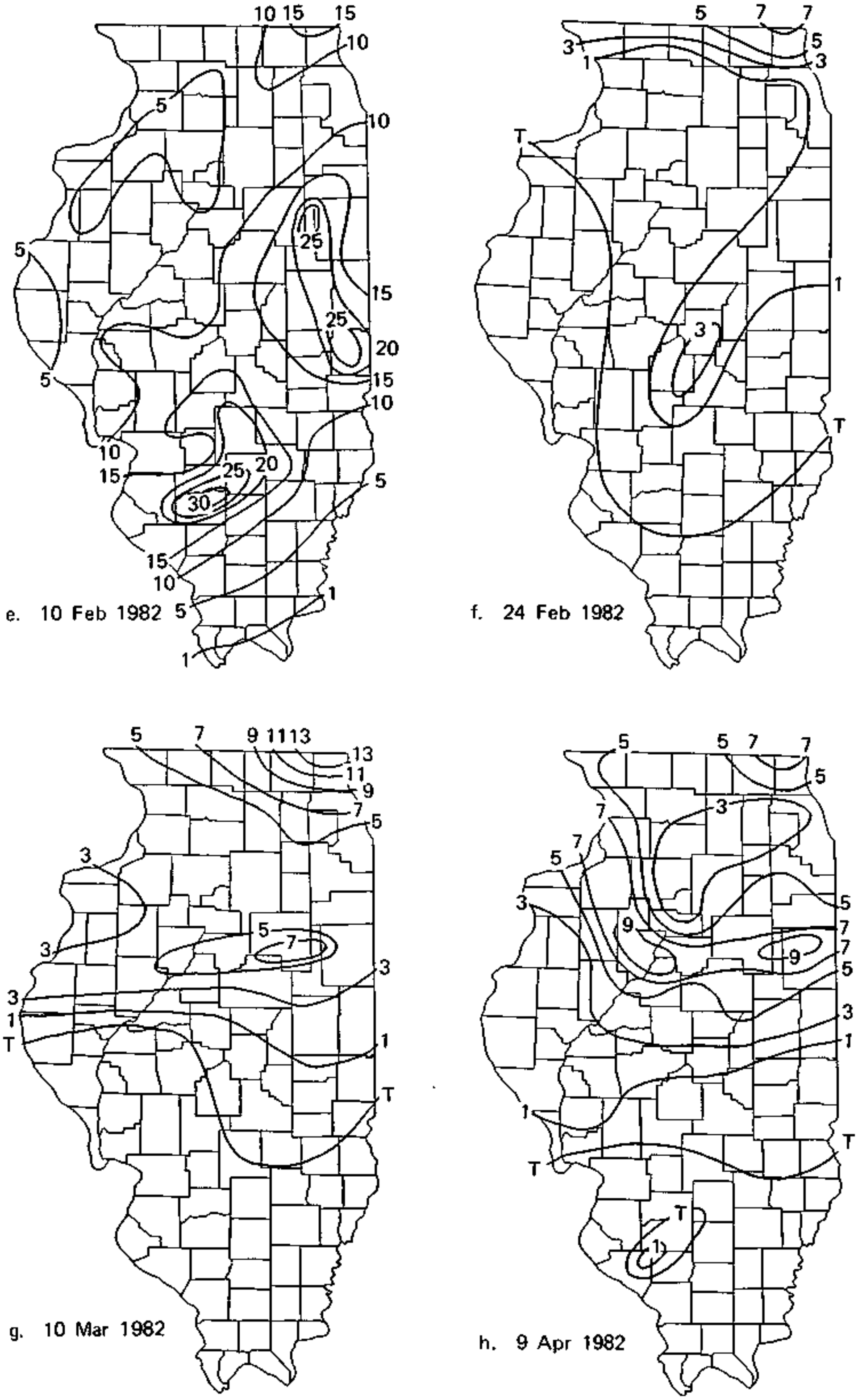


Figure 3. Concluded

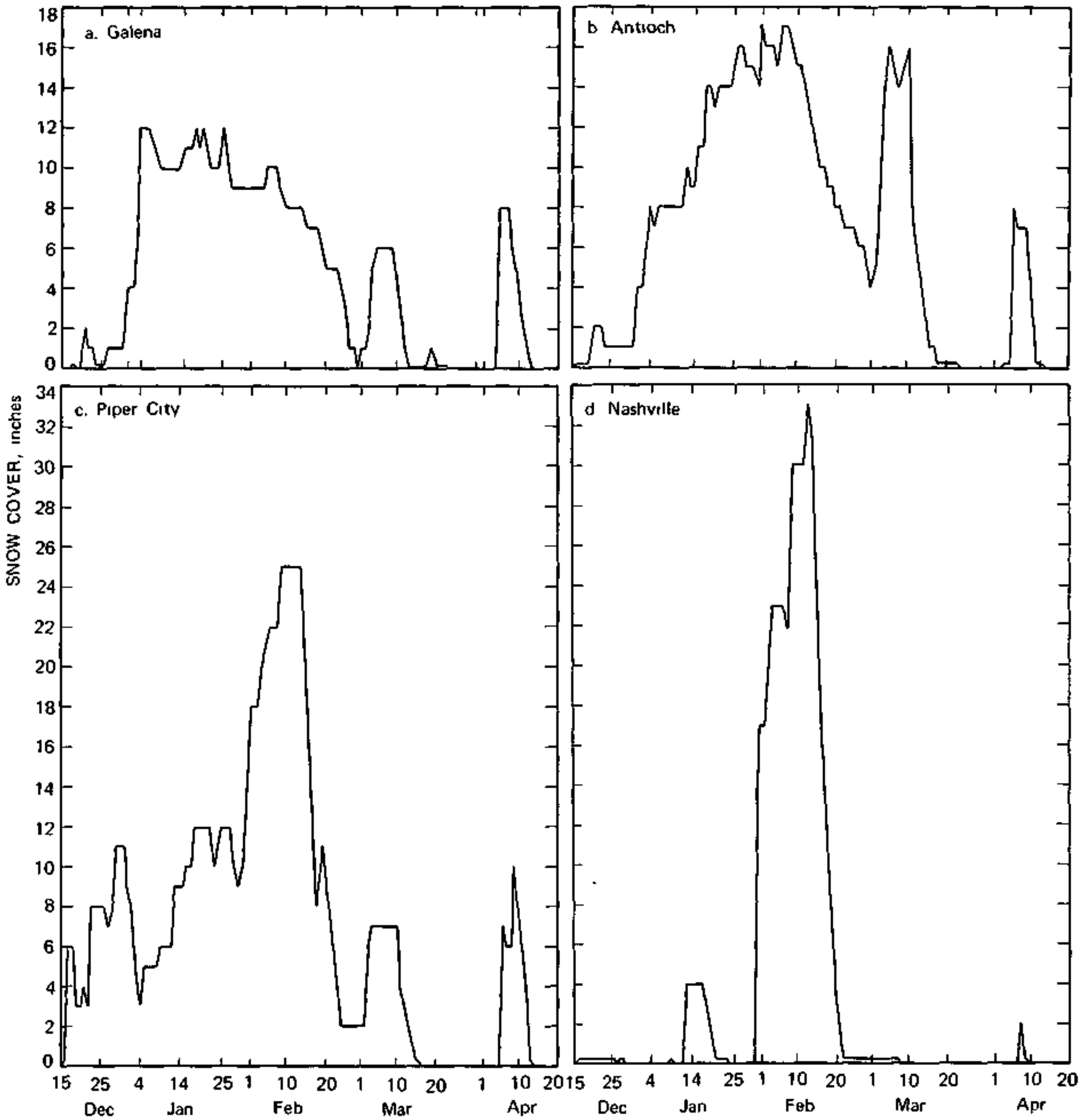


Figure 4. Time trend of snow cover at four stations during winter-spring 1982

The next 2-week period was critical to the total snow cover over central and southern Illinois. As seen in figures 4a and b, little additional snow occurred between 27 January and 10 February in northwest and northeast Illinois. However, the 2-week period from 27 January to 10 February showed large increases in snow cover over central and southern Illinois. Three major snowstorms maximized over the southern part of Illinois. The first storm began on the afternoon of 29 January and continued through the morning of 30 January, with heavy rains in central and southern Illinois (3.55 inches at Fairfield). These heavy rains soaked the ground in southern Illinois and caused some melting in central Illinois. However, the rains on 30 January changed to heavy snow and continued through the afternoon of 31 January. In southern Illinois 6 to 20 inches of new snow fell, and central Illinois was beset by extreme blizzard conditions and 4 to 15 inches of new snow. Figures 4c and d show the new snow accumulations at Piper City and Nashville. The dramatic increase of 17 inches of new snow at Nashville is especially evident in the period from 30 January to 1 February. Two more storms moved across Illinois before 10 February, and both maximized over southern Illinois, dropping 5 to 15 inches more snow over central and southern Illinois. Both storms were caused by lows moving south of Illinois. These dramatic increases in snow cover can be seen in figures 4c and d. At the same time these snows were occurring in central and southern Illinois, only minor amounts of new snow were added to the snow cover in northwest and northeast Illinois (figures 4a and b).

The snow cover on 10 February (figure 3e) was at its maximum across most of Illinois for the winter of 1981-1982. The largest increase in snow cover had occurred in southern Illinois, where there was no snow cover on 27 January and as much as 30 inches recorded on the ground by 10 February (at Nashville). In central Illinois snow cover increased by from 2 to 3 inches in western Illinois to as much as 25 inches at Paris in east central Illinois, which had only a trace of snow on 27 January. The northern part of Illinois had only minor increases in snow cover. The snow cover again maximized over east central Illinois. The largest increase in central Illinois occurred during the blizzard on 30-31 January.

On 12 February a minor snow storm moved across southern Illinois, giving 1 to 3 inches of additional snow cover, and Nashville attained its maximum snow cover of 33 inches (figure 4d). Additional rain and snow occurred over Illinois on 18 February, adding up to 0.5 inch of water over central and northern Illinois. A major break in the temperature occurred across all of Illinois on 14 February, when maximum temperatures rose above 32°F. This thaw began the first major snowmelt of 1981-1982 in all sections of Illinois. In southern Illinois, all but some traces of snow melted by 22 February as temperatures climbed into the mid 30's to upper 40's. The temperature break occurred on 13-14 February, and for the week of 14 to 20 February the average temperatures were above freezing even in northern Illinois, accelerating the melting process.

Almost all the snow had melted across Illinois by 24 February (figure 3f) except for northern Illinois and some isolated sections in central and eastern Illinois. The biggest decrease in snow cover occurred in southern and east central Illinois. The April snowstorms had little effect in southern Illinois, and little or no additional snow cover was reported for the rest of the winter (figure 4d).

The snow cover continued to melt until 1 March when temperatures dropped. New snow then fell over northern and central Illinois on 2-4 and 8-9 March, maximizing in central and northern Illinois. These additions can be seen from the snow cover recorded at

Galena, Antioch, and Piper City. The snow cover map on 10 March (figure 3g) presents a picture of the maximum snow cover resulting from the early March storms. Nearly 16 inches of snow was on the ground in northeast Illinois, and the remnants of the heavy snow band through central Illinois can be seen running from Canton to Watseka. The snow cover melted rapidly beginning on 10 March as temperatures as far north as northern Illinois rose to 40°F. These higher maximum temperatures continued to prevail over all of Illinois, rising into the 60's and 70's in extreme southern Illinois and into the 40's and 50's in northern Illinois. The snow cover in all of Illinois was melted by 24 March.

The last two winter storms of 1981-1982 occurred in northern and central Illinois during the periods of 4-5 and 7-8 April. The first storm dropped 4 to 10 inches of new snow in blizzard conditions over northern Illinois and 2 to 5 inches of snow across central Illinois. This increase in snow cover in northern and central Illinois can be seen in figures 4a-d. The second storm maximized in central Illinois with 2 to 8 inches of new snow, and up to 2 inches of new snow fell in northern Illinois. Up to 10 inches of snow was on the ground by 9 April at Peoria and Piper City. Some snow was still on the ground in southwest Illinois (Sparta, 1 inch), but most of the snow from the storm of 7-8 April melted quickly in southern Illinois. The total snow cover melted across Illinois rapidly as maximum temperatures climbed into the 50's and 60's in northern Illinois and into the 60's and 70's in southern Illinois. This was the last snow cover recorded in Illinois during the spring of 1982.

Table 2 presents some snow cover statistics for the consecutive longest runs of snow at four stations: Antioch, Galena, Piper City, and Nashville. Normally, the longest runs and the greatest amount of snow are found in the northern part of the state (Changnon and Changnon, 1978; Changnon et al, 1980). During the winter of 1981-1982 the stations with the longest runs of snow cover of 20 inches or more occurred in central and southern Illinois. Piper City had 12 days and Nashville had 13 days with snow cover greater than or equal to 20 inches during the first half of February. The total number of days from north to south

Table 2. Snow Cover Statistics for Stations in Northern, Central, and Southern Illinois

	Consecutive longest runs of snow cover								
	≥ 20 inches			*≥ 10 inches*			*≥ 1 inch*		
	Dates from	*to*	*Total days*	*Dates from*	*to*	*Total days*	*Dates from*	*to*	*Total days*
Antioch (North)				1/16	2/17	33	12/21	3/17	87
Galena (North)				1/4	1/26	23	12/27	2/27	70
Piper City (Central)	2/4	2/15	12	1/30	2/17	19	12/16	3/14	89
Nashville (South)	2/3	2/15	13	1/31	2/18	19	1/31	2/21	22

	Total number of days with snow cover		
	≥ 20 inches	*≥ 10 inches*	*≥ 1 inch*
Antioch		45	102
Galena		23	94
Piper City	12	28	96
Nashville	13	19	31

for consecutive days of 10 inches or more of snow was near normal. For days with 1 inch or more of snow, Piper City in central Illinois had 89 consecutive days compared to Antioch's 87. In northwest Illinois, Galena had 70 consecutive days of 1 inch or more of snow. To the south Nashville had only 22 days of 1 inch or more of snow. Interestingly enough 19 of those days had 10 inches or more of snow and 13 of the days had 20 inches or more of snow. The total number of days with snow cover greater than 20, 10, and 1 inch shows interesting differences. Piper City in central Illinois had 96 days of 1 inch or more of snow compared to 94 for Galena and 102 for Antioch. The station with the largest amount of snow cover recorded during the winter of 1981-1982, Nashville, had only 31 days of 1 inch or more of snow.

In northern Illinois the 94 days with 1 inch or greater snow at Galena are 20 to 30 days less than the snow cover recorded in the record winters of 1977-1978 and 1978-1979 (Changnon and Changnon, 1978; Changnon et al., 1980). However, the 96 days of snow cover across east central Illinois recorded at Piper City is similar to the 95 days recorded during the winter of 1977-1978 at Urbana, and only 70 days of 1 inch or greater snow cover was recorded at Urbana in east central Illinois during the winter of 1978-1979. The areas with the greatest amount of snow cover during the winter of 1981-1982 were central and southern Illinois, whereas normally the greatest amount of snow cover is recorded in the northern regions of Illinois.

The number of consecutive days with 1 inch or more of snow on the ground for Illinois is shown in figure 5. The area with the greatest number of consecutive days with snow cover was Piper City in east central Illinois, with 89 days. A large gradient occurred over central Illinois, and most of southern Illinois had fewer than 25 days of 1 inch or more of consecutive snow cover.

The periods of consecutive snow cover in Illinois during the winter of 198-1-1982 can be divided into four sections (figure 6). The earliest snows fell in central Illinois where the snow began to accumulate in mid December and lasted to mid February or early March. The snow cover in the northern sections began in late December and lasted to the end of February to mid March. Most of this snow melted by the end of February, and only in extreme northeast Illinois did the snow cover remain uninterrupted until mid March. The snow cover in southern Illinois began on 31 January or early February. These snows melted by mid February in extreme southern Illinois, and in south central Illinois the snow cover melted in mid to late February.

Rainfall and Snowmelt

Heavy rains by themselves can induce large runoff and flooding, but when heavy rains are combined with melting snow from a deep snow cover, such as the snow cover of 1981-1982, the results are compounded. Snowmelt and heavy rains were observed during several snowmelt periods in the late winter and spring of 1982. Some heavy rains occurred just after snowmelt concluded but while the ground was saturated and all the water could result in direct runoff.

29-31 January. Thunderstorms and associated heavy rains moved into central and southern Illinois, and light snow moved into northern Illinois, on the afternoon of 29 January. The rains began to change to snow over the central and all but the extreme southern part of Illinois on 30 January, as precipitation continued over most of Illinois through

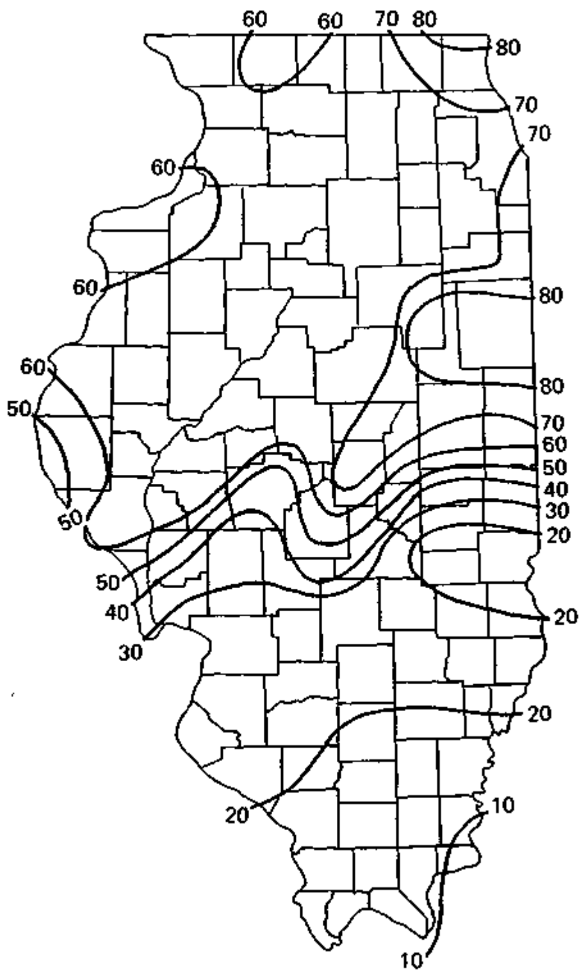


Figure 5. Number of consecutive days with 1 inch or more snow on the ground

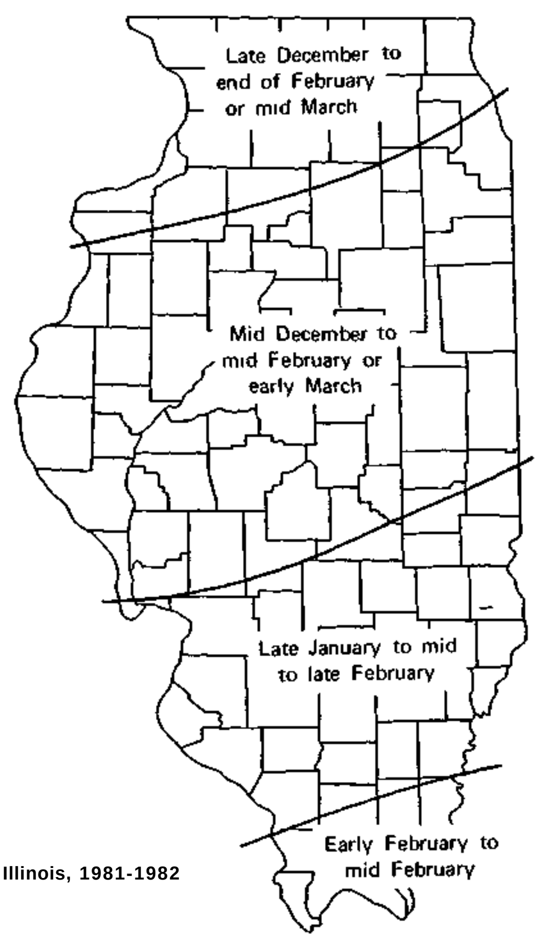


Figure 6. Snow cover periods in Illinois, 1981-1982

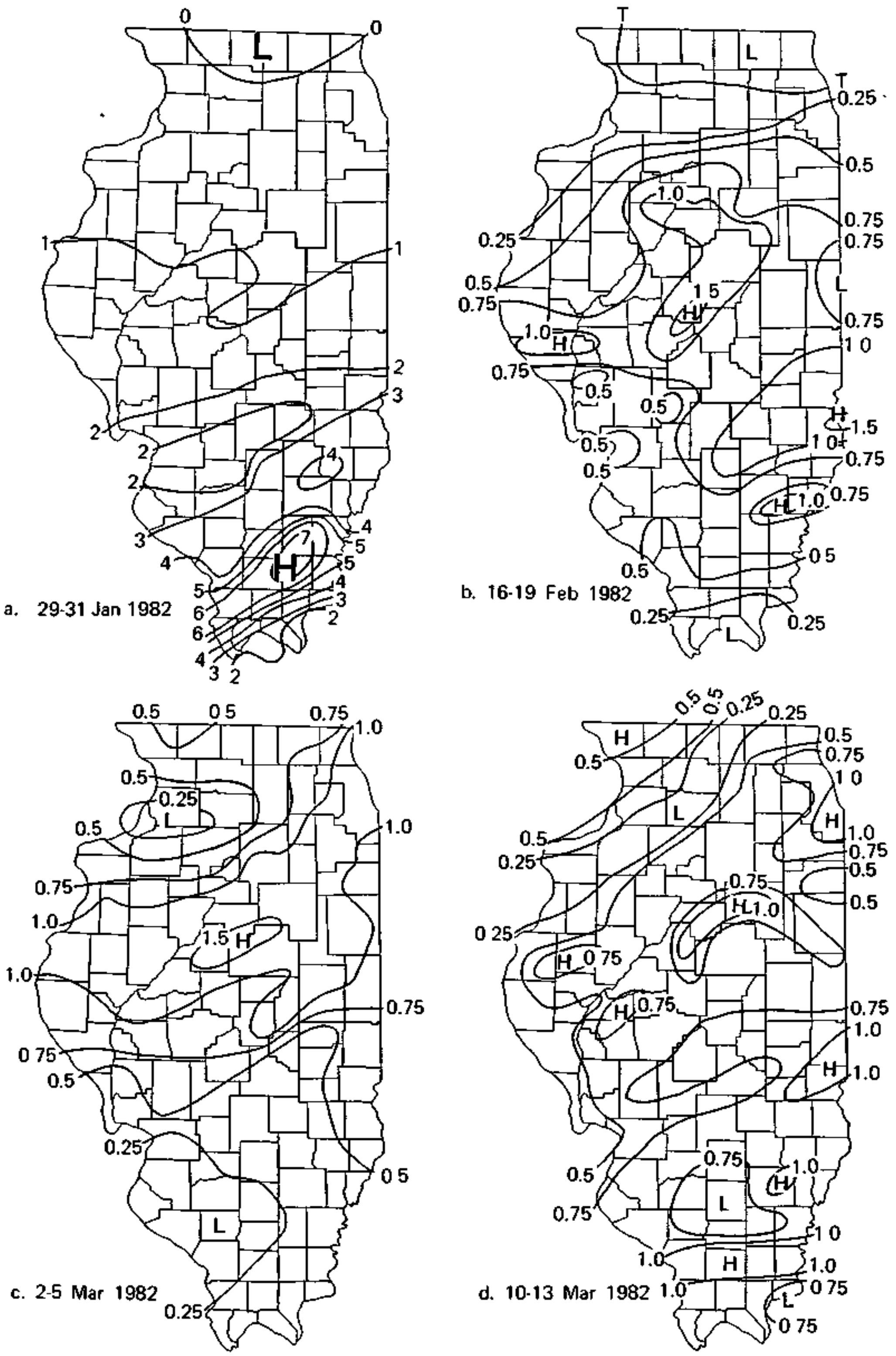
31 January. Rainfall amounts associated with this storm are shown in figure 7a. Only the precipitation that fell in the form of rain is shown; the water equivalent of the heavy snows associated with this storm are not included. More than 7 inches of rain occurred over southeast Illinois in the vicinity of McLeansboro and Harrisburg. Three inches or more of rain was observed over the southern third of Illinois. In addition to the heavy rains, more than 10 to 17 inches of snow fell over parts of central and southern Illinois, adding to or establishing the snow pack which would begin to melt on 14 February.

14-28 February. The first large snowmelt in Illinois began on 14 February when temperatures from south to north soared above freezing. About 3-5 inches of snow disappeared in southern and central Illinois and 1-2 inches in northern Illinois during the first few days. Soils in many areas of Illinois during this period were frozen and saturated, and much of the water from the melted snow ran directly into streams and rivers. On 16 to 18 February rain and some snow fell across Illinois. This storm was particularly heavy in the central portions of Illinois, where totals of 0.75 inch or more were observed (figure 7b). In some parts of central and southeast Illinois, rains of more than 1 inch were observed. Most of the water from these storms ran off directly because of the saturated and/or frozen soil conditions across Illinois. A few inches of new snow were added during this storm in central Illinois; for example, see Piper City (figure 4c).

At Nashville in southern Illinois, the snow began to melt on 13 February and by 22 February 33 inches of snow had melted and nearly 0.75 inch of rain was added to this snowmelt. The total water equivalent of the snowmelt and rainfall was 6.75 inches of water running into swollen streams and rivers. At Piper City in central Illinois 23 inches of snow melted and 0.90 inch of rain was added to the snowmelt, resulting in a total water equivalent of 6.9 inches of water into streams. The magnitude of this additional water can be seen in the rise of river stages in central Illinois (see figures 25 and 26 in the hydrology section). In northern Illinois approximately 5 to 8 inches of snow melted due to above freezing maximum temperatures during this period. However, only trace precipitation amounts were recorded in extreme northern Illinois between 16 and 19 February, and the water equivalent of melted snow was 1 to 1.4 inches.

1-20 March. By mid to late February the snow was melted in southern Illinois, and snow cover and snowmelt conditions were no longer a big threat in the southern third of the state. However, the remainder of Illinois still had snow depths ranging from 1 to 2 inches in central Illinois to as much as 4 to 6 inches in northern Illinois (figure 3f)- The next heavy precipitation in Illinois was on 2 to 5 March (figure 7c). The northern third of Illinois received added snow and the snow cover in this region increased again. Central and northeast Illinois received over an inch of rain and/or snow, while southern Illinois and parts of northwest Illinois had less than 0.25 inch of water equivalent. Antioch (figure 4b) in northeast Illinois received 12 more inches of snow and Piper City (figure 4c) in east central Illinois received 5 additional inches of snow.

On 10 March maximum temperatures in Illinois rose above the freezing mark, and the snow began to melt again across central and northern Illinois. Heavy precipitation fell from 10 to 12 March. Most of Illinois received 0.5 inch or more of rain during these storms (figure 7d). Snowmelt continued until about 20 March. At Piper City the water equivalent of the snow and rain was equal to 2.9 inches. At Antioch in northern Illinois the water equivalent of melted snow and rain was 3.6 inches. The runoff associated with these storms



'Figure 7. Rainfall during winter-spring 1982

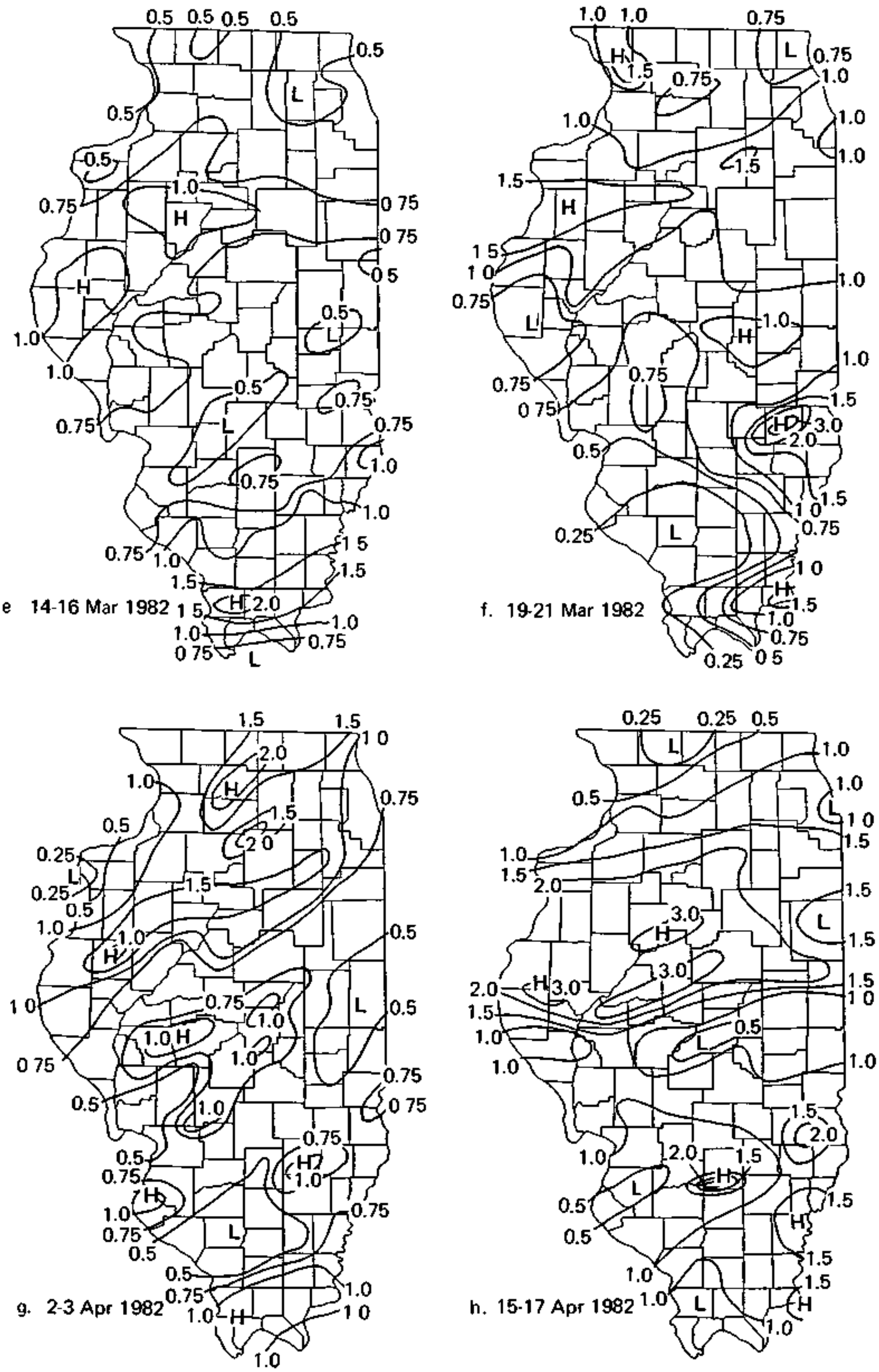


Figure 7. Concluded

was quickly added to the streams in north central and northern Illinois. In southern Illinois, 0.75 inch or more of rain fell across most of the region from 10 to 12 March. These rains caused runoff to streams and rivers.

Other heavy rainstorms which occurred between 1 and 20 March were the storms of 14-16 March and 19-20 March (figures 7e and f). The heaviest precipitation, during the storm of 14-16 March, occurred in southern Illinois with up to 2 inches of rain (Anna). A secondary maximum occurred across central Illinois with amounts of 1 inch or more. The storm of 19-20 March maximized in southeast Illinois with rains of 3.18 inches at Olney. Other rainfall amounts in excess of 1 inch were observed across central and northwest Illinois. Most of the rain associated with these storms resulted in runoff because of the saturated soil conditions prevalent across a large portion of Illinois. Thus, these rains added to the swollen river and stream conditions in many parts of Illinois.

1-12 April. On 2-3 April 1 inch or more of rain was observed over large parts of northern Illinois, and rains of 0.5 inch or more were observed over most of the rest of Illinois (figure 7g). These rains saturated the soils and in some instances led to runoff. On 5-6 April snow again fell across northern Illinois, bringing snow cover back (see figure 4). Temperatures during the next several days remained at freezing or just below freezing, and more snow fell over all but extreme southern Illinois between 7-8 April. By 9 April the snow cover at Antioch was 7 inches, Galena had 8 inches, and Piper City had 10 inches. The snows melted quickly beginning on 9 April when temperatures rose into the 40's and 50's across most of Illinois. The water equivalent from these snows was 1 to 3 inches.

15-17 April. The last major storm during April occurred on 15 and 16 April with an inch or more of rain falling across most of Illinois (figure 7h). Two inches or more of rain occurred in central Illinois and at several locations in southern Illinois.

Water Equivalents of **Snow** Cover. The amount of water stored in the snow reservoir was found for 10 February, 24 February, 10 March, and 9 April. Maps of the water equivalent of snow cover (i.e., the total amount of water stored in the snow) are shown in figures 8a-d for these four days. On 10 February, there were two major centers of stored water: one over central Illinois, and the other over southern Illinois. More than 6 inches of water was stored in snow at Piper City, Paris, and Nashville. The whole state had at least a trace of snow cover, and 89% of the area in Illinois had at least 1 inch or more of water equivalent stored in snow.

Table 3 gives the water equivalent of the snow cover for four days. The 7-inch isopleth over central Illinois on 10 February enclosed 100 square miles, and had an average water equivalent of 7.2 inches. Within this 100 square miles there was 1.7 billion cubic feet of water, 12.5 billion gallons of water, or, on the average, 125 million gallons of water stored on each square mile. The 3-inch isopleth defined the boundaries of the central and southern Illinois water equivalent maximums. In central Illinois, there was an average of 4.4 inches of water stored within this isopleth. The maximum water equivalent zone in southern Illinois had an average of 4 inches of water stored at the surface. The whole state of Illinois had an equivalent of 2.4 inches of water or 41.8 million gallons of water on each square mile.

By 24 February, or only 10 days after the snow cover over Illinois began to melt, 95% of all the water that had been stored at the surface on 10 February was gone. This water had evaporated, had seeped into the ground, or had run off into streams and rivers. In

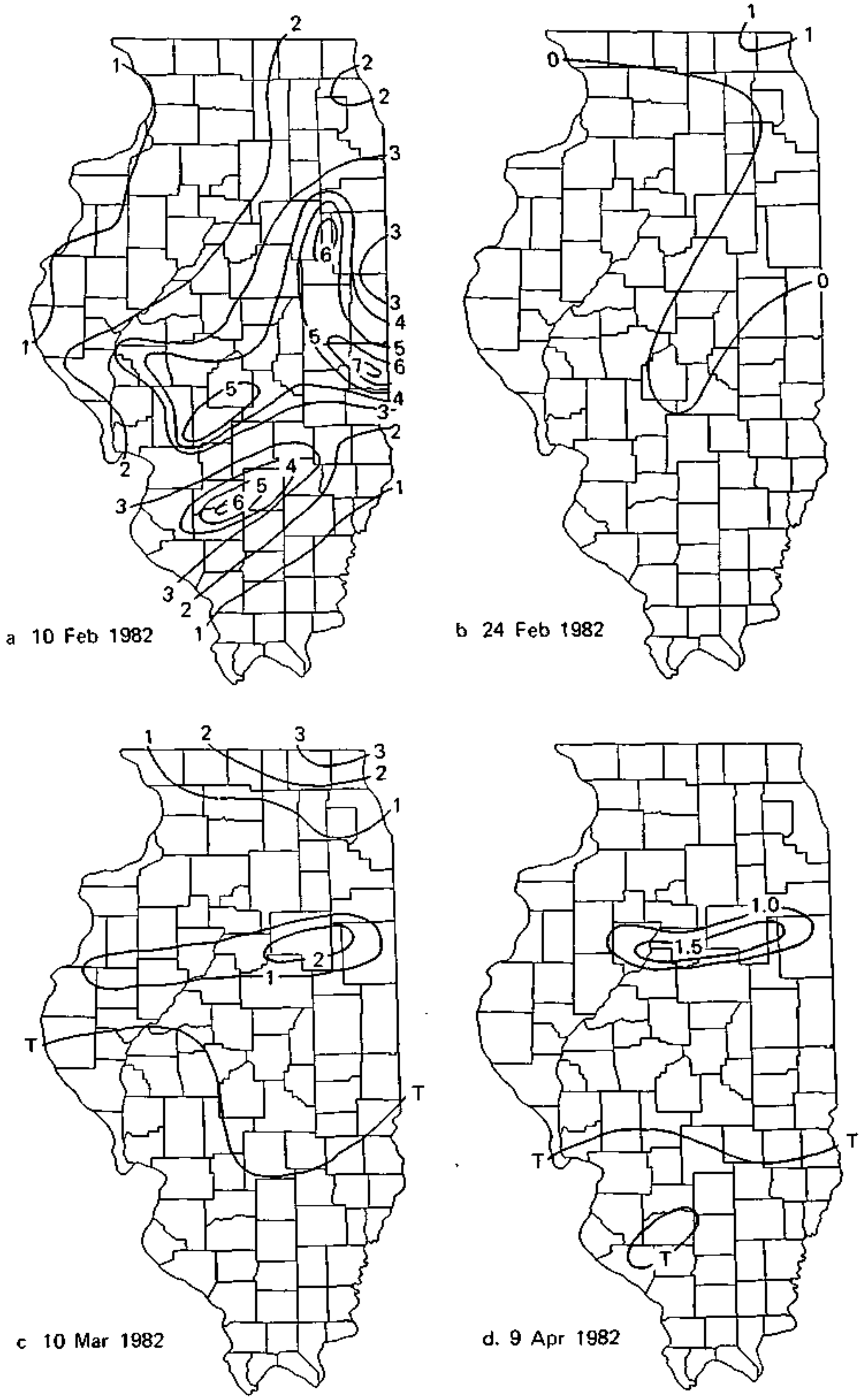


Figure 8. Water equivalents, in inches, stored in snow cover on selected dates

Table 3. Water Equivalent Totals in Snow Cover

Isopleth magnitude	*Region in Illinois*	*Area, sq mi*	*Avg. depth of water equivalent inches*	*Cubic feet of water, billions*	*Gallons of water, billions*	*Gallons of water per sq mi, millions*
				10 February 1982		
7-inch	Central	100	7.2	1.7	12.5	125.1
6-inch	Central	520	6.6	8.0	60.0	115.3
5-inch	Central	3,660	5.7	48.1	360.1	98.3
4-inch	Central	8,720	5.0	101.0	755.9	86.7
3-inch	Central	14,260	4.4	146.1	1092.8	76.6
6-inch	South	80	6.2	1.2	8.6	107.7
5-inch	South	500	5.6	6.5	48.8	97.5
4-inch	South	1,580	4.9	17.8	133.2	84.3
3-inch	South	4,260	4.0	39.6	296.3	69.5
2-inch	Central, S	21,950	4.0	205.6	1538.1	70.1
1-inch	Most of State except SE	50,440	2.6	304.9	2280.9	45.2
	Total snow cover area	56,400	2.4	315.3	2358.6	41.8
				24 February 1982		
1-inch	NE	300	1 5	1.1	7.8	26.1
	Total snow cover area	13,180	0.5	16.0	119.7	9.1
				10 March 1982		
3-inch	NE	320	3.5	2.6	19.5	60.8
2-inch	NE	1,360	2.7	8.6	64.7	47.5
1-inch	NE	10,580	1.7	41.9	313.4	29.6
	Total snow cover area	28,000	1.0	63.3	473.3	16.9
				9 April 1982		
1-inch	Central	2,740	1.7	10.8	81.0	29.5
	Total snow cover area	42,320	0.6	56.8	424.9	10.0

those areas in central and southern Illinois enclosed by the 3-inch isopleth, there was the potential of adding nearly 185 billion cubic feet of water to streams and rivers. This does not include any precipitation that occurred between 10 and 24 February.

The water equivalent of snow cover on 10 March was considerably less than that observed on 10 February. However, the area encompassed by the 1-inch isopleths in central and northern Illinois contained the equivalent of nearly 42 million cubic feet of water. The average water stored in snow over the northern half of Illinois was equal to 1 inch.

The maximum water equivalent from the snows that occurred in early April 1982 was again concentrated in central Illinois. However, only 10.8 billion cubic feet of water were contained within the area enclosed by the 1-inch isopleth, and the total water equivalent of the snow cover was 0.6 inch.

Summary. Rainfall combined with the large water reservoirs stored in the snow cover caused flooding at various times during the winter and spring of 1982 across Illinois. The water reservoir from the snow cover was released at various times during this period. In southern and central Illinois the snowmelt and the associated heavy rains occurred in mid to late February. The snow cover and subsequent heavy rains provided the impetus for flooding in northern Illinois and again in southern Illinois in March.

From mid to late February much of the snow cover melted in Illinois. This snowmelt and the release of the stored water were accompanied by heavy rains on 16 to 18 February. Large amounts of runoff in all but extreme northern Illinois occurred at this time.

More snow fell in early March, and the remainder of the snow left from winter melted in mid March (10 to 21). Associated with this snowmelt were heavy rains on 10-12, 14-16, and 19-20 March.

The last snows occurred in early April and these snows melted from 10-14 April. No major storms were associated with this snowmelt. However, the snows saturated the ground and the heavy rains of 15-16 April resulted in large amounts of direct runoff across northern and central Illinois.

Soil Conditions

Soil Moisture. To help measure the influence of soil moisture conditions on the flooding during 1982, the soil moisture deficit was computed at 16 locales around the state. The soil moisture deficit (SMD) is used to quantify the amount of water the soil is able to hold. SMD is defined as the amount of water that is necessary to increase the soil moisture to field capacity. Positive values of SMD deficit indicate that the soil is between wilting point and field capacity, whereas negative SMD values indicate that the soil moisture exceeds field capacity. When soils are above field capacity in the layers near the surface, surface infiltration will be minimal, and any additional input of water from precipitation will result in surface runoff and an increase in the potential for flooding.

Soil moisture was measured, using a neutron probe, at 16 sites in Illinois as part of the data collection program of the State Water Survey (Hendrie, 1981). In this flood study, the SMD for the top layer (0 or surface to 6 inches [15 cm] below the surface) was used to investigate the ability of the soil layers nearest the surface to retain water. The values of SMD were determined from measurements, and varied with soil types. The characteristics of certain soil types permit high infiltration rates, whereas others permit little infiltration before field capacity is reached.

Figures 9a-f show temporal distributions of computed soil moisture deficits at the 0-6-inch level, plotted along with the total amount of precipitation recorded between measurements of soil moisture. The six sites for which such graphs are presented are DeKalb and Galesburg in northern Illinois, Bondville aridi Perry in central Illinois, Brownstown in south-central Illinois, and Dixon Springs in extreme southern Illinois. The period of time represented is October 1981 to mid April 1982 This embraces the pre-flood period and the flood periods at the end of January, mid to late February, and mid March. Soil moisture measurements at Bondville were taken at least every two weeks throughout the period, while measurements at the other sites were taken only once a month during the winter season.

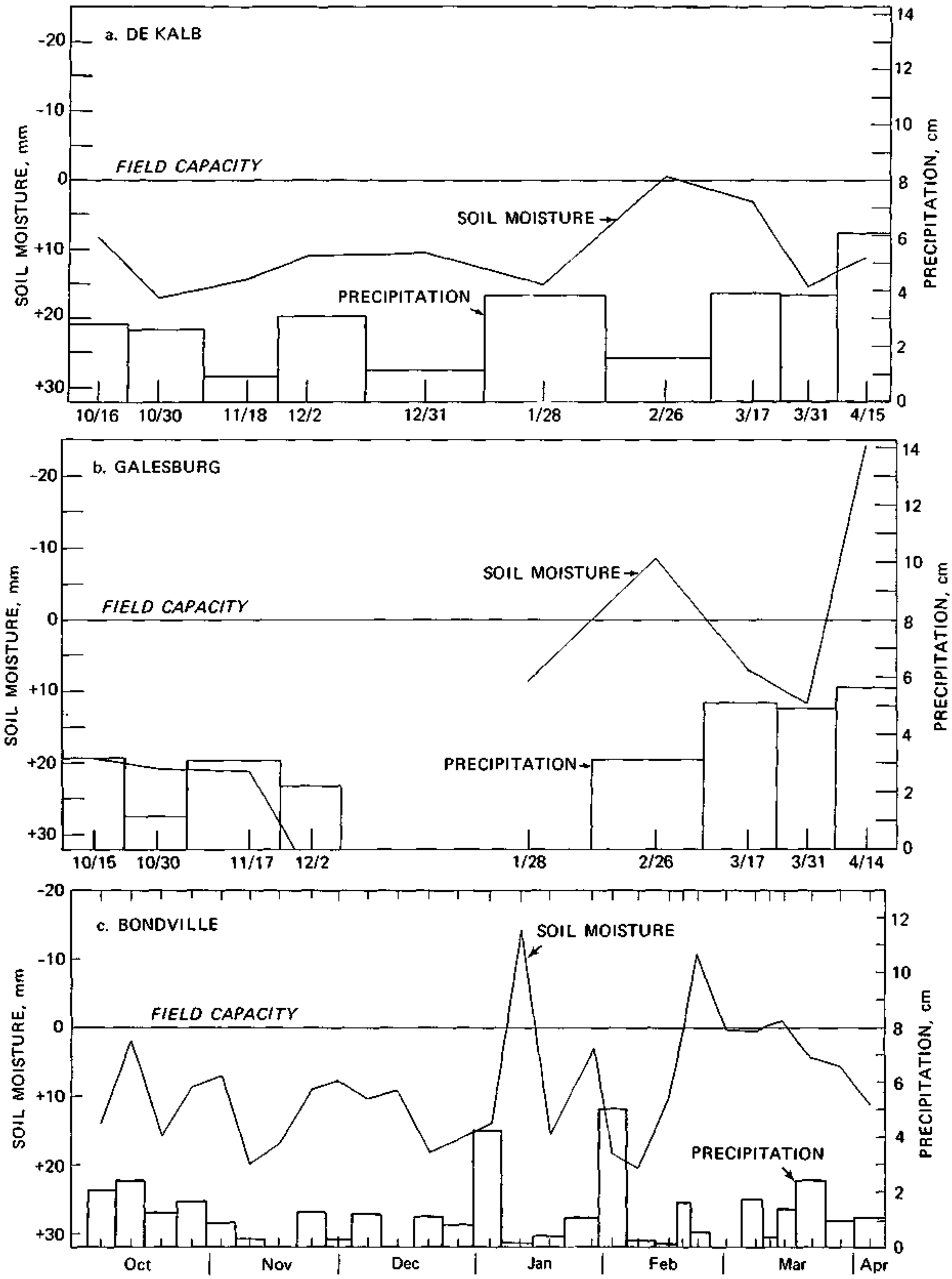
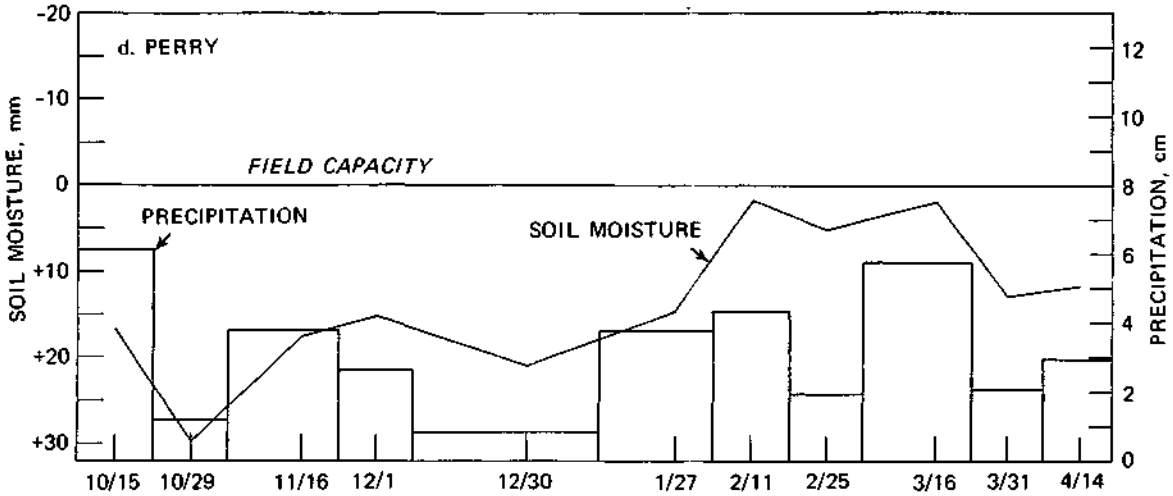
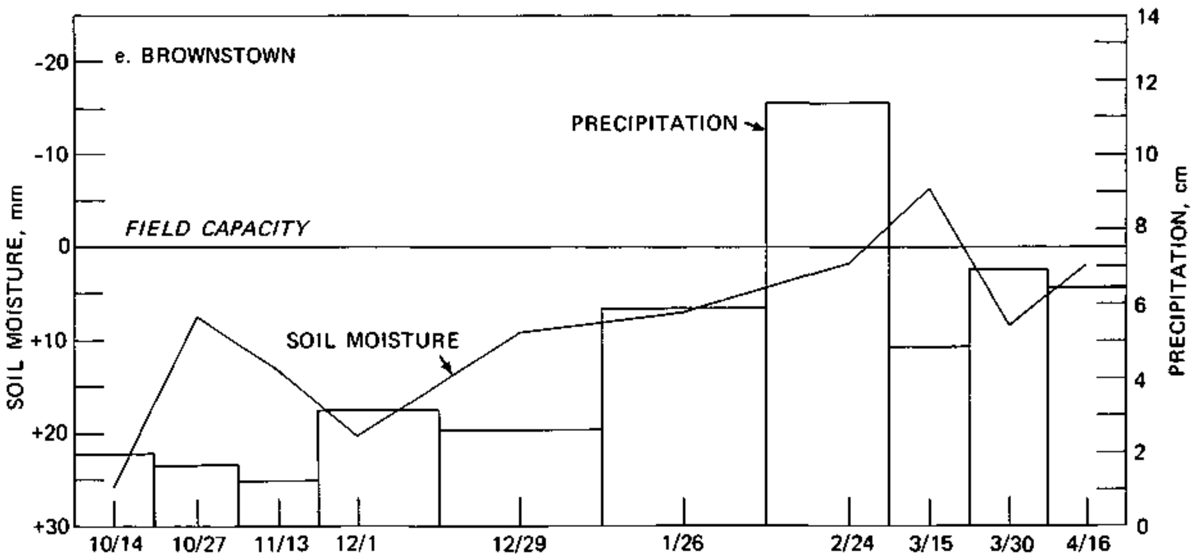


Figure 9. Soil moisture and precipitation for selected areas in Illinois





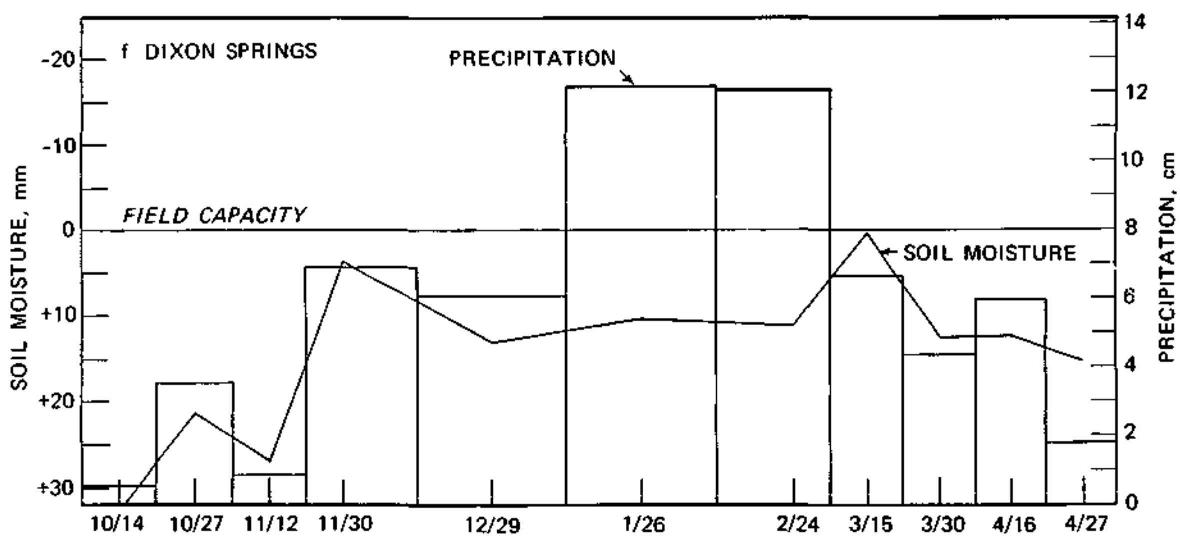


Figure 9. Concluded

The Bondville graph of SMD (figure 9c) shows clearly that conditions of minimum infiltration potential (negative values) existed on 12 January, 22 February, 12 March, and 15 March. The highest level of saturation of the upper soil layer occurred on 12 January for this central Illinois site. This was during a period of extreme cold following a wet period two weeks previous to the measurement. The other dates with low infiltration potential occurred in conjunction with thawing periods. The 22 February soil moisture measurement occurred during the melting of a record snow pack. The measurement of soil moisture deficit on 2 February indicated high infiltration potentials following an extremely wet period (29 January-2 February previous to the measurement). This is not surprising since most of the precipitation that fell was frozen and did not begin melting until two weeks later.

The SMD did not go above field capacity at Perry or Dixon Springs during the entire period, but it should be noted that these are monthly measurements and that month-ending measurements at Bondville (figure 9c) would not have revealed the field capacity values that were attained during January, February, and March. Conditions of minimal infiltration potential did exist at Perry on 11 February following some significant snowfall (but prior to the melting of the snow pack) and on 16 March following the occurrence of some heavy rainfall. The SMD at Dixon Springs approached field capacity on 15 March, following 2 months of above normal precipitation. Unfortunately, the measurements do not reflect conditions at and after the flooding that occurred in this area at the end of January. The soil moisture measurement on 26 January was taken 2 days prior to the storm that caused the flooding, and the next measurement was not until 24 February, several weeks after that flood had ended.

In northern Illinois, the DeKalb SMD exceeded field capacity on 26 February and was near field capacity on 17 March. Conditions of minimal infiltration potential occurred during periods of snowmelt. The Galesburg soil moisture deficit was well above field capacity on 26 February and 15 April. These periods of low infiltration potential again coincide with periods of snowmelt. The 15 April measurement followed two late winter storms that occurred during the first two weeks of April.

The Brownstown site in south central Illinois was near the center of heavy snowfall occurrences in late January and early February. Snow depths in that region exceeded 20 inches at many locations. The SMD was near field capacity on 24 February and 16 April, and above field capacity on 15 March. The 24 February measurement occurred during the melting of a record snow pack. The 15 March and 16 April measurements were taken following the occurrence of substantial rainfall. In most cases it can be seen that periods of minimal infiltration potential occurred during the melting of the snow pack, or following the occurrence of significant rainfall.

Soil Temperature. It is difficult for water to infiltrate soil that is frozen. Frozen soil enhances surface runoff and increases flood potential. There were 16 sites in Illinois which had soil temperature data available on a daily basis for the time period under study. These are data for the 4-inch level under both grass and bare ground, including the maximum and minimum soil temperatures for each day. The 4-inch minimum temperatures under grass were used to determine which days and the length of time the soil was frozen. The soil temperature sites at, or closest to, those sites where soil moisture was investigated were chosen for presentation.

Table 4. Periods with Frozen Soils (beneath grass) at 4-Inch Depth during November 1981 - March 1982

Elwood	*Rockford*	*Peoria*
8 Jan to 18 Feb	22 Nov to 24 Nov	19 Dec
9 March to 11 March	19 Dec to 24 March	2 Jan to 3 Jan
	26 March to 30 March	6 Jan
		9 Jan to 17 March

Urbana	*Perry*	*Brownstown*
11 Dec to 14 Dec	21 Dec to 27 Dec	21 Jan
16 Dec to 21 Dec	10 Jan to 13 March	23 Jan
23 Dec	15 March	28 Jan to 29 Jan
25 Dec to 31 Dec		11 Feb
3 Jan to 3 March		
5 March to 13 March		

Dixon Springs
11 Jan to 28 Jan
30 Jan to 31 Jan
4 Feb to 11 Feb

There was no soil-temperature site at DeKalb, the two closest being those at Rockford and Elwood. The closest soil temperatures to Galesburg were those at Peoria. Urbana soil temperatures were nearest to Bondville, while Perry, Brownstown and Dixon Springs all had soil temperature data available at their sites. Table 4 shows those days during the winter of 1981-1982 when the minimum temperature at 4 inches under grass went below 32°F (0°C).

The results show that shallow soils in northern and central Illinois became frozen by early January and remained frozen until about mid March, with some latitudinal variation. Thus frozen soils existed during the snowmelt thaws of February, and during the major February and March flooding. In southern Illinois soils at the 4-inch depth reached freezing for a few days but never remained below freezing for the prolonged periods found farther north.

Meteorological Conditions

This section provides information about the general weather conditions that contributed to the cold and stormy winter of 1981-1982 and the accompanying flooding, using weather indices to describe the general weather conditions and the short-term climate. The indices are: 1) the relative position of the polar-front jetstream, 2) the positions of troughs and ridges in the upper air flow fields, and 3) the surface path of cyclones. These indices are used in the following general manner.

Jetstream. The polar-front jetstream is a narrow band of strong winds circling the mid latitudes of the earth between 10,000 to 35,000 feet. The position of the jetstream gives an indication of the surface position of the cyclones and of the boundary of polar air masses. The farther south the polar-front jetstream is positioned, the farther south the colder air can intrude. Wind speeds associated with the jetstream also give an indication of the intensity of storms. Generally, higher wind speeds are accompanied by more intense storms.

Troughs and Ridges. Troughs and ridges are elongated areas of low or high pressure. Elongated troughs and ridges in the upper air are often associated with the more intense weather systems. Strong meridional flow (from the north or south) in the 5-day or monthly-mean patterns gives an indication of the intensity of the system. Weather systems associated with meridional flow are often more intense and move slower.

Major troughs, as they approach from the west, are preceded by strong southerly flow, which brings warm air into a region. As the trough moves over the region, it is accompanied by strong northerly flow to the west which allows cold air to move into the low levels of the atmosphere. The influx of cold and warm air into the region produces strong temperature gradients (fronts), which further add to the energy of the weather systems. If the southerly flow is from the Gulf of Mexico, large amounts of atmospheric moisture will also be present, which is a key ingredient if heavy precipitation amounts are to occur. Thus, major storms are often associated with major troughs.

Flow from west to east, or zonal flow, is often associated with fast moving weather systems. Weather systems associated with zonal flow do not usually have temperature gradients (fronts), nor are there usually large amounts of atmospheric moisture present. As a result, these systems are usually not as severe, and though on occasions they can produce some locally heavy precipitation amounts, they are not often associated with widespread heavy precipitation.

The mean trough or ridge position also provides an indication of the source of the air masses affecting a region. For example, the air associated with a trough east of Illinois in predominately zonal flow will often have its origin over the Pacific Ocean. By the time that air arrives in Illinois it has been modified, and the temperatures are moderate. On the other hand, the air associated with a trough with strong meridional flow east of Illinois will often have its origin in the interior of Canada, and cold temperatures would be expected over the area. Similar analyses can be done for the relative positions of ridges. Thus, the placement and the flow type associated with troughs and ridges for a 5-day or monthly mean pattern provide an analytic tool to describe the past.

Surface Cyclone Tracks. Surface cyclone tracks reflect the upper-air flow. If there is large meridional flow and the jetstream is south of its normal position, cyclones can be expected to travel south of their normal path. During winter the cyclone path is an important determining factor of the types of weather that can be expected. For example, severe winter storms across southern and central Illinois are typically associated with the cyclonic storms which track along or near the Ohio River Valley. Severe winter storms across Illinois are often associated with storms which track across central or southern Illinois.

During the winter there are two normal cyclone tracks (Zishka and Smith, 1980). The first originates near the Oklahoma Panhandle and extends northeast across northern Illinois to the northern Great Lakes. The second track is across southern Canada. During a winter, if the mean cyclone paths deviate from these normals, either north or south, substantial changes in the winter weather over a region can be expected.

December 1981

The mean 700-mb map (about 10,000 ft) for December 1981 (Taubensee, 1982) showed a slight ridge over the West Coast and a trough extending from Northern Lake Superior to southern Texas (figure 10a). The main core of the jetstream was across Arkansas, Alabama, and Mississippi. The normal position of the jetstream during December is along the United States-Canadian border to North Dakota, then southeast across southern Illinois and the Ohio River Valley to the mid-Atlantic states. Thus, the jetstream during December was about 300 miles south of its normal position.

The circulation over Illinois shifted in mid-December. Moderate air masses from the Pacific dominated in the first half of the month, while in the second half cold air masses from the interior of Canada were the rule. Thus, the second half of December experienced much below normal temperatures, while in the first half temperatures were generally above normal.

During the first two weeks of December the temperatures across Illinois ranged from near normal to 3°F above normal. The 5-day upper-air patterns (figure 10b) at 700 mb during this period showed a trough west of Illinois through 5 December, followed by a small amplitude ridge centered over the western part of the United States which brought mild maritime air across Illinois through 11 December.

The upper-air pattern shifted from 14 to 18 December as a trough developed almost directly over Illinois. The meridional circulation increased and brought Arctic air from Canada. Coincident with the development of this trough over the central United States was a major storm which moved across central Illinois beginning on 16 December. From 3 to 9 inches of snow fell across central Illinois, while southern and extreme northern Illinois received only trace amounts of snow (figure 3). With the snow came much lower temperatures. Figure 11 shows the weekly average temperatures and their departures from normal from 6-12 December and from 13-19 December. The change between the two weeks is dramatic. The 13-19 December period was more than 15°F cooler in northwest Illinois and 10°F cooler in southern Illinois than the previous week, and averaged 9 to 12°F below normal. The temperatures during the week of 20-26 December moderated as the meridional flow lessened and the center of the cold air remained north, but the temperatures in southern Illinois were still 6° F below normal.

Two major cyclone tracks were observed during December. One track went northeast across Arkansas, northern Mississippi, and northern Alabama, and was about 450 miles south of the normal path. The second track took cyclones across the northern plains and southern Canada.

Cyclones during the first half of December moved north of Illinois, following the more northern track. During the second half of December, when the trough was situated over or in the vicinity of Illinois, the cyclones tracked south of Illinois or up the Ohio River Valley. This meant that central Illinois was most susceptible to heavy or severe snowstorms. Thus, the snow map on 30 December (figure 3b) shows a maximum amount of snow across the central portions of Illinois with lighter snow across the northern part of the state.

January 1982

The mean 700-mb map for January 1982 (figure 12a) was similar to the map for December 1981 (figure 10a). The major difference was the tightening of the height lines over

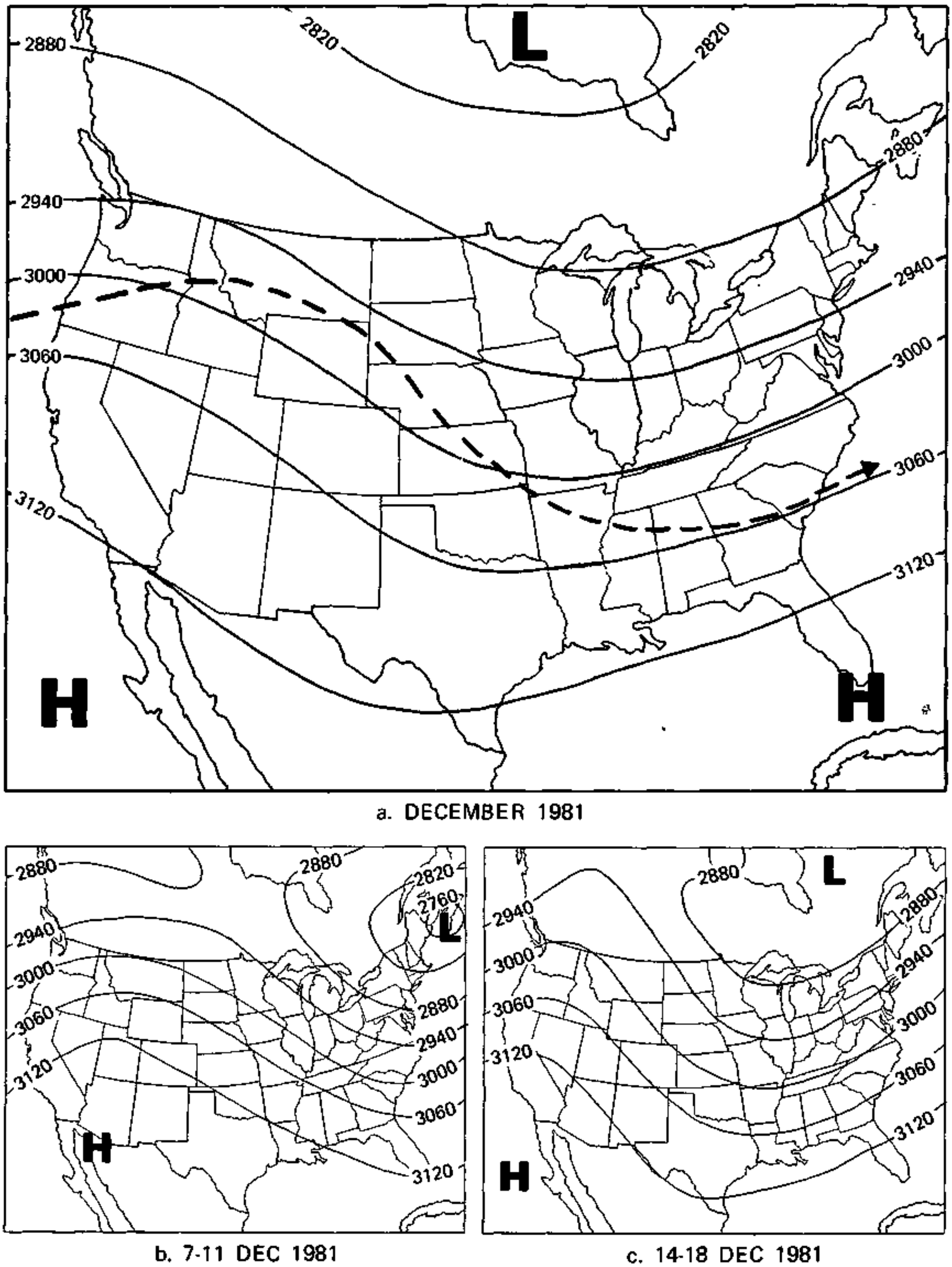


Figure 10. Mean 700-mb height map (in meters) for December 1981 and selected 5-day mean 700-mb maps (After Taubensee, 1982)

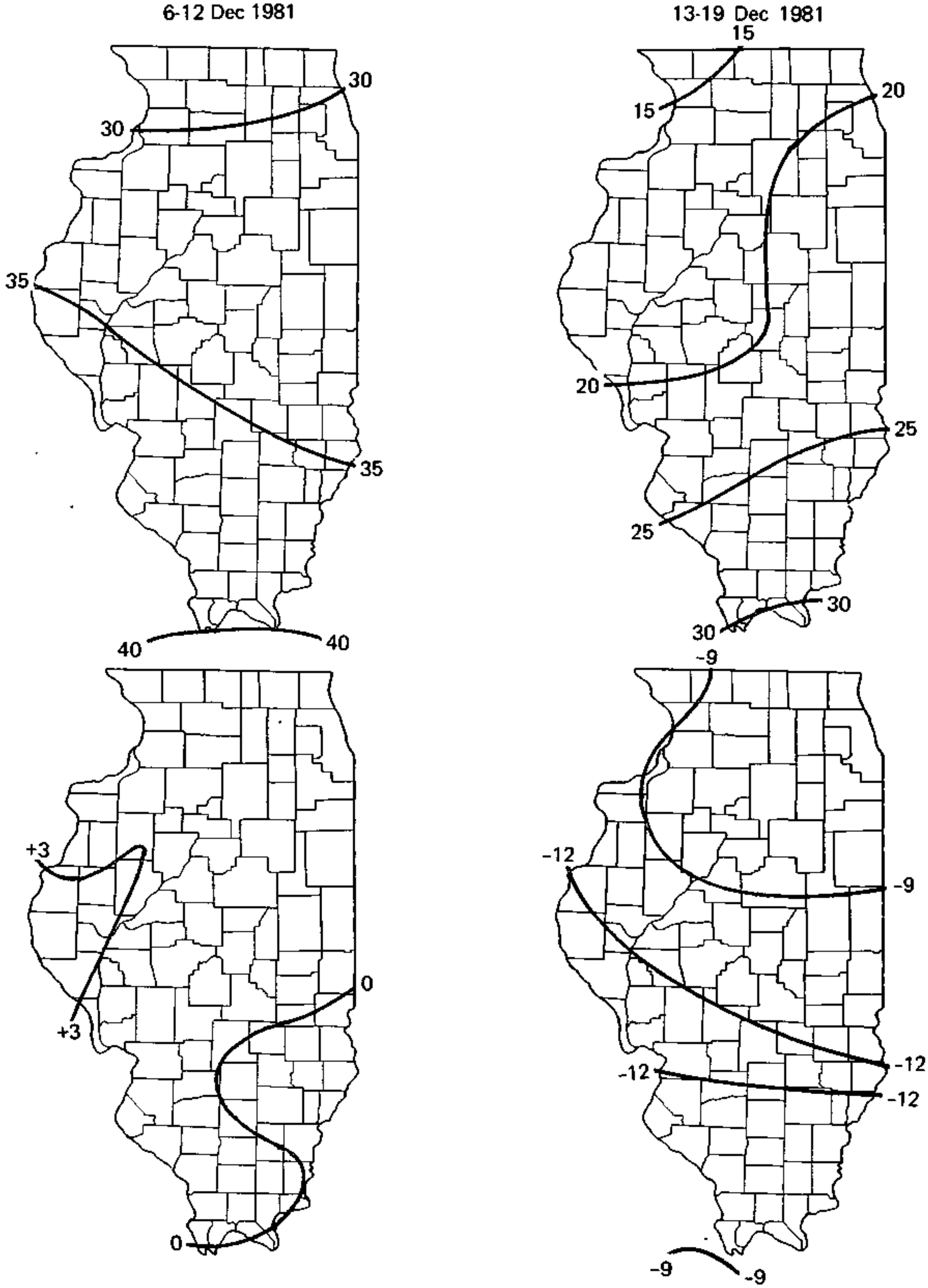


Figure 11. Selected weekly average temperatures (°F) and their departures from normal during December

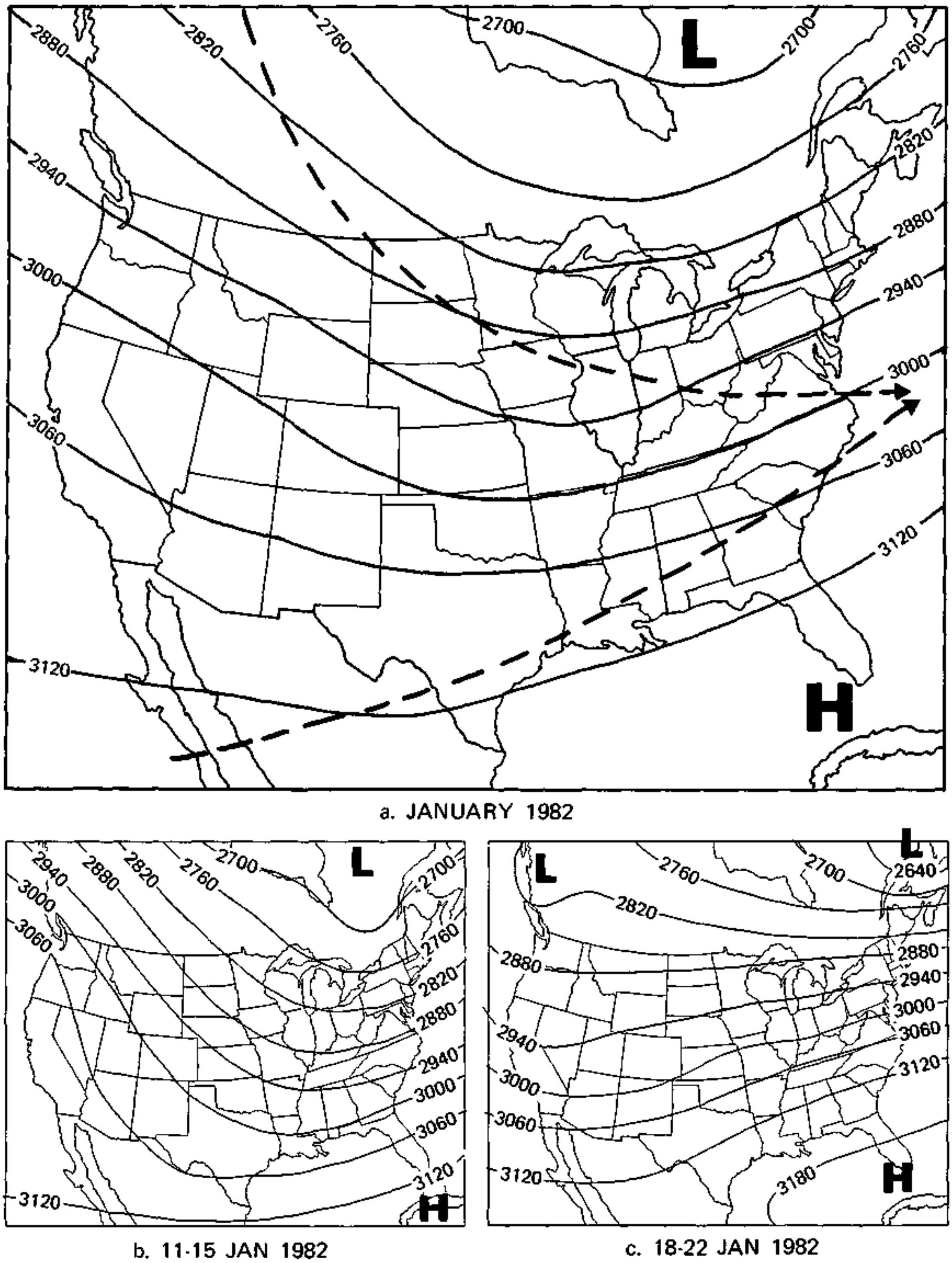


Figure 12. Mean 700-mb height map (in meters) for January 1982 and selected 5-day mean 700-mb maps (After Wagner. 1982)

the eastern United States. This tightening reflects increased wind speeds and is an indication of the intense activities that passed through the United States during January. The axes of maximum wind speed were near their normal positions for January with one branch extending from northwest Mexico across the northern Gulf States and the second axis extending from northeast Montana across central Illinois to the mid-Atlantic states. The 700-mb pattern during January 1982 was strongly amplified (Wagner, 1982), with a broad strong trough over eastern North American and the western Atlantic. The moderately amplified ridge over the eastern Pacific was far enough off the West Coast to drive cold Canadian air into the mid sections of the United States, dropping the temperatures much below normal.

The mean trough position during the first two weeks of January extended from the upper Great Lakes through the central portions of the Mississippi Valley into the lower Mississippi Valley. However, from 11 to 15 January the trough-ridge combination amplified (figure 12b), allowing the penetration of Arctic air into the northern Great Plains and the Mississippi Valley. The Arctic air allowed the temperatures to plummet dramatically on 10 January. The temperatures on 10 January in Illinois ranged from —27°F in northern Illinois to —6°F in the extreme tip of Illinois (Hilberg et al., 1983). Temperatures during the week of 10-16 January (figure 13) ranged from —5°F in northwest Illinois to only 15°F in extreme Illinois, and were 21-24°F below normal. The last cold day in this stretch of extremely cold temperatures was 17 January, when the minimum temperatures ranged from —27°F to-7°F.

Beginning on 17 January the upper-air flow pattern changed and the trough over the central part of the United States moved rapidly east to the Atlantic Ocean. A ridge developed over the central United States (figure 12c). The net result was moderating temperatures with rises of nearly 20°F in the average daily temperature in northern Illinois and 15°F in the average daily temperature across southern Illinois. During this week the temperatures averaged only 6 to 9°F below normal. This pattern continued through 29 January.

During the 5-day period from 29 January to 2 February, the trough off the West Coast of the United States progressed east to the Great Plains, again intensifying the weather patterns across the Midwest. With the upper-air trough west of Illinois southwesterly winds advected large amounts of moisture from the Gulf of Mexico. The warmer temperatures and the moisture contributed to showers and thunderstorms on 29-30 January. As the trough moved east, colder air advected into Illinois and the showers and thunderstorms gradually changed to snow storms with blizzard conditions in central Illinois. By the end of January snow covered the whole of Illinois from the north to the south (figure 3).

In January the cyclone tracks during the first half were displaced south relative to the December tracks. Cyclones moved predominately from southern Texas across the Gulf Coast and then up the East Coast. During the second half of the month, most cyclones took a more northerly track moving across Illinois or the northern tier of states. This is in contrast to December when cyclones moved across the northern tier states or southern Canada. The heaviest storm during January occurred on 29-31 January when a cyclone passed through Arkansas and Kentucky (Hilberg et al., 1983). This was a very intense cyclonic disturbance.

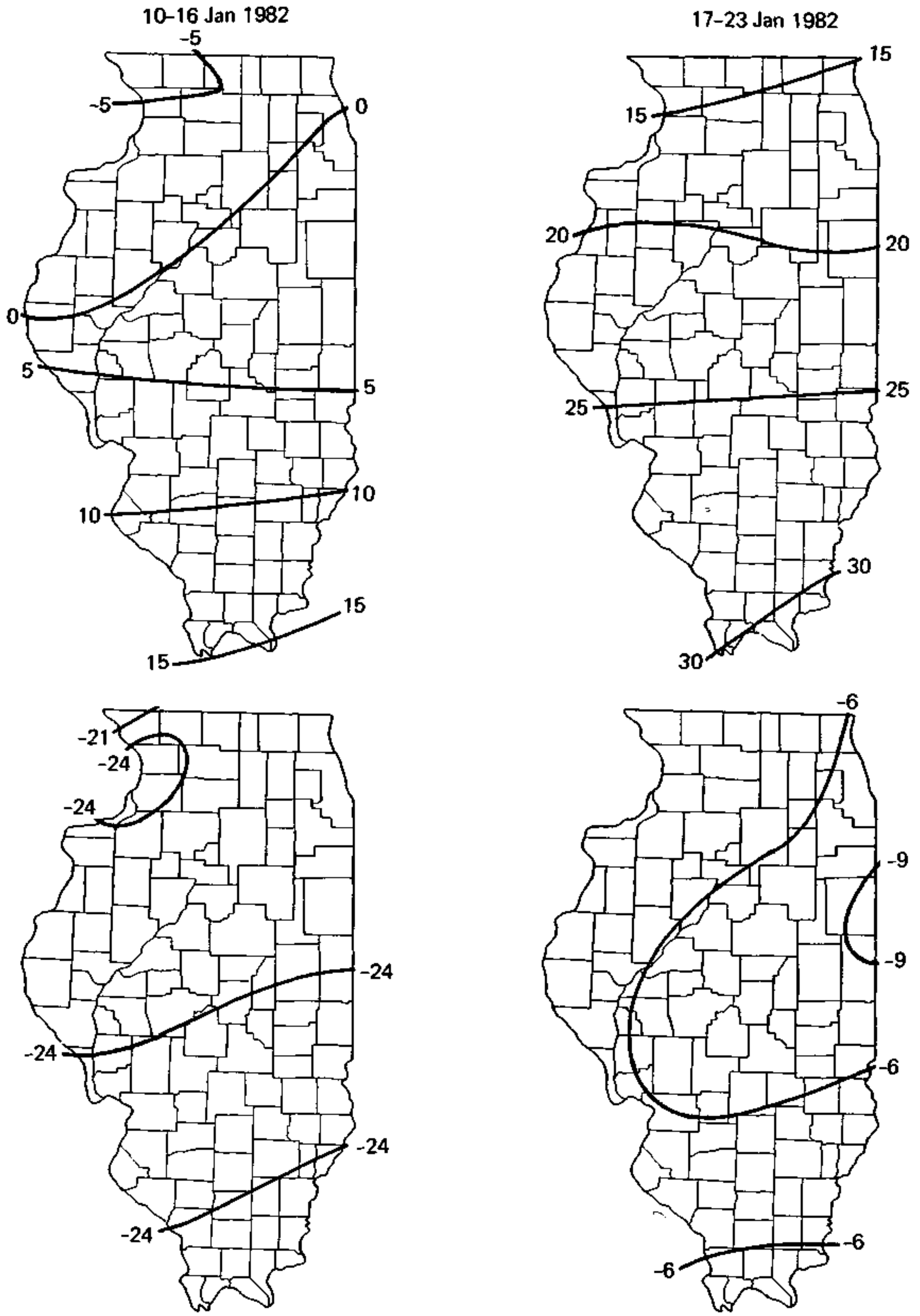


Figure 13. Selected weekly average temperatures (°F) and their departures from normal during January

February 1982

The mean 700-mb map for February 1982 (figure 14a) showed a flattening of the trough over the central United States and more of a southwest-northeast orientation than the north-south orientation of December and January. There was little meridional flow across the United States, and the zone of intense westerly winds over the eastern United States began to break down somewhat (Dickson, 1982). The southern axis of maximum winds was close to its normal position across the extreme southern part of the United States. However, the northern jetstream, observed in southern Canada, was 400 miles north of its normal position through the upper Mississippi Valley and the mid Atlantic states.

Below normal temperatures continued through the first 13 days of February, with weekly average temperatures ranging from 5°F in northwest Illinois to about 25°F in southern Illinois, or 12° to 18°F below normal across all of Illinois. The upper-air flow during the first two weeks of February was dominated by a large intensified trough through the central Plains. There were large amounts of north to south flow as the ridge off the West Coast of the United States built and large amounts of Arctic air were driven into the central and mid sections of the United States, dropping temperatures dramatically (figure 14b). The amplitude of the wave decreased during the second week as the ridge moved west into the Pacific and the Gulf of Alaska region, and by the week of 14 February the flow across the United States was much more zonal (figure 14c). This pattern continued through the end of February.

As a result of this shift in the upper-air flow, the temperatures at the surface warmed dramatically. On 13 February the temperatures rose above freezing in southern Illinois and by 14 February the maximum temperatures were above freezing throughout Illinois. From 15 December to 14 February maximum temperatures in northern and central Illinois exceeded or equalled 32°F on fewer than 20 days of this 2-month period, and only half of the days in southern Illinois had temperatures equal to or in excess of 32°F. Thus, above freezing temperatures in northern and central Illinois lasted only for a few hours from mid December to mid February, and the snow cover could not melt.

The dramatic shift in the average daily temperatures from the week of 7-13 February to the week of 14-20 February can be seen in figure 15. The temperatures over most of Illinois rose between 20 and 25°F in one week, from 12-18°F below normal during the week of 7-13 February to 3 to 9°F above normal during the week of 14-20 February. These warmer temperatures began to melt the vast water reservoir contained in the snow cover across Illinois. This melting process was aided by a heavy rainstorm on 16-18 February.

The more northerly position of the jetstream during February was reflected by a major track of cyclones across southwestern Canada and Hudson Bay to the Atlantic Ocean. Another major track took cyclones across Oklahoma and Tennessee to the mid Atlantic states. Both cyclone tracks were north of the cyclone tracks experienced during December and January, and north of their normal tracks.

March 1982

The average 700-mb map for March 1982 (figure 16) showed strong westerly flow from central North America to the eastern Atlantic, with minor troughs across the central Great Plains and again off the West Coast of North America. The dominant flow for March was zonal (Winston, 1982). Very little meridional flow was apparent.

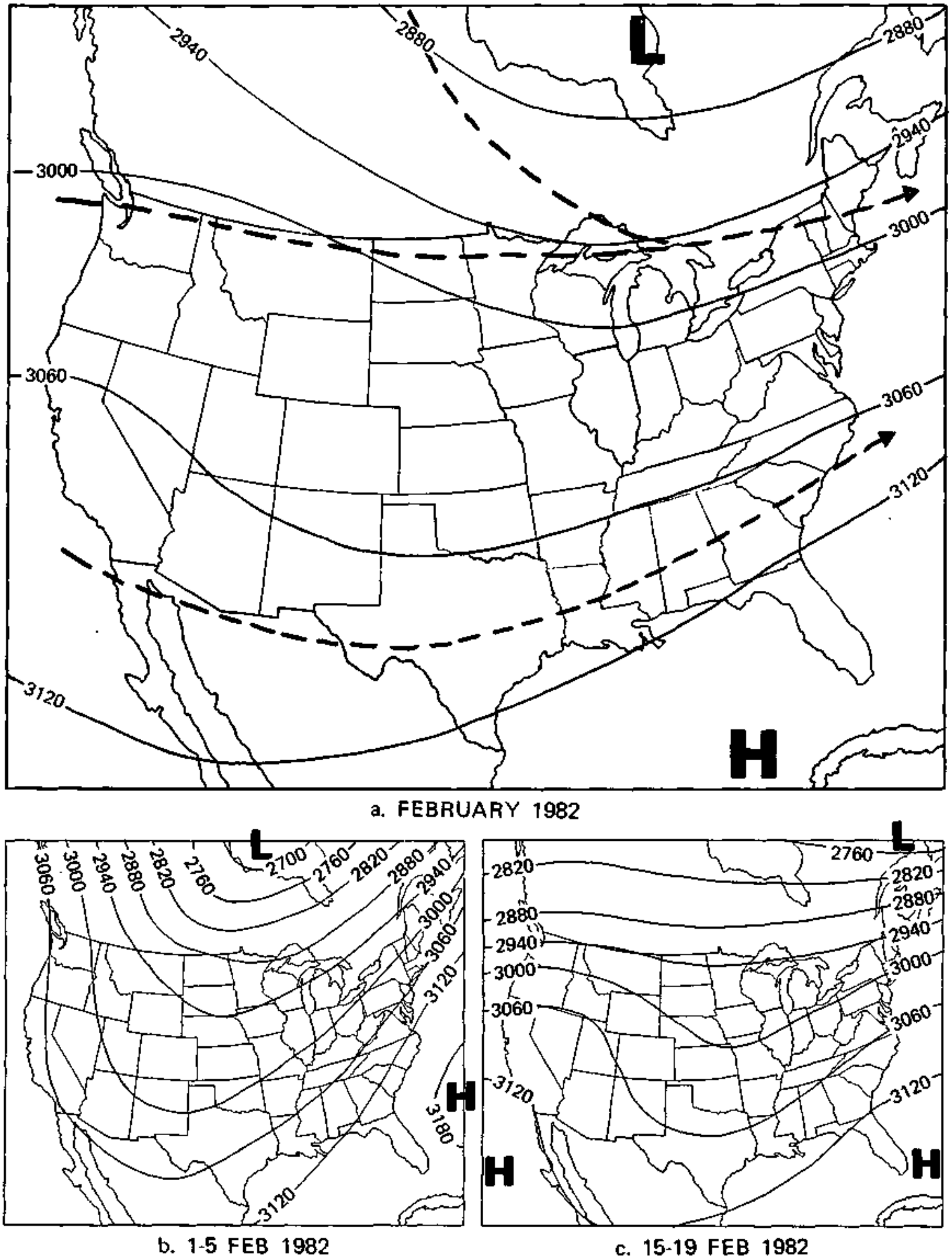


Figure 14. Mean 700-mb height map (in meters) for February 1982 and selected 5-day mean 700-mb maps (After Dickson, 1982)

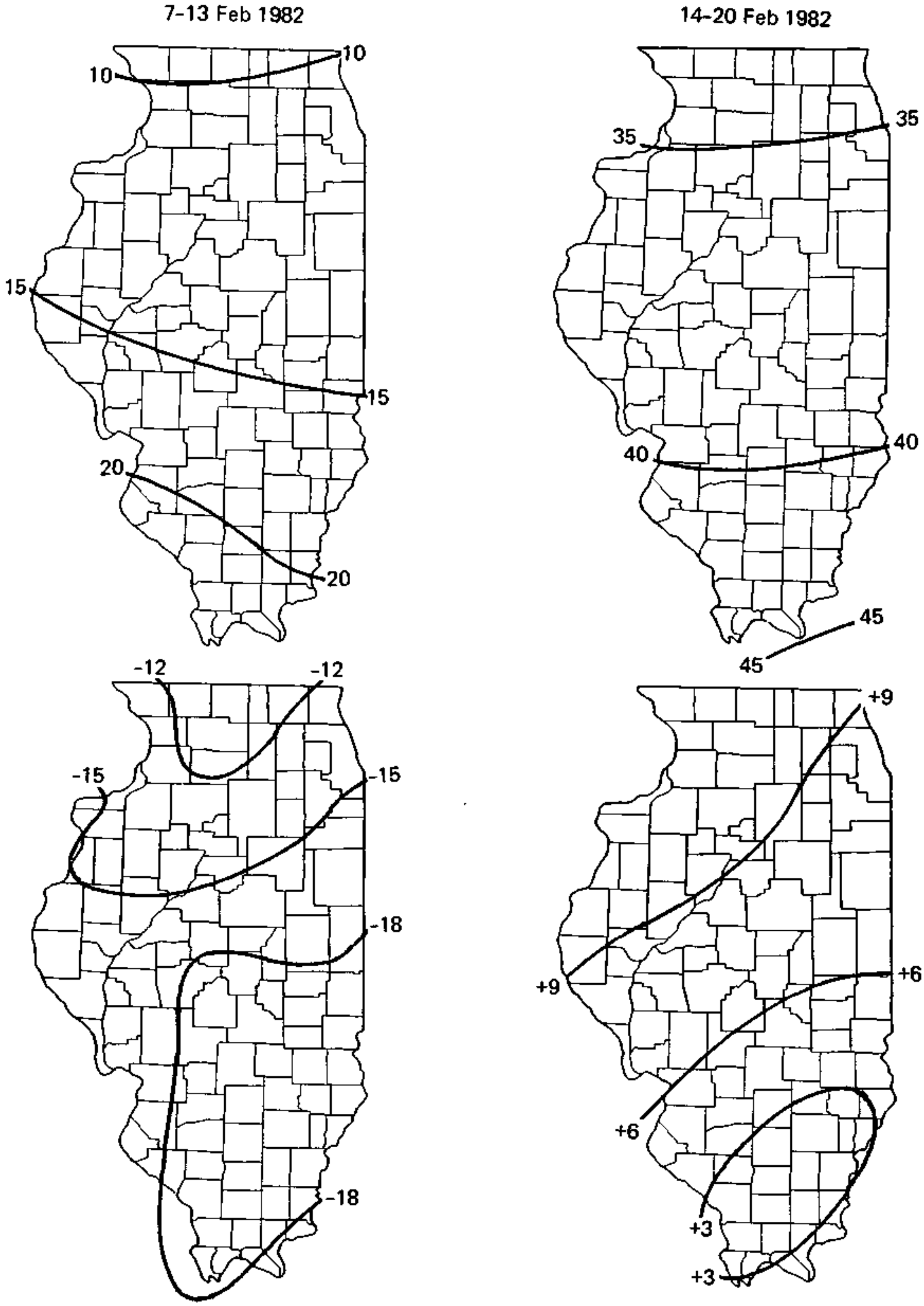


Figure 15. Selected weekly average temperatures (°F) and their departures from normal during February

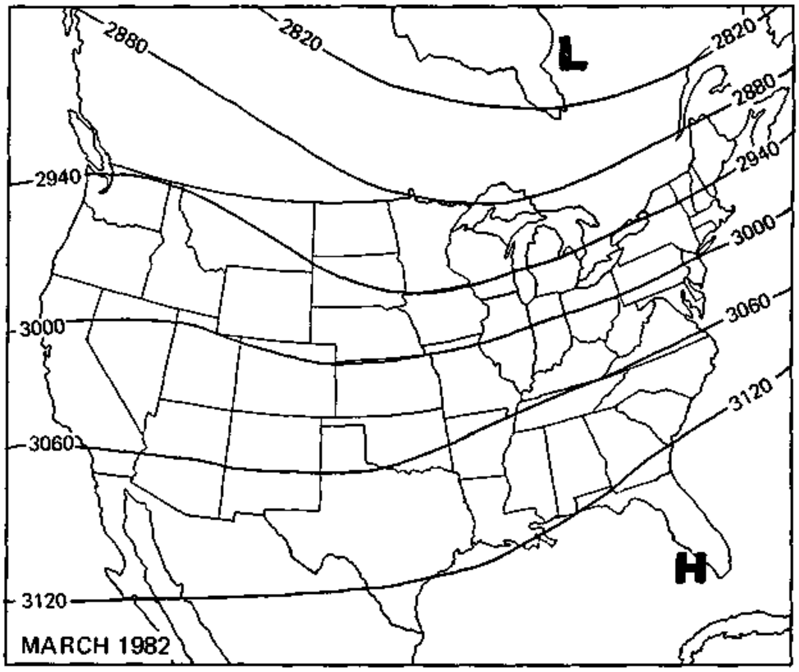


Figure 16. Mean 700-mb height map (in meters) for March 1982 (After Winston, 1982)

The upper-air flow during the first 10 days of March was characterized by zonal flow with several short-wave troughs moving across the Midwest, and a general trough over the Upper Mississippi Valley. On 3-4 March an upper-air trough and a surface cyclone moved across central Illinois, dropping 3 to 9 inches of new snow over northern Illinois and some freezing rain and snow over the rest of Illinois. Storms were also noted on 6 and 8 March. The general trough and the succession of cyclones over the Midwest brought slightly cooler temperatures to northern Illinois and new snow cover to central and northern Illinois (see figure 3).

From 13-19 March the trough deepened on the West Coast and brought warmer air from the southwest into Illinois. The temperature across Illinois during this period ranged from 40°F in the north to near 60°F in the south, allowing the remaining snow cover in Illinois to melt. During the remainder of March a series of ridges and troughs moved east across the midsection of the United States, bringing periods of showers. However, the dominant flow across the central United States during March was zonal with little meridional north-to-south movement in the mean upper-air patterns.

The zonal flow brought more storms than normal across the Rockies (Winston, 1982). During March most cyclones moved across the northern Rockies to the Great Lakes in a general west-to-east direction. The cyclones moving across Illinois were associated with various cold fronts and upper-air disturbances which induced heavier than normal precipitation over the Great Plains, the Midwest, and most of Illinois.

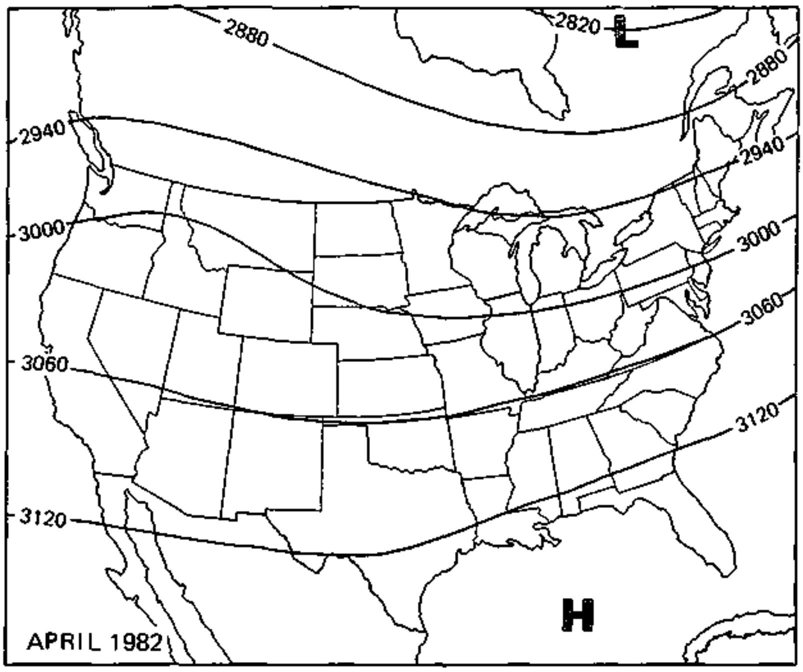


Figure 17. Mean 700-mb height map (in meters) for April 1982 (After Winston, 1982)

April 1982

During April westerly flow continued for most of the month (figure 17). However, the westerlies were less intense over the central and eastern part of the United States (Winston, 1982), and the general intensity of storms during April was less. Nevertheless, there was a slight trough over the eastern United States, resulting in below normal temperatures for much of April.

A slight trough over Illinois and Indiana from 1-7 April allowed colder than normal air to advect into the region, and there were two unseasonable snowstorms on 5 April and 7-8 April. These snowstorms were associated with surface cyclones that moved northeast across southern Illinois. These new snowstorms dropped 4 to 10 inches of new snow across most of Illinois. The temperatures from 4 to 10 April ranged from a chilly 25°F in northwest Illinois to around 40° F in southern Illinois, some 18-21°F below normal for this time of year (figure 18). The week of 11-17 April saw a 20-25°F rise in temperatures as the upper-air trough moved east and the flow became more zonal through 18 April. The zonal flow broke down from 14-23 April and was replaced by a strong southwest-northeast trough from James Bay to northern Baja, California. With this configuration, moisture from the Gulf of Mexico became available to the central United States. A cyclone moved across Illinois on 15-16 April, and 2-3 inches of rain fell over much of central and southern Illinois.

During April cyclones in the United States followed two major paths. The first path found cyclones moving across the Gulf States and then up the East Coast of the United States. The second path was more northerly, with cyclones moving across the northern Great Plains to the northern Great Lakes. Both of these tracks take cyclones too far north

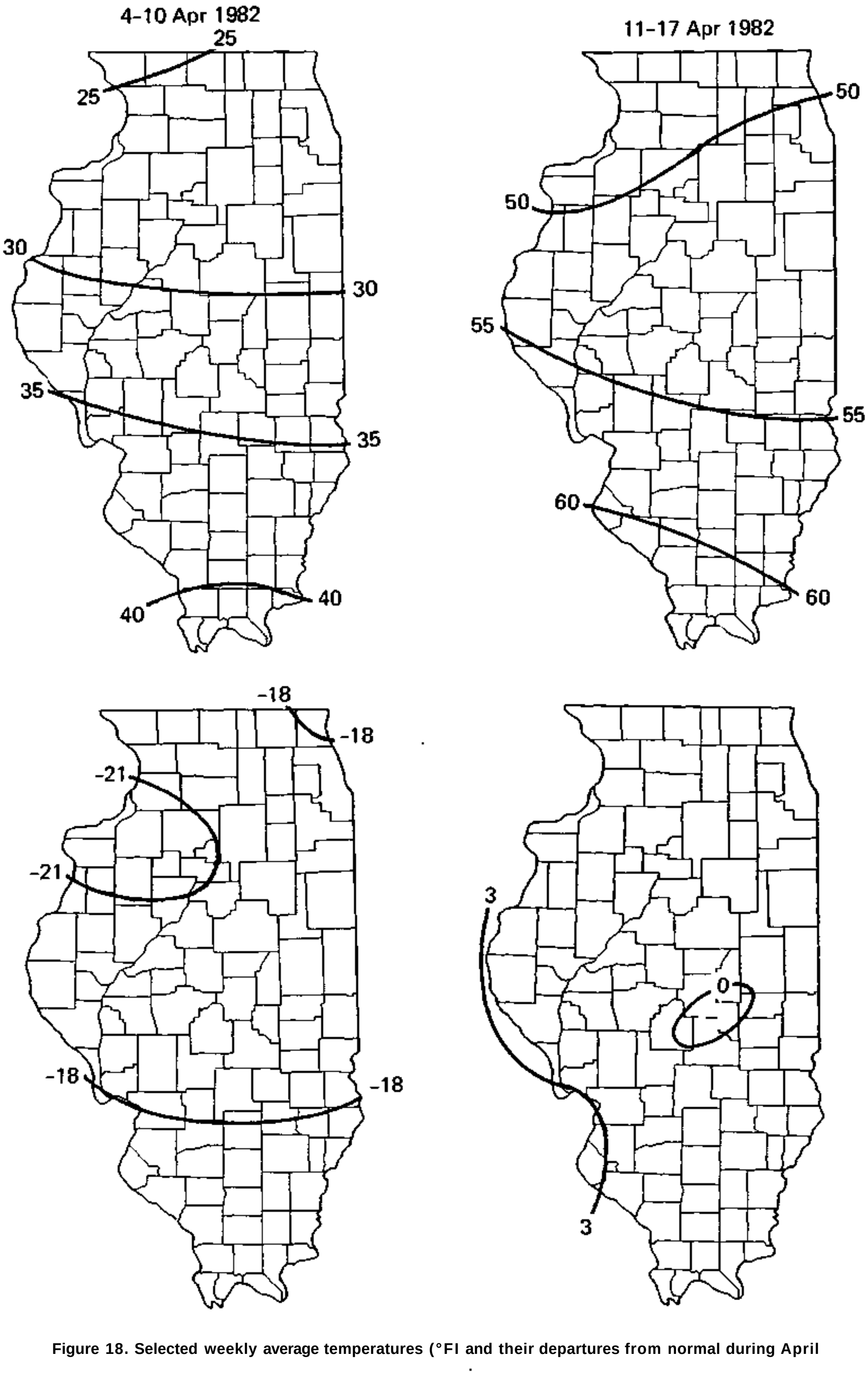


Figure 18. Selected weekly average temperatures (°FI and their departures from normal during April

or south to cause major precipitation or storms over Illinois. As a result, the only major storms in Illinois were the two snowstorms in early April and the rainstorms of 15-16 April.

Predictions of Flooding and Future Precipitation

In mid February 1982, the National Weather Service (NWS) issued its first "flood outlook" of the winter for various major rivers of Illinois. It indicated that there would be minor to moderate flooding in most Illinois rivers if normal spring rains occurred. The 19 March Spring Snowmelt Flood Outlook indicated that the snows had melted and no further flooding could be expected after the ongoing floods ended. Both of these NWS outlooks proved correct.

The State Water Survey issued monthly and seasonal precipitation outlooks at the end of January, February, March, and April 1982. These outlooks, as issued at the end of February 1982, appear in table 5. They were important because the degree of spring flooding (March and April) hinged on the spring precipitation: with normal or lower rains the flooding would be relatively minor, and with above normal rains the flooding would reach severe proportions.

Water Survey scientists have utilized their historical climate data base with their long-range prediction research to develop best estimates, or outlooks, for future precipitation in Illinois. Precipitation outlooks, although not perfect, offered guidance to local and state officials about critical spring water conditions.

The probabilities for March precipitation for four areas of Illinois are shown in table 5. Probabilities called for the most likely March precipitation values to be below normal. These reveal that the likelihood for below normal precipitation was 65% in northern Illinois and 50% in southern Illinois. Importantly, the probabilities for above normal precipitation

Table 5. Precipitation Outlooks and Actual Values for March and Spring 1982 in Illinois

Areas	*March 1982 outlooks*	*Actual*	*Spring 1982 (March-May) outlooks*	*Actual*
Northern*	<u>Below normal 65%</u> Near normal 20% Above normal 15%	Above normal	Above normal (11.7 inches or more)	Near (11.1") normal
North Central*	<u>Below normal 43%</u> Near normal 36% Above normal 21%	Near normal	Near normal (8 3 to 12.7 inches)	Near (12.6") normal
South Central*	<u>Below normal 50%</u> Near normal 35% Above normal 15%	Near normal	Near normal (8.2 to 14.2 inches)	Near normal (10.9")
Southern*	<u>Below normal 50%</u> Near normal 20% Above normal 30%	Below normal	Below normal (9.6 inches or less)	Below normal (9.5")

"<u>NORTHERN</u> = northwest and northeast crop districts, <u>NORTH CENTRAL</u> = west central and east central districts, <u>SOUTH CENTRAL</u> = west-southwest districts and east-southeast districts, <u>SOUTHERN</u> = southwest and southeast districts

in March, which would have compounded the flooding problem, are shown to have been small, being 30% in the south and 21% or less in the northern three-fourths of Illinois. The actual March departures are also shown. Above normal rain did fall in the northern fourth of Illinois. The outlook was perfect for southern Illinois, with a near miss (off by one class) in the north central and south central areas.

The seasonal outlooks for spring (March-May) precipitation in table 5 show only the most likely outcome. These reveal that below normal spring precipitation was the most likely value for the southern fourth of Illinois. Near normal precipitation was considered most likely in the north central and south central areas of Illinois, and above normal in the north. A comparison of the outlooks with the actual seasonal values in table 5 shows that 3 of 4 conditions were correctly forecast, and the above normal outlook in the north was close to the actual, or near normal, value. Research and subsequent testing have shown that the Survey's seasonal outlooks are correct between 60 and 65% of the time.

Importantly, the seasonal outlooks indicated precipitation levels favorable from the flooding standpoint. There was no indication of above normal spring rainfall in three-fourths of the state, and that was the outcome.

HYDROLOGIC ASPECTS OF THE FLOODS

Introduction

The four factors mentioned earlier (antecedent precipitation, snow cover, soil moisture, and ice jams) did not produce severe flooding, in terms of record flood heights, on Illinois rivers during the first four months of 1982. They did combine, however, to push some rivers in Illinois above flood stage for unusually long durations. Table 6 lists the number of days above flood stage and the peak discharges for the stream gages on the nine river basins shown in figure 19. Peak flood discharges for almost all the rivers had a frequency expected at least once every 2 to 5 years. The Kankakee River is the exception, where near record

Table 6. Peak Discharges and Duration above Flood Stage for Selected Illinois Rivers during January-April 1982

River	*Number of days above flood stage**	*Peak discharge, * cfs*	*Frequency return period, years*
Illinois River at Meredosia	>105	96,300	5
Des Plaines River at Riverside	2	1,710	<2
LaMome River at Ripley	>8	11,000	2-5
Kankakee River at Momence	17	13,700	>100
Rock River at Joslin	6	26,500	2-5
Little Wabash River at Carmi	27	20,000	5
Embarras River at Ste. Marie	14	21,500	5
Big Muddy River at Murphysboro	55	20,000	5
Sangamon River at Oakford	7	29,400	2-5

**Based on U.S. Geological Survey provisional data and National Weather Service Flood Statements*

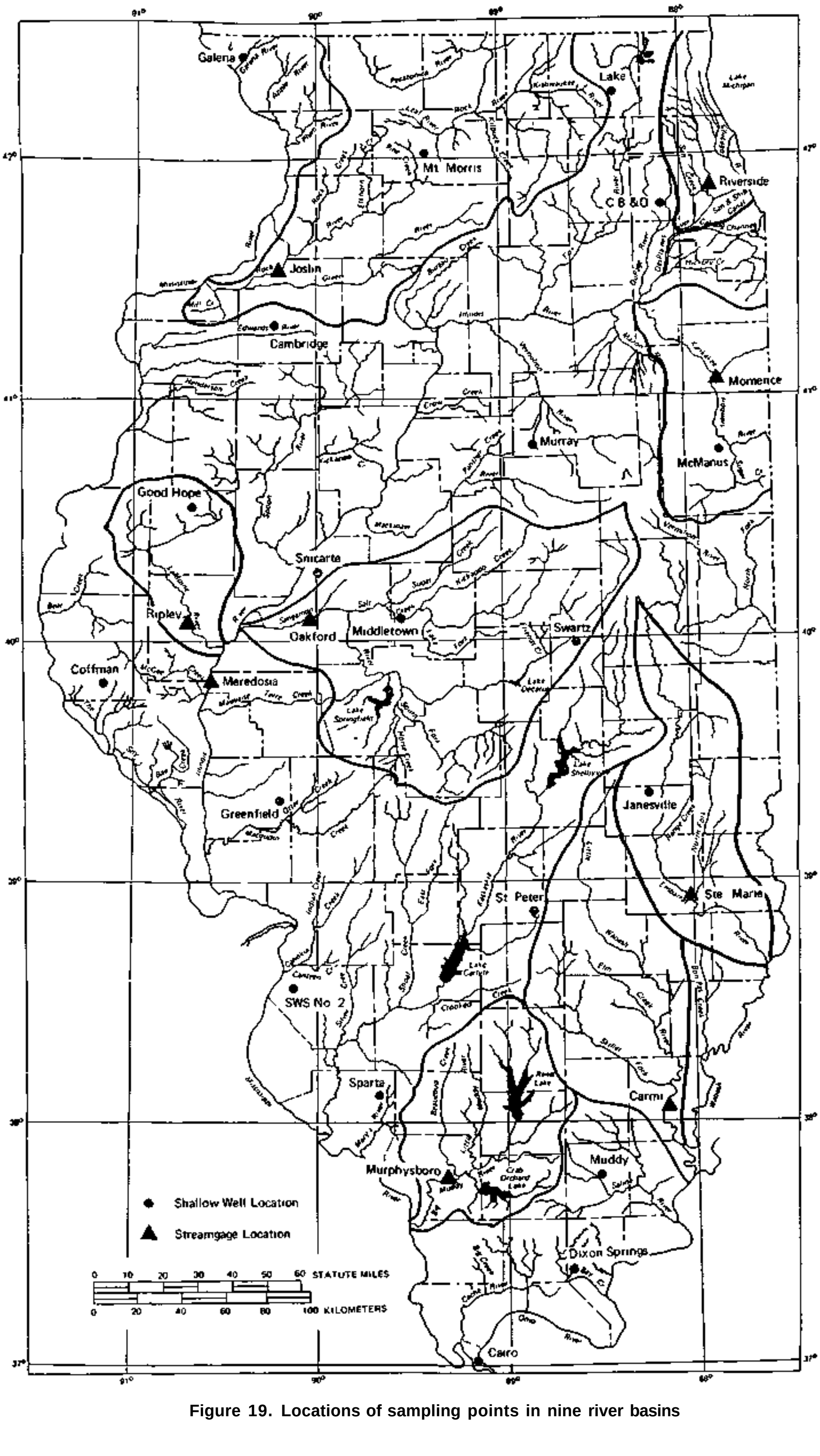


Figure 19. Locations of sampling points in nine river basins

stages occurred at an expected frequency of once in 100 years. The durations of river levels at or above flood stages for these rivers nearly equaled, or in some cases exceeded, previous historical durations.

The hydrologic aspects affecting streamflow in Illinois during the 1982 winter-spring flood season are examined in this section. This includes a discussion of streamflow and surface runoff conditions, groundwater storage, ice formation, and melting snow.

Runoff and Streamflow Conditions

As described earlier in this report, a contributing factor that produced the flood conditions during the early months of 1982 was the large amount of antecedent precipitation. In figure 20, the average monthly flows for the October 1981 to March 1982 period along six of the nine streams in figure 19 are shown. As can be seen from figure 20, prior to January 1982 most streamflow (except for the Big Muddy River) was at or above mean flow [based on USGS provisional data]. Mean flow indicates that over the entire record for a given month, streamflow is expected to be above or below the mean flow value half of the time. Given this initial streamflow, the subsequent rainfall and snowmelt during the first three months of 1982 pushed monthly average streamflows above that to be expected only 10% of the time or less. Rivers that were particularly high were the Kankakee, Sangamon, Des Plaines, Embarras, and Big Muddy Rivers. These high monthly average streamflows further indicate the long durations above flood stage for most rivers as noted in table 6.

Flooding during the late winter and early spring in Illinois is not an unusual phenomenon. Table 7 lists the distribution of the number of floods and number of days at or above flood stage for the 5-month period, January through May, for eight of the same nine rivers during the last 42 years of record. From 62 to 95% of all flood occurrences happen during the 5-month period between January and May. Between 63 and 95% of days at or above flood stage also occur then.

Whether or not the precipitation that falls on a basin eventually becomes runoff to streams, or instead infiltrates into groundwater storage, depends on several factors. The first

Table 7. Percent of Flood Events and Days above Flood Stage for the 5-Month Period January-May during the Period 1940-1982

Basin	*Percent of flood events**	*Percent of days at or above flood stage**
Illinois River at Meredosia	69(80/115)	75(1263/1689)
Des Plaines River at Riverside	67(31/46)	78(104/133)
LaMoine River at Ripley	62 (31/50)	63 (113/180)
Kankakee River at Momence	95 (19/20)	95 (21/22)
Rock River at Joslin	77 (52/67)	84 (393/463)
Little Wabash River at Carmi	77(130/169)	80(1435/1796)
Embarras River at Ste. Marie	73 (25/34)	75 (73/98)
Sangamon River at Oakford	65 (26/40)	77 (195/251)

**Tbe first number in parentheses shows the frequency during the January-May period, and the second number shows the total frequency in 1940-1982*

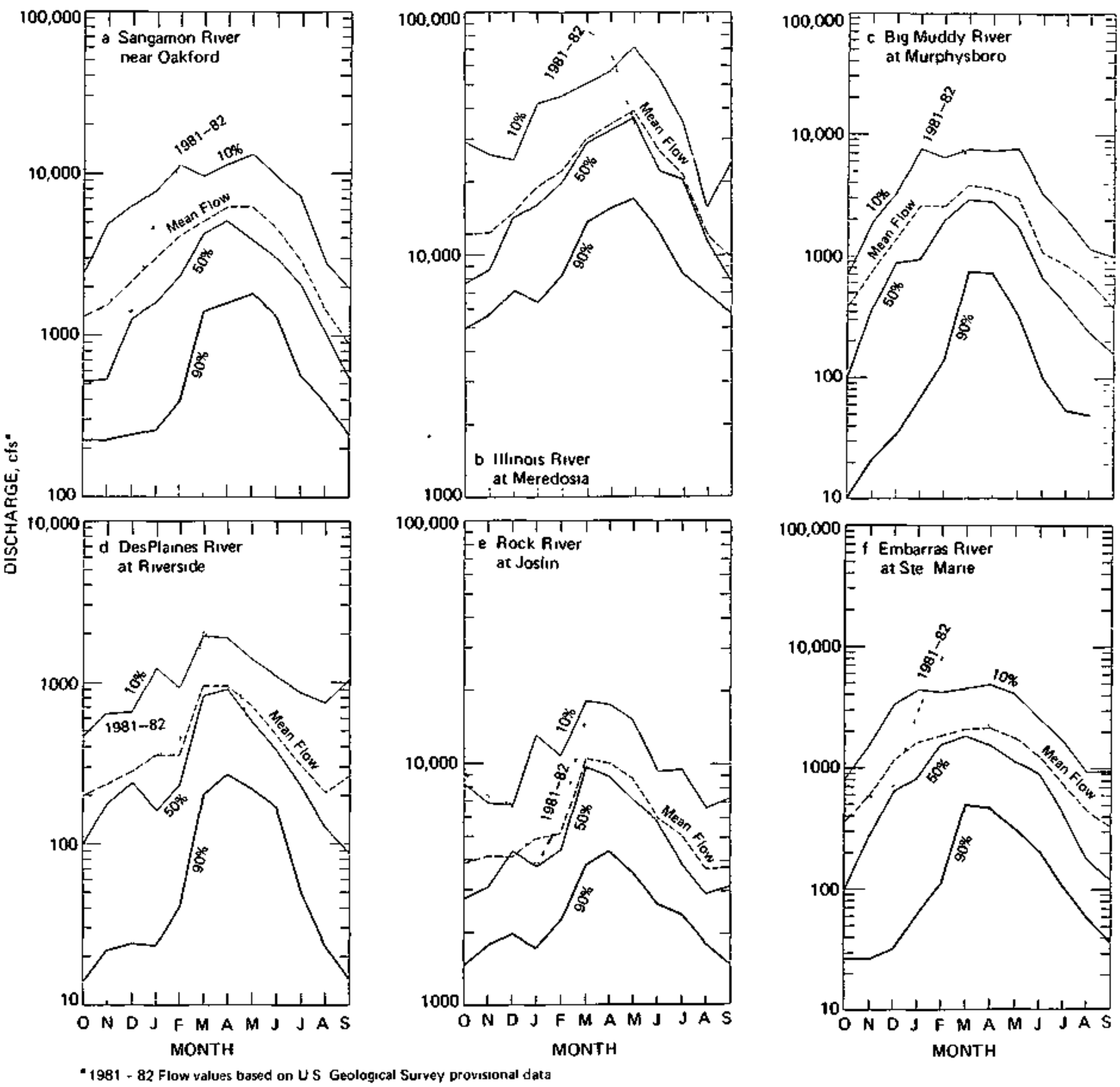


Figure 20. Average monthly streamflows

factor is the ability of a drainage basin to absorb and detain water that falls on it as rain or comes to it from melting snow. This is a key to understanding the surface runoff process. This characteristic is defined as the infiltration capacity of the basin. The infiltration capacity is the combined result of the interaction among many factors. The most important are precipitation intensity, soil moisture, thickness of the saturated layer of soil, vegetative cover, and temperature. As might be expected, the combined effect of all of these factors can produce conditions most conducive to runoff during the late winter and early spring months in Illinois. For instance, during the first five months of 1982, soils in all of Illinois were at or near field capacity (figure 2). Thus, they could not retain any more moisture through the surface down to about 3 feet. During this period, the lack of vegetation such as leaves on trees and row crops allowed nearly all the precipitation to reach the already saturated ground. The prolonged cold weather (table 1) further reduced the infiltration capacity of the soils by freezing them to depths ranging from 10 inches in the south to 30 inches in the north. This allowed little downward movement of water due to the inhibiting forces of the frozen water trapped within the soil.

The combined effect of the factors can be seen by examining the runoff ratio for a selected basin. The runoff ratio is the amount of runoff that reaches a stream divided by the amount of precipitation that falls on the basin. As an example, the monthly runoff ratio for the past 42 years of record is summarized in figure 21 for the Embarras River Basin. The upper curve indicates the runoff ratio for 1982. As would be expected, runoff ratios were highest during January, February, March, and April when hydrologic and climatological conditions are most suited for precipitation to become surface runoff.

The fact that runoff ratios during the first four months of 1982 [based on provisional USGS data] were higher than average indicates that the combination of saturated and frozen soils and lack of vegetative cover allowed more of the available precipitation to reach the river than would normally be expected. The fact that the runoff ratio for February was greater than 1.0 indicates a large sustained baseflow contribution from 1) antecedent precipitation, and 2) the significant amount of water stored in the snow pack which was released during the February thaw.

The runoff ratio of other basins in Illinois exhibited similar results. However, basins in southern Illinois had their highest runoff ratios during early spring while those in northern Illinois had the highest ratio delayed due to the later spring thaw.

Groundwater Storage

Shallow groundwater levels throughout the state are monitored by a network of observation wells maintained by the Illinois State Water Survey (see figure 19). These wells are equipped with recording instruments which continuously register groundwater stage data.

Figure 22 is a series of groundwater hydrographs of four of the shallow observation wells. Each well represents groundwater conditions in a different section of the state: Mt. Morris, north; McManus, east; Good Hope, west; and Sparta, south (see figure 19). The hydrographs show water levels in feet below land surface. They have been constructed using these three data points in each month: a maximum depth to water, a minimum depth to water, and a random water level corresponding to the date the recording instrument was serviced.

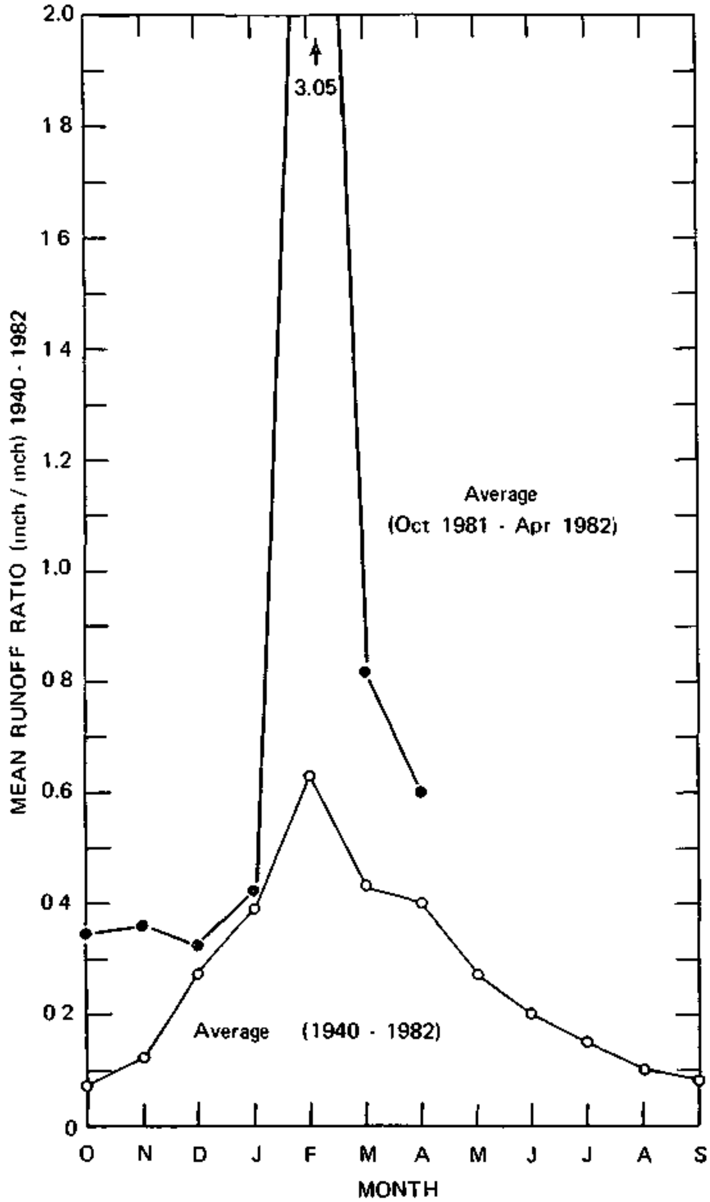


Figure 21. Mean runoff ratio vs month, Embarras River Basin above Ste. Marie

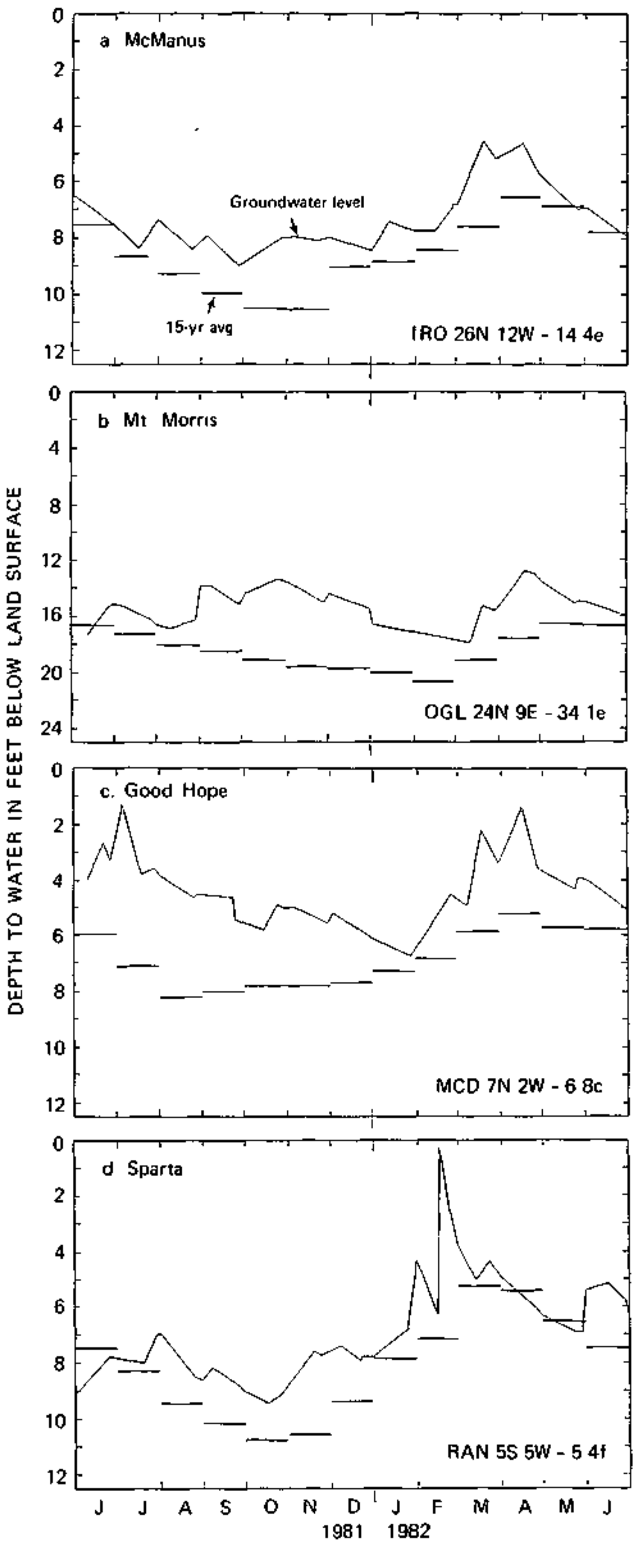


Figure 22. Groundwater hydrographs for representative observation wells

Additionally, each graph displays the running average, or normal, groundwater levels over the past 18 years for each month.

In June 1981, groundwater levels were in the process of recovering from drought conditions experienced in April 1981 and the prior 14 months (Changnon et al., 1982). Precipitation met or exceeded evapotranspiration and soil moisture requirements throughout much of the summer and into early fall, resulting in groundwater recharge. Often this recharge rate exceeded losses due to groundwater runoff to streams and underflow, the excess contributing to groundwater storage. This increase in storage could be observed directly as the water table rose.

By July 1981, shallow groundwater levels at the sites of most of the observation wells had returned to normal. Because of the recharge in summer and early fall, most statewide groundwater levels entered the late fall and early winter months well above normal, a situation that combined with other factors to produce the above average streamflows which were previously described. During the late fall and winter, groundwater recharge is minimized by frozen conditions such as those experienced during the cold winter of 1981-1982. Losses were limited to groundwater runoff (streamflow) and underflow as lack of plant life and growth held evapotranspiration losses to a minimum. Thus, groundwater levels normally decline slowly from late fall into winter until a thaw occurs. All of the observation well hydrographs (figure 22) show this gradual decline from late fall through winter until the late winter-early spring thaw. These hydrographs also show that even with the gradual decline of groundwater levels over the winter months, they still entered the thaw period at or above the normal state, thus still providing sizable baseflow to rivers and streams.

During the thaw periods, which occurred in the last half of both February and March, evapotranspiration losses were still minimal. Once soil moisture requirements are met, groundwater recharge need only exceed groundwater runoff and underflow for additions to storage to be made. The hydrographs clearly show that well sites all experienced additions to storage as 3- to 7-foot rises in the groundwater levels occurred. The Sparta observation well in the south displayed the largest and sharpest rise (about 7 feet), while the smallest rise (about 3 feet) occurred at the McManus well in the eastern part of Illinois.

In summary, the above normal groundwater levels in 1981 provided a significant baseflow contribution to antecedent (fall) streamflow of rivers in Illinois. Groundwater levels exhibited declines during the long period of cold winter weather, and the largest increases in water levels occurred during late February and early March, coinciding with the period of highest streamflow along the major Illinois rivers.

Ice Formation and Ice Jams

Ice flows tend to be a problem associated with rivers in northern Illinois. For the nine basins shown in figure 19, table 8 lists the number of years when the maximum annual gage height was the result of ice jams. Of the nine basins, the Kankakee, Des Plaines, and Rock Rivers experience significant ice jams. On the Kankakee River 34 of the *66* annual values were related to ice jams. In fact, 10 of the 12 highest river stages in the 66-year gage record were due to ice jams. Although ice jams produced the maximum yearly gage height only four times on the Des Plaines River, the three highest gage heights were caused by these events. Similarly, two of the highest five gage heights for the Rock River were due to ice

Table 8. Occurrence of Maximum Annual Gage Height due to Ice Jams

Gage	*Years of record*	*Number of maximum annual gage heights due to ice jams*
Illinois River at Meredosia	102	0
Des Plaines River at Riverside	89	4
LaMoine River at Ripley	60	6
Kankakee River at Momence	66	34
Rock River at Joslin	43	8
Little Wabash River at Carmi	41	0
Embarras River at Ste. Mane	66	0
Big Muddy River at Murphysboro	65	0
Sangamon River at Oakford	66	0

jams. Thus, for most rivers in northern Illinois, ice jams occur infrequently but tend to cause severe flooding when they do occur.

The formation of ice in a river begins with what is called frazil ice. These are tiny ice crystals which collect to form larger masses until a complete ice sheet is formed (Chow, 1964). Once frozen over, the stream no longer flows as an open channel. Instead, the flow characteristics take on the property of a closed conduit with the ice sheet forming a friction surface on top. This tends to reduce the hydraulic conveyance of the stream section. Rivers with high water tables contributing to streamflow may form very thick masses if the water table is high enough to reach above the ice surface. Since rivers in northern Illinois have large baseflow contributions, this could be a reason for the large ice jams that plague these rivers, along with colder temperatures in this part of the state.

When above freezing temperatures begin to produce rising stages during late winter and early spring, this induces cracks in the ice. Eventually the ice cover breaks up and moves with the stream. Once this process begins, the ice is removed quickly. However, encroachments in the river and the adjacent floodplain, such as bridges, tend to trap the floating ice. This was the case during February 1982 in Wilmington, Illinois, along the Kankakee River. An ice jam formed on the upstream side of the Route 53 bridge, and this forced the water to flow at higher levels around the bridge and through the town.

Ice on rivers not only increases the severity of flooding but also disrupts barge traffic along the Illinois and Mississippi Waterways. During the winter of 1982, a record 20 inches of ice was reported on the Illinois River at Peoria. Although the locks on the Illinois River did not close, traffic was curtailed.

Figure 23 displays the ice thickness at four lock and dam sites along the Mississippi River in the northern half of Illinois. Lock and Dam 22 remained open throughout the winter, but the other three locks closed when the ice thickness was from 7 to 10 inches. These three locks remained closed until March. This was the third latest opening date since records began in 1963.

Flooding due to ice jams is particularly important since it is largely ignored in standard flood frequency estimates that are based entirely on flood discharges. The probability of severe flooding is underestimated along rivers in Illinois subject to ice jams since the high

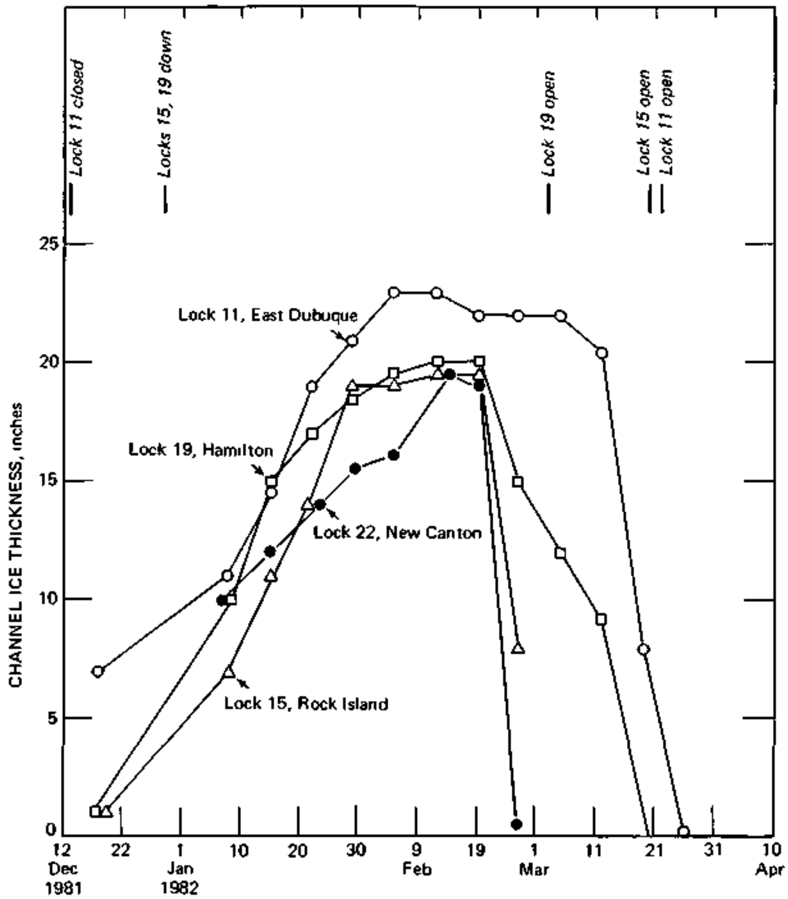


Figure 23. Ice thickness along the Mississippi River during winter-spring 1982

flood heights are not usually accompanied by large discharges. For example, along the Des Plaines River at Riverside, the peak discharge expected once in 100 years (100-year flood) is 7,890 cubic feet per second (cfs). This flow occurs at a gage height of 8.6 feet. This same gage height, however, has been exceeded twice since 1944 during ice jam events when the discharge was significantly lower than 7,890 cfs.

Influence of Melted Snow

Snowmelt was another condition that contributed to the flooding during late winter and early spring of 1982. The amount of snow cover and the extent of its melting are discussed in an earlier section. The presence of snow cover on a drainage basin greatly influences its runoff characteristics, especially when the melting process is accompanied by rainfall, as occurred during the early months of 1982. Snowmelt made a significant contribution to streamflow, a condition which was particularly evident during late February in central and southern Illinois, and during mid March in northern Illinois.

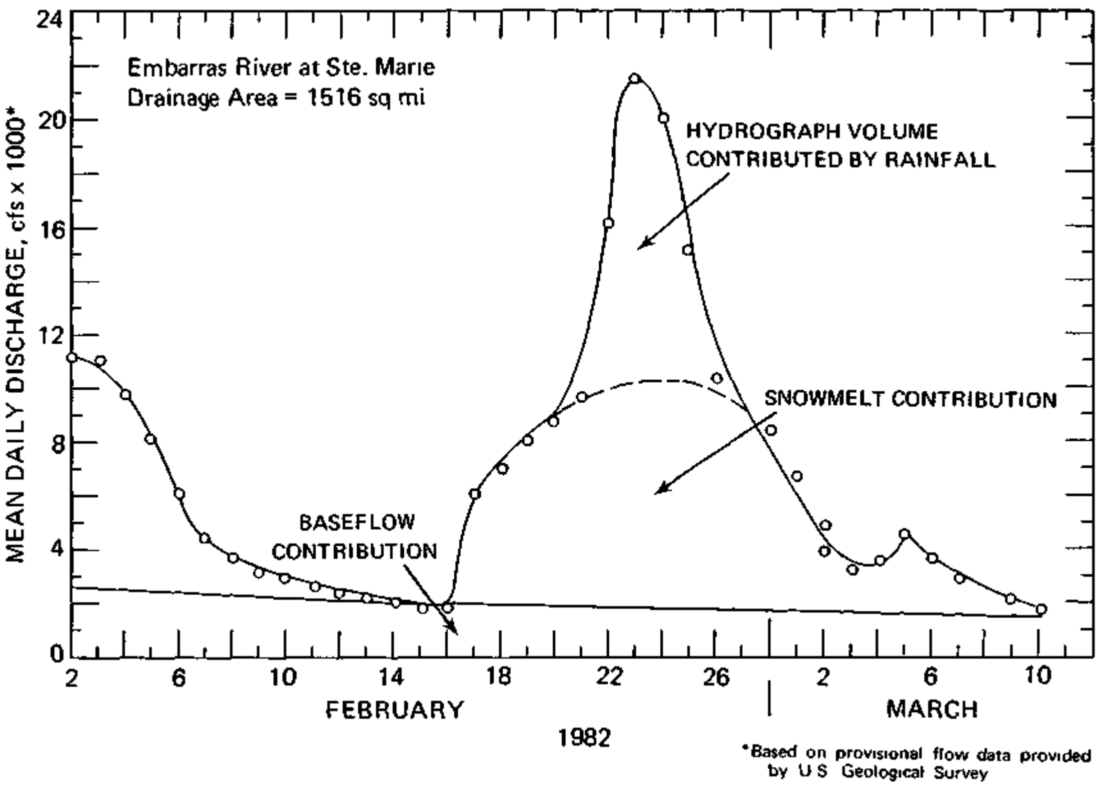


Figure 24. Hydrograph of mean daily discharge of the Embarras River in February-March 1982

The Embarras River was typical of the flooding which occurred in central and southern Illinois, except for some rivers in southern Illinois which experienced more severe flooding. The hydrograph of the mean daily discharge in figure 24 shows the river flowing at a fairly high sustained flow during early February 1982. This is the result of both heavy rains that fell during late January and groundwater outflow. These rains sent the river rising until cold weather and snowfall caused the runoff to recede during mid-February.

Figure 2 5 shows the snow depletion curves of the four snow depth measuring stations in the Embarras River basin. By comparing these curves with the discharge curve (figure 24) one notes that nearly half the snow depth had disappeared before the river began to respond. This is a typical response of a drainage basin to snowmelt since the slow melting process allows some water to be absorbed into the ground or to be evaporated. Soon the ground became saturated and the meltwater began to cause a gradual rise in the river stage, again typical of snowmelt runoff. High temperatures during the period averaged in the low 40's (°F) and daily low temperatures averaged in the low 30's throughout the basin. Most of the melt occurred from the conduction of warm air and radiant heat from the sun. (Some may have occurred due to the latent heat of vaporization when the dew point was above 32°F).

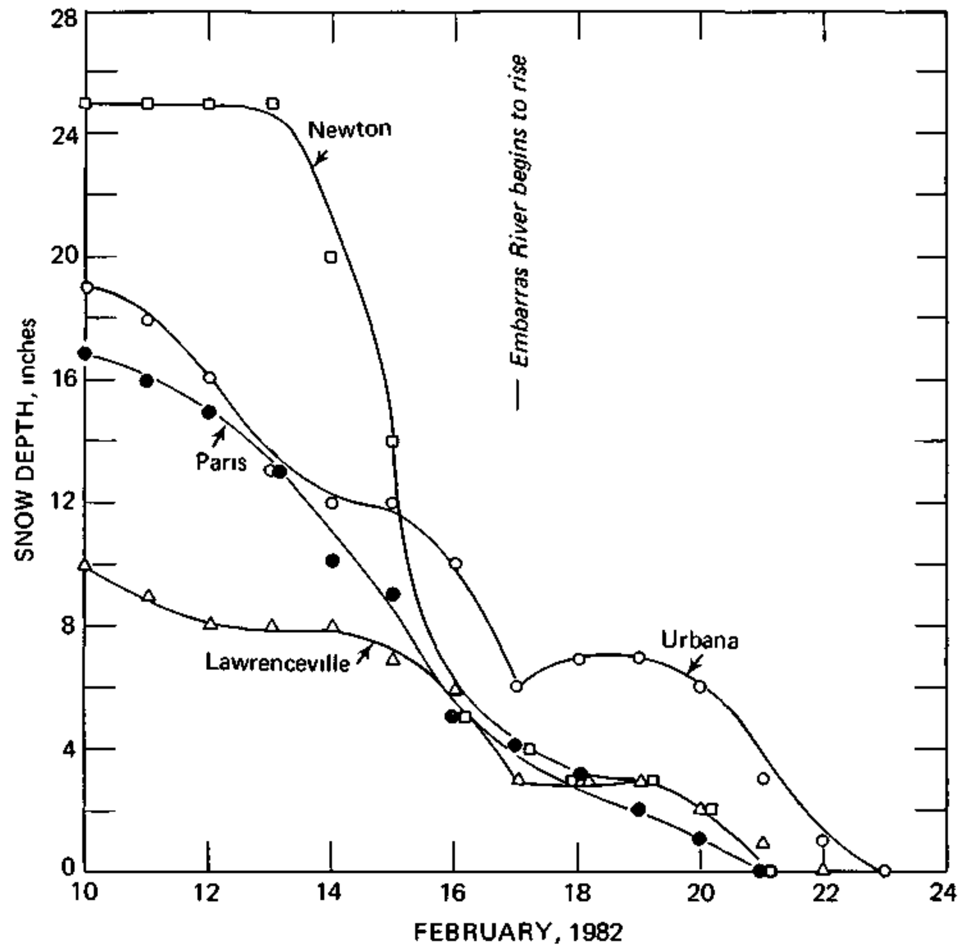


Figure 25. Snow depths in the Embarras River basin during February 1982

On 17-18 February, a mean rainfall of 1.01 inches fell over the basin. The response of the basin to this rainfall was immediate since the ground had become saturated with snow-melt. The dashed line on the hydrograph in figure 24 is an estimate of the separation of snowmelt and rainfall contributions to the hydrograph. The volume of runoff under the rainfall portion represents 0.87 inches of runoff from 1.01 inches of rainfall, or a runoff ratio of 87%.

Summarizing, it can be seen that the snowmelt provided' a large baseflow and that subsequent rainfall had a tendency to move quickly to the river.

This same situation occurred in the Illinois River basin during March 1982. The river levels were high from the melted snow of the mid February thaw. When a 5-8 inch snowfall during early March in northeast Illinois was followed by two periods of rainfall, the river began to rise, eventually cresting during late March.

IMPACTS OF THE FLOODING

General Impacts

The study of the impacts of the flooding events which occurred throughout Illinois during the January-April 1982 period was based on data and information in Water Survey files and from the newsclips of the *Illinois Daily Press Summary.* There were no lives lost, and the total value of losses was estimated at between $20 million and $25 million.

The impacts of the flooding were varied and would have been much greater had the flooding been more widespread. The major impacts occurred in three geographical areas. The first area impacted was extreme southern Illinois due to the heavy rain-induced floods that occurred in late January. The second related to the flooding in Kankakee and Will Counties due to ice jams in the Kankakee River during late February. A third series of major impacts occurred along the Illinois River during mid to late March, principally in the reach of the Illinois River from Beardstown upstream to Chillicothe (figure 19). There was also spring flooding along the Wabash River which brought minor impacts solely to bottomland farming areas in Illinois. Minor flooding along the Rock River did not produce any significant impacts.

The impacts due to the flooding have been organized around seven areas: 1) government agencies; 2) transportation; 3) households; 4) human health, safety, and anxiety; 5) business; 6) agriculture, and 7) the environment. Probably the greatest broad area of impacts related to local, state and federal government entities. The second important broad area of impacts related to those individuals who had to relocate because of the flooding.

Government Agencies

At the local level, a few sewage treatment plants were damaged and closed. At West Frankfort, the January floods produced $52,000 worth of damage to the sewage plant, and the plant at Wilmington sustained up to $1 million worth of damage in February. Anticipating the Illinois River floods in March, Pekin dismantled its Number One sewage treatment plant. The Herrin sewage treatment system backed up, resulting in raw sewage going into basements of several homes. The water plant was closed at Wilmington, and many communities were involved in boil orders for water in central and southern Illinois areas, where polluted flood waters were perceived to have affected the local water supplies. Water testing was performed by the Will County Health Department as a result of the late February floods in that area.

At the state level, a wide variety of impacts occurred. As the flood problems grew, the Governor established a Flood Task Force in February composed of representatives from the Division of Water Resources (DWR); the Emergency Services and Disaster Agency (ESDA), ENR/State Water Survey, the National Guard, and the State Police. In a news release on 19 February, ESDA predicted heavy flooding in Illinois. Excessive spring flooding did not occur in Illinois, but it was severe in certain locales. The National Guard was involved in sandbagging efforts in various parts of the state, and the State Police assisted in traffic control and maintaining local order in flooded communities such as Wilmington. The State Water Survey, DWR, and ESDA monitored the flooding and issued special public information releases during February and March reporting on the status of the flooding and on remedial actions. The Governor declared Will and Kankakee Counties as disaster areas on 26 February. This allowed three possible local actions: assessments of property value could be lowered for those damaged by flooding; ESDA could use state disaster assistance funds; and those with damages were eligible for federal aid. Then, on 23 March, in response to a plea from Peoria, the Governor declared Peoria County as a disaster area.

Important impacts on local, state and federal government agencies included financial losses such as public property losses along the Kankakee River. ESDA estimated that the total damages were $6.9 million due to damages to public bridges, sewers, buildings, and roads. The estimated analyzed losses for Kankakee County are of interest. These include: 1) $750,000 to the Kankakee State Park, 2) $125,000 due to damages at other Kankakee Valley state parks, 3) $80,000 to roads near Momence, 4) $75,000 to retaining walls at Momence, 5) $60,000 to buildings at Momence, 6) $75,000 to Iroquois River homes, 7) $60,000 to the river road along the Iroquois, and 8) $60,000 to farm fields. The total estimated loss due to the late February flooding along the Kankakee River, including the $6.9 million to public facilities, was $8.75 million.

The only federal agency that experienced major impacts was the U.S. Army Corps of Engineers. The Corps used two tug boats and a barge to help break up the ice jam on the Kankakee River in late February. A channel was cut north of Wilmington which helped lower the river level and remove the ice jam that had formed at a bridge. During 13-22 March the Corps of Engineers also distributed 120,000 sand bags along the Illinois River. They charged between 10¢ and 25¢ per bag, with costs being paid by local and state agencies.

Transportation

The flooding in southern Illinois and central Illinois brought closures of many roads and highways. Bridges were washed out in southern Illinois in late January. Damages to bridge pilings occurred along the Kankakee and Illinois Rivers, largely due to the very thick ice floes. Bridges, narrow areas, and/or sharp bends in rivers and the thick ice floes were frequently the causes of the local flooding because of the development of ice dams.

The ice and the flooding along the Illinois River had serious effects on barge traffic. On 1 March, it was reported that the barge traffic was badly jammed near Chillicothe. It took three barges three days to go 9 miles through what was effectively an ice gorge in a narrow 9-mile stretch of the river. Thirty-six other barges were totally blocked for 6 days.

Household Residents

One of the major impacts of flooding related to the relocation of persons in the lowland areas. The late January rainstorms and resulting flooding in southern Illinois brought relocations of residents of 75 homes in Marion, 17 homes in West Frankfort, and 7 in Harrisburg. Damages to residences in West Frankfort were estimated at $70,000.

The rapidly rising water in the Wilmington area on 22 February along the Kankakee River necessitated the evacuation of 40 families on 24 February. Then, a second ice jam caused 85 to be evacuated along the Kankakee River downstream from Wilmington on 1

March. In late March, 80 families were evacuated along the Illinois River. The Red Cross estimated that 72 houses were flooded on 22 March along the Illinois River between Peoria and Chillicothe.

Human Health, Safety, and Anxiety

There were no reported deaths due to the flooding. There were major concerns among the residents of Wilmington during late February from fears that the ice dam upstream of Wilmington might break before the one downstream could be opened. Such an event would have produced sizable and sudden flooding of the community. Concerns and costs due to damages to homes and automobiles existed in those parts of the state with major flooding. The principal concerns related to health were about polluted drinking water and homes flooded with sewage waters or flood waters. Cleansing and disinfection of houses were required for several hundred homes.

Business

Several businesses along the Kankakee River were flooded, principally at Wilmington and Momence. Certain businesses in low areas including two motels were flooded in southern Illinois. Of interest, a Chillicothe bank offered $800 interest-free loans to flood victims. Restaurants and other businesses along the Illinois River in the Peoria area were affected and some were closed during the two weeks of high water there.

Agriculture

Major effects of the floods pertained to lowland flooding of prime farm lands. This occurred along the Wabash River, principally north of New Harmony, Indiana. By late March, nearly 16,000 acres of prime farm land had been flooded along the Illinois River near Havana. The costs of damages were not reported. Some erosion likely occurred, as well as delays in spring planting.

Environment

One environmental impact of the floods related to the inability of several sewage treatment plants to handle the floods. Plants at West Frankfort and Wilmington were totally flooded, and there were major releases of untreated sewage into rivers. Soil erosion relating to the flooding undoubtedly occurred, due to both the heavy rainstorms in southern Illinois in late January and then the bottomland flooding.

SUMMARY

Flood Factors

The four factors that produced the spring 1982 flooding in Illinois were: 1) the antecedent precipitation and the heavy snowfall, 2) snow cover, 3) soil moisture, and 4) ice jams. In the broadest sense, the floods of winter-spring 1982 were a result of two weather conditions: above normal precipitation over several months, and below normal winter temperatures. Collectively, these acted to create the identified four factors. The ongoing trend to colder and wetter climatic conditions (Changnon, 1981) will likely bring more such flooding than in prior years.

The first input factor, *precipitation,* was high in Illinois for the 12 months preceding the spring of 1982 (table 1). The March 1981-February 1982 precipitation ranged from 9 to 28% above normal throughout the state, ranking as once in 35-year heavy 12-month totals in the central sections, and once in 5-year events in the south and north sections. The winter (December-February) precipitation was well above normal except in the northern third of Illinois. In the southern half of Illinois, the winter precipitation ranged from 13 to 44% above normal. Locally heavy rains in mid-March in central and northern Illinois brought flooding, as did a record January rainstorm in southern Illinois.

Snow cover was a second critical factor. Near record winter snowfalls occurred in the southern half of Illinois. Most of this accumulated because of the near record cold spell from mid-December to mid-February (temperatures averaged —6°F below normal). Snow depths in central Illinois reached record heights by 10 February, with 15 to 20 inches on the ground over about 14,000 square miles of central and south central Illinois. This largely melted as a result of 10 warm days, 15-24 February.

The third critical factor producing the flooding was the *soil moisture* situation. The heavy winter snowfalls, plus the heavy earlier summer and near normal fall precipitation, brought all Illinois soils to above or near field capacity. By early spring 1982 many soils were unable to retain any more moisture from the surface down to at least 36 inches. The soil also was frozen by late February to depths of 5 to 10 inches in the south, 10 to 20 inches in the central sections, and 20 to 30 inches in the north, further restricting the downward movement of moisture. Hence, the melting snow cover in the warm last half of February had only two directions to go. One was upwards as evaporation, which helped cause frequent and extensive fogs in the state in February. The second and most major direction of the snowmelt water was runoff.

The fourth factor influencing the 1982 flooding was the ice cover on the rivers and the development of *ice jams,* such as occurred in the Kankakee River near Wilmington in late February. The near record low temperatures for two months led to considerable ice cover. The thickness of ice on the Illinois River at Peoria was at an all time record of 20 inches. The melting and dispersion of this ice had a major influence on local floods along the Illinois River in March and early April.

Implications

The actions of local, state, and federal agencies and volunteer service groups relating to the floods of 1982 can be characterized within four general areas of activities: 1) preparedness, 2) flood warning, 3) emergency responses, and 4) recovery and restoration. A review of these 1982 actions in Illinois has implications for planning and actions relating to future floods.

In the *preparedness area,* Illinois follows federal procedures for floodplain information, as related to the National Floodplain Insurance Program. The State Water Survey maintains a Floodplain Information Repository. The Survey also issues seasonal outlooks for precipitation which can be used to become better prepared for flooding in the next 30 to 90 days. The Division of Water Resources of IDOT monitors the flow of Illinois rivers on a day-to-day basis, and is prepared to detect incipient flood events. ESDA and the Department of Commerce and Community Affairs (DCCA) react to natural hazards and provide information about preparing for such events. However, there is no state preparedness plan for floods.

One can expect that local government agencies have different views about flood preparedness than do state agencies. Leaders in most local municipal governments change often and thus knowledge and concepts of preparedness are difficult to maintain. State agencies which have a greater permanency of personnel are better able to cope with flood preparedness concepts.

Another apparent emerging flood preparedness issue relates to the changing climate. With a shift to colder winters and more snow (Changnon, 1981), and the greater development of river ice, winter-spring flooding will increase (Changnon, 1983). Experiences in 1982 indicate a lack of awareness among local, state and federal agencies about what to do about thick ice, ice flows, and ice dams on major rivers. Equipment and experienced personnel will be needed to deal with the emerging and more frequent ice-related flood problems. Since 1921, the winter precipitation in Illinois has increased 5% and temperatures have decreased 16%. As a result, the duration of winter-spring floods has increased 43% during the 1921-1980 period, with the greatest increases in the northern third of the state (Changnon, 1983).

The second phase, *flood warning,* relates to two types of warnings. Institutional roles of issuing flood outlooks and warnings may need clarification. There is the long-range outlook (that is, "spring flooding is likely within the next few weeks") versus the short-range flood warning which is issued on an hour-day basis, with recommendations for area evacuation. The National Weather Service (NWS) issued a flood "outlook" on 12 February for Illinois. It called for minor to moderate flooding, which proved to be generally correct. Minor flooding is defined by rivers just topping the flood stage.

Reactions to NWS warnings must be done at the local level, frequently with local officials involved in and responsible for the distribution of the warning to those in danger. One cannot depend on the TV and radio media. Flood warning activities can include 1) the federal efforts (National Weather Service) outlooks and warnings, 2) the state efforts such as DWR alerts for short-term actions, and 3) the outlooks based on Water Survey long-range predictions. Local officials must deal with the translation of the federal-state short-term warnings for dissemination to the local endangered residents who may need to be evacuated. Study of the winter-spring 1982 floods in southern Illinois in January, and those along the

Kankakee River in February, revealed the lack of adequate long-range (weeks to months) flood outlooks for these areas. The fact that there was no loss of life indicated, however, that at the local scale, evacuation of endangered residents was handled well, at least on the time scale involved in the winter-spring floods.

The 1981 Illinois State Water Plan recommends a "Climate Detection and Advisory Board" which would have the role of monitoring incipient climate extremes, including flood conditions, weeks to months in advance, and of issuing outlooks. This activity needs implementation. It appears likely that the state needs winter-spring season runoff models, at the operating level, which can incorporate various levels of predicted precipitation and temperatures.

The third area of flood activities relates to *emergency responses.* Here we deal with local, state, and federal entities, as well as volunteer groups such as the Red Cross, plus the news media. A limited assessment of the role of the news media in the 1982 floods indicates that they transmitted useful and correct information to endangered residents at the time of the floods, as well as immediately after the floods when there was need for information about water treatment and related matters.

There was considerable confusion at Wilmington in late February during the flooding. DWR did send out information manuals to alert city officials in Illinois, and held meetings in the Wilmington area. Emergency responses need to be better coordinated and to involve several state agencies. This points to the need to have a state plan relating to flooding responses.

The U.S. Corps of Engineers also became involved. They used their equipment to break the ice flows on the Kankakee River, and provided sand bags for use along the Illinois River. The Red Cross also participated and aided in the Wilmington and Peoria area floods. The Governor appointed a Flood Task Force which should have been in operation before late February. A state flood contingency plan should be developed, possibly with a permanent flood mangement board of state agencies including ESDA, the National Guard, the State Police, the Division of Water Resources, and the State Water Survey. It would seem appropriate that in major floods, an emergency operation center should be established to coordinate flooding responses and to help inform those endangered and damaged.

The *recovery and restoration* activities are as yet not very well documented. The Governor declared Kankakee and Will Counties, and subsequently Peoria County, as disaster areas. These declarations provide benefits and potential assistance to damaged local residents. This may be adequate in light of the moderate floods.

This assessment points to the need for a comprehensive flood contingency plan for Illinois. Local, state, and federal roles need to be defined for the preparedness, warning, emergency response, and recovery and restoration phases. A reaction approach to flooding is frought with confusion, waste, and lack of attention to those who need to be protected and served.

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REFERENCES

Changnon, S. A. 1980. *Removing the confusion over droughts and floods the interface between scientists and policy makers.* Water International, 5(2):10-18.

Changnon, S. A. 1981. *Changing climate or not, weather extremes cost money* Illinois Issues, 5:19-20.

Changnon, S. A. 1983. *Trends in floods and related climate conditions in Illinois.* Submitted for publication in Climate Change.

Changnon, S. A., G. Achtemeier, S. Hilberg, V. Knapp, R. Olson, W. Roberts, and P. Vinzani. 1982. *The 1980-1981 drought in Illinois causes, dimensions, and impacts.* Illinois State Water Survey Report of Investigation 102, 113 p.

Changnon, S. A., Jr., and D. Changnon. 1978. *Record winter storms in Illinois, 1978-1979* Illinois State Water Survey Report of Investigation 88, 23 p.

Changnon, S. A., Jr., D. Changnon, and P. Stone. 1980. *Illinois third consecutive severe winter, 1978-1979.* Illinois State Water Survey Report of Investigation 94, 36 p.

Chow, V. T. 1964. *Handbook of Hydrology,* Chapters 10 and 16. McGraw-Hill, New York.

Dickson, R. R. 1982 *Weather and circulation of February 1982 — a highly variable month over the United States* Monthly Weather Review, 110:446-451.

Hendrie, L. K. 1981. *Illinois solar weather program.* Illinois State Water Survey Contract Report 276, 41 p.

Hilberg, S., P. Vinzani, and S. A. Changnon. 1983. *The severe winter of 1981-1982 in Illinois* Illinois State Water Survey Report of Investigation 104.

Huff, F. A. 1981. *Hydrometeorology of heavy rainstorms in selected Illinois basins.* Illinois State Water Survey, Report of Investigation 96, 91 p.

Huff, F. A., and S. A. Changnon. 1961. *Severe rainstorms in Illinois, 1958-1959.* Illinois State Water Survey, Report of Investigation 42, 70 p.

Huff, F. A., R. G. Semonin, S. A. Changnon, and D.M.A. Jones. 1958. *Hydrometeorological analysis of severe rainstorms in Illinois, 1956-1957, with summary of previous storms.* Illinois State Water Survey Report of Investigation 35, 79 p.

Illinois State Water Survey. 1979. *Floodplain information assistance.* 5 p.

Singh, K., and A. Snorrason. 1982. *Sensitivity of outflow peaks and flood stages to the selection of dam breach parameters and simulation models* Illinois State Water Survey Contract Report 289, 179 p.

Task Force, State Water Plan. 1982. *1981 progress report, Illinois State Water Plan.* Division of Water Resources, Illinois Department of Transportation, Springfield, IL, 202 p.

Taubensee, R. E. 1982. *Weather and circulation of December 1981 — dryness alleviated overthe southwest.* Monthly Weather Review, 110:230-236.

Wagner, A. J. 1982. *Weather and circulation of January 1982 — a stormy month with two record cold waves.* Monthly Weather Review, 110:310-317.

Winston, J. S., 1982. *The climate of spring 1982 — a season of abnormally strong subtropical westerlies.* Monthly Weather Review, 110:1729-1744.

Zishka, K. M., and P. J. Smith. 1980. *The climatology of cyclones and anticyclones over North America and surrounding ocean environs for January and July 1950-77.* Monthly Weather Review, 108:387-401.