Relation Between Precipitation and the 25th Percentile of June and September Flows in Streams in the Great Lakes, Ohio, and Upper Mississippi River Basins

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U.S. Department of the Interior
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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow Rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Relation Between Precipitation and the 25th Percentile of June and September Flows in Streams in the Great Lakes, Ohio, and Upper Mississippi River Basins

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Abstract

Regression models were developed for the 25th percentile of June and September flows (first quartile of flow) for 47 streamflow-gaging stations (gaging stations) in the Upper Mississippi, Ohio, and Great Lakes drainage basins. The gaging stations that were selected for this analysis are on unregulated rivers, have at least 40 years of record, and have a nearby weather station with at least 70 years of precipitation record. Regression models were developed for each gaging station relating annual 25th percentile of June and September flows to selected precipitation variables. The explanatory variables are monthly precipitation (April–June, July–September) for each year of record, precipitation for the previous year, and average precipitation for the preceding 5-, 10-, 15-, 20-, 25-, and 30-year periods.

Short-term precipitation (April–June or July–September monthly precipitation) variables are the most common significant variables in the regression equations for the 25th percentile of June and September streamflows. May and June monthly precipitation are the most common significant variables among the regression models of the 25th percentile of June flows. August and September monthly precipitation are the most common significant variables in the regression models of the 25th percentile of September streamflow. July precipitation also is a significant explanatory variable in regression models of September streamflow.

The 25th-percentile flows in this study also are related to intermediate- and long-term precipitation variables. The intermediate-term precipitation variable (previous-year's precipitation) has a more distinct spatial pattern than the long-term precipitation variable (multiyear running averages of annual precipitation) and is more likely to be significant in the western part than in the eastern part of the study area.

Introduction

Understanding the characteristics of the low range of streamflow is important for managing water resources for water supply, waste disposal, and aquatic habitats. For example, many agencies use the minimum 7-day average streamflow with a 10-year recurrence interval (7-day, 10-year low flow) as a target for making regulatory decisions.

A small study was done, using low flows at five streamflow gaging stations (gaging stations) in Minnesota, to determine if there was a relation between recent and long-term precipitation and low streamflow (Lorenz, 2004). An analysis of the 25th percentile of June flows and the median January flows at the five gaging stations showed that those flows were affected by recent and long-term precipitation. In that analysis, the flows at the gaging stations were modeled by use of linear regression. The explanatory variables used in the models were precipitation for the current month and each of the 2 previous months, the previous year's precipitation, and average precipitation for the preceding 5-, 10-, 15-, 20-, 25-, and 30-year periods. It was assumed that the selected percentile of flow would be affected by several rainfall trends. First, it was assumed that the rate of ground-water discharge to the stream would be affected by recent rainfall, which is represented by the rainfall in the current and 2 previous months. Second, it was assumed that the ground-water discharge would be affected by rainfall in the previous year. Finally, it was assumed that the ground-water discharge to the stream would be affected by long-term rainfall trends; for example, it would be less after 10 dry years than it would be after 10 wet years. These factors could influence ground-water storage in aquifers discharging to the stream. For four of the five gaging stations, the average precipitation for the 15- or 20-year period was highly significant.

On the basis of Lorenz's results, a regional study was done to determine whether similar relations between selected flows and precipitation are evident in the larger area of the Great Lakes, Ohio, and Upper Mississippi River Basins. The methodology of Lorenz's study was applied to the 25th percentile of June and September flows of 47 gaging stations in these basins. The 25th percentiles of June and September flows were used in this study to characterize the upper end of the low range in streamflow. The 25th percentile of June flows was selected because it represents flows from spring recharge, generally the period of greatest recharge to aquifers in the study area. The 25th percentile of September flows was selected because it represents flows after the summer period, when recharge from rainfall is reduced because of losses to evapotranspiration.

The purpose of this report is to describe the methods and results of the study to determine the relation between precipitation and the 25th percentile of June and September flows of the 47 gaging stations. The gaging stations are in the Great Lakes, Ohio, and Upper Mississippi River Basins. The gaging stations are on unregulated rivers, have at least 40 years of record, and have a nearby weather station with at least 70 years of precipitation record.

This was an exploratory study using readily available data. The study involved only gaging stations that were part of the USGS Hydro-Climatic Data Network and weather stations that were part of the U.S. Historical Climatology Network. The data from these data sets were not edited in this study except to estimate missing data.

Regression models were developed to relate the 25th percentile of June flows and September flows to precipitation near the 47 gaging stations. The response variables are the natural logarithm of the first quartile of daily mean flows for June or September for each calendar year of record. The explanatory variables are monthly precipitation (April–June or July–September) for each year of record, precipitation for the previous year, and average annual precipitation for the previous 5-, 10-, 15-, 20-, 25-, and 30-year periods.

The regression models were not developed for predictive purposes but, instead, to show the variables most important in determining the 25th percentile of flow.

Preparation of Data for Analyses

Gaging station data were retrieved from the USGS Hydro-Climatic Data Network (HCDN) (Slack and others, 1993) for the Great Lakes, Ohio, and Upper Mississippi River Basins (hydrologic regions 04, 05, and 07) (fig. 1). The HCDN is "A national data set of streamflow records that are relatively free of confounding anthropogenic influences [that] has been developed for the purpose of studying the variation in surface-water conditions throughout the United States." (Slack and others, 1993, p. 1).

Like the gaging stations, the weather stations were selected from an existing data set: the U.S. Historical Climatology Network (USHCN). The USHCN is "… a high-quality moderate sized data set of monthly averaged maximum, minimum, and mean temperature and total monthly precipitation developed to assist in the detection of regional climate change." (National Climatic Data Center, 2005).

The USHCN weather data contain three data sets of precipitation data: areal edited, time of observation, and filnet. The first data set, areal edited, contains the raw data that have been screened to flag monthly data that are suspect or outliers. The second data set, time of observation, contains the areal edited data that have been adjusted to remove the time of observation bias so that the data will be consistent with a midnight-to-midnight observation schedule. The third data set, filnet, contains the time of observation data that have been adjusted for station moves or station-change bias; it contains estimated values for missing or outlier data. The filnet data set was used in the analyses except for station 202737, Fayette 4SW, in Michigan. That station did not have a filnet data set, so the time-of-observation data set was used instead.

Selection of Gaging Stations

From the list of HCDN gaging stations, 47 stations were selected that met the following criteria:

1. They had at least 40 years of record through 2003, the last year of streamflow data. The starting and ending dates of the period of record were used to determine the length of record.

2. They were not affected by regulation or diversion. This was determined from the station descriptions of the gaging stations in the water resources data reports for each state in the study area, except for Michigan (Hauck and Nagel, 2005; Hornlein and others, 2005; McClain, Moses, and Darnell, 2005; Mitton and others, 2005; Morlock, Nguyen, and Majors, 2005; Nalley and others, 2005; Robl, Angel, and Norris, 2003; Shindel, Mangus, and Frum, 2005; Siwicki, 2005; Ward, Rosier, and Crosby, 2005; Waschbusch and others, 2005).

3. The selected gaging station was not upstream or downstream from another selected gaging station.

4. The streamflow record at the gaging station was judged suitable for low-flow analysis by the surface-water specialist in the U.S. Geological Survey Science Center for each state in the study area.

5. They were not close to another gaging station. It was desired to have an even distribution of gaging stations across the study area. Gaging stations were removed from the selection to create as even a distribution as possible.

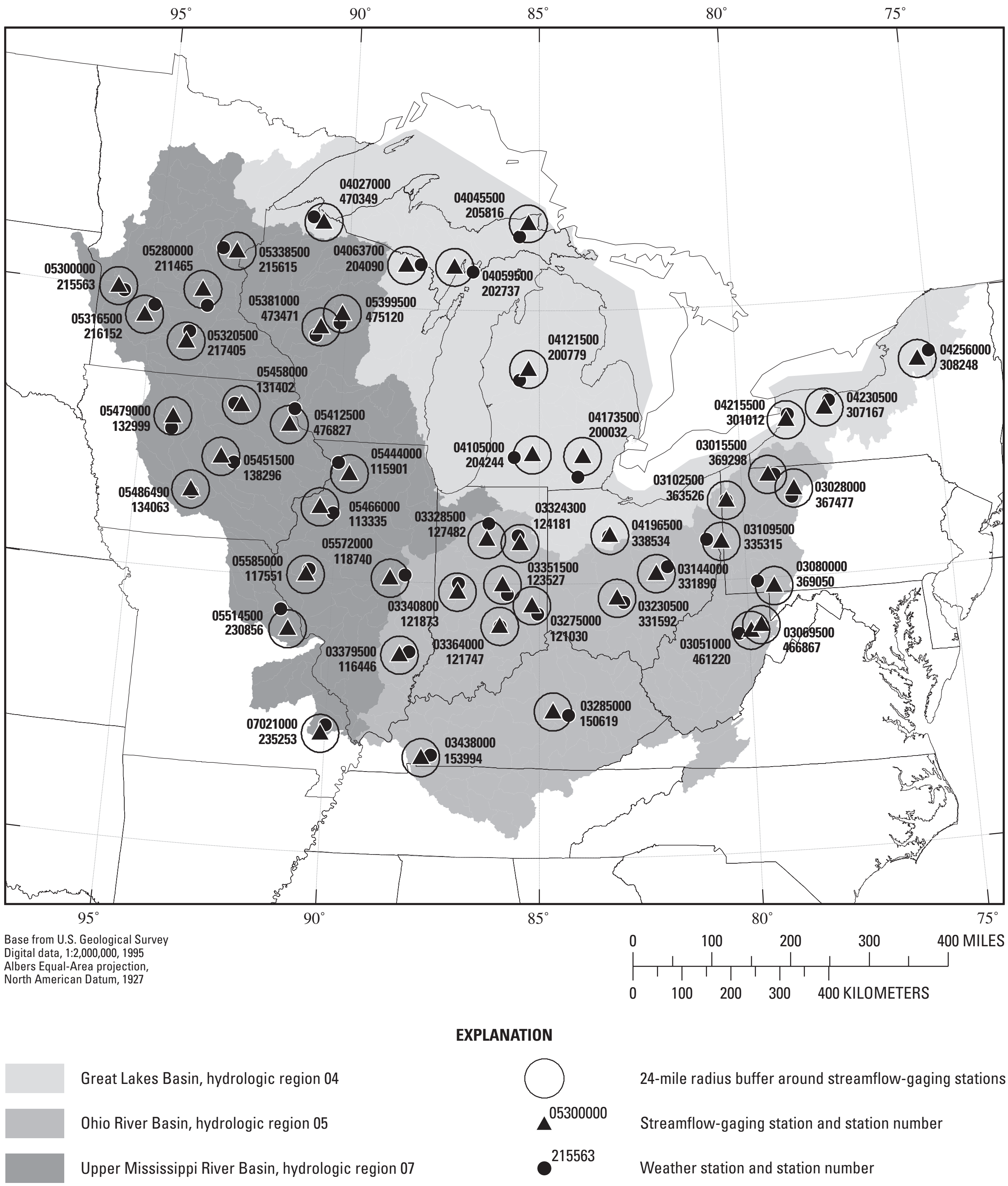

Figure 1. Study area and location of streamflow-gaging stations and weather stations.

6. A National Weather Service weather station with at least 70 years of record was within 24 miles of the gaging station. Precipitation records from weather stations that lie inside the basin upstream from the gaging stations are more representative of the rainfall falling over the basin than a weather station outside of the basin but near the mouth of the basin. However, weather stations did not fall inside the upstream basins of most of the gaging stations that met the first five criteria. As a result, in order to use only one set of selection criteria in the analysis, only weather stations that were within 24 miles of the gaging stations were used. Also, 70 years of precipitation record were needed in order to determine the 30-year running average of precipitation for the first year of streamflow record.

The 47 gaging stations are shown in figure 1 and are listed in table 1. The weather stations used with the selected 47 gaging stations are shown in figure 1 and are listed in tables 1 and 2.

The data were retrieved as electronic files from the internet. The streamflow data sets were retrieved from the USGS National Water Information System–Web Interface (U.S. Geological Survey, 2005) as files of daily mean discharge for each year of record. The USHCN data set (National Climatic Data center, 2005) consists of monthly and annual precipitation totals for each year of record.

Missing Data

The first and last years of the period of record for the streamflow and precipitation data were used to determine the length of record for these data. However, there were years of missing record in some of the streamflow data sets. Even though the filnet precipitation data set, in which the National Weather Service estimated missing values, was used, there were years in the filnet precipitation data sets in which one or more months of precipitation data were missing for April through June or July through September or for which annual precipitation totals were missing for the year. A summary of the missing data is in table 3 for the streamflow data and in table 4 for the precipitation data.

Running averages of annual precipitation were not computed across missing years of annual precipitation except when annual precipitation was missing for a single year. A single year of missing precipitation was estimated by averaging the previous 5 years and the following 5 years of annual precipitation if these bracketing 5-year periods did not have missing annual precipitation. The USHCN weather stations for which annual precipitation were estimated are in table 5.

Determining the Regression Models

The explanatory variables for the regression models were chosen to represent three different temporal scales of the contribution of precipitation to 25th-percentile flows. The short-term contribution is represented by April–June or July–September monthly precipitation. The intermediate contribution is represented by the precipitation that fell in the previous calendar year. The long-term contribution is represented by the multiyear running averages of annual precipitation.

The 5-, 10-, 15- 20, 25-, and 30-year running averages of annual precipitation were computed for each weather station except when missing annual precipitation data would have been included in the running average. There often were not enough data to compute the 30-year running average of annual precipitation because of 1 or more years of missing annual precipitation data in the weather-station records (table 4). When this happened, either the running averages of annual precipitation were not used in the development of the model or only 5- to 20-year running averages were used, as indicated in tables 6 and 7 (at back of report).

Sometimes two models were developed for a gaging station. One used the longest length of streamflow and precipitation records possible, but the running averages of precipitation were not used in the development of the regression model. The other used a shorter length of record and included running averages in the development of the regression model. For example, two regression models were developed for the 25th percentile of June flows at gaging station 03102500, Little Shenango River at Greenville, Pa. (table 6). The precipitation record for the corresponding weather station, 363526, Greenville 2NE, Pa., (period of record 1884–1996) is missing annual precipitation data in 1927 and 1928. One model was developed for the period 1930–1996. The second model was developed for the period 1958–1996. The 5-year through 30-year running average precipitation data for this period could be determined, so these explanatory variables were tested for inclusion in the model. The 20-year running average precipitation variable was significant.

Three transformations for the 25th percentile of June and September flows were tried to see which resulted in the most linear and homoscedastic regression: untransformed, natural-log transformed, and square-root transformed. The natural-log transformed 25th percentile flows produced the most linear and homoscedastic models, and so the natural-log transformed first quartile values were used as the response variable in all of the multiple linear-regression models.

Table 1. Streamflow-gaging stations and corresponding weather stations used in the study.

[USGS, U.S. Geological Survey]

USGS streamflow-gaging station number	Station name	Hydrologic unit code	Drainage area, in square miles	Corresponding weather station
	Ohio River drainage basin			
03015500	Brokenstraw Creek At Youngsville, Pennsylvania	05010001	321	369298
03028000	West Branch Clarion River At Wilcox, Pennsylvania	05010005	63	367477
03051000	Tygart Valley River At Belington, West Virginia	05020001	408	461220
03069500	Cheat River Near Parsons, West Virginia	05020004	718	466867
03080000	Laurel Hill Creek At Ursina, Pennsylvania	05020006	121	369050
03102500	Little Shenango River At Greenville, Pennsylvania	05030102	104	363526
03109500	Little Beaver Creek Near East Liverpool, Ohio	05030101	496	335315
03144000	Wakatomika Creek Near Frazeysburg, Ohio	05040004	140	331890
03230500	Big Darby Creek At Darbyville, Ohio	05060001	534	331592
03275000	Whitewater River Near Alpine, Indiana	05080003	522	121030
03285000	Dix River Near Danville, Kentucky	05100205	318	150619
03324300	Salamonie River Near Warren, Indiana	05120102	425	124181
03328500	Eel River Near Logansport, Indiana	05120104	789	127482
03340800	Big Raccoon Creek Near Fincastle, Indiana	05120108	139	121873
03351500	Fall Creek Near Fortville, Indiana	05120201	169	123527
03364000	East Fork White River At Columbus, Indiana	05120205	1,707	121747
03379500	Little Wabash River Below Clay City, Illinois	05120114	1,131	116446
03438000	Little River Near Cadiz, Kentucky	05130205	244	153994
	Great Lakes drainage basin			
04027000	Bad River Near Odanah, Wisconsin	04010302	597	470349
04045500	Tahquamenon River Near Paradise, Michigan	04020202	790	205816
04059500	Ford River Near Hyde, Michigan	04030109	450	202737
04063700	Popple River Near Fence, Wisconsin	04030108	139	204090
04105000	Battle Creek At Battle Creek, Michigan	04050003	241	204244
04121500	Muskegon River At Evart, Michigan	04060102	1,450	200779
04173500	Mill Creek Near Dexter, Michigan	04090005	128	200032
04196500	Sandusky River Near Upper Sandusky, Ohio	04100011	298	338534
04215500	Cazenovia Creek At Ebenezer, New York	04120103	135	301012
04230500	Oatka Creek At Garbutt, New York	04130003	200	307167
04256000	Independence River At Donnattsburg, New York	04150101	88.7	308248
	Upper Mississippi River drainage basin			
05280000	Crow River At Rockford, Minnesota	07010204	2,520	211465
05300000	Lac Qui Parle River Near Lac Qui Parle, Minnesota	07020003	983	215563
05316500	Redwood River Near Redwood Falls, Minnesota	07020006	629	216152
05338500	Snake River Near Pine City, Minnesota	07030004	958	215615
05381000	Black River At Neillsville, Wisconsin	07040007	749	473471
05399500	Big Eau Pleine River Near Stratford, Wisconsin	07070002	224	475120

Table 1. Streamflow-gaging stations and corresponding weather stations used in the study.—Continued

[USGS, U.S. Geological Survey]

USGS streamflow-gaging station number	Station name	Hydrologic unit code	Drainage area, in square miles	Corresponding weather station
	Upper Mississippi River drainage basin—*continued*			
05412500	Turkey River At Garber, Iowa	07060003	1,545	476827
05444000	Elkhorn Creek Near Penrose, Illinois	07090005	146	115901
05451500	Iowa River At Marshalltown, Iowa	07080208	1,564	138296
05458000	Little Cedar River Near Ionia, Iowa	07080201	306	131402
05466000	Edwards River Near Orion, Illinois	07080104	155	113335
05479000	East Fork Des Moines River At Dakota City, Iowa	07100003	1,308	132999
05486490	Middle River Near Indianola, Iowa	07100008	503	134063
05514500	Cuivre River Near Troy, Missouri	07110008	903	230856
05572000	Sangamon River At Monticello, Illinois	07130006	550	118740
05585000	La Moine River At Ripley, Illinois	07130010	1,293	117551
07021000	Castor River At Zalma, Missouri	07140107	423	235253

Table 2. Weather stations used in the study.

[USHCN, U.S. Historical Climatology Network]

USHCN station number	Latitude, decimal degrees	Longitude, decimal degrees	State	Station name
113335	41.17	-90.05	Illinois	Galva
115901	42.1	-89.98	Illinois	Mount Carroll
116446	38.7	-88.07	Illinois	Olney 2S
117551	40.12	-90.55	Illinois	Rushville
118740	40.1	-88.23	Illinois	Urbana
121030	39.42	-85.02	Indiana	Brookville
121747	39.2	-85.92	Indiana	Columbus
121873	39.97	-86.93	Indiana	Crawfordsville 5S
123527	39.78	-85.75	Indiana	Greenfield
124181	40.85	-85.5	Indiana	Huntington
127482	41.07	-86.22	Indiana	Rochester
131402	43.05	-92.67	Iowa	Charles City
132999	42.5	-94.2	Iowa	Fort Dodge
134063	41.37	-93.55	Iowa	Indianola
138296	41.98	-92.58	Iowa	Toledo
150619	37.57	-84.3	Kentucky	Berea College
153994	36.83	-87.5	Kentucky	Hopkinsville
200032	41.92	-84.02	Michigan	Adrian 2NNE
200779	43.7	-85.48	Michigan	Big Rapids Waterworks
202737	45.67	-86.72	Michigan	Fayette 4SW
204090	45.78	-88.08	Michigan	Iron Mountain Kingsford WWTP

Table 2. Weather stations used in the study.—Continued

[USHCN, U.S. Historical Climatology Network]

USHCN station number	Latitude, decimal degrees	Longitude, decimal degrees	State	Station name
204244	42.28	-85.6	Michigan	Kalamazoo State Hospital
205816	46.33	-85.5	Michigan	Newberry State Hospital
211465	44.8	-93.58	Minnesota	Chaska
215563	44.93	-95.75	Minnesota	Montevideo 1SW
215615	45.88	-93.3	Minnesota	Mora
216152	44.72	-94.93	Minnesota	Olivia 3SE
217405	44.3	-93.97	Minnesota	Saint Peter 2SW
230856	39.37	-91.18	Missouri	Bowling Green 2NE
235253	37.3	-89.97	Missouri	Marble Hill
301012	42.93	-78.73	New York	Buffalo WSCMO AP
307167	43.13	-77.67	New York	Rochester Airport
308248	43.88	-75.03	New York	Stillwater Reservoir
331592	39.62	-82.95	Ohio	Circleville
331890	40.25	-81.87	Ohio	Coshocton WPC Plant
335315	40.72	-80.9	Ohio	Millport 2NW
338534	40.83	-83.28	Ohio	Upper Sandusky
363526	41.42	-80.37	Pennsylvania	Greenville 2NE
367477	41.42	-78.75	Pennsylvania	Ridgway
369050	39.92	-79.72	Pennsylvania	Uniontown 1NE
369298	41.85	-79.15	Pennsylvania	Warren
461220	38.98	-80.22	West Virginia	Buckhannon
466867	39.1	-79.67	West Virginia	Parsons 1NE
470349	46.57	-90.97	Wisconsin	Ashland Experiment Farm
473471	44.4	-90.73	Wisconsin	Hatfield Hydro Plant
475120	44.65	-90.13	Wisconsin	Marshfield Experiment Farm
476827	43.03	-91.15	Wisconsin	Prairie Du Chien

Table 3. Streamflow-gaging stations with missing record between 1960 and 2003.

[USGS, U.S. Geological Survey]

USGS streamflow-gaging station number	Streamflow-gaging station name	Number of years of missing streamflow record
04173500	Mill Creek Near Dexter, Michigan	11
04196500	Sandusky River Near Upper Sandusky, Ohio	18
05300000	Lac Qui Parle River Near Lac Qui Parle, Minnesota	1
05338500	Snake River Near Pine City, Minnesota	8
05514500	Cuivre River Near Troy, Missouri	15
07021000	Castor River At Zalma, Missouri	8

Table 4. Weather stations with missing record from 1930 through 2003.

[USHCN, U.S. Historical Climatology Network]

USHCN station number	USHCN station name	Number of years of missing monthly precipitation record for April through June	Number of years of missing monthly precipitation record for July through September	Number of years of missing annual precipitation record
113335	Galva, Illinois	0	0	7
116446	Olney 2s, Illinois	11	0	12
117551	Rushville, Illinois	1	3	3
123527	Greenfield, Indiana	0	1	0
127482	Rochester, Indiana	2	2	4
134063	Indianola, Iowa	3	3	4
138296	Toledo, Iowa	0	4	4
200032	Adrian 2NNE, Michigan	0	0	2
200779	Big Rapids Waterworks, Michigan	2	1	2
202737	Fayette 4SW, Michigan	2	1	3
204090	Iron Mountain Kingsford WWTP, Michigan	0	0	1
204244	Kalamazoo State Hospital, Michigan	0	1	13
205816	Newberry State Hospital, Michigan	1	0	2
211465	Chaska, Minnesota	3	3	4
215563	Montevideo, Minnesota	0	2	2
215615	Mora, Minnesota	10	10	10
216152	Olivia 3SE, Minnesota	0	0	7
217405	Saint Peter 2SW, Minnesota	0	0	1
230856	Bowling Green 2NE, Missouri	0	0	3
307167	Rochester Airport, New York	1	0	0
308248	Stillwater Reservoir, New York	0	1	1
331592	Cicleville, Ohio	1	0	3
331890	Coshocton WPC Plant, Ohio	1	0	6
369298	Warren, Pennsylvania	1	1	0
466867	Parsons 1NE, West Virginia	7	6	7
473471	Hatfield Hydro Plant, Wisconsin	10	10	11
475120	Marshfield Experiment Farm, Wisconsin	2	0	2
476208	Prairie Du Chien, Wisconsin	6	3	11

Table 5. Years for which annual precipitation values were estimated.

[USHCN, U.S. Historical Climatology Network]

USHCN station number	Year	USHCN station number	Year	USHCN station number	Year
116446	1987	134063	1987	307167	1989
117551	1930	138296	1902	331592	1984
117551	1938	138296	1908	331890	1945
121030	1937	138296	1916	338534	1927
123527	1917	150619	1948	369050	1893
123527	1972	153994	1937	369050	1905
124181	1921	204090	1910	369298	1937
124181	1950	204090	1987	369298	1978
132999	1903	205816	1910	461220	1899

S-PLUS statistical software (Insightful Corporation, 2005) was used to determine the linear-regression models. The models were of the form:

$$1\mathrm{n}(Q_{25,June}) = aP_{April} + bP_{May} + cP_{June} + dP_{Prev.Year} + eP_{Run.Average} + I \quad (1)$$

or

$$1\mathrm{n}(Q_{25,September}) = aP_{July} + bP_{August} + cP_{September} + dP_{Prev.Year} + eP_{Run.Average} + I \quad (2)$$

where

$Q_{25,June}$ is the 25th percentile of flow for June,

$Q_{25,September}$ is the 25th percentile of flow for September,

P_{April}, P_{May}, P_{June} are the monthly precipitation for April, May, and June, respectively,

P_{July}, P_{August}, $P_{September}$ are the monthly precipitation for July, August, and September, respectively,

$P_{Prev.Year}$ is the annual precipitation for the previous calendar year,

$P_{Run.Average}$ is the 5-, 10-, 15-, 20-, 25-, or 30-year running average of precipitation,

I is the intercept of the regression,

and

a, b, c, d, e are estimated coefficients.

The explanatory variables were retained in the model if their p-value was 0.01 or less. This value was selected to retain only significant explanatory variables but not to be so restrictive that regional patterns could not be detected if there were any.

The multiple linear-regression models were developed in two steps.

1. Step 1 was to use as explanatory variables in the regression April, May, and June monthly precipitation and the previous year's annual precipitation to estimate the log-transformed 25th percentile of June flows; or July, August, and September monthly precipitation and previous year's annual precipitation to estimate the log-transformed 25th percentile of September flows. As described above, explanatory variables with p-value greater than 0.01 were excluded from the regression model, and the regression model was recalculated.

2. In step 2, a model was developed that included the running averages of annual precipitation. Each running average was added, one at a time, to the model developed in step 1. The running average with the lowest p-value, if the p-value was less than 0.01, was retained in the model.

The models are listed in tables 6 and 7. The intercepts for the models are not listed in tables 6 and 7 because the models are not intended to be used for prediction but to describe the relation between precipitation and the 25th percentile of streamflow. They show the explanatory variables that explain the largest amount of variation in the 25th percentile of flow.

Sometimes, none of the variables in the best regression model had a p-value less than or equal to 0.01. These regression models are noted in tables 6 and 7.

Relation Between Precipitation and 25th-Percentile Flows

Regression models for 25th percentile of June flows were developed for 45 of the 47 gaging stations (table 6). May and June precipitation explanatory variables are the most common among the regression models. Both are in the regression models for 42 gaging stations. The previous year's precipitation was a significant explanatory variable in the regression models for 13 gaging stations, and April precipitation was a significant explanatory variable in the regression models for 10 gaging stations. Thirteen of the gaging stations where previous year's precipitation was a significant variable were in the western part of the study area (fig. 2). The gaging stations where April precipitation was a significant variable in the regression model were primarily in the western part of the study area (fig. 3). There were enough annual precipitation data for 39 of the gaging stations to test running averages of annual precipitation in the regression models. Running multiyear averages of annual precipitation were significant at eight of the stations. As shown in figure 2, five of these gaging stations are in the western part of the study area, but three are near the Ohio-Pennsylvania border.

Regression models for 25th percentile of September flows were developed for 46 of the 47 gaging stations (table 7). August and September precipitation explanatory variables are the most common among the regression models. August precipitation is a significant explanatory variable in regression models for 37 gaging stations, September precipitation is a significant explanatory variable in regression models for 33 gaging stations, and both are in the regression models for 29 gaging stations. July precipitation is a significant explanatory variable in 21 regression models of 25th percentile of September flows. Previous year's precipitation was a significant explanatory variable in regression models for four gaging stations. These gaging stations are in the western part of the study area (fig. 2). There were enough annual precipitation data at 39 of the 47 gaging stations to test running averages of annual precipitation in the regression models. The multiyear running averages of annual precipitation were significant explanatory variables in regression models for 12 of the gaging stations. These gaging stations show no spatial pattern and are distributed across the study area (fig. 2).

It appeared that the previous year's precipitation variable may be significant in June and September regression models at the western edge of the study area. It was postulated that this was because annual precipitation is more variable there (fig. 4). To test this, the coefficient of variation of annual precipitation was calculated for the weather stations used in this study as a surrogate of precipitation variability. The coefficient of variation is the standard deviation of annual precipitation at the weather station divided by the mean of precipitation at the weather station; the standard deviation and the mean were calculated for the period of record at each weather station. Chi-squared tests were done using S-PLUS to determine whether the apparent correlation between significant previous year's precipitation and coefficient of variation was more than chance. The previous year's precipitation variable was divided into two categories for the June and September regression models: significant and not significant. The coefficients of variation of annual precipitation for the 47 weather stations were ranked from lowest to highest. The lowest 23 were classified as low; the remaining 24 were classified as high. The null hypothesis of the chi-squared test is that there is no correlation between the variables. The tests indicated that the null hypothesis can be rejected for June regression models but not for September regression models. The χ^2 of the chi-square test for June regression models was 11.66, and the *p*-value was 0.006, which means that the correlation between the significant previous year's precipitation variables and larger coefficients of variation of annual precipitation was not due to chance at an α less than 0.05. The χ^2 of the chi-squared test for the September regression models was 2.3228 and the *p*-value was 0.1275.

The monthly precipitation and previous year's precipitation explanatory variables that were significant in a regression model commonly changed when the period of record was changed. For instance, at gaging station 03069500, Cheat River near Parsons, W. Va., monthly precipitation for May and June are significant explanatory variables for the 84-year period of record, 1913–52 and 1960–2003, but only monthly precipitation for June was significant when a shorter period of record, 1978–2003, was analyzed (table 6). Models were developed for different periods of record at 13 gaging stations for 25th percentile of June flows and at 12 gaging stations for 25th percentile of September flows. Changing the period of record analyzed changed the explanatory variables that were significant in 7 of the 13 models of June flows and in 7 of the 12 models of September flows.

Although relations are less pronounced than reported by Lorenz (2004), the 25th-percentile flows in this study appear to be related to short- and intermediate-term precipitation patterns. The intermediate-term precipitation (previous-year's precipitation) has a more distinct spatial pattern than short-term precipitation (April–June or July–September) and is more likely to be significant in the western part than in the eastern part of the study area. This pattern corresponds to the general pattern of variability in annual precipitation (greater variability in the western part). There is no distinct spatial pattern to gaging stations where long-term running average precipitation is significant, which may indicate that other variables, such as local geohydrology and landscape characteristics, not present in the model, are important factors pertaining to the effect of long-term precipitation on 25th percentile of flows in streams.

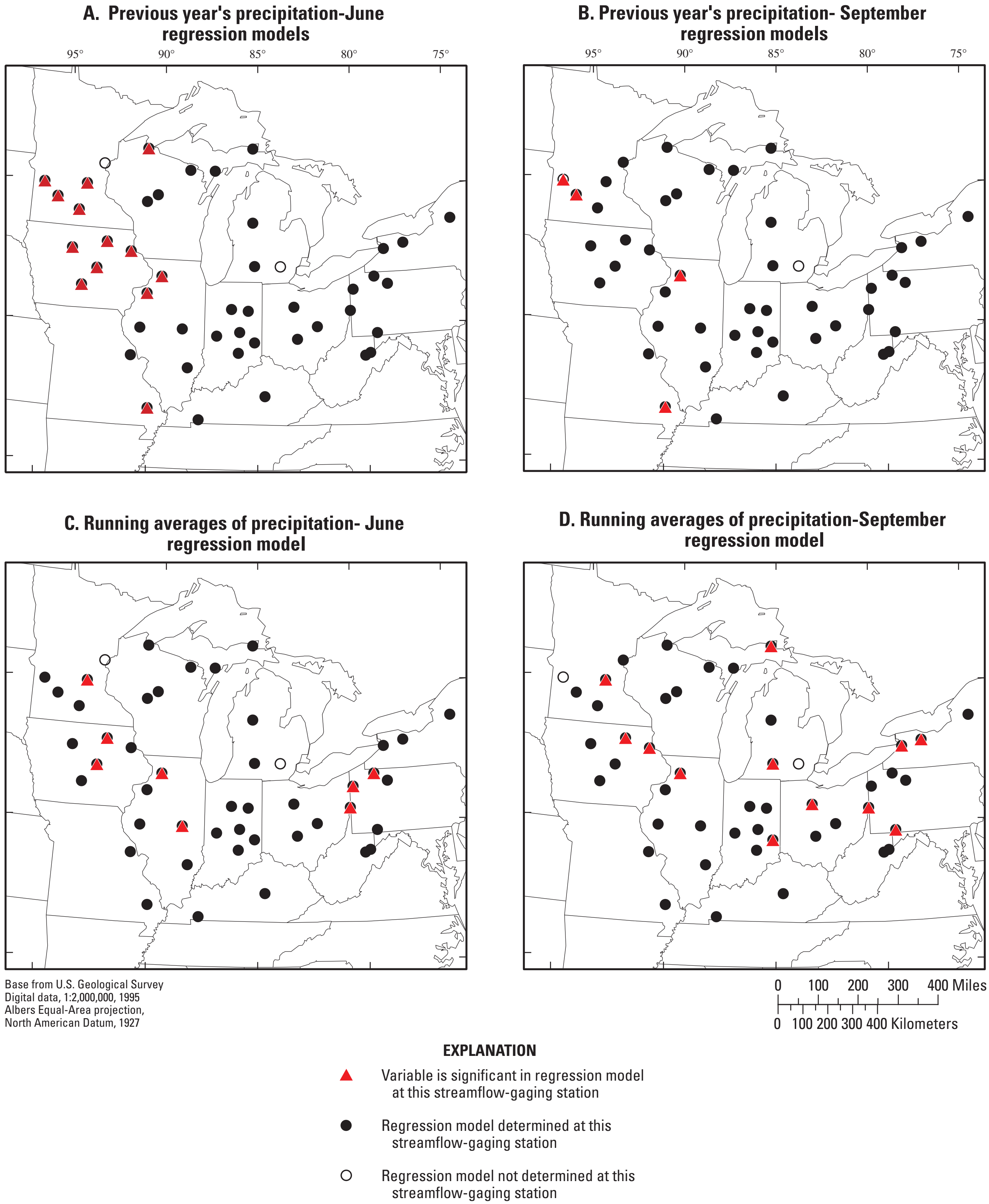

Figure 2. Streamflow-gaging stations where previous year's precipitation was a significant variable in the regression models for 25th percentile of (***A***) June and (***B***) September flows and a running average of precipitation was a significant variable in the regression models for 25th percentile of (***C***) June and (***D***) September flows.

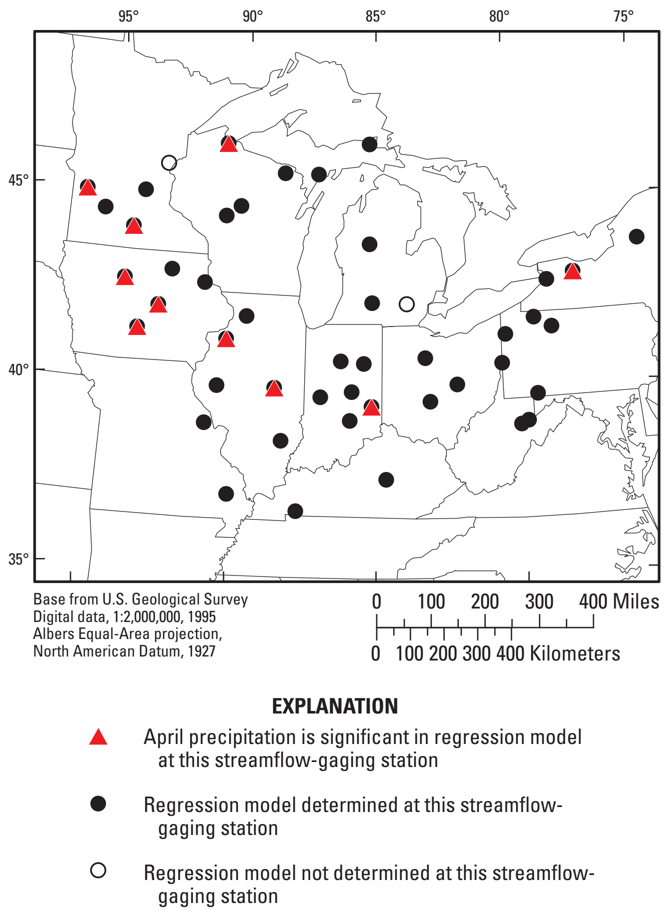

Figure 3. Streamflow-gaging stations where April precipitation was a significant variable in the regression model for 25th percentile of June flow.

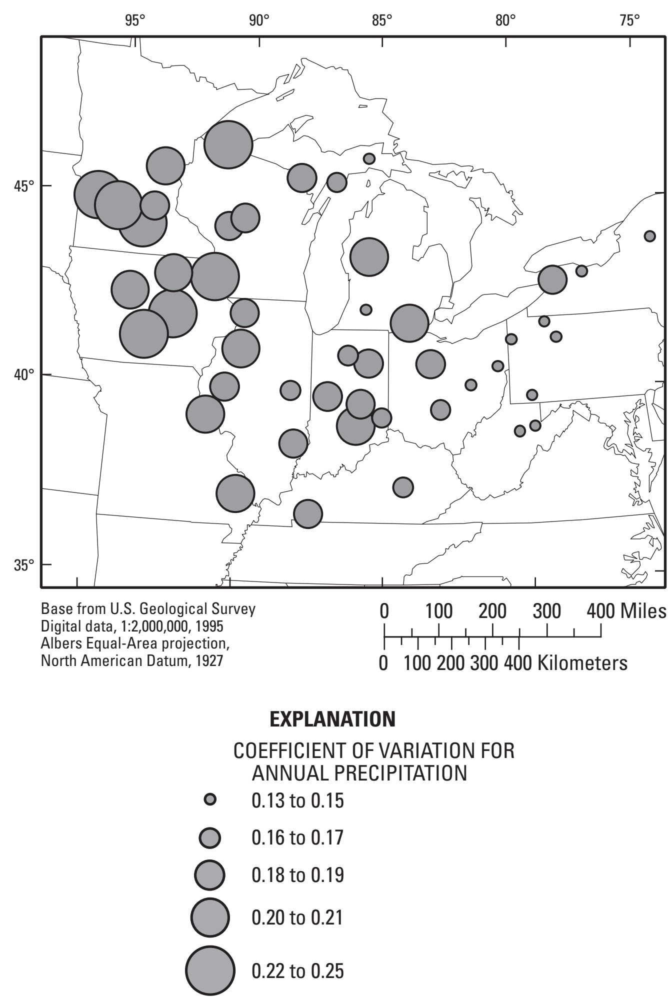

Figure 4. Coefficient of variation for the period of record at weather stations used in this study.

Suggestions for Future Studies

The authors feel that the following changes may improve the derived relations between precipitation and 25th-percentile flows:

(1) Selecting weather stations within the basin of the gaging station. Because this was an exploratory study, USHCN weather stations within 24 miles of the gaging station were used as the source of precipitation data. The precipitation recorded at the weather stations may not be representative of the precipitation falling within the basin upstream from the gaging stations.

(2) Using statistical methods to estimate missing precipitation data to fill in the gaps in the precipitation record.

(3) Taking into account the timing between the 25th-percentile flows and precipitation may improve the strength of the relations between them. For example, for gaging station 03069500, Cheat River Near Parsons, W. Va., the 25th percentile of streamflow for June 1998 (390.75 ft^3/s) occurred between the ninth and tenth day of the month on the rising limb of a peak (fig. 5). The precipitation for that month was 11.65 inches at weather station 466867, Parsons 1 NE, W. Va.—the highest recorded in the period of analysis (1960–2003). The daily rainfall record indicates that most of the precipitation for the month fell near or after June 10 and so precipitation from the previous 30 days (4.28 inches in May) would be a much better predictor of this 25th-percentile flow value than the precipitation for June.

(4) Including other potentially relevant explanatory variables, such as measures of surficial geology or topography, was outside the scope of the study; however, these variables can influence the movement of ground water to streams. Including them may improve the models.

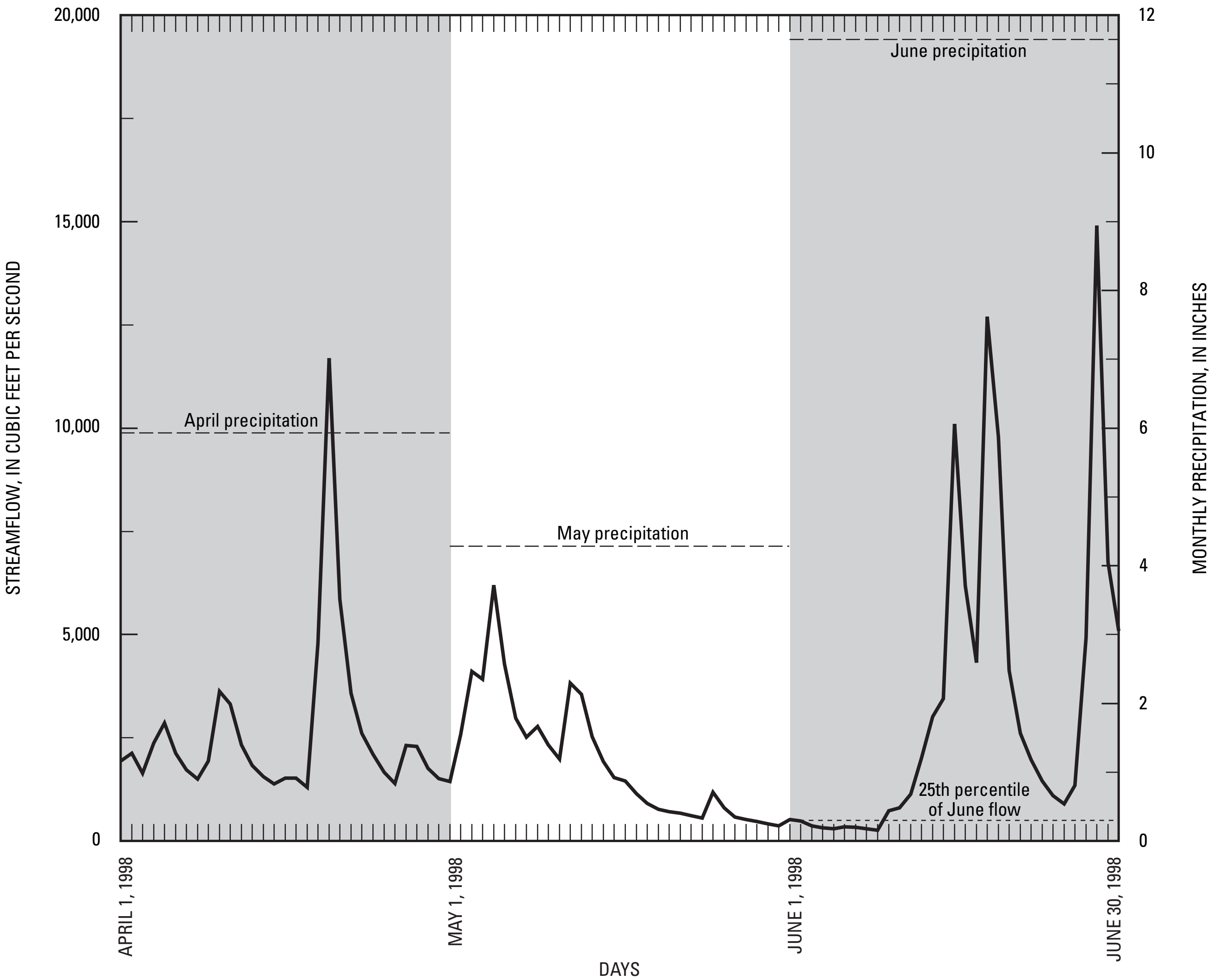

Figure 5. Daily streamflow at gaging station 03069500, Cheat River near Parsons, West Virginia, and monthly precipitation at weather station 466867, Parsons 1NE, West Virginia, April–June, 1998.

Summary

Regression models were developed for the 25th percentile of June and September flows (first quartile of flow) for 47 streamflow-gaging stations (gaging stations) in the Great Lakes, Ohio River, and Upper Mississippi River Basins. The gaging stations that were selected for this analysis are on unregulated rivers, have at least 40 years of record, and have a weather station within 24 mi of the gaging station with at least 70 years of precipitation record. Because this was an exploratory study, only gaging stations that were part of the U.S. Geological Survey Hydro-Climatic Data Network and weather stations that were part of the U.S. Historical Climatology Network were used.

Regression models were developed for each gaging station relating the natural logarithm of the 25th percentile of June and September flows to selected precipitation variables. The explanatory variables are monthly precipitation (April–June or July–September) for each year of record, precipitation for the previous year, and average annual precipitation for the previous 5-, 10-, 15-, 20-, 25-, and 30-year periods.

Regression models for the 25th percentile of June flows were developed for 45 of the 47 gaging stations. May and June precipitation explanatory variables are significant in 42 regression models. Previous year's precipitation was a significant explanatory variable in 13 regression models, and April precipitation was a significant explanatory variable in 10 regression models. Running multiyear averages of annual precipitation were significant in eight regression models.

Regression models for 25th percentile of September flows were developed for 46 of the 47 gaging stations. August precipitation is a significant explanatory variable in 37 regression models, September precipitation is a significant explanatory variable in 33 regression models, and both are in 29 regression models. July precipitation is a significant explanatory variable in 21 regression models. Previous year's precipitation was a significant explanatory variable in four regression models. Running multiyear averages of annual precipitation were significant explanatory variables in 12 regression models.

A chi-squared test for the June regression model indicated that significant previous year's precipitation variables were associated with larger coefficients of variation of annual precipitation, which occur primarily in the western part of the study area.

The 25th-percentile flows in this study appear to be related to short- and intermediate-term precipitation variables patterns. The intermediate-term precipitation (previous-year's precipitation) has a more distinct spatial pattern than short-term precipitation (April–June or July–September) and is more likely to be significant in the western part than in the eastern part of the study area. This pattern corresponds to the general pattern of variability in annual precipitation (greater variability in the western part). There is no distinct spatial pattern to gaging stations where long-term running average precipitation is significant, which may indicate that other variables, such as local geohydrology and landscape characteristics, not present in the model, are important factors pertaining to the effect of long-term precipitation on 25th percentile of flows in streams.

The regression models may be improved by (1) selecting weather stations within the basin of the gaging station, (2) using statistical methods to estimate missing precipitation data to fill in the gaps in the precipitation record, (3) taking into account the timing between precipitation and the occurrence of 25th-percentile flows, and (4) including variables representing surficial geology and topography in the models.

References Cited

Hauck, H.S., and Nagel, C.D., 2005, Water resources data, Missouri, water year 2004: U.S. Geological Survey Water-Data Report MO–04–1, 775 p.

Hornlein, J.F., Szabo, C.O., Zajd, H.J., and Welsh, M.J., 2005, Water resources data, New York, water year 2004—Volume 3, Western New York: U.S. Geological Survey Water-Data Report NY–04–3, 345 p.

Insightful Corporation, 2005, S-PLUS 7 for Windows User's Guide: Seattle, Washington, 653 p.

Lorenz, D.L., 2004, Seasonal trends in Minnesota streamflow [abs.] *in* Final program and book of abstracts, 37th Annual Water Resources Conference, University of Minnesota, College of Continuing Education, Brooklyn Center, Minnesota, October 26, 2004.

McClain, D.L., Moses, C.R., and Darnell, R.S., 2005, Water resources data, Kentucky, water year 2004: U.S. Geological Survey Water-Data Report KY–04–1, 667 p.

Mitton, G.B., Guttormson, K.G., Stratton, G.W., and Wakeman, E.S., 2005, Water resources data, Minnesota, water year 2004: U.S. Geological Survey Water-Data Report MN–04–1, 427 p.

Morlock, S.E, Nguyen, H.T., and Majors, D.K., 2005, U.S. Geological Survey water resources data, Indiana, water year 2004: U.S. Geological Survey Water-Data Report IN–04–1, 500 p.

Nalley, G.M., Gorman, J.G., Goodrich, R.D., Miller, V.E., and Housel, K.S., 2005, Water resources data, Iowa, water year 2004— Volume 1, Surface water and precipitation: U.S. Geological Survey Water-Data Report IA–04–1, 503 p.

National Climatic Data Center, 2005, United States historical climatology network (USHCN): Accessed October 17, 2005, at *http://www.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html*

Robl, A.D., Angel, J.W., and Norris, J.R., 2003, Water resources data, Illinois, water year 2002: U.S. Geological Survey Water-Data Report IL–02 [CD-ROM]

Shindel, H.L., Mangus, J.P., and Frum, S.R., 2005, Water resources data, Ohio, water year 2004—Volume 1, Ohio River Basin excluding project data: U.S. Geological Survey Water-Data Report OH–04–1, 350 p.

Siwicki, R.W., 2005, Water resources data, Pennsylvania, water year 2004—Volume 3, Ohio and St. Lawrence River Basins: U.S. Geological Survey Water-Data Report PA–04–3, 337 p.

Slack, J.R., Lumb, A.M, and Landwehr, J.M., 1993, Hydro-climatic data network (HCDN)—Streamflow data set, 1874–1988: U.S. Geological Survey Open-File Report 92–129, 193 p., accessed October 17, 2005, at *http://pubs.usgs.gov/wri/wri934076/*

U.S. Geological Survey, 2005, National Water Information System–Web Interface, accessed October 17, 2005 at *http://waterdata.usgs.gov/nwis*

Ward, S.M., Rosier, M.T., and Crosby, G.R., 2005, Water resources data, West Virginia, water year 2004: U.S. Geological Survey Water-Data Report WV–04–1, 286 p.

Waschbusch, R.J., Olson, D.L., Marsh, S.B., and Stark, P.A., 2005, Water resources data, Wisconsin, water year 2004: U.S. Geological Survey Water-Data Report WI–04–1, 990 p.

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Table 6. Multiple linear regression models for the 25th percentile of June streamflows.

[Table shows coefficients of variables that were significant at a *p*-value at 0.01 or less. Shaded cells show variables that could not be computed and thus were not used in the regression. --, not calculated]

Streamflow-gaging station	Weather station	Years used in regression	Multiple R squared	Coefficients of best regression model										Footnotes
								Running average precipitation						
				April	May	June	Previous year precipitation	5-year	10-year	15-year	20-year	25-year	30-year	
03015500	369298	1914 - 2003	0.62		**0.066**	**0.155**				**0.047**				
03028000	367477	1954 - 2003	.57		**.132**	**.129**								
03051000	461220	1916 - 2003	.51		**.155**	**.211**								
03069500	466867	1913 - 1952 1960 - 2003	.37		**.097**	**.143**								
…	…	1978 - 2003	.34			**.189**								
03080000	369050	1919 - 2003	.40		**.101**	**.185**								
03102500	363526	1930 - 1996	.54		**.130**	**.161**								
…	…	1958 - 1996	.71		**.154**	**.169**					**-0.066**			
03109500	335315	1923 - 2003	.38		**.147**	**.205**				**-.112**				
03144000	331890	1937 - 2003	.59		**.175**	**.185**								
03230500	331592	1942 - 2003	.46		**.163**	**.155**								
…	…	1962 - 2003	.49		**.138**	**.181**								
03275000	121030	1929 - 2003	.50	**0.072**	**.129**	**.071**								
…	…	1956 - 2003	.31		**.112**									
03285000	150619	1943 - 2003	.58		**.215**	**.318**								
03324300	124181	1957 - 2003	.60		**.175**	**.184**								
03328500	127482	1952 - 2003	.48		**.149**	**.111**								
…	…	1971 - 2003	.53		**.116**	**.121**								
03340800	121873	1958 - 2003	.58		**.120**	**.144**								
03351500	123527	1942 - 2003	.54		**.106**	**.092**								
03364000	121747	1948 - 2003	.59		**.116**	**.141**								
03379500	116446	1965 - 2003	.44		**.153**	**.199**								
03438000	153994	1940 - 2003	.61		**.172**	**.109**								
04027000	470349	1948 - 2003	.56	**.119**		**.184**	**0.031**							
04045500	205816	1954 - 2001	.54		**.159**	**.190**								
04059500	202737	1955 - 1996	.45		**.251**	**.202**								1
04063700	204090	1964 - 2002	.51		**.164**	**.252**								

Table 6. Multiple linear regression models for the 25th percentile of June streamflows.—Continued

[Table shows coefficients of variables that were significant at a *p*-value at 0.01 or less. Shaded cells show variables that could not be computed and thus were not used in the regression. --, not calculated]

Streamflow-gaging station	Weather station	Years used in regression	Multiple R squared	Coefficients of best regression model										Footnotes
								Running average precipitation						
				April	May	June	Previous year precipitation	5-year	10-year	15-year	20-year	25-year	30-year	
04105000	204244	1933 - 1990	0.46		**0.130**	**0.116**								
04121500	200779	1940 - 2003	.48		**.088**	**.101**								
…	…	1968 - 2003	.48		**.081**	**.080**								
04173500	200032	1953 - 1964 1967 - 1982	--											2
04196500	338534	1938 - 1981	.61		**.307**	**.250**								
04215500	301012	1940 - 2003	.52		**.187**	**.165**								
04230500	307167	1946 - 2003	.61	**0.118**	**.176**	**.103**								
04256000	308248	1943 - 2003	.50		**.089**	**.124**								
…	…	1955 - 2003	.49		**.103**	**.116**								
05280000	211465	1929 - 1999	.52		**.238**	**.151**	**0.070**			**0.304**				3
05300000	215563	1931 - 1963 1966 - 1999 2001 - 2003	.49	**.408**	**.300**	**.214**	**.121**							
…	…	1966-1999	.21		**.432**									
05316500	216152	1931 - 1976 1984 - 2003	.41		**.398**	**.267**	**.136**							
05320500	217405	1940 - 1945 1950 - 2002	.56	**.334**	**.277**	**.198**	**.064**							
05338500	215615	1952 - 1981	--											4
05381000	473471	1938 - 1992	.35		**.136**	**.179**								
05399500	475120	1915 - 1925 1937 - 1939 1942 - 2003	.34			**.234**								
…		1961 - 2003	.46			**.254**								
05412500	476827	1933 - 2003	.67		**.228**	**.119**	**.054**							
05444000	115901	1940 - 2003	.69		**.105**	**.102**	**.030**						**0.355**	
05451500	138296	1915 - 1927 1933 - 2003	.60	**.198**	**.199**	**.200**	**.042**							
…	…	1984 - 2003	.79	**.287**		**.167**				**.254**				

Table 6. Multiple linear regression models for the 25th percentile of June streamflows.—Continued

[Table shows coefficients of variables that were significant at a *p*-value at 0.01 or less. Shaded cells show variables that could not be computed and thus were not used in the regression. --, not calculated]

Streamflow-gaging station	Weather station	Years used in regression	Multiple R squared	Coefficients of best regression model										Footnotes
								Running average precipitation						
				April	May	June	Previous year precipitation	5-year	10-year	15-year	20-year	25-year	30-year	
05458000	131402	1955 - 2003	0.55		**0.153**	**0.134**	**0.051**							
05466000	113335	1941 - 1964 1971 - 2003	.77	**0.160**	**.206**	**.186**	**.028**							
05479000	132999	1950 - 2003	.57	**.160**	**.313**	**.157**	**.068**							
05486490	134063	1940 - 1962 1967 - 2003	.66	**.172**	**.273**	**.245**	**.050**							
…	…	1940 - 1962	.76		**.2878**	**.2942**								
05514500	230856	1922 - 1972 1979 - 1986 1997 - 1999 2002 - 2003	.38		**.213**	**.232**								
05572000	118740	1923 - 2003	.55	**.109**	**.159**	**.163**							**0.124**	
05585000	117551	1921 - 2003	.56		**.177**	**.221**								
…	…	1921 - 1975	.65		**.204**	**.240**								
07021000	235253	1921 - 1991	.24				**.033**							
…	…	1949 - 1991	--											5

[1]This weather station did not have filnet data in the United States historical climatology network (USHCN) data set. Time-adjusted data for this weather station were used instead.

[2]Best regression model had one coefficient, previous year's precipitation, whose *p*-value was 0.0143.

[3]10-year to 30-year running averages were significant. The model shown had the most significant variables.

[4]Best regression model had one coefficient, June precipitation, whose *p*-value was 0.0144.

[5]Best regression model had one coefficient, the 5-year running average precipitation, whose *p*-value was 0.0170.

Table 7. Multiple linear regression models for the 25th percentile of September streamflows.

[Table shows coefficients of variables that were significant at a *p*-value at 0.01 or less. Shaded cells show variables that could not be computed and thus were not used in the regression; --, not calculated]

Streamflow-gaging station	Weather station	Years used in regression	Multiple R squared	Coefficients of best regression model				Running average precipitation						Footnotes
				July	August	September	Previous year precipitation	5-year	10-year	15-year	20-year	25-year	30-year	
03015500	369298	1914 - 2003	0.54	**0.087**	**0.113**	**0.198**								
03028000	367477	1954 - 2003	.62	**.169**	**.171**	**.252**								
03051000	461220	1916 - 2003	.53		**.335**	**.369**								
03069500	466867	1914 - 1951 1959 - 2003	.43		**.143**	**.255**								
…	…	1978 - 2003	.59		**.279**									
03080000	369050	1923 - 2003	.51		**.209**	**.297**		**0.098**						
03102500	363526	1926 - 1996	.57	**.092**	**.107**	**.276**								
…	…	1958 - 1996	.60		**.165**	**.287**								
03109500	335315	1923 - 2002	.53	**.088**	**.177**	**.134**				**-0.094**				
03144000	331890	1937 - 2003	.17		**.134**									
03230500	331592	1942 - 2003	.38	**.187**	**.146**	**.146**								
…		1962 - 2003	.23	**.222**										
03275000	121030	1929 - 2003	.12	**.093**										
…		1956 - 2003	.35	**.114**				**.092**						
03285000	150619	1943 - 2003	.30		**.405**	**.439**								
03324300	124181	1957 - 2003	.16			**.146**								
03328500	127482	1951 - 2003	.34		**.080**	**.073**								
…		1971 - 2003	.21			**.007**								
03340800	121873	1957 - 2003	.50		**.374**	**.214**								
03351500	123527	1941 - 2003	.28	**.131**										
03364000	121747	1948 - 2003	.35	**.098**	**.125**	**.113**								
03379500	116446	1965 - 2003	.45		**.242**	**.336**								
03438000	153994	1940 - 2003	.56	**.097**	**.175**	**.136**								
04027000	470349	1948 - 2003	.52	**.086**	**.120**	**.160**								
04045500	205816	1953 - 2003	.49		**.114**	**.147**			**0.154**					
04059500	202737	1955 - 1996	.43		**.243**	**.175**								1
04063700	204090	1964 - 2002	.39			**.259**								

Table 7. Multiple linear regression models for the 25th percentile of September streamflows.—Continued

[Table shows coefficients of variables that were significant at a *p*-value at 0.01 or less. Shaded cells show variables that could not be computed and thus were not used in the regression; --, not calculated]

Streamflow-gaging station	Weather station	Years used in regression	Multiple R squared	Coefficients of best regression model										Footnotes
				July	August	September	Previous year precipitation	Running average precipitation						
								5-year	10-year	15-year	20-year	25-year	30-year	
04105000	204244	1934 - 1990	0.29					0.080						2
04121500	200779	1940 - 2003	.26		0.072									
…	…	1968 - 2003	.28		.073									
04173500	200032	1952 - 1964 1967 - 1982	--											3
04196500	338534	1931 - 1935 1938 - 1981	.48		.337	.328					-0.356			
04215500	301012	1940 - 2003	.26					.068						4
04230500	307167	1946 - 2003	.42	0.104	.098					0.470				
04256000	308248	1943 - 2002	.50		.089	.124								
…	…	1955 - 2002	.44		.114	.152								
05280000	211465	1918 - 1999	.65	.117	.229	.212		.243						
05300000	215563	1931 - 1963 1966 - 1999 2001 - 2003	.43	.577		.589	.253							
05316500	216152	1930 - 1976 1984 - 2003	.30		.308		.130							
05320500	217405	1940 - 1945 1949 - 2002	.48	.216	.334									
05338500	215615	1951 - 1993	.79	.141	.232	.221								
05381000	473471	1938 - 1992	.48		.157	.249								
05399500	475120	1914 - 1925 1937 - 2003	.65		.246	.311								
…		1960 - 2003	.67		.262	.310								
05412500	476827	1932 - 2003	.58	.082	.119	.077		.069						5
05444000	115901	1940 - 2003	.52		.083		.024						0.311	
05451500	138296	1915 - 1927 1933 - 2003	.33	.116	.140	.128								
…	…	1983 - 2003	.31	.161										
05458000	131402	1955 - 2003	.43		.114			.122						

Table 7. Multiple linear regression models for the 25th percentile of September streamflows.—Continued

[Table shows coefficients of variables that were significant at a *p*-value at 0.01 or less. Shaded cells show variables that could not be computed and thus were not used in the regression; --, not calculated]

Streamflow-gaging station	Weather station	Years used in regression	Multiple R squared	Coefficients of best regression model: July	August	September	Previous year precipitation	Running average precipitation: 5-year	10-year	15-year	20-year	25-year	30-year	Footnotes
05466000	113335	1941 - 2003	0.57	**0.209**	**0.280**	**0.163**								
05479000	132999	1950 - 2003	.20		**.238**									
05486490	134063	1940 - 1962 1967 - 2003	.34		**.222**	**.197**								
05514500	230856	1922 - 1971 1979 - 1986 1997 - 1999 2002 - 2003	.42	**.208**	**.272**	**.224**								
…	…	1953 - 1971 1979 - 1986 1997 - 1999 2002 - 2003	.25			**.375**								
05572000	118740	1923 - 2003	.46	**.167**	**.330**	**.181**								
05585000	117551	1921 - 2003	.37	**.129**		**.192**								
…	…	1921 - 1975	.29			**.169**								
07021000	235253	1921 - 2003	.17				**0.017**							
…	…	1950 - 2003	.24				**.025**							

[1]This weather station did not have filnet data in the USHCN data set. Time-adjusted data for this weather station were used instead.

[2]Another model with August as the only variable was also significant. However, the multiple R-squared for the model was lower, 0.1042.

[3]Best regression model had one coefficient, previous year's precipitation, whose *p*-value was 0.0419.

[4]Another model with September as the only variable was significant. However, the multiple R-squared for the model was lower, 0.2388.

[5]Another model was significant. It had July, August, September, and previous-year's precipitation as variables. Its multiple R-squared was 0.5766.

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