PHYSICAL ENVIRONMENT

Climate, geology and soils affect the availability of surface-water and ground-water resources. Climatic factors largely determine the amount of available precipitation in the basin. Geologic and soil factors determine the proportion of precipitation which runs off the land to become surface water, as opposed to that which infiltrates the soil and *percolates* through underlying materials to become ground water. Geology and soils also determine surface drainage characteristics, the vulnerability of *aquifers* to contamination, and the limits of ground-water development.

CLIMATE

Water availability and use in the Kankakee River Basin is directly linked to the regional climate, which is the long-term composite of daily weather events. The climate of the basin is broadly classified as temperate continental, which describes areas located within the interior of a large continent and characterized by warm summers, cool winters, and the absence of a pronounced dry season.

Precipitation and temperature throughout the basin vary considerably on a daily, seasonal and yearly basis. This variability is primarily the result of interactions between tropical and polar *air masses*, the passage of low-pressure systems, and the shifting location of the jet stream, a powerful air current about 6 miles above the land surface.

Water, topographic and land-use features in northwest Indiana produce unique climatic variations in parts of the Kankakee River Basin. As discussed later in this section under the subheading ***Lake Effect***, the most widespread and well-documented modifications of the basin's climate stem from its position relative to Lake Michigan.

Areas in the main Kankakee River valley south of the Valparaiso Moraine experience greater-than-normal temperature fluctuations and a shorter frost-free crop-growing season because of the low-lying terrain and the poor heat retention of sand, muck and peat soils. This land-based feature is described later in this section under the subheading ***Growing Season***.

An unusual precipitation record at LaPorte may be linked to urban-induced weather modifications originating from the Chicago-Gary metropolis, but the validity of the anomaly remains debatable (see box on next page).

Sources of climatic data

Most climatic data for Indiana are collected and analyzed by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). The agency gathers data from more than 100 Indiana stations belonging to one or more of three networks (climatic, hydrologic or agricultural).

Temperature and precipitation data from the **climatic** network are primarily intended to represent long-term conditions over large areas of uniform terrain and climate. Rainfall-intensity data collected from the **hydrologic** network of recording precipitation gages are used for river forecasting, flood forecasting and related planning purposes. (About two-thirds of these recording gages are co-located with non-recording gages belonging to the climatic network.) Data on precipitation, air and soil temperature, relative humidity and other parameters are collected at **agricultural** stations. All but two of these agricultural stations also belong to the climatic or hydrologic networks, or both.

At most NWS stations, precipitation and/or temperature data are collected once daily by observers who typically are employed by water utilities, wastewater facilities, industries, municipalities or agribusiness. More detailed meteorological data are collected at the 24-hour NWS offices at Indianapolis, South Bend, Ft. Wayne and Evansville. The NWS Midwest Agricultural Weather Service Center at Purdue University also collects and maintains detailed meteorological records, including hourly updates of weather and soil conditions at automated agricultural stations throughout the state.

Figure 8 shows the locations of official NWS stations in or adjacent to the Kankakee River Basin in Indiana. Table 8 presents selected information for these stations and additional stations located within 8 miles of the basin boundary. The 8-mile limit was selected primarily for convenience rather than meteorological considerations.

Climatic stations in and near the Illinois portion of the Kankakee River Basin are not listed in table 8 or

LaPorte anomaly

Although the greater-than-normal snowfall amounts at LaPorte and other areas in the Lake Michigan snowbelt can be attributed directly to lake-effect processes, the causes of LaPorte's so-called rainfall anomaly have not been conclusively determined. Since the publication of papers by Stout (1962) and Changnon (1968a), the climatological record at LaPorte has been cited widely as evidence of urban-related increases in convective precipitation and storm events. The validity of the alleged anomaly, however, has been questioned by those who attribute the unusual precipitation record to poor gage exposure or observer error.

Changnon (1968a) showed that from about 1925 to the mid-1960s, LaPorte experienced 1) increases in annual and monthly precipitation totals during the warm season of April through October, and 2) increases in the frequency of moderate to heavy rain days, thunderstorms and hailstorms. He presented evidence that the large metropolis and industrial activities in the Gary-South Chicago area, particularly the smoke and haze emanating from the area, may be responsible for increased summer precipitation downwind in LaPorte.

The LaPorte findings focused scientific interest on the controversial subject of inadvertent weather modification, which generally refers to artificially induced changes in weather occurring over fairly small geographic areas and under certain atmospheric conditions. The cumulative effect of these modifications over many years can potentially result in local or regional climate changes.

Throughout the 1970s, the Illinois State Water Survey and many other investigators conducted detailed studies of urban-related weather impacts in Chicago, St. Louis, Detroit, Cleveland, Houston, New Orleans, Washington, D.C. and other large cities. A brief summary of research projects and an extensive list of references are presented by Changnon and Semonin (1979). Additional results of studies conducted in the Chicago area have been published since that time (Changnon and others, 1979; Changnon, 1980a, 1980b).

Although the degree to which atmospheric processes originating over Chicago may influence LaPorte's rainfall remains debatable, the existence of urban-induced weather modification is well documented and is largely accepted by the scientific community. In general, large cities experience more clouds or haze than rural areas, more summer convective storms (including hailstorms and thunderstorms), and higher average temperatures. These differences result primarily from (1) the addition to the atmosphere of microscopic particles that serve as nuclei for the formation of tiny water droplets or ice crystals, and (2) the addition of heat from streets, buildings and other surfaces.

The existence of a precipitation anomaly at LaPorte during the 1930s to 1960s is supported by not only meteorological but also geophysical, economic and crop-yield data (Changnon and others, 1979). Moreover, Hidore (1971) established a correlation between rainfall data recorded at LaPorte and stream-flow data recorded on the Kankakee River at Davis.

Despite the documented evidence for urban-induced rain changes at LaPorte, the true existence of the anomaly was questioned throughout the 1970s (Holzman and Thom, 1970; Holzman, 1971a, 1971b; Maxwell, 1975; Machta and others, 1977). Critics typically discredited the precipitation record at LaPorte because of suspected observer bias, improper observational techniques, change in station location, or change in precipitation reporting procedures.

It is interesting to note that more than 10 years before discussions of the local precipitation anomaly appeared in the scientific literature, published weather records contained comments regarding the possibility of a non-representative gage location at LaPorte. The average annual precipitation of 50 inches for the 18-year period between 1931 and 1948, for example, exceeded averages of other basin stations by 12 to 15 inches (National Oceanic and Atmospheric Administration, [1958]).

Later data summaries for LaPorte did not contain any qualifying statements, but 30-year averages continued to be significantly higher than averages at nearby locations. The most recent 30-year average of 41.6 inches is at least 4 inches more than averages at other stations in and near the Kankakee River Basin (table 9).

This unusually high average of 41.6 inches can be partially attributed to the extremely high precipitation totals recorded in 1954 (71 inches) and 1959 (66 inches). Moreover, annual amounts of at least 45 inches were recorded in 1951, 1955, 1957, 1958, 1961 and 1968. However, the accuracy of these annual totals remains questionable.

The debate over the existence of the LaPorte anomaly was further complicated when the rain gage was relocated in 1967 and the station was moved in 1970. Changnon and Huff (1977) postulated that the LaPorte anomaly was fallaciously ended when the gage was moved to a poor exposure, which subsequently yielded erroneously low rainfall readings. The 30-year average for the period 1951-80 shown in table 9 thus encompasses two periods, one of questionably high values and one of questionably low values.

In any case, the LaPorte anomaly has not been detectable since the 1960s. Causes for its disappearance or lack of detection do not appear to be related to alterations in urban influences. Instead, climatological evidence indicates that meteorological conditions resulting from changes in general circulation patterns could have produced a temporal and/or spatial shift in the anomaly to an ungaged area over Lake Michigan (Changnon, 1980c).

shown in figure 8. However, precipitation and temperature data are available for the following locations in Illinois: Crete and Peotone in Will County; Kankakee in Kankakee County; Watseka in Iroquois County; and Hoopeston in Vermilion County. Data from any of these five stations in northeastern Illinois can supplement data collected in northwestern Indiana. The general locations of these stations are apparent in figure 4.

Climatic data collected at NWS stations are published in a variety of formats by NOAA's National Climatic Data Center (NCDC) in Asheville, North Carolina (see Hatch, 1983). Most of the data presented in the following pages were obtained from tabular summaries for

Indiana stations (National Oceanic and Atmospheric Administration, 1976, 1982a, 1982b, 1983a, 1984, 1985). The data in four of these source documents encompass the most recent climatic base period, 1951-80. A 30-year period ending on the decade is used by NOAA to evaluate climatic conditions and to calculate climatic *normals* (National Oceanic and Atmospheric Adminstration, 1983b).

Data are available from the NCDC on a monthly and annual basis in several serial publications, including three entitled ***Climatological Data***, ***Hourly Precipitation Data***, and ***Local Climatological Data***. Additional data are available in other serial and periodic publications.

A vast array of climatic data and climate-related products also are available at the Midwestern Climate Center, a federally funded regional center located at the Illinois State Water Survey in Champaign, Illinois. The center collects, analyzes and disseminates climatic data for nine midwestern states, including Indiana. Some databases and special data products are oriented toward agriculture and water resources, and could therefore be of benefit to water management applications in the Kankakee River Basin.

Unpublished daily and monthly precipitation data are collected at official NWS stations recently established at North Liberty, Knox, Fair Oaks, and Morocco. In addition, unpublished daily and monthly precipitation data are available from the NWS forecast office in Indianapolis for several unofficial stations in and near the Kankakee River Basin. Data from unofficial stations are collected by amateur radio operators as part of a statewide volunteer network used to enhance the NWS river and flood forecasting program. Data from this network would be of limited use for most water management applications because the network is modified often and the data are filed only on a temporary basis.

The Indiana Department of Natural Resources, Division of Water operates a network of precipitation stations in Indiana, including five stations in the Kankakee River Basin (figure 8). Data from these stations are used for hydrologic and hydraulic studies. Precipitation records are filed for an indefinite period at the division.

Climatic features

Although the climate of the Kankakee River Basin encompasses variations in wind, clouds, humidity, solar radiation and other elements, the following sections focus on variations in precipitation, temperature, and *evapotranspiration*. Precipitation is the source of fresh water occurring on or below the land surface. Temperature defines the frost-free growing season for most crops, and largely controls the process of evapotranspiration, which consumes about 70 percent of the average annual precipitation in northern Indiana.

The discussion of climatic features is intended to present an overview of the basin's climate rather than to provide detailed data for site-specific planning or design work. Moreover, the discussion does not address long-term climatic changes or future trends. Additional data for specialized applications can be found in references cited in the text.

In some regional summaries of climate, data are grouped and analyzed on the basis of geographic areas having homogeneous climate. The U.S. Department of Agriculture has divided Indiana into nine crop-reporting districts, which are synonymous with the nine climatic divisions defined by NOAA.

In the following sections of this report, however, summaries of precipitation and temperature for the Kankakee River Basin are derived from analyses of station data for Kentland, LaPorte, Plymouth and Wheatfield. These stations are located within the basin boundary and have at least 30 years of data record. Data for Rensselaer are not included in the discussion because published climatic summaries are not available (table 8, column 6).

Because the historical precipitation record at LaPorte has been of questionable accuracy (see box on previous page), precipitation amounts at Valparaiso and South Bend are included in some analyses. Both cities are located within 2 miles of the basin boundary and data from these stations are considered to be representative of climatic conditions in the northern basin. Moreover, South Bend, like LaPorte, lies within the major snow belt associated with Lake Michigan.

Lake effect

The presence of Lake Michigan produces unique climatic conditions in northwestern Indiana, including modifications of temperature, humidity, cloudiness,

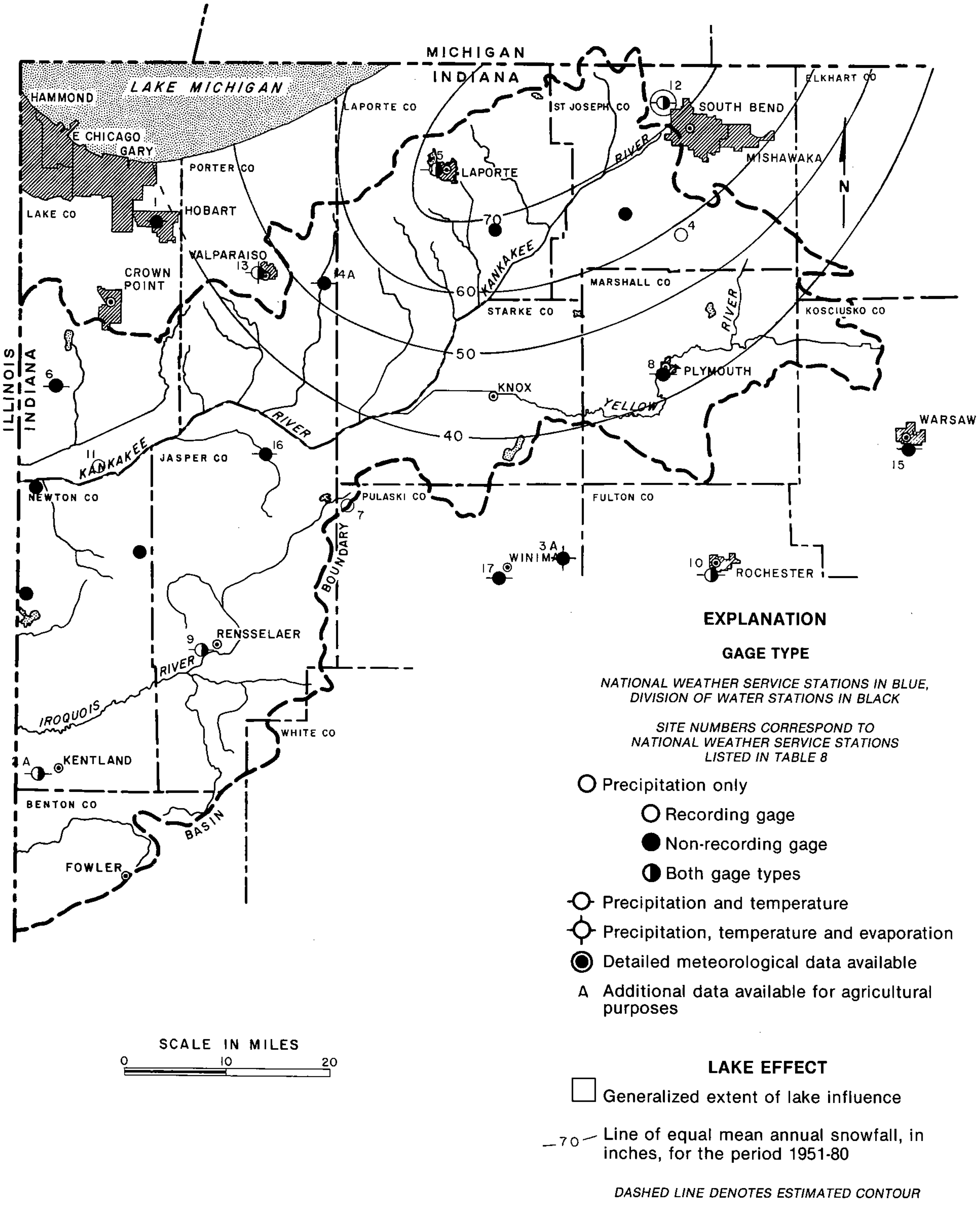

Figure 8. Location of climate stations, extent of lake effect, and mean annual snowfall in and near the Kankakee River Basin

Table 8. National Weather Service stations in and near the Kankakee River Basin

Map number: Station locations are shown in figure 8.

Station: Only active stations are tabulated. Historical data for discontinued stations in Indiana are available for Culver, Fowler, Michigan City, University of Notre Dame, and Winona Lake, all of which were located either in the basin (Fowler) or within 8 miles of the basin boundary.

Data network: A, climatological network and/or B, hydrologic network (National Weather Service); AG, agricultural network (Purdue University).

Data type: P, precipitation; T, temperature; E, evaporation and wind; S, soil temperature; D, detailed data on a variety of parameters. Additional agricultural-related data are collected at Kentland, Kewanna, and Wanatah, but are not published by the National Oceanic and Atmospheric Administration.

Publication, ongoing: Precipitation and/or temperature data are published monthly and annually by the National Oceanic and Atmospheric Administration in the following reports — CD, *Climatological Data* (precipitation amounts are from non-recording gages); HP, *Hourly Precipitation Data* (precipitation amounts are from recording gages); LCD, *Local Climatological Data* (detailed data published).

Publication, periodic: Climatological summaries are published every 10 years, generally at the end of a 30-year period. Numbers refer to footnotes.

Period of record: Approximate total length of precipitation record, through 1980 inclusive. Years of record are taken from 1980 annual summaries of *Climatological Data* and *Hourly Precipitation Data*. Hourly precipitation data may not be available for all years of record at hydrologic (B) network stations.

Map no.	Station name	Data network	Data type	Publication		Period of record	
				Ongoing	Periodic	Years	Dates
1	Hobart[1]	A	P,T	CD	2,3,4	61	1920-
2	Kentland	A,B,AG	P,T	CD,HP	3,4	41	1940-
3	Kewanna[1]	A,AG	P,T,E,S	CD	——	4	1977-
4	Lakeville	B	P	HP	——	39	1942-
5	LaPorte	A,B	P,T	CD,HP	2,3,4	86	1895-
6	Lowell	A	P,T	CD	——	18	1963-
7	Medaryville St. Nursery[1]	B	P	HP	——	39	1942-
8	Plymouth Power Substation	A	P,T	CD	2,3,4	76	1905-
9	Rensselaer[5]	A,B	P,T	CD,HP	——	84	1897-
10	Rochester[1]	A,B	P,T	CD,HP	2,3,4	67	1914-
11	Shelby	B	P	HP	——	40	1941-
12	South Bend NWSO[1,6]	A,B,AG	P,T,D	CD,HP,LCD	3,7	93	1888-
13	Valparaiso Waterworks[1]	A,B	P,T,E	CD,HP	3,4	81	1900-
14	Wanatah	A,AG	P,T,S	CD	——	20	1961-
15	Warsaw[1]	A	P,T	CD	——	72	1909-
16	Wheatfield	A	P,T	CD	3	63	1918-
17	Winamac[1]	A	P,T	CD	3,4	74	1907-

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[1] Within 8 miles of basin boundary in Indiana.
[2] National Oceanic and Atmospheric Administration, 1976.
[3] ________1982a, 1983a.
[4] ________1985.
[5] Located at Collegeville until July 1970.
[6] NWSO, National Weather Service Office.
[7] National Oceanic and Atmospheric Administration, 1982b.

wind and precipitation. The effects of Lake Michigan on local and regional climate are discussed in detail by Changnon (1968b), Changnon and Jones (1972), and Eichenlaub (1979).

Although modifications of climate by Lake Michigan are most pronounced within a mile or two of the shore, several lake-effect features extend about 25 miles inland. As figure 8 shows, this lake-effect area encompasses the northern part of the Kankakee River Basin, particularly the morainal areas lying north of the main river valley.

In general, northern parts of the Kankakee River Basin can experience warmer falls, cooler springs, higher humidity, increased winter cloudiness, and greater amounts of snow than other areas of comparable latitude. The most critical factor producing these and other climatic modifications is the lag in the warming and cooling rate of the lake's water surface relative to temperature changes of the adjacent land surface (Changnon and Jones, 1972).

The slower change in water temperature tends to moderate extremes in air temperature, a feature which typically is ascribed to a semi-marine climate rather than a continental climate. Although local lake breezes during summer reach only a mile or two inland, lake-induced changes in air-mass temperature can extend far enough south to help reduce the number of extremely hot or bitterly cold days in northern portions of the Kankakee River Basin.

Seasonal temperatures in northern parts of the basin also may reflect lake influences. Because the lake retains some of its summer warmth through midwinter, minimum temperatures during the fall and early winter are higher than in areas farther south. Conversely, the water retains its winter chill long after the land has thawed; hence, areas near the lake tend to experience maximum spring temperatures that are cooler than those in areas of comparable latitude.

Lake-effect clouds in the Kankakee River Basin most commonly occur in Lake, Porter, LaPorte and northwestern St. Joseph Counties, especially during the fall when the lake is warm relative to land. Depending on wind speed, wind direction and other weather conditions, large areas of the basin also may experience occasional periods of lake-induced cloudiness during the fall and winter.

Winter-season clouds and snow can develop near Lake Michigan when polar air gains warmth and moisture as it passes over the relatively warm water. As the warmed, moisture-laden air rises, it cools *adiabatically*. If the air is cooled to its condensation point, clouds, rain or snow may form.

Under certain weather conditions, an additional impetus for winter-season cloud formation and snowfall may be provided by frictional effects as the air passes over land, which can produce further lifting of the moist air. Another impetus for cloud formation and snowfall may be provided by *orographic lifting* as the air ascends the elevated Valparaiso Moraine (see figure 14), whose crest is as much as 300 feet above the lake surface.

Lake-effect snows of the Great Lakes region are unique because only a few areas of the world experience this mesoscale feature on a significant scale (Eichenlaub, 1979). In Indiana, lake-effect snows are most common in Lake, Porter, LaPorte and St. Joseph Counties, an area which includes the northern Kankakee River Basin (figure 8). Depending on weather conditions, lake-effect snows sometimes can occur farther inland, affecting other portions of northern and even central Indiana.

Fetch, the length of wind travel over the open water surface, is a major factor in determining where the heaviest lake-effect snow will occur. North or northwest winds sweeping over Lake Michigan have a very large fetch and can aquire large amounts of warmth and moisture before crossing the downwind shoreline.

The major snow belt in Indiana associated with these northwest lake winds encompasses the northernmost part of the Kankakee River Basin in LaPorte and St. Joseph Counties (figure 8). Annual snowfall in the northern basin averages about 70 inches, which is twice the annual amount normally received in southern and western areas of the basin.

In unusually snowy years, annual snowfall amounts often exceed 100 inches in the snow-belt area of the northern Kankakee River Basin. Although storm systems deriving their moisture from the Gulf of Mexico can produce heavy snows, the higher average snowfall amounts in the northern basin are largely attributable to the high frequency of moderate to heavy lake-effect snows deriving their moisture from Lake Michigan. Changnon and Jones (1972) estimated that lake-effect snows account for 30 to 50 percent of the annual average snowfall in the snow belt.

Figure 9 illustrates the difference in average monthly snowfall amounts at cities located within and outside of the snow belt. Monthly amounts are considerably higher at LaPorte and South Bend, where lake-effect snows are common, than at other basin

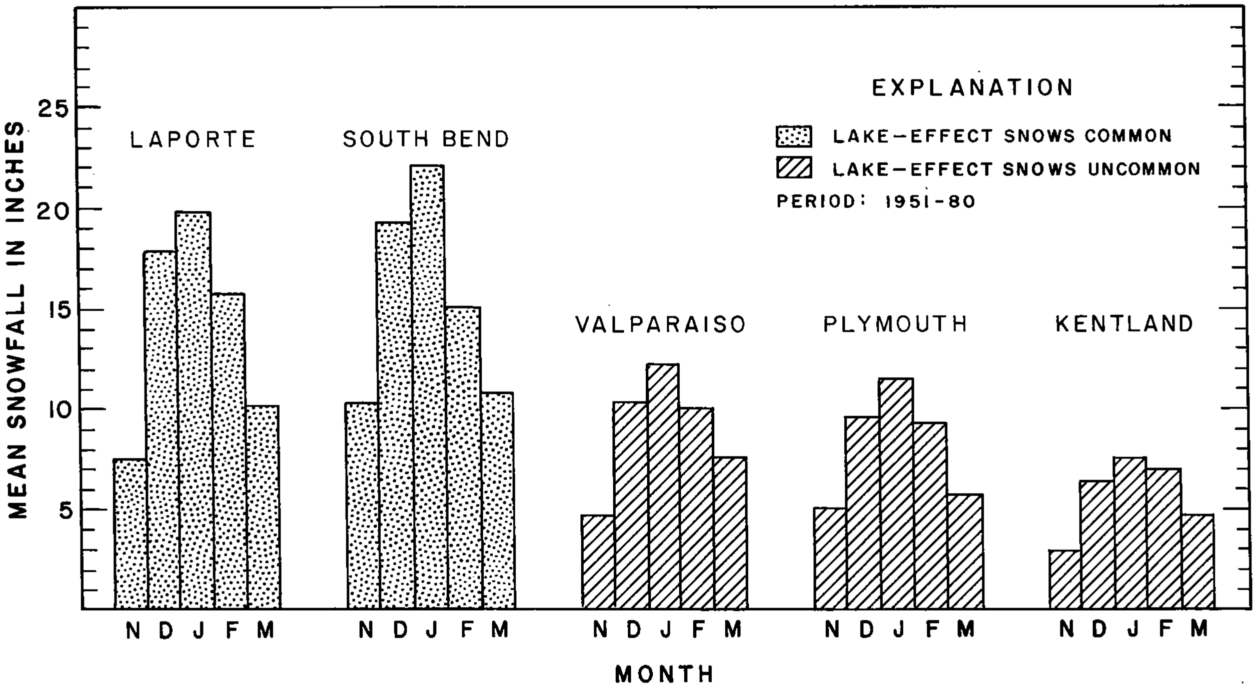

Figure 9. Comparison of mean November-March snowfall in and near the Lake Michigan snowbelt
(Data from National Oceanic and Atmospheric Administration, 1984, 1985)

cities, where lake-effect snows are relatively uncommon. Moreover, snowfall at LaPorte and South Bend constitutes about half of the average precipitation occurring from November through March. Elsewhere in the basin, less than one-third of the precipitation during this 5-month period is snow.

Figure 10 illustrates the variability in mean snowfall for November through March at selected cities. Snowfall amounts are plotted as 5-year *moving averages* to help detect possible trends in snowfall and to facilitate comparisons among different stations.

As figure 10 shows, seasonal snowfall amounts at the snow-belt city of South Bend are consistently higher than amounts at Valparaiso and Plymouth, which are located outside of the major snow belt. The values for South Bend also reflect several unusually snowy years. In the three snowfall seasons between 1976 and 1979, the city received a total of 400 inches of snow, or roughly twice the total amount which normally would have been expected. In the heavy snow season of 1981-82, South Bend received 135 inches of snow, which is second only to the 172 inches received in the 1977-78 season.

The steep and steady decline in 5-year mean snowfall at LaPorte appears to be anomalous, but no studies addressing the snowfall record were found during the preparation of this report. However, an analysis by Changnon (1979) revealed an anomalous trend toward decreasing winter precipitation at LaPorte and an increasing trend at South Bend.

The abrupt increases in 5-year values at Plymouth and Valparaiso during the late 1970s primarily reflect the heavy snowfall seasons of 1976-77 and 1977-78. The heaviest snows during these two seasons derived their moisture from the Gulf of Mexico, rather than from Lake Michigan.

Precipitation

Variations in **daily** precipitation are produced by daytime convection and the periodic passage of frontal systems. Precipitation events typically are interspersed among several dry days. The greatest 24-hour precipitation amount in the basin (6.4 inches) was recorded at Kentland on July 22, 1963.

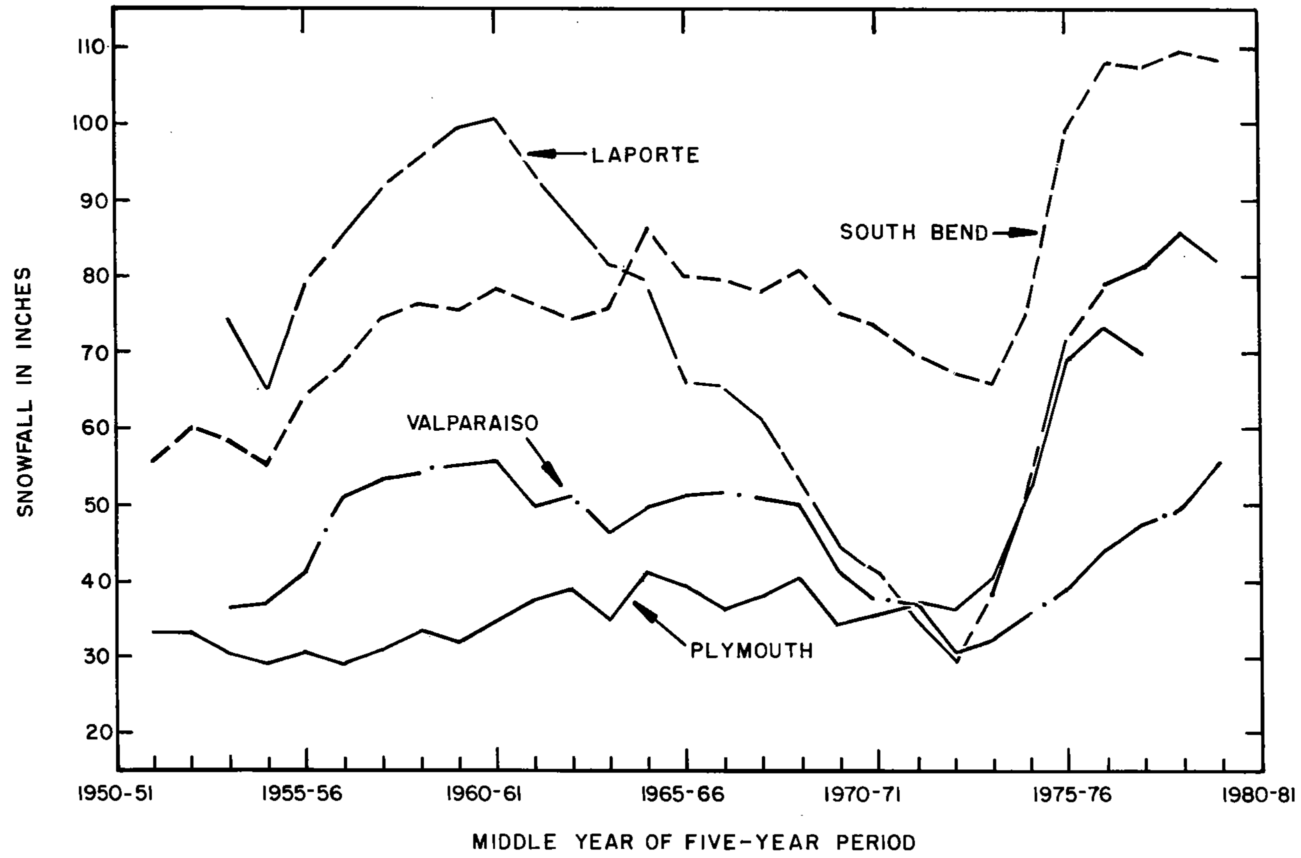

Figure 10. Five-year moving averages of total November-March snowfall

The National Oceanic and Atmospheric Administration has computed normal daily precipitation for South Bend by using a statistical function to *interpolate* from the less variable monthly normals. These daily values range from 0.07 inch in February, the driest month, to 0.14 inch in June, the wettest month. Although daily normal values do not exhibit the typical daily random patterns, they can be used to compute normal precipitation over selected time intervals (National Oceanic and Atmospheric Administration, 1982b).

Normal **monthly** precipitation at Kentland, Plymouth, Wheatfield, Valparaiso and South Bend ranges from 1.5 inches in February to 4.8 inches in June (table 9). Normal **seasonal** precipitation averages 6.2 inches in winter (December-February), 10.5 inches in spring (March-May), 12.1 inches in summer (June-August), and 8.9 inches in fall (September-November).

Precipitation during spring and autumn, which typically is associated with the passage of frontal systems, often occurs in the form of slow, steady rains over large areas. Most of the rainfall in late spring and throughout the summer is produced during localized thundershowers generated by the passage of cold fronts or by daytime convection. Local thunderstorms occasionally can become severe, and may be accompanied by strong winds, large hail, frequent lightning, funnel clouds or tornadoes.

In most areas of the Kankakee River Basin, about two-thirds of the winter-season precipitation falls as rain, and the remainder falls primarily as snow. The majority of snowfall occurs between the months of November and March, although light snows have been recorded as early as September and as late as May near the basin's northern boundary. (As defined by the National Weather Service, the annual snowfall season ex-

Table 9. Normal monthly, seasonal and annual precipitation for the period 1951-80

{All values in inches; monthly data from National Oceanic and Atmospheric Administration, 1982a.}

Month	Kentland	Plymouth	Wheatfield	LaPorte[1]	Valparaiso	South Bend
SPRING						
March	2.9	2.8	2.9	3.2	2.9	3.1
April	4.1	4.1	4.1	4.3	4.3	4.1
May	3.7	3.5	3.4	3.2	3.6	2.8
Seasonal	*10.7*	*10.4*	*10.4*	*10.7*	*10.8*	*10.0*
SUMMER						
June	4.8	4.4	4.4	4.2	4.1	3.9
July	4.5	4.0	4.1	4.5	4.0	3.7
August	3.5	3.4	3.6	4.1	4.0	3.9
Seasonal	*12.8*	*11.8*	*12.1*	*12.8*	*12.1*	*11.5*
AUTUMN						
September	3.1	3.2	3.3	3.8	3.7	3.2
October	2.6	3.1	2.7	3.8	3.4	3.2
November	2.5	2.6	2.4	2.8	2.6	2.8
Seasonal	*8.2*	*8.9*	*8.4*	*10.4*	*9.7*	*9.2*
WINTER						
December	2.3	2.5	2.4	3.1	2.6	3.0
January	1.7	1.9	1.7	2.4	2.0	2.5
February	1.6	1.8	1.5	2.2	1.6	2.0
Seasonal	*5.6*	*6.2*	*5.6*	*7.7*	*6.2*	*7.5*
ANNUAL	37.3	37.3	36.5	41.6	38.8	38.2

[1] Base data may be anomalous.

tends from July of a given year to June of the following year.)

As mentioned previously in this section under the subheading ***Lake Effect***, annual snowfall in the basin ranges from about 70 inches in northern areas lying within the Lake Michigan snow belt to 30 inches in southern and western portions. In northern areas which frequently experience lake-effect snows, about 20 percent of the total annual precipitation falls as snow. In areas not significantly influenced by the lake, about 9 percent of the annual precipitation is snow.

Monthly and seasonal precipitation at any given location varies widely from year to year. Monthly precipitation during the frost-free season commonly ranges from about 2 to 6 inches (see National Oceanic and Atmospheric Administration, 1985), but monthly extremes may range from trace amounts to more than 14 inches. In general, total monthly rainfall amounts are more variable during the warm season than during the cool season.

The maximum monthly precipitation amounts in the basin for the period 1951-80 were recorded in October 1954, when a massive storm system passed through northwest Indiana. Plymouth received 14.5 inches of rain from the storm, and Valparaiso, located just outside the basin boundary, received 11.6 inches. LaPorte may have received as much as 18.3 inches, but this amount may be erroneously high.

Normal **annual** precipitation at Kentland, Plymouth, Wheatfield, Valparaiso and South Bend averages 37.6 inches for the period 1951-80 (see table 9). Normal precipitation appears to be highest along the basin's northern edge, as based on the historically higher annual averages at Valparaiso and LaPorte.

Total annual precipitation in the Kankakee River Basin ranges from about 25 inches, recorded at Wheat-

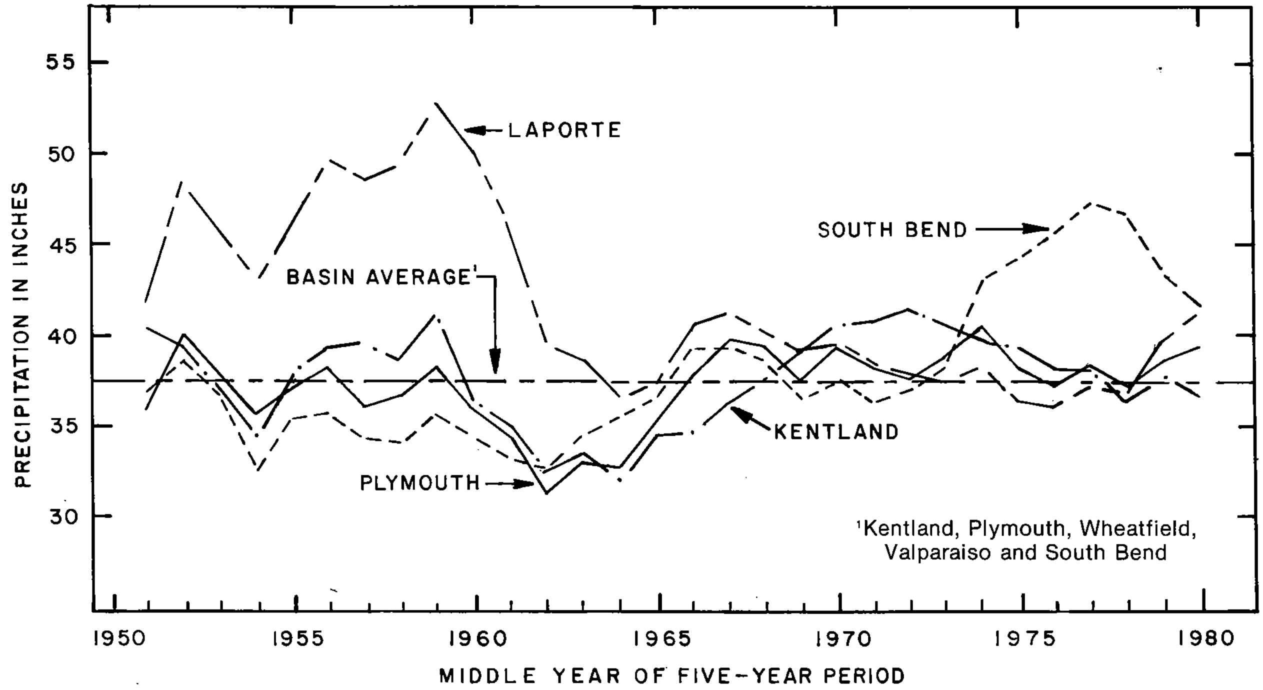

Figure 11. Five-year moving averages of total annual precipitation

field in 1956, to nearly 55 inches, recorded at Plymouth in 1954. An annual total of nearly 71 inches was reported at the LaPorte station in 1954, but the accuracy of the data is questionable.

Figure 11 illustrates the temporal and spatial fluctuations in annual precipitation at four stations in and near the basin. Values for Valparaiso and Wheatfield were not plotted because nearly all the points lie within the range defined by the curves for Kentland, Plymouth and South Bend.

The figure illustrates the fairly dry period of the 1950s to early 1960s, and the wet period of the 1970s. Also evident is the unusually wet period experienced at South Bend during the 1970s. It is likely that LaPorte experienced a very wet period from the 1930s (see box on previous page) through the mid-1960s (figure 11), but the degree of departure from normal is debatable.

Annual probability data (National Oceanic and Atmospheric Administration, 1983a) show that there is a 9-in-10 chance that the annual precipitation over a long period of time will average 30 inches or greater. Conversely, there is only a 1-in-10 chance that the annual precipitation will average 45 inches or greater.

The data also reveal that annual amounts at Valparaiso are slightly more variable than amounts at other stations, perhaps owing to the presence of lake and topographic influences.

Temperature

The normal annual temperature at Kentland, LaPorte, Plymouth, and Wheatfield averages 50° F (degrees Fahrenheit). Normal seasonal temperature averages 49° F in spring, 72° F in summer, 53° F in autumn, and 26° F in winter.

Spring and autumn months generally are characterized by moderate temperatures, although brief periods of unusually cool or warm temperatures may occasionally occur. Summer months bring warm, humid conditions and occasional periods of oppressive heat. Winter months are characterized by short periods of extreme cold alternating with several days of milder temperatures.

January, the coldest month, has an average normal monthly temperature of 23° F and an average normal daily minimum of 14° F. On the average, about 5 days in January have minimum daily temperatures less than 0° F.

July, the warmest month, has an average normal monthly temperature of 74° F and an average normal daily maximum of 86° F. In most of the basin, an average of about 8 days in July have maximum daily temperatures of at least 90° F. In the basin's northern area between Valparaiso and South Bend, maximum temperatures of at least 90° F typically occur on only about 5 days, primarily because of the tempering effect of the cool lake on air mass temperature.

The range in daily temperature is generally least in winter, and greatest in summer. The average difference between normal daily maximum and minimum temperatures in the Kankakee River Basin is 17° F in winter, 22° F in spring and fall, and 24° in summer.

Near the basin's northern boundary, daily average temperature variations are about 2 to 3 degrees less than in southern portions because of the moderating effect of Lake Michigan on air-mass temperature. The lake's influence is especially apparent during autumn when the water's relative warmth causes average daily minimum temperatures to be higher in northwest Indiana than in areas farther south.

Extreme temperatures recorded at Kentland, LaPorte, Plymouth and Wheatfield for the period 1951-80 range from -24° F to 104° F. The highest temperature ever recorded in Indiana, 116° F, occurred at the Collegeville station on July 14, 1936 (Schaal, 1959). Also in 1936, the Wheatfield station reported a temperature of 112° F on July 10, 12 and 14.

Growing season

Along the northern edge of the Kankakee River Basin, the warming effect of Lake Michigan reduces the risk of early fall frosts. Conversely, spring cooling prevents the premature budding of sensitive fruit trees and other early crops, thus reducing the chances of crop loss due to late spring frosts. As a result of the fall warming and spring cooling, the length of the frost-free growing season for most crops is generally 2 or 3 weeks longer than in areas farther south. The average length of the growing season near the basin's northern boundary is about 170 days. The season typically extends from late April through the middle of October.

The longer growing season in the northern Kankakee River Basin, in combination with the moderate temperatures, higher humidity and hilly terrain, produces an environment suitable for the growing of frost-sensitive fruit crops such as apples, pears, peaches, grapes and berries. Orchards are especially commmon in northern LaPorte County along and just north of the Kankakee River Basin boundary.

In the southern part of the Kankakee River Basin, the length of the growing season is about 160 days. The season generally extends from early May through early October. The date of the last freezing temperature in spring and the first killing frost in fall varies greatly from year to year. For example, frost has been reported as late as June and as early as September.

In the main valley of the Kankakee River, the length of the average frost-free growing season is only about 150 days. The season, which typically extends from the middle of May through early October, is the shortest average season in Indiana. The unusually short season is mainly the result of the low-lying terrain and the predominance of sandy soils covered in places by mucks or peats. Because the soils gain and lose heat quite rapidly, they are highly susceptible to frost and freezing temperatures (Schaal and Newman, 1981).

Evapotranspiration

Precipitated water is continually being returned to the atmosphere as vapor through the processes of evaporation and plant *transpiration*. The combined processes of evaporation from water, soil, snow, ice, vegetation and other surfaces commonly are referred to as evapotranspiration.

In general, the rate of evapotranspiration ultimately is limited by the availability of water. The rate is affected by 1) meterological variables, including solar radiation, air temperature, vapor pressure gradients, and wind, 2) soil moisture, and 3) vegetative features such as plant type, plant growth characteristics, and the surrounding plant density.

Measurements of evaporation from the water surface in a shallow, circular pan can be used to estimate the maximum water loss possible from shallow lakes or saturated soils. The standard Class A evaporation pan used by the National Weather Service is an unpainted, galvanized metal tank about 4 feet in diameter and 10 inches deep. The pan typically is mounted on a wood frame a few inches above the ground. Proper

Table 10. Estimated mean monthly pan evaporation at South Bend

{Monthly values, from Farnsworth and Thompson (1982b), are averages of estimated pan evaporation derived from hydrometeorological measurements using a form of the Penman equation.}

Month and season	Estimated evaporation, in inches (1956-70)
WARM SEASON	
May	5.63
June	6.73
July	6.64
August	5.93
September	4.26
October	3.17
Season total	32.36
COOL SEASON	
November	1.61
December	0.88
January	0.83
February	1.00
March	2.08
April	3.80
Season total	10.20
Annual total	42.56

observation techniques are described in a National Weather Service handbook (National Oceanic and Atmospheric Administration, 1972).

Pan evaporation stations typically are operated between May and October, the frost-free growing season for most crops. In general, evaporation pans are not operated between November and April because frequent ice cover would produce erroneous measurements. Estimated monthly means of pan evaporation at South Bend (Farnsworth and Thompson, 1982b) show that nearly 25 percent of the annual total pan evaporation occurs during the 6-month winter period (table 10).

Although no pan evaporation stations are located within the Kankakee River Basin, stations within 8 miles of the basin boundary are located at Valparaiso and Kewanna (figure 8, table 8). Another Class A pan station in northwestern Indiana is operated south of the Kankakee River Basin at West Lafayette in Tippecanoe County. From 1961-74, pan measurements also were recorded at Culver, which is just south of the basin boundary in Marshall County.

Table 11 presents period-of-record averages of monthly and seasonal pan evaporation at the four stations. Differences in station exposure, observational techniques, and years of data record may largely account for the considerable variations among the average values.

As table 11 shows, mean monthly pan evaporation during the growing season ranges from an average of

Table 11. Warm-season mean monthly pan evaporation in northwest Indiana

{Monthly values, in inches, are from evaporation summaries in unpublished files of the Indiana Department of Natural Resources, Division of Water, August 1988.}

Station	May	June	July	Aug.	Sept.	Oct.	Total
Valparaiso 1947-87	5.27	5.90	5.89	5.06	3.43	2.22	27.77
Kewanna 1977-87	6.28	7.03	6.96	5.42	4.16	2.60	32.45
West Lafayette 1957-87	6.36	7.35	7.39	6.13	4.81	3.38	35.42
Culver 1961-74	6.64	7.69	7.38	6.25	4.77	3.20	35.93

about 7 inches in June and July to less than 3 inches in October. Although not shown in the table, monthly extremes range from a summer maximum of more than 9 inches (measured at West Lafayette) to an October minimum of about 1 inch (measured at Valparaiso).

It is generally accepted that multiplying total annual pan evaporation by a factor of 0.70 to 0.75 yields a reasonable estimate of annual evaporation from lakes or reservoirs. In turn, annual lake evaporation can be considered as approximately equivalent to free-water evaporation, which is defined as the evaporation from a thin film of water having no appreciable heat storage (Farnsworth and Thompson, 1982a). This interchanging of terms is probably valid for general usage because the net change in heat storage in a lake is negligible over a 12-month period, particularly if the lake is shallow.

Estimates of lake or free-water evaporation are important in reservoir design, rainfall-runoff modeling, and various water-supply studies. In most applications, the free-water value represents potential evaporation, which is the maximum water loss expected to occur from a shallow water body, saturated soil, or an adequately watered vegetative surface with an unlimited supply of water. As a good index to the maximum consumptive use of water by evaporation and transpiration, estimates of potential evaporation (or potential evapotranspiration) also can be helpful in determining soil moisture deficits for irrigation.

If average seasonal pan evaporation for the Kankakee River Basin is assumed to be 33 inches (see table 11), average annual pan evaporation is about 43 inches, according to the seasonal-to-annual ratio for South Bend (see table 10). Average annual lake (potential) evaporation, therefore, is 70 percent of this value, or about 30 inches. Visual extrapolation from maps of eastern Illinois (Jones, 1966) also yields a basin estimate of 30 inches.

This evaporation value of 30 inches is a generalized indicator of the maximum water loss that could be expected in a year of normal precipitation. Because the average annual precipitation in the Kankakee River Basin is nearly 38 inches, it can be concluded that there is, on the average, a potential water surplus in years of normal precipitation.

In dry years, the amount of moisture available from precipitation may be less than the potential maximum moisture needs for evapotranspiration. The moisture deficit in a dry year can be considered a conservative index of the amount of water that must be applied through irrigation to supplement precipitation. However, the actual amount of water needed would depend on many variables, including local rainfall, soil type and soil moisture conditions.

In theory, it can be assumed that when soil moisture is not limiting to crop growth, the potential evapotranspiration is the same as the actual evapotranspiration. Because the availability of moisture for evapotranspiration varies continually in time and space, however, actual evapotranspiration often occurs at less than the potential rate.

Studies in central Illinois revealed that average annual evapotranspiration is roughly 84 percent of the average annual potential evapotranspiration during years of normal or above-normal precipitation (Schicht and Walton, 1961). If annual potential evapotranspiration in the Kankakee River Basin is assumed to be 30 inches, then the actual evapotranspiration is about 25 inches during years of normal precipitation.

Estimated values of 25 to 26 inches also have been obtained by Jones (1966), who used a water-budget approach for the Illinois part of the basin, and by Newman (1981), who used the Thornwaite method as described by Palmer and Havens (1958) for the crop-reporting districts of Indiana. The agreement among values derived from different methods is notable, considering the large basin size, the spatial-temporal variability of rainfall and runoff, and the theoretical and empirical weaknesses inherent in estimating techniques.

The loss of 25 inches (nearly 70 percent) of the average annual precipitation to evaporative processes represents the single largest consumptive use of water in the Kankakee River Basin. Although the remaining 12 to 13 inches of water is considered adequate with respect to the basin's overall water budget, the spatial and temporal variability of rainfall from year to year and its uneven distribution during any given year can occasionally limit crops and water supplies.

Climatic extremes

Extreme climatic events such as droughts and flood-producing storms are infrequent but can have far-reaching economic impacts. In the Kankakee River Basin, economic losses caused by floods and drought are most widespread in agriculture areas, although some urban and residential areas also can sustain major damage.

Heavy rainstorms can be described statistically using rainfall frequency analysis. Rainfall frequency data are used primarily in developing design criteria for drainage, flood-control and water-supply projects. These water-control projects generally are designed for flood events of selected magnitude and frequency in order to achieve an economic balance between the average cost of damages from occasional floods, and the cost of protecting facilities against larger, less frequent floods.

Three reports published by NOAA summarize rainfall frequency data for selected durations from 5 minutes to 10 days and return periods from 1 to 100 years (Hershfield, 1961; U.S. Weather Bureau, 1957, 1964; National Oceanic and Atmospheric Administration, 1977). Other reports provide data on *probable maximum precipitation* (Schreiner and Riedel, 1978; Ho and Riedel, 1980) and rainfall intensity-duration-frequency (U.S. Weather Bureau, 1955). A report by the Indiana Department of Natural Resources (1982e) summarizes the NOAA data for Indiana and provides interpolated estimates of rainfall values.

The Midwestern Climate Center in Illinois is updating heavy-rainfall frequency values for midwestern states. The analyses, which utilize data from NWS stations, will provide values on a more detailed scale than values published by NOAA. A preliminary report was in preparation in early 1990 (J. Angel, Illinois State Water Survey, personal communication, 1990).

The term **drought** is generally associated with a sustained period of abnormally low water or moisture supply. Drought, unlike a flood, is not a distinct event because its onset and termination are difficult to recognize. Moreover, the variation in duration, severity and spatial extent leads to a wide variation in environmental and socioeconomic impacts.

Although the most well-known droughts encompass large areas, the variability of rainfall in combination with other factors can produce localized drought conditions in areas having an overall water surplus. In the Kankakee River Basin, for example, rainfall deficits in localized areas may lead to crop stress during critical periods of the crop-growing season, even though precipitation in the basin as a whole may be at normal levels.

Because of its complex nature, drought can be defined in several ways. Terms referring primarily to the physical conditions of moisture deficiency include **meteorologic drought**, which focuses on deficiencies of precipitation, and **hydrologic drought**, which explains drought in terms of reduced stream flow, ground-water levels, or reservoir storage.

Terms referring to impacts of below-normal precipitation on sectors of society include **agricultural drought** and **urban** or **water-supply drought**. Agricultural drought is defined as a continued period of moisture deficiency so serious that crops, trees and other vegetation fail to develop and mature properly. In a water-supply drought, water shortages lead to adjustments in water-supply management, such as the implementation of conservation measures or the use of alternate water supplies.

One well-known measure of the severity and extent of meteorologic drought is the Palmer Drought Severity Index, one of three Palmer indices (see Palmer, 1965; also see Alley, 1984, 1985). Values of the Palmer Index for climatic divisions of each state are reported monthly, and sometimes weekly, in documents published jointly by the U.S. Departments of Commerce and Agriculture. Other drought indices are based on cumulative precipitation deficits, reservoir storage, stream flows, ground-water levels, or other hydrologic factors relevant to water supply and agricultural activities.

Because drought severity indices commonly are used to initiate drought response activities such as water conservation measures and financial assistance, it is crucial that the selected indices provide a representative assessment of drought conditions. Researchers at Purdue University are working cooperatively with the Indiana Department of Natural Resources, Division of Water to develop regional drought indicators for Indiana (Delleur and others, 1990).

Although the drought of 1988 brought the driest April-June period on record and the hottest June-August period on record to northwest Indiana, a discussion of its characteristics and impacts is beyond the scope of this report. A report by Fowler (in preparation) describes the drought's effects in Indiana.

Several publications describe various aspects of drought preparedness. Reports by the former Indiana Drought Disaster Preparedness Committee (1977), the former Indiana Drought Advisory Committee (1988), and the Great Lakes Commission (1989) discuss drought preparedness and planning for Indiana. Articles by Changnon (1987), Easterling and Changnon (1987), and Changnon and Easterling (1989) are three among many publications by staff of the Illinois State Water Survey which address drought climatology, impacts and preparedness in Illinois.

GEOLOGY

Geology of the Kankakee River Basin affects water resource availability by influencing the distribution of precipitation between surface-water and ground-water regimes. Geology also helps control the storage of water in the basin because it largely determines the *topography*, soils and *aquifers*.

The surface deposits in the basin are of glacial origin. A complex series of sediments deposited during repeated advances of *glacial lobes* (figure 12) form the major unconsolidated aquifers of the Kankakee River Basin.

Sources of geologic data

Ground-water and aquifer information for the Kankakee River Basin comes from many sources including water-well records, the observation-well network, *lithologic* descriptions from oil- and gas- well records, engineering borings, *seismic* information, and local project results, which include *pumping tests* and other analytical and mathematical models.

Since 1959, water-well drilling contractors have been required to submit to the Indiana Department of Natural Resources (IDNR) a complete record of every water well that is drilled in the state. More than 15,000 water-well records on file at the IDNR, Division of Water were analyzed for the ground-water assessment portion of this study. Most of the records are for shallow domestic wells less than 150 feet deep.

In 1987-88, the Division of Water and Indiana Geological Survey (IGS) drilled 54 test holes to supplement the water-well records and provide information on deep unconsolidated formations (appendix 2). Geologists from both offices made on-site geologic descriptions and collected samples for laboratory analysis by the IGS. This information was important in determining aquifer characteristics and the geologic history of the basin. Much of the interpretation of the glacial geology in this report comes from an unpublished report by Bleuer and Fraser (1989).

Physiography

Indiana can be divided into three broad *physiographic regions* according to the effect of glaciers on the landscape: 1) the area south of the Wisconsinan glacial boundary where bedrock controls the physiography; 2) a central area with a gently undulating *till-plain* surface; and 3) a northern region of glacial deposits characterized by fairly rugged relief.

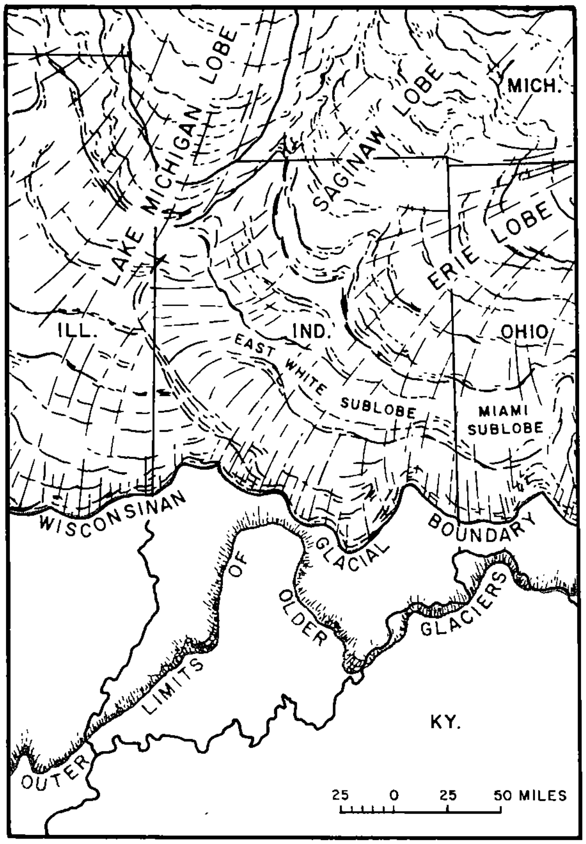

Figure 12. Extent of major ice lobes in Indiana during the Wisconsinan glaciation
(Adapted from Wayne, 1965)

Guided by the topography of these regions, Malott (1922) divided the state into nine physiographic regions (figure 13). Except for a small part of the basin in Benton County which is part of the Tipton Till Plain, the Kankakee River Basin lies in the Northern Lake and *Moraine* Region. Within this region, the Kankakee River Basin includes part of the Valparaiso Morainal Area, Kankakee Outwash and Lacustrine Plain, and Steuben Morainal Lake Area (figure 13).

Most of the landscape of the Kankakee River Basin is a product of latest Wisconsinan glacial events of the Lake Michigan Lobe (figure 12). The landscape of the

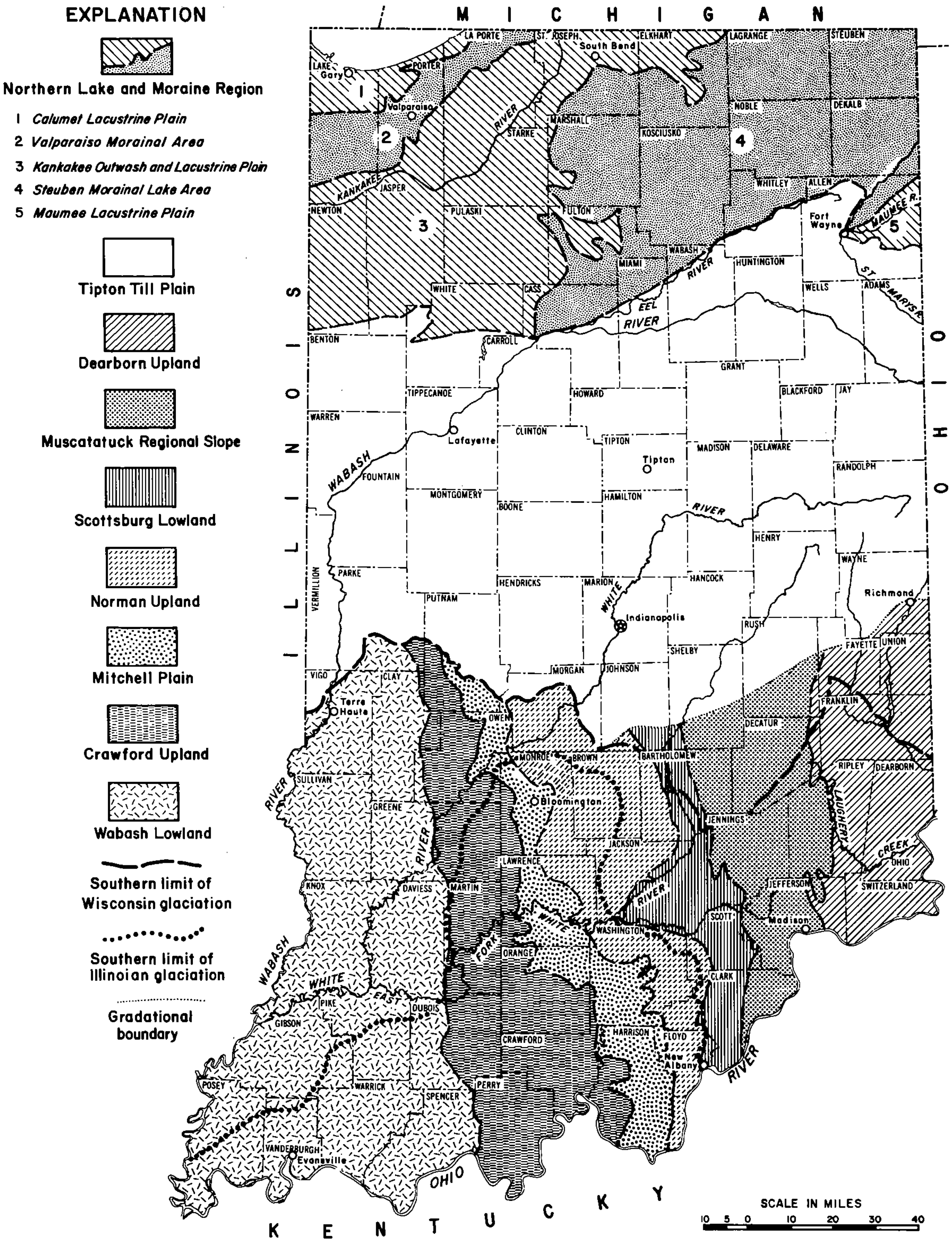

Figure 13. Physiographic regions of Indiana
(After Malott, 1922; modified by Wayne, 1956)

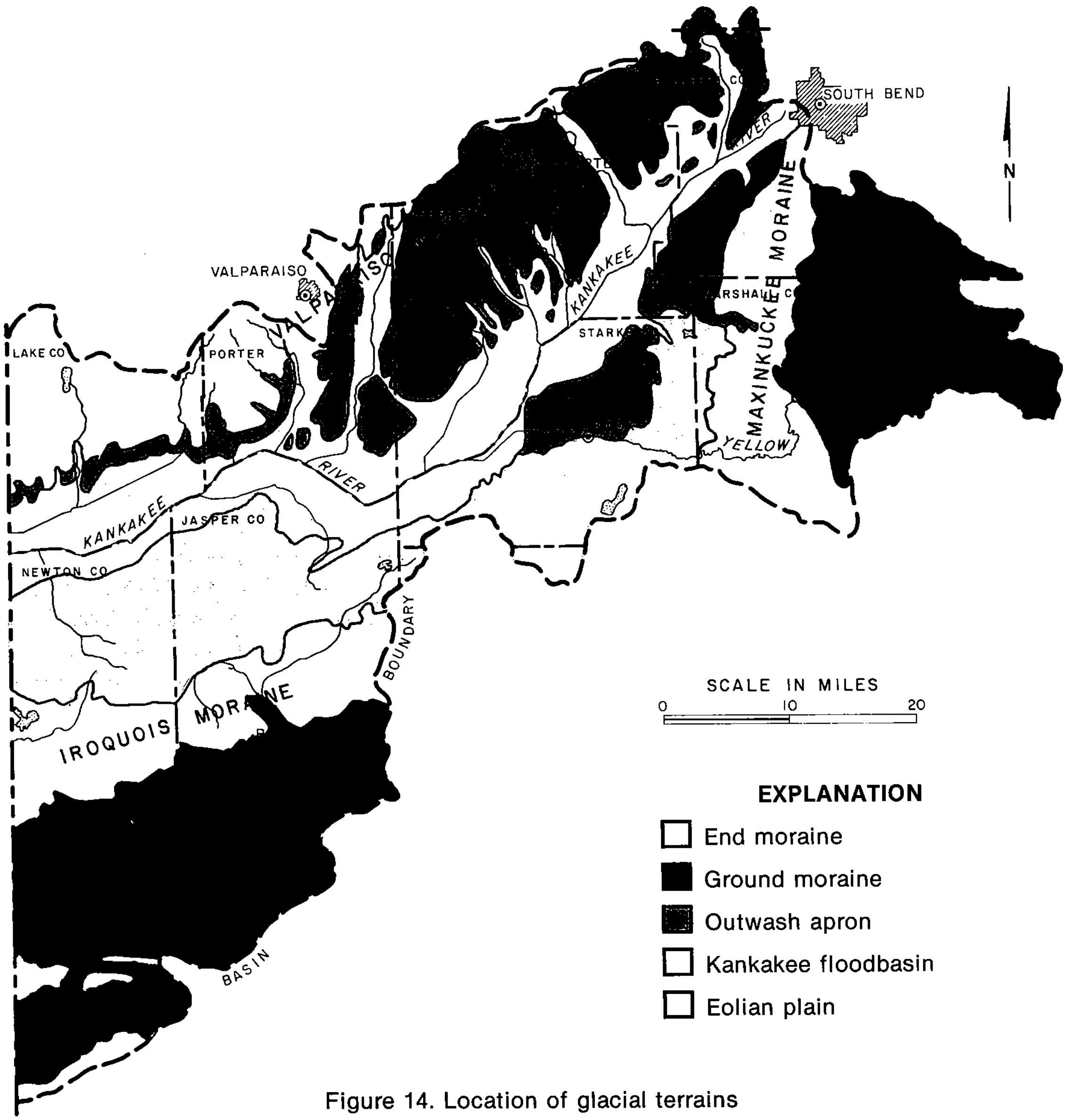

Figure 14. Location of glacial terrains
(Adapted from Wayne and others, 1966 and Schneider and Keller, 1970)

easternmost part of the basin, however, is a product of the Lake Michigan Lobe and eastern lobes, and in places overlies subdued or scoured topography on older *drifts*.

Various landscape elements in the basin have been identified on the basis of topographic form and internal composition. These elements, mapped as glacial terrains in figure 14, are characterized as *end moraine*, *ground moraine*, *outwash apron*, *floodbasin*, and *eolian plain*.

End moraines are the elements of greatest internal relief and highest regional elevation. End moraines are traditionally thought to be representative of ice-marginal or near-ice-marginal deposition.

The end moraines recognized in the Kankakee River Basin are of three general types: 1) classic till-rich, 2) dominantly *outwash*, and 3) tectonic. The portion of the Valparaiso Moraine west of the city of Valparaiso, which most closely resembles the classic concept of a till-rich moraine, is composed of thick, stacked tills of the Lake Michigan Lobe, overlying *outwash-fan* sediments. The Maxinkuckee Moraine and the portion of the Valparaiso Moraine east of the city of Valparaiso are composed of predominantly outwash materials which represent *subaqueous* and *subaerial* fans. Both outwash moraines have inner zones of complex ice-contact terrain; however, the inner zones are dissimilar in architecture as a result of different mechanisms of deposition. The Iroquois Moraine, a tectonic moraine and a form of push-moraine, is cored by up-thrust *lacustrine* sediments and till of the Lake Michigan Lobe, and is capped by till of the Huron-Erie Lobe.

The Valparaiso Moraine (figure 14) is an *arcuate* ridge that can be traced around the south end of Lake Michigan from southern Wisconsin through northeastern Illinois and northwestern Indiana to west-central Michigan. In Indiana, the moraine forms the northern boundary of the Kankakee River Basin.

The surface of the moraine in Indiana is asymmetric, being steeper on the north slope than on the south slope. Moreover, the moraine's thickness and surface elevation increases to the east.

West of Valparaiso, the moraine's crest elevation ranges from 700 to 800 feet m.s.l. (mean sea level). East of Valparaiso, the crest elevation is more than 800 feet m.s.l. and in some areas exceeds 950 feet m.s.l. Local relief east of Valparaiso exceeds 100 feet in many places along the crest and northern flank of the moraine.

The Maxinkuckee Moraine, which trends north-south through Marshall County and part of St. Joseph County (figure 14), is not as topographically distinct as the Valparaiso Moraine. The moraine has crest elevations as much as 900 feet m.s.l and average local relief of 75 feet.

The Iroquois Moraine, which trends northeast-southwest through Newton and Jasper Counties (figure 14), is an even more subtle topographic feature than the Valparaiso and Maxinkuckee Moraines. The moraine, characterized by *hummocky* local topography, stands as much as 80 feet above the till plain to the south. The elevation of its crest is about 740 feet m.s.l., and average local relief is 60 feet or less.

Across much of its northern boundary in Newton and Jasper Counties, the Iroquois Moraine is well defined, but becomes less defined to the northeast in Pulaski and Starke Counties. In this northeastern area it drops in elevation and grades into the till underlying the intermoraine lowland, which is identified as part of the Eolian Plain on figure 14.

Ground moraine, best illustrated by the relatively flat landscape south of the Iroquois Moraine, represents deposition of sediment by bottom meltout from ice disintegrated (downmelted) in place. The composition of the ground-moraine till is similar to that found in end moraines, but the topography of ground moraines is less pronounced.

Ground moraine underlies the Iroquois River Basin and the area east of the Maxinkuckee Moraine (figure 14). These areas have gently rolling topography and average local relief less than 40 feet. The Iroquois River Basin is surrounded by uplands, and the basin-floor elevation ranges from 630 to 700 feet m.s.l. The ground moraine east of the Maxinkuckee Moraine is a relatively high area and has elevations ranging from 800 to 850 feet m.s.l.

The **outwash apron** of the Valparaiso Moraine (figure 14) is a large wedge of sandy sediment that forms the southern slope of the moraine. The slope descends about 5 to 10 feet per mile from the crest of the moraine to the *scarp* of the *incised* valley of the Kankakee River.

The Kankakee **floodbasin** (figure 14) is a broad, nearly level, featureless plain that was once occupied by a glacial lake and is now surrounded by the uplands of moraines. The elevation of the floodbasin is about 700 feet m.s.l. in upstream reaches near South Bend, and descends to about 630 feet m.s.l. at the Indiana-Illinois state line. The floodbasin is about 2 miles wide near South Bend and widens to about 8 miles at the Indiana-Illinois state line. Part of the floodbasin is occupied by the modern floodplain of the Kankakee River.

An **eolian plain** (figure 14) has formed on the nearly level surface of the southern margin of the central lowland of the Kankakee River Basin. Dunes derived from fine-grained outwash sediment formed on the southern margin of the floodplain and migrated into the intermoraine lowland in Starke County. The dunes are oriented with their long axis north-south, indicating dominantly westward winds. The dunes stand 15 to 50 feet above the surrounding floodplain, which has an average elevation of about 650 feet m.s.l.

The topography of the eolian sand sheet is somewhat complex in Pulaski County where two different dune types occur. Areas covered with large coalesced dunes form ridges generally oriented north-south. Interdune areas are relatively level and merge gradually into the

Kankakee River floodplain. Isolated smaller dunes are scattered on the interdune surfaces.

Glacial geology

The landscape elements in the Kankakee River Basin are primarily the product of glacial processes (see box on next page). The occurrence of ground water within glacial deposits depends on the detailed *stratigraphy* of the deposits. Grain size, sorting, thickness, and the arrangement of deposits are important factors of an aquifer's hydraulic characteristics, and the occurrence of these hydrogeologic elements can be understood from the glacial context.

Meltwater streams flowing from a glacier carry and sort glacial debris. The finest material is carried farthest from the glacial front, whereas coarser material is deposited near the glacial front. The deposits of meltwater streams, or outwash, may form aquifers.

Till is a sediment that has been transported and deposited by or from glacier ice, with little or no sorting by water. The matrix material of till is generally fine-grained and can restrict rapid ground-water flow. An intratill aquifer is formed where outwash is surrounded by till in a complex glacial deposit.

Lakes occurring in glacial environments often form as meltwater is trapped by ice or glacial debris. In calm lake water, fine sediment deposits on the lake bed. Fine-grained lacustrine deposits can restrict rapid ground-water flow.

The previous discussion on physiography focused primarily on topographic forms in the Kankakee River Basin. The following discussion emphasizes internal composition of the landscape elements to provide a context for assessing ground-water availability.

Unconsolidated deposits

The **Valparaiso Moraine** west of the Valparaiso topographic sag generally is characterized by a broad till-capped area of subdued topography which is flanked to the south by a narrow apron of *outwash-fan* deposits. Thick surficial tills were deposited directly from glacial ice as it advanced over the fan deposits.

The moraine east of Valparaiso is characterized by a till cap of pronounced topography which covers the moraine's north flank and a narrow area on its crest. Glacial ice apparently did not advance far over the wide fan surface draping the moraine's southern slope. In some places in LaPorte County, no tills are present, and sand and gravel occur at the top of the sequence.

Medium-grained sands occur beneath the tills in the area west of Valparaiso and are the predominant *facies* of the outwash fan to the east. These sands extend from the morainal complex into the Kankakee River floodplain. The sands may occur as stacked channel fills with erosional *basal contacts*.

Lacustrine muds, underlying the Valparaiso moraine in most places, consist of interbedded laminated silt, silty *loam*, and silty clay loam containing small localized amounts of fine sand in thin layers. In some cases, the muds form a distinct coarsening-upward deposit that culminates in *deltaic* sands. In most places, however, the sands overlie muds with a sharp contact, which suggests an intervening period of erosion or nondeposition. The muds are thickest in the lower basin beneath the Valparaiso Moraine.

Thinner, less extensive deposits of lacustrine muds occur in the elevated part of the moraine. In this area the muds probably originated in depressions on the moraine surface that formed closed basins. The lacustrine muds are commonly interbedded with *debris-flow* tills or sands in deltaic sequences.

Despite variation in the occurrence of the morainal deposits, the vertical sequences of the Valparaiso Moraine usually indicate that deposition occurred with increasing proximity to the ice through time, which in turn suggests that much of the complex was deposited during a time of ice advance. The thinning and fining-upward sequences in channel deposits indicate the occurrence of channel abandonment, and coarsening and thickening-upward sequences indicate *progradation* of depositional lobes away from the ice front.

The typical sequence of deposits is related to the distance between the deposits and the ice front. In the most common sequence, lacustrine muds deposited far from the ice margin in a large glacial lake are overlain by sands deposited on the outer and middle parts of an outwash fan. The outwash sands are interbedded with black shale gravels deposited in mid-fan debris flows.

Black shale gravels occur throughout the Valparaiso Moraine and its outwash apron. Shale *clasts* can be as large as cobbles. In the lower basin the gravels fill channels which were cut in till, probably by debris flows. In the outwash fan east of Valparaiso, gravels

Glacial History of the Wisconsinan Stage

During the Pleistocene Epoch, glaciers advanced into Indiana several times, from several directions (figure 12). Most of the surficial deposits of the Kankakee River basin are the result of the latest events of the Wisconsinan Stage of glaciation, which lasted from 24,000 to 10,000 years ago.

Earliest Wisconsinan ice entered the basin area from the northwest and the east. Ice covered the entire basin, but representative deposits are found only in upland areas north and east of Plymouth in the subsurface of the Maxinkuckee Moraine and landscape to the east. In general, deposits derived from the earliest Wisconsinan advances are mutually exclusive in their distribution within this eastern area.

The two sequences of deposits appear to be plastered onto the edges and atop a pre-existing drift upland. Gray *loam* till of the Huron-Erie Lobe, derived from the southeast, occurs beneath surficial moraine/fan deposits in the Kosciusko County part of the basin. A pinkish loam till of the Lake Michigan Lobe, derived from the northwest, was deposited at about the same time and is present beneath surficial moraine/fan deposits in the Plymouth area.

Latest Wisconsinan ice entered the Kankakee River Basin area from the northwest, northeast and east. The deposits of these advances include a shaley, greenish-gray till of the Lake Michigan Lobe; a pinkish clayey till of the Saginaw Lobe; and a loamy till of the Huron-Erie Lobe (figure 12). The advance of the Lake Michigan and Saginaw Lobes appear to be roughly contemporaneous, followed by the advance of the Huron-Erie Lobe.

The shaley, greenish-gray till of the Lake Michigan Lobe in Indiana, is considered to be the equivalent of the Snider till in Illinois. This Snider-equivalent till, along with its thin cap of Trafalger till, constitutes most of the surficial materials in and south of the Iroquois Moraine. The Snider-equivalent till is associated with the stratified sediments of the Maxinkuckee Moraine to the east, and is present discontinuously beneath the Kankakee plain, where it is associated with lacustrine clays.

The Iroquois and the Maxinkuckee are topographically distinguishable moraines associated with the Snider till. The Iroquois Moraine is cored by Snider till and lacustrine clays, the clays apparently having been placed by ice thrust. The Maxinkuckee Moraine is predominantly a complex of outwash fans that drained eastward and southeastward.

The pinkish, clayey till deposited by the latest Wisconsinan advance of the Saginaw Lobe was deposited at about the same time as the shaley, greenish-gray till of the Lake Michigan Lobe. Associated, collapsed *supraglacial* outwash, expressed as *kames* near Nappanee, discharged westward from the Saginaw Lobe. *Proglacial* outwash fans from the Saginaw ice converged with distal aspects of the Maxinkuckee fan(s) in the lowland south of Bremen. A series of northwest-southeast trending ridges between Bremen and Nappanee may represent minor ridged moraine forms associated with this advance.

The later advance from the Huron-Erie Lobe, derived from the east, covered the southern part of the Kankakee River Basin along and south of the Iroquois Moraine. This ice left a thin cap of loamy till of the Trafalgar Formation. The Trafalgar till in the basin is associated with low-relief *disintegration* landforms, and is not associated with major topographic forms. The overall ground-moraine and moraine landscape reflects relief on the surface of the underlying till.

During the late stages of Wisconsinan glaciation of the Kankakee River Basin, the central part of the basin was covered by a large lake fed by *meltwater* streams. The lake formed as meltwater from the Lake Michigan Lobe was trapped by moraines to the east and south, ice to the north, and a bedrock high to the west near Momence, Illinois. This lake may have been part of a larger system of lakes whose deposits are found scattered throughout northeastern Illinois. The fine-grained sediment carried by meltwater streams was deposited on the lakebed, thus forming a distinctive clay layer.

The Lake Michigan Lobe formed the Valparaiso Moraine during the last major advance of the general recession of the Late Wisconsinan ice. The *prograding* deposits of the glacial streams formed an apron of sediment in front of the glacier. The south edge of the moraine is generally considered to mark a terminal position of the Lake Michigan lobe during the latest Wisconsinan.

When the ice moved southward following a brief northward retreat, meltwater streams deposited outwash sand and gravel over the glacial lakebed in most of Lake, Porter and LaPorte Counties, and parts of Jasper, Newton, and Starke Counties. In places, the glacial ice advanced over its outwash apron. When the glacial ice finally retreated from the basin, the wasting glacier deposited till over its outwash apron, forming the crest of the Valparaiso Moraine.

Since the retreat of the glaciers from the Kankakee River Basin 11,000 years ago, the existing surface drainage system of the basin has developed. The Grand Marsh formed where the Kankakee River flowed through the low-lying lake basin. Tributaries of the Kankakee River have incised their channels into the moraines and fan surfaces, reversed flow direction, or made other adjustments following the retreat of the glaciers and the discontinuation of the meltwater discharge.

LAKE MICHIGAN LOBE	***SAGINAW LOBE***	***ERIE LOBE***
Retreat		
Advance out of basin, building of Valparaiso Moraine **(event 4)**		
		Advance of sublobe of Huron-Erie Lobe from east, deposition of basal Trafalger till; general disintegration deposits across terrain south of valley **(event 3)**
Collapse into lake basin, basal and glaciolacustrine mudflow deposition in Kankakee lowland *(present basal deposits)*	General retreat or zonal stagnation	?
Advance out of basin over lake sediments, general recession, building of Iroquois Moraine — fan(s), western fan-delta additions to Bremen lowland *(shaley, greenish-gray till; Snider equivalent)* **(event 2)**	Advance onto existing eastern uplands, deposition of proglacial fan sequences, culminating in contributions to fill of Bremen lowland *(pinkish-clay till)*	?
Recession into lake basin	?	?
East edge of lobe advances to west edge of existing upland deposits near Plymouth. *(pink loam till; found only in subsurface beneath moraine/fan in Plymouth area)* **(event 1)**		West edge of lobe advances to south rim of existing upland deposits *(gray till, associated with kame topography of collapsed fan southeast of Plymouth; found only in subsurface beneath moraine/fan in Koscuisko County)*