Contract Report 561

# Influence of Wetlands on Streamflow in Illinois

by Misganaw Demissie and Abdul Khan
Office of Sediment & Wetland Studies

Prepared for the
Illinois Department of Conservation

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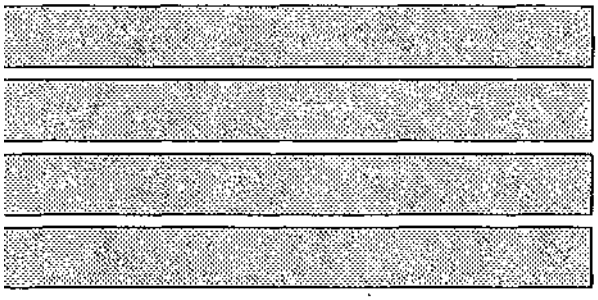

Illinois State Water Survey
Hydrology Division
Champaign, Illinois

A Division of the Illinois Department of Energy and Natural Resources

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## ABSTRACT

One of the major functions of wetlands is to store water for gradual release to surface and ground-water bodies. It is generally assumed that wetlands reduce flooding, increase low flows, and serve as recharge areas for ground water. However, there have not been systematic studies to quantify the influence of wetlands on flooding and low flows. This research was initiated to investigate the hydrologic functions of wetlands in Illinois based on available streamflow records. The research was designed to answer the more general question, "how does the presence or absence of variable size wetlands in a watershed influence streamflow?"

Streamflow records from 30 gaging stations monitoring watersheds with variable wetland areas were analyzed to assess the influence of wetlands on streamflow. The main objective of the analysis was to determine if streamflow parameters of streams draining watersheds with varying percentage of wetland areas were related to the percentage of wetlands in the watersheds. The streamflow parameters analyzed included peakflow, floodflow volume, and low flow. From the results of this analysis, in general, it can be concluded that peakflow and floodflow volume decrease, and low flows increase with increasing percentage of wetlands in the watershed. The influence of wetlands was more noticeable on peakflow and low flow than on floodflow volume. For all the gaging stations analyzed, the peakflow to average precipitation ratio decreased on the average by 3.7 percent, floodflow volume to total precipitation ratio decreased by 1.4 percent, and low flow (represented by $Q_{95}$) increased by 7.9 percent for an increase of one percent wetland area in a watershed. There were, however, significant regional and seasonal differences in the rate of change.

Regionally, wetland influence was more noticeable in central and northern Illinois than in southern Illinois for both peakflow and floodflow volume. The influence of wetlands on low flow was more noticeable in southern and northern Illinois than in central Illinois, however. The peakflow to average precipitation ratio decreased by 5.9 to 7.9 percent, while floodflow volume to total precipitation ratio decreased by 4.5 and 2.3 percent in central and northern Illinois, respectively. For low flow, $Q_{95}$ increased by 15.9 and 15.0 percent in southern and northern Illinois, respectively.

Seasonally, for the state as a whole, wetland influence was the most prominent in fall for the peakflow to average precipitation ratio (5.7 percent decrease) and in summer for the floodflow volume to total precipitation ratio (3.1 percent decrease). For low flow, the influence of wetlands was equally noticeable in fall (8.4 percent increase in $Q_{95}$) and summer (8.0 percent increase in $Q_{95}$).

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## INTRODUCTION

The objective of this project was to assess the influence of wetland acreage on streamflow by analyzing existing streamflow records in Illinois. Analysis of streamflow records for streams with various ratios of wetlands in their watersheds may provide information on how wetlands influence the hydrology of the watershed. If streams draining watersheds with different percentages of wetland area to total drainage area have different hydrologic responses, then general relationships can be developed between percentages of wetland and streamflow parameters. These relationships can then be used to evaluate wetland functions and impacts of land-use practices that affect wetland acreage.

There are four major mechanisms by which wetlands can influence streamflows: runoff generation, flow retardation due to increased flow resistance, flood storage, and low-flow augmentation. Runoff generation is linked to wetlands' soil moisture and land-cover conditions, important parameters that greatly influence how much runoff is generated from various rainfall events. For example, if an area is already saturated from antecedent rainfall, even small amounts of precipitation can produce large surface runoff. On the other hand, if an area is dry, large amounts of precipitation may produce little or no runoff as most of the precipitation infiltrates into the ground. An area with dense vegetation will intercept more incoming rainwater and have less surface runoff than an area with little or no vegetative cover. Delayed flow from an area with dense vegetation will be greater than from an area with less vegetative cover, however.

The presence of wetland vegetation in the watershed and along drainage channels will increase flow resistance over land and in the stream channels, resulting in slow delivery of runoff from upstream to the stream channel. When a flood event occurs along a stream in a watershed with wetlands along the streambanks, the streamflow increases and eventually overflows the banks. The water then has to flow through the adjoining wetlands, which significantly increases the resistance to flow. Since wetlands typically support a large amount of vegetation, the resistance to overbank flow is greater for a

stream adjoining a wetland than for a stream not adjoining a wetland. As a result, a significant difference will exist between the flow characteristics of a stream adjacent to a wetland and one not adjoining a wetland.

Another major influence that wetlands exert on streamflow is the flood storage capacity they provide. Since most wetlands are located in depressions and poorly drained areas, they provide significant storage potential. By storing runoff from adjoining areas, wetlands retard or reduce the amount of runoff that reaches stream channels. Therefore depending on initial conditions, wetland areas could significantly affect the streamflow.

The presence of wetlands in a watershed may also result in low-flow augmentation in streams. In wetland areas, water stored in surficial depressions and underground is gradually released to adjoining streams during periods of low flows. This generally results in higher low-flow conditions for streams that drain areas containing wetlands.

One of the parameters that can be used to characterize and distinguish watersheds containing different areas of wetlands is the ratio of wetland area to the total drainage area of the watershed. The major objective of this study, therefore, was to investigate streamflow records in Illinois and then relate various streamflow parameters to the percentage of wetlands in the watershed. Although it is generally accepted that wetlands reduce streamflow peaks and increase low flows, this generalized concept may not always be true. The hydrologic response of wetlands may vary depending on geographic location, storm intensity and duration, and season of the year. Because of significant regional and seasonal differences in Illinois, it is important to ascertain if the influence of wetlands varies between regions and by season. This research effort has attempted to address issues related to the regional and seasonal influence of wetlands on streamflow in Illinois. However, because of the small number of gaging stations in the different regions, the regional analysis needs to include more stations in the analysis.

## REVIEW OF LITERATURE

The role of wetlands on streamflow has been the subject of considerable debate. Past studies have served only to highlight this debate and the differing conclusions. Irwin and Whiteley (1983), Bardecki (1987), and Brunner (1988) have reviewed results from previous studies related to the influence of wetlands on streamflow.

McCubbin (1938) concluded that drainage activity had no impact on the peakflow values of the Grand River or the Thames River in Ontario, Canada. O'Kelly (1955), while investigating the influence of artificial drainage on flood hydrographs, found that the peakflow increased substantially after drainage. Prior and Hess (1961) performed flood frequency analysis for Minnesota and decided that flood magnitude was reduced with increasing percentage of marshes in the watershed. They assumed that a percentage of lakes represented the percentage of marshes in the watershed.

In a series of studies, Haan and Johnson (1968), DeBoer and Johnson (1971), and Campbell and Johnson (1975) used the Iowa State Model to examine the influence of wetland drainage on streamflow by using storm hydrograph simulations. They concluded that drainage usually increased the runoff volume irrespective of the rainfall intensity and duration. For high-intensity, short-duration rainfall, the peakflow values remain unchanged even with improved drainage, while for low-intensity, long-duration events, peakflows in general increased with increased drainage. Moore and Larson (1979), using an improved version of the Iowa State Model, called the Minnesota Model, reached essentially similar conclusions.

Burke (1968), in an investigation of two watersheds, one drained and the other undrained, found that peakflow was lower in the drained watershed than in the undrained watershed. Kloet (1971), in a similar study, reached exactly the opposite conclusion. McGill and Bennet (1971) studied the effect of drainage on runoff using a synthetic hydrograph approach and concluded that drainage resulted in an insignificant reduction in peak discharge value.

Moklyak et al. (1972) investigated a drained and an undrained watershed, and concluded that drainage decreased both annual runoff and peakflow. Eggelsmann (1972) investigated two adjoining high water table peat watersheds, one undrained and the other drained by a tile drainage system. He found that while the runoff volumes from the two watersheds were similar, peakflows from the undrained peat basin were much greater (up to three times) after a rainfall event than those from the tile-drained watershed. Bailey and Bree (1980), in a study of 12 boggy watersheds, found that flood peaks were substantially increased as a result of drainage. Novitzki (1982) studied the influence of wetlands on

streamflow in Wisconsin and concluded that flood peaks may be as much as 80 percent lower in basins with much lake and wetland area. Eli and Rauch (1982), in a study of two wetland watersheds in northern West Virginia, concluded that wetlands had little effect on peakflows or low flows of the studied watersheds. Skaggs and Broadhead (1982) studied the impact of drainage on runoff volume and peakflow using the model DRAINMOD. They concluded that subsurface tile drainage decreased the runoff volume and peakflow values.

Ogawa and Male (1983) studied the role of wetlands on streamflow in Massachusetts and found that peakflow increased with decreasing wetland percentage in the watershed. Demissie et al. (1983) studied the upper Kankakee and Iroquois Rivers in Illinois and Indiana. Significant wetlands were present along the upper Kankakee River and absent along the Iroquois River. They found that a 50-year flood in the Iroquois River was almost twice as great as a 50-year flood in the upper Kankakee River for the same drainage area. On the other hand, the 7-day, 10-year low flow for the upper Kankakee River was more than ten times of that in the Iroquois River for the same drainage area.

It was mentioned previously that it is generally accepted that wetlands reduce streamflow peaks and increase low flows. This function of wetlands is attributed to their ability to store floodwater during storm events for release later. However, this generalized concept may not always be true as illuminated by the review of literature of work done by researchers in the past. Depending on the extent of the wetland, its geographic location, storm intensities and durations, and seasons of the year, the influence of wetlands on streamflow may vary greatly with the region as well as the specific wetland type. As a result, it is imperative that these factors be given careful consideration when investigating the influence of wetlands on streamflow.

## DATA ANALYSIS METHODOLOGY AND STUDY SITE SELECTION

This section outlines the basis of selecting the watersheds and streamgaging stations for analysis. The methods and procedures used are also described.

### Selection of Watersheds and Gaging Stations

Before analyzing streamflow records, it was necessary to exclude streams and watersheds that are significantly affected by known natural or man-made features. For example, streams greatly influenced by large rivers and lakes like the Mississippi and Ohio Rivers and Lake Michigan were excluded from analysis. All gaging stations located downstream of dams and major discharge points were also excluded. After considering these factors, 30 gaging stations were selected: 11 in southern Illinois, 8 in central Illinois, and 11 in northern Illinois. Table 1 lists the selected watersheds and the gaging stations, and figure 1 shows their locations. The drainage areas of the selected stations ranged from 7 to 1,282 square miles. The percentages of wetlands in these watersheds varied from a minimum of 0.2 percent to a maximum of 13.7 percent. The streamflow data for these watersheds were available for periods of at least ten years from 1979 to 1988. The frequency distributions of the watershed drainage areas and wetland percentages are provided in figures 2 and 3, respectively.

### Methods and Procedures

#### *Flow Synthesis*

The analysis was conducted for a ten-year period from 1979 to 1988. This period was selected to closely correspond to the wetland area data that were determined from the National Wetland Inventory conducted in the early 1980s. Daily flow values for the ten-year period were obtained for each of the gaging stations. Three streamflow parameters were selected for analysis: peakflow, floodflow volume, and low flow. Daily precipitation data from a station in the watershed for the same period were also obtained to normalize the streamflow.

**Peakflow and Floodflow Volume.** For peakflow and floodflow volume analyses, daily streamflow data for each year were examined and several flood events were selected. The peakflow values in cubic feet per second (cfs) were divided by drainage area and converted to inches per day. The corresponding volumes of the flood were also computed, and the seasons in which the floods occurred were identified. From the daily precipitation data, the average, peak, and total precipitation values associated with the selected flood events were determined. In order to remove the influence of the variability

Table 1. Information on Streamflow Gaging Stations Used in the Study

| *Streamflow station* | *ID number* | *Stream name* | *Drainage area (sqmi)* | *Wetland (percent)* | *Period of record* |
|---|---|---|---|---|---|
| 03336645 | 1 | Middle Fork Vermilion | 428.00 | 1.34 | 1979-1988 |
| 03336900 | 2 | Salt Fork River | 131.10 | 0.22 | 1960-1988 |
| 03379500 | 3 | Little Wabash | 1118.90 | 1.06 | 1915-1988 |
| 03380500 | 4 | Skillet Fork | 457.83 | 4.04 | 1929-1988 |
| 03382100 | 5 | South Fork Saline | 145.10 | 9.29 | 1966-1988 |
| 03384450 | 6 | Lusk Creek | 42.40 | 0.47 | 1969-1988 |
| 05466500 | 7 | Edwards River | 440.30 | 1.08 | 1935-1988 |
| 05469000 | 8 | Henderson Creek | 430.30 | 0.82 | 1935-1988 |
| 05495500 | 9 | Bear Creek | 345.20 | 1.87 | 1944-1988 |
| 05532000 | 10 | Addison Creek | 22.90 | 0.76 | 1952-1988 |
| 05534500 | 11 | North Branch Chicago | 19.50 | 4.41 | 1953-1988 |
| 05536000 | 12 | North Branch Chicago | 98.10 | 3.52 | 1951-1988 |
| 05536275 | 13 | Thorn Creek | 102.90 | 8.64 | 1947-1988 |
| 05539900 | 14 | West Branch DuPage | 27.90 | 6.06 | 1961-1988 |
| 05540095 | 15 | West Branch DuPage | 92.30 | 7.53 | 1969-1988 |
| 05550500 | 16 | Poplar Creek | 35.50 | 7.28 | 1952-1988 |
| 05551700 | 17 | Blackberry Creek | 69.60 | 4.19 | 1961-1988 |
| 05568800 | 18 | Indian Creek | 62.20 | 0.47 | 1960-1988 |
| 05570370 | 19 | Big Creek | 40.70 | 8.43 | 1972-1988 |
| 05570380 | 20 | Slug Run | 7.10 | 13.68 | 1975-1988 |
| 05570910 | 21 | Sangamon | 237.70 | 0.80 | 1979-1988 |
| 05585000 | 22 | La Moine | 1281.80 | 2.27 | 1921-1988 |
| 05591200 | 23 | Kaskaskia | 468.90 | 0.87 | 1971-1988 |
| 05593520 | 24 | Crooked Creek | 251.60 | 5.80 | 1975-1988 |
| 05594450 | 25 | Silver Creek | 152.49 | 4.17 | 1967-1988 |
| 05594800 | 26 | Silver Creek | 460.75 | 5.64 | 1971-1988 |
| 05595200 | 27 | Richland Creek | 127.12 | 2.65 | 1970-1988 |
| 05595730 | 28 | Rayse Creek | 90.40 | 4.23 | 1979-1988 |
| 05597000 | 29 | Big Muddy River | 783.60 | 11.78 | 1915-1988 |
| 05597500 | 30 | Crab Orchard | 31.30 | 8.09 | 1952-1988 |

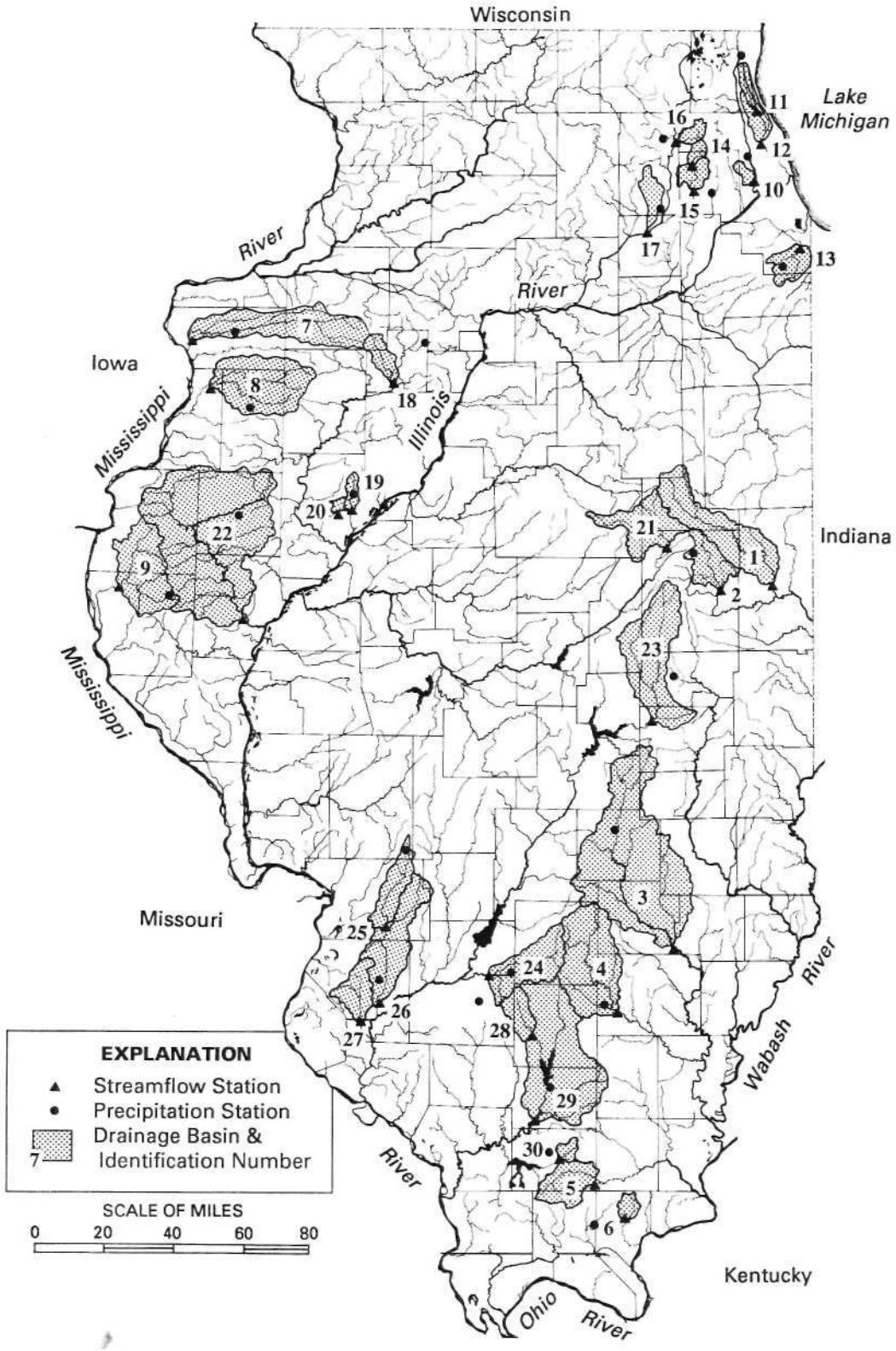


Figure 1. Locations of selected drainage basins, streamgaging stations, and precipitation stations

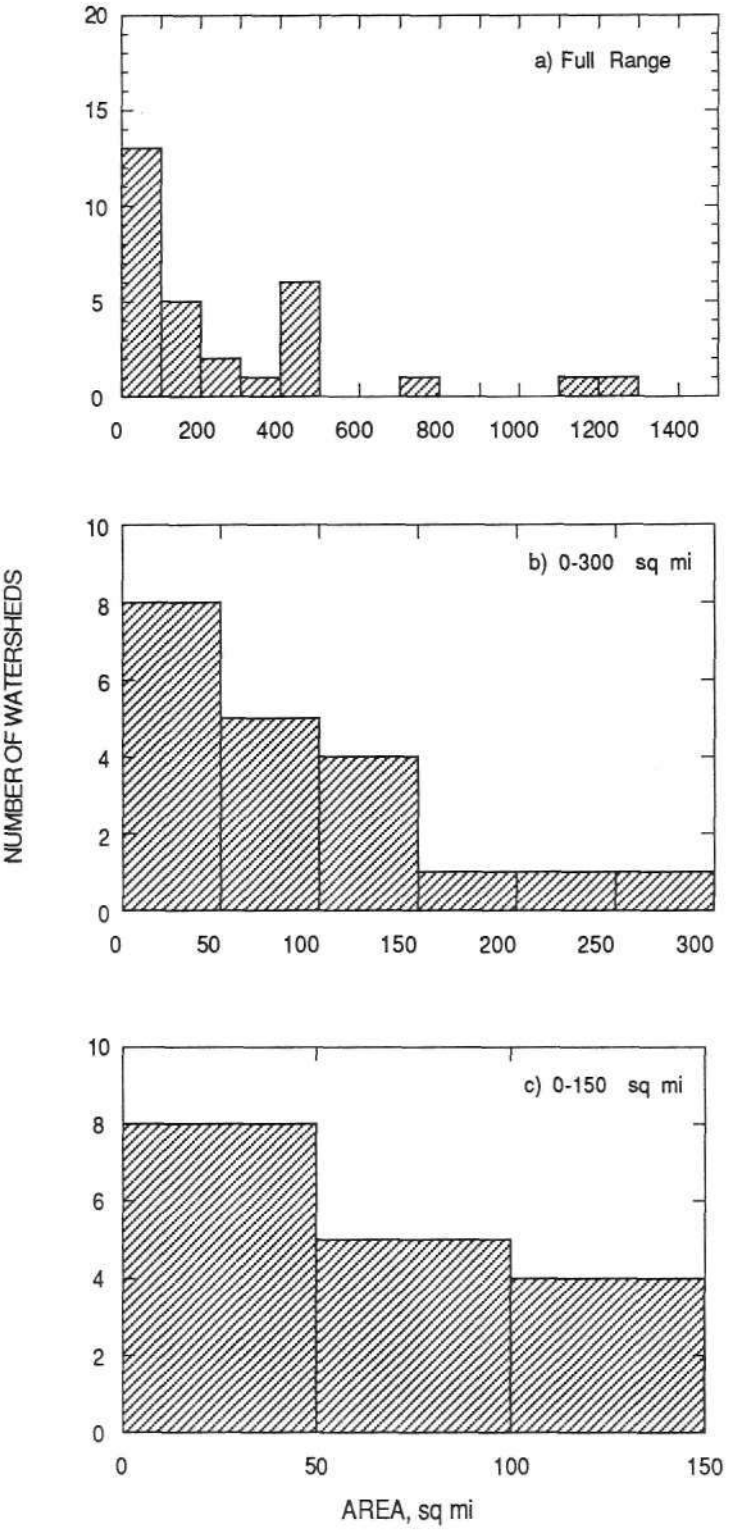


Figure 2. Frequency distribution of drainage areas of selected watersheds

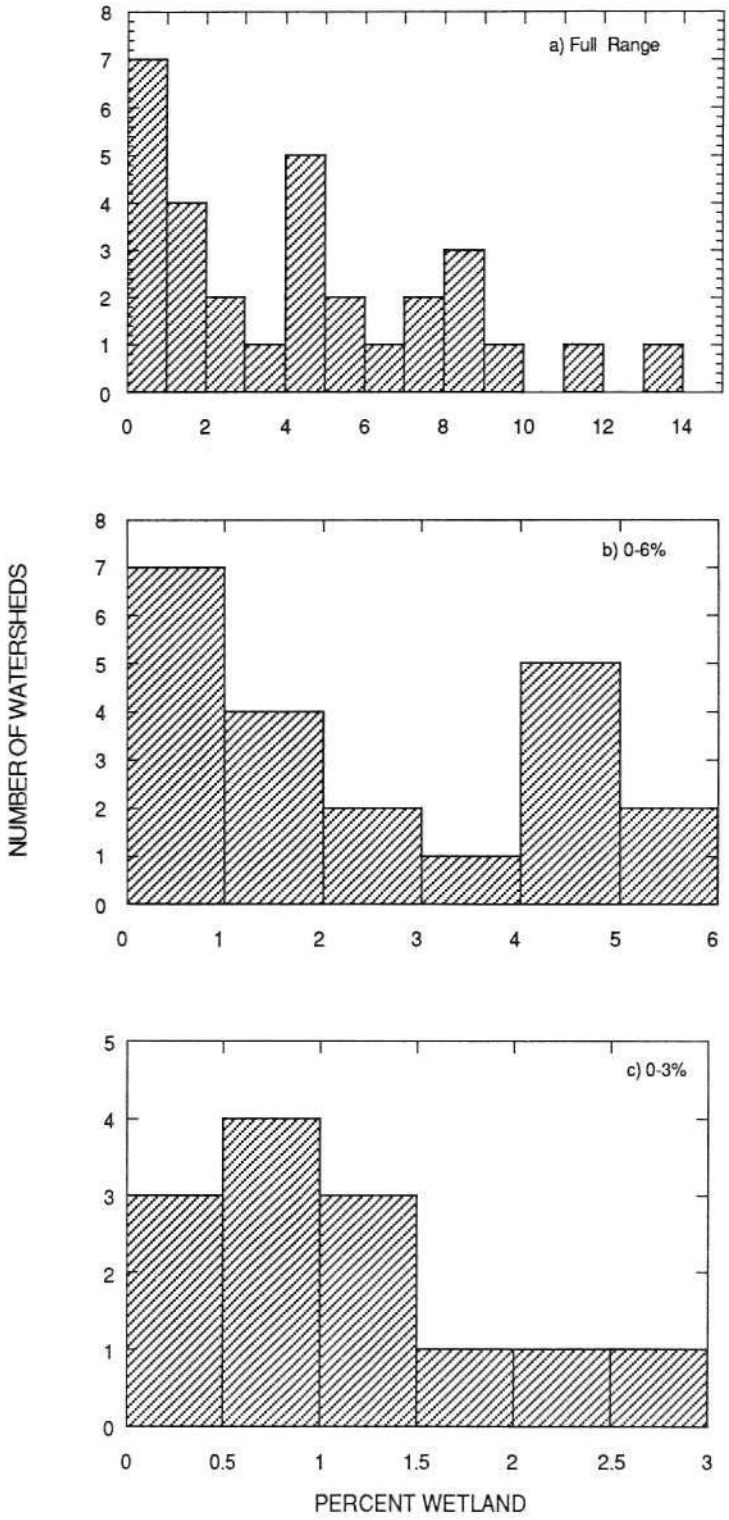


Figure 3. Frequency distribution of wetland percentages in selected watersheds

in precipitation from the analysis, four ratios were then calculated for each flood event to aid in the analysis: peakflow to average precipitation ratio; peakflow to peak precipitation ratio; peakflow to total precipitation ratio; and floodflow volume to total precipitation ratio.

For each station, the mean value for each normalized parameter was computed from the data for all the flood events. The frequency distribution of the individual values (used to compute the mean values) of the four parameters for Skillet Fork, Big Creek, and Crooked Creek are shown in figures 4-7. The distributions for the other stations were similar. The mean normalized parameters so computed were plotted against the corresponding percentages of wetlands for the watershed. The independent variable was the percentage of wetlands within each watershed. These values were generated by the Illinois Natural History Survey from the Illinois component of the National Wetland Inventory.

To investigate the regional influence on the peakflow and volume ratios, the mean normalized parameters were plotted by grouping the watersheds into three regions: south, central, and north. To investigate the seasonal influence of wetlands on streamflow, parameters were grouped on the basis of the four seasons. For each station, the mean parameters for each season were then plotted against their percentages of wetlands.

**Low Flow.** For low-flow analysis, flow duration curves were used. The lower limb of the flow duration curve provides the means to choose a range of low-flow values for analysis. For each watershed, the corresponding flow duration curve was developed by using the daily streamflow data for the selected ten-year period. The low-flow parameters selected for analysis were the discharges at 95 and 99 percent probability of exceedance: $Q_{95}$ and $Q_{99}$, respectively. The schematics of how the low flows were determined from the flow duration curve are illustrated in figure 8. The low-flow values in cfs were divided by the drainage areas and converted to inches per day. Each low-flow parameter was then plotted against the corresponding percentage of wetlands in the watershed to determine if any relationship existed.

To investigate the regional influence on the low-flow parameters, the parameter values were plotted by grouping the watersheds into the three regions: south, central, and north. To investigate the seasonal influence of wetlands on low flow, flow duration curves were developed and low-flow parameters were computed by grouping the data on the basis of the four seasons. For each station, the low-flow parameters for each season were then plotted against their percentages of wetlands.

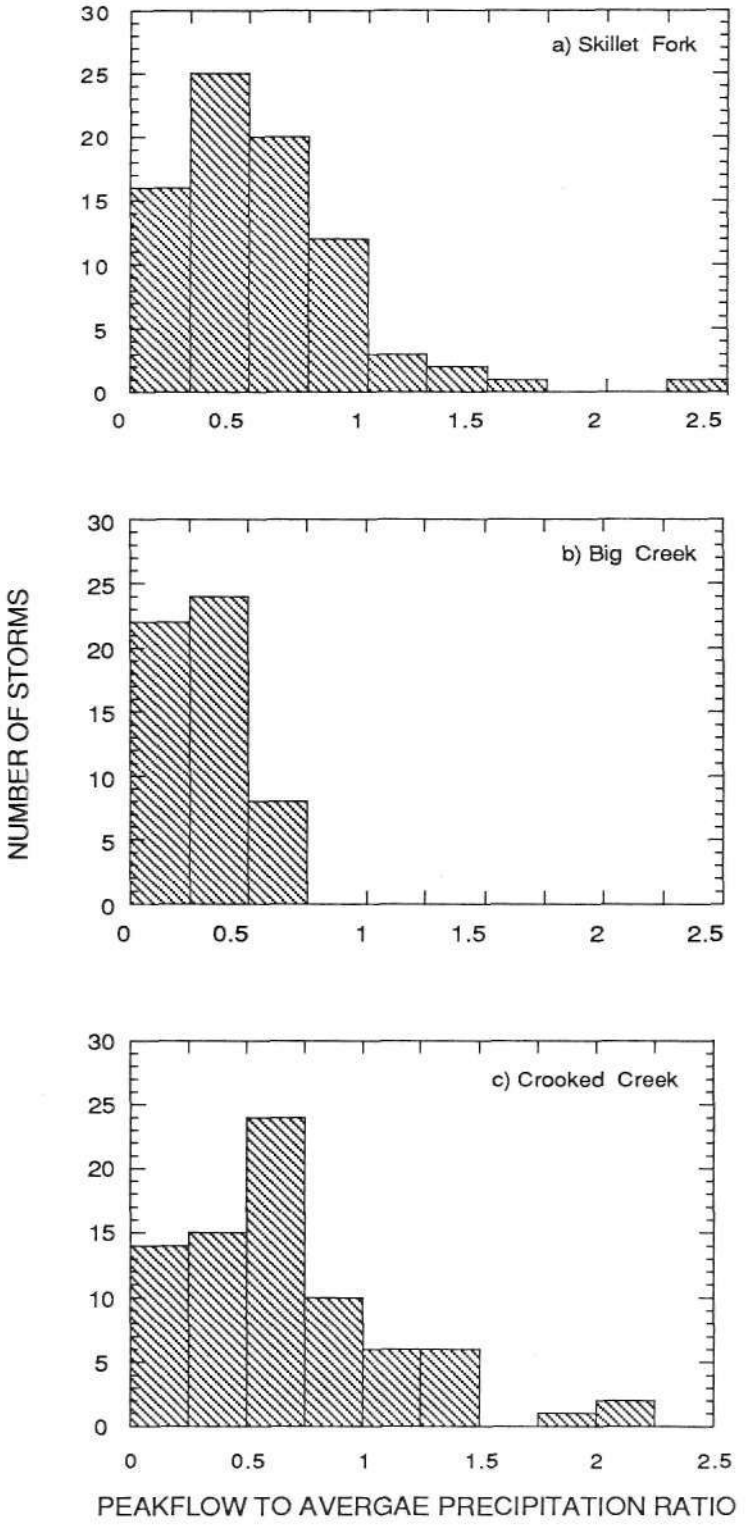


Figure 4. Frequency distribution of storm values of peakflow to average precipitation ratio for three selected stations

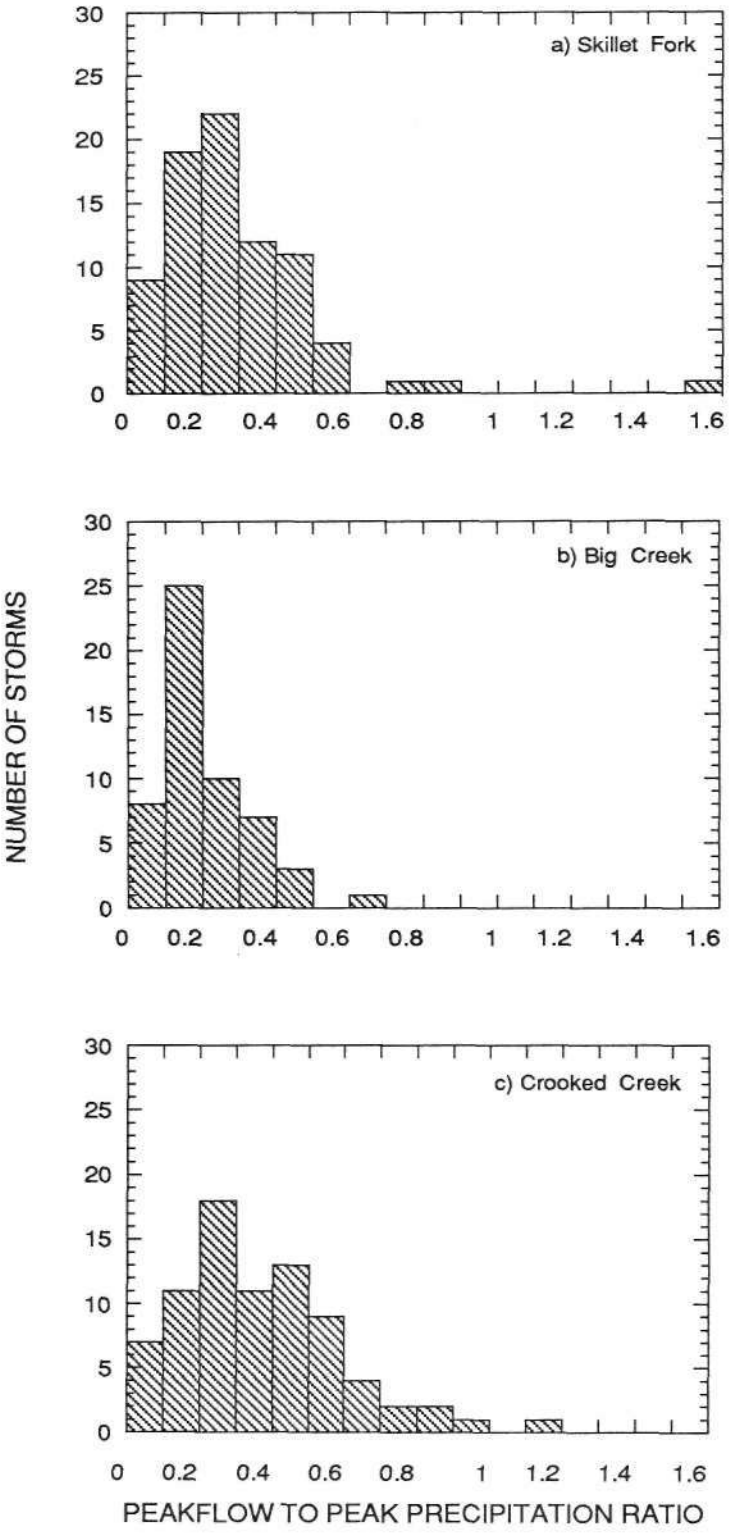


Figure 5. Frequency distribution of storm values of peakflow to peak precipitation ratio for three selected stations

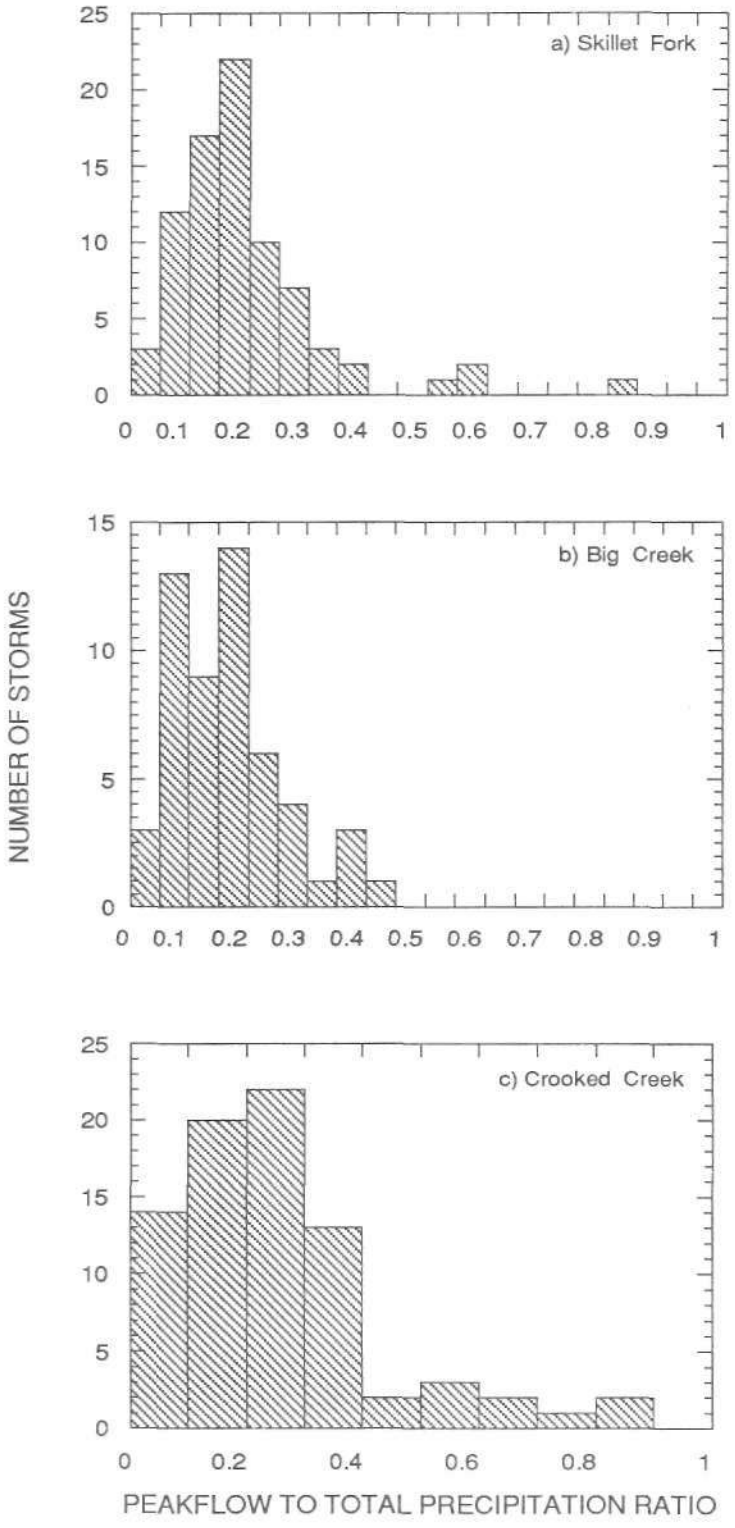


Figure 6. Frequency distribution of storm values of peakflow to total precipitation ratio for three selected stations

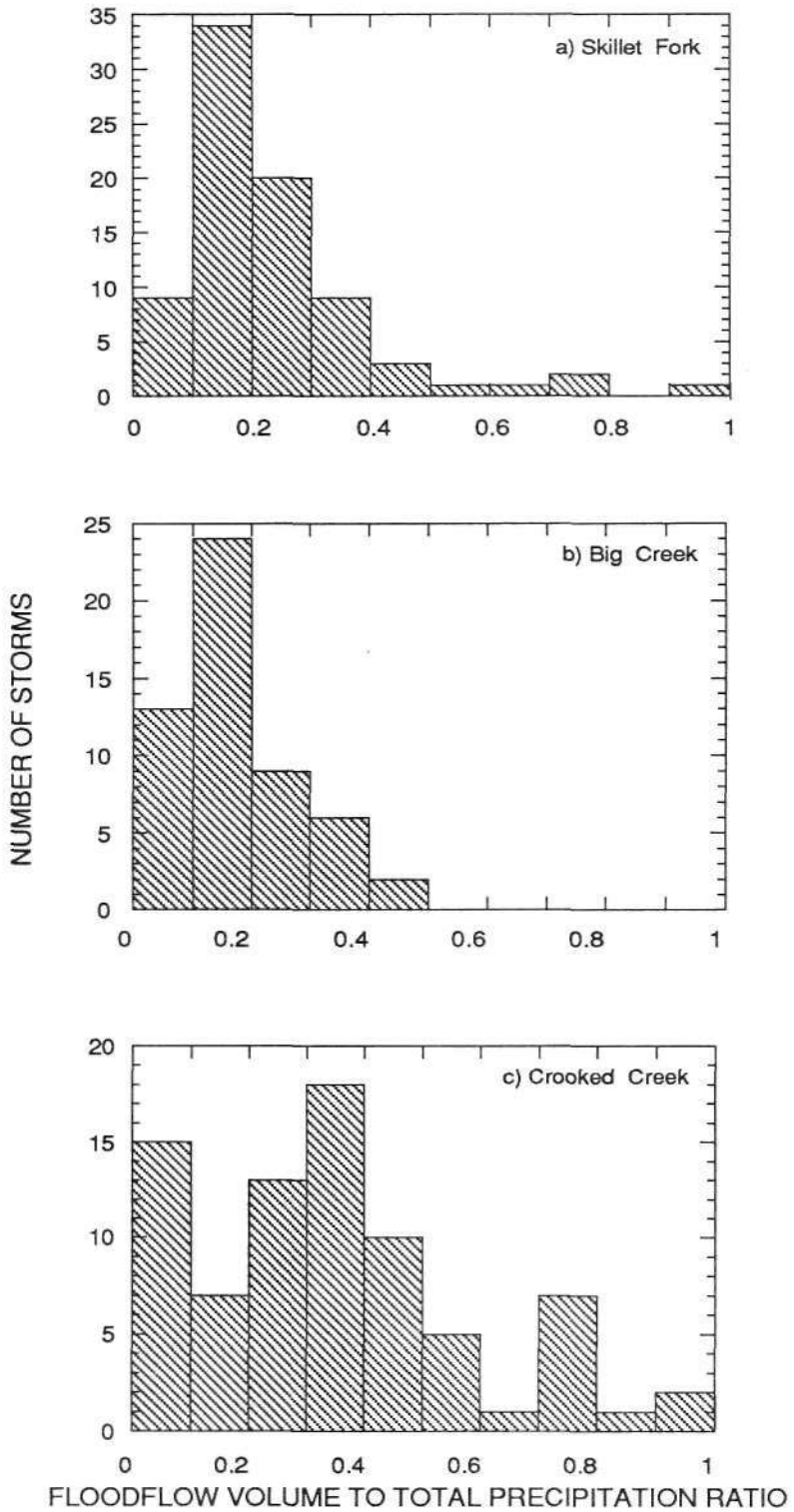


Figure 7. Frequency distribution of storm values of floodflow volume to total precipitation ratio for three selected stations

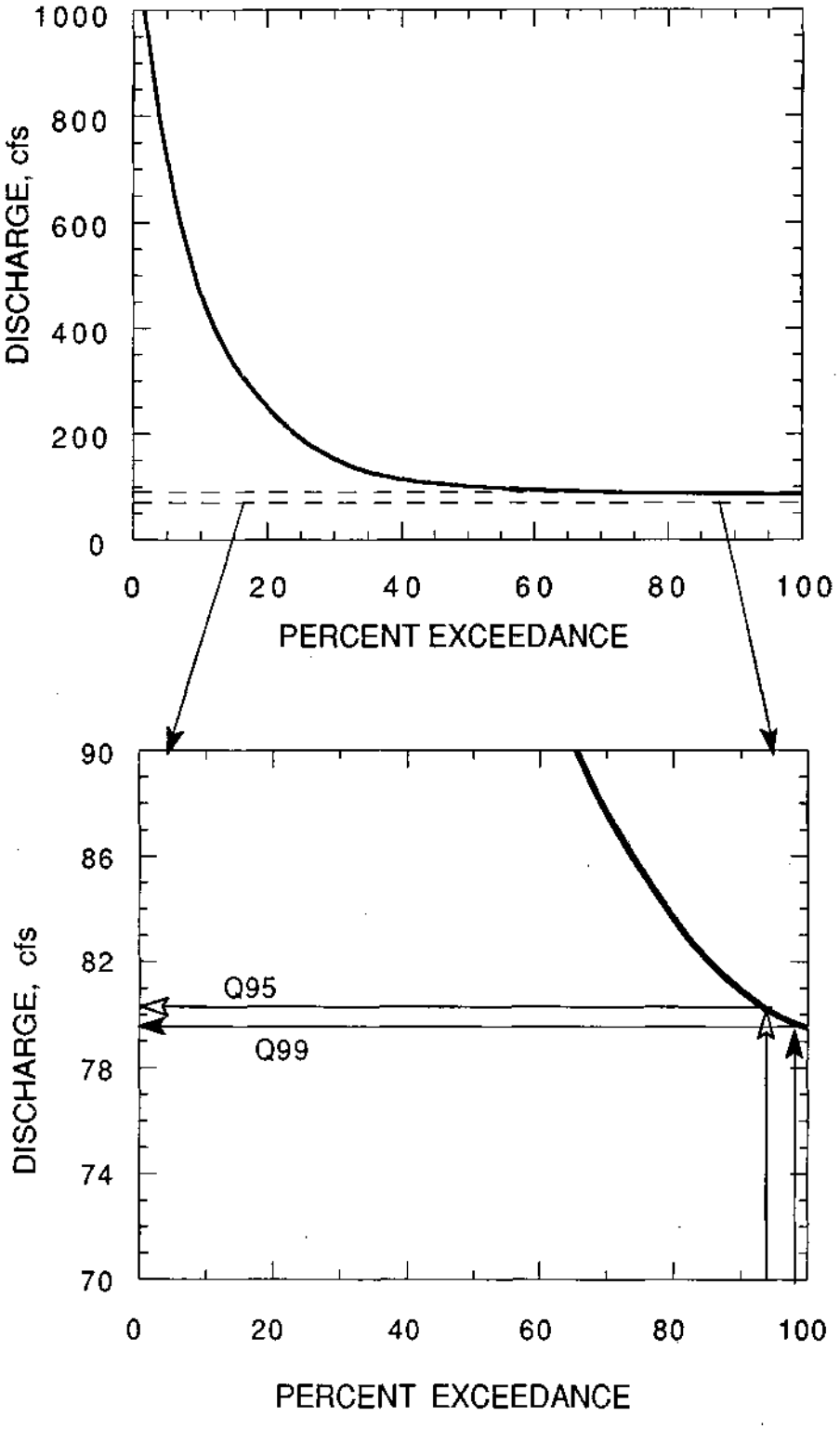


Figure 8. Determination of flows at different exceedance probabilities

***Evaluation Procedure***

For each flow parameter, the influence of wetlands on streamflow was studied using the linear regression analysis method. Regression analysis is a procedure for fitting an equation to a set of data. For a given set of measurements on two or more variables, regression analysis provides a means for finding coefficients $b_0$, $b_1$,....,$b_p$ in the regression model of the form:

$$y = b_0 + b_1 x_1 + .... + b_p x_p \tag{1}$$

where $y$ is the dependent variable and $x_1$,....,$x_p$ are the independent variables. The preceding equation is a general form of the linear multivariate model in which $p$ is the number of independent variables, $x_i$ is the ith independent variable, $b_i$ is the ith slope coefficient, and $b_0$ is the intercept coefficient.

The values of the slopes and intercept in the above equation are computed using the principle of least squares. The principle of least squares is a process to obtain the best estimate of the coefficients and is referred to as the regression method. Regression is the tendency for the expected value on one or more jointly correlated random variables to approach more closely the mean value of its set than any other. The principle of least squares is used to regress $y$ on $x_i$ values in equation (1). In a least-squares analysis, the error, $e$, or residual is defined as the difference between the predicted and measured values of the dependent variable:

$$e_i = y_i - \hat{y}_i \tag{2}$$

where $\hat{y}_i$ is the ith predicted value of $y$, $y_i$ is the ith measured value of $y$, and $e_i$ is the ith residual or error. The principle of least squares assumes that these errors are independent of each other and are normally distributed having a zero mean and a constant variance.

The objective function to minimize on the basis of the principle of least squares is the sum of squares of the errors, mathematically represented by:

$$F = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \tag{3}$$

where $n$ is the sample size. The function can be minimized by taking the derivative of $F$ with respect to each unknown coefficient, setting these derivatives equal to zero, and then solving for the unknown coefficients.

In this study, percentage of wetlands in the watershed was the only independent variable while the streamflow parameters were the dependent variables.

***Testing Method***

The influence of wetlands on streamflow was examined by evaluating the percent change in each of the parameters for a one percent change in wetland area. For each flow parameter, a value was selected as the limiting or threshold percent change for an increase of one percent wetland area in the watershed. If the calculated percentage change of the parameter based on the best-fit regression line exceeded this threshold value, then the influence of wetlands on the streamflow parameter was considered to be significant.

The percentage change (PC) for each parameter for an increase of one percent wetland area in the watershed is computed as follows:

$$PC = 100 * S / y_{avg} \tag{4}$$

where $S$ is the slope of the best-fit regression line and $y_{avg}$ is the average value of the parameter. The procedure is illustrated in figure 9.

The percent change concept was selected here instead of using the slope of the regression line to provide a meaningful interpretation of the relationship between percent wetland and other hydrologic parameters. Conceptually, PC represents by how much each parameter changes for one percent change in wetland area. We believe this concept is more understandable than providing the rate of change in the peakflow to average precipitation ratio or the floodflow volume to total precipitation ratio:

Based on the observation of the scatter plots and the regression lines of the streamflow parameters, the threshold percentage change was selected to be 0.5 percent. The significance of wetland influence on a streamflow parameter was then decided as follows:

$$|PC| \geq PC_t \quad \rightarrow \quad \text{wetland influence is significant} \tag{5}$$

$$|PC| < PC_t \quad \rightarrow \quad \text{wetland influence is not significant} \tag{6}$$

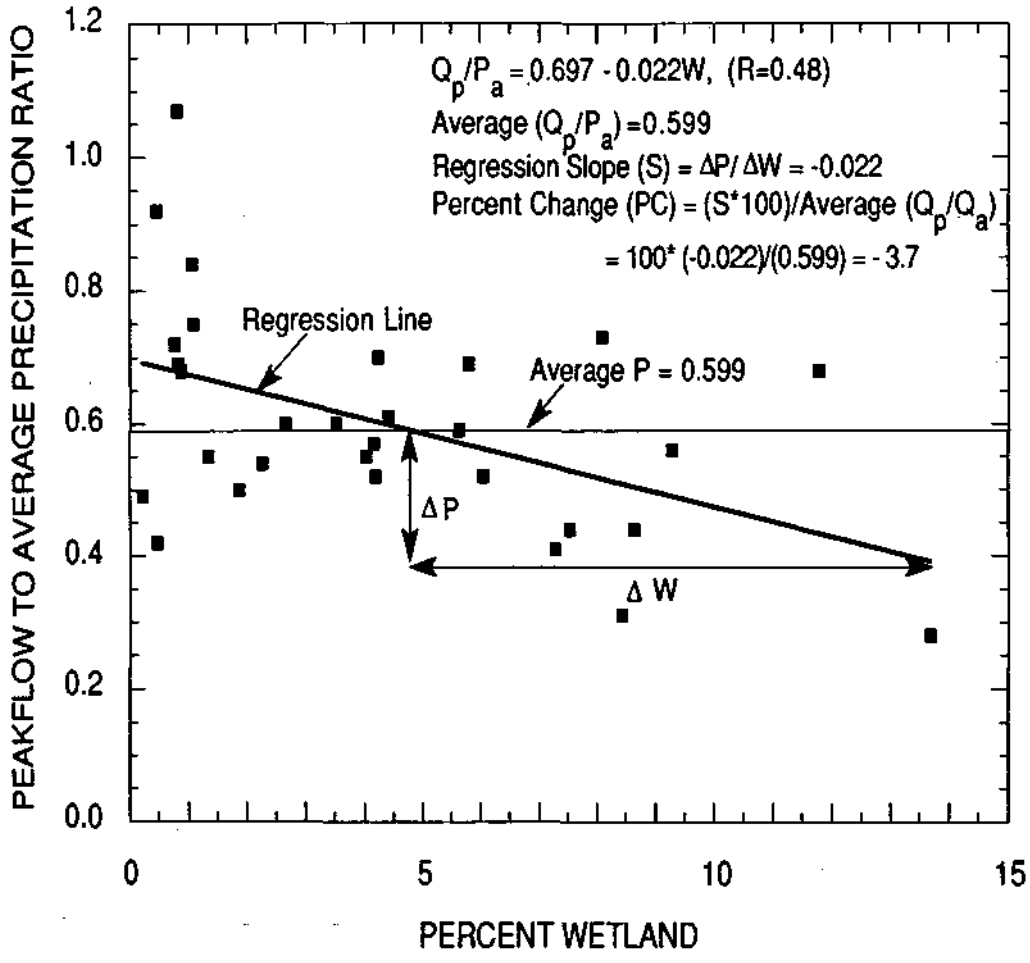


Figure 9. Percent change (PC) determination from regression parameters

where *PC* is the calculated percentage change for an increase of one percent wetland area in the watershed and $PC_t$ is the threshold percentage change. The symbol | | implies absolute value. A positive (+) sign of the computed *PC* represents an increase in the parameter value and a negative (-) sign of the computed *PC* represents a decrease in the parameter value with increasing wetland percentage in the watershed.

## RESULTS

The results of this study relating changes in peakflow, floodflow volume, and low flow to percent wetland change are presented in this section. The results are based on the statewide analysis (all the stations are included in one group), regional analysis (the stations are grouped into three regions), and seasonal analysis (the data are segregated for the four seasons).

### Peakflow and Floodflow Volume

*Statewide Analysis*

The results for the statewide analysis are shown in figures 10-13 and table 2. In general, the results of the analysis show that the peakflow and floodflow volume parameters decrease with increasing percentage of wetlands in the watersheds. For an increase of one percent wetland area in the watershed, the corresponding decreases are 3.7 percent for peakflow to average precipitation ratio, 2.6 percent for peakflow to peak precipitation ratio, and 3.0 percent for peakflow to total precipitation ratio. Thus among the three peakflow parameters analyzed, the peakflow to average precipitation ratio shows the most discernible relationship.

Table 2. Regression Analysis Results and Percent Change for Statewide Analysis

| | | *Regression coefficients* | | |
|---|---|---|---|---|
| *Flow* | *parameters* | *Intercept* | *Slope* | *Percent change* |
| $Q_p/P_a$ | | 0.696 | -0.022 | -3.7 |
| $Q_p/P_p$ | | 0.369 | -0.0086 | -2.6 |
| $Q_p/P_t$ | | 0.286 | -0.0075 | -3.0 |
| $V/P_t$ | | 0.318 | -0.0041 | -1.4 |

The floodflow volume to total precipitation ratio decreases by 1.4 percent for an increase of one percent wetland area in the watershed (figure 13). The decrease in the floodflow volume parameter is significantly lower than for the peakflow parameters.

### Regional Analysis

The results from the regional analysis are summarized in figure 14 and table 3. The relations between the three peakflow parameters and percent wetland for the three regions are compared with the relation for the statewide analysis in figures 14a-14c. The analysis indicates that all three peakflow parameters decrease with increasing percentage

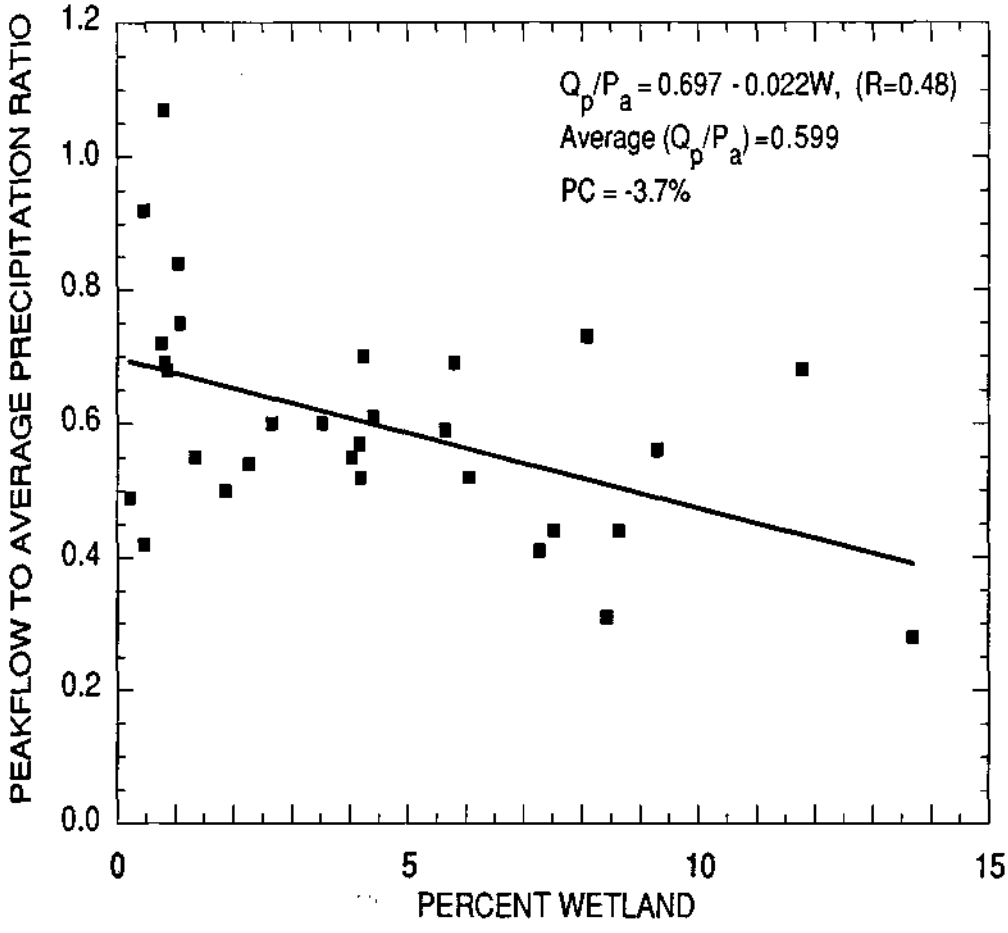


Figure 10. Relation between peakflow to average precipitation ratio and percent wetland for Illinois

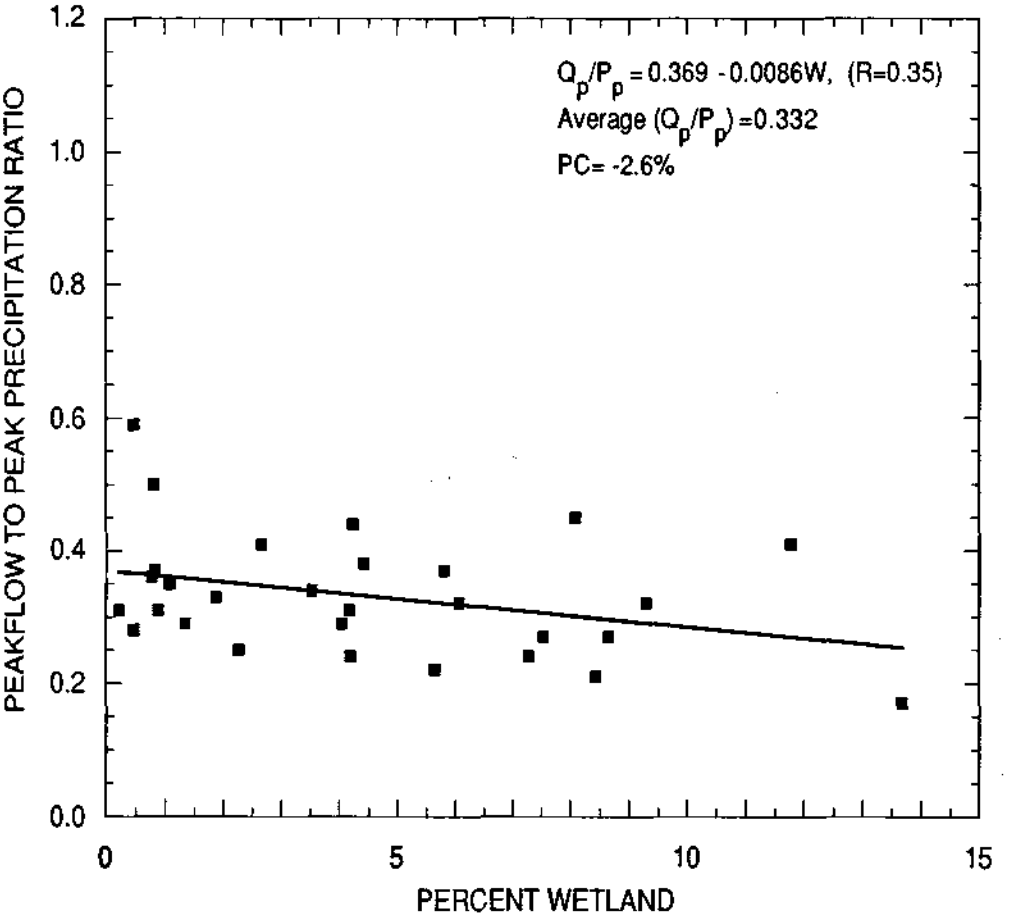


Figure 11. Relation between peakflow to peak precipitation ratio and percent wetland for Illinois

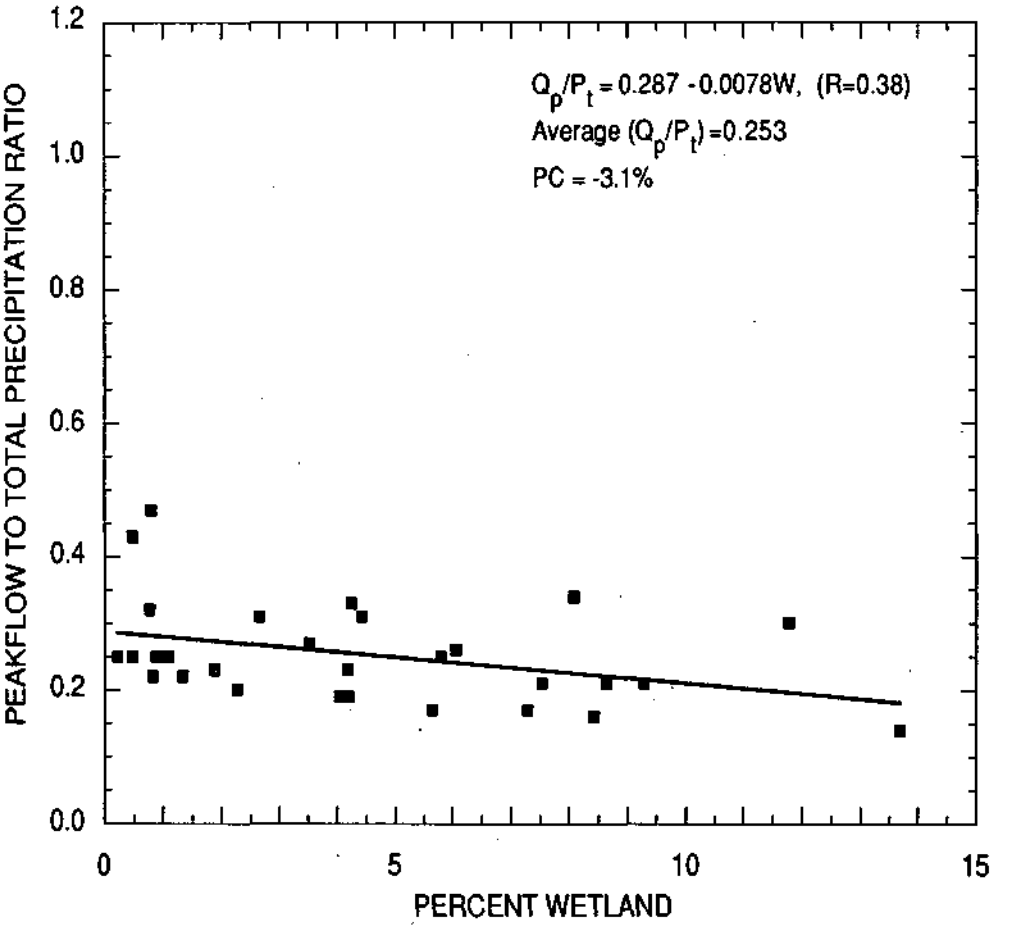


Figure 12. Relation between peakflow to total precipitation ratio and percent wetland for Illinois

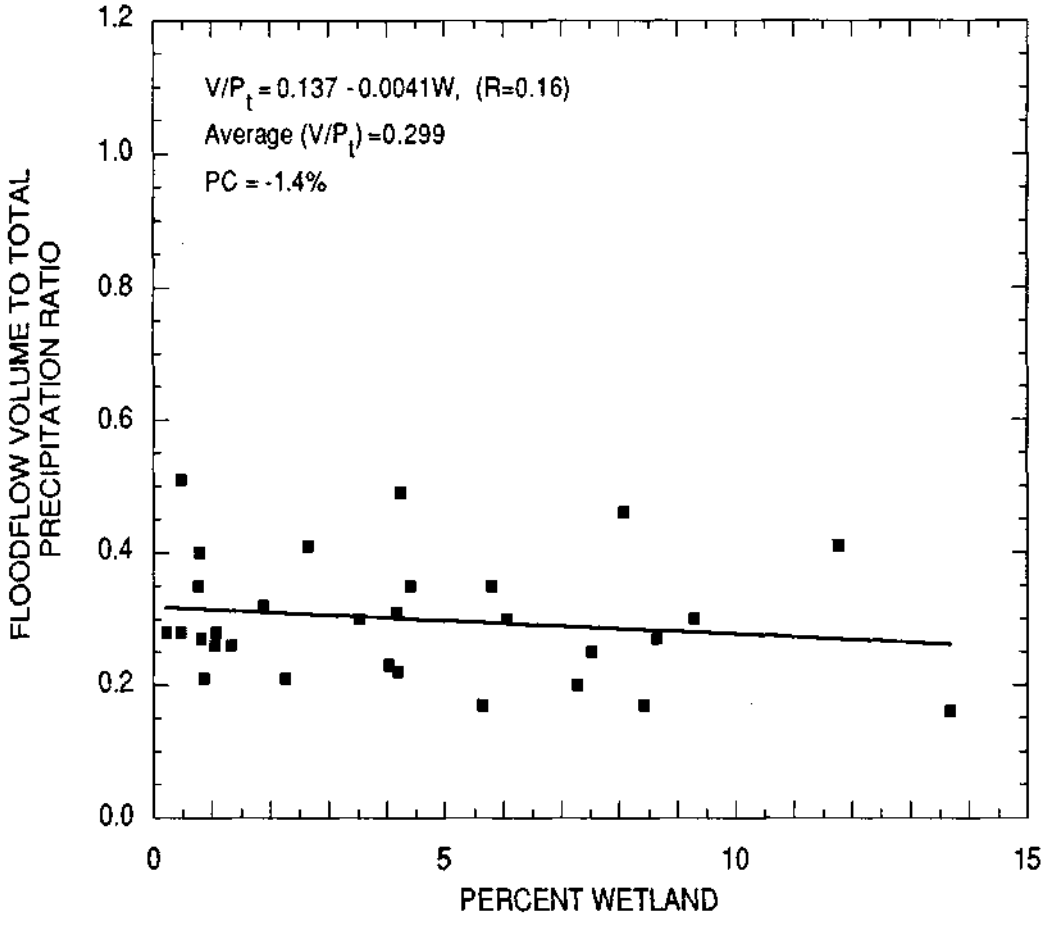


Figure 13. Relation between floodflow volume to total precipitation ratio and percent wetland for Illinois

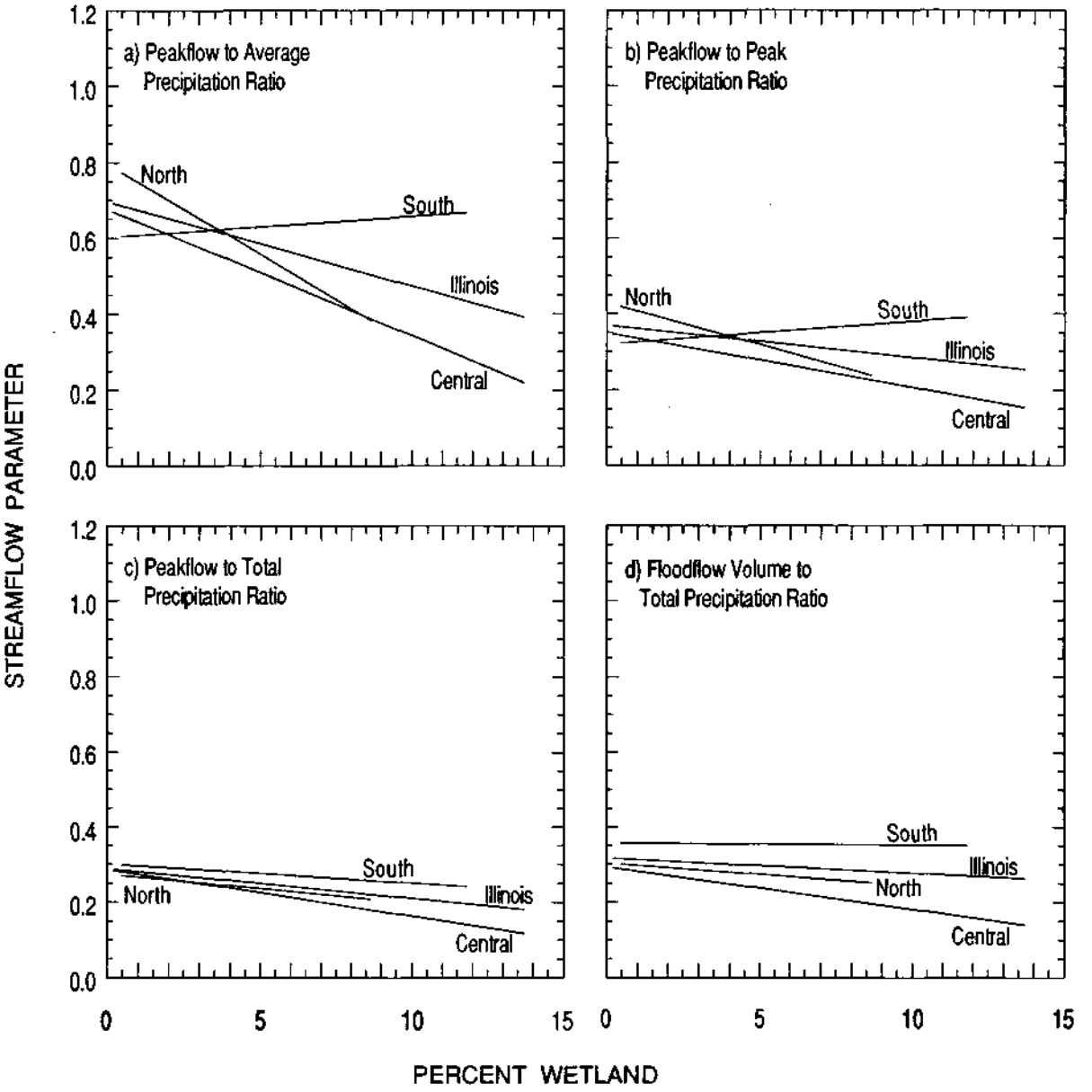


Figure 14. Regional variation of the relations between peakflow and floodflow volume parameters and percent wetland

of wetlands for central and northern Illinois. The peakflow to average precipitation ratio shows the most significant relationship. The percent decreases for central Illinois are 5.9, 4.9, and 5.0 percent for peakflow to average precipitation ratio, peakflow to peak precipitation ratio, and peakflow to total precipitation ratio, respectively. For northern Illinois the decreases for the three peakflow parameters are 7.9, 6.5, and 2.9 percent, respectively.

Table 3. Regional Regression Coefficients and Percent Change Values for Peakflow and Floodflow Parameters

| | | *Regression parameters* | | | |
|---|---|---|---|---|---|
| *Flow parameter* | | *Region* | *Intercept* | *Slope* | *Percent change* |
| $Q_p/P_a$ | | statewide | 0.696 | -2.22 | -3.7 |
| | | southern | 0.601 | 0.53 | 0.8 |
| | | central | 0.673 | -3.29 | -5.9 |
| | | northern | 0.797 | -4.78 | -7.9 |
| $Q_p/P_p$ | | statewide | 0.369 | -0.86 | -2.6 |
| | | southern | 0.320 | 0.57 | 1.6 |
| | | central | 0.350 | -1.44 | -4.9 |
| | | northern | 0.427 | -2.20 | -6.5 |
| $Q_p/P_t$ | | statewide | 0.286 | -0.75 | -3.0 |
| | | southern | 0.301 | -0.51 | -1.9 |
| | | central | 0.285 | -1.20 | -5.0 |
| | | northern | 0.271 | -0.71 | -2.9 |
| $V/P_t$ | | statewide | 0.318 | -0.41 | -1.4 |
| | | southern | 0.355 | 0.00 | 0.0 |
| | | central | 0.294 | -1.10 | -4.5 |
| | | northern | 0.304 | -0.70 | -2.3 |

In southern Illinois, peakflow to average precipitation ratio and peakflow to peak precipitation ratio increase by 0.8 and 1.6 percent, respectively, while peakflow to total precipitation ratio decreases by 1.9 percent. Thus, the relationships for southern Illinois are less noticeable and contradictory than those for central and northern Illinois.

The relations between the floodflow volume parameters and percent wetland for the three regions are compared in figure 14d. The floodflow volume to total precipitation ratio decreases for central and northern Illinois by 4.5 and 2.3 percent, respectively. For

southern Illinois, however, the percentage of wetlands appears to have no influence on the floodflow volume ratio; it essentially remains constant irrespective of the percentage of wetlands in the watershed.

***Seasonal Analysis***

The influence of wetlands on streamflow could depend on seasonal variation of wetland functions and the general hydrologic cycle of precipitation, infiltration, storage, and runoff. In Illinois seasonal variations in precipitation, soil moisture and runoff are significant. Therefore it was decided to evaluate if significant differences in the influence of wetlands on streamflow could be detected based on available streamflow data. The selected flood events were grouped in the season that they occurred, and similar analyses were performed to evaluate the differences. The results are also compared to the total set of data.

The results from the seasonal analysis are summarized in figures 15-19 and tables 4-7. The seasonal analysis indicates that all three peakflow parameters decrease with increasing percentage of wetlands for all seasons. The greatest decrease is found in fall and the least during winter. The percent decreases in fall, for an increase of one percent wetland area in the watershed, are 5.7, 4.1, and 5.6 percent for peakflow to average precipitation ratio, peakflow to peak precipitation ratio, and peakflow to total precipitation ratio, respectively. The corresponding values for winter are 2.4, 1.6, and 1.4 percent. The decreases in peakflow parameters for spring and summer are very similar; for spring, the decreases are 4.0, 2.8, and 2.7 percent, respectively; and for summer, the decreases are 4.2, 3.4, and 3.4 percent, respectively. The peakflow ratios for the four seasons are compared in figures 15a-15c.

The relationships for the floodflow volume parameter are much less perceptible than those for the peakflow parameter. The decreases for floodflow volume for fall, winter, spring, and summer are 2.0, 0.0, 1.0, and 3.1 percent, respectively. Figure 15d compares the floodflow volume ratio for the four seasons.

**Seasonal-Regional.** Since the storm events were separated on the basis of the season in which they occurred for the seasonal analysis discussed in the preceding section, it was decided to evaluate if the general seasonal patterns vary from region to region within Illinois. In a similar fashion to that for the regional analysis, the data for the seasonal analysis were grouped into regions to assess the seasonal influence in different regions of the state. A summary of the statewide analysis is provided in the seasonal analysis discussed in the preceding section. The regional aspect of the seasonal analysis is

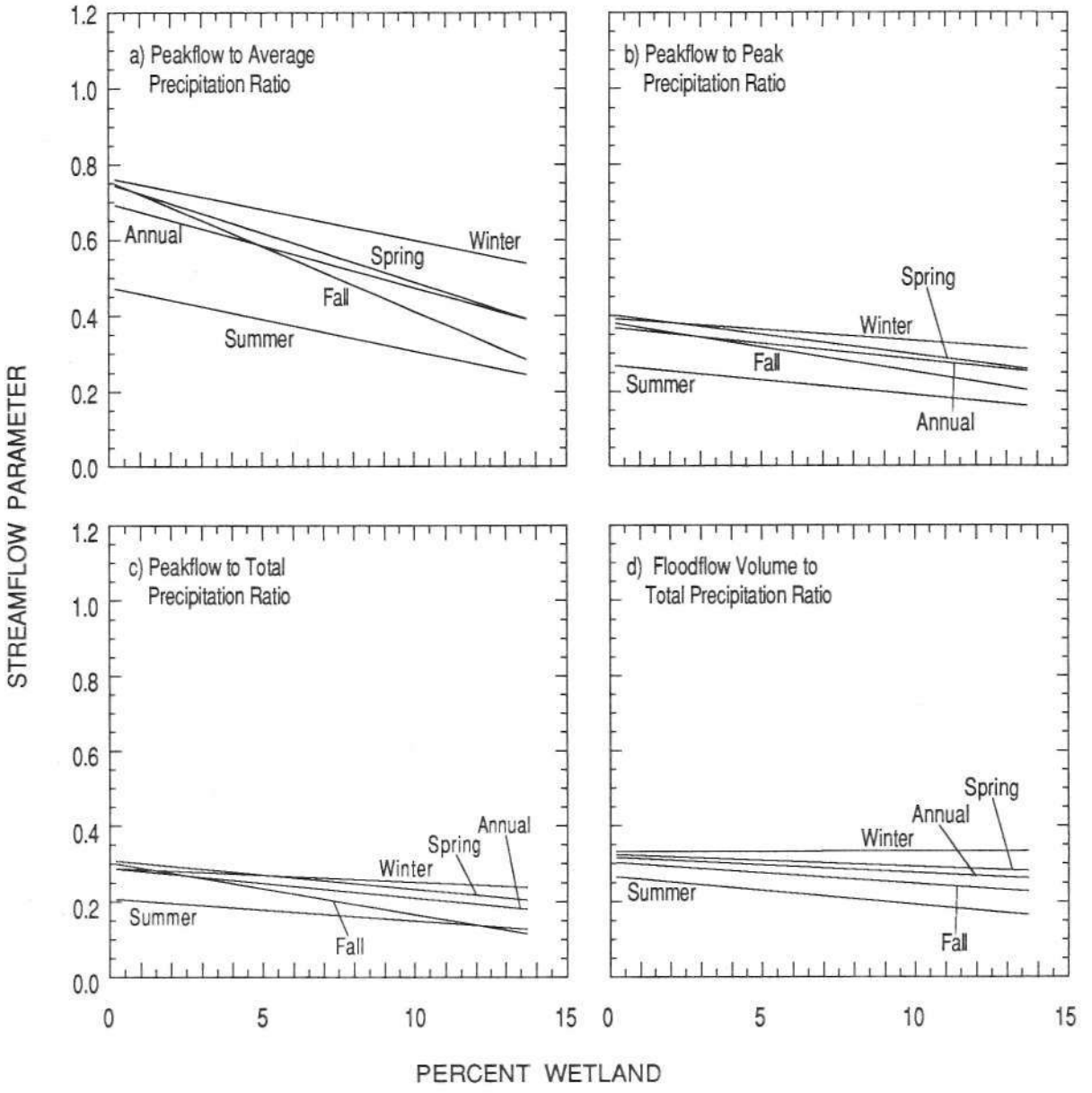


Figure 15. Seasonal variation of the relations between peakflow and floodflow volume parameters and percent wetland

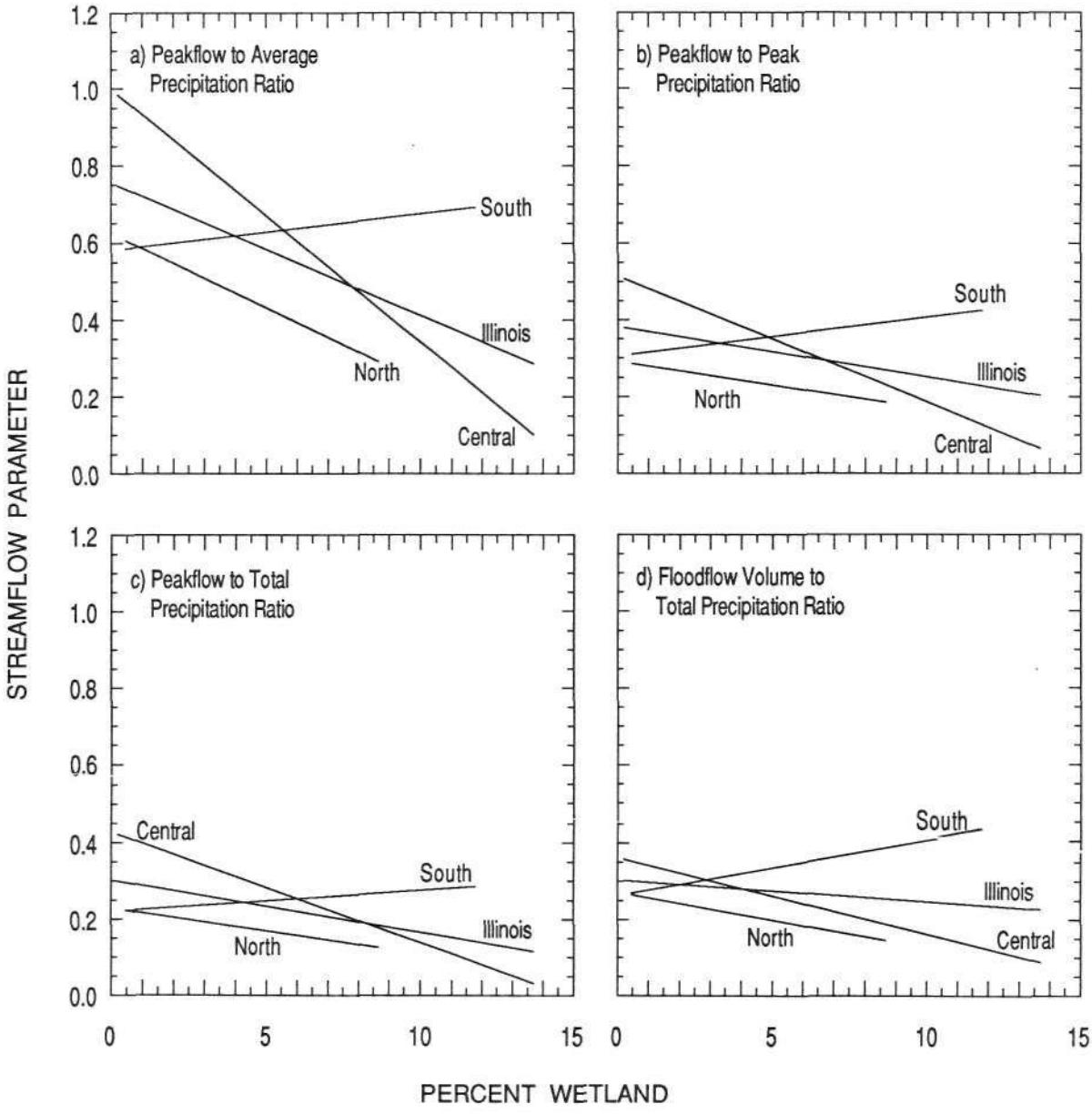


Figure 16. Regional variation of the relations between peakflow and floodflow volume parameters and percent wetland for fall

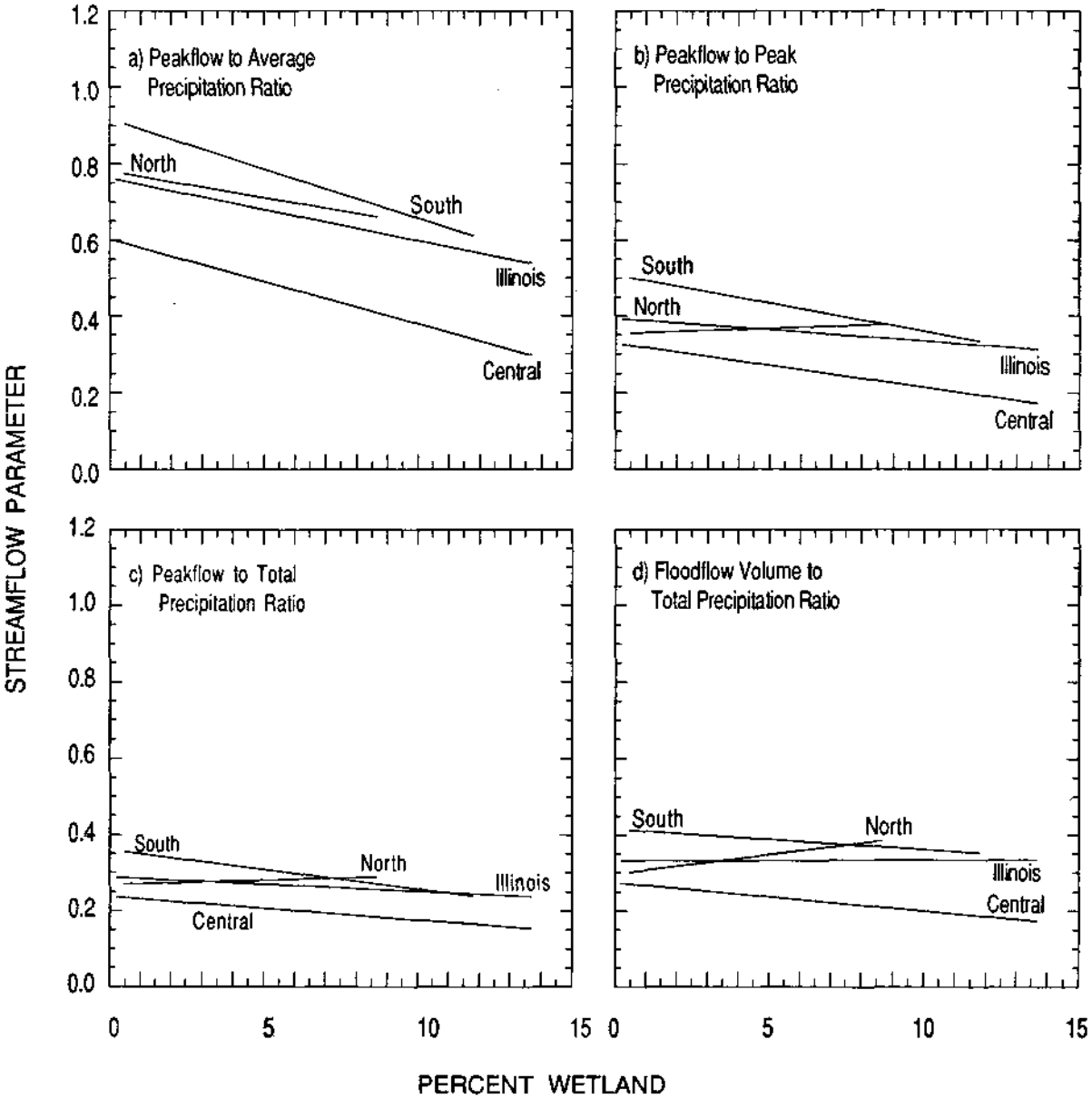


Figure 17. Regional variation of the relations between peakflow and floodflow volume parameters and percent wetland for winter

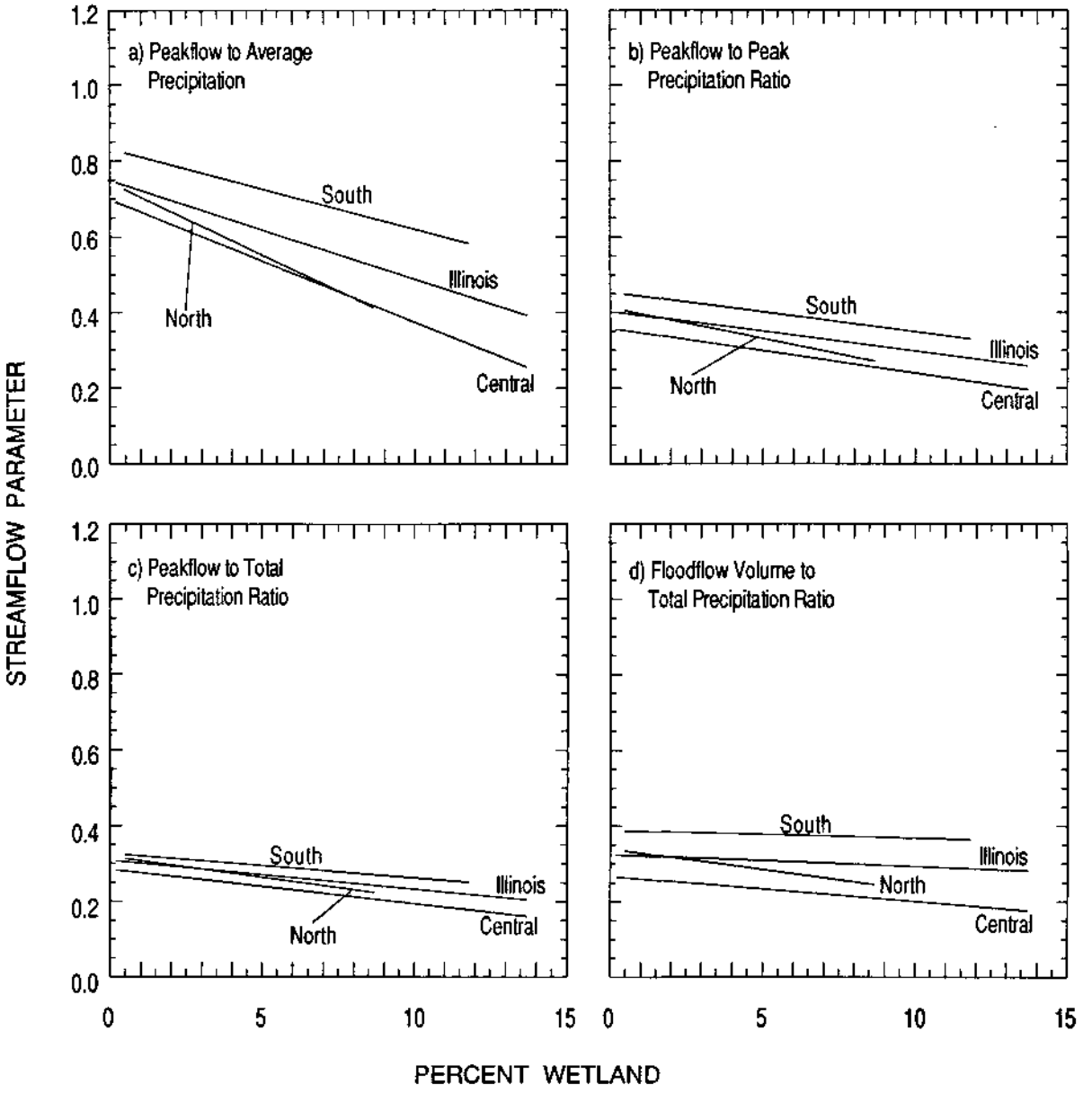


Figure 18. Regional variation of the relations between peakflow and floodflow volume parameters and percent wetland for spring

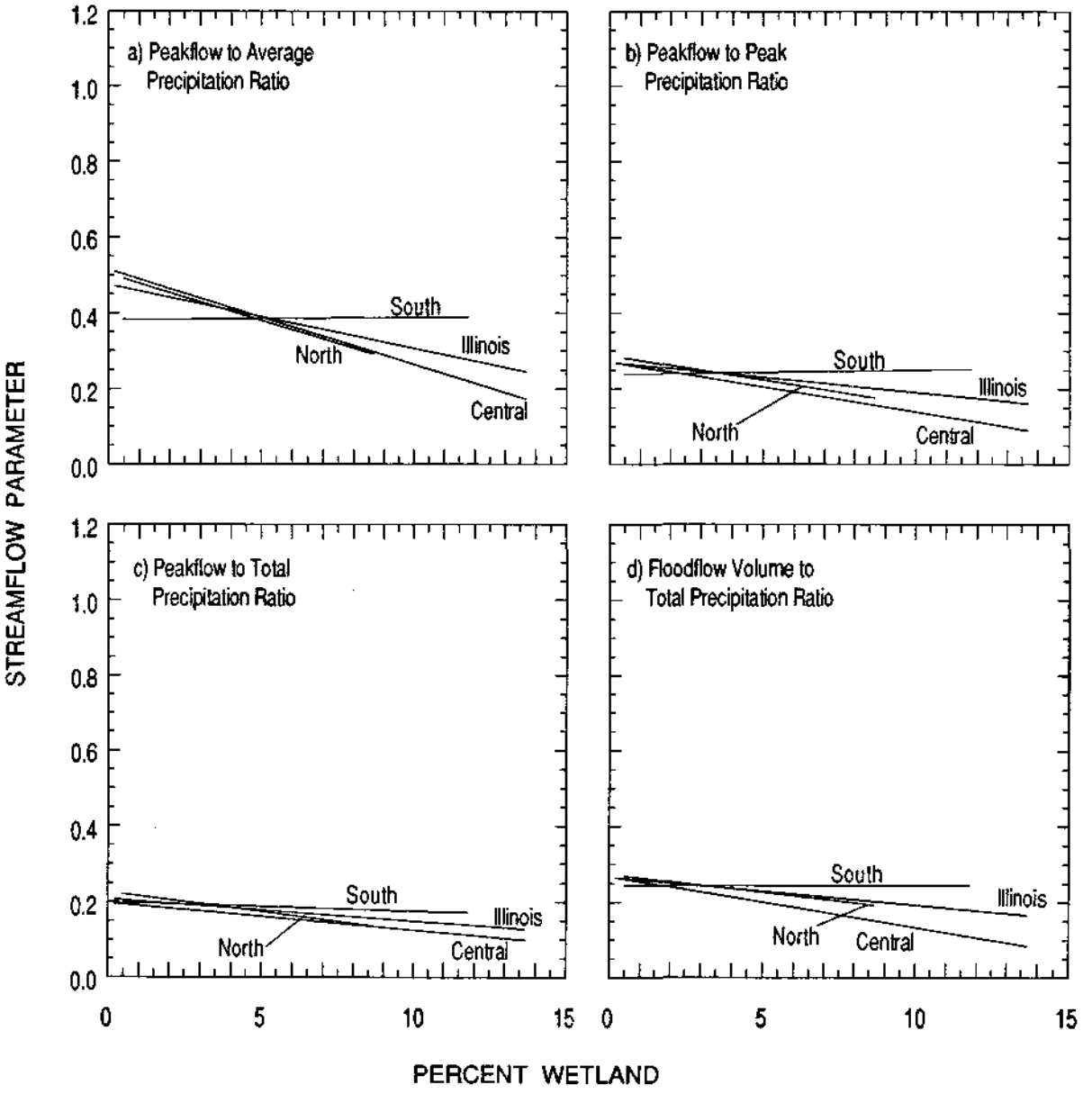


Figure 19. Regional variation of the relations between peakflow and floodflow volume parameters and percent wetland for summer

Table 4. Influence of Wetlands on Peakflow as Measured by the Percent Change in the Ratio of Peakflow to Average Precipitation Ratio ($Q_p/P_a$) for a One Percent Change in Wetland Area

| | *Annual* | *Fall* | *Winter* | *Spring* | *Summer* |
|---|---|---|---|---|---|
| **Illinois (statewide)** | **-3.7** | **-5.7** | **-2.4** | **-4.0** | **-4.2** |
| South | +0.8 | +1.5 | -3.3 | -2.9 | +0.3 |
| Central | -5.9 | -8.7 | -4.3 | -5.3 | -5.9 |
| North | -7.9 | -8.2 | -1.9 | -6.5 | -6.1 |

Table 5. Influence of Wetlands on Peakflow as Measured by the Percent Change in the Ratio of Peakflow to Peak Precipitation ($Q_p/P_p$) for a One Percent Change in Wetland Area

| | *Annual* | *Fall* | *Winter* | *Spring* | *Summer* |
|---|---|---|---|---|---|
| **Illinois (statewide)** | **-2.6** | **-4.1** | **-1.6** | **-2.8** | **-3.8** |
| South | 1.6 | 2.7 | -3.4 | -2.7 | +0.5 |
| Central | -4.9 | -8.3 | -4.0 | -3.6 | -6.0 |
| North | -6.5 | -5.1 | 0.8 | -4.6 | -5.5 |

Table 6. Influence of Wetlands on Peakflow as Measured by the Percent Change in the Ratio of Peakflow to Total Precipitation ($Q_p/P_t$) for a One Percent Change in Wetland Area

| | *Annual* | *Fall* | *Winter* | *Spring* | *Summer* |
|---|---|---|---|---|---|
| **Illinois (statewide)** | **-3.0** | **-5.6** | **-1.4** | **-2.7** | **-3.4** |
| South | -1.9 | 2.3 | -3.5 | -2.2 | -1.4 |
| Central | -5.0 | -9.0 | -3.0 | -3.5 | -4.4 |
| North \ | -2.9 | -6.2 | 0.9 | -3.8 | -5.6 |

Table 7. Influence of Wetlands on Floodflow Volume as Measured by the Percent Change in the Ratio of Floodflow Volume to Total Precipitation ($V/P_t$) for a One Percent Change in Wetland Area

| | *Annual* | *Fall* | *Winter* | *Spring* | *Summer* |
|---|---|---|---|---|---|
| **Illinois (statewide)** | **-1.4** | **-2.0** | **0.0** | **-1.0** | **-3.1** |
| South | 0.0 | +4.4 | -1.5 | -0.6 | +0.2 |
| Central | -4.5 | -6.9 | -3.0 | -2.3 | -6.1 |
| North | -2.3 | -6.9 | +3.1 | -3.7 | -4.1 |

presented in the following sections. The results of this analysis are provided in figures 16-19 and tables 4-7.

***Fall.*** The results for the fall season are shown in figure 16. The results show that all the peakflow parameters decrease with increasing percentage of wetlands for both central and northern Illinois. The decreases for central Illinois are 8.7, 8.3, and 9.0 percent for peakflow to average precipitation ratio, peakflow to peak precipitation ratio, and peakflow to total precipitation ratio, respectively. The decreases for northern Illinois are 8.2, 5.1, and 6.2 percent, respectively. For southern Illinois, however, the peakflow ratios increase with increasing percentage of wetlands: the increases are 1.5, 2.7, and 2.3 percent, respectively. Among the three peakflow parameters, the most noticeable relationship is for the peakflow to average precipitation ratio. Among the three regions, the relationships for central and northern Illinois are more perceptible.

The floodflow volume parameter exhibits results similar to the peakflow parameters, where the parameter decreases in northern and central Illinois and increases in southern Illinois (figure 16c). The decreases for central and northern Illinois are 6.9 percent and the increase for southern Illinois is 4.4 percent.

***Winter.*** The results for the winter season are summarized in figure 17. The results show that, in general, the peakflow parameters decrease with increasing percentage of wetlands in the watershed for southern and central Illinois. The decreases for southern Illinois are 3.3, 3.4, and 3.5 percent for peakflow to average precipitation ratio, peakflow to peak precipitation ratio, and peakflow to total precipitation ratio, respectively. The decreases for central Illinois are 4.3, 4.0, and 3.0 percent, respectively. For northern Illinois, only peakflow to average precipitation ratio decreases by 1.9 percent, while peakflow to peak precipitation ratio and peakflow to total precipitation ratio increase by 0.8 and 0.9 percent, respectively. Among the three peakflow parameters, the most noticeable relationship is for peakflow to average precipitation ratio. Among the three regions, the relationship for central Illinois is the most perceptible.

The floodflow volume parameter exhibits similar results to those of the peakflow parameters (figure 16d). The floodflow volume to total precipitation ratio decreases by 1.5 and 3.0 percent for southern and central Illinois, and increases by 3.1 percent for northern Illinois.

***Spring.*** The results for the spring season are shown in figure 18. The results show that the peakflow parameters decrease with increasing percentage of wetlands for all three regions. The decreases for southern Illinois are 2.9, 2.7, and 2.2 percent for peakflow to average precipitation ratio, peakflow to peak precipitation ratio, and peakflow to total precipitation ratio, respectively, for an increase of one percent wetland

area in the watershed. The corresponding decreases for central Illinois are 5.3, 3.6, and 3.5 percent, and for northern Illinois they are 6.5, 4.6, and 3.8 percent. Among the three peakflow ratios, the most significant relationship is for peakflow to average precipitation ratio. Among the three regions, the relationship for northern Illinois is the most perceptible.

The floodflow volume parameter also decreases with increasing wetland percentage for all three regions (figure 18d). The decreases are 0.6, 2.3, and 3.7 percent for southern, central, and northern Illinois, respectively.

***Summer.*** The results for the summer season are shown in figure 19. The results show that the peakflow parameters decrease with increasing percentage of wetlands in the watershed for central and northern Illinois. The decreases for central Illinois are 5.9, 6.0, and 4.4 percent for peakflow to average precipitation ratio, peakflow to peak precipitation ratio, and peakflow to total precipitation ratio, respectively, for an increase of one percent wetland area in the watershed. The corresponding decreases for northern Illinois are 6.1, 5.5, and 5.6; for southern Illinois, peakflow to average precipitation ratio is not significantly influenced by the presence of wetlands, peakflow to peak precipitation ratio increases by 0.5 percent, while peakflow to total precipitation ratio decreases by 1.4 percent. Among the three peakflow ratios, the most significant relationship is for peakflow to average precipitation ratio. Among the three regions, the relationships for central and northern Illinois are more perceptible.

Similar to the peakflow parameters, the floodflow volume parameters also decrease by 6.1 and 4.1 percent for central and northern Illinois, respectively. For southern Illinois, however, floodflow volume is not significantly affected by the percentage of wetlands in the watershed.

## Low Flow

### *Statewide Analysis*

The results from the low-flow analysis for the state as a whole are shown in figures 20-21 and tables 8 and 9. The results indicate that flows at both 95 and 99 percent probability of exceedance ($Q_{95}$ and $Q_{99}$) generally increase with increasing wetland percentage in the watershed. For the whole state, the percent increases for $Q_{95}$ and $Q_{99}$ for an increase of one percent wetland area in the watershed are 7.9 and 8.4 percent, respectively. As figures 20 and 21 show, there is a wide scatter in the data points for both $Q_{95}$ and $Q_{99}$ for Illinois as a whole; however, the scatter in the data can be considerably reduced for both the low-flow parameters when they are grouped on a regional basis.

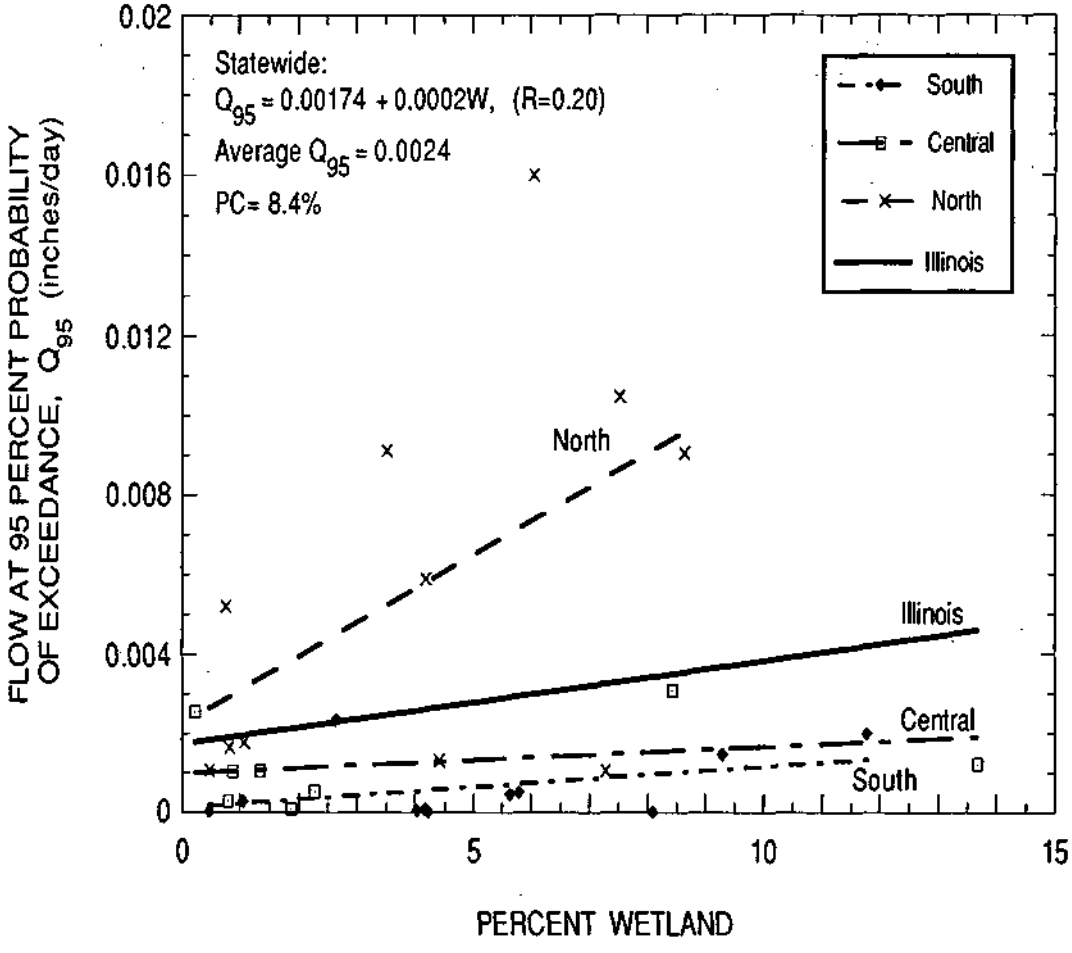


Figure 20. Relation between low-flow parameter, $Q_{95}$, and percent wetland for Illinois

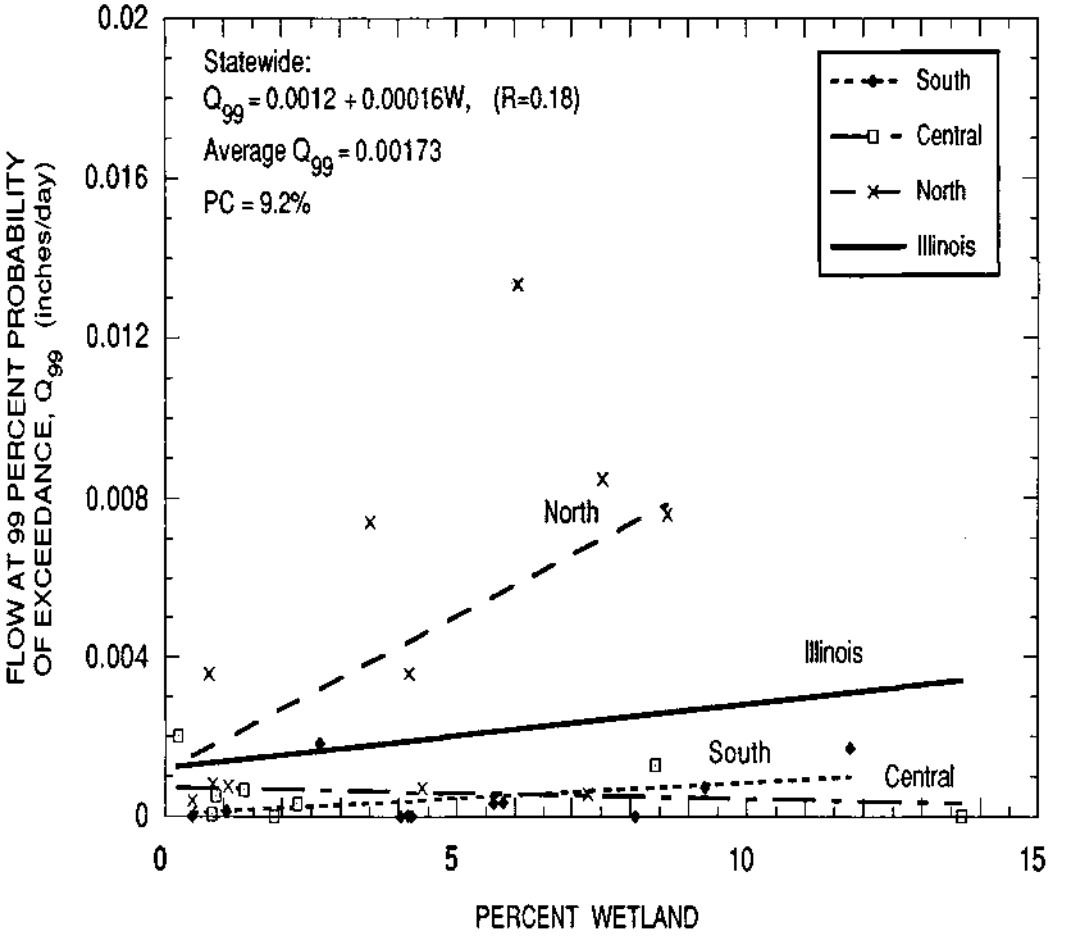


Figure 21. Relation between low-flow parameter, $Q_{99}$, and percent wetland for Illinois

Table 8. Regional Variability of Influence of Wetlands on Low Flow in Illinois as Measured by the Percent Change in $Q_{95}$ and $Q_{99}$

| | *$Q_{95}$ (percent change)* | *$Q_{99}$ (percent change)* |
|---|---|---|
| Illinois (statewide) | +7.9 | +8.4 |
| Southern Illinois | +15.9 | +17.2 |
| Central Illinois | +5.5 | -4.6 |
| Northern Illinois | +15.0 | +18.2 |

Table 9. Seasonal Variability of Influence of Wetlands on Low Flow in Illinois as Measured by the Percent Change in $Q_{95}$ and $Q_{99}$

| | *$Q_{95}$ (percent change)* | *$Q_{99}$ (percent change)* |
|---|---|---|
| Annual | +7.9 | +8.4 |
| Fall | +8.4 | +9.2 |
| Winter | +7.6 | +7.6 |
| Spring | -1.8 | -2.4 |
| Summer | +8.0 | +9.4 |

Notes:
$Q_{95}$ = flow at 95 percent probability of exceedance
$Q_{99}$ = flow at 99 percent probability of exceedance
+ = parameter value increases with increasing wetland percentage
- = parameter value decreases with increasing wetland percentage

***Regional Analysis***

The results from the regional analysis are also shown in figures 20-21 and table 8. The results indicate that both low-flow parameters increase with increasing percentage of wetlands. The percent increases for $Q_{95}$ and $Q_{99}$ for southern Illinois are 15.9 and 17.2 percent, respectively. For northern Illinois, the increases are 15.0 and 18.2 percent, respectively. The influence of wetlands on low flow is significantly less in central Illinois compared to that in either southern or northern Illinois. $Q_{95}$ increased by 5.5 percent, while $Q_{99}$ decreased by 4.6 percent. Thus, based on the data analyzed, influence of wetlands on low flow is more dominant in southern and northern Illinois than in central Illinois.

***Seasonal Analysis***

The results from the seasonal analysis are shown in figure 22 and table 9. The seasonal analysis indicates that both $Q_{95}$ and $Q_{99}$ increase with increasing wetland percentage for fall. The percent increases in fall are 8.4 and 9.2 percent for $Q_{95}$ and $Q_{99}$, respectively. The relationships are similar for winter and summer. The percent increases in winter are 7.6 percent for both $Q_{95}$ and $Q_{99}$, while the percent increases in summer are 8.0 and 9.4 percent for $Q_{95}$ and $Q_{99}$, respectively. For spring, however, $Q_{95}$ and $Q_{99}$ decrease by 1.8 and 2.4 percent, respectively.

**Seasonal-Regional.** As mentioned previously, low-flow parameters were computed for each season by grouping the data on the basis of the four seasons. The following sections discuss the seasonal influence for the different regions. The results of this analysis are summarized in table 10.

***Fall.*** The results show that both $Q_{95}$ and $Q_{99}$ increase with increasing wetland percentage in the watershed for southern as well as northern Illinois. The increases for southern Illinois are 17.2 and 19.3 percent for $Q_{95}$ and $Q_{99}$, respectively. The increases for northern Illinois are 15.6 and 18.7 percent, respectively. For central Illinois, however, $Q_{95}$ increases by 6.4 percent, while $Q_{99}$ decreases by 2.8 percent. Thus the relationships for southern and northern Illinois show more influence of wetlands on low flow compared to central Illinois for fall. The rate of increase is, however, much higher for northern Illinois than that for southern Illinois.

***Winter.*** The results show that both $Q_{95}$ and $Q_{99}$ increase with increasing wetland percentage in the watershed for all three regions: southern, central, and northern Illinois during winter. The percent increases for southern Illinois are 9.1 and 8.9 percent

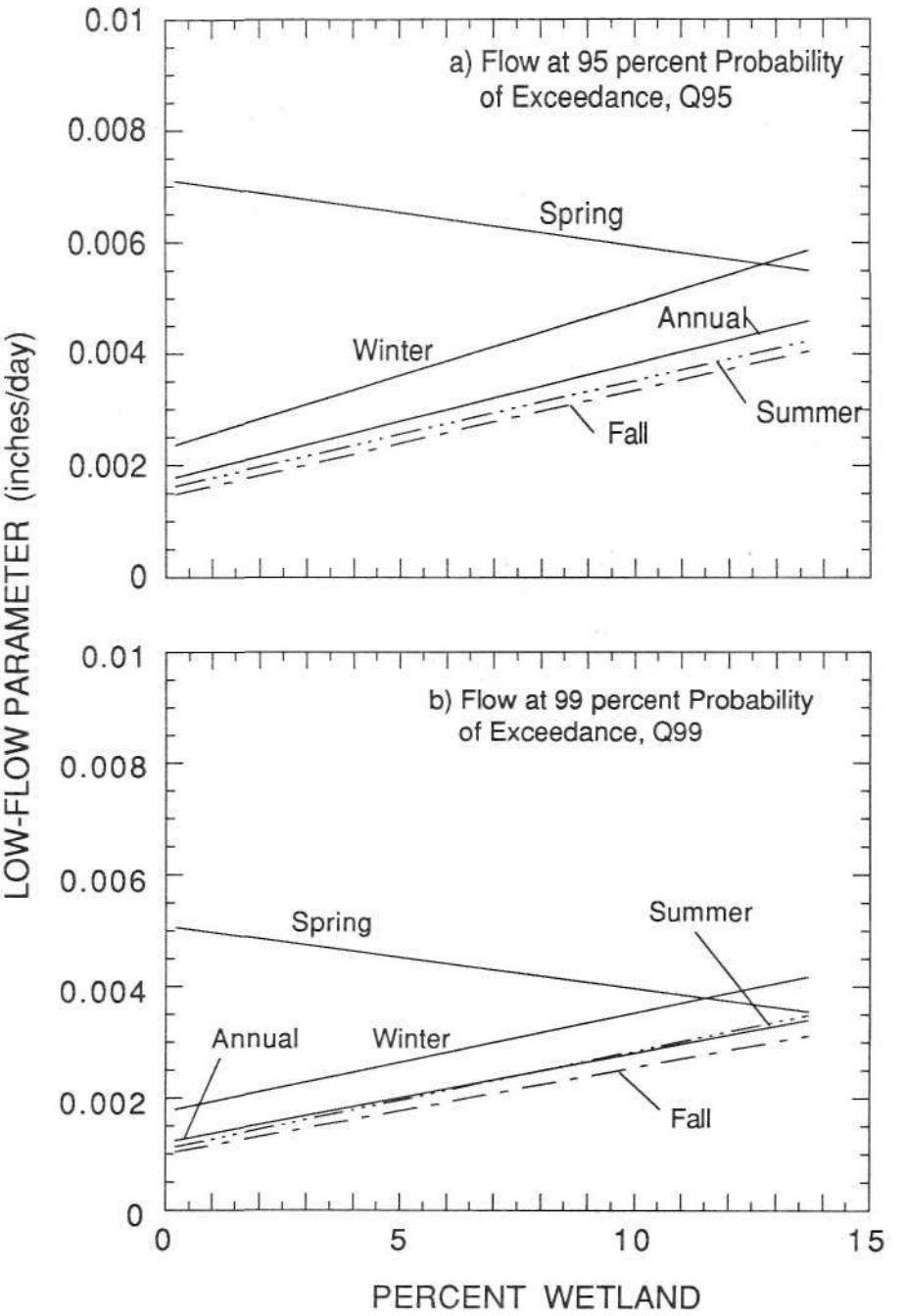


Figure 22. Seasonal variation of the relation between parameters $Q_{95}$ and $Q_{99}$ and percent wetland low flow

Table 10. Seasonal Variability of Influence of Wetlands on Low Flow by Region in Illinois as Measured by the Percent Change in $Q_{95}$ and $Q_{99}$

| | *Fall* | | *Winter* | | *Spring* | | *Summer* | |
|---|---|---|---|---|---|---|---|---|
| | *$Q_{95}$* | *$Q_{99}$* | *$Q_{95}$* | *$Q_{99}$* | *$Q_{95}$* | *$Q_{99}$* | *$Q_{95}$* | *$Q_{99}$* |
| Illinois | +8.4 | +9.2 | +7.6 | +7.0 | -1.8 | -2.4 | +8.0 | +9.4 |
| Southern Illinois | +17.2 | +19.3 | +9.1 | +8.9 | -0.4 | +5.3 | +22.0 | +20.9 |
| Central Illinois | +6.4 | -2.8 | +10.2 | +5.7 | -2.1 | -4.2 | -4.7 | -8.0 |
| Northern Illinois | +15.6 | +18.7 | +12.9 | +14.1 | +3.8 | +2.2 | +16.2 | +20.0 |

Notes:
$Q_{95}$ = flow at 95 percent probability of exceedance
$Q_{99}$ = flow at 99 percent probability of exceedance
\+ = parameter value increases with increasing wetland percentage
\- = parameter value decreases with increasing wetland percentage

for $Q_{95}$ and $Q_{99}$, respectively. The percent increases for central Illinois are 10.2 and 5.7 percent, respectively. The percent increases for northern Illinois are 12.9 and 14.1 percent, respectively. Thus the relationships for all three regions in Illinois show similar influence of wetlands on low flow for winter. The rate of increase is again higher for northern Illinois than that for either southern or central Illinois.

***Spring.*** The results show that for all three regions - southern, central, and northern Illinois - $Q_{95}$ as well as $Q_{99}$ are influenced much less by wetlands in spring than in the other seasons. For southern Illinois, $Q_{95}$ is not significantly influenced by wetlands in spring, while $Q_{99}$ shows an increase of 5.3 percent. For central Illinois, there are decreases of 2.1 and 4.2 percent for $Q_{95}$ and $Q_{99}$, respectively For northern Illinois, there are increases of 3.8 and 2.2 percent for $Q_{95}$ and $Q_{99}$, respectively.

***Summer.*** The results show that both $Q_{95}$ and $Q_{99}$ increase with increasing wetland percentage in the watershed for southern as well as northern Illinois. The increases for southern Illinois are 22.0 and 20.9 percent for $Q_{95}$ and $Q_{99}$, respectively. The increases for northern Illinois are 16.2 and 20.0 percent for $Q_{95}$ and $Q_{99}$, respectively. For central Illinois, however, $Q_{95}$ and $Q_{99}$ decrease by 4.7 and 8.0 percent, respectively. Thus the relationships for southern and northern Illinois show more influence of wetlands on low flow compared to central Illinois., The rate of increase is again much higher for northern Illinois than that for southern Illinois.

## SUMMARY AND CONCLUSIONS

Existing streamflow records from 30 gaging stations in different geographic regions of Illinois with different percentages of wetlands in their watersheds were analyzed to assess the influence of wetlands on streamflow. The objective of the research was to determine if streamflow parameters were influenced by the percentage of wetlands in the watersheds. The streamflow parameters analyzed included three peakflow parameters (peakflow to average precipitation ratio, peakflow to peak precipitation ratio, and peakflow to total precipitation ratio), a floodflow parameter (floodflow volume to total precipitation ratio), and two low-flow parameters (flows at 95 and 99 percent exceedance probability, $Q_{95}$ and $Q_{99}$). Because of significant regional differences in physiography and hydrology in Illinois, the data were synthesized to evaluate if there were regional patterns in the relations. The stations were grouped into three regions: northern, central, and southern Illinois. Even though the regionalization reduces the number of stations for analysis, important observations were made based on this analysis. It is also reasonable to assume that wetland functions could change with changes in the seasons because of the associated changes in climate and land cover. Therefore variability of the influence of wetlands was evaluated for the different seasons.

The major conclusions of the study follow. It should be mentioned that for the sake of brevity, the conclusions for peakflow were made on the basis of the results for peakflow to average precipitation ratio only. Even though the patterns are similar, the peakflow to average precipitation parameter showed the most consistent result among the three peakflow ratios. The conclusions for low flow were made on the basis of the results for $Q_{95}$, since the total number of zero values associated with it was less than that with $Q_{99}$

1. Peakflow decreases as the percentage of wetland areas increases in the watershed. For the state as a whole, including the 30 stations, the peakflow parameter decreased by an average of 3.7 percent for one percent increase in wetland area. The percent change in the peakflow parameter varied from a decrease of 8.7 percent for central Illinois to an increase of 1.5 percent in southern Illinois during the fall season. The influence of wetlands on peakflow is more pronounced in northern and central Illinois than in southern Illinois. Seasonally, wetland acreage influences peakflow more significantly in the fall than during the other seasons.
2. Floodflow volume decreases to a lesser extent as compared to peakflow, as wetland percentage increases. For the whole state, the floodflow volume parameter decreased by an average of 1.4 percent for one percent increase in wetland area. The percent

change in the floodflow parameter varied from a decrease of 6.9 percent for northern and central Illinois to an increase of 4.4 percent in southern Illinois during the fall season. The influence of wetland acreage on floodflow volume is more pronounced in central and northern Illinois than in southern Illinois. Seasonally, wetland acreage influences floodflow volume more during fall than during the other seasons.

3. Low flows increased with increasing wetland acreage in the watershed. For the whole state, the low-flow parameter increased by an average of 7.9 percent for one percent increase in wetland area. The percent change in the low-flow parameter varied from an increase of 22 percent in southern Illinois to a decrease of 4.7 percent in central Illinois during summer. The influence of wetland acreage on low flow is more pronounced in southern and northern Illinois than in central Illinois. Seasonally, the influence of wetland acreage on low flow is more significant during summer, fall, and winter, and less significant during spring.

Limitations of the database should be remembered in generalizing the results of this study. The first limitation is the limited database used in the regional analysis: 11 stations for southern Illinois, 8 stations for central Illinois, and 11 stations for northern Illinois. For Illinois as a whole, data were for 30 stations. Therefore, results and conclusions for the whole state may be considered more definitive.

Another weakness of the database is the skewed distribution of wetland percentages in the watersheds analyzed. Although wetland percentage ranged from 0.2 to 13.7 percent, 11 watersheds (37 percent) had percentages of wetlands less than or equal to 2 percent, 19 watersheds (63 percent) had percentages of wetlands less than or equal to 5 percent, while 28 watersheds (93 percent) had percentages of wetlands less than or equal to 10 percent. Thus, a relatively uniform distribution of wetland percentage was not available. As a result, the conclusions drawn based on the study of these watersheds should be viewed with some caution until the range of percent wetland area is expanded.

The present analysis can be improved by increasing the number of stations for each region to at least 20. This will provide a broader database for each region, and the regional and seasonal-regional conclusions will be more reliable. Attempts should also be made to select other watersheds in Illinois and from neighboring states so as to obtain a wider distribution of the percentage of wetlands in the watersheds. This will significantly improve both the scope and reliability of the conclusions from the current study.

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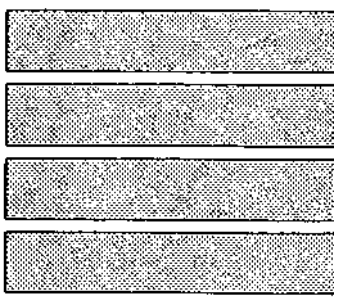
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