constituted by the Kankakee River and its minor tributaries, only 16 miles remain in a natural state (Robertson, 1971).

Sources of stream-flow data

Stream gages in the Kankakee River Basin monitor flow variations among different streams and throughout the lengths of the basin's three major watercourses. Hydrologic parameters derived from stream-flow records can be used to evaluate the potential of streams for water-supply development.

The U.S. Geological Survey, in cooperation with other government agencies and private industry, has maintained records of daily stream flow in the Kankakee-Yellow River Basin since 1905. Currently, records of daily *mean* discharge are collected at five *continuous-record stations* on the mainstem Kankakee River, at two stations on its tributaries, and at two stations on the Yellow River (table 13, figure 23).

Seven active stations in the Kankakee-Yellow River Basin are part of a cooperative program between the U.S. Geological Survey (USGS) and the State of Indiana. The Kankakee River station at Shelby is operated by the USGS in cooperation with the U.S. Army Corps of Engineers. The Kankakee River station near Kouts is operated in cooperation with the Northern Indiana Public Service Company.

Data from most stations in the Kankakee-Yellow River Basin are used primarily for flood hydrology and river forecasting. More than half of the stations are equipped with telemetering instruments for audible reporting of real-time water-level data. The station at Shelby is equipped with a special device for transmitting encoded data via an earth-orbiting satellite.

A continuous-record network was established in the Iroquois River Basin in 1948 through a cooperative agreement between the USGS and the State of Indiana. Records of daily discharge currently are collected at four stations on the mainstem Iroquois River (table 13, figure 23). Discharge data also are collected for Bice Ditch.

Two stations, both located in the Kankakee-Yellow River Basin, currently operate as *partial-record* stations (table 13). At the low-flow partial-record site on Eagle Creek in Starke County, flow measurements are made during dry periods when stream flow is primarily composed of ground-water discharge.

A series of low-flow discharge measurements collected at a partial-record site can later be correlated with simultaneous daily mean discharges at a nearby continuous-record gage on a stream draining a hydrologically similar basin. From this discharge relation, low-flow frequency characteristics of the partial-record site can then be estimated using frequency characteristics for the continuous-record gage. Table 13 lists active and discontinued partial-record stations for which low-flow frequency data have been reported by Stewart (1983).

The partial-record site on Eagle Creek also serves as a *crest-stage* station, as does Cobb Ditch near Valparaiso (table 13). A crest-stage gage is a device which registers the peak stream stage occurring between inspections of the gage. Stage readings can later be converted to discharge values, and flood frequency characteristics can be determined. Table 13 lists active and discontinued partial-record stations for which flood frequency data have been reported by Glatfelter (1984).

The U.S. Geological Survey, in cooperation with the Indiana Department of Natural Resources, has collected sediment data at gaging stations on the Kankakee River at Shelby and the Iroquois River at Foresman since the 1960s. The frequency of data collection has averaged about once a month. These data are published annually in water-resource data reports by the U.S. Geological Survey, and are incorporated in a summary report by Crawford and Mansue (1986).

Stream gaging networks in the Kankakee-Yellow River Basin and Iroquois River Basin were evaluated by Neyer (1985) as part of a Division of Water review of Indiana's hydrologic data collection networks. As Neyer observed, the Kankakee-Yellow River Basin is heavily gaged on the larger watercourses but sparsely gaged on tributaries draining areas less than 100 sq. mi. As table 13 shows, only one gage in the Kankakee-Yellow River Basin (Cobb Ditch near Kouts) currently monitors tributary flows in a small watershed.

Neyer suggested the establishment of new stations on Wolf Creek in Jasper County, and/or Cook Ditch (Porter County), Geyer Ditch (St. Joseph County), or Robbins Ditch (Starke County) to help offset the lack of data on tributary flows. Neyer also suggested that gaging stations in the Iroquois River Basin should be added in irrigated and non-irrigated areas of Newton and Jasper Counties to more adequately assess potential irrigation impacts. Partial-record stations which operated only during selected periods would probably be sufficient for this purpose.

Neyer also pointed out that interpreting discharge data from the North Marion gage on the Iroquois River is complicated by the potential diversion of flow via Ryan Ditch. A supplemental station on Ryan Ditch could be established to monitor the diverted flow; otherwise, funding for the North Marion gage could better be applied to the installation of a new gage site.

Factors affecting stream flow

Stream flow varies in response to available precipitation, topographic features, soil conditions, land cover, hydrogeologic characteristics, and channel geometry. Changes in land use, drainage patterns, stream geometry, and ground-water levels also produce variations in stream flow.

The time variation in stream flow and its relation to temperature and precipitation can be illustrated by a graph of mean monthly values (figure 24). It might be expected that stream flow would directly parallel total precipitation, which is the source of all available water. However, as figure 24 shows, mean monthly precipitations is least in February, whereas mean monthly *runoff* is least in September. Conversely, precipitation is greatest in June whereas runoff is greatest in March and April.

These differences in precipitation and runoff can be attributed primarily to differences in evapotranspiration rates, although soil and ground-water conditions also can play an important role. In late summer and early fall, temperatures are warm and evapotranspiration losses are high; hence, much of the precipitation that would otherwise be available to streams is lost to the atmosphere. Moreover, ground-water levels are at or near their seasonal low, and *base flow* may be limited.

In late winter and early spring, temperatures are mild, plants are dormant or very young, and evapotranspiration rates are low. The ground often is either frozen or saturated, and may be covered by melting snow. As a result of these factors, more of the total precipitation is available to streams in the form of *overland flow* and base flow.

The geographic variation in stream flow can be illustrated by comparing runoff characteristics along the same stream and among different streams. Although many stream-flow parameters can be used to compare runoff characteristics, flow-duration analysis is used in this illustration because it does not depend on the chronological sequence of daily flows.

The annual flow-duration curve of daily mean discharges is a cumulative frequency curve that shows the percent of time that specified daily discharges are equaled or exceeded during a given period of record. For example, daily mean flows of the Kankakee River near North Liberty were at least 52 cfs (cubic feet per second) on 99.9 percent of the days during the period 1952-85 (figure 25, in red). Daily flows for this period exceeded 750 cfs only 0.1 percent of the time.

The shape of the duration curve is related to the storage characteristics of the drainage basin, which in turn are related to topographic and hydrogeologic features. A steeply sloping duration curve indicates a stream draining a basin with little surface or subsurface storage. Flood peaks on this type of stream are high and rapid because most excess precipitation runs off the land surface and enters the stream. During dry periods when overland flow has ceased, this type of stream may cease flowing because the amount of base flow is negligible.

A duration curve that is gently sloping indicates a stream draining an area with substantial basin storage. Flood peaks on this type of stream are attenuated because much of the excess precipitation is stored in surface depressions, permeable soils, or surficial geologic deposits. During dry periods, stream flow is sustained by the slow, steady release of water from these surface and/or underground sources.

Duration curves for the Kankakee River and Singleton Ditch, one of its major tributaries, illustrate the effect of topography and geology on stream-flow characteristics. A common period of record was used for the duration analysis to minimize flow differences which may be attributed to differences in local precipitation from short-term events. Discharge was calculated on a per-square-mile (*unit*) basis to minimize the effect of unequal basin sizes on stream-flow characteristics.

As figure 25 shows, the duration curve for Singleton Ditch is fairly steep in relation to the Kankakee River curve. The higher unit discharges on Singleton Ditch at durations less than 15 percent indicate a higher runoff rate per square mile of drainage basin during periods of heavy rainfall.

The higher unit flows on Singleton Ditch primarily reflect the limited amount of floodplain storage and the channel's relatively steep slope. The high levee along

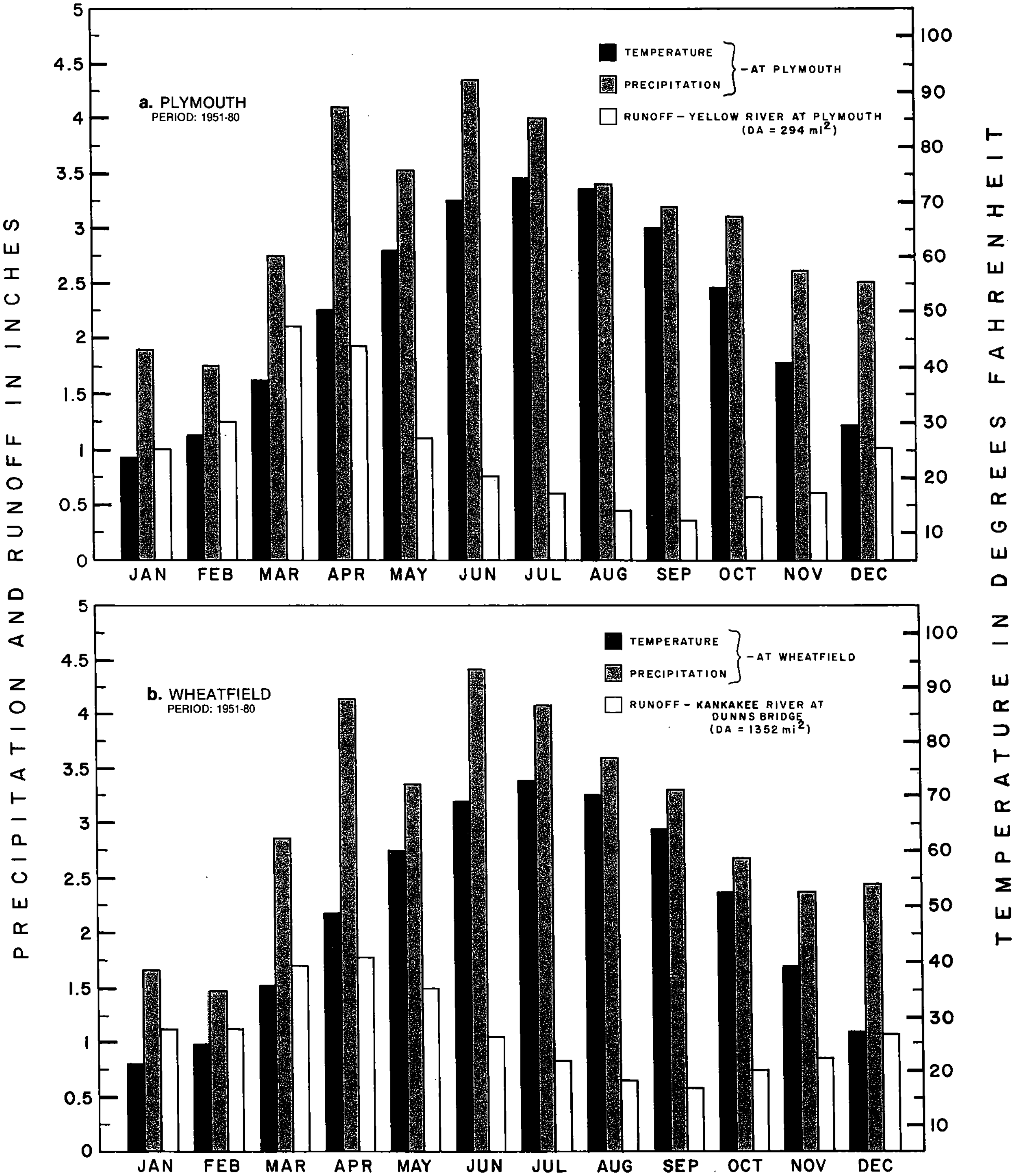


Figure 24. Variation of mean monthly temperature, precipitation and runoff
(Data from National Oceanic and Atmospheric Administration, 1985 and U.S. Geological Survey, unpublished data)

Singleton Ditch and the nearly straight flow path confine flood runoff to a narrow, deeply dredged channel; hence, flood peaks are reached quickly with little attenuation.

Differences in *channel slope* also help create differences in stream-flow characteristics. The channel gradient of 3.2 feet per mile upstream of the Schneider gage is nearly three times that of the Kankakee River gradient upstream of the gage at North Liberty (see Glatfelter, 1984). The length of each stream is nearly equal (about 23 miles).

Moreover, northern tributaries of Singleton Ditch descend from the elevated Valparaiso Moraine (figure 14); consequently, tributary gradients can be quite steep. The rapid runoff from these clayey till uplands is subsequently reflected in high flows along Singleton Ditch.

Unlike the duration curve for Singleton Ditch, the relatively flat upper end of the Kankakee River curve (figure 25) indicates the presence of flow-attenuating factors. The large amount of *overbank* storage available

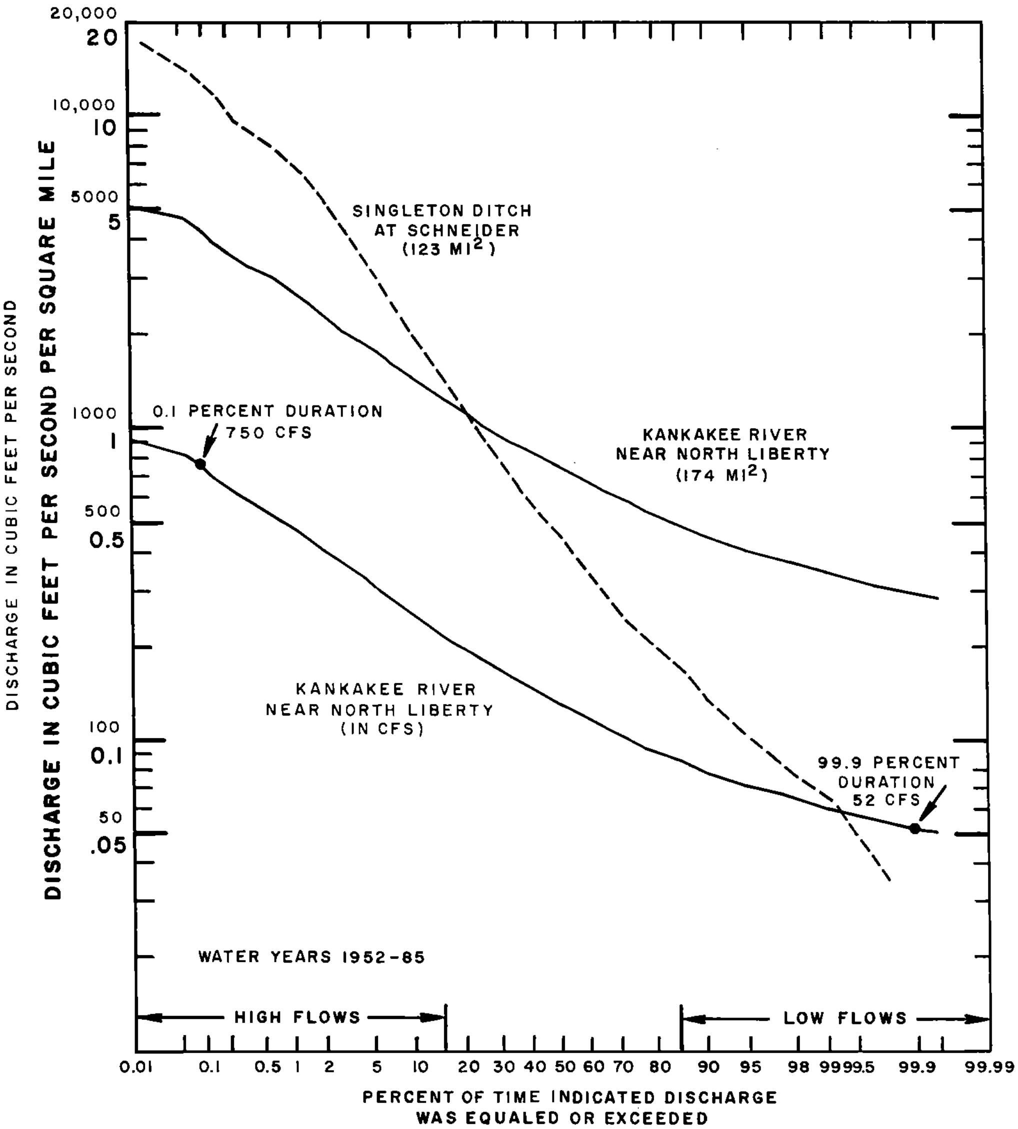


Figure 25. Duration curves of daily mean stream flow for Singleton Ditch at Schneider and Kankakee River near North Liberty

in the Kankakee River valley is primarily responsible for the reduced peak flows.

Closed depressional areas, most of which are located in the tributary basins of County Line and Geyer Ditches (figure 23) provide additional surface storage in the Kankakee River Basin upstream of North Liberty. These depressional areas, which include some small lakes or wetland remnants, do not contribute directly to surface runoff because of their lack of a defined drainage outlet. The large amount of ground-water storage afforded by the valley deposits of permeable sands and gravels also helps reduce flood peaks along the Kankakee River.

The large storage capacity of outwash deposits in the Kankakee River valley helps attenuate flood peaks during storm events, and also helps sustain low stream flows during periods of little or no rainfall. Ground water stored during recharge events is available for later discharge to streams, lakes and wells. The high base flow at the Kankakee River above North Liberty is evident in figure 25 by the sustained unit low flows at durations greater than 85 percent.

The steep lower end of the duration curve for Singleton Ditch indicates a limited amount of base flow. The main channel of Singleton Ditch lies within the Kankakee River valley, but about three-fourths of its drainage area is developed on clayey tills; hence, ground-water contribution from its upper reaches is minimal. In addition, Brown Ditch may intercept some of the ground-water flow which may have discharged into Singleton Ditch upstream of the Schneider gage.

SURFACE-WATER DEVELOPMENT POTENTIAL

The potential of surface-water systems for water-supply development can have a great impact on agricultural development and other economic activities. Rivers, streams and ditches are expected to remain the major source for surface-water development in the Kankakee River Basin. Although withdrawals occur on ponds, gravel pits, lakes, and within wetlands, these systems are not considered as significant water supply sources because of their limited storage capacity, water-quality considerations, economic constraints, and in some cases, regulatory and environmental constraints.

Wetlands and lakes

As described previously in the ***Surface-Water Resources*** section of this chapter, there are two types of non-riverine wetlands in the Kankakee River Basin. Palustrine wetlands include marshes, swamps, bogs, and other areas covered at least periodically by shallow water. Lacustrine wetlands include the deep portions of lakes, gravel pits, and large ponds.

Although some palustrine wetlands in the Kankakee River Basin may store considerable amounts of water at certain times, the shallow water depths and the temporary nature of ponding does not make these wetlands suitable as water-supply sources. Moreover, regulatory and non-regulatory programs administered by state and federal agencies (appendix 4) discourage the detrimental exploitation of wetlands, including certain land uses which would adversely affect nearby wetlands. The values of wetlands and the need for their conservation was discussed earlier in this chapter.

Surface-water withdrawals in the Kankakee River Basin occur on many privately owned ponds and small lakes, primarily for irrigation purposes. Other withdrawals occur on ponds at sand and gravel production facilities.

Public freshwater lakes in the basin generally are not used for water supply. An exception is Flint Lake in Porter County, which is used as a supplementary water-supply source by the Valparaiso Waterworks. In Lake County, an inlet ditch to Cedar Lake is used to supply water for golf-course irrigation.

As discussed previously in this chapter, existing state laws discourage both direct and indirect pumpage from natural lakes. Most notably, IC 13-2-13 requires that lakes having a legally established average normal water level are to be maintained at that level. Temporary lowering of the lake level below its designated elevation requires prior approval from a local circuit court and the Natural Resources Commission.

Even if state laws were amended to allow lowering of lakes levels for water-supply purposes, treatment and distribution costs probably would limit uses to irrigation, livestock watering, or fire protection. Pumpage-induced lowering of water levels could detrimentally affect existing water quality, fisheries habitat, and adjacent wetlands. Moreover, even a minor lowering of lake levels would be objectionable to most lakeside property owners.

Adding lake storage for supply purposes also has considerable drawbacks. Amendments to current lake laws or approval for temporary lake-level increases would be required. Moreover, existing control structures at potential supply sites would have to be modified, because few lake-level control structures are designed to store water at elevations above the legal level. Furthermore, the inundation of lakefront property would be objectionable to lakeside property owners.

Streams

The water-supply potential of streams can be evaluated on the basis of selected stream-flow characteristics, which are defined as statistical or mathematical parameters derived from records of stream discharge. In this report, average and low stream-flow characteristics were defined at gaged sites using flow-duration curves, frequency analysis, and hydrograph separation techniques. The characteristics and techniques described below also can be used in other applications, including the design and operation of water-supply facilities, waste-treatment plants, reservoirs, and hydroelectric power plants; water-quality studies; waste-discharge regulation; and management of fish and wildlife habitat.

Methods of analysis

Average flow

Average flow is the arithmetic mean of individual daily mean discharges during a selected time period, such as a week, month, season, year, or period of several years. The long-term mean annual discharge, commonly known as the average flow, is the arithmetic mean of the annual mean discharges for the period of data record.

Because the statistical distribution of stream flows is *skewed*, average discharge usually is greater than the median discharge, which is the flow equaled or exceeded 50 percent of the time. On the Yellow and Iroquois Rivers, average discharge is equaled or exceeded 25 to 30 percent of the time. On the mainstem Kankakee River, average flow is equaled or exceeded 35 to 40 percent of the time. Average flow on the Kankakee River more closely approximates median flow because discharge values are more normally distributed.

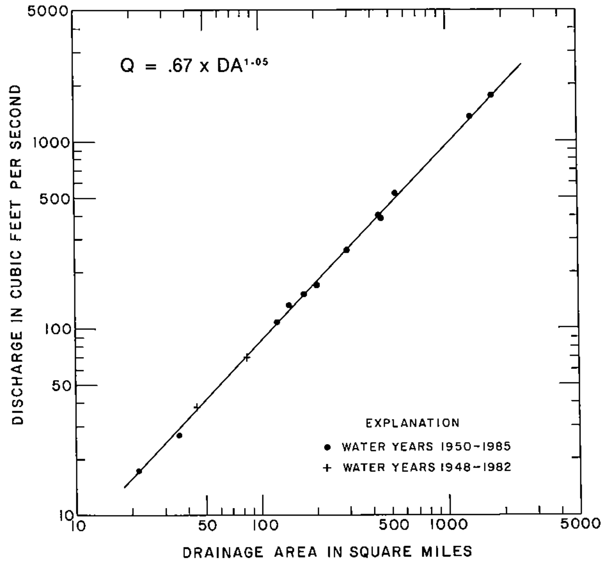


Figure 26. Relation of average annual discharge at continuous-record gaging stations to total drainage area

The relation between average flow and drainage area is commonly used in hydrologic applications. Figure 26 illustrates a relation derived from concurrent long-term flows for selected continuous-record gages in the Kankakee River Basin. The equation shown can be used to estimate average flows at ungaged sites on streams in the Indiana part of the basin that drain areas of at least 20 square miles.

Because average flow encompasses the amount of water leaving a basin as both surface-water runoff and ground-water discharge to streams, this flow can be considered as the theoretical upper limit of the long-term yield that can be developed from a stream. If it were possible to store, in a single hypothetical reservoir, all the water that flows from a watershed during a specified period and then release the water at a uniform rate over the same period, that rate would be the average flow. **Average runoff** is defined as the depth to which a drainage basin would be covered by water if the average discharge for a given time period were uniformly distributed upon the land surface of that basin.

Flow duration

Flow-duration curves, as described in a previous section, show the percent of time that specified daily discharges are equaled or exceeded during a given period of record. Because duration curves provide information on a stream's entire range of flows, these curves are useful in characterizing overall flow characteristics and in identifying differences in stream-flow variability. Duration curves also can be used to estimate the percent of time that a given demand for stream flow can be met, on average, over a long period of time. However, curves cannot be used to determine the sequence, statistical frequency, or duration of either adequate or deficient flows.

For example, if a daily flow of 100 cubic feet per second were needed on the Kankakee River near North Liberty to support a designated withdrawal, the flow would be sufficient about 70 percent of the time (figure 25), or an average of 235 days per year over a period of many years. In any one year, however, all 235 days of sufficient flow would not occur consecutively. Moreover, the total number of days having sufficient flow would vary widely from year to year.

Flow ratio is a general term that can apply to many stream-flow parameters. In this report, the maximum-to-minimum ratio of annual mean flows and the ratio of 20-percent-duration to 90-percent-duration flows are used to indicate the variability of stream flow.

The 20-to-90-percent **flow-duration ratio** is a numerical index that represents the slope of the middle portion of the flow-duration curve (figure 25). As described previously, the flow-duration ratio (slope) reflects not only the presence in a watershed of flood-attenuating factors, but also the degree of base flow.

The Kankakee River near North Liberty, for example, has a flow-duration ratio of approximately 2, whereas Singleton Ditch at Schneider has a ratio of nearly 9 (figure 25). The lower ratio of the Kankakee River relative to Singleton Ditch indicates a higher amount of base flow and the existence of more sustained stream flows during dry weather.

Low flows

Low-flow frequency data can be used to estimate how often, on the average, minimum mean flows are expected to be less than selected values. Low-flow characteristics commonly are described by points on low-flow frequency curves prepared from daily discharge records collected at continuous-record gaging stations. Correlation techniques can be used to estimate curves, or selected points on curves, for sta-

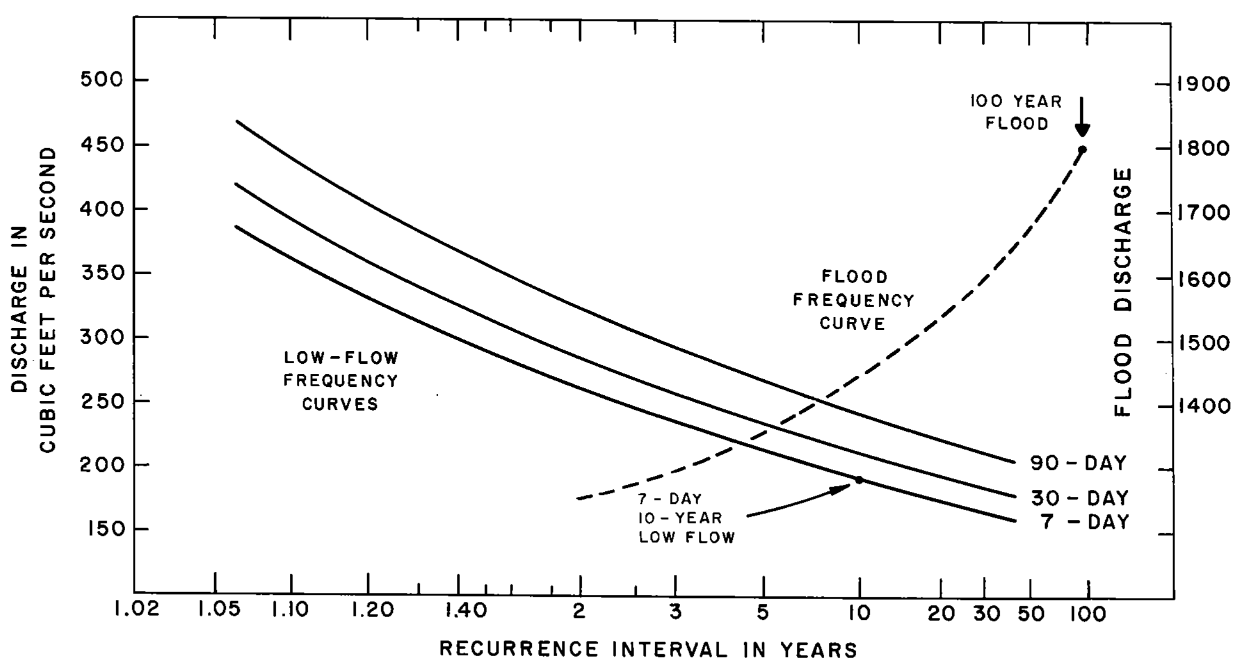


Figure 27. Frequency curves of annual peak discharge and annual lowest mean discharge for indicated number of consecutive days for the Kankakee River at Davis

tions where short-term records and/or base-flow measurements are available.

Low-flow frequency curves show the probability of minimum mean flows being equal or less than given values for a specified number of consecutive days. Figure 27 shows the relation of annual minimum mean discharges for 7-day, 30-day, and 90-day periods for the Kankakee River at Davis. The 1-day curve is not shown because it nearly coincides with the 7-day curve.

In this report, the following points on the 1-day and 7-day curves have been selected as indices of low flow: the minimum daily (1-day mean) flow having a 30-year *recurrence interval,* and the annual minimum 7-day mean flow having a 10-year recurrence interval (figure 27).

The 1-day, 30-year low flow is the annual lowest 1-day mean flow that can be expected to occur once every 30 years, on the average. In other words, it is the annual lowest daily mean flow having a 1-in-30 chance of occurrence in any given year. In this report, the 1-day, 30-year low flow indicates the dependable supply of water without artificial storage in reservoirs or other impoundments. In many cases, the 1-day, 30-year low flow equals or closely approximates the minimum daily discharge of record for streams in the Kankakee River Basin.

The 7-day, 10-year low flow is the annual lowest mean flow for 7 consecutive days that can be expected to occur, through a long period, on the average of once every 10 years. There is a 1-in-10 chance that the annual minimum 7-day mean flow in any given year will be less than this value.

In Indiana, the 7-day, 10-year low flow (7Q10) is the index for water-quality standards. The flow is used for siting, design, and operation of wastewater-treatment plants; for evaluating wastewater discharge applications and assigning wasteload limits to industrial and municipal dischargers; and as an aid in setting minimum water-release requirements below impoundments. In the future, the 7Q10 or other low-flow parameters may be used by the Indiana Department of Natural Resources to establish minimum flows of selected streams.

The U.S. Geological Survey has developed a method for estimating the 7Q10 on ungaged streams in Indiana (Arihood and Glatfelter, 1986). Regression analysis was used to derive an equation which is most accurately applied to unregulated streams in northern and central Indiana which drain areas between 10 and 1000 square miles, and have 7Q10s greater than zero. The equation determined by Arihood and Glatfelter (1986) is as follows:

$$7Q10 = 1.66 \times DA^{1.03} \times RATIO^{-1.51}$$

where

DA = the contributing drainage area, in square miles;

and

RATIO = the 20-to-90 percent flow duration ratio.

In the Kankakee River Basin, regionalized flow-duration ratios mapped by Arihood and Glatfelter (1986) are summarized as follows:

* Mainstem Kankakee River Basin — 3
* Kankakee River tributaries in Lake, Newton and Jasper Counties — 5-10
* Upper Yellow River Basin — 10
* Lower Yellow River Basin — 3-5
* Iroquois River Basin — 20-25
* Bice Ditch, selected tribs. to Iroquois River — 25
* Carpenter Creek Basin — flow-duration ratio is undefined (7Q10 = 0).

Although 7Q10s estimated from the equation and flow-duration ratios shown above may differ from values based on other regionalization techniques or partial-record data, the estimates are suitable for broad planning purposes. Site-specific design flows should be determined according to local watershed conditions and more detailed analyses.

Hydrograph separation

Hydrograph separation is a technique used to divide stream flow (*total runoff*) into its component parts of surface runoff, interflow and base flow. *Surface runoff* is the combination of precipitation falling directly upon the stream and water flowing over the land surface toward the stream (*overland flow*). *Interflow* occurs when precipitation that has infiltrated the soil moves laterally through the soil toward the stream. For convenience, interflow and surface runoff can be combined into one category called *direct runoff.* Base flow is the portion of stream flow that is derived largely or entirely from ground-water discharge.

A graphical technique can be used to separate the base-flow hydrograph from a stream-flow hydrograph

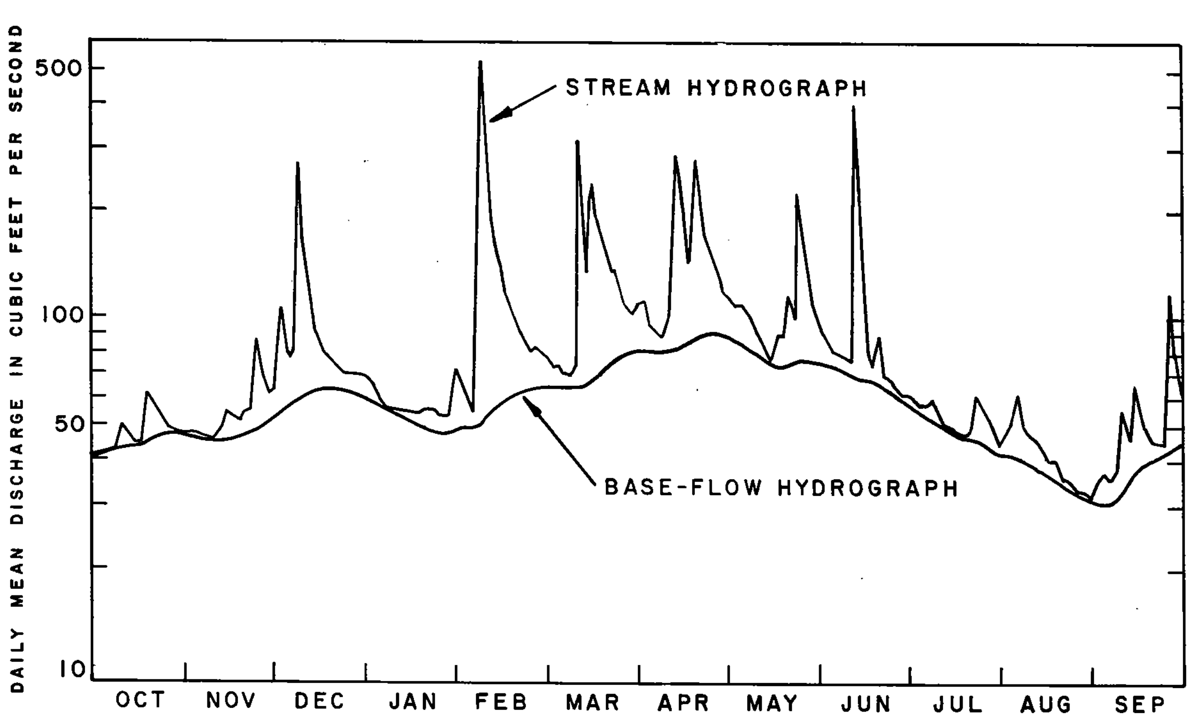


Figure 28. Example of stream-flow and base-flow hydrographs

of daily discharges. As figure 28 shows, the hydrograph of daily stream flows is composed of peaks and valleys which often are quite sharp. The peaks represent the quick response of stream flow to storm runoff received as overland flow and interflow, and occasionally as ground-water flow from hillslopes adjacent to the stream. The base level to which the peaks return represents the base flow which continues to occur after overland flow has ceased. The base-flow hydrograph therefore can be approximated by eliminating the sharp hydrograph peaks and drawing a smooth curve (figure 28).

The volume of total runoff for a given water year is computed by converting each daily discharge to a daily volume, then summing these values over the year in question. The total runoff volume can then be converted to inches by dividing it by drainage area. A similar technique can be used to compute the total annual base-flow volume.

The ratio of base flow to total runoff is one measure of the degree to which stream flow is sustained by ground-water discharge. This ratio therefore is an indicator of the dependability of a stream for water supply.

Average runoff of Kankakee River Basin

The total water-supply potential of a basin is the average precipitation that falls on the land surface and is not lost to evapotranspiration or used consumptively, such as being incorporated into a manufactured product. The theoretical maximum supply potential of the Kankakee River Basin as a whole can be defined as the long-term average runoff, which includes both surface runoff and ground-water discharge to streams.

Table 14 shows the mean monthly stream flow leaving the Indiana portion of the Kankakee River Basin. These values represent all the water leaving the basin as stream flow, including flows in upper reaches of minor tributaries which drain to streams in Illinois.

Average discharges for gages on the Kankakee River at Shelby, Singleton Ditch at Schneider, and the Iroquois River at Iroquois, Illinois were used to approximate the total volume of water leaving the Indiana portion of the Kankakee River Basin. Discharges were modified to represent flows at the Indiana-Illinois state line by using drainage-area adjustments. Discharges also were adjusted to a long-term base period 1922-85.

Table 14. Average monthly runoff of the Kankakee River Basin

{Values were approximated for a total drainage area of 2,989 sq. mi.}

Month	Vol. (bg)	Discharge (cfs)	Runoff (in)
April	91.3	387.7	1.75
May	74.9	318.1	1.44
June	53.9	228.9	1.03
July	36.4	154.6	0.70
August	23.9	101.5	0.46
September	21.6	91.7	0.41
October	27.6	117.2	0.53
November	33.5	142.3	0.64
December	48.3	205.1	0.93
January	55.6	236.1	1.07
February	60.1	255.2	1.16
March	87.2	370.3	1.68
Total	614.3	2608.7	11.81

Table 14, like the graphs in figure 24, show that water availability in the form of stream flow generally is greatest in spring and least in late summer and early fall. In any given year, however, water availability may vary greatly from the tabulated values. Moreover, future developments which cause increased consumptive use could potentially reduce the amount and temporal distribution of available water.

Supply potential of streams

The potential of individual streams in the basin for water-supply development is discussed in the following pages. It should be emphasized that stream flows are assessed without regard to the potential construction of impounding reservoirs (either in-channel or off-channel) that could greatly improve the water-supply potential of some streams. Moreover, the LaPorte precipitation anomaly is not considered because the existence of a true climatic anomaly remains questionable. Variations in stream-flow characteristics are interpreted primarily on the basis of geologic, soil and topographic differences among and within drainage basins.

Table 15 lists selected stream-flow characteristics for active and inactive continuous-record gaging stations having at least 15 years of data record as of water year 1985. Average and low-flow values for these stations and low-flow values for partial-record stations are plotted in figure 29 to facilitate an assessment of the geographic variation in flows.

Mainstem Kankakee River Basin

The stream-flow values in table 15 indicate that the Kankakee River has by far the greatest potential for water-supply development of any basin stream. As described later in this report, the Kankakee River currently supports the largest number of high-capacity withdrawals, mainly for irrigation purposes.

The abundant supply of water in the Kankakee River is attributable to the large drainage area and the geomorphic and hydrogeologic features of the river valley. As discussed earlier in the ***Physical Environment*** chapter of this report, the Kankakee River valley is characterized by permeable loamy and sandy soils overlying medium- to coarse-grained outwash deposits, predominantly sands.

The large amount of ground water stored in the Kankakee River valley and discharged to surface-water systems produces well-sustained stream flows throughout the year that can support a variety of withdrawal and instream uses. The river's value as a potential water-supply source is further increased by the fairly small variability of flows.

The small range in flows on the Kankakee River is evident in several stream-flow parameters, including flow ratios. Maximum annual mean flows calculated for four gaging stations average three times the minimums (table 15). In contrast, maximum annual means on the Yellow River are nearly four times the minimums, and maximums on the Iroquois River are eight to ten times the minimums. Maximum-to-minimum ratios for other major rivers in northern and central Indiana range from 4 to 8 (see Arvin, 1989).

The nearly horizontal slopes of flow-duration curves for the mainstem Kankakee River (figure 30) also reflect the small range in stream flows. The slope of the middle portion of the duration curve, which can be defined as the ratio of the 20-percent duration flow to the 90-percent duration flow (Arihood and Glatfelter, 1986), ranges from about 2 at the North Liberty gage to 4 at the Dunns Bridge gage. In contrast, flow-duration ratios for gages on the Yellow and Iroquois Rivers range from 5 to 13.

Table 15. Stream-flow characteristics at selected continuous-record gaging stations

{Stations selected had at least 15 years of data record through water year 1985.}

Total drainage area, average discharge, annual runoff, extremes: From Arvin (1986) except as noted. Contributing drainage area is shown in parentheses for watersheds with non-contributing portions.

Extremes: Daily maximum represents maximum instantaneous peak discharge; daily minimum represents minimum daily mean discharge.

Low flows: Estimated by Division of Water using regression analysis.

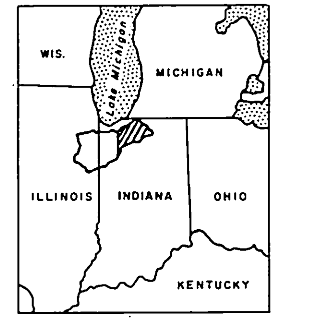
Ground-water contribution: Estimated by Division of Water using graphical method of hydrograph separation. Values are for water year 1970 except as noted.

Station name	Total drainage area (sq mi)		Average discharge (cfs)	Annual runoff (in)	Extremes (cfs)				Low flows			Baseflow (percent of total runoff)
					Annual mean		Daily		1-day, 30-year	7-day, 10-year		
					max	min	max	min	cfs	cfs	cfsm	
KANKAKEE RIVER												
near North Liberty	174	(116)	152	11.9	206	95	908	46	47	56.4	0.32	83
at Davis	537	(400)	539[1]	13.6[1]	755	293	1920	154	159	188	0.35	86
at Dunns Bridge	1352	(1160)	1336	13.4	1980	618	5870	280	300	345	0.26	80
at Shelby	1779	(1578)	1751[1]	13.4[1]	2720	775	7650	260	347	423	0.24	85
YELLOW RIVER												
near Bremen[2]	135		104	10.5	171	46	1650	6.2	5.5	6.3	0.05	—
at Plymouth	294	(272)	261	12.0	434	119	5390	13	15.5	20	0.07	43
at Knox	435	(384)	398	12.4	661	180	5660	50	57.1	73.5	0.17	65
IROQUOIS RIVER												
at Rosebud	35.6		27.1	10.3	48	6	475	0.5	1.05	2.0	0.06	56
near North Marion	144		133	12.5	245	24	2040	1.6	2.29	4.19	0.03	47
at Rensselaer	203		169	11.3	303	30	2550	2.2	3.34	5.74	0.03	45
near Foresman	449		384	11.6	683	78	5930	6.3	6.94	11	0.02	40
TRIBUTARIES												
Kingsbury Creek near Laporte	7.08	(3.0)	4.3	8.2	7.4	2.9	306	0.8	0.86	1.2	0.17	87
Cobb Ditch near Kouts	30.3		33.7	15.1	48	19	795	8.9	9.12	10.9	0.36	60
Singleton Ditch at Schneider	123		109	12.0	211	24	3550	3.6	4.84	7.4	0.06	46
West Creek near Schneider[2]	54.7		41.4	10.3	70	11	1840	2.6	2.83	4.6	0.08	—
Bice Ditch near South Marion	21.8		17.5	10.9	36	3.5	1080	0	0	0.08	0.01	24
Slough Creek near Collegeville[2]	83.7		70.1	11.4	135	16	2390	0.7	0.83	1.43	0.01	—
Carpenter Creek at Egypt[2]	44.8		38.3	11.6	75	9	3720	0	0	0	0	—

[1]Calculated for water years 1950-85 to allow comparison with values for North Liberty and Dunns Bridge gages.
[2]Gage discontinued.

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

UPPER KANKAKEE RIVER BASIN



EXPLANATION

7 A / B — C / D / E

7- Map number

A- Stream gaging station or wastewater discharge point

- 05517530 U.S. Geological Survey stream gaging station number
- WTF Municipal wastewater treatment facility
- NM Non-municipal wastewater discharge
- IN Industrial wastewater discharge

NOTE: ONLY WASTEWATER DISCHARGES REGULATED UNDER THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM PERMIT PROGRAM ARE MAPPED

B- Drainage are in square miles

C- 1-day, 30-year low flow in cubic feet per second

D- 7-day, 10-year low flow in cubic feet per second

E- Average flow in cubic feet per second

NA- Data not available

/ Water quality problems documented in some reaches since 1982

▲ Put-and-take trout stream

Figure 29a. Selected stream-flow characteristics

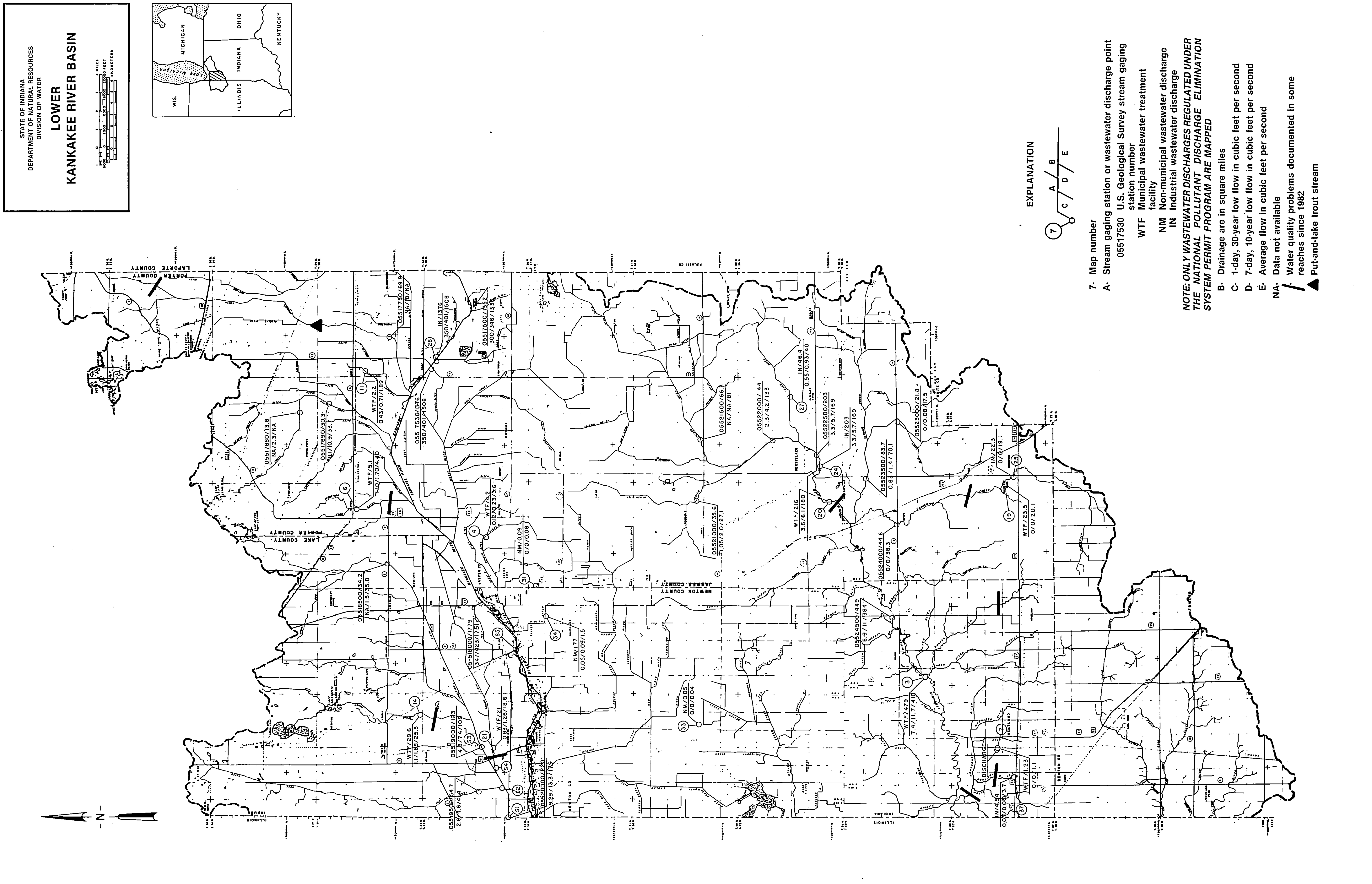


Figure 29b. Selected stream-flow characteristics

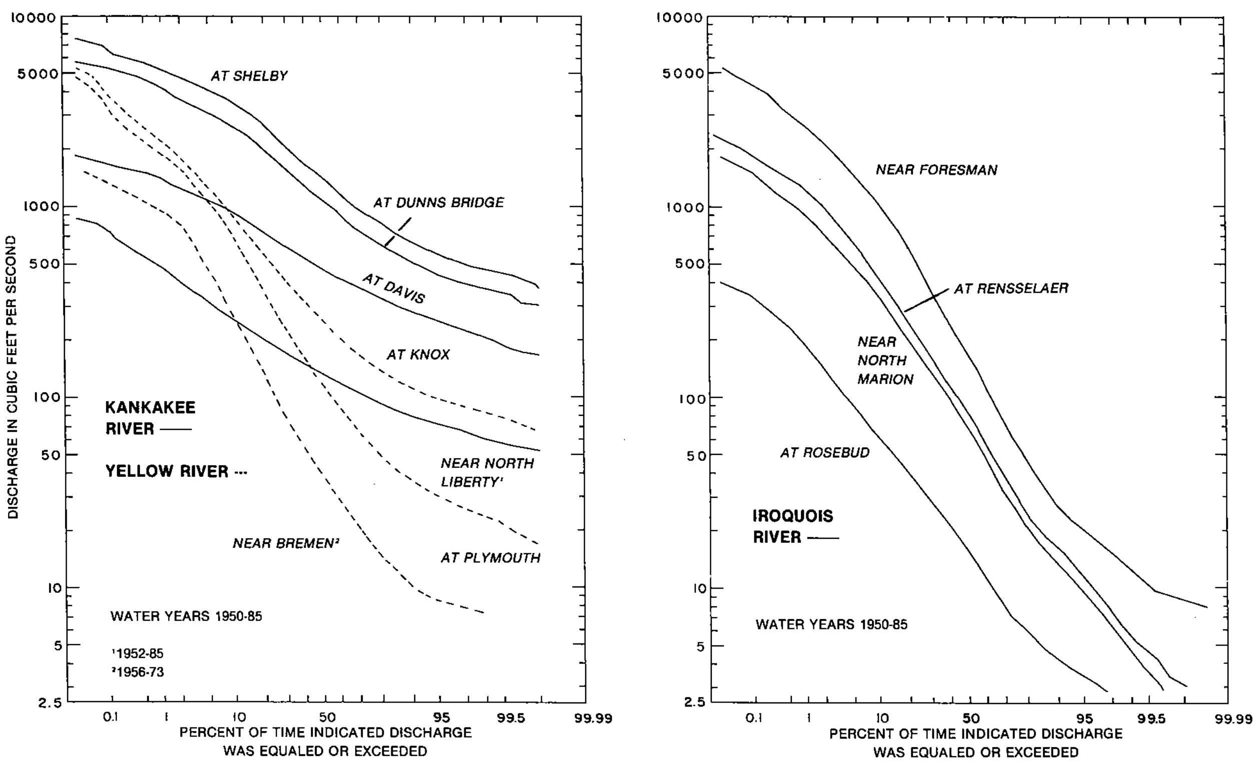


Figure 30. Duration curves of daily mean stream flow for gaging stations on the Kankakee, Yellow and Iroquois Rivers

The large amount of ground-water contribution to the Kankakee River is apparent from hydrograph analysis. As table 15 shows, base flow constitutes at least 80 percent of the flow on the Kankakee River during years of normal runoff.

The large amount of ground-water contribution to the Kankakee River also is reflected in low-flow parameters, including the lowest daily flows of record (table 15). These values are considerably higher than values for sites on the Yellow and Iroquois Rivers having comparable drainage areas.

As table 15 shows, low flows on the Kankakee River increase as drainage area increases. However, on a per-square-mile basis, low flows are slightly greater in upper reaches of the Kankakee River, as represented by the North Liberty and Davis gages, than in lower reaches, as represented by the Dunns Bridge and Shelby gages.

The amount of ground-water contribution may be greater in upper reaches of the Kankakee River than in lower reaches because of the presence of thick, coarse-grained, and laterally extensive outwash deposits. These productive deposits are found in the main valley but are most extensive north of the river in LaPorte, eastern Porter and northwestern St. Joseph Counties.

In the river's lower reaches, outwash deposits are thinner and finer grained than in upper reaches. The deposits are largely confined to the main river valley, and are flanked by clay- or silt-dominated morainal systems.

The lower unit flows in downstream reaches of the Kankakee River also could be reflecting the influence of the moderately to poorly sustained unit flows of the Yellow River, whose watershed is encompassed by the drainage basin of the lower Kankakee River. Unit values at and downstream of Dunns Bridge can be interpreted as composites of the less sustained flows of the Yellow River and the more sustained flows of the upper Kankakee River.

A third explanation for the lower unit flows of the lower Kankakee River may be related to the large number of stream withdrawals in southern Lake County and southwestern Porter County. However, a comparison of 7-day, 10-year low flows for the periods ending in 1958 (Rohne, 1962), 1978 (Stewart, 1983), and 1985 (Arvin, 1989) reveal the same trend of lower unit flows downstream of Dunns Bridge, even though the number of stream withdrawals increased during these three decades. Although a detailed analysis may have revealed temporal trends in stream flow, it appears that geomorphic and hydrogeologic features are the major factors determining low stream-flow characteristics.

Selected tributaries

Kingsbury Creek, Cobb Ditch, Singleton Ditch and West Creek are four northern tributaries of the Kankakee River which have at least 15 years of data record through 1985 (see table 13). Of these tributaries, Cobb Ditch exhibits the most sustained low flows, probably because the Cobb Ditch watershed is underlain by outwash sand and gravel deposits very similar in nature to deposits underlying the mainstem Kankakee River valley. The sustained nature of flows on Cobb Ditch is illustrated by the relatively flat slope of its flow duration curve (figure 31).

Several northern tributary watersheds of at least 30 sq. mi. which similarly encompass major extensions of the Kankakee River valley outwash system include the following: Sandy Hook Ditch, Crooked Creek, and Greiger Ditch watersheds in Porter County; the Little Kankakee River and Mill Creek watersheds in LaPorte County; and the Geyer Ditch watershed in St. Joseph County. These and other major tributaries in the main valley of the Kankakee River are expected to yield dependable quantities of water during much of the year because of their high base flows.

The drainage basin of Kingsbury Creek in LaPorte County has developed on productive outwash deposits; however, the creek's small drainage area limits the amount of ground-water storage available for discharge to the stream system. Based on its small drainage area and low unit flows (table 15), Kingsbury Creek is not expected to yield significant quantities of water on a dependable basis. Similar limitations are expected on other tributaries having small drainage areas.

Singleton Ditch supports the largest number of high-capacity withdrawals of any tributary in the Kankakee River valley. As described in a previous section entitled ***Factors Affecting Stream Flow***, Singleton Ditch traverses clayey morainal till in its upper reaches and productive outwash sands in its lower reaches. Most withdrawals occur in the outwash portion of the Singleton Ditch watershed, which is located primarily south of State Road 2 in Lake County (see figure 29).

Because the number and density of irrigation withdrawals from Singleton Ditch is large, the potential exists for water-supply conflicts, particularly during dry years. Other main-valley tributary ditches that support several registered withdrawals include Brown Ditch and Griesel Ditch in Lake County; Greiger Ditch in Porter County; and Pitner Ditch and Hanna Arm of Tuesberg Ditch in LaPorte County. A discussion of potential conflicts on selected tributaries is included in the final chapter of this report under the subheading ***Impacts of Stream Withdrawals***.

Southern tributaries of the mainstem Kankakee River are not used extensively for water withdrawals. Robbins Ditch in Starke County, Beaver Lake and Curtis Ditches in Newton County, and Dehaan and Barnard Ditches in Jasper County are examples of a few major ditches used as sources of irrigation water. Unit low flows on these and other ditches in the main valley are expected to approximate those of the mainstem Kankakee River, but small drainage areas may limit the quantity of available water.

Yellow River Basin

Although not as significant as the Kankakee River, the Yellow River is a major source of surface-water supply, particularly in its middle to lower reaches. Several registered water withdrawal facilities currently are located downstream of Plymouth, near the Marshall-Starke county line, and near Knox.

Flows on the Yellow River, like those on the Kankakee River, increase as drainage area increases (table 15). Unlike unit flows on the Kankakee River, however, unit flows along the Yellow River increase downstream.

The difference between unit flows on the upper and lower Yellow River is primarily the result of geologic differences between upper and lower portions of the Yellow River Basin. The Yellow River upstream of Plymouth drains a geologically complex area dominated by clayey tills; hence, only a moderate to limited amount of ground water is available for storage and discharge to streams. As the river approaches the main Kankakee River valley, it traverses productive outwash deposits, where more ground water is available.

The higher degree of ground-water seepage from the sands and gravels of the lower Yellow River valley is illustrated by the flatter duration-curve slope (figure 30) and the greater unit flows for the Yellow River at Knox relative to flows at Plymouth (table 15). Hydrograph analysis shows that ground water constitutes about 65 percent of the stream flow at Knox, in contrast to about 43 percent at Plymouth.

Because of the predominance of clayey or silty tills in the middle to upper Yellow River Basin, tributaries of the Yellow River have little potential for development. Unit low flows for Dausman Ditch and Wolf Creek (see figure 29) indicate a limited degree of ground-water contribution.

Iroquois River Basin

Of the Kankakee River Basin's three major rivers, the Iroquois River has the most limited potential for water-supply development. Very few withdrawals occur on the river, even in its lower reaches.

As table 15 shows, low flows on the Iroquois River increase as drainage area increases. Unit flows, however, decrease between the upper reaches, as represented by the Rosebud gage, and middle to lower reaches, as represented by the North Marion, Rensselaer, and Foresman gages.

About 60 percent of the drainage basin upstream of Rosebud is developed on windblown sand deposits; hence, ground-water contribution from tributary ditches probably helps to sustain flow in the mainstem Iroquois River. Farther downstream, the drainage basin of the Iroquois River is dominated by clayey and silty tills with a limited ability to transmit water; consequently, unit flows are smaller than those at Rosebud (table 15).

The three continuously gaged tributaries of the Iroquois River are not expected to yield significant quantities of water on a dependable basis. Flows on Slough Creek, Bice Ditch and Carpenter Creek approach zero during dry periods because of the limited degree of ground-water contribution from underlying till and lacustrine deposits.

As table 15 shows, Bice Ditch and Carpenter Creek have ceased flowing during extremely dry years because of the lack of ground-water discharge. Ground water constitutes only about 24 percent of the stream

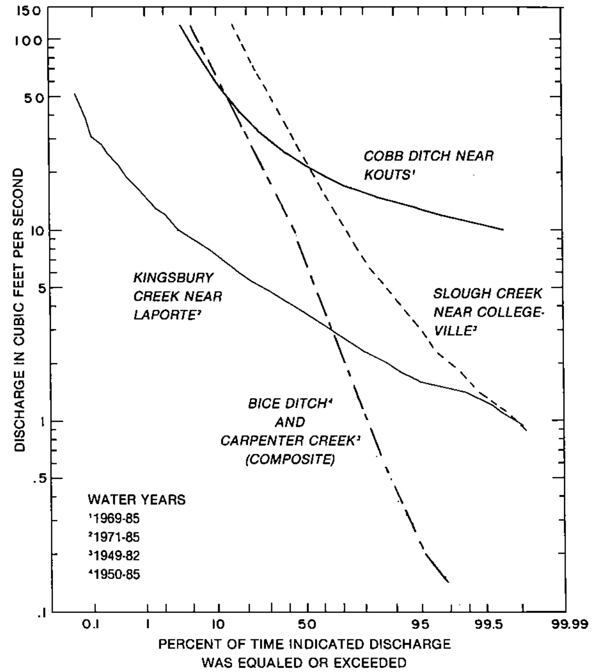


Figure 31. Duration curves of daily mean stream flow on selected tributaries

flow at the Bice Ditch gage. The steep duration-curve slopes for all three tributaries (figure 31) further illustrate the poorly sustained nature of low flows.

Although streams in the Iroquois River Basin are not expected to be a major source of future water-supply development, upland reservoirs could provide additional water supply where the soils and topography are suitable for reservoir construction. Water stored in these upland (side-channel) reservoirs during periods of high stream flows can later be made available for various uses.

Unlike in-channel reservoirs, upland reservoirs do not require a spillway and sedimentation is much less of a problem. Moreover, the storage capacity of upland reservoirs can be increased by excavating and contructing additional storage units or cells.

FLOODING

River flooding occurs when the transport capacity of a river is exceeded and its banks are overflowed. The Kankakee River overflows its banks, on average, about three times per year, causing minor to moderate damage. The average duration of flooding is about 3 to 7 days, but flood conditions may occur for several weeks to several months. Severe floods occur infrequently but cause extensive damage to agricultural, residential and urban areas.

About 135 square miles along the Kankakee River and 150 square miles in its tributary basins in Indiana are prone to flooding. Floods primarily inundate roads and farmland, although the cities of Plymouth and Knox along the Yellow River and some residential and resort communities flanking lower reaches of the Kankakee River can incur considerable damage during major floods.

The largest and most damaging floods of record typically occur during early spring when saturated or frozen soils, prolonged or widespread rainfall, and snowmelt can combine to produce maximum runoff over large areas. Major floods also can occur in summer, fall and winter under certain combinations of precipitation events and hydrologic conditions.

Flooding along the Kankakee River and its major tributaries often becomes most severe after breaches develop in dikes and levees (U.S. Army Corps of Engineers, 1979). Flooding can be aggravated when accumulated debris and sediment obstructs outlets of drainage ditches, or when extremely high river stages cause backwater in drainage tiles, thus flooding fields that are not otherwise flooded by direct bank overflow.

The highest floods of record on the mainstem Kankakee River were established during the March 1982 flood when melting of a dense snowpack in combination with saturated or frozen soil and moderate rains resulted in record-breaking runoff (see Glatfelter and others, 1984; Glatfelter and Chin, 1988).

Severe floods on the Kankakee River also have occurred in December 1927, April 1950, July 1953, October 1953, October 1954, June 1958, February 1959, February 1968, January 1973, March 1976, April 1978, March 1979, and March 1985. Major floods also have occurred prior to and during the channelization projects of 1893-1917, including a series of severe floods in the 1850s.

The highest recorded floods on middle to lower reaches of the Yellow and Iroquois Rivers occurred in October 1954 and June 1958, respectively, following widespread rains and heavy thunderstorms. Hale (1954), Huff and others (1955), and Daniels and Hale (1955) provide detailed discussions of the 1954 flood.

Flood-flow characteristics of the Kankakee River

Although historic channelization projects, levee construction and associated drainage projects probably have altered the hydrology of the Kankakee River Basin, the flood-flow characteristics of the mainstem Kankakee River remain unique among Indiana rivers. Flood volumes on the mainstem Kankakee River are quite large, but floods have unusually low peaks and unusually long durations. These and other factors combine to produce a flood hydrograph that is nearly flat relative to flood hydrographs of other major rivers in Indiana.

The availability of a large amount of *overbank* storage in most of the Kankakee River valley is the principal cause of reduced peak runoff and sustained flood duration. In upper reaches, however, depression storage on pitted outwash and morainal surfaces is a major attenuating factor. Because many depressional areas near the LaPorte-St. Joseph County line have no defined drainage outlet, they do not significantly contribute to surface runoff during flood events. These non-contributing drainage areas may cover up to several square miles and may contain lakes, ponds, or other isolated wetlands.

The low topographic relief, flat stream gradient, sandy soils with a low soil runoff coefficient, and permeable surficial deposits of the Kankakee River valley are among the other factors contributing to the relatively low rate of runoff along the mainstem. The low drainage density and elongated basin shape may also help reduce flood peaks along the mainstem, although these and other geomorphic factors have more pronounced influences on flood-flow characteristics of smaller basins.

The Kankakee River flows through a wide, flat floodplain surrounded by an upland plateau of nearly uniform width. The 100-year floodplain varies in width from about 2500 feet near the Jasper-Starke County line to nearly 5 miles at the town of English Lake.

The *channel slope* of the mainstem Kankakee River is the least of any major Indiana river (see Glatfelter, 1984). Although slightly steeper in upper and extreme lower reaches, most of the mainstem Kankakee River in Indiana has a downstream gradient of about one foot per mile.

The Kankakee River and its principal tributaries within the main valley are quite shallow. Maximum water depth on the floodplain is about 5 feet for an extreme flood event. However, most of the floodplain experiences flooding of a much shallower nature (Chenoweth, 1977).

The floodplain of the mainstem Kankakee River does not convey substantial amounts of water during flood periods, primarily because water depths on the floodplain are very shallow and the downstream gradient is nearly flat (Chenoweth, 1977). However, great expanses of the river floodplain periodically are inundated as floodwaters overtop the riverbanks.

Overbank flooding is so prevalent along the mainstem Kankakee River that flood runoff appears to reflect characteristics typical of a shallow reservoir (Dodson, Kinney and Lindblom, 1968). Small increases in river stage and rate of flow produce significant increases in overbank flooding.

Flood frequency

Although the initial indicator of a flood is the river's water stage, the determination of a flood's relative size is related to the peak discharge, because ice, debris or vegetation can cause higher water stages than would otherwise occur for a given flow. Peak-discharge data in the Kankakee River Basin are collected from a network of continuous-record and crest-stage partial-record stream gaging stations operated jointly by the U.S. Geological Survey and IDNR Division of Water (see figure 23, table 13).

Deriving peak-flow characteristics from stream gage records is one step in helping mitigate flood damages and in planning for future floods. Discharge-frequency characteristics can be used for 1) the design and construction of roads, bridges, dams, levees and spillways; 2) the regulation of floodplains; 3) the management of water-control works such as dams and spillways; 4) the mapping of flood-prone lands; and 5) flood forecasting.

Table 15 presents maximum peak flows recorded at continuous-record gaging stations in the Kankakee, Yellow, and Iroquois Basins having at least 30 years of data for the period of record ending in 1985. The relatively low peak flows on the mainstem Kankakee River are apparent. The drainage basins of Singleton Ditch at Schneider, Iroquois River at North Marion, and the Kankakee River at North Liberty are of comparable size, for example, but maximum peak flows at the Singleton Ditch and Iroquois River gages are two to four times greater than maximum peaks on the Kankakee River.

The unusually low peak runoff rates per square mile on the mainstem Kankakee River also are apparent from table 15. Except for a slightly higher rate per square mile at the North Liberty gage, unit discharges for maximum flood peaks on the mainstem Kankakee River average 5 cubic feet per second per square mile (cfsm) of contributing drainage area, as derived from columns 2 and 7 of table 15.

The variability of flood or peak flows, like the variability of low flows, can be statistically described by frequency curves. Flood frequency is generally expressed as the probability, in percent, that a flood of a given magnitude (discharge) will be equaled or exceeded in any one year. The recurrence interval, the reciprocal of the exceedance probability multiplied by 100, is the average number of years between exceedances of a given flood magnitude.

The *100-year flood*, for example, is the peak discharge that is expected to be equaled or exceeded on the average of once in a 100-year period (see example in figure 27). In other words, there is a 1 percent chance that a peak discharge of at least this magnitude will occur in any given year. Similarly, the 50-year flood has a 2 percent chance of occurring in any given year, the 25-year flood has a 4 percent chance, and the 10-year flood has a 10 percent chance.

It should be noted that recurrence interval, or frequency, represents the long-term average time period during which a flood exceeding a certain magnitude is expected to occur once. It does not imply a regular periodicity between floods. A peak discharge having a 100-year recurrence interval, for example, could possibly occur in two consecutive years, or even in two consecutive weeks. On the other hand, the 100-year flood may not occur for several hundred years.

Moreover, the discharge-frequency values only are accurate to the extent that the available discharges used in the statistical analysis are representative of the long-term discharge record. In general, a minimum of 30 years of data record is required to yield reliable flood frequency values for large floods.

Since 1976, the Division of Water has coordinated with the U.S. Geological Survey, U.S. Soil Conservation Service and U.S. Army Corps of Engineers to determine peak discharge-frequency values for Indiana streams (Indiana Department of Natural Resources, 1988). A comparison of computed flood frequency values with maximum recorded discharges on the Kankakee, Yellow and Iroquois Rivers reveal that, with the exception of the Iroquois River at Foresman, peak