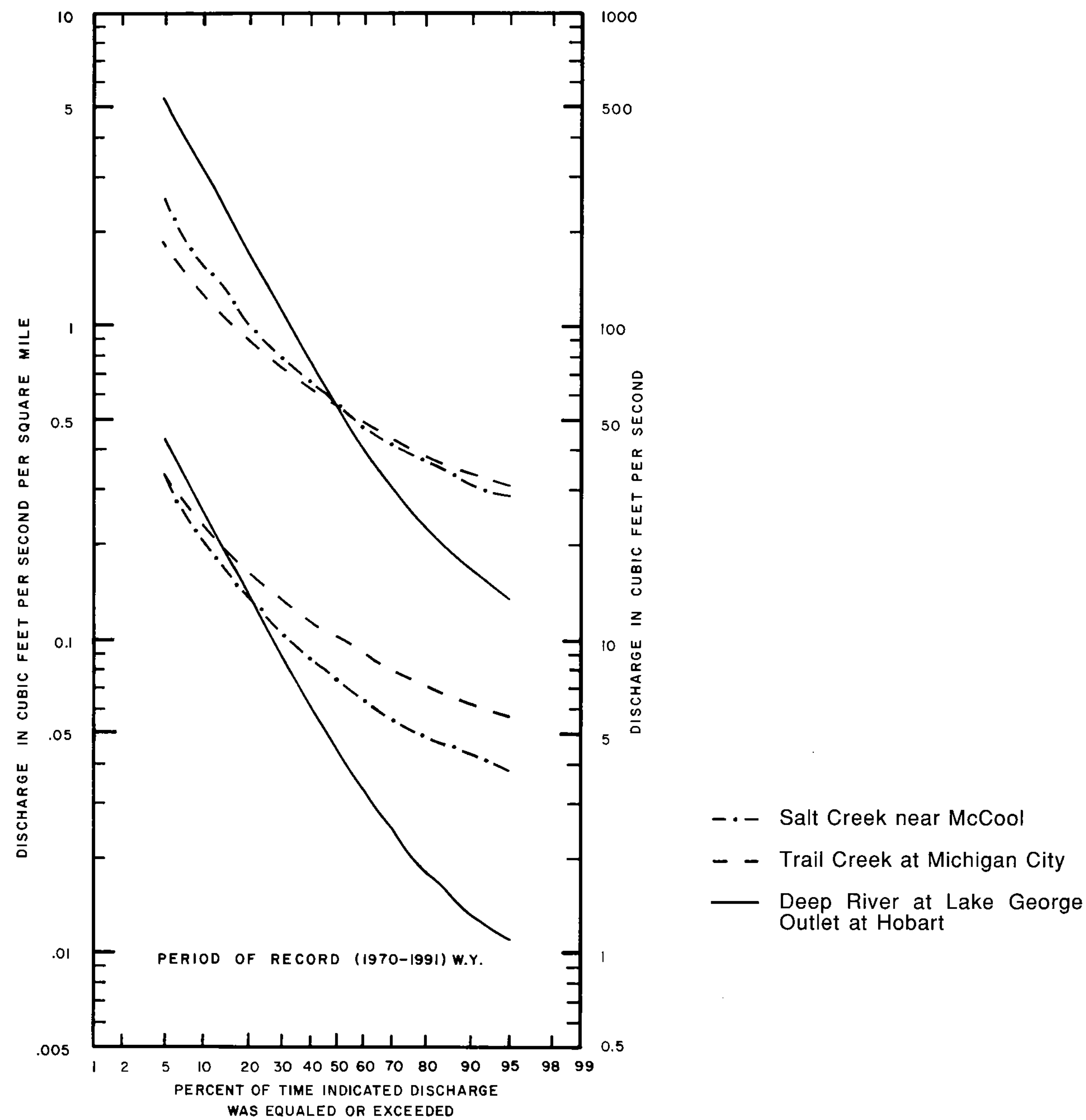


Figure 33. Duration curves of daily mean stream flow for Deep River at Lake George outlet, Salt Creek near McCool, and Trail Creek at Michigan City

more of the total precipitation is available to streams in the form of overland flow and base flow.

The spatial variation in stream flow can be illustrated by comparing runoff characteristics among different streams. Of the many stream-flow parameters that can be used to compare runoff characteristics, flow-duration analysis offers the advantage of not being influenced by the chronological sequence of daily flows.

Flow-duration curves of daily mean discharges, as presented in figure 33, show the percent of time that specified daily discharges are equaled or exceeded during a given period of record. The overall slope and shape of the duration curve is related to the storage characteristics of the drainage basin, which in turn are related to the topography and geohydrology of the basin.

A gently sloping duration curve of stream flow indicates a drainage basin with substantial surface and/or subsurface storage. Common surface storage features include lakes, ponds and depressions, while subsurface storage is promoted by permeable soils and sediments. Both surface and subsurface storage increase the time lag between the precipitation event and peak runoff, resulting in reduced overland flow rates and attentuated flood peaks. During dry periods, stream flow is sustained by the slow, steady release of water from the surface and/or underground sources.

A steeply sloping flow-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. However, negligible overland flow and baseflow during dry periods may cause the stream to cease flowing.

Duration curves of stream flow in Deep River at Lake George Outlet, Salt Creek near McCool and Trail Creek at Michigan City, for the period of record 1970-1991 water year, are shown in figure 33. The flow-duration analysis was based on a common period of record to minimize flow differences which may be attributed to differences in local precipitation from short-term events. Two types of discharge, total discharge and *unit* discharge, were used to construct the duration curves. Although stream flow is commonly reported as total discharge, unit discharge measurements, i.e. flow rate per unit area of watershed, is preferred when making comparisons among different streams because the effect of unequal basin sizes on stream flow characteristics is minimized. Among the three flow-duration curves shown in figure 33, the curve for Deep River at Lake George Outlet at Hobart is the steepest by far. Data from Glatfelter (1984) suggest that surface storage may not be the primary factor influencing the overall shape of the duration curves because lakes, ponds and wetlands are four times more abundant in the Trail Creek (at Michigan City) watershed than in the Salt Creek (near McCool) watershed, yet the duration curves of both watersheds are relatively similar. Instead, geohydrology and perhaps land cover may be the predominant factors that influence the overall shape of the curves.

Surficial deposits in the watershed of Deep River upstream from the Lake George outlet consist of thick basal tills of the Valparaiso Morainal Complex and lacustrine clays and silts of the Calumet Lacustrine Plain (figure 17). The low permeability of these sediments promote surface runoff, while infiltration rates are kept low. In addition, the small amount of forest cover in the watershed (5.9 percent) (Glatfelter, 1984) do not intercept significant amounts of precipitation, thereby providing little delay and attenuation of flood peaks. The runoff coefficient or the fraction of total precipitation that runs off the land surface in this watershed is 0.45 (Glatfelter, 1984).

In contrast, the watersheds of Salt Creek near McCool and Trail Creek at Michigan City have runoff coefficients of 0.40 and 0.35 respectively (Glatfelter, 1984). Less surface runoff and greater subsurface storage in the watersheds are primarily due to surficial sediments of significantly greater permeability. Mixed drift, debris-flow tills, and lacustrine clays, silts and sand, form the surface of most of the Salt Creek (near McCool) watershed and the upper part of the Trail Creek (at Michigan City) watershed. Highly permeable deposits of beach and dune sands in the watershed of Trail Creek above Michigan City (figure 17) allow considerable infiltration of precipitation.

The abundance of springs along the eastern part of the northern flank of the Valparaiso Morainal Complex, which form the major source areas of Salt Creek and Trail Creek, indicates the existence of well-developed, shallow ground-water systems. Additional temporary storage due to interception of precipitation is probably significant in these watersheds since forest cover in the Salt Creek (near McCool) and Trail Creek (at Michigan City) watersheds are 12.6 and 20.1 percent of the respective drainage areas (Glatfelter, 1984).

SURFACE-WATER DEVELOPMENT POTENTIAL

The development potential of the surface-water systems for water supply purposes can have a great impact on several economic activities. The Lake Michigan Region will continue to utilize the abundant supply of fresh water in Lake Michigan for almost all of its water use. The development of streams as potential water supply sources may be possible in some cases, but other surface-water systems such as ponds, lakes, and wetlands are not considered as significant water supply sources because of their limited storage capacity, water-quality considerations, and in some cases regulatory and environmental constraints.

Lake Michigan and the other Great Lakes

Lake Michigan, the other Great Lakes, and the connecting channels form an invaluable surface-water system that provide the surrounding areas with enormous quantities of fresh-water for public supply, manufacturing, and both fossil fuel and hydroelectric power plants. In fact, industrial development of the region was based mainly on the availability of abundant freshwater supplies from the lake. In addition, the Great Lakes is used for commercial navigation, fishing, and various types of recreation.

The Great Lakes System, having a storage volume of approximately 5,440 cubic miles at low water datum, contains the single largest supply of fresh surface water on this planet. The volume of water within the Great Lakes is approximately six quadrillion gallons or 20 percent of the world supply of fresh surface water and approximately 95 percent of fresh surface water in the United States Great Lakes Basin Commission, appendix 11 (1975c).

The most immediate source of water supply to the Great Lakes System is an average annual direct precipitation of approximately 32 inches over a surface area of approximately 95,000 square miles. Another water supply source is runoff over the lands, which reaches the lakes over a period of time. The amounts of runoff to the lakes are relatively well-known, since records have been kept for a number of tributary streams. In general, runoff to the lakes is proportionate to amounts of precipitation. Average annual runoff to the Great Lakes System is approximately 32 inches.

Evaporation, a loss of water from the Great Lakes System, is approximately proportionate to depth of individual lakes. Lake Superior, the deepest has the lowest evaporative rate loss, losing an average of 21 inches per year. Lake Erie, the most shallow has an evaporative rate of 33 inches per year. Lowest evaporation for the Great Lakes System generally occurs in spring when the water temperature is close to or below the dew-point temperature of the air. The largest amount occurs in the fall when the water temperature is considerably higher than the dew-point temperature of the air.

Ground water inflow to the Great Lakes has been estimated by the U.S. Geological Survey to be nearly 2,000 cubic feet per second. Since the amount of ground water supplied to any of the lakes is small compared to runoff and precipitation, many investigators assume the difference between ground-water inflow and outflow to be negligible (Great Lakes Basin Commission, 1975b).

Lake Michigan contains approximately 22 percent, or 1180 cubic miles, of the total volume of Great Lakes water. Average annual direct precipitation for the Lake is approximately 30 inches over a surface area of 22,300 square miles. Average annual runoff from the land is approximately 23 inches, and evaporation is estimated to be 26 inches per year, on average. At the Lake Michigan outlet to the Strait of Mackinac average outflow is approximately 52,000 cfs. The volume or rate of flow of ground water entering or leaving Lake Michigan has not been quantified.

Analysis of the surface-water hydrology of the Great Lakes or Lake Michigan is beyond the scope of this report. Information of a more detailed nature, however, may be found by Sub-area in the Great Lakes Basin Commission Framework Study, Appendices 2 (1976a) and 11 (1975c).

Wetlands and lakes

As described previously in the Surface-Water Resources section of this chapter, there are numerous types of non-riverine wetlands in the Lake Michigan Region. Palustrine wetlands include marshes, swamps, bogs, and other areas covered at least periodically by shallow water. Lacustrine wetlands include the deep portion of lakes, gravel pits, and large ponds.

Although some palustrine wetlands in the Lake Michigan Region may store considerable amounts of water at certain times, the shallow water depth 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 5) 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 Lake Michigan

Region 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 Region generally are not used for water supply. As discussed previously in this chapter, existing state laws discourage both direct and indirect significant pumpage from natural lakes. In accordance with Indiana law, lakes with a legally established average level are to be maintained at that level. Temporary lowering of the lake level requires approval by a local court and the Natural Resources Commission. Approval typically is granted only for shoreline improvements or lake restoration.

Even if state laws were amended to allow lowering of lake levels for supply purposes, treatment costs would probably 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, significant 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.

Because of these and other limitations, lakes other than Lake Michigan are not considered as potential water supply sources in the Lake Michigan Region.

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 stream-flow records. In this report, average and low-flow characteristics were defined at gaged sites using flow-duration curves, frequency analysis, and hydrograph separation techniques. These methods, which are 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 defined as the arithmetic mean of individual daily mean discharges for a selected time period, such as a week, month, season, year, or period of several years. However, average flow is commonly used to refer to the long-term mean annual discharge, which is the arithmetic mean of the annual mean discharges for the period of data record.

Recently, the U. S. Geological Survey replaced the term average flow with **annual mean**. However, in this report, the term average flow is used because its common meaning is widely known.

From statistical analysis of stream flow data, stream discharges do not follow a normal distribution, but rather a *skewed* distribution. The average discharge usually is greater than the median discharge, which is the flow rate equaled or exceeded 50 percent of the time.

Based on more than 40 years of record, the average flow in Deep River and Salt Creek is equaled or exceeded 25 to 30 percent of the time. Stream flow in Trail Creek shows a similar frequency characteristic based on 22 years of record.

The relation between average flow and drainage area is commonly used in hydrologic applications. In the Lake Michigan Region, a good correlation exists between long-term flows for selected continuous-record gages, which have been active for at least 20 years, and the respective drainage areas (figure 34). The mathematical relation shown in figure 34 may be used to estimate average flows at ungaged sites on streams in the Lake Michigan Region that drain areas of at least 17 square miles.

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. By incorporating the entire range of stream flows, duration curves are useful for indicating overall flow characteristics and identifying differences in stream-flow variability. Duration curves also can be

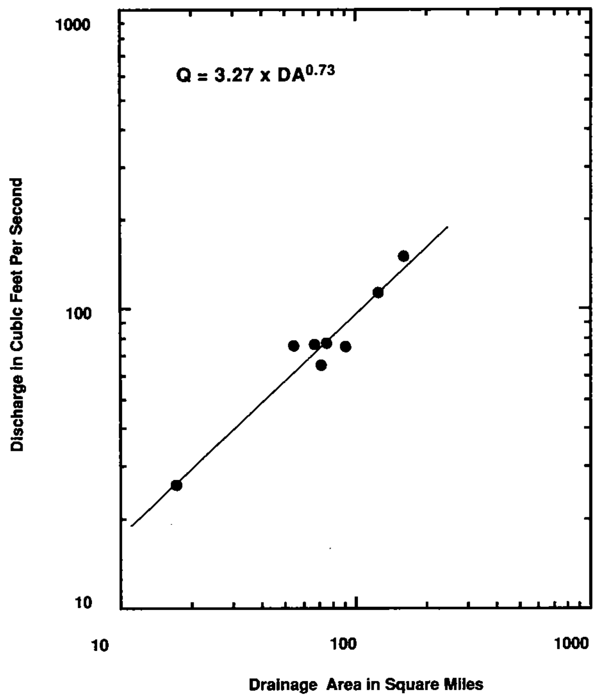


Figure 34. Relation of average discharge at continous-record gaging stations to total drainage area

used to estimate the percent of time that a given demand for stream flow can be satisfied, 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.

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 33). As described previously, the flow-duration ratio (slope) reflects not only the presence of flood-attenuating factors in a watershed, but also the relative component of stream flow due to base flow.

The two major tributaries of the Little Calumet River, Deep River and Salt Creek, have flow duration curves of about 11 and 3, respectively. The lower ratio of Salt Creek indicates substantially higher amount of base flow, which leads to more sustained stream flows during dry weather.

Low flows

Low-flow frequency data can be used to estimate how often, on 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. At stations where short-term records and/or base-flow measurements are available, correlation techniques can be used to estimate curves, or selected points on curves.

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 35 shows the relation of annual minimum mean discharges for 1-day and 7-day periods for Salt Creek at McCool and Trail Creek at Michigan City.

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 35).

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 closely approximates the minimum daily discharge of record for streams in the Lake Michigan Region.

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

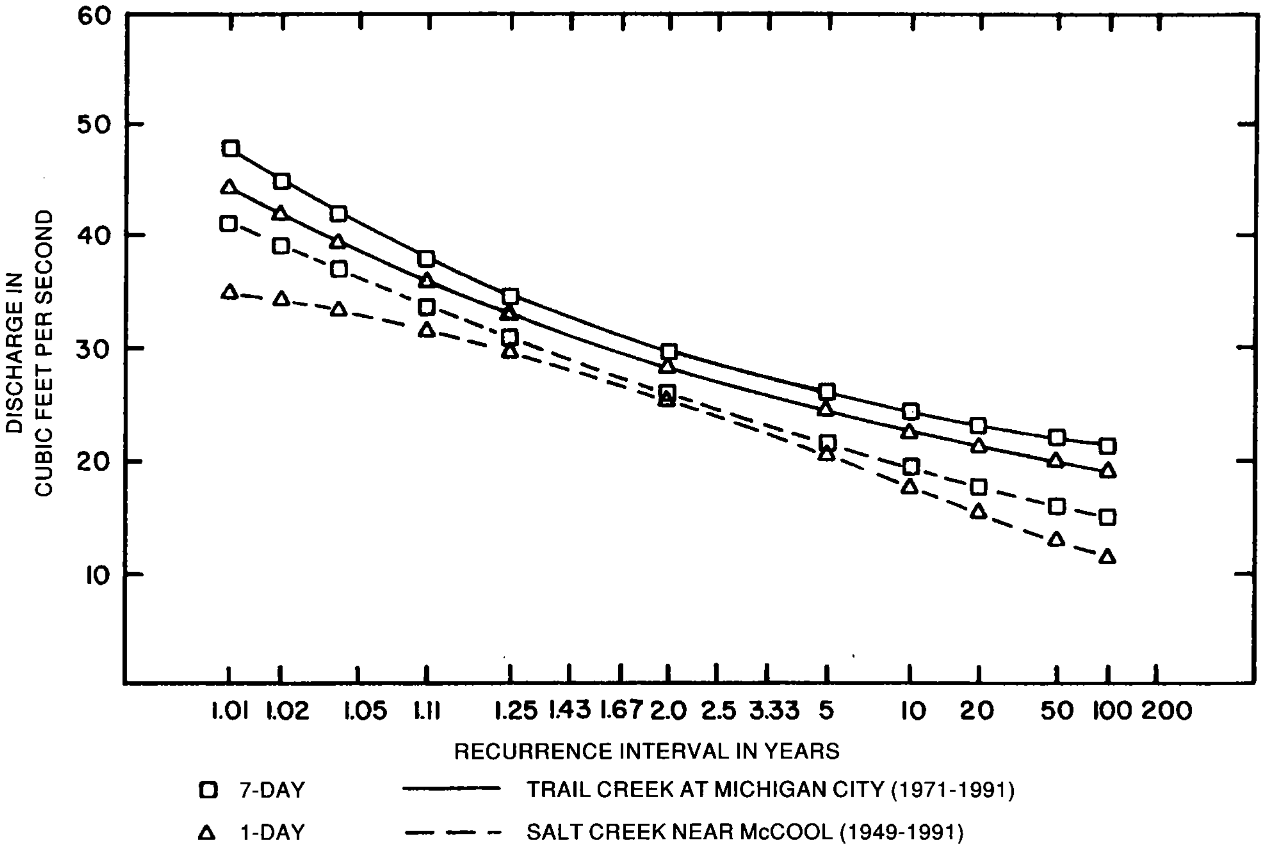


Figure 35. Frequency curves of annual lowest mean discharge for indicated number of consecutive days for Trail Creek at Michigan City and Salt Creek at McCool

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 Lake Michigan Region, regionalized flow-duration ratios mapped by Arihood and Glatfelter (1986) are summarized as follows:

* Little Calumet River Basin east of Burns Harbor – 3
* Little Calumet River Basin west of Burns Harbor – 10
* Grand Calumet River Basin – 10
* Galena River Basin – 3
* Trail Creek Basin – 3
* Selected tributaries to Lake Michigan – 3.

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

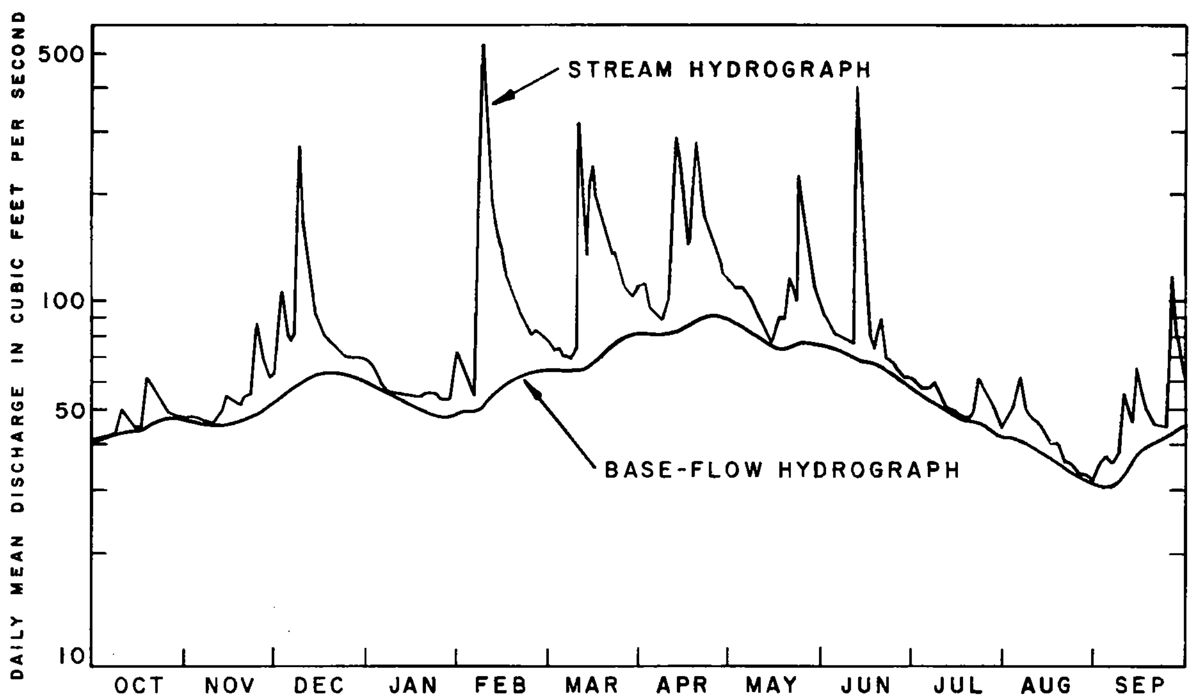


Figure 36. Example of stream-flow and base-flow hydrographs

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 of daily discharges. As figure 36 shows, the hydrograph of daily stream flows is composed of peaks and valleys which often are quite sharp. 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. After peaking, stream flow recedes to a level which represents base flow contributions only because overland flow has ceased. The base-flow hydrograph therefore can be approximated by eliminating the sharp hydrograph peaks due to storm runoff, and drawing a smooth curve (figure 36).

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 Lake Michigan Region

The total water-supply potential of a basin is the

Table 12. Average runoff of subareas within the Lake Michigan Region.

Watershed	Drainage Area (sq mi)	Unit flow (cfsm)	Discharge (cfs)	Runoff (in)	Volume (bg)
Little Calumet River into Lake Michigan	331	1.00	331.22	13.58	78.0
Little Calumet River into state of Illinois	56.6	0.83	46.98	11.27	11.1
Drainage into state of Michigan	56.6	1.50	84.90	20.36	20.0
Trail Creek and other streams directly into Lake Michigan	93.2	1.39	129.55	18.87	30.5
Grand Calumet River into Lake Michigan and adjoining Lake Michigan drainage	65	—	—	—	—

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 a drainage basin as a whole can be defined as the long term average runoff, which includes both surface runoff and ground-water discharge to streams. However, the Lake Michigan Region is not a single drainage basin, but rather a mosaic of several watersheds of complex hydrology.

Accurate determination of average runoff of the Lake Michigan Region is an almost impossible task. Natural flow rates in the Grand Calumet River cannot be reliably estimated because most of the flow in the river is industrial cooling and processing water and waste treatment plant effluents. In addition, flow reversals between Lake Michigan and the contributing streams in the Region during periods of wind setup at the southern end of Lake Michigan can often lead to inaccurate determination of flow rates in the lowest reaches of the streams.

Table 12 shows the average runoff of various subareas in the Lake Michigan Region. The runoff of each subarea is determined using stream flow records at active and inactive gages, which have period of record data for at least 20 years as of water year 1991. This technique is based on the assumption that the average unit flow, as determined from gaging station records, is truly representative of the entire subarea. Surficial geology maps by Schneider and Keller (1970) and Gray (1989) were used to help delineate subareas of similar geohydrology within the Lake Michigan Region.

Supply potential of streams

The potential of individual streams in the Region for water-supply development is based on stream flows without regard to the potential construction of impounding reservoirs (either in-channel or off-channel), which would otherwise improve the water-supply of some streams. Variations in stream-flow are interpreted primarily on the basis of geologic, soil and land use differences among and within drainage basins.

Stream-flow characteristics for active and inactive continuous-record gaging stations having at least 20 years of data record as of water year 1991 are shown in table 13. Average and low-flow values for these stations are plotted in figure 37 to facilitate an assessment of the geographic variation in flows.

Streams that have relatively high sustained flows are more reliable than streams of low sustained flows, and thus are preferred for water-supply development. However, water quality determines the actual use of the water, and therefore plays an important role in water-supply development.

In the following discussion, only the Little Calumet River, its major tributaries and Trail Creek are considered in detail. Most of the other drainage networks in

Table 13. Stream-flow characteristics at selected continuous-record gaging stations.

{Stations had at least 20 years of data through water year 1991.}
Total drainage area, annual runoff, extremes: From Stewart & Deiwert (1992) except as noted. Contributing drainage area is shown in parenthesis for watersheds with non-contributing portions.

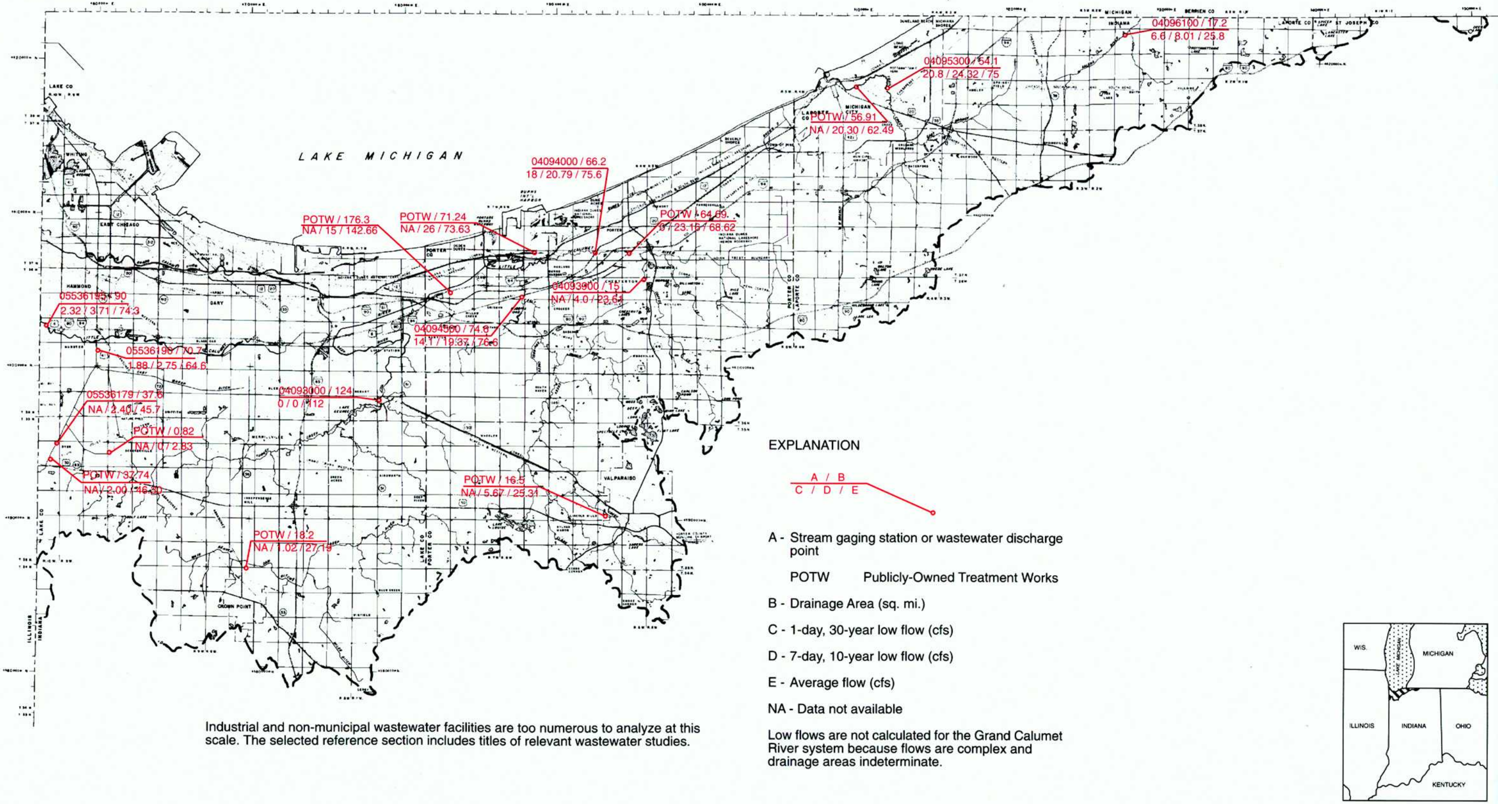
Extremes: Daily maximum represents maximum daily mean discharge; daily minimum represents minimum daily mean discharge

Low flows: Estimated by Division of Water using regression analysis

Ground-water contribution: Estimated by Division of Water using methodology of Pettyjohn and Henning, 1979, for hydrograph separation. Values are for water year 1988 except as noted.

Station name	Total drainage area (sq mi)	Annual runoff (in)	Extremes (cfs)				Low flows			Base flow (percent of total runoff)
			Annual mean		Daily		1-day,30-yr	7-day,	10-yr	
			max	min	max	min	(cfs)	(cfs)	(cfsm)	
LITTLE CALUMET RIVER										
at Porter	66.2	15.5	124	36.5	3040	17	18	20.79	0.31	68
at Munster	90	11.21	121	23.5	1160	1.9	2.32	3.71	0.04	—
TRAIL CREEK										
at Michigan City	54.1	18.85	109	50.5	2550	20	20.8	24.32	0.45	76
GALENA RIVER										
near LaPorte	17.2 (14.9)	20.35	32.6	21.0	650	6.7	6.6	8.01	0.47	83
TRIBUTARIES										
Deep River at Lake George outlet at Hobart	124	12.26	199	35.3	3900	0	—	—	—	—
Salt Creek at McCool[1]	74.6	13.95	121	36.2	2740	10	14.1	19.37	0.26	64
Hart Ditch at Munster	70.7	12.41	136	19.2	2600	1.6	1.88	2.75	0.04	43

[1] Gage discontinued



Industrial and non-municipal wastewater facilities are too numerous to analyze at this scale. The selected reference section includes titles of relevant wastewater studies.

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

LAKE MICHIGAN REGION

Figure 37. Selected stream-flow characteristics

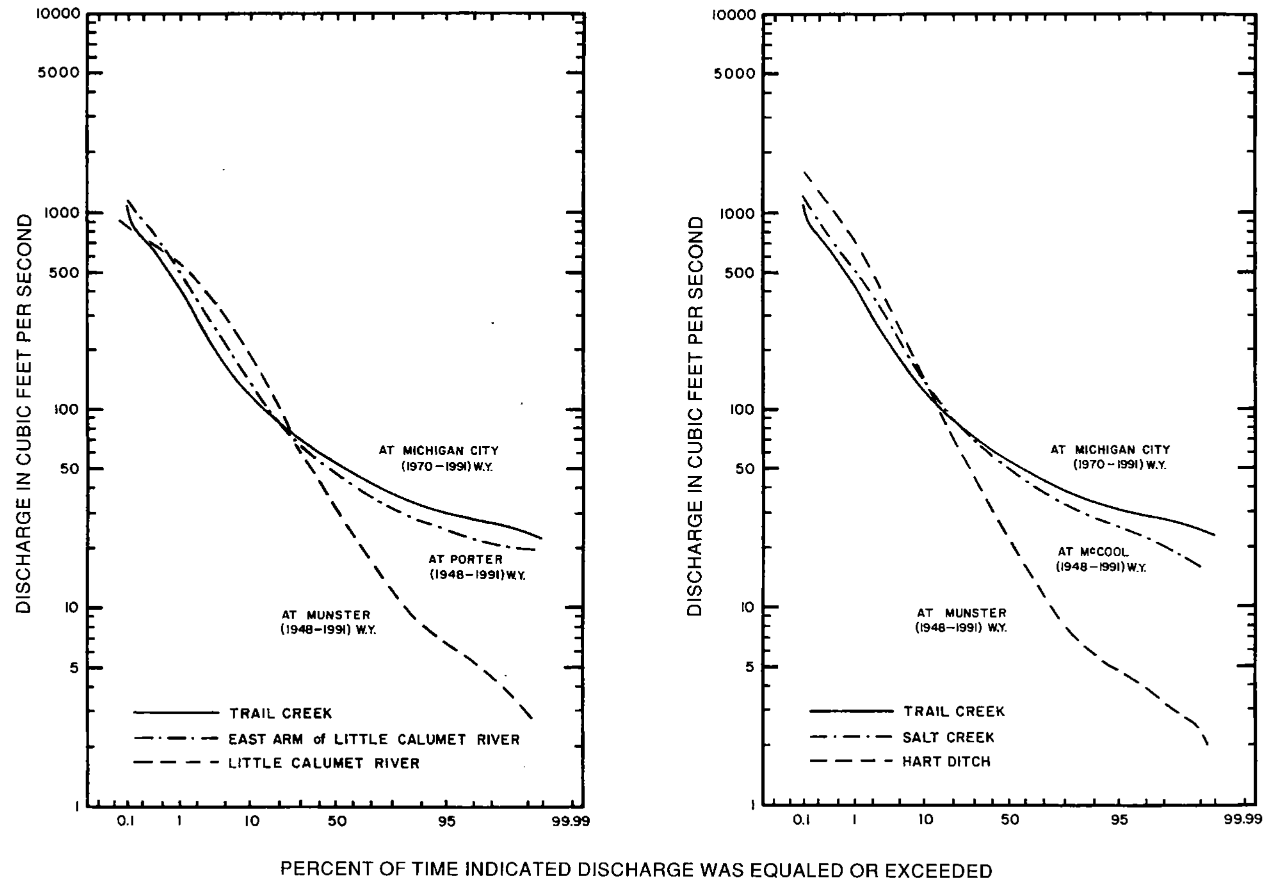


Figure 38. Duration curves of daily mean stream flow for gaging stations on Trail Creek, Salt Creek, Hart Ditch and Little Calumet River

the Region are too small for significant water-supply development. The Grand Calumet River has considerable flow, but natural-flow analysis is almost impossible because most of the flow in the river is industrial cooling and processing water and waste treatment plant effluents.

Little Calumet River System

The water-supply potential of the Little Calumet River and its tributaries varies considerably across the Lake Michigan Region because of the geographic variation in flows. Evidence for the spatial variation in development potential comes from low-flow and flow-duration curve comparisons, in addition to the relative extremes in mean annual stream flow.

The water-supply potential of the Little Calumet River and its major tributaries is greater along the reaches in Porter County than in Lake County. At the gaging station in the town of Porter, Porter County, the 1-day 30-year (1Q30) and the 7-day 10-year (7Q10) low flows in the East Arm of the Little Calumet River are 18.0 and 20.8 cfs, respectively (table 13). In contrast, the 1Q30 and 7Q10 low flows in the Little Calumet River at Munster, Lake County, are 2.32 and 3.71 cfs, respectively. When unit low flows are considered, the flow differences become even greater because the drainage area above the Porter gage is about 66 mi^2, whereas the drainage area above the Munster gage is about 90 mi^2. The ratio of maximum to minimum annual stream flow in the Little Calumet River is about 3 at Porter, and about 5 at Munster. Similar geographic trends in stream flow are seen among the major tributaries of the Little Calumet River. In Salt Creek near McCool, Porter County, the 1Q30 and 7Q10 low flows are 14.1 and 19.37 cfs, respectively, but in Hart Ditch at Munster, Lake County, the 1Q30 and the 7Q10 low flows are 1.88 and 2.75 cfs, respectively (table 13). The unit low-flow comparisons closely follow the actual low-flow comparisons because the drainage areas of both watersheds are similar in size, each just above 70 mi^2 (table 13). The ratio of maximum to minimum annual stream flow is about 3 in Salt Creek at McCool, and about 7 in Hart Ditch at Munster.

Low flows, i.e. 1Q30 and 7Q10, in Deep River at Lake George Outlet at Hobart (Lake County) could not be determined because of periods of no flow. However, the ratio of maximum to minimum annual stream flow is greater than 5, falling between the ratios of the Little Calumet River at Munster and Hart Ditch at Munster.

The high variability in flow at the gaging stations in Lake County is mainly due to the low permeability of the soils and the considerable degree of urbanization and development in the northern part of the county. The presence of impervious surfaces, such as roads, parking lots and buildings in a watershed amplifies flood peaks during storms by increasing runoff and decreasing the *time of concentration.*

Conversely, greater sustained (low) flows and lower ratios of maximum to minimum annual stream flow occur in the drainage networks of the Little Calumet River in Porter County because of higher ground water contributions. This geographic variation in stream flow is apparent in the flow duration curves shown in figure 38.

As explained earlier in the section entitled **Factors Affecting Stream Flow**, the surficial sediments in the tributary and mainstem areas of the Little Calumet River in Porter County are more permeable than in Lake County. Greater infiltration of precipitation leads to higher ground water contributions to streams in Porter County.

In both the Little Calumet River at Porter and Salt Creek at McCool, base flow comprises about 68 and 64 percent of the respective stream flow during a year of average precipitation (table 13). In Hart Ditch at Munster, base flow comprises, on average, about 43 percent of the total stream flow. Hydrograph separation techniques could not be used to determine base flow contributions to the Little Calumet River at Munster. A hydraulic divide across the streambed just east of the Hart Ditch confluence causes complex flow patterns during periods of varying water levels in Hart Ditch and the Little Calumet River.

Trail Creek

The water-supply potential of Trail Creek is the most favorable of all the streams in the Lake Michigan Region based on low-flow records at gaging stations which have been active for at least 20 years. Estimates of Trail Creek's 1Q30 and the 7Q10 low flows at the gage in Michigan City are 20.8 and 24.32 cfs, respectively (table 13). The ratio of maximum to minimum annual stream flow is slightly more than 2, by far the lowest of all major streams in the Region.

As discussed previously in the section entitled **Factors Affecting Stream Flow**, the surficial sediments in the watershed of Trail Creek are highly permeable compared to other watersheds in the Region. On average, base flow comprises about 76 percent of total stream flow in Trail Creek during a year of normal precipitation (table 13). In Galena River near LaPorte, base flow comprises an average of 83 percent of stream flow; however, total stream flow is small because the drainage area above the gage is only 17.2 mi^2.

At present, registered water withdrawals from Trail Creek are used for irrigation of two golf courses. A high-withdrawal facility used for energy production purposes is located in the mouth of Trail Creek. However, since the mouth of Trail Creek and Lake Michigan are parts of a contiguous surface-water body, withdrawals by the energy production facility do not come entirely from the Trail Creek watershed.

Water-quality problems in Trail Creek limit its water-supply development potential. Water quality of Trail Creek is discussed in the **Surface-Water Quality section** of this report.

FLOODING

Flooding in the Lake Michigan Region is primarily due to overbank flow and inadequate storm drainage. Overbank flow is commonly caused by a reduction in either channel slope or cross-sectional area, both of which reduce the transporting capacity of a river and lead to higher flood stages. For example, when structures are constructed in a floodway, the cross-sectional area available for flood flows is reduced, *backwater* levels are elevated, and flood peaks become amplified upstream of the structures.

In developed areas flooding can be caused by storm drainage systems which were built to handle excess runoff generated by the increase in impervious cover. When storm runoff exceeds the capacity of a designed drainage system, water backs up and causes flooding.

Most of the critical flooding in the Lake Michigan Region occurs along the mainstem and tributaries of the Little Calumet River in Lake County. Extensive development of the area, poor drainage characteristics of the soil, inadequate channel capacity to handle flood flows, and high water table all contribute to prolonged floods.

The largest and most damaging floods typically occur during early spring when saturated or frozen soil, 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. Floods are aggravated by the accumulation of debris, sediment, and ice at bridges and culverts because of backwater effects.

Flooding in the Little Calumet River watershed is most disastrous in northern Lake County because of the high concentration of development. During the major floods of October 1954 and July 1957, the communities of Gary, Griffith, Hammond, Highland and Munster incurred considerable property damage. Health hazards were created by the backup of sanitary sewers, while road damage in Griffith and Highland added to losses due to the floods.

In these flooded areas near the mainstem of the Little Calumet River, inadequate capacity of the channel had forced water into temporary storage across levees. Most of the levees were built during early urbanization and industrialization of the Region, with little, if any, attention given to design and floodway considerations.

Communities in the tributary areas, including Dyer, Hobart, Lake Station, and Schererville, also incurred property damage during the 1954 flood. Unfortunately, flooding in parts of Lake Station was aggravated by flow through gaps in the levees.

The widespread flooding in the Lake Michigan Region during October 1954 was due to an extensive storm which also affected the watersheds of the East Arm of the Little Calumet River in Porter County and Trail Creek in LaPorte County. In the town of Porter (Porter County), about 10 inches of rain fell during a 30-hour period. Considerable damage to roads and bridges occurred within the corporate limits of Portage and Porter. Daniels and Hale (1955) provide detailed discussions of the 1954 flood.

The most recent major flood in the Lake Michigan Region occurred in late November of 1990, when a high-intensity rain event dumped about 6 inches of rain over a 5-hour period in parts of Lake County (Federal Emergency Management Agency or FEMA, 1990). Slightly less rain occurred in Porter County, but the cumulative effects caused record flooding in many parts of the Region. Records for both highest daily mean and instantaneous peak flows were set at five of the Region's seven continuous-record gaging stations, which had "period of record" data for at least 20 years (table 11). Instantaneous peak stage records were established at four of the stations.

As a result of the destruction and damage caused by the late November 1990 flood, the President declared a major disaster for the state of Indiana, and Lake County was declared eligible for Individual Assistance. Losses due to flood waters from the Little Calumet River and its tributaries in Lake County totalled more than $7.2 million (Federal Emergency Management Agency, 1990).

Condition of damage due to the flood ranged from moderate to heavy in Dyer, the Black Oak section of Gary, and Schererville to severe in the Wicker Park section of Highland. Several possible health and environmental problems arose because of the flood. A significant threat was posed in Highland when leaks of petroleum products from a nearby gas station and above-ground home heating-oil tanks contaminated both water and homes (Federal Emergency Management Agency, 1990). Highly toxic polychlorinated biphenyls (PCBs), which are carcinogenic, were found in concentrations of 1,200 parts per million (ppm) in oil cleaned from the area. Generally, state and federal officials must be notified of cases when the concentration of PCBs exceeds 50 ppm. The source of the PCBs was initially believed to be contaminated heating oil, but the testing of oil from several tanks and homes proved negative. The original source of the PCB's was never determined, but the EPA has certified that the area is free of the contaminant (Federal Emergency Management Agency, 1990).

Flooding problems along the mainstem of the Little Calumet River in Lake County are expected to be alleviated to a considerable degree after completion of the Little Calumet River Flood Control and Recreation Project. Work on the project began in 1990 and is scheduled for completion by 1998. Details of the project are discussed previously in the subsection entitled **Levees and Flood Control.**

The other watersheds of the Lake Michigan Region have experienced flooding, but the damages incurred were minor. Past flooding problems in Michigan City, LaPorte County, are attributed to inadequate storm sewers and poor drainage characteristics of areas within the corporate limits. Although considerable extension and separation of the storm sewers have been performed, full benefits have not been realized or quantified.

The Grand Calumet River does not have a flooding problem. Most of the flow in the river is industrial cooling and processing water and waste treatment plant effluents.

Flood-flow characteristics of the Lake Michigan Region

The natural hydrology of the Lake Michigan Region has been considerably altered because of channelization projects, construction of canals and ditches, and modification of the shoreline and near-shore landscape in many parts of the Region. The influence of these man-made changes, in addition to differences in the surficial geology, topography, and degree of urbanization in the various watersheds combine to create complex flood-flow characteristics in the Lake Michigan Region. Further complexity in flow characteristics occur during periods of high lake levels and wind setup on the lake which can lead to actual flow reversals between the discharging streams and Lake Michigan. Figures 39 and 40 illustrate the spatial variation in the 10-year and 100-year flood flows in the Lake Michigan Region.

In the tributary areas of Deep River and Turkey Creek, which lie along the northern extent of the Valparaiso Morainal Complex, poorly-drained depressions and basins of internal drainage allow considerable storage of floodwaters. Consequently, the 10-year and 100-year flood flows in the tributaries of Deep River and Turkey Creek are among the lowest for a given drainage area in the Lake Michigan Region. The relatively low slope of these curves is also caused by the attenuating effects of depression storage.

Flood-flow characteristics in the Deep River and Salt Creek watersheds are not very different from each other (figures 39 and 40). The surficial geology and topography of both watersheds are similar. Depression storage in these watersheds may not be significant, but

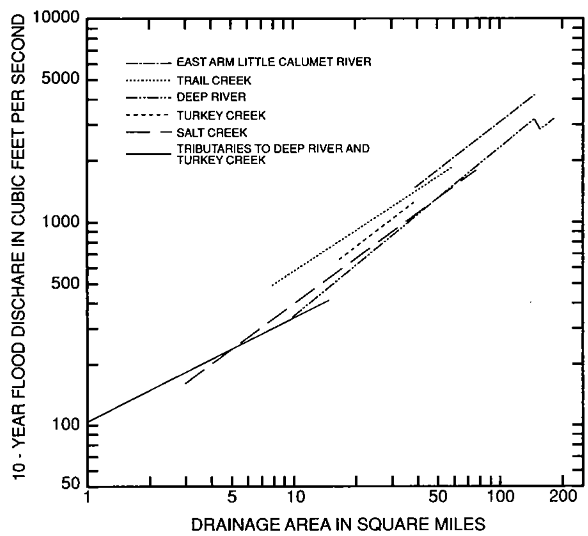


Figure 39. Relationship between drainage area and 10-year flood discharge for Salt Creek, Trail Creek and selected tributaries of the Little Calumet River

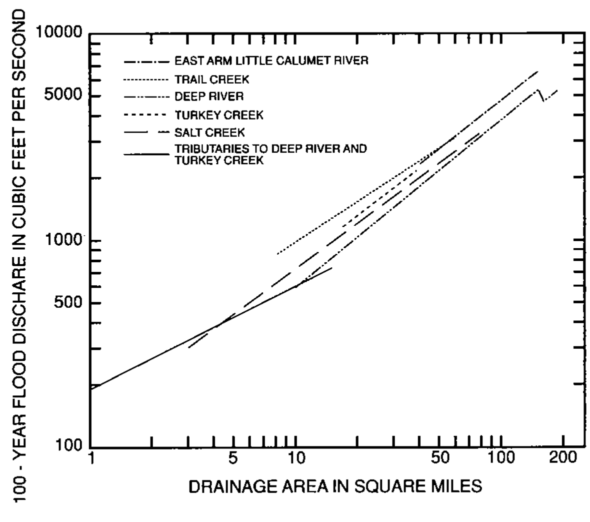


Figure 40. Relationship between drainage area and 100-year flood discharge for Salt Creek, Trail Creek and selected tributaries of the Little Calumet River

alluvial silt, sand and gravel along the mainstem valleys serve as temporary storage features, especially during periods of flooding.

Significantly higher 10-year and 100-year flood discharges occur in Turkey Creek for a given drainage area when compared to floods in Deep River and Salt Creek (figures 39 and 40). Alluvium in the Turkey Creek valley does not extend significantly beyond the channel, resulting in little bank storage during floods.

In the East Arm of the Little Calumet River and Trail Creek, the 10-year and 100-year flood discharge for a given drainage area are the highest among all major streams in the Lake Michigan Region (figures 39 and 40). This characteristic is probably attributed to greater precipitation in the eastern part of the Region, as well as high water-table and ground-water discharge zones in the downstream areas of the watersheds.

Leeward of Lake Michigan, lake-effect precipitation occurs when cold air passes over warmer lake water (Indiana Department of Natural Resources, 1990a). The frequency, intensity and duration of precipitation can be higher in these areas because of the orographic lifting of moist air over the topographic highs along the ridges of the Lake Border and Valparaiso Moraines.

Flood frequency

The initial indicator of a flood is the stage of a river, which is defined as the elevation of the river's water surface above a base elevation or datum. However, the relative size of a flood is based on the peak discharge rather than river stage because backwater effects due to ice, debris or vegetation can cause higher stages than would otherwise occur for a given flow. Peak-discharge data is 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 31, table 11).

Stream gage records are used to determine peak-flow characteristics, which are helpful in both mitigating flood damages and 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 13 presents maximum peak flows recorded at continuous-record gaging stations having at least 20 years of data for the period of record ending in 1991.

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, 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. 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 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 the 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. 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.

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, 1990b).

For a given flood frequency, a relation between peak discharge and drainage area can be developed to allow the estimation of discharges at ungaged sites within a watershed, or within other watersheds having similar basin characteristics.

Floodplain management

Since the Lake Michigan Region was first settled in the 1800's, public and private agencies have expended

Table 14. Community participation in the National Flood Insurance Program for major region counties.*

(all communities in regular phase of NFIP as of July 15, 1994)

County	Community
Lake	Crown Point
	Dyer
	East Chicago
	Gary
	Griffith
	Hammond
	Highland
	Hobart
	Lake Station
	Merrillville
	Munster
	New Chicago
	Schererville
	Whiting
Porter	Beverly Shores
	Burns Harbor
	Chesterton
	Dune Acres
	Ogden Dunes
	Portage
	Porter
	Valparaiso
LaPorte	Long Beach
	Michiana Shores
	Michigan City

* The unincorporated areas of Lake, Porter, and LaPorte Counties participate in the National Flood Insurance Program under their respective counties.

billions of dollars to improve drainage and control flooding. Although most methods of floodplain management historically have involved channelization, ditching, dredging, levee construction, and land-treatment measures, increasing emphasis is being placed on floodplain regulation and non-structural alternatives, such as land-use regulations, flood insurance, floodproofing, flood warning, and flood damage relief.

A report by Grady and Rutledge (1982) describes floodplain management measures and various aspects of land-use planning for Indiana communities. Detailed floodplain management reports and flood insurance studies are available for most counties of the Lake Michigan Region. Most of these reports have been prepared by cooperative efforts of the U.S. Department of Agriculture (Soil Conservation Service), the Federal Emergency Management Agency, the State of Indiana (Department of Natural Resources), soil and water conservation districts, planning commissions, and other local agencies.

Existing floodplain management regulations in Indiana are governed by a combination of statutory laws at both the state and federal levels. In brief, the state establishes minimum standards governing the delineation and regulation of flood hazard areas. Moreover, the 1945 Indiana Flood Control Act (I.C. 13-2-22) prohibits construction, excavation or the placement of fill in a floodway without prior approval from the Natural Resources Commission.

The Indiana Department of Natural Resources, Division of Water administers the flood control law and also acts as the state coordinator of the National Flood Insurance Program, which further helps to regulate the development of flood-prone lands. According to requirements of the program, new construction in a flood hazard area must be located and built in such a way that the potential for damages and loss of life is minimized.

Under this program, which is administered by the Federal Insurance Administration of the Federal Emergency Management Agency, property owners are eligible to purchase federal flood insurance if their flood-prone community adopts and enforces adequate floodplain management regulations.

A community can initially enter the **emergency phase** of the flood insurance program by adopting preliminary floodplain management regulations to guide new construction in flood-prone areas, which are approximately delineated on a flood hazard boundary map based on a generalized study. During the initial emergency phase, limited amounts of flood insurance become available to local property owners.

The community can then enter the **regular phase** of the program after a detailed flood insurance rate map is issued following a flood insurance study, and after local officials enact comprehensive regulations that require all new or substantially improved structures to be built in accordance with federal floodplain management criteria. Under the regular program, the full limits of flood insurance coverage become available.

Table 14 shows participation in the National Flood Insurance Program by communities within the Lake Michigan Region. The term "community" refers to both unincorporated and incorporated areas which have a government authority capable of adopting and enforcing floodplain management regulations. By virtue of this definition, an incorporated town is considered independent of unincorporated areas, which are collectively defined as a separate community.

SURFACE-WATER QUALITY

Surface-water quality can be an important factor in developing sustainable and beneficial land- and water-use strategies. The presence of high-quality surface water can facilitate or enhance development by providing water suitable for public supply, industrial cooling, irrigation, livestock watering, recreation and aquatic life. In contrast, surface water containing certain toxic substances may pose a health threat to humans who consume tainted fish taken from contaminated waters. Moreover, the value of a surface-water source can be diminished by bacterial pollution, high levels of nutrients or unacceptable concentrations of inorganic and organic chemicals.

Degradation of water quality may result from urban, industrial, and agricultural land uses, because practices associated with these uses may introduce sources of pollution into the watershed. Such pollution sources include wastewater discharge, contaminated runoff, *combined sewer overflow* (CSO), atmospheric deposition, and accidental spills or discharges. There may also be a tendency for pollution sources to be grouped together along the banks of a river or shores of a lake, a result of numerous users needing water for cooling, manufacturing, transportation and other purposes. Water quality degradation can occur in urban and agricultural areas if sufficient pollution-control practices are not properly implemented.

Historical Overview

Water-quality planning in northwest Indiana

The northwestern part of the Lake Michigan Region, often referred to as the Calumet Area, is one of the major industrial centers of the United States. Steel, petrochemicals and other industries have been integral parts of the Calumet Area's economy for over a century. This extensive urban and industrial development has had detrimental effects on the environment and surface-water resources of the Calumet Area. Consequently, various agencies at the federal and state level have produced strategies for protection and restoration of Calumet Area surface-water resources.

Because much of the Region's drainage ultimately discharges into Lake Michigan, pollution in the Calumet Area has been a source of concern for Indiana and other states along the Great Lakes coast. One dispute concerning pollution in southern Lake Michigan resulted in some early environmental action in the Calumet Area. In 1944, the State of Illinois and the City of Chicago filed suit against the state of Indiana; the cities of Gary, Hammond, East Chicago and Whiting; and 16 Indiana-based industries regarding alleged water pollution in Lake Michigan. The plaintiffs in the suit claimed that pollution originating from northwest Indiana was impairing the use of Lake Michigan as a water supply. A consent decree specifying corrective measures was entered in 1945, and all involved parties were deemed in compliance by 1948 (U.S. Department of Health, Education and Welfare, 1965).

In the 1960s, evidence from various studies, reports, and surveys indicated that chronic water-quality problems were damaging the aquatic ecosystem of near-shore Lake Michigan. Bottom dredgings of the Lake between 1961 and 1963 indicated that much of the Lake floor off the Calumet Area was covered with dense, organic material. Subsequently, the *benthic* community was dominated by aquatic worms, fingernail clams and other pollution-tolerant organisms. Game fish species, such as trout and perch, were scarce in the Calumet Area shores of Lake Michigan because of poor water and bottom-sediment quality. Instead, pollution-tolerant species of fish such as carp, buffalofish, and sucker dominated the *nektonic* community (U.S. Department of Health, Education and Welfare, 1965).

Water-quality problems in Lake Michigan also decreased the utility of the Lake for people. For example, beaches along Lake Michigan in Hammond and Whiting were frequently closed because of high bacteria counts in the Lake waters. Water purification facilities in Hammond, Gary and East Chicago reported taste and odor problems attributed to phenols and other organic compounds. The Gary facility also reported some excessive ammonia concentrations at its intake crib during January of 1963; and January, February and March of 1964 (U.S. Department of Health, Education and Welfare, 1965).

It was also recognized in the early and mid-1960s that most streams in northwestern Lake County were affected by pollution (U.S. Department of Health, Education and Welfare, 1965). The Grand Calumet and Little Calumet Rivers were characterized by low dissolved oxygen, high *biochemical oxygen demand* (BOD), and aquatic communities dominated by pollution-tolerant organisms. Oil, grease, floating debris and offensive odors made these rivers unappealing to recreational boaters; and high coliform bacteria densities made them unfit for any body contact. Poor water quality was also inhibiting development of public recreation areas along the Little Calumet River in Cook County (Illinois) and was responsible for lowering property value assessments along the Grand Calumet River (U.S. Department of Health, Education and Welfare, 1965). Water-quality problems were causing negative impacts on the environment, public health, and the general quality of life in the Calumet Area.

One of the first government agencies to become involved with environmental issues in the Calumet Area was the U.S. Department of Health, Education and Welfare (DHEW). In December 1964, the secretary of DHEW organized a conference which focused on water pollution in northwest Lake County, Indiana and the Chicago area. Reports were presented on water quality and biotic conditions for Wolf Lake, Lake Michigan, the Grand Calumet River, Little Calumet River and other surface-water bodies in order to quantify the causes and extent of surface-water pollution in the area. Evidence from these reports indicated that the discharge of inadequately-treated industrial and municipal wastewater was the principal cause of surface-water quality degradation. Furthermore, factors such as CSOs, spills and dredging were having serious short-term or local effects on water quality (U.S. Department of Health, Education and Welfare, 1965).

The DHEW recommended numerous corrective actions to help alleviate the pollution load to Lake Michigan and Calumet Area streams. Most of the DHEW suggestions established pollution-control objectives and water-quality monitoring criteria for the Area. The recommendations included: 1) elimination, by treatment or exclusion of phenols, ammonia, phosphorous, acids, oil, tar and suspended matter from industrial discharges; 2) regular effluent sampling by industry to provide reliable estimates of waste outputs; 3) long-term monitoring of surface-water quality by state and local agencies; 4) secondary treatment for all municipal wastes; 5) disinfection of sanitary wastes prior to discharge.

In March 1965, a second conference was organized by the Secretary of the DHEW to address interstate water pollution in the Calumet Area. The meeting included representatives from the Indiana Stream Pollution Control Board, the Illinois Sanitary Water Board, the Metropolitan Sanitary District of Chicago, and the Federal Government. A technical committee was subsequently formed with representatives from each of these agencies. The committee would be responsible for monitoring water quality, determining reasons for the lack of improvement in water quality, and suggesting remedial actions (Technical Committee on Water Quality, 1970).

Progress evaluations were conducted by the Technical Committee in March and September of 1967 and December of 1968 to assess the implementation and effectiveness of the recommended pollution-control measures. These evaluations concluded that, although numerous pollution-control measures had been initiated, surface-water quality had not improved significantly (Technical Committee on Water Quality, 1970). In 1970, the fourth progress evaluation by the Technical Committee concluded that, although most recommended pollution-control measures had been emplaced by 1970, the surface waters in the Calumet Area were still seriously polluted. The failure of existing abatement measures was attributed to intermittent wastewater discharges and inadequate wastewater treatment, at some localities.

The Technical Committee also concluded that planned future pollution-control measures would not be sufficient to meet all future water-quality goals, and the committee suggested additional abatement measures. Some of these additional measures recommended by the Committee included: 1) recycling treated industrial and municipal wastewaters; 2) elimination or control of CSOs; 3) development by state or municipal agencies of contingency plans to deal with accidental discharges, such as spills or equipment failures; 4) daily sampling of wastes at each industrial outfall; 5) establishment of adequate and consistent effluent criteria for the area (Technical Committee on Water Quality, 1970).

New federal laws enacted in the 1970s provided a framework for a more systematic and comprehensive approach toward pollution control. Section 208 of the Federal Water Pollution Control Act of 1972 mandated that water pollution management be executed on an area-wide basis, and that involved agencies prepare comprehensive pollution-control plans for areas under their jurisdiction (Northwestern Indiana Regional Planning Commission, 1978). In 1975, the state of Indiana designated the Northwestern Indiana Regional Planning Commission (NIRPC) as the planning agency to develop the section 208 water-quality management plan for Lake and Porter Counties.

The section 208 water-quality plan was completed by the NIRPC in 1978. The plan described the surface-water conditions in Lake and Porter Counties, and presented strategies for controlling point and non-point sources of pollution in the two counties.

The primary goal of the NIRPC 208 plan was to protect high-quality surface waters and ground waters in the two counties (Northwestern Indiana Regional Planning Commission, 1978). The plan was not intended to serve as a strategy for remediation of water-quality problems in the area; therefore, it did not have any provisions for remediating areas of environmental degradation, nor did it address problems such as contaminated sediments, toxic pollutants in wastewater discharges, or cumulative pollutant loads on Lake Michigan (Holowaty and others, 1991).

Water-quality planning in the Lake Michigan Region has also been influenced by basin-wide environmental management strategies developed by the American - Canadian International Joint Commission (IJC - see insert on page 100). In 1972, IJC recommendations became the basis of the first Great Lakes Water-Quality Agreement between the United States and Canada. The primary goal of the agreement was to reduce pollutant loads to the Great Lakes and to control cultural eutrophication (Great Lakes Water-Quality Board, 1987). Emphasis was placed on municipal and industrial point-source discharge problems which had been documented by the IJC (Indiana Department of Environmental Management, [1988b]). The 1972 agreement was initially applied to the Lower Great Lakes Basin, but was extended to the entire basin in 1978 (Great Lakes Water-Quality Board, 1987).

In 1977-1978, the two countries conducted a formal review of the 1972 Water-Quality Agreement. It was concluded that, although discharge limits established in the 1972 agreement were generally being met, there were still major environmental problems in the Great Lakes Basin (Indiana Department of Environmental Management, [1988b]). Additional strategies were needed to correct long-term problems with sediment quality, indigenous fish populations, persistent toxic chemicals, and rehabilitation of ecologically degraded areas in the Great Lakes Basin (Great Lakes Water-Quality Board, 1987; Indiana Department of Environmental Management, [1988b]). The 1977-1978 review produced a second, more comprehensive water-quality agreement between the U.S. and Canada.

The second water-quality agreement requires restoration and maintenance of the physical, chemical and biological integrity of the Lakes. The IJC also requested that an "ecosystem-based" approach be used to restore and maintain water quality in the Lakes. An ecosystem-based strategy focuses on complex interactions among water, air, land and biota; it requires that the relationships among all components of the ecosystem be considered while in the process of addressing environmental problems. Such a strategy also requires that ecosystem improvement be used as the criteria for measuring the effectiveness of solutions (Indiana Department of Environmental Management, [1988b], 1993). The U.S. and Canadian governments endorsed the second water-quality agreement in 1978, and it remains the basic framework used by the IJC for developing Great Lakes water-quality policy.

A scientific subcommittee of the IJC called the Great Lakes Water-Quality Board (GLWQB) began to use the ecosystem-based approach in 1981 to identify sites within the Basin where environmental degradation was severe enough to necessitate special actions. Previously, the board had designated "problem areas" in the Great Lakes Basin where environmental guidelines and standards had been exceeded. However, there were no consistent criteria, either for identifying the problem areas, or for assessing the extent of environmental degradation within them. Furthermore, the problem areas were generally defined solely on the basis of water-quality data (Indiana Department of Environmental Management, [1988b]). After 1981, the Board began to designate Areas of Concern (AOC) which were assessed by using environmental quality data gathered from all media and evaluated with uniform standards (Indiana Department of Environmental Management, [1988b]).

The Great Lakes Water Quality Board identifies areas of concern (AOC) as locations where the objectives of the Great Lakes Water Quality Agreement have not been achieved or where jurisdictional standards and guidelines are violated. Each AOC requires remedial action to restore all beneficial, water-related uses. Designated areas of concern include municipal and industrial centers along rivers, harbors, and connecting channels in the Great Lakes Basin (Great Lakes Water-Quality Board, 1987).

The International Joint Commission

The American-Canadian Boundary Waters Treaty of 1909 outlines the basic principles for resolving disputes between the United States and Canada over the waters along common borders. One aspect of the agreement authorized the establishment of a binational organization to administer the terms of the treaty and to advise the two governments on boundary-water issues. The organization established under the agreement is known as the Great Lakes International Joint Commission (IJC). The IJC was first assembled in 1912, and remains involved in administration of the 1909 treaty and planning of Great Lakes policy (International Joint Commission, [nd]).

The IJC acts as an intermediary for boundary-water issues between the U.S. and Canada and it develops policies that are based on consensus between the two governments. Both nations appoint commissioners to the IJC; however, these commissioners do not work as representatives of their respective governments. Instead, the Commission attempts to act as a single body seeking common solutions to boundary-water issues. IJC recommendations are non-binding; therefore, implementation is at the discretion of both governments. The 1909 treaty however, does contain a provision allowing the two governments to refer issues to the IJC for a binding decision (International Joint Commission, [nd]).

In 1972, a scientific subcommittee of the IJC known as the Great Lakes Water Quality Board (GLWQB) was established to investigate a variety of water-quality problems occurring in the Great Lakes Basin. The GLWQB is composed of experts from both the U.S.A. and Canada who analyze Great Lakes water-quality issues and advise the IJC on options to resolve these issues. Water-quality issues studied by the Board include eutrophication in the Great Lakes, persistent toxic substances, remediation of ecologically degraded areas, and the overall ecological conditions in the Great Lakes Basin (Great Lakes Water Quality Board, 1987).

The Water-Quality Board is also involved with environmental remediation in the Great Lakes Basin. Using data from annual assessments of water quality, the Board designates Areas of Concern (AOC - see page 99) in the Basin. The Board also assists individual states and provinces in developing Remedial Action Plans (RAPs) for each AOC under their jurisdiction, and it evaluates the RAPs for adequacy and efficiency in resolving environmental problems. This review and assistance process assures that the RAPs utilize comprehensive, ecosystem-based strategies in restoration programs even though the RAPs are prepared by different jurisdictions with varying needs and resources.

Early in the 1980s, parts of northwest Lake County were placed on the list of Areas of Concern (AOC) by the Water-Quality Board. The northwest Lake County AOC consists of the west and east branches of the Grand Calumet River, the Indiana Harbor Canal, Indiana Harbor and nearshore Lake Michigan in the vicinity of Indiana Harbor (Indiana Department of Environmental Management, [1988b]).

At a 1983 public meeting sponsored by the IJC, local environmental groups met with USEPA representatives to press for remediation of the Grand Calumet River system. The USEPA Region V Administrator, subsequently committed to developing a Master Plan for Improving Water Quality in the Grand Calumet River/Indiana Harbor Canal (Holowaty and others, 1991).

The Master Plan was developed by the USEPA with the cooperation of the Army Corps of Engineers and the Indiana State Board of Health. A draft of the plan was submitted for public scrutiny and comment in 1984; the final form was issued in 1985. The Master Plan contains a summary of existing environmental problems, pollution sources, and water-quality control programs in the Grand Calumet River and Indiana Harbor Canal. The report concludes with recommendations for improving water quality and aquatic habitat in these streams (U.S. Environmental Protection Agency, 1985a). However, the Master Plan only addressed water-quality concerns and did not consider other issues relevant to the AOC such as air deposition, solid wastes and hazardous wastes disposal (Holowaty and others, 1991).

Shortly after the Master Plan was completed, pollution-control responsibilities were transferred from the Indiana State Board of Health to the Indiana Department of Environmental Management (IDEM). The IDEM was soon committed to developing a comprehensive plan to restore ecological integrity and beneficial uses to the AOC. The result of the efforts was the 1987 Northwest Indiana Environmental Action Plan (EAP). The EAP was developed in consultation with the USEPA, the USGS, the IDNR, the Army Corps of Engineers and the U.S. Fish and Wildlife Service. Public participation in the development process of the EAP was facilitated through a state established Citizen's Advisory Committee (CAC) composed of citizens-at-large, business and industry representatives, environmentalists, and educators (Holowaty and others, 1991).

The EAP did not represent a single document with a limited number of defined goals. Instead, it was a comprehensive plan which encompassed numerous programs, efforts and ongoing regulatory or investigative activities. The different programs encompassed by the EAP include the 1985 Master Plan and a comprehensive Remedial Action Plan (RAP) for coordinating