BASIN HYDROLOGY

CLIMATE

The climate of east-central Indiana, classified as temperate continental, is characterized by warm, occasionally hot summers, cold winters, and considerable daily variations in temperature.

East-central Indiana frequently encounters *cyclonic* disturbances generated by the interactions of northeast-moving tropical and south-moving arctic air masses. Locally heavy amounts of rain or snow associated with the eastward passage of low pressure centers are often recorded, although basinwide, precipitation is fairly evenly distributed throughout the year.

Spring is generally mild and rather wet, and is often characterized by periods of prolonged rainfall over large areas. Summers have some extended periods of hot and sultry weather alternating with more pleasant conditions. Summer rainfall often occurs as local thunderstorms of short duration. Autumn is relatively dry and mild, and winter is characterized by short periods of freezing weather alternating with several days of milder temperatures.

Other climatic characteristics of the Whitewater Basin include moderate to high humidities, light to moderate winds (typically from the southwest), and a large proportion of partly cloudy to cloudy days interspersed with clear days. The frost-free *growing season* for most crops generally extends from late April or early May through middle or late October. Severe local storms generated by daytime convection or by the passage of cold fronts are most common in spring and early summer. These storms may produce frequent lightning, strong winds, and large hail, as well as occasional funnel clouds and tornadoes.

Although parameters such as wind, solar radiation, relative humidity, and soil temperature constitute an area's climate, only air temperature and precipitation will be summarized here. Temperature defines the growing season and largely controls the process of *evapotranspiration*, which consumes about 70 percent of the average annual precipitation in east-central Indiana. Precipitation is the source of fresh water either on the surface or in the subsurface of the earth. The amount, distribution, and type of precipitation help to define a region's water supply and its hydrologic regime.

Climatic Data

Climatic data in the Whitewater River Basin are gathered as part of several statewide networks operated by federal and state agencies. The most extensive networks are operated and maintained by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). Climatic data are collected at NWS cooperative observer stations operated by water and wastewater utilities, municipalities, or private citizens.

Additional precipitation data in the basin are gathered by about seven amateur radio operators as part of a statewide volunteer network which aids the NWS river and flood forecasting program. Other precipitation data are collected by the U.S. Army Corps of Engineers, U.S. Geological Survey, and the Indiana Department of Natural Resources, Division of Water for hydrologic and hydraulic studies and daily water management operations.

Table 5 lists climatic stations in and within 10 miles of the Whitewater River Basin. Locations of stations lying within the basin boundary are shown in fig. 14. Amateur radio stations are neither tabulated nor mapped, because the statewide network changes frequently.

The majority of temperature and precipitation data from NWS stations are published by NOAA in monthly and annual summaries. However, measurements of temperature, hourly rainfall, pan evaporation, relative humidity, and soil temperature at the Liberty station remain unpublished. Temperature and precipitation data from seven of the NWS stations in table 5 are periodically published in climatic summaries (National Oceanic and Atmospheric Administration, 1976, 1982a, 1983, 1985). Data from networks operated by the Corps of Engineers, U.S. Geological Survey, and Division of Water are not published but are available at each office.

The distribution of National Weather Service stations, the availability of published and unpublished precipitation data, and the availability of published climate summaries are sufficient for the Division of Water's present and anticipated climatic data needs in the Whitewater Basin.

Temperature[2]

Normal annual temperature within the Whitewater Basin averages 51^{0} F (degrees Fahrenheit) and ranges from near 50^{0} F in northernmost areas to 52^{0} F in the far southwest near Greensburg. Normal seasonal

Table 5. Climatic stations in and near the Whitewater River Basin

Agency: National Weather Service (NWS); U.S. Army Corps of Engineers (USCE); Division of Water (DOW); U.S. Geological Survey (USGS).

Element: Precipitation (P); Temperature (T); Additional parameters (A) - e.g., evaporation, relative humidity, soil temperature.

Gage: Recording precipitation gage (R) - data automatically recorded at selected intervals; non-recording precipitation gage (NR) - data manually collected once daily.

Publication: Precipitation and/or temperature data published monthly and annually by the National Oceanic and Atmospheric Administration (p); unpublished (up).

Station	County	Agency	Element	Gage	Publication
Alpine 2NE	Fayette	NWS	P	R	p
Batesville Waterworks[1]	Ripley	NWS	P	R	p
Brookville	Franklin	NWS	P,T	NR	p
Brookville Lake (at dam)	Franklin	USCE	P,T	R	up
Brookville (at mainstem gage)	Franklin	USGS	P	R	up
Cambridge City	Wayne	NWS	P,T	NR	p
Franklin 1	Franklin	DOW	P	NR	up
Franklin 2	Franklin	DOW	P	NR	up
Greensburg[1]	Decatur	NWS	P,T	NR	p
Henry 1[1]	Henry	DOW	P	NR	up
Lewisville[1]	Henry	NWS	P	R	p
Liberty	Union	NWS	P (T,A)	NR (R)	p (up)
New Castle[1]	Henry	NWS	P,T	NR	p
Richmond Waterworks	Wayne	NWS	P,T	R,NR	p
Ripley 1[1]	Ripley	DOW	P	NR	up
Rushville Sewage Plant[1]	Rush	NWS	P,T	NR	p
Springersville	Fayette	USCE	P	R	up
Winchester Airport[1]	Randolph	NWS	P,T	NR	p

[1]Within 10 miles of basin boundary.

temperatures average 50° F in spring (March-May), 71° F in summer (June-August), 53° F in autumn (September-November), and 28° F in winter (December-February).

January, the coldest month, has an average monthly temperature of 26° F and an average daily minimum of 16° F. In contrast, the warmest month of July has an average temperature of 73° F and an average daily maximum of 85° F.

Diurnal temperature variations (the difference between normal daily maximums and minimums) typically range from about 19° F in winter to 25° F in summer and fall. Extreme temperature readings recorded for the period 1951-80 range from -28° F (Cambridge City, 1963) to 104° F (Brookville, 1951).

The growing season for most crops ranges from 165 to 175 days, although the extreme southwestern part of the basin has a slightly longer season. Vegetative cover, soils, impervious surfaces, and obstructions to wind are factors which can influence climatic features, particularly the length of growing season. However, these factors typically affect climate only over small areas.

Precipitation

Normal annual precipitation in the basin averages about 40 inches and ranges from less than 38 inches in northernmost areas to more than 40 inches in far southwestern regions.

Although variations in annual precipitation totals generally are not extreme, yearly amounts recorded

[2]Temperature and precipitation data discussed here are taken or derived from data found in several NOAA publications (National Oceanic and Atmospheric Administration, 1976, 1982a, 1982b, 1983, and 1985). Data from Brookville, Cambridge City, and Richmond Waterworks for the Period 1951-80 were used to obtain the various in-basin averages and extremes, while nearby station data were used to define temperature and precipitation ranges from the northernmost to southernmost basin boundary.

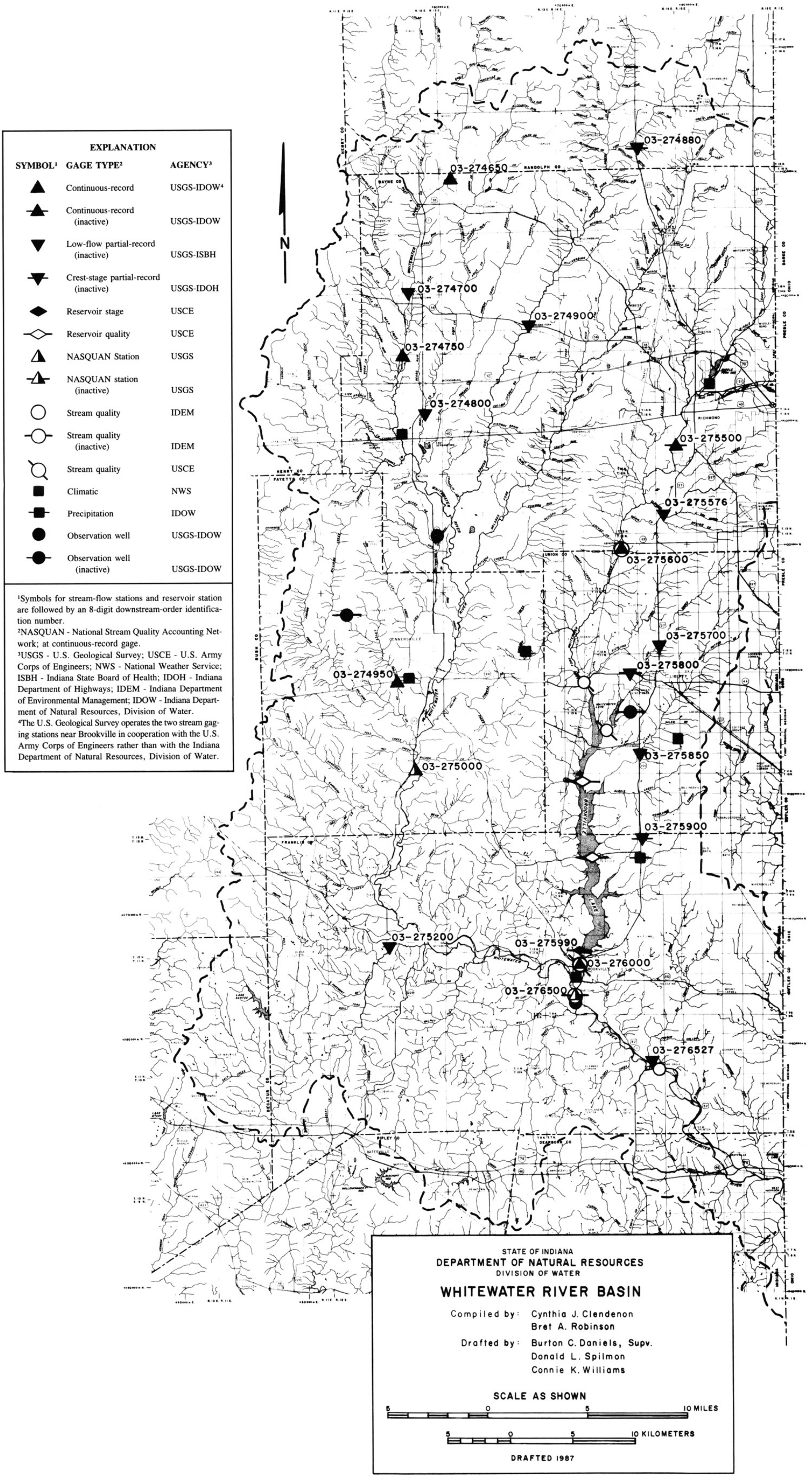

Figure 14. Location of hydrologic data collection stations

Table 6. Monthly and annual precipitation at selected probability levels

{From National Oceanic and Atmospheric Administration, 1985, 1983; all precipitation amounts in inches; values were determined from the incomplete gamma distribution; dash indicates no published data.}

Station 1: Richmond Waterworks.
Station 2: Cambridge City.
Station 3: Brookville.

Probability level[1]	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
.10	1	4.33	4.33	5.74	6.24	7.00	7.51	7.31	6.11	5.38	4.58	4.94	5.38	46.86
	2	4.38	4.53	5.78	7.01	6.89	7.49	7.80	6.04	5.34	4.98	5.49	5.53	47.84
	3	5.26	4.69	6.26	6.25	7.53	6.71	7.26	6.90	5.29	4.94	4.99	5.58	47.93
.30	1	3.12	2.74	3.99	4.45	4.97	5.13	4.88	3.98	3.29	3.01	3.49	3.52	—
	2	3.17	2.81	4.07	4.82	4.99	5.10	5.07	4.07	3.30	3.08	3.77	3.52	—
	3	3.46	2.91	4.33	4.39	5.19	4.92	5.51	4.51	3.30	3.14	3.42	3.56	—
.50	1	2.43	1.90	3.01	3.44	3.82	3.81	3.55	2.84	2.21	2.16	2.67	2.52	38.37
	2	2.48	1.91	3.10	3.61	3.90	3.78	3.60	2.99	2.24	2.09	2.82	2.45	39.30
	3	2.48	1.99	3.25	3.35	3.88	3.88	4.48	3.22	2.26	2.19	2.55	2.48	40.22
.70	1	1.85	1.26	2.21	2.59	2.87	2.74	2.49	1.94	1.40	1.49	1.99	1.74	—
	2	1.89	1.23	2.31	2.62	2.98	2.71	2.45	2.12	1.44	1.34	2.04	1.63	—
	3	1.71	1.29	2.37	2.49	2.82	3.01	3.58	2.20	1.47	1.46	1.84	1.66	—
.90	1	1.19	0.62	1.33	1.64	1.80	1.60	1.39	1.02	0.64	0.80	1.24	0.93	30.98
	2	1.23	0.58	1.42	1.55	1.94	1.57	1.28	1.20	0.68	0.63	1.20	0.81	31.84
	3	0.92	0.61	1.41	1.53	1.66	2.00	2.52	1.17	0.70	0.73	1.08	0.83	33.38

[1]Probability that precipitation will be equal to or greater than the indicated amount.

Table 7. Normal monthly and annual precipitation, 1951-80

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

Month	Richmond Waterworks	Cambridge City	Brookville
January	2.63	2.68	2.85
February	2.25	2.30	2.39
March	3.33	3.40	3.60
April	3.74	4.01	3.68
May	4.17	4.21	4.32
June	4.26	4.24	4.17
July	4.03	4.17	4.73
August	3.28	3.37	3.71
September	2.69	2.70	2.70
October	2.48	2.52	2.58
November	2.93	3.14	2.84
December	2.91	2.89	2.92
Annual	38.70	39.63	40.49

during very dry and wet years have ranged from about 29 inches to nearly 50 inches. There is a 90 percent probability, however, that annual precipitation over a long period of time will average at least 31 inches in northern areas of the basin to 33 inches in southern areas. Annual and monthly precipitation amounts at selected probability levels are given in table 6 for Richmond, Cambridge City, and Brookville.

Monthly precipitation totals for the period 1951-80 have varied from zero to nearly 12 inches, but monthly normals range from about 2 to 5 inches (table 7). Seasonal normals average roughly 8 inches in fall and winter, and between 11 and 12 inches in spring and summer.

Approximately 21 inches, or 54 percent of the average annual precipitation, falls from May through October, the growing season for most crops. During this six-month period, monthly amounts average slightly less than 3.6 inches. In any one crop season, however, extended periods of little to no rainfall may occur.

Daily precipitation is quite variable due to the periodic passage of frontal systems, and 24-hour amounts for the period 1951-80 have ranged from zero to more than 5 inches. Although precipitation events are generally interspersed among several dry days, daily normals fall between 0.08 and 0.14 inch, as determined from monthly normals at Indianapolis (National Oceanic and Atmospheric Administration, 1982b).

Average annual snowfall in the basin ranges from about 24 inches in northern areas to 19 inches in the south. Annual snowfall averages 22 inches basinwide, which is roughly equivalent to 2.2 inches of rain. On average, snowfall in the basin accounts for less than 6 percent of the normal annual precipitation.

Evapotranspiration

The amount of water lost through evaporation from the soil and surface-water bodies and by plant transpiration is referred to as evapotranspiration. By far the largest consumptive use of water in the basin, evapotranspiration consumes about 70 percent of the average annual precipitation (J. Newman, Purdue University, personal communication, 1987).

Newman (1981) has used the Thornwaite method as described in Palmer and Havens (1958) to estimate annual evapotranspiration for nine regions in Indiana. According to Newman's regional estimates based on 1941-70 climatic data, normal annual evapotranspiration in the Whitewater River Basin ranges from about 27 inches in northern areas to 28 inches in southern areas. These values are regional averages which may be expected over a period of many years; however, variations in temperature and other climatic factors can produce significant variations in evapotranspiration from year to year.

SURFACE-WATER HYDROLOGY

Drainage Characteristics

Drainage in the Whitewater Basin is well developed, particularly in southern areas where glacial deposits are older or absent. The Whitewater River and its major tributaries have long and fairly straight valleys with many small *first-order* and *second-order* streams feeding directly into the trunk channels.

The Whitewater River is entrenched in glacial drift along its upper reaches. Lower reaches in Franklin and Dearborn Counties are cut into bedrock and are flanked by high ridges of limestone and shale which often exceed 300 feet in relief. Limestone and shale is also exposed along much of the deeply entrenched East Fork Whitewater River, especially near Richmond and in the vicinity of Brookville Lake.

Tributary channels have relatively low relief in their headwater areas and then lose elevation rapidly as they leave the uplands and drop to the level of the major valley bottoms. Average *channel slopes* of 20 to 40 ft/mi (feet per mile) are not uncommon for western tributaries of the Whitewater River, and some short tributaries have even greater slopes. Several tributaries of the East Fork Whitewater River upstream of Brookville Lake have gradients exceeding 20 ft/mi.

The channel slope of the East Fork Whitewater River decreases from 12.8 ft/mi at Richmond to 9.2 ft/mi at Brookville (Glatfelter, 1984). These slopes are among the highest in the state for rivers draining more than 100 sq. mi. The gradient of the Whitewater River at Brookville (7.3 ft/mi) is the highest for Indiana rivers draining more than 1000 sq. mi.

Stream-Flow Data

The U.S. Geological Survey, in cooperation with other government agencies, has collected daily stream-flow records in the Whitewater River Basin since 1915. Although daily stage readings were obtained for the Whitewater River at Cedar Grove between 1915 and 1917, the two earliest long-term stations were Whitewater River at Brookville (established in 1915) and Whitewater River near Alpine (established in 1928).

As data needs grew and funding became available, a network of stream gaging stations gradually developed. Currently, records of daily discharge are collected at four *continuous-record stations* on the Whitewater River (Economy, Hagerstown, Alpine and Brookville), at two stations on the East Fork Whitewater River (Abington and Brookville), and on Little Williams Creek at Connersville (table 8). From 1949 to 1978, data had also been collected for the East Fork Whitewater River at Richmond.

The two active gaging stations near Brookville are operated by the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers. The other five stations are part of a cooperative program between the U.S. Geological Survey and the State of Indiana. Stream-flow data for these seven gages are published in U.S. Geological Survey reports prepared annually for the entire state.

Records of stream discharge during periods of low flow and high flow have been collected at *partial-record stations* where daily discharge data were not available.

Table 8. Stream gaging stations and selected stream-flow characteristics

Station number: Numbers are U.S. Geological Survey downstream-order identification numbers; station locations are shown in fig. 14. Lettered abbreviations are as follows: discontinued gaging station (D); low-flow partial-record station (L); crest-stage partial-record station (C); telemark station (T); satellite station (S); occasional regulation at low flow by upstream powerplant, and some effect by diversion for municipal water supply (OR); regulation by Brookville Lake since January 1974 (R).

Total drainage area: Data from Glatfelter and others (1985), Stewart (1983), or Glatfelter (1984), depending on station type.

Period of record: Refers to calendar year or portion thereof; in some cases, records are not continuous.

Station number and name		Total drainage area (sq mi)	Period of record	Average discharge		7-day, 10-year low flow	
				cfs[1]	cfs/sq mi	cfs[2]	cfs/sq mi
03-274650	Whitewater River near Economy	10.4	1970-	10.8	1.04	0.4	0.03
03-274700 L	Whitewater River at Hagerstown	29.2	1969	—	—	—	—
03-274750	Whitewater River near Hagerstown	58.7	1970-	67.9	1.16	7.1	0.12
03-274800 L	Martindale Creek near Cambridge City	58.1	1960-67	66.5	1.14	1.2	0.02
03-274880 C	Greens Fork tributary near Lynn	0.78	1973-82	—	—	—	—
03-274900 L	Greens Fork at Greens Fork	66.7	1968-75	76.0	1.14	1.6	0.02
03-274950	Little Williams Creek at Connersville	9.16	1968-	10.2	1.11	0.4	0.04
03-275000 T	Whitewater River near Alpine	522	1928-	552	1.06	45.5	0.09
03-275200 L	Salt Creek near Metamora	115	1954-67	126	1.10	0.9	0.01
03-275500 D, OR	E.F. Whitewater River at Richmond	121	1949-78	115[3]	0.95	4.2[4]	0.04
03-275576 L	Elkhorn Creek at Richmond	27.5	1954	35.2	1.28	0	0
03-275600	E.F. Whitewater River at Abington	200	1965-	229	1.14	18.9	0.09
03-275700 L	Silver Creek near Liberty	9.67	1960-67	11.1	1.15	0	0
03-275800 C	West Run near Liberty	0.26	1973-	—	—	—	—
03-275850 L	Hanna Creek near Roseburg	22.3	1959-78	25.5	1.14	0.3	0.01
03-275900 C	Templeton Creek near Fairfield	5.39	1973-82	—	—	—	—
03-275900 T	Brookville Lake at Brookville	379	1974-	—	—	—	—
03-276000 R	E.F. Whitewater River at Brookville	380	1954-	396	1.04	20[5]	0.05
03-276500 S, R	Whitewater River at Brookville	1224	1915-	1273	1.04	89[5]	0.07
03-276527 L	Big Cedar Creek at Cedar Grove	29.6	1980	33.8	1.14	0	0

[1]Data for continuous-record stations from Glatfelter and others (1985) and through water year 1984 except as noted; data for partial-record stations estimated with regression equation.
[2]Data for continuous-record stations from U.S. Geological Survey data and through climatic year 1984 except as noted; data for partial-record stations from Stewart (1983) and through climatic year 1978.
[3]Data from Stewart (1983) and through water year 1978 (station discontinued).
[4]Data from Stewart (1983) and through climatic year 1978 (station discontinued).
[5]Data from Stewart (1983) and through climatic year 1974; represents low flows before regulation by Brookville Lake.

Additional measurements of discharge have been obtained at miscellaneous sites. Data from partial-record and miscellaneous sites are primarily used in regional hydrology studies to estimate flow characteristics at both gaged and ungaged locations.

Table 8 lists continuous-record gaging stations in the Whitewater Basin as well as 11 partial-record stations for which discharge-frequency data has been published in Stewart (1983) and Glatfelter (1984). Gaging locations are shown in fig. 14. Miscellaneous station listings and locations are not tabulated or mapped.

Table 8 also indicates continuous-record stations equipped with telemetering instruments for transmitting encoded information over telephone lines or via an earth-orbiting satellite. Data obtained from telemetered stations are primarily used for flood hydrology, flood forecasting, and the operation of Brookville Lake.

As water management programs develop further, additional stream-flow data may be needed to better define regional hydrology, determine low-flow and flood frequency discharges, and relate stream-flow characteristics to local and regional hydrogeology. Neyer (1985) has recommended that the establishment of gaging stations should be considered on Greens Fork or Nolands Fork, Salt Creek or Pipe Creek, and Middle Fork of the East Fork Whitewater River (upstream of Middle Fork Reservoir). These gages would provide regional hydrology data for non-urbanized basins. Reinstatement of the Richmond gage as a low-flow partial-record station was also suggested to provide low-flow data for an urban river reach.

To help balance the cost of these possible additions, Neyer also recommended that the currently operating gages near Connersville, Economy, and Hagerstown be discontinued by 1990. The 20 years of record at these three sites are sufficient for regional hydrology functions. Other gages in the basin, used for regional hydrology, flood forecasting, and the operation of Brookville Lake, should remain in operation.

Reservoirs

Although there are no natural lakes in the Whitewater River Basin, hundreds of small manmade lakes, ponds, and gravel pits are scattered throughout the area. The lakes and ponds, generally only a few acres in size, are primarily used for recreation, stock watering, or aesthetic purposes.

Whitewater Lake, the largest manmade, single-purpose recreational lake in the basin, covers 200 acres and has a 1.1 billion gallon storage capacity at normal pool elevation. Lake Santee (261 acres, 0.9 billion gallons) is primarily used for recreation, but also serves as a water supply source for a nearby subdivision.

Middle Fork Reservoir in eastern Wayne County supplies more than half of Richmond's water needs. Completed in 1960, this reservoir is located 2 miles north of Richmond on the Middle Fork of the East Fork Whitewater River (fig. 14). The reservoir covers 161 acres and has a storage capacity of 881 million gallons, as determined from a recent Division of Water survey (see fig. 34).

Brookville Lake is a flood control, recreational, and water supply reservoir on the East Fork Whitewater River (fig. 14). The dam is about 1.5 miles north of Brookville in Franklin County, and upstream areas of the reservoir extend northward to near Brownsville in Union County. The lake controls runoff from a drainage area of 379 sq. mi. Table 9 summarizes storage and lake area data at different pool elevations. Fig. 15 shows the typical operation schedule.

Construction of Brookville Lake began in November 1965, and outlet works were completed in January

Table 9. Storage and area of Brookville Lake

Designation	Elevation range (ft msl)	Allocated storage		Lake area	
		ac-ft	bg	acres	sq mi
Minimum pool	713	55,600	18.1	2250	3.5
Water supply pool (winter)	713 - 740	89,300	29	4510	7.0
Seasonal pool (summer)	740 - 748	39,000	12.7	5260	8.2
Flood control pool	740 - 775	214,700	70	7790	12.2

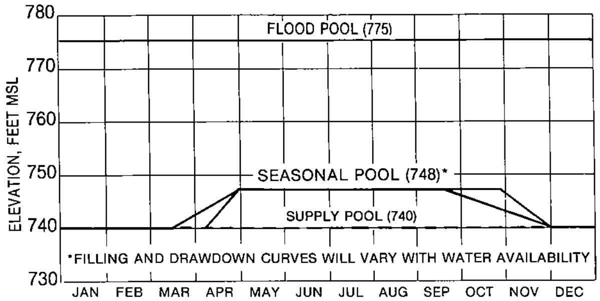

Figure 15. Typical operation schedule for Brookville Lake

1968. Since impoundment began in January 1974, the reservoir has been operated by the U.S. Army Corps of Engineers as part of a general plan to reduce flooding in the Ohio River Basin. The lake not only reduces flood stages in the Whitewater Valley, but also contributes to flood hazard mitigation along the Ohio River (U.S. Army Corps of Engineers, 1981). Flood damages prevented since January 1974 are estimated to be $2,560,000 (C. Schumann, U.S. Army Corps of Engineers, Louisville District, personal communication, 1987).

At emergency spillway crest (elevation 775 feet m.s.l.), total storage capacity of Brookville Lake is 359,000 acre-feet, or 117 billion gallons (see table 9). Depending on the season, from 175,700 to 214,700 acre-feet of this total storage capacity is available for flood control. During flood periods, the upstream end of the lake extends 24 miles northward to near Brownsville.

At summer pool elevation (748 feet m.s.l.), Brookville Lake extends northward about 16 miles, and has a total storage capacity of 183,900 acre-feet (60 billion gallons). Of this capacity, 39,000 acre-feet (12.7 billion gallons) is allocated for seasonal recreation and fish and wildlife purposes. About 16,450 acres of reservoir land and water have been leased to the State of Indiana for these two purposes.

From mid-September to mid-April, the lake level is maintained at 740 feet m.s.l. in order to allow storage of winter and spring runoff (fig. 15). Of the total winter storage capacity of 144,900 acre-feet below 740 feet m.s.l., 89,300 acre-feet is allocated for water supply. This water supply storage has been purchased by the State of Indiana from the U.S. Government for sale to any interested party. The State of Indiana has a contract with the Franklin County Water Association that allows the IDNR to sell up to an annual average of 500,000 gallons per day. (For more information on water supply, see the ''Surface-Water Availability'' section later in this report).

Stream-Flow Characteristics

Although the amount of available precipitation determines the theoretical upper limit of stream flow, the following factors affect the spatial and temporal distribution of flow: climate; soils and land cover (vegetation, lakes, impervious surfaces); topography and physiography (including drainage area, *drainage density*, channel geometry); geology (surficial and bedrock); interactions of surface water with ground water (areas of recharge, areas of discharge); and man-made modifications (stream channelization, dams, diversions, and pumpage).

Geographic variations of these factors account for the diversity of stream-flow characteristics within and among basins. Data on flow characteristics are needed for a wide range of hydrologic and hydraulic applications, including the determination of the water supply potential of streams. Selected hydrologic parameters derived from discharge records provide a semi-quantitative framework for characterizing the basin's surface-water system.

Average Flows

Of all hydrologic parameters, average discharge is the most easily understood and one of the most widely used. Average discharge is the arithmetic average of daily flows for all complete water years of record, whether consecutive or not.

The combined effects of the factors listed in the previous section are reflected in average discharge, which can be interpreted as follows: 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 it at a uniform rate over the same period, that rate would be the average flow. This flow represents the theoretical upper limit of the long-term yield which can be developed from a stream, even with *regulation*.

Average daily discharges of record are given in table 8. Based on average discharge and flow duration data reported by Stewart (1983), average discharges at continuous-record stations in the Whitewater Basin are equaled or exceeded 25 percent of the time. This percentage, which is less than exceedence percentages for average flows in northern Indiana, primarily reflects the higher flood discharges in the Whitewater Basin. In some northern Indiana basins characterized by slight topographic relief, poorly developed drainage, and extensive, highly permeable outwash deposits, for example, average discharge would be expected to more closely approximate the *median* discharge.

If average discharge is divided by the area drained, the similarity of *unit discharges* becomes apparent. As table 8 shows, average unit discharge for continuous-record stations in the Whitewater River Basin is slightly more than 1 cfs (cubic foot per second) per square mile.

Average runoff, which is the depth to which a drainage area would be covered if the average discharge for a given time period were uniformly distributed, represents the amount of water leaving a basin as both surface-water runoff and ground-water discharge. Except for flows at Richmond, *runoff* at continuous-record stations averages about 14.5 inches per year.

Low Flows

Low-flow discharge information is essential to the planning, management, and regulation of activities associated with surface-water resources. Low-flow data are used in the design and operation of wastewater treatment facilities, power plants, engineering works (such as dams, reservoirs and navigation structures), and water supply facilities. Low-flow information is also used to evaluate water quality and its suitability for various uses. Some low-flow parameters may also be used in the development of regional draft-storage relations, in the forecasting of seasonal low flows, or as indicators of the amount of ground-water influx to streams.

Low-flow characteristics are commonly described by points on low-flow frequency curves prepared from daily discharge records at continuous-record gaging stations. Correlation techniques can be used to estimate

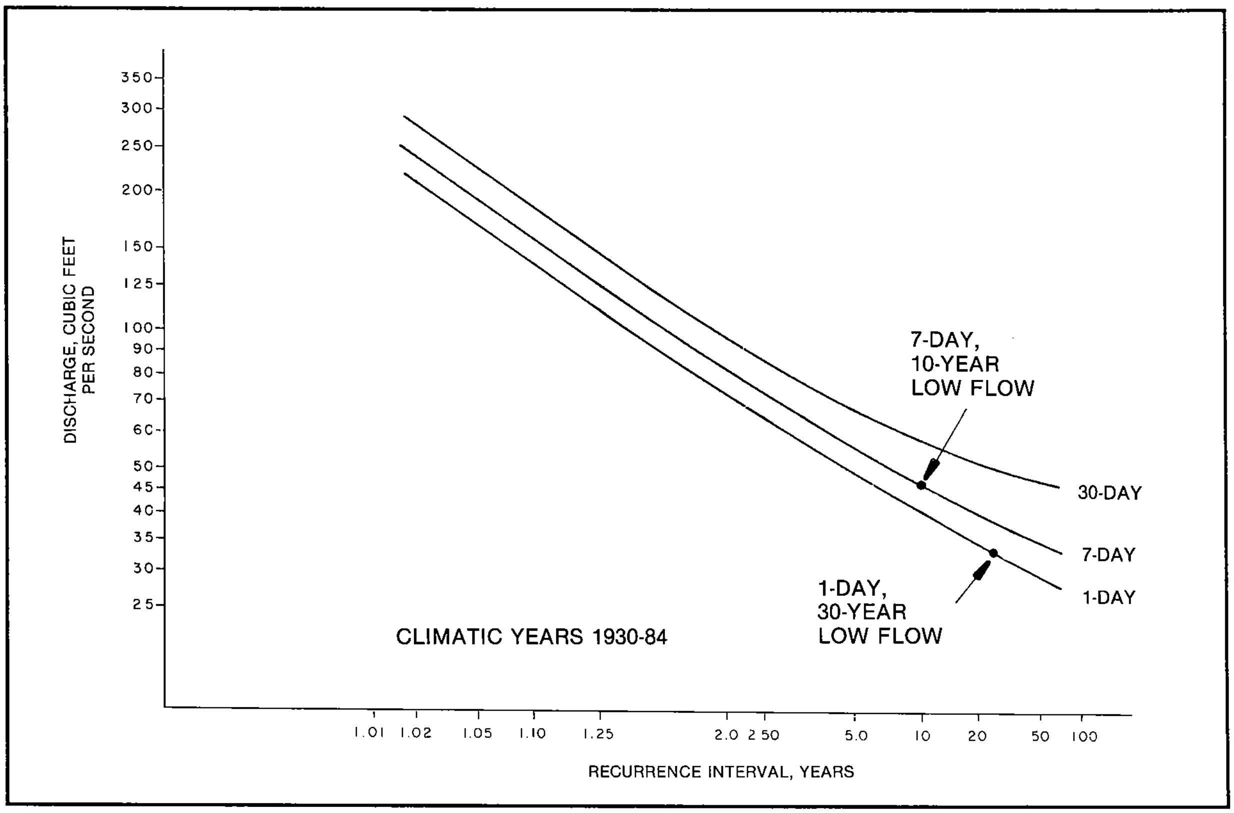

Figure 16. Low-flow frequency curves, Whitewater River near Alpine

curves, or selected points on curves, for stations where short-term records and/or *base-flow* measurements are available.

Curves can be developed from a *frequency analysis* of annual minimum flows for selected numbers of consecutive days. Fig. 16 shows the relation of annual minimum average discharges for 1-day, 7-day, and 30-day periods for the Whitewater River near Alpine during *climatic years* 1930-84. 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 average) flow having a 30-year *recurrence interval*, and the annual minimum 7-day average flow having a 10-year recurrence interval.

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 flow indicates the dependable supply of water without storage, and is discussed further in the "Surface-Water Availability" section.

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 one-in-ten chance that the annual minimum 7-day average discharge in any given year will be less than this value. Based on data reported by Stewart (1983), stream flows at continuous-record stations in the Whitewater Basin are greater than 7-day, 10-year values about 99.5 percent of the time.

In Indiana, the 7-day, 10-year low flow is the index for water quality standards. This 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, 7-day, 10-year low flows or other low-flow parameters may be utilized by the IDNR to establish minimum flows of selected streams.

Table 8 presents annual 7-day, 10-year low flows at continuous-record gaging stations as calculated through *water year* 1984. The non-concurrency of data among these seven stations prevents a strict comparison of low-flow parameters. However, the tabulated values are statistically more representative of each site because the maximum lengths of record were used.

The 7-day, 10-year values tabulated for the two stations downstream of Brookville Lake represent pre-reservoir (unaffected) flows. These values are considered more appropriate low-flow characteristics than values which include 10 additional years of affected data. (The effect of Brookville Lake on downstream flows is discussed in a later section.)

Unit low flow is one indicator of the degree to which stream flow is sustained by ground-water contribution. The highest 7-day, 10-year unit low flow at a continuous-record gaging station occurs on the Whitewater River near Hagerstown. This value (0.12 cfs/sq. mi.) was calculated for a selected base period 1972-84. The next highest unit flow at an unaffected continuous-record site occurs farther downstream near Alpine. This concurrent value (0.11 cfs/sq. mi.) is slightly higher than the long-term value shown in table 8, which includes flows measured during drought periods of the 1930s and 1940s. The third highest unit flow for the period 1972-84 occurs on the East Fork Whitewater River at Abington. This value does not differ significantly from the value shown in table 8 for the period 1965-84.

At partial-record stations, unit low flows are highest for Martindale Creek and Greens Fork in Wayne County. Similar unit flows are expected along middle reaches of Nolands Fork, which drains an area of similar size, basin shape, and surficial geology.

As table 8 shows, low flows for Martindale Creek and Greens Fork are significantly less than flows at the three continuous-record sites near Hagerstown, Alpine, and Abington. Although Martindale Creek and Greens Fork, like upper reaches of the Whitewater River and its east fork, drain watersheds developed primarily on outwash sand and gravel deposits, the degree of ground-water contribution to these two tributary reaches appears to be considerably less.

Low flows for tributaries of Brookville Lake in Union County and for tributaries of the Whitewater River in Franklin County either approach or equal zero (table 8). These tributary basins contain large quantities of glacial till and minimal amounts of sand and gravel; therefore, precipitation quickly leaves these watersheds as surface runoff. During periods of little or no rainfall, the streams cease flowing due to limited ground-water discharge.

Surface- and Ground-Water Interactions

Interactions between surface- and ground-water systems in the Whitewater Basin account for much of the diversity of stream-flow characteristics, particularly low flows. The use of unit flow as an indicator of ground-water inflow was discussed in the previous section. Other semi-quantitative approaches described below are also useful for making inferences regarding system interactions and for generalizing the water supply potential of selected streams. Additional analyses which define available stream flow and storage requirements are discussed in the ''Surface-Water Availability'' section later in this report.

Flow Duration

The flow duration curve is a cumulative frequency curve that shows the percent of time that specified discharges are equaled or exceeded during a given period of record. For example, daily mean flows of the Whitewater River at Brookville were at least 135 cfs during 95 percent of the time for water years 1956-73 (as derived from fig. 17). Daily flows for this period exceeded 11,750 cfs only 1 percent of the time.

Even though all chronological sequence of daily discharges is lost in a duration analysis, a duration curve can be taken as a probability curve that the flow distribution over several years will be approximately equal to that of prior years (Rohne, 1972). Because duration data provide a great deal of information on a stream's overall flow regime, such data are useful for water supply and hydroelectric power studies, industrial and waste treatment plant siting, reservoir design, and pollution control.

The shape of the duration curve is an index of the natural storage within a basin that is utilized by the stream. The more nearly horizontal the curve, the greater is the storage effect, and the greater the potential for high sustained yields from both surface and ground water.

If duration curves are plotted on a per-square-mile (unit) basis for a concurrent period, comparisons of storage can be made among drainage basins in areas of differing geology. For example, the three curves in fig. 17 show that the ability of a drainage system to accommodate high flows and sustain low flows

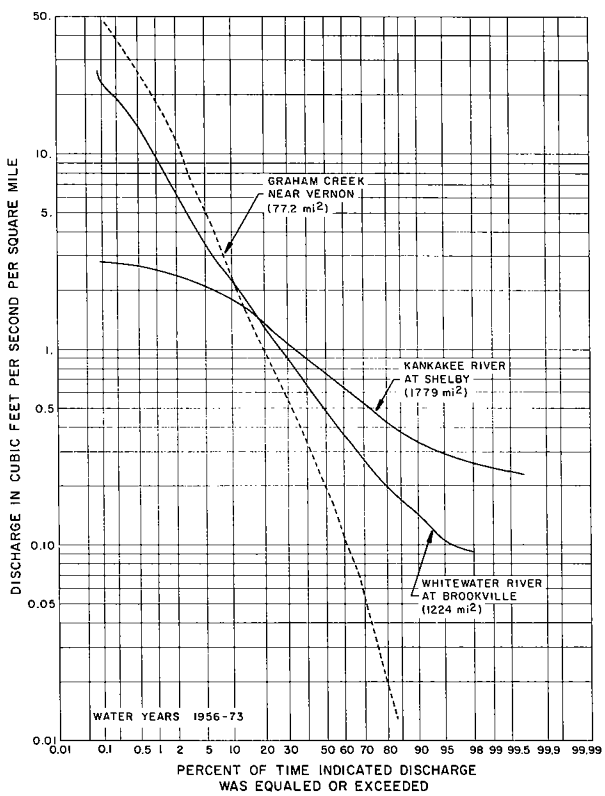

Figure 17. Flow duration curves for selected stream gages in Indiana

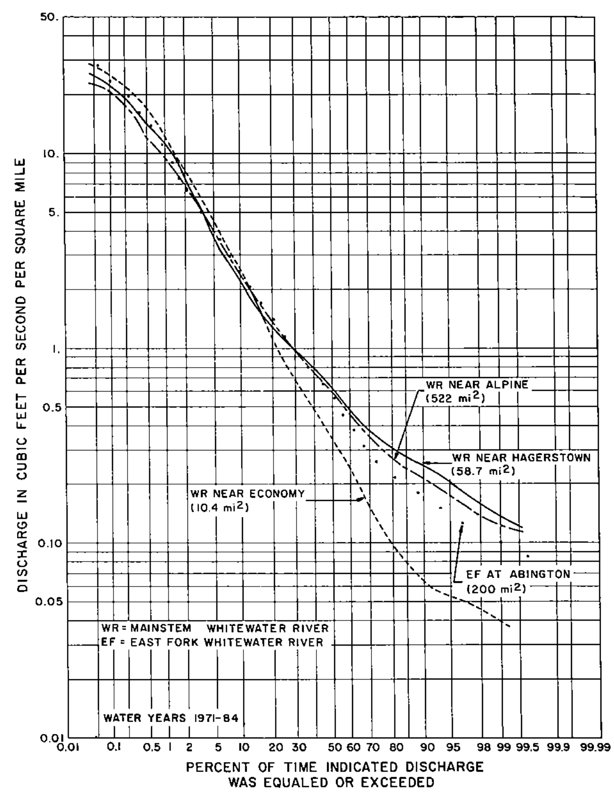

Figure 18. Flow duration curves for major stream gages in the Whitewater River Basin