State Water Survey Division

GROUNDWATER SECTION

Illinois Institute of Natural Resources

SWS Contract Report 248

SURFACE WATER-GROUNDWATER QUALITY RELATIONSHIPS FOR A CENTRAL ILLINOIS WATERSHED

by

James P. Gibb
and
Michael O'Hearn

Prepared for the
Illinois Environmental Protection Agency
Contract No. 1-47-26-84-362

Champaign, Illinois
January 1981

DISCLAIMER

This pamphlet was published as part of the 208 Water Quality Management Planning Program. Funding was provided in part by the USEPA under provisions of Section 208 of the Federal Water Pollution Control Act Amendments of 1972 (PL 95-217) under Federal Statewide Water Quality Grant No. P005470 01. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Shallow groundwater quality data and 10 years of monthly surface water quality and mean daily flow data were used to determine groundwater-surface water quality relationships for the Mackinaw River above Congerville, Illinois. The 40-year medians of shallow groundwater quality data, were shown to be of limited value for predicting the base flow water quality for this basin. Stepwise multiple regression analysis of surface water quality and flow data revealed decreasing concentrations of sulfate in base flow and surface runoff for the study period. Analysis of data also revealed significant relationships between the amount of base flow and base flow sulfate, chloride, and nitrate concentrations. Relationships between the amount of surface runoff and the concentrations of total dissolved solids, sulfate, and total iron in the surface runoff also were revealed.

The results of the multiple regression analysis are discussed in terms of their importance to the development of water quality management strategies and the determination of realistic water quality goals. Monthly average chemical load calculations indicate that on a yearly basis only 30 to 40 percent of the total dissolved solids, hardness, sulfate, and nitrate loads can be attributed to surface runoff. In the average year about 60 to 80 percent of the total iron load can be attributed to surface runoff. Surface runoff chloride loads vary from 0 to 70 percent of total loads.

INTRODUCTION

Stream water chemistry is not static; rather it is the result of a combination of dynamic natural processes involving climatology, atmospheric chemistry, soil erosion, soil chemistry, hydrology, geochemistry, and biology. In addition, stream water quality in Illinois is affected by anthropogenic activities. Aside from the practical difficulties, determination of the relative importance of each of these factors is made more complex by their variation in space and time [Whittemore, 1978]. Yet, an understanding of the natural controls on stream water quality is essential to the development of realistic water quality management strategies. Such strategies must account for regional and temporal variations in water chemistry in order to be effective.

Numerous studies aimed at quantification of the contribution of point and non-point chemical loads to stream water quality have been undertaken. These range from attempts to directly measure non-point surface runoff with special sampling devices [Willis and Laflen, 1968] to sophisticated digital computer models of entire watersheds [Overcash and Davidson, 1980]. Though difficult to verify, the results of such studies often provide valuable insights into the natural controls on stream water quality for a particular basin. However, one significant non-point source of chemical loadings to streams is frequently neglected in stream water quality investigations: groundwater inflow.

A recent study [O'Hearn and Gibb, 1980] has shown that, on the average, the major portion of total streamflow in Illinois is derived from groundwater discharge. The purpose of this related investigation is to: 1) determine the relative impacts of groundwater base flow and direct surface runoff on stream water quality for one basin in Illinois using historical streamflow and water quality data: 2) determine if studies using existing data can provide economical first estimates of base flow and surface runoff water quality in Illinois watersheds; and 3) discuss the use of such data for the development and evaluation of water quality control programs.

Acknowledgements

The authors wish to thank Susan Richards, Assistant Hydrologist, Illinois State Water Survey, for her invaluable assistance in plotting data, determining chemical characteristics, and performing statistical analyses. Anne Bogner, student Systems Analyst, generated streamflow hydrographs and plotted data. Jill Davidson, student at the University of Illinois, also plotted some of the chemical data in the early stages of this project and performed some of the base flow separations. .

This project was conducted under the general supervision of Richard J. Schicht, Assistant Chief, Illinois State Water Survey. The artwork was done by Linda Riggin, William Motherway, and John Brother. Pam Lovett typed the draft and final manuscripts and Loreena Ivens edited the final manuscript.

BASIN DESCRIPTION

The Mackinaw River basin above Congerville, Illinois (USGS gaging station no. 5567500), was selected for study because of the availability of streamflow and water quality data. In addition, the land use of the drainage basin is primarily agricultural with no major urban areas or industries. As such, there are no significantly large point sources of discharge. The virtual absence of point discharges, urban areas, and industrial activity has the effect of reducing the number of complicating factors that must be considered in the interpretation of the chemical results.

The basin drains 767 square miles and is primarily located in McLean and Woodford Counties (see figure 1) in north-central Illinois. It is located in the Till Plains section of the Central Lowland physiographic

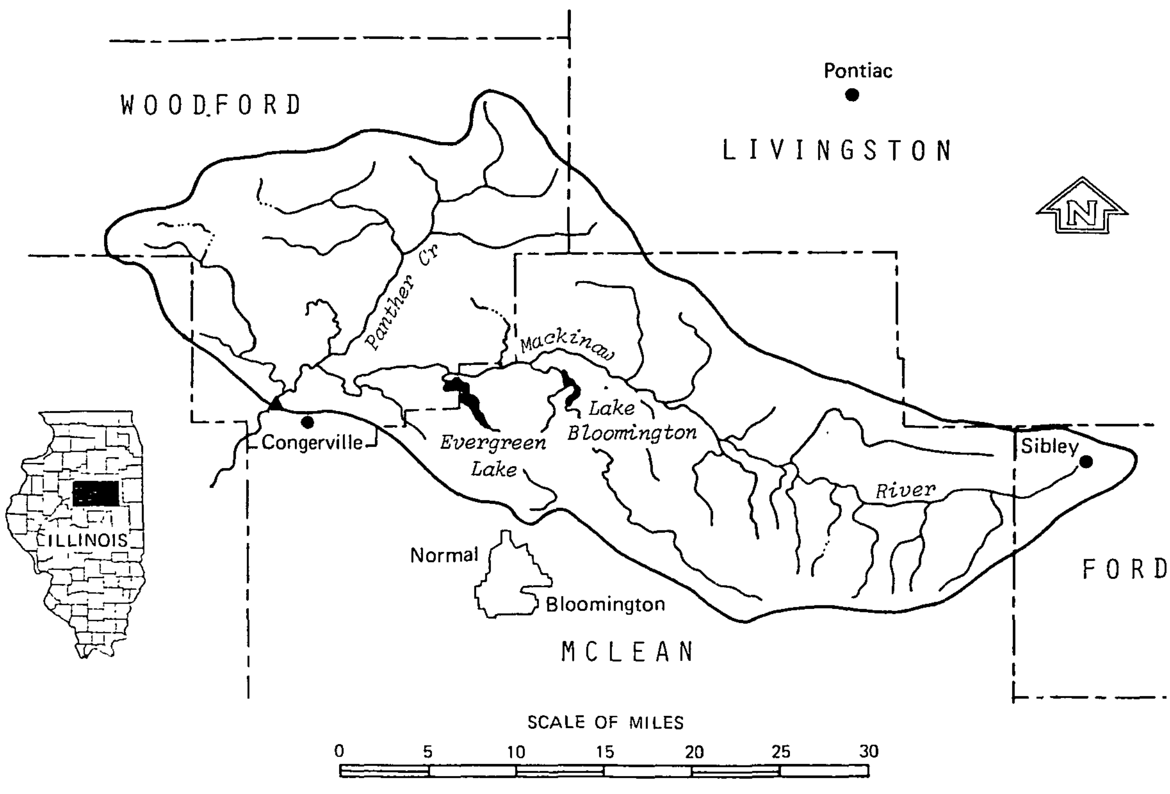

Figure 1. Basin location map.

province [Fenneman, 1914]. The topography consists of gently undulating uplands in the east and north and becomes more diverse to the west where the river is more deeply entrenched. Rolling hills are found in belts along the northeastern and southwestern boundaries of the basin.

The elevation of the land surface declines from 830 feet at the head-waters east of the Village of Sibley to about 620 feet at the gaging station 2 miles northwest of Congerville. The topographic relief seldom exceeds 20 feet per mile except in the west where land surface declines of 50 feet per ¼ mile are found along the river valley. The basin drainage system is shown in figure 1. The Mackinaw River is the principal stream that flows in a generally westward course entering the Illinois River below Pekin. Panther Creek, the major tributary, drains 177 square miles on the northern portion of the basin. Two man-made reservoirs, Lake Bloomington on Money Creek and Evergreen Lake on Six Mile Creek, collectively drain 100.4 square miles (about 13% of the total drainage area). The monthly average flow from the basin for the period of record (1945-1980) and period of study (1966-1976) are shown in figure 2.

The principal land use in the basin is farming. Urban areas comprise only 3% of the total land area and the remainder is in row crops, pastures, woodland, and farm lots. Soils in the area are derived from loess which was deposited on top of Wisconsinan age glacial till. The till varies in depth from about 2 to 10 feet. In scattered areas of limited extent the loess has been eroded and soil has developed from the exposed till. Soil permeabilities are moderately slow and often require artificial drainage (field tile) for agricultural purposes. The permeability of the materials beneath the subsoils is generally moderate to slow [Schicht and Walton, 1961].

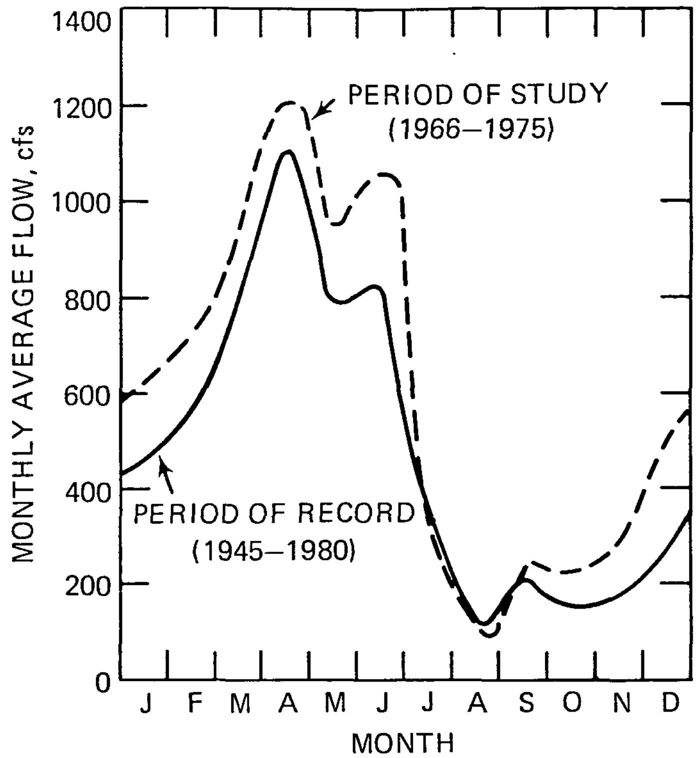

Figure 2. Monthly average discharge from basin.

The population of the basin is chiefly rural, and according to the U.S. Census Bureau [1971] the population density was about 35 persons per square mile in 1970. The populations of the 6 largest municipalities [State of Illinois, 1975] within the basin are as follows:

Municipality	1970 Population
Eureka	3,028
El Paso	2,291
Roanoke	2,040
Lexington	1,615
Pleasant Hill	1,064
Gridley	1,007

DATA BASE DESCRIPTIONS

Streamflow records in Illinois are obtained as a result of cooperative agreements between the U.S. Geological Survey, the State Water Survey, the Illinois Department of Transportation, and the U.S. Army Corps of Engineers. Mean daily streamflow values (in cubic feet per second) are recorded for approximately 200 gaging stations in Illinois. Streamflow data for the Mackinaw River near Congerville have been collected since October 1944. Data for the period October 1966 through September 1976 were used in this study.

The State Water Survey and U.S. Geological Survey have maintained a continuous program of surface water sampling and analysis since 1945. The Illinois Environmental Protection Agency began conducting chemical analyses of samples in 1968. Until 1977, monthly grab samples were collected, and in 1977 the transition was made to monthly collection of depth integrated samples. Data for this report are for grab sample analyses as presented by Harmeson and others [1973 and unpublished].

METHODOLOGY

Analyses of data for this project can be divided into two general categories: 1) comparison of base flow chemistry to historical groundwater quality in the shallow drift deposits, and 2) determination of the chemical characteristics of base flow and surface runoff. Six commonly analyzed constituents were chosen for study: total dissolved solids (TDS), hardness, sulfate, chloride, nitrate-nitrogen, and total iron.

Base Flow-Shallow Groundwater Quality Comparisons

For the purposes of this study, streamflow is assumed to consist of two components: surface runoff, or that water which reaches the stream without percolating through the soil; and base flow, or that water which infiltrates into the subsurface and later emerges as seepage into the stream.

Under this simplifying assumption, the total mineral load in the stream is the sum of that contributed by each of the two components of flow. This is described by the mass-balance equation

$$Q_T C_T = Q_B C_B + Q_R C_R \tag{1}$$

where

Q_T = total stream discharge, cfs

C_T = chemical concentration in stream water sample, mg/l

Q_B = base flow, cfs

C_B = chemical concentration in base flow, mg/l

Q_B = Q_T-Q_B = surface runoff, cfs

C_R = chemical concentration in surface runoff, mg/l

For each sampling event, Q_T and C_T are obtained from the historical flow and chemical analysis data.

For samples collected at times when the streamflow is entirely base flow, the surface runoff component is zero. Empirical relationships were determined from the chemical data for these events using stepwise multiple regression. Multiple regression analyses have been used successfully in past studies [Zison, 1980] to give insight into stream processes which control variations in water quality parameters. It has been shown in numerous investigations [Whittemore, 1978; Vendl, 1979; Visocky, 1970] that stream water quality is strongly correlated with stream discharge. In addition, long-term trends in groundwater quality in shallow aquifers in Illinois have been described [Gibb and O'Hearn, 1980]. Therefore, $\log_{10} Q_B$ and elapsed time (ET) in months beginning September, 1966 were chosen as the independent variables in the regression. The regressions were performed on the University of Illinois CYBER 175 computer utilizing the STAT statistical package. The significance of each regression was tested using the F-sta-tistic. It was also used to determine if the addition of the second variable represented a significant improvement over the previous step [Griffiths, 1967]. If no significant improvement was indicated, then the variable in question was dropped. In cases where neither variable yielded a significant relationship, the mean value for that constituent was considered the best estimate. The multiple regressions were not forced through the origin.

Characterization of base flow-surface runoff chemistry

For samples collected during storm events, it was first necessary to determine the amounts of base flow and surface runoff in the streamflow at the time of sampling. The graphical base flow separation method described by O'Hearn and Gibb [1980] was used to analyze computer-generated hydrographs of mean daily streamflow. Once Q_B was determined for a sample date, Q_R was calculated by subtraction, and C_B was estimated from the empirical relationships developed from 100% base flow events. Equation (1) can then be solved easily for C_R given Q_T, C_T, Q_B, C_B, and Q_R. When the developed regression equations for estimating C_B yielded negative values, they were set to zero. The calculated C_R values for each of the six constituents were then subjected to the same stepwise multiple regression analysis applied to the C_B values for 100% base flow events. Negative values for C_R were set to zero before the regression analysis were performed. The results of these analyses are presented in the "Results" section of this report.

After the empirical relationships describing base flow and surface runoff chemistry were determined, an attempt was made to calculate the monthly average daily concentrations and loads for each flow component and chemical constituent. Monthly average base flow values were estimated from the base flow probability curves generated for the basin in the study of groundwater discharge in Illinois streams by O'Hearn and Gibb [1980]. The median base flow at the monthly average flow was determined from the curves, and monthly average runoff was calculated by subtraction. These estimates were entered into the appropriate regression equations to determine monthly average chemical concentrations and daily chemical loads.

RESULTS

Base Flow-Shallow Groundwater Quality Comparisons

Figures 3 through 8 illustrate the general chemical quality of water from shallow (less than 50 feet deep) drift wells in the study basin [Gibb and O'Hearn, 1980]. The area-weighted averages of shallow groundwater quality in the basin also are presented in figures 3 through 8. Table 1 lists the area-weighted averages of six chemical constituents in the shallow groundwater of the basin and the 10-year average values from stream water samples collected during 100% base flow events.

Table 1. Base Flow-Shallow Groundwater Quality Comparisons

Chemical constituent	Area-weighted average of shallow groundwater (mg/l)	Average base flow quality (mg/l)
Total dissolved solids	720	441
Hardness (as $CaCO_3$)	415	359
Sulfate	119	69.9
Chloride	31.4	21.0
Nitrate	35.5	40.5
Iron	0.69	1.51

Differences between the historical shallow groundwater quality and base flow quality for the period studied may be due to instream chemical reactions. As groundwater moves out of its anaerobic environment into the aerobic environment of the stream, temperature changes, photochemical reactions, sediment-water reactions, and biological activity may cause chemical changes to occur.

The concentrations of nonreactive, or conservative, constituents (TDS, hardness, sulfate, and chloride) are higher for the 40-year median shallow

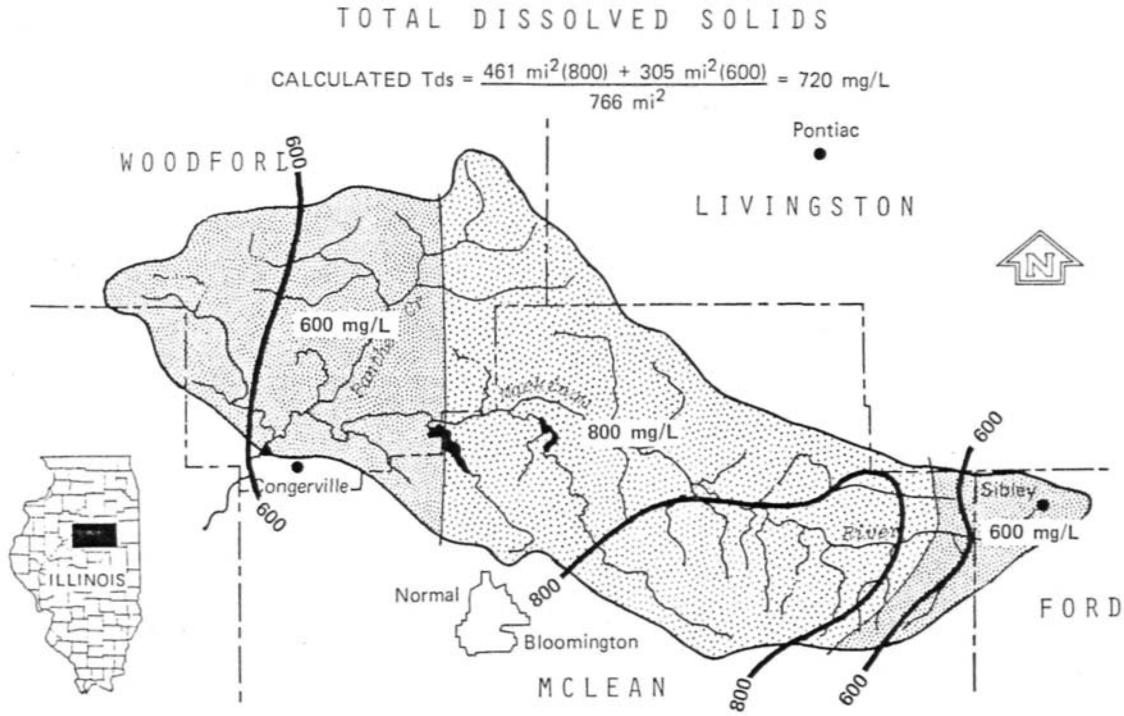

Figure 3. Shallow groundwater total dissolved solids.

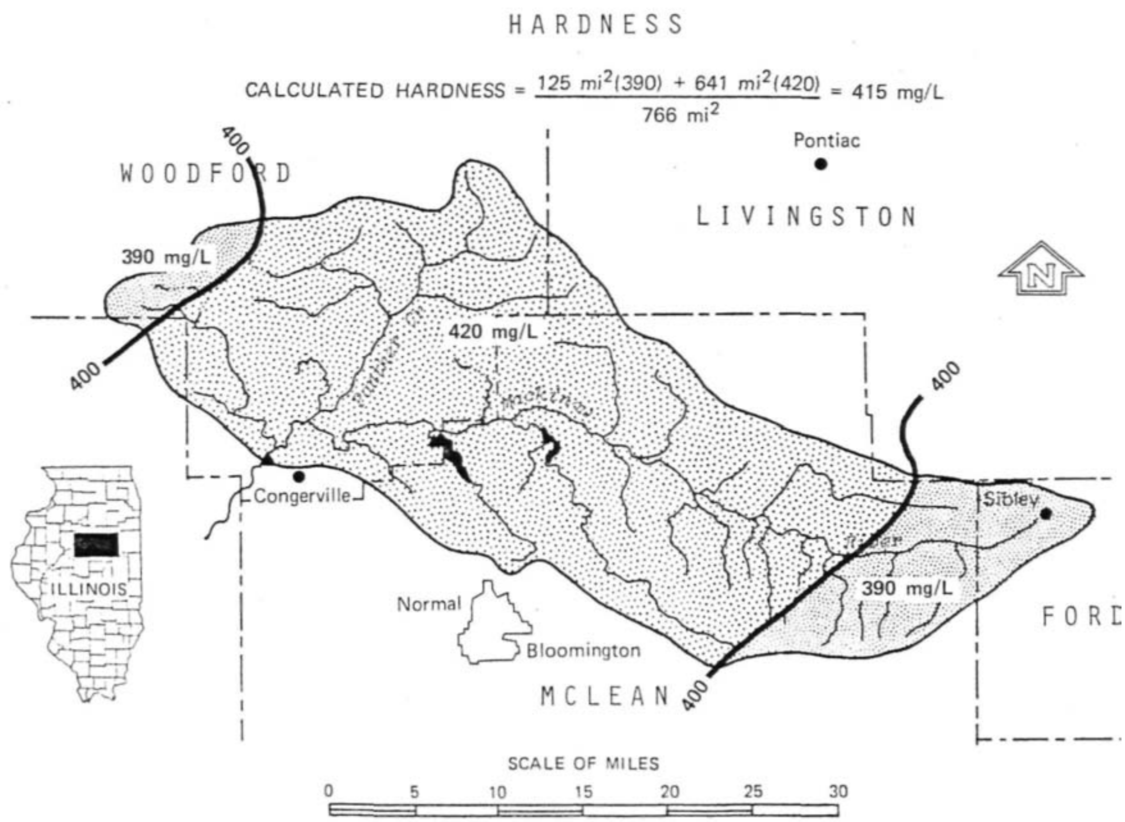

Figure 4. Shallow groundwater hardness.

SULFATE

CALCULATED $SO_4 = \dfrac{24\ mi^2(90) + 742\ mi^2(120)}{766\ mi^2} = 119$ mg/L

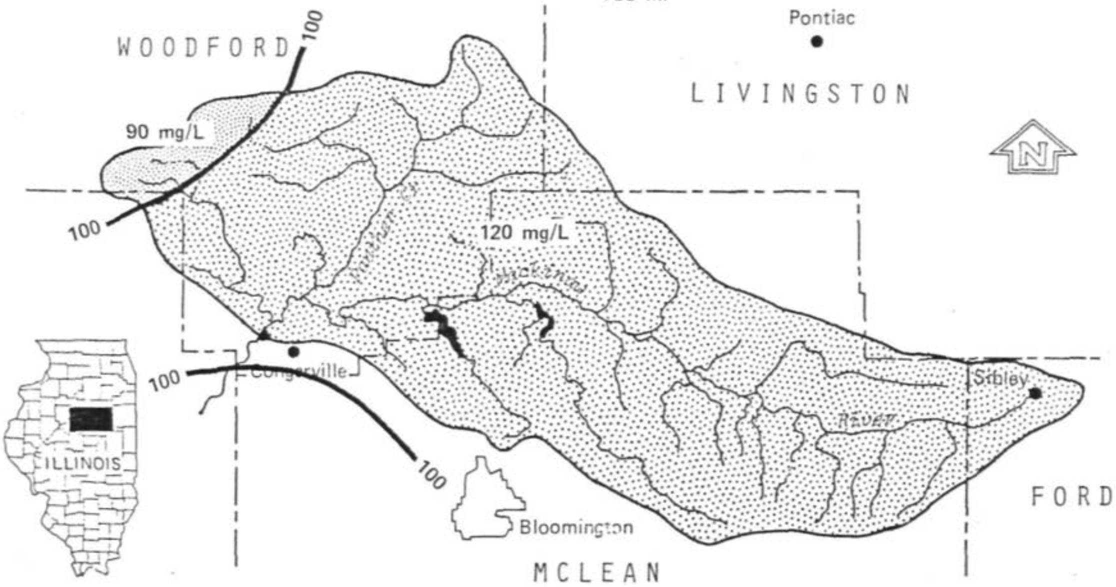

Figure 5. Shallow groundwater sulfates.

CHLORIDE

CALCULATED $Cl = \dfrac{329\ mi^2(20) + 437\ mi^2(40)}{766\ mi^2} = 3.4$ mg/L

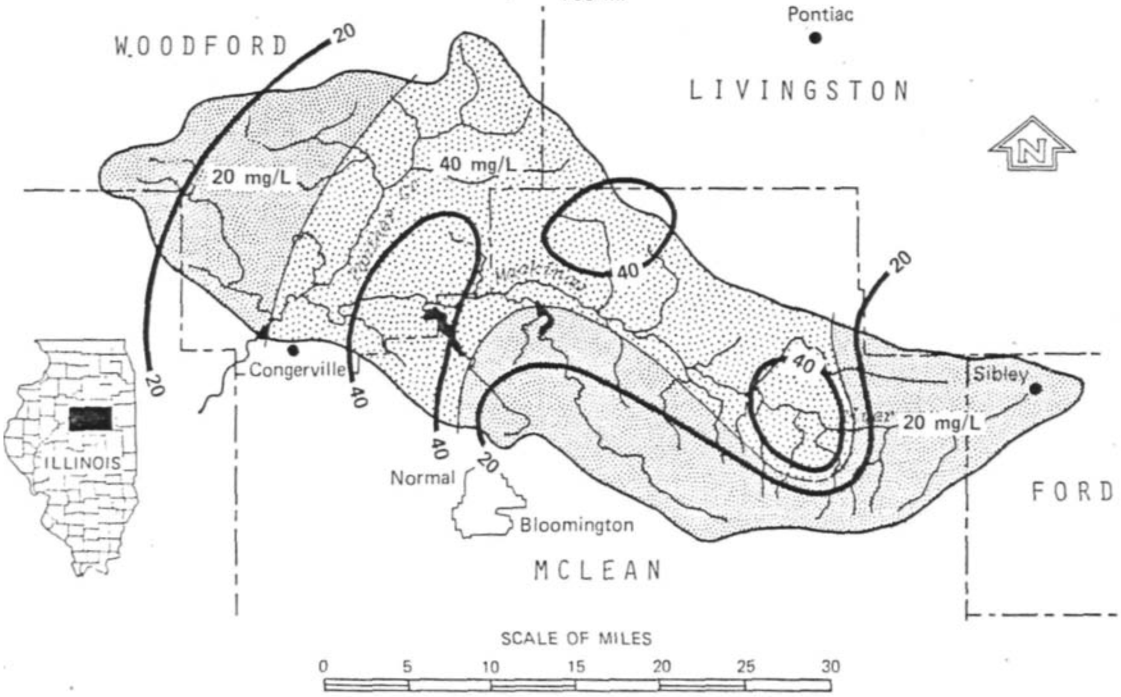

Figure 6. Shallow groundwater chlorides.

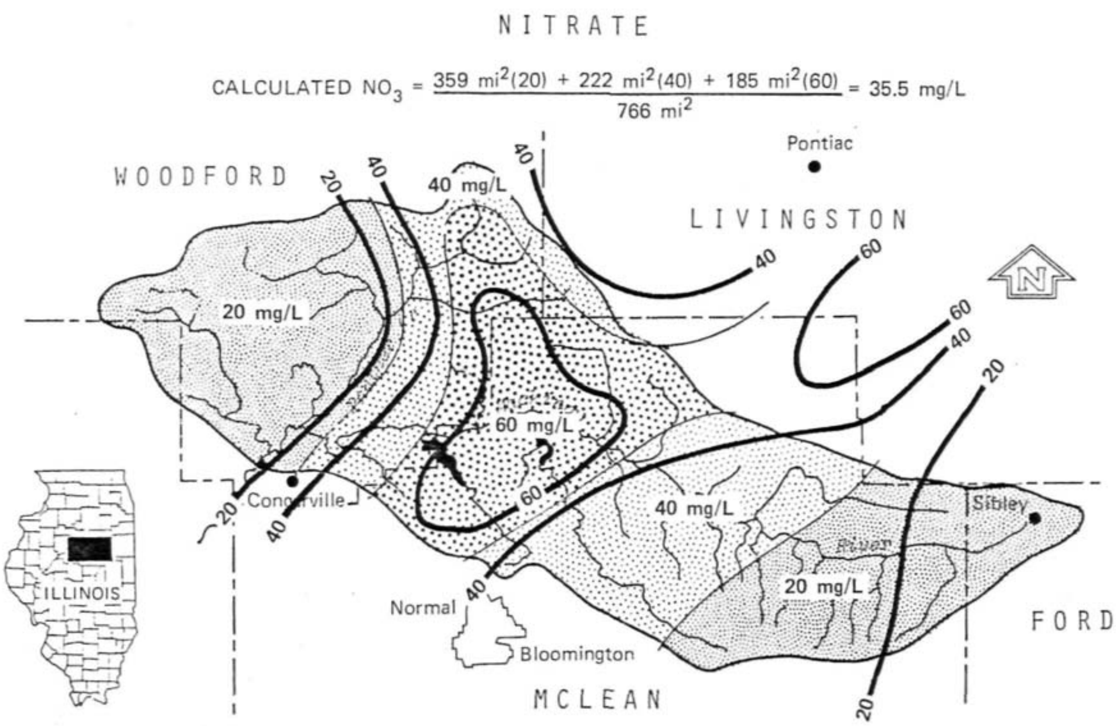

Figure 7. Shallow groundwater nitrates.

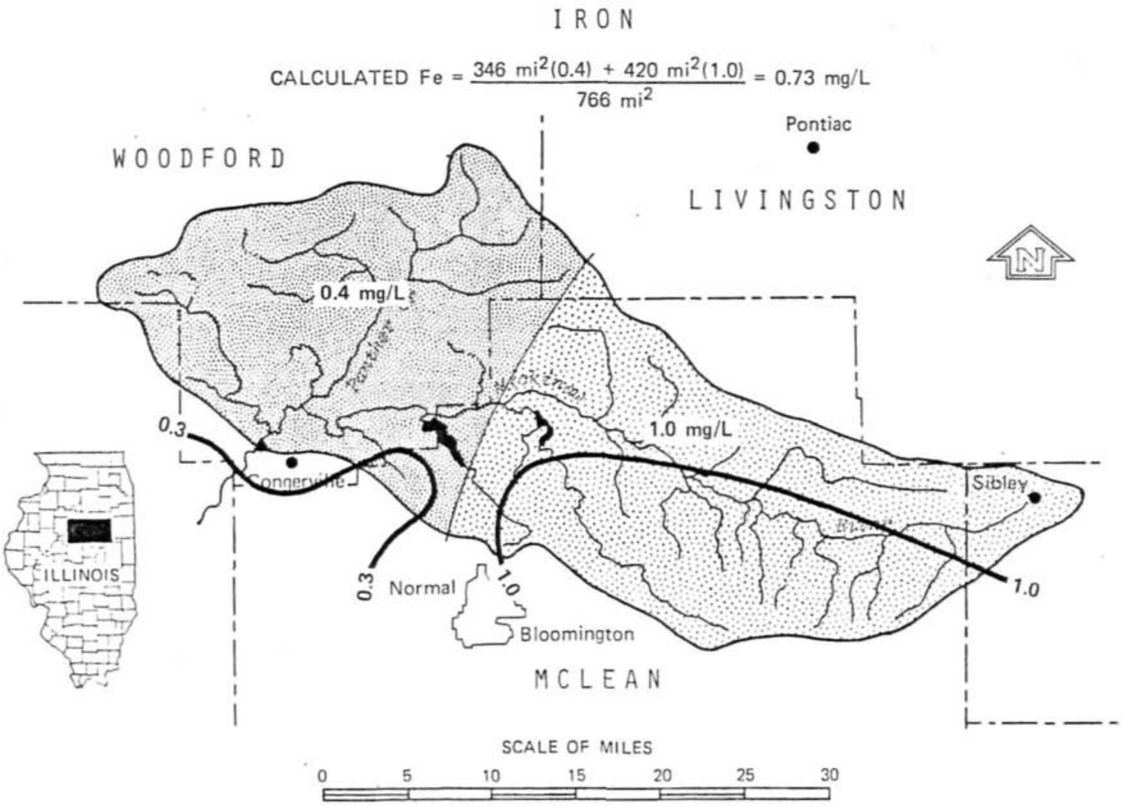

Figure 8. Shallow groundwater total iron.

groundxjater values than in the base flow. The shallow groundwater quality information for the basin is based on samples from wells that range from about 25 to 50 feet deep. Therefore, the area-weighted averages represent the quality of groundwater at those depths. The entrenchment of the streams draining the basin generally ranges from 1 or 2 feet in the upland portions of the watershed to about 50 feet near the gaging station. Most of the groundwater contributed to the streams of the basin to form base flow probably doesn't penetrate to the 25-to 50-foot depths. It therefore doesn't become as highly mineralized, which may account for the differences in these comparisons. The discharge of shallow groundwater would most likely occur during periods of high groundwater levels and, therefore, higher base flows.

The average nitrate and total iron values for the base flow are higher than that of the shallow groundwater. The nitrates probably are the result of agricultural fertilizer applications and subsequent discharge through field tile drainage. The higher total iron concentrations in the base flow samples may result from the collection and acidification of suspended soil particles in the surface water samples.

Base Flow Water Quality Characteristics

Stepwise multiple regressions were performed on the chemical data for samples collected at times when streamflow was composed entirely of base flow. The independent variables were $\log_{10}$ of base flow ($\log_{10} Q_B$) in cfs and elapsed time (ET) in months from September 1966 to the date of sample collection. The information from this analysis was used to determine the best estimator of base flow quality for use in determining surface runoff concentrations during storm events.

Figures 9 through 14 represent the base flow chemical-flow data and the respective regression equations or average values for the six chemical constituents of interest. No significant relationships were found for TDS, hardness, or total iron. Therefore, average values (see table 1) were used when estimating base flow concentrations during storm events. Significant relationships were found for chloride and nitrate versus $\log_{10}$ of base flow. The following equations show the developed relationships where chemical concentrations are expressed in mg/l and the base flow (Q_B) is in cfs.

$$Cl = 31.2 - 4.38 \ (\log_{10} Q_B) ; \ N = 63 \qquad (2)$$

$$NO_3 = -36.3 + 32.6 \ (\log_{10} Q_B) ; \ N = 63 \qquad (3)$$

Both are significant at the 95 percent level [Arkin and Colton, 1963; p. 24].

Equation (2) shows that there is an inverse relationship between chloride and base flow. That is, as the quantity of base flow decreases, the chloride concentration increases. It seems plausible that as the quantity of base flow decreases, the groundwater discharged to the stream would be derived from deeper or more distant sources. Because of its longer residence time in the ground, the deeper water would contain more chlorides. It is also possible that dilution of point source chloride loads by groundwater is reduced.

The opposite is true for nitrate-nitrogen. Equation (3) suggests that higher nitrate values are associated with higher base flows. The limited depth of nitrate-nitrogen movement into the soil profile and underlying deposits has been documented by numerous researchers [Davenport and others, 1973; Duke and others, 1977]. Therefore, it is reasonable that the higher

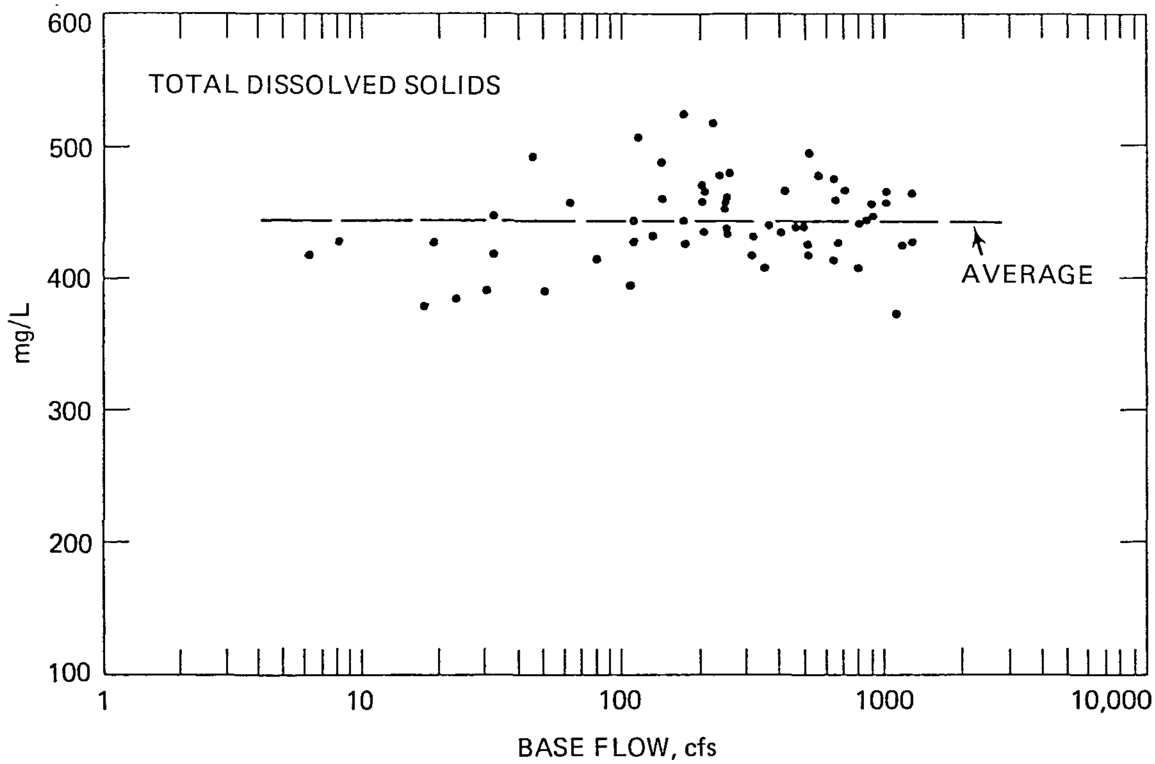

Figure 9. Base flow-chemical data relationship for total dissolved solids.

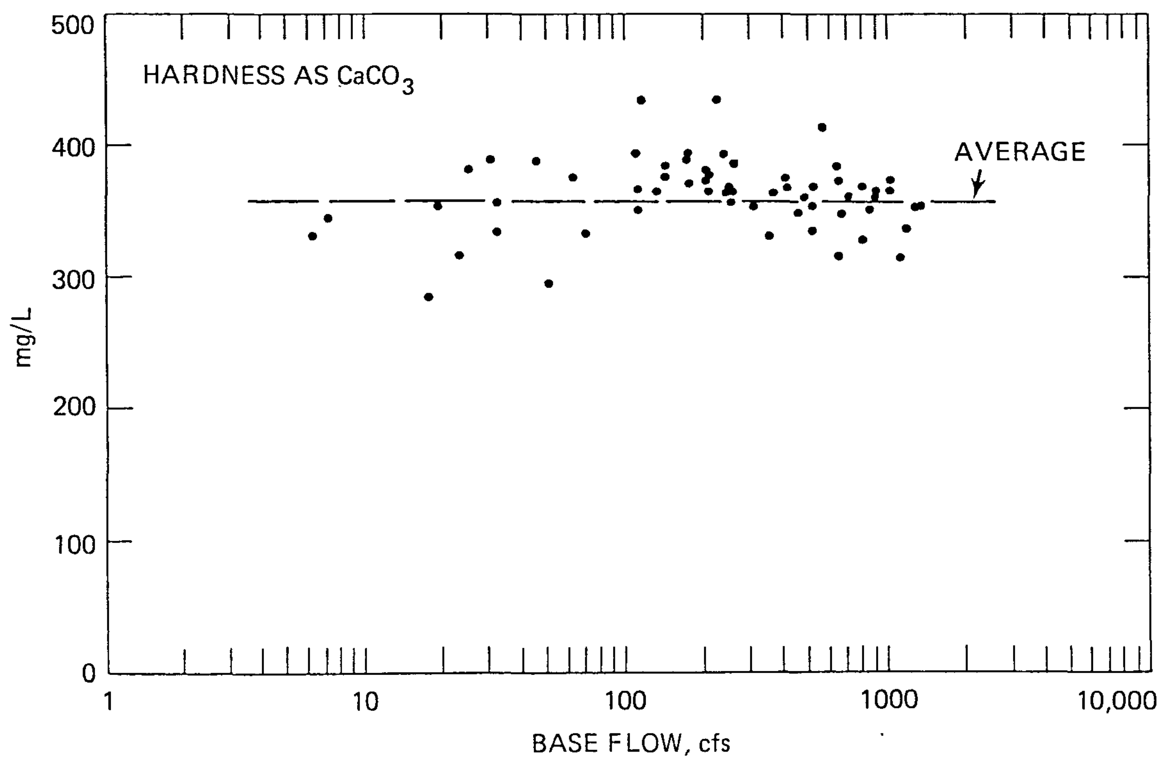

Figure 10. Base flow-chemical data relationship for hardness.

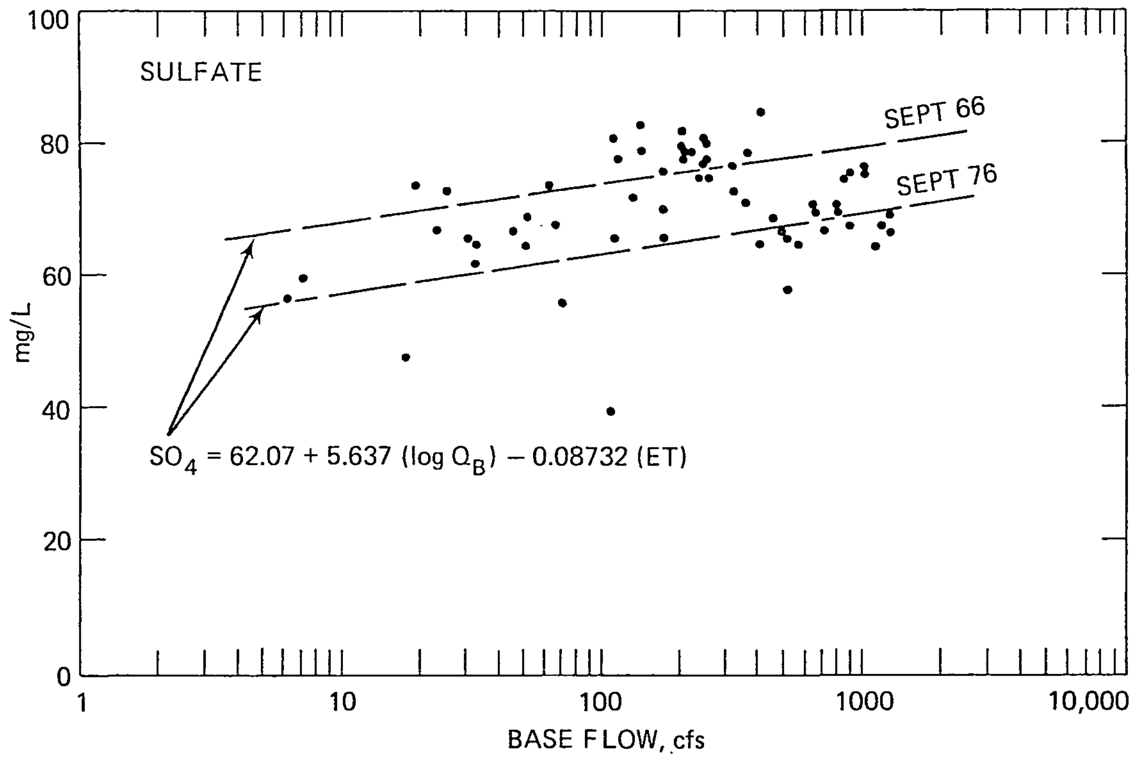

Figure 11. Base flow-chemical data relationship for sulfate.

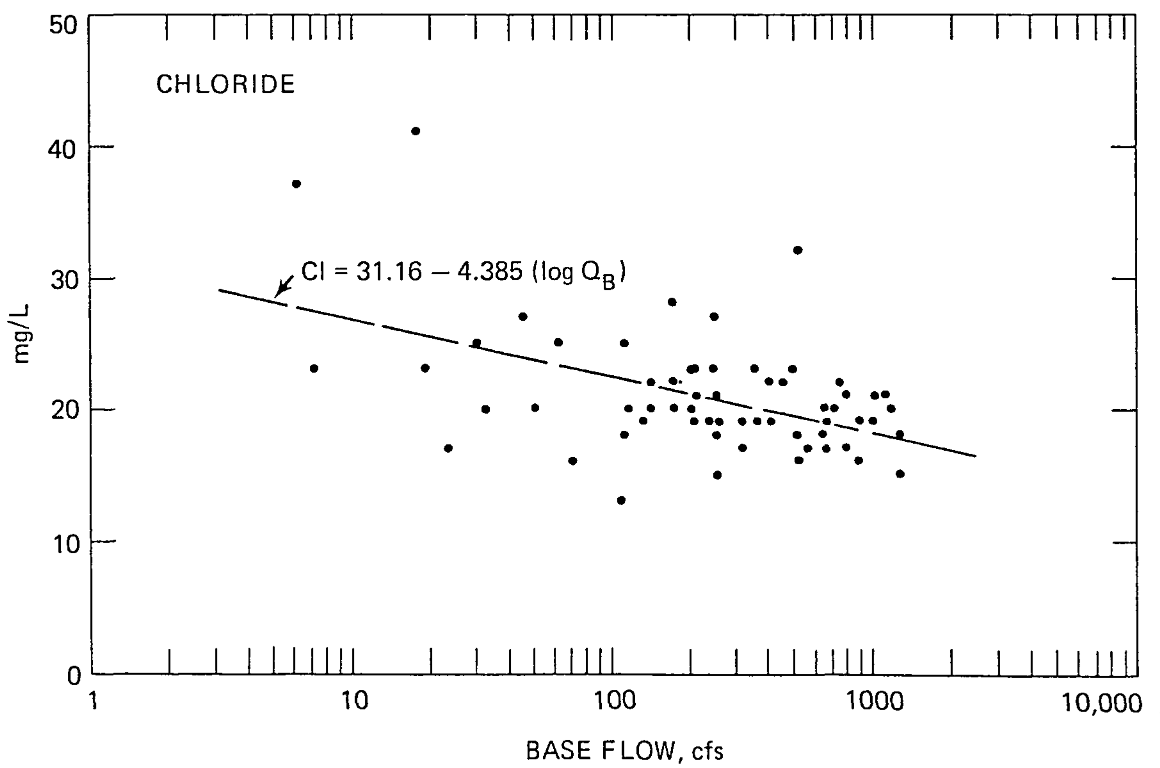

Figure 12. Base flow-chemical data relationship for chloride.

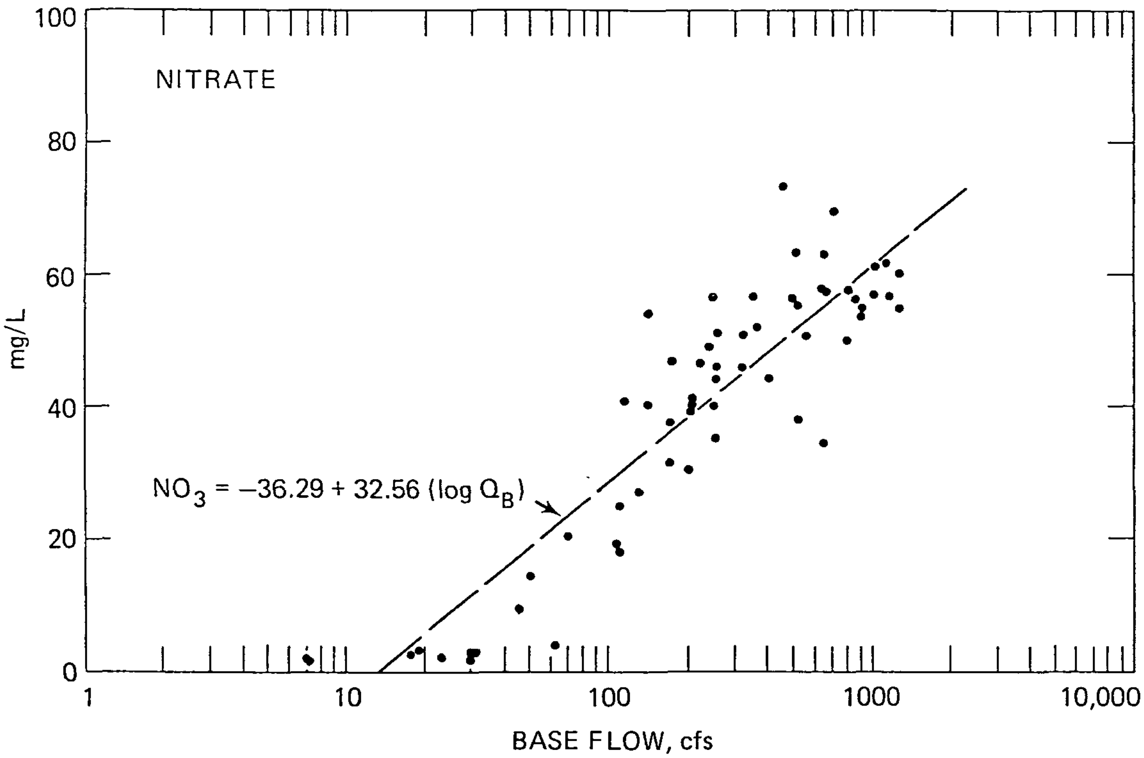

Figure 13. Base flow-chemical data relationship for nitrate.

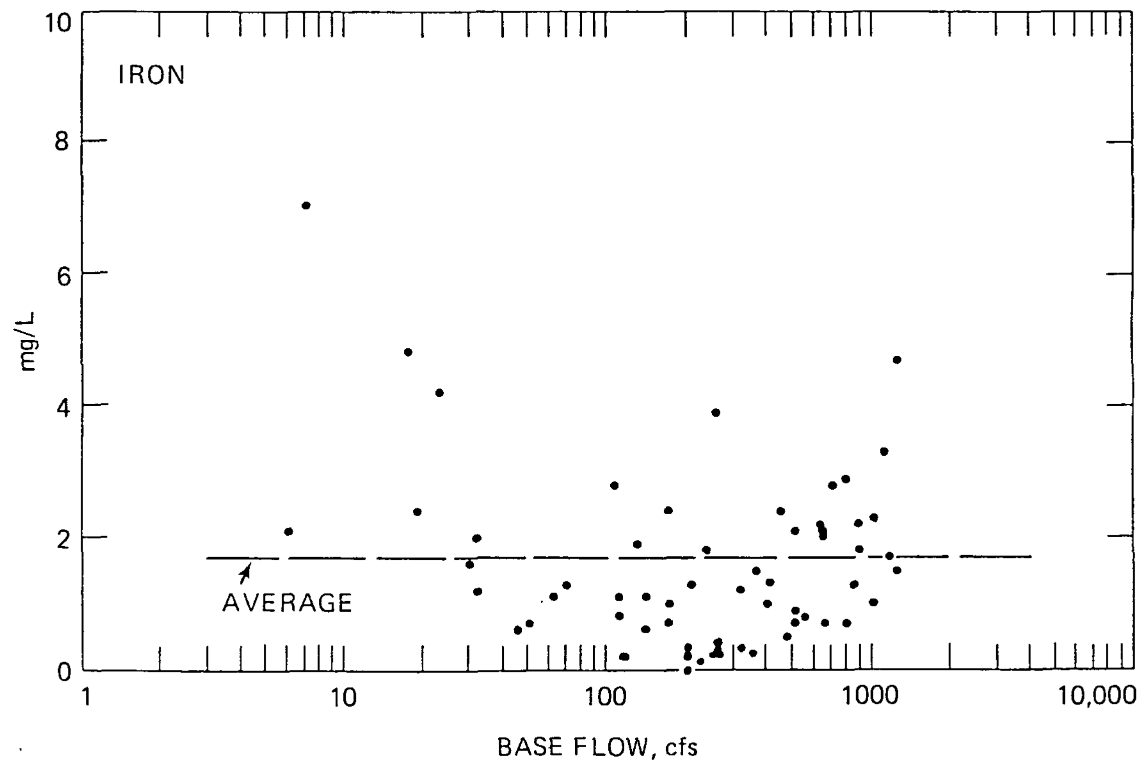

Figure 14. Base flow-chemical data relationship for total iron.

nitrate concentrations should be noted when base flows are large and proportionally more groundwater is discharged from the shallower soil zones. A greater contribution of nitrates from field tile drainage also is likely during higher base flow events.

A relationship was found for sulfate versus $\log_{10} Q_B$ and elapsed time in months (ET), since the beginning of the time period covered by the study as shown in equation (4).

$$SO_4 = 62.1 + 5.64 \ (\log_{10} Q_B) - 0.0873 \ (ET); \ N = 63 \qquad (4)$$

This relationship was found to be significant at the 95 percent level [Arkin and Colton, 1963].

Equation (4) shows that the sulfate concentrations in base flow water samples have been declining at an average rate of about 0.087 mg/l per month or about 1.04 mg/1 per year since October 1966. This decreasing trend in base flow sulfate content infers a similar trend in the sulfate content of the shallow groundwater of the basin. The most likely cause of this trend is the shift away from the use of ammonium sulfate fertilizers and toward the increased use of anhydrous ammonia [Morgan, 1978]. This is discussed later as it relates more directly to the sulfate content in surface runoff waters of the basin.

Equation (4) also shows that as the quantity of base flow increases the sulfate content increases. This suggests that the sulfate concentrations in the shallower soil zones are higher than in the deeper units. Slow downward migration of sulfates from agricultural fertilizer applications and atmospheric deposition could account for this gradation in groundwater sulfate content. Flemal [1978] and Gatz [1979] have discussed the problems associated with quantifying the atmospheric deposition of sulfates. However, both conclude that atmospheric deposition is probably a significant source of sulfates. As the sulfates are scavenged by precipitation and fall on the basin in the form of acid rain or sulfuric acid, the acid is neutralized by calcium carbonate in the soil. As the rain percolates into the soil profile, calcium sulfate is precipitated and filtered by the soil matrix preventing its migration into underlying groundwater systems. Data from this study suggest that the application of agricultural fertilizers was a more significant source of sulfates than atmospheric deposition.

Surface Runoff Water Quality Characteristics

To examine the relationships between surface runoff (Q_R) and variations in chemical concentration (C_R) with flow and time, data from samples collected during storm events were analyzed. First, base flow separations were performed for each event to quantify Q_B and Q_R. Once Q_B and Q_R were estimated, the long-term average values for TDS, hardness, and total iron and the regression equations developed for base flow chloride, nitrate, and sulfate were used to determine the quality (C_B) of the base flow component. These values were applied to the mass-balance equation (1), and corresponding surface runoff concentrations (C_R) were determined for each event. Stepwise multiple regression analysis was performed on the surface runoff concentrations to determine their relationships to surface runoff (Q_R) and elapsed time (ET).

Figures 15 through 20 present the surface runoff chemical-flow data and the respective regression equations or average values for the six chemical constituents of interest. No significant relationships were noted for hardness, chlorides, or nitrates. Average values of 330, 18.8,

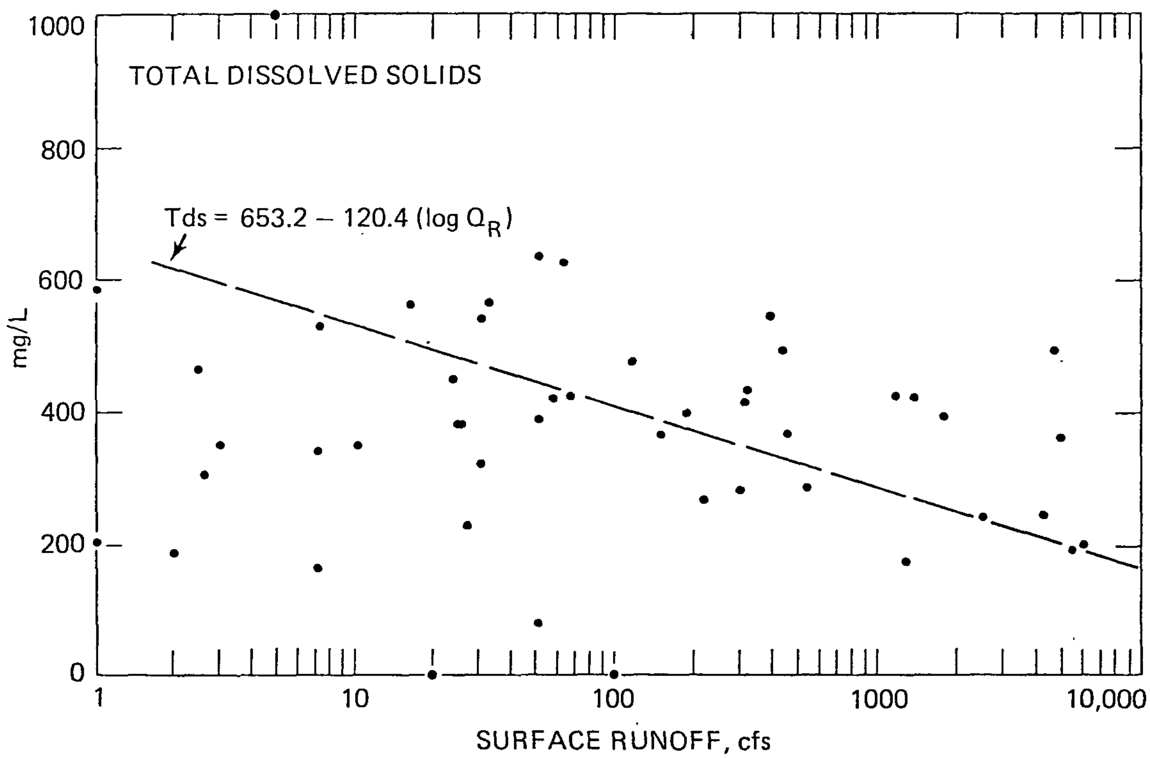

Figure 15. Surface runoff-chemical data relationship for total dissolved solids.

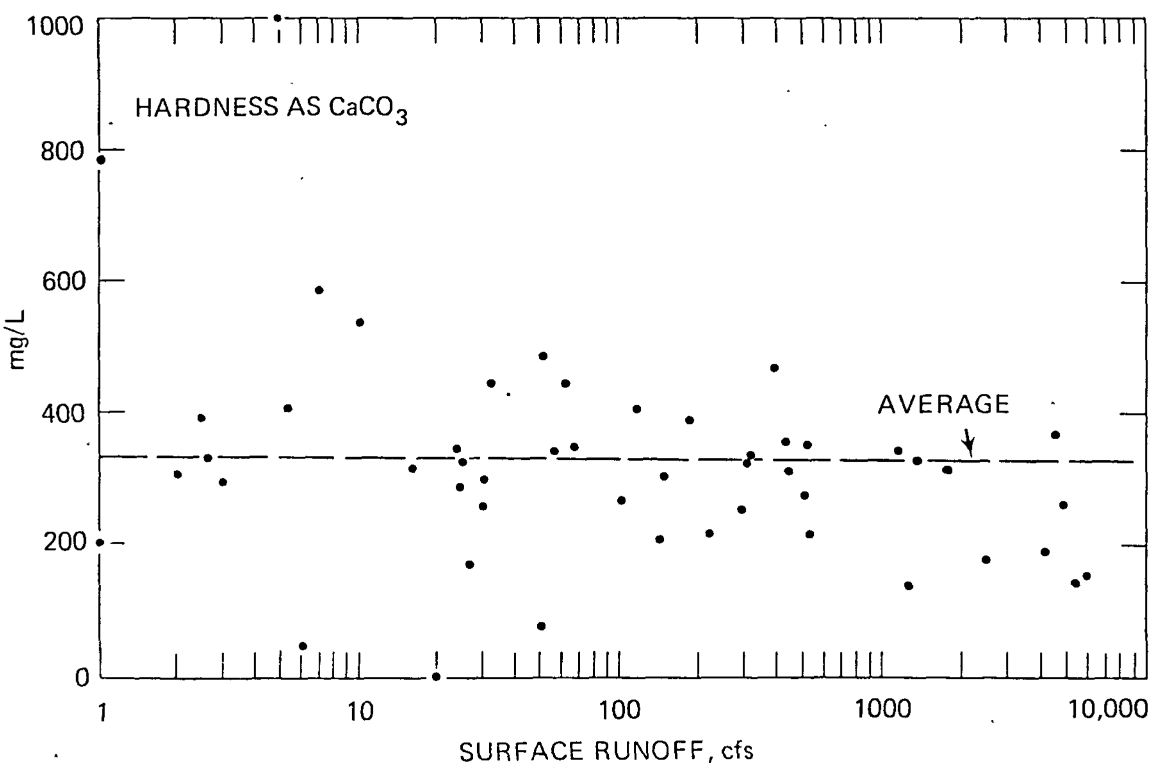

Figure 16. Surface runoff-chemical data relationship for hardness.

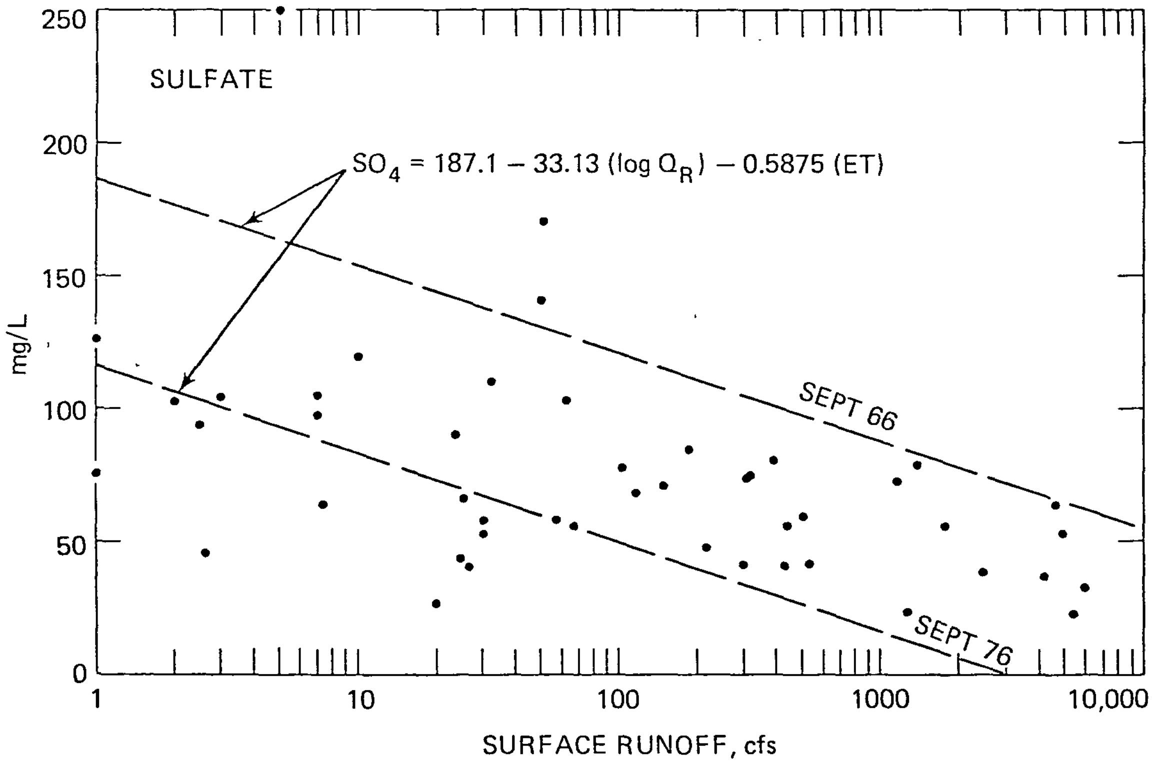

Figure 17. Surface runoff-chemical data relationship for sulfate.

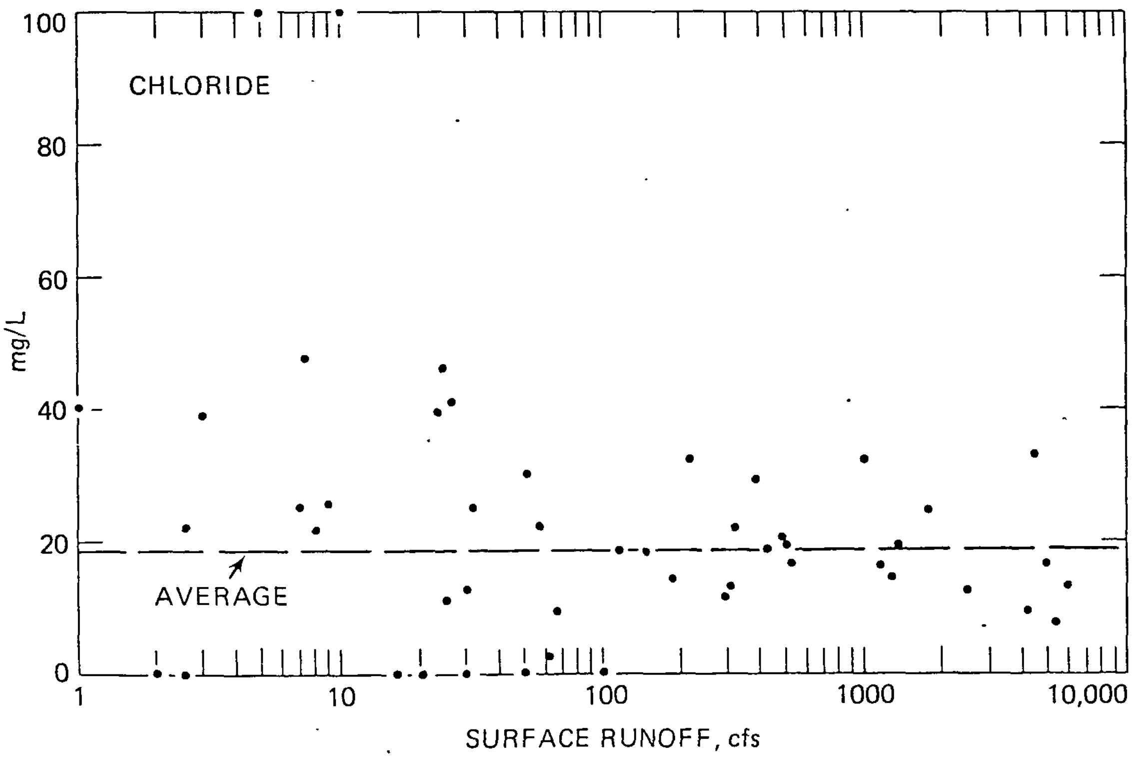

Figure 18. Surface runoff-chemical data relationship for chloride.

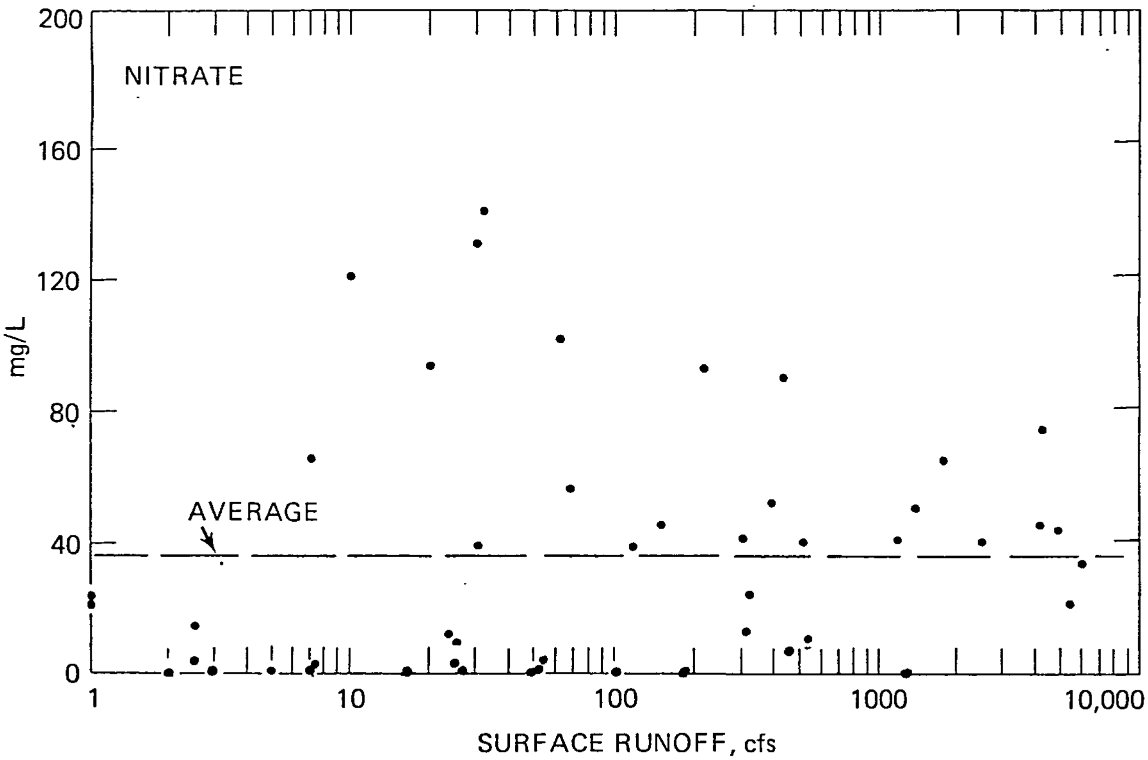

Figure 19. Surface runoff-chemical data relationship for nitrate.

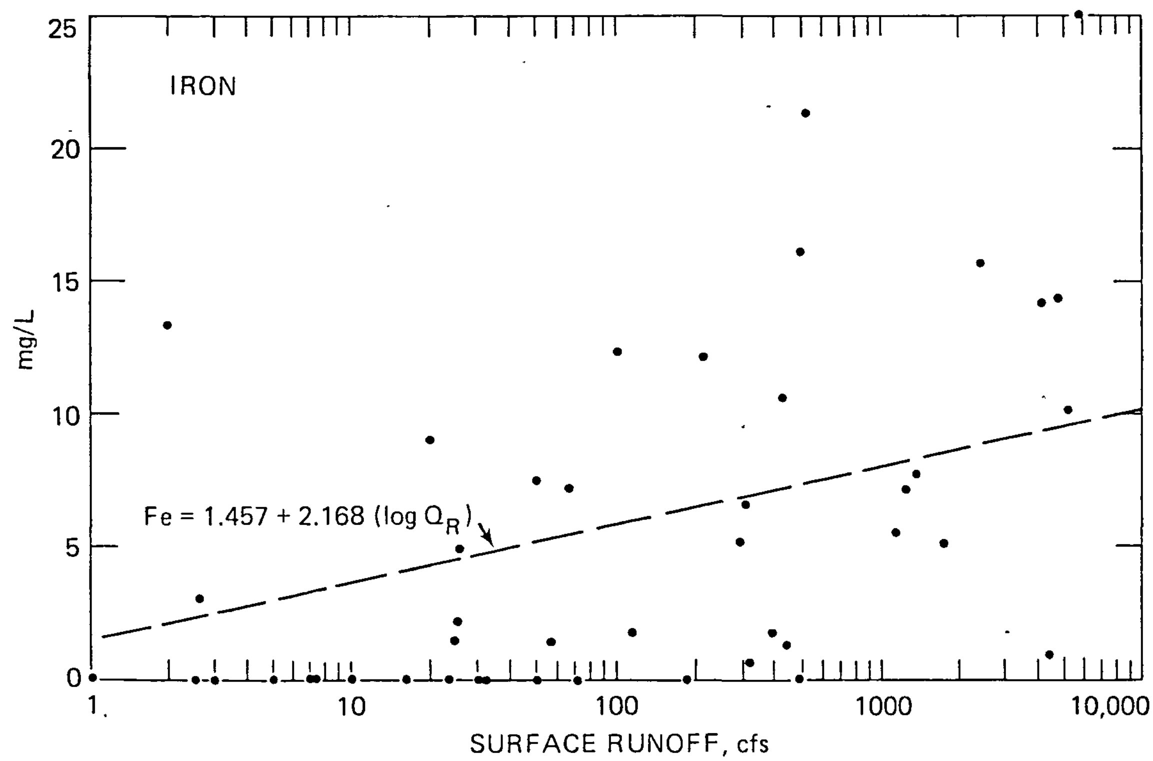

Figure 20. Surface runoff-chemical data relationship for total iron.

and 36.5 mg/1, respectively, were calculated. Relationships for $\log_{10}$ of Q_R versus TDS and iron concentrations (mg/1) in the runoff water were determined from the regression analysis.

$$TDS = 653 - 120 \ (\log Q_R) ; \ N = 49 \quad (5)$$

$$Fe = 1.46 + 2.17 \ (\log Q_R) ; \ N = 49 \quad (6)$$

Both relationships were found to be significant at the 95 percent level.

Equation (5) shows that as the amount of surface runoff increases, the dissolved mineral content decreases. • Because surface runoff is generally less mineralized than base flow, an increase in the proportion of surface runoff results in dilution of the channel water. In addition, higher flows are likely to follow periods of substantial precipitation which would leach the soluble salts from the upper soil zones or transport it to the stream via surface runoff. Thus, a reduced amount of readily dissolved minerals on the soil surface would probably be correlated with higher precipitation and higher flows.

Equation (6) shows a rather dramatic direct relationship between surface runoff iron concentrations and surface runoff quantities. Vendl [1979] found similar results in four basins he studied. As noted by Vendl, iron which enters the stream from groundwater typically is in the soluble ferrous state. As it reaches the stream it becomes oxidized and if stream velocities are low, the ferric iron precipitates accumulate on the stream bottom. Then, during larger flow events (higher velocities) the precipitated iron and iron rich sediments are resuspended and greatly elevate the iron concentrations.

Relationships also were found for sulfate versus $\log_{10}$ of surface runoff (Q_R) and elapsed time since the beginning of the study period (ET).

$$SO_4 = 187 - 33.1\ (\log_{10} Q_R) - 0.594\ (ET);\ N = 49 \quad (7)$$

This relationship was found to be significant at the 95 percent level.

Equation (7) shows an inverse relationship for sulfate versus ET and $\log_{10} Q_R$. The decreasing trend in surface runoff sulfate concentrations probably is due to the change in agricultural fertilizer practices noted earlier. The shift from ammonium sulfates to anhydrous ammonia appears to have created a larger effect on surface runoff sulfate values than on base flow sulfate (7.1 mg/l per year as compared to 1.04 mg/l per year for base flow). This is not surprising considering the mechanisms that tend to hold the sulfates near the surface.

Additionally, the inverse relationship of sulfate versus surface runoff suggests that as surface runoff increases, the relative amount of sulfates delivered to the stream decreases. Intuitively, a slight increase in sulfates may have been expected with increasing surface runoff. This may in fact be experienced in relatively small runoff events but the data used in this report were not detailed enough to either verify or discredit such a theory. During larger surface runoff events, dilution of surface runoff by rainwater and the relatively slow mobilization of sulfates from the surface soils and debris appear to be the controlling factors.

For the purpose of exploring seasonal effects on base flow and surface runoff chemical concentrations, figures 21 through 26 are presented. No significant seasonal trends are noted in the base flow or surface runoff concentrations for TDS or hardness (figures 21 and 22).

Figure 23 shows a general decrease in surface runoff sulfate concentrations during the summer months. This is in conflict with the developed regression equation for surface runoff sulfate concentrations (equation (7)).

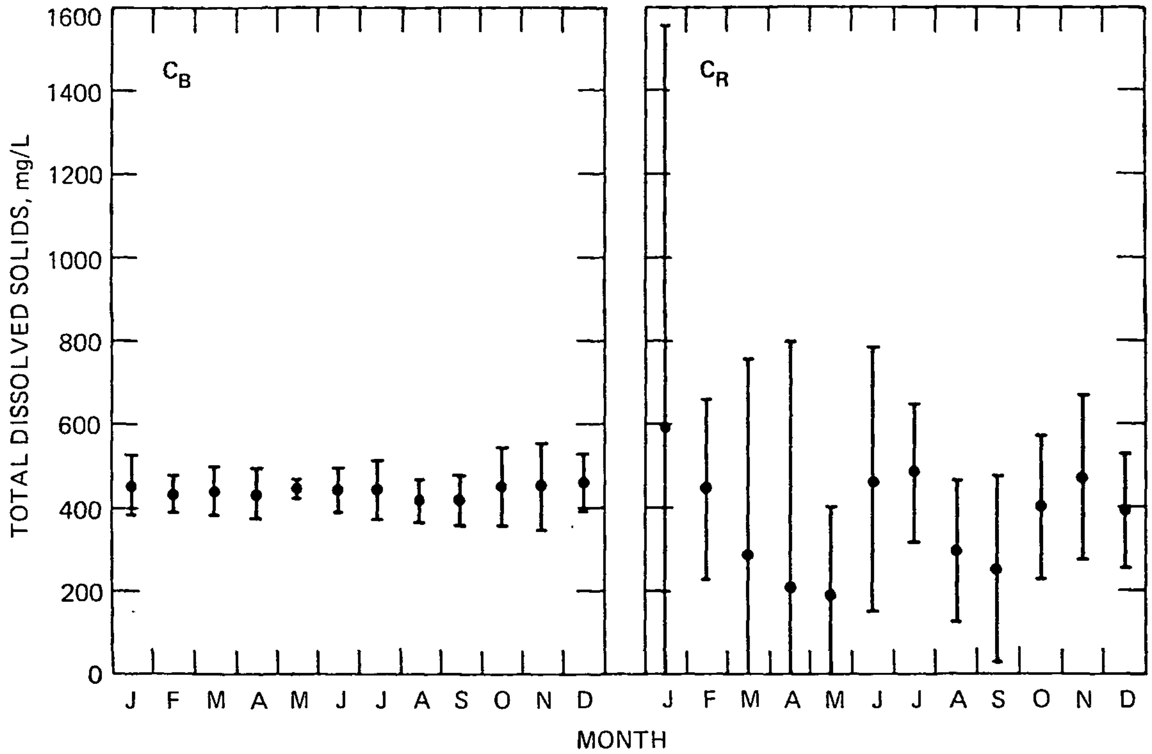

Figure 21. Monthly average total dissolved solids concentrations in base flow and surface runoff.

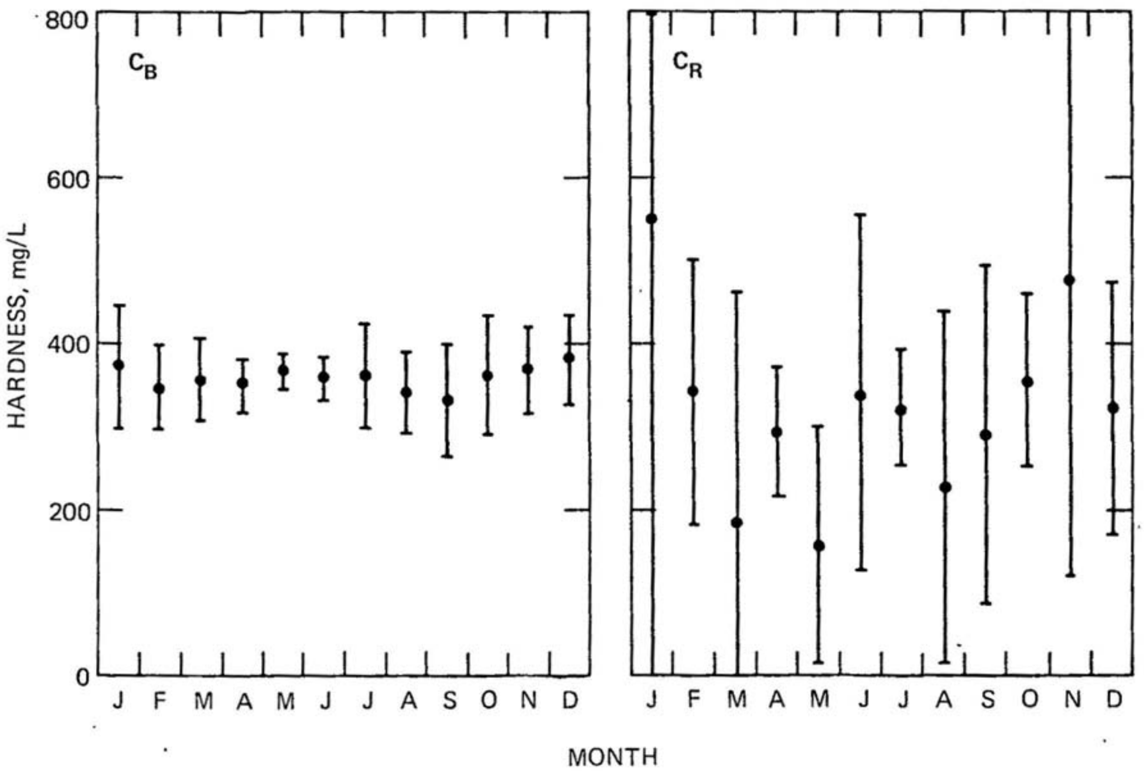

Figure 22. Monthly average hardness concentrations in base flow and surface runoff.

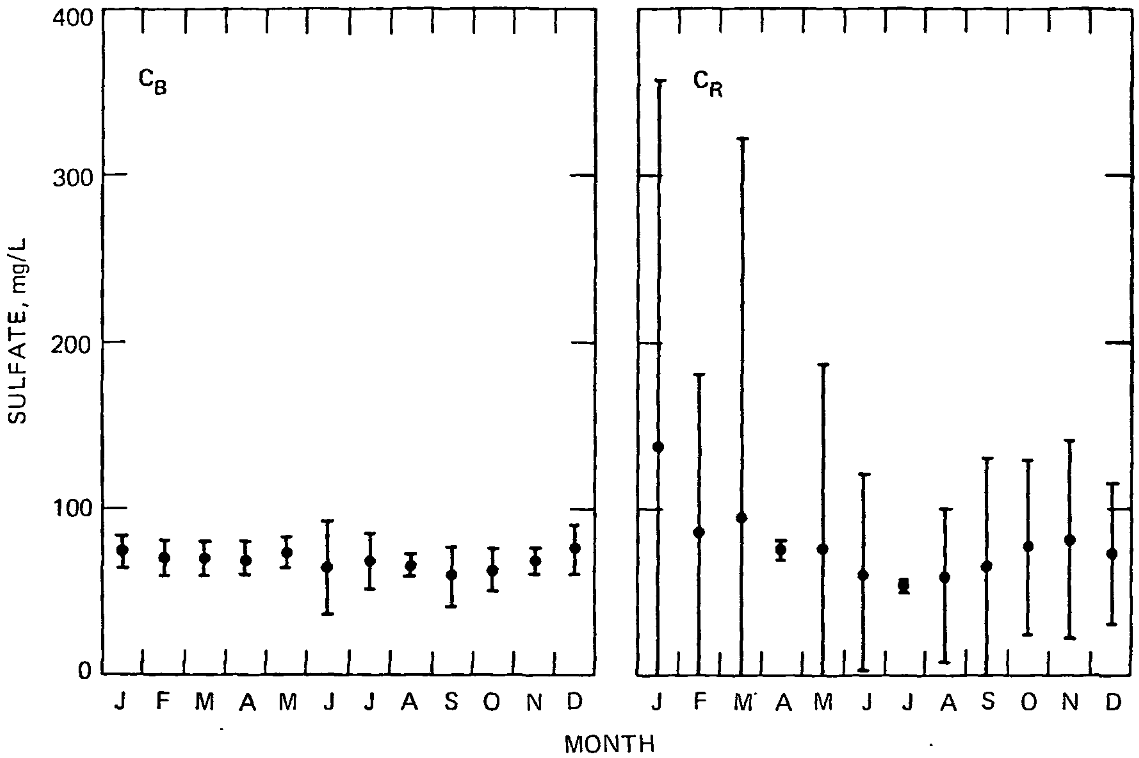

Figure 23. Monthly average sulfate concentrations in base flow and surface runoff.

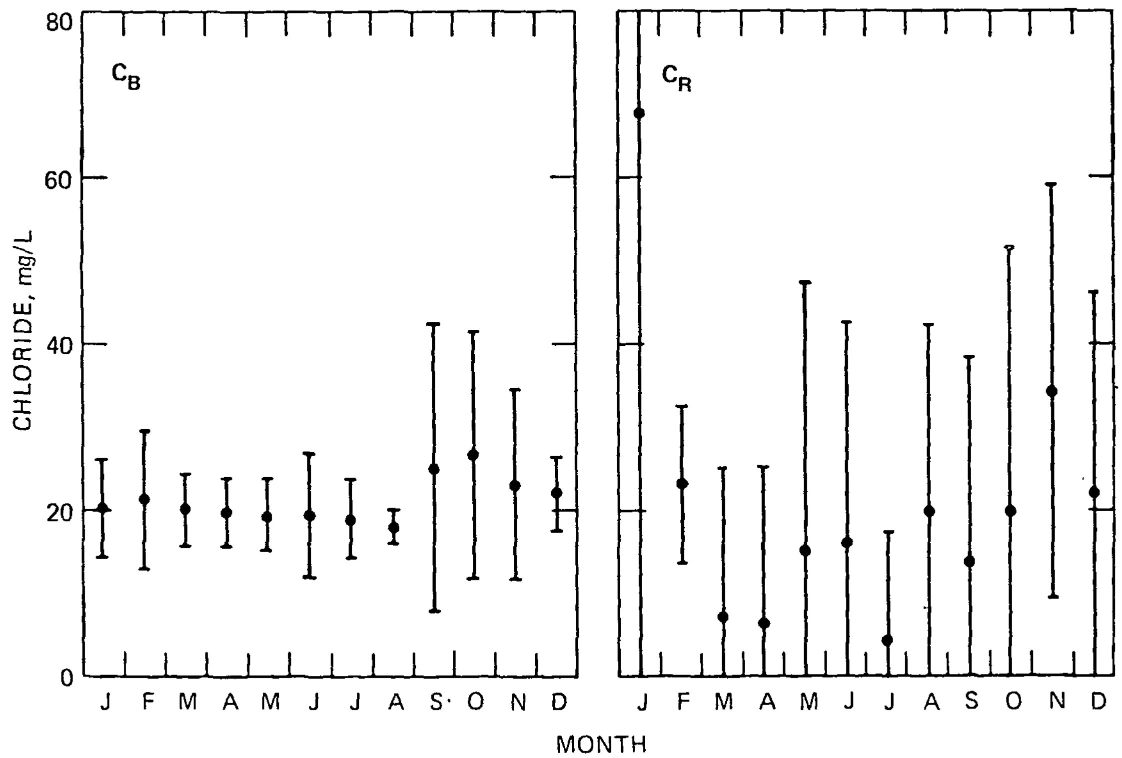

Figure 24. Monthly average chloride concentrations in base flow and surface runoff.

The lower total flows and surface runoff values encountered during the summer months should have resulted in higher surface runoff sulfate concentrations. However, since the most significant source of sulfates in the basin appears to be from agricultural fertilizers, the availability of sulfates during the summer months would be limited. Early spring and late fall applications of fertilizer generally are practiced in the basin.

Figure 24 illustrates slightly higher chloride concentrations for both base flow and surface runoff during the winter months, November through February. These elevated values probably are the result of highway deicing salt applications on the major highways and roads in the basin.

Figure 25 illustrates the seasonal variations in nitrate concentrations for both base flow and surface runoff. The base flow variations can probably be explained by the contribution of tile drainage to base flow during the wetter parts of the year. During the dry summer months, very little contribution is obtained from tile drainage and the nitrate concentrations are therefore smaller. The nitrate concentration variations in the runoff can be related to the available nitrate (time of application) and size of runoff events (effective dilution). Early spring and late fall applications of nitrogen fertilizer and the increased size of runoff events from November through June would both contribute to increased nitrate concentrations during this period.

Figure 26 illustrates the seasonal variation in iron concentrations for base flow and surface runoff. The large monthly variations in surface runoff iron concentrations can be explained by the size of individual runoff events and the preceding streamflow conditions. After prolonged periods of low flows, an accumulation of iron precipitates on the stream bottom from

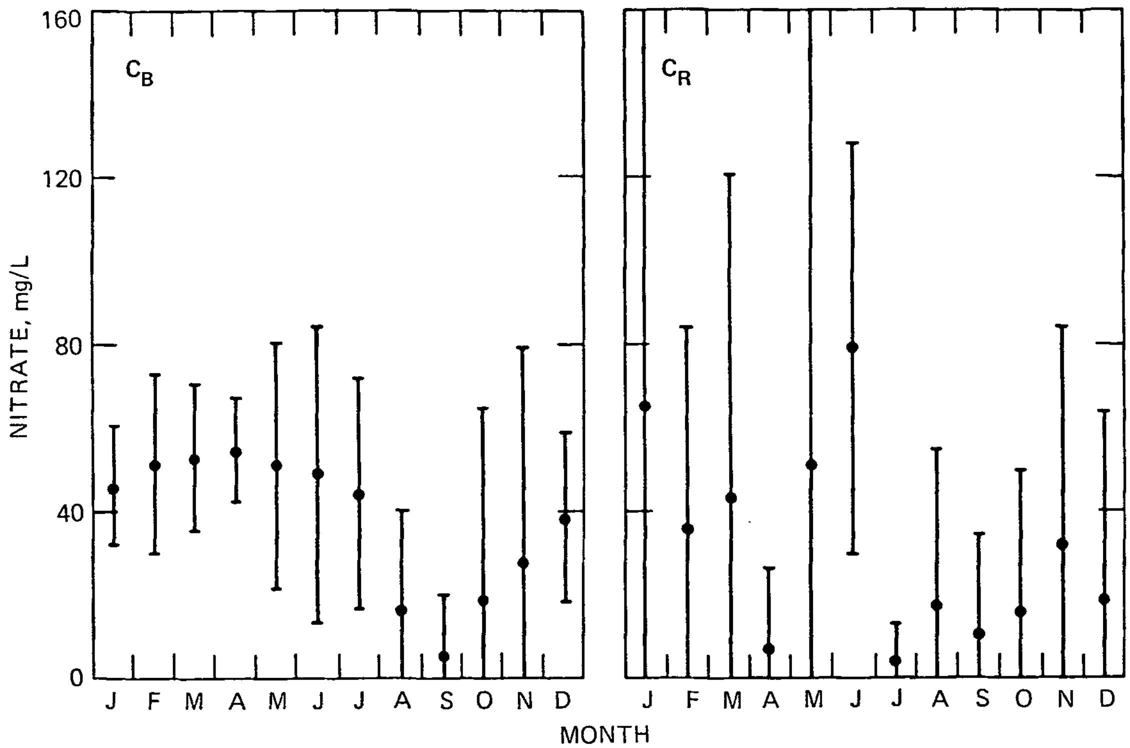

Figure 25. Monthly average nitrate concentrations in base flow and surface runoff.

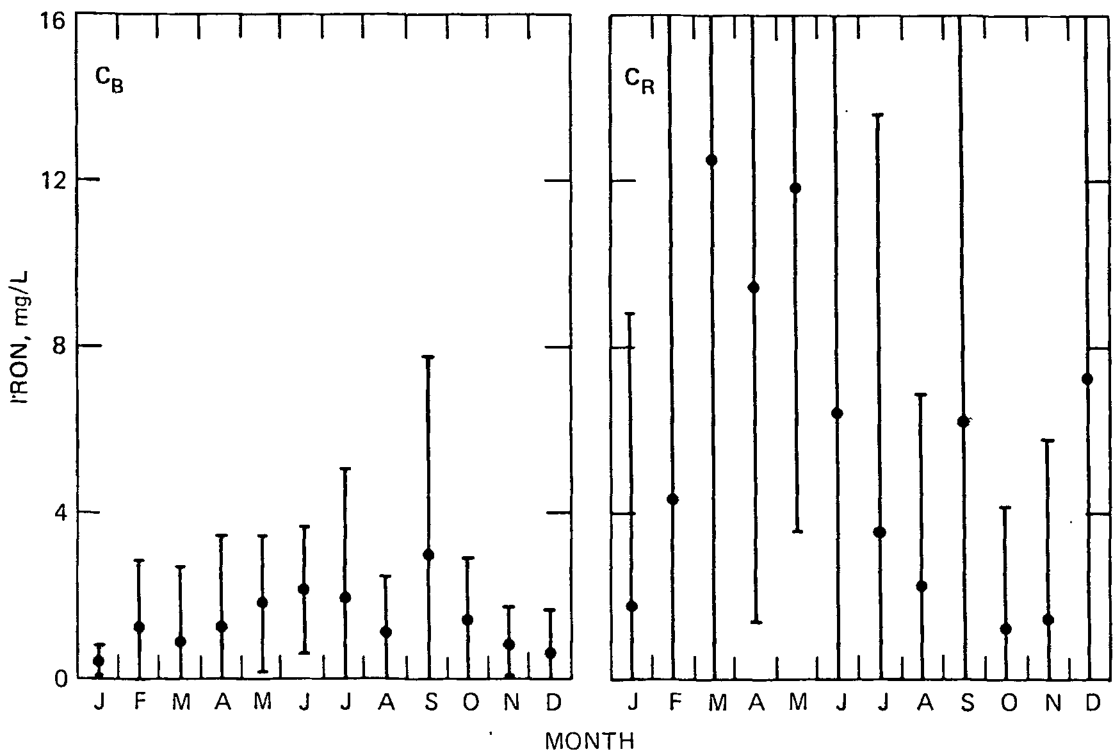

Figure 26. Monthly average total iron concentrations in base flow and surface runoff.

infiltrating groundwater will be available for resuspension during later runoff events. Erosion of high iron-content soils into the stream by surface runoff during large flow events also would contribute iron to the surface runoff.

<u>Chemical Loading Characteristics</u>

The developed relationships provide insight into the sensitivity of various chemical constituents to the quantities of base flow and runoff. These relationships can be used to determine realistic goals for surface water quality. With the developed relationships, average daily flows for each month for the study basin, and the base flow statistics developed for the study basin by O'Hearn and Gibb [1980], average daily chemical loadings for each month were calculated (see figure 27).

The seasonal distribution of chemical concentrations and loadings can be used to develop management strategies. The concentration distribution curves (figures 21 through 26) should be used to provide the primary guide, as the loading curves (figure 27) are too heavily dependent upon flow. The importance of seasonal efforts to control runoff water quality can be easily seen. Common sense also suggests that very little can be done to control base flow water quality.

Realistic goals and performance yard sticks also can be determined from the chemical load distribution curves. By comparing the relative runoff to base flow loads, realistic expected improvements can be determined. Figure 28 shows the monthly percentage of daily surface runoff chemical loads compared to total daily chemical loads. For the study basin, even if a 50% reduction in runoff chemical quality were accomplished, it

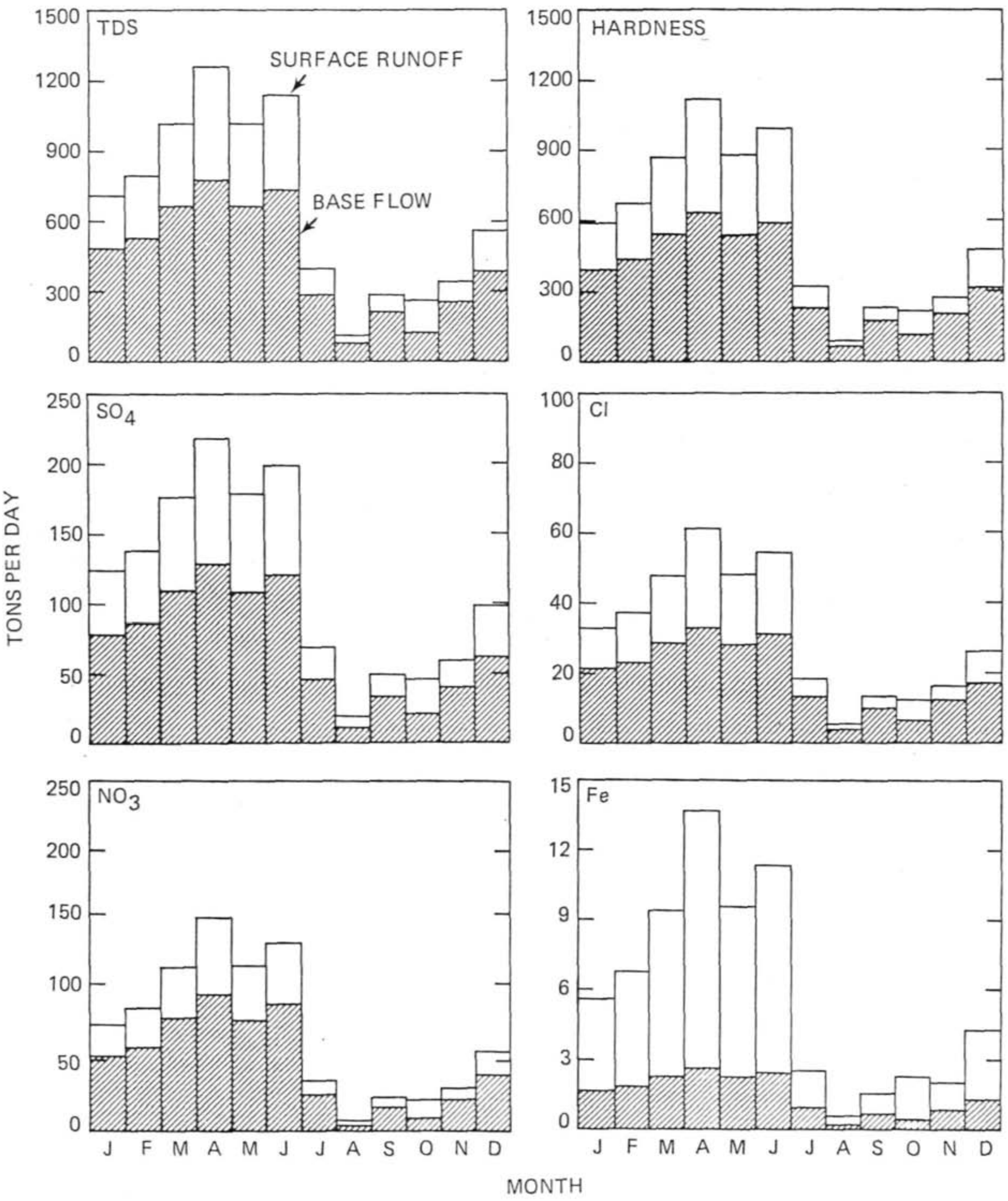

Figure 27. Monthly average chemical loadings for TDS, hardness, sulfates, chlorides, nitrates, and total iron.

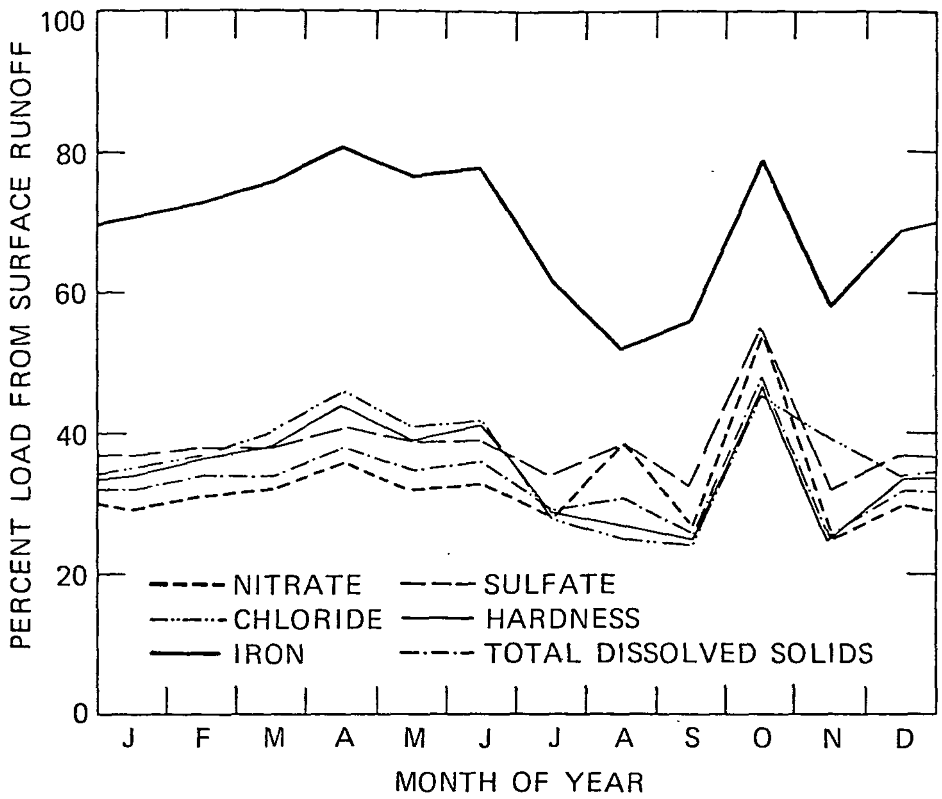

Figure 28. Percent of total chemical load contributed by surface runoff.

would result in only a 15% reduction in the total TDS, hardness, nitrates, and sulfates. For the fall and winter months, 30% reductions in total chloride loads could be realized. It is doubtful that iron loadings would be proportionately reduced because of the precipitation resuspension mechanisms discussed earlier.

This study has demonstrated the usefulness of available surface water chemical and streamflow data for understanding surface water quality and setting appropriate water quality goals. Because of the pioneering nature of the study, the costs of completing the project may be somewhat higher than for future projects of this type. Additional similar studies should be accomplished more economically.

The estimated costs for accomplishing this study are as follows:

Salaries	$ 8,500
Fringe Benefits	1,390
Computer	300
Commodities	100
Printing	150
Total Direct Costs	$10,440
Indirect Costs	
20% of $10,440 =	2,088
Total Cost	$12,528

CONCLUSIONS

1. Quality of shallow glacial deposits has limited value for predicting base flow quality. The differences are most likely due to chemical reactions which take place after the groundwater enters the stream channel. Base flow samples showed lower average concentrations of TDS, hardness, sulfate, and chlorides than groundwater in the drift deposits between about 25 and 50 feet in depth. Average base flow concentrations for nitrate-nitrogen and total iron were higher than for shallow groundwater. Consideration of instream processes, areal variations in soil permeabilities, and base flow contributions from different areas of the study basin may improve the agreement between base flow and shallow groundwater quality data.
2. The regression analysis of both base flow and surface runoff data have shown long-term decreasing trends for sulfate for the period of study. The decreasing trend in base flow sulfate concentrations could be construed to represent a decrease in shallow groundwater sulfate concentrations. However, due to the relatively shallow entrenchment of the streams in the basin, the noted trend probably reflects only a change in water quality in the upper 10 to 15 feet of the soil profile.
3. The regression analyses have shown definite relationships between base flow quantities and base flow sulfate, chloride, and nitrate concentrations and between surface runoff quantities and surface runoff total dissolved solids, sulfate, and iron concentrations. The developed relationships provide insight into the sensitivity of various chemical constituents to the quantities of base flow and surface runoff. Knowledge

of these relationships may be helpful in determining realistic goals for surface water quality and in the management of stream water quality.

4. Plots of the seasonal variations in monthly average base flow and surface runoff chemical loads indicate that, except for total iron, about 65 percent of the chemical loads on a yearly basis are derived from base flow. The proportion of monthly average chemical loads from each source varies with the time of year. Common sense suggests that very little can be done to control base flow water quality. The highest percent of chemical loads from surface runoff generally coincided with the seasonal spring rains, except for chloride load which showed a maximum percent coming from surface runoff in the fall and winter months. Spring was also the time of year when total loads were highest. The seasonal distribution of surface runoff chemical concentrations and total loadings should both be used to develop management strategies. The surface runoff concentration distribution curves should be the primary guide for maximum effectiveness since the loading curves are heavily dependent upon flow. The importance of the seasonal variation on efforts to control surface runoff water quality can be easily seen from the concentration distribution curves.

5. This study has demonstrated the feasibility of using available surface water chemical and streamflow data for understanding the natural controls on stream water quality and for setting appropriate water quality goals for a particular basin. Because of the pioneering nature of the study, the costs of completing this study may be somewhat higher than future studies of this type. Additional similar studies should be accomplished more economically.

RECOMMENDATIONS

1. The chemical characteristics of surface runoff and base flow vary from region to region. Studies of basins representing a cross section of climate, geology, and water quality should be undertaken using available data and the procedures discussed in this study. An understanding of the regional and temporal variability of base flow and surface runoff quality is essential to the development of practical water quality goals and effective management approaches in Illinois. Funding should include travel costs for at least one field visit to each basin studied. This direct observation of salient basin characteristics could be very important in the interpretation of the results of such studies.
2. One or two small basins should be studied in detail to more accurately determine the relationship between groundwater and base flow water quality. Detailed monitoring of surface water and groundwater would be necessary. Such a study would aid in determining the practicality of using shallow groundwater quality data to predict base flow water quality in other parts of Illinois.
3. Periodic analyses of monthly water quality and daily flow data should be undertaken to determine the effectiveness of past and present water quality control practices. In addition, this study, and many others, have shown the importance of accounting for the effects of flow variations when interpreting stream water quality data.

To better understand the base flow water quality in more heavily-urbanized or industrialized basins, point sources of discharge need to be quantified and their quality more effectively monitored.

REFERENCES

Arkin, H., and R. R. Colton, ed. 1963. *Tables for statisticians.* Barnes and Noble, New York.

Davenport, L. A., W. D. Lembke, and B. A. Jones. 1973. *Nitrate reduction in the vicinity of tile drains.* Research Report No. 64, University of Illinois Water Resources Center, Urbana, Illinois.

Duke, H. R., D. E. Simka, and D. F. Heermaan. 1977. *Groundwater contamination from fertilizer nitrogen.* ASCE Fall Convention and Exhibit, San Francisco, California.

Fenneman, N. M. 1914. *Physiographic boundaries within the United States.* Annals of the Association of American Geography, v. 4.

Flemal, R. C. 1978. *Relationships between atmospheric sulfur and quality of surface water in Illinois.* Report of Investigation No. 3, Illinois Water Information System, DeKalb, Illinois.

Gatz, D. F. 1979. *An urban influence on deposition of sulfate and soluble metals in summer rains.* Proceedings of the Second Life Sciences Symposium, Potential Environmental and Health Consequences of Atmospheric Sulfur Deposition, Gatlinburg, Tennessee, pp. 245-261.

Gibb, J. P., and M. O'Hearn. 1980. *Illinois groundwater quality data summary.* Contract Report 230, Illinois State Water Survey, Champaign, Illinois.

Griffiths, J. C. 1967. *Scientific method of analysis of sediments.* McGraw-Hill

Harmeson, R. H., T. E. Larson, L. M. Henley, R. A. Sinclair, and J. C. Neil. 1973. *Quality of surface water in Illinois, 1966-1971.* Bulletin 56, Illinois State Water Survey, Champaign, Illinois.

Harmeson, R. H., R. A. Sinclair, and L. M. Henley. *Quality of surface water in Illinois, 1971-1976.* Illinois State Water Survey, Champaign, Illinois, unpublished.

Morgan, B. E. 1978. *Analysis of the sulfur content of Illinois streams with emphasis on contributions from the atmosphere.* Report of Investigation No. 12, Illinois Water Information System Group, DeKalb, Illinois.

O'Hearn, M., and J. P. Gibb. 1980. *Groundwater discharge to Illinois streams.* Contract Report 246, Illinois State Water Survey, Champaign, Illinois.

Overcash, M. R., and J. M. Davidson, eds. 1980. *Environmental impact of nonpoint source pollution.* Ann Arbor Science, Ann Arbor, Michigan. -

Schicht, R. J., and W. C. Walton. 1961. *Hydrologic budgets for three small watersheds in Illinois.* Report of Investigation 40, Illinois State Water Survey, Champaign, Illinois.

State of Illinois. 1975. *Counties and incorporated municipalities of Illinois.*

U.S. Bureau of the Census. 1971. *U.S. census of population: 1970, number of inhabitants, final report PC(1)-A15, Illinois.* U.S. Government Printing Office, Washington, D.C.

Vendl, L. J. 1979. *Relationships between concentration and discharge on selected Illinois streams.* Report of Investigation No. 17, Illinois Water Information System Group, DeKalb, Illinois.

Visocky, A. P. 1970. *Estimating the ground-water contribution to storm runoff by the electrical conductance method.* Ground Water, Vol. 8, No. 2, pp. 5-10.

Whittemore, D. 0. 1978. *Factors controlling variations in river water quality in Kansas.* Kansas Water Resources Research Institute.

Willis, G. H., and J. M. Laflen. 1968. *Measuring and sampling runoff from flat lands.* Water Resources Research, Vol. 4, No. 6.

Zison, S. W. 1980. *Sediment-pollution relationships in runoff from selected agricultural, suburban, and urban watersheds: a statistical correlation study.* Report EPA-600/3-80-022, USEPA Environmental Research Laboratory, Athens, Georgia.