Bankfull Discharge of Indiana Streams

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Introduction

Bankfull discharge is considered an important parameter of stream behavior for two reasons. First, it represents the flow volume above which flood activity commences, and second, it is thought by many researchers to be equivalent to the channel-forming flow. Recurrence interval of bankfull discharge rather than discharge at bankfull stage is employed as the basis of stream behavior comparison. Use of recurrence intervals allows comparison of stream discharges in a form not primarily dependent on basin area or downstream order. Thus, a statistical property of the flood series is used to render discharges of large and small streams comparable.

Bankfull discharges (Q_b) is the flow volume which completely fills the channel to the top of the bank. Any additional discharge would cause water to flow over the floodplain surface. Recurrence interval (RI) is the expected number of years between occurrences of a given event. Therefore, the recurrence interval of bankfull discharge (RI Q_b) is a measure of the frequency of the discharge which completely fills the stream channel. A high RI Q_b indicates infrequent flooding while a low RI Q_b indicates frequent flooding. In light of increasing floodplain usage, knowledge of RI Q_b has utility for individuals and agencies confronted with tradeoffs between locational advantage and flood hazard.

The geomorphological significance of bankfull discharge has been established in the literature over the last two decades. This recent research was stimulated by Wolman and Leopold's assertion that streams flowing in diverse climatic and physiographic regions flood with a relatively uniform frequency of once every year or every other year (12). Data from 177 streams in the United States and India showed RI Q_b to be closer to 1 than 2 years where floodplain elevations were accurately known.

Subsequent investigations in Australia (5,14), England (6,9), the United States (1, 11) and particularly Indiana (4, 8) have yielded remarkably similar values. These studies showed RI Q_b to range from 0.51 to 4 years on the annual series, with most values between 1 and 2 years.

Theoretical justification for uniform flood frequency was provided by Wolman and Miller's examination of the concept of "effective force" in landform development (13). Reasoning that above the level of competency the "effective force" of a process is the product of the rate of sediment movement times the frequency with which that rate of transport is attained, graphs relating transport rate times frequency as a function of applied stress will attain a maximum which represents the "effective force" of the process. In the case of sediment transport by rivers, the graphs showed most of the work to be done by frequent flows of moderate magnitude. They concluded from this result that

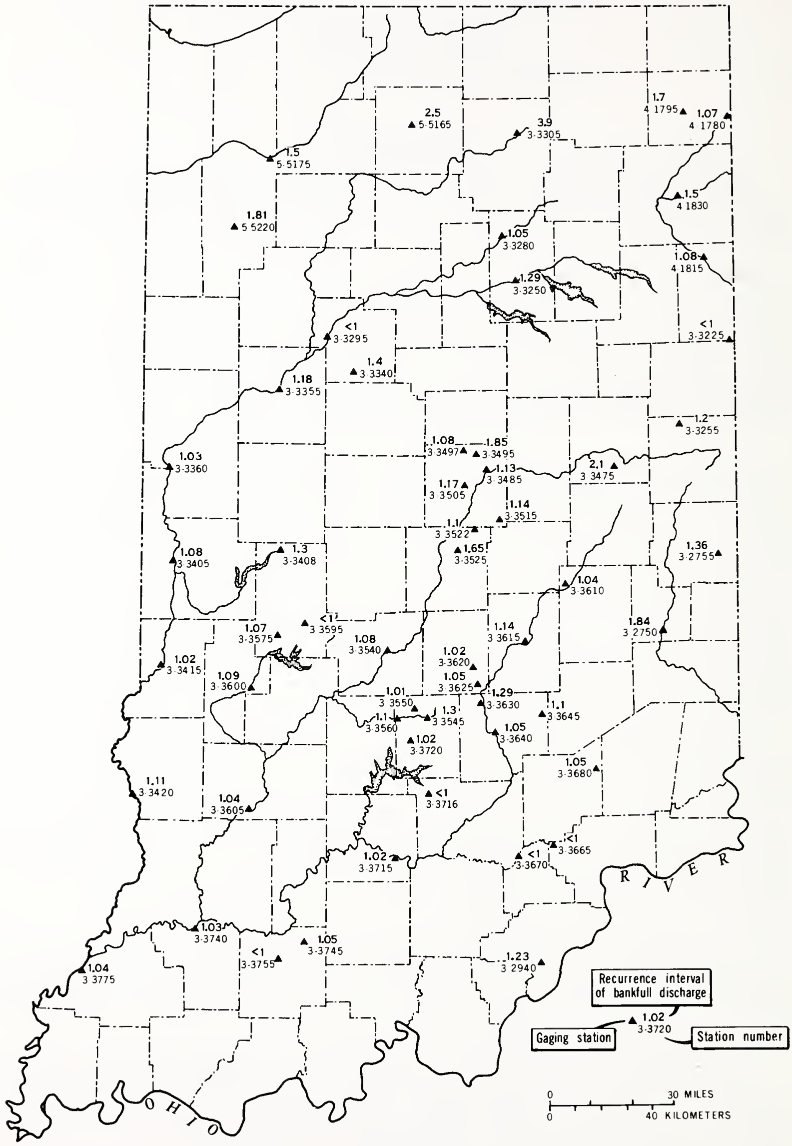

FIGURE 1. *Gaging station locations and RI Q*$_b$

channel and floodplain morphology are related to discharges approximating the bankfull stage.

In most cases these studies employed laborious field methods to determine bankfull stage. The present study develops a method of deriving bankfull stage directly from rating curves. Problems in identifying the topographic bankfull level are averted by consulting readily available United States Geologic Survey (USGS) records.

Data Collection

Morphological considerations concerning the inception of overbank flow lead to the conclusion that bankfull discharge is concomitant with an observable change in the relationship between gage height and stream discharge. Below bankfull stage, increases in gage height are accompanied by regular increases in discharge due to higher water velocity and larger flow area. Above bankfull stage, however, additional increments of gage height are accompanied by extremely large increases in discharge as wide areas of floodplain surface become available for flow. Therefore, rating curves, which relate discharge to gage height, display smooth changes in slope below bankfull stage but flatten rapidly along the discharge axis as the bank is overtopped. The point of maximum slope change on the rating curve represents bankfull discharge.

This method was employed to obtain 56 bankfull discharge observations from rating curves prepared by the USGS. Conversion from discharge to recurrence interval was accomplished by plotting, on log-Pearson Type III probability paper, the discharge associated with the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence interval flood as given in Davis (3). This type of annual series analysis (7) yields a straight line plot. Identification of RI Q_b is then simply a matter of locating Q_b on the line and recording the associated RI.

Data derived by this method agrees well with values found by others (4, 8) for 21 of the stream gages used in this study. Differences between the 21 published values and those used herein are attributible to either the use of regional flood frequency analysis (8) as opposed to the individual station analysis used herein or the use of flood damage records (4) which may reflect stages above or below bankfull.

Spatial Characteristics

The map of gaging stations and RI Q_b (Fig. 1) shows most of the observations to be well distributed over the vast midsection of Indiana with relatively few observations in the extreme north and south. RI Q_b ranges from less than 1 year, generally in the south-central part of the state, to 3.9 years in the north-central part of the state. The mean value is 1.26 years and the median and the mode are both 1.1 years. The frequency distribution of observations conforms well to the general form of Pearson Type III distributions (2) in that it is skewed to the right with limited range to the left.

Power series polynomials were used to produce generalized computer trend surface maps and equations of RI Q_b. This technique produces a least-squares fit by treating x and y map-coordinates as independent variables and RI Q_b as the dependent variable.

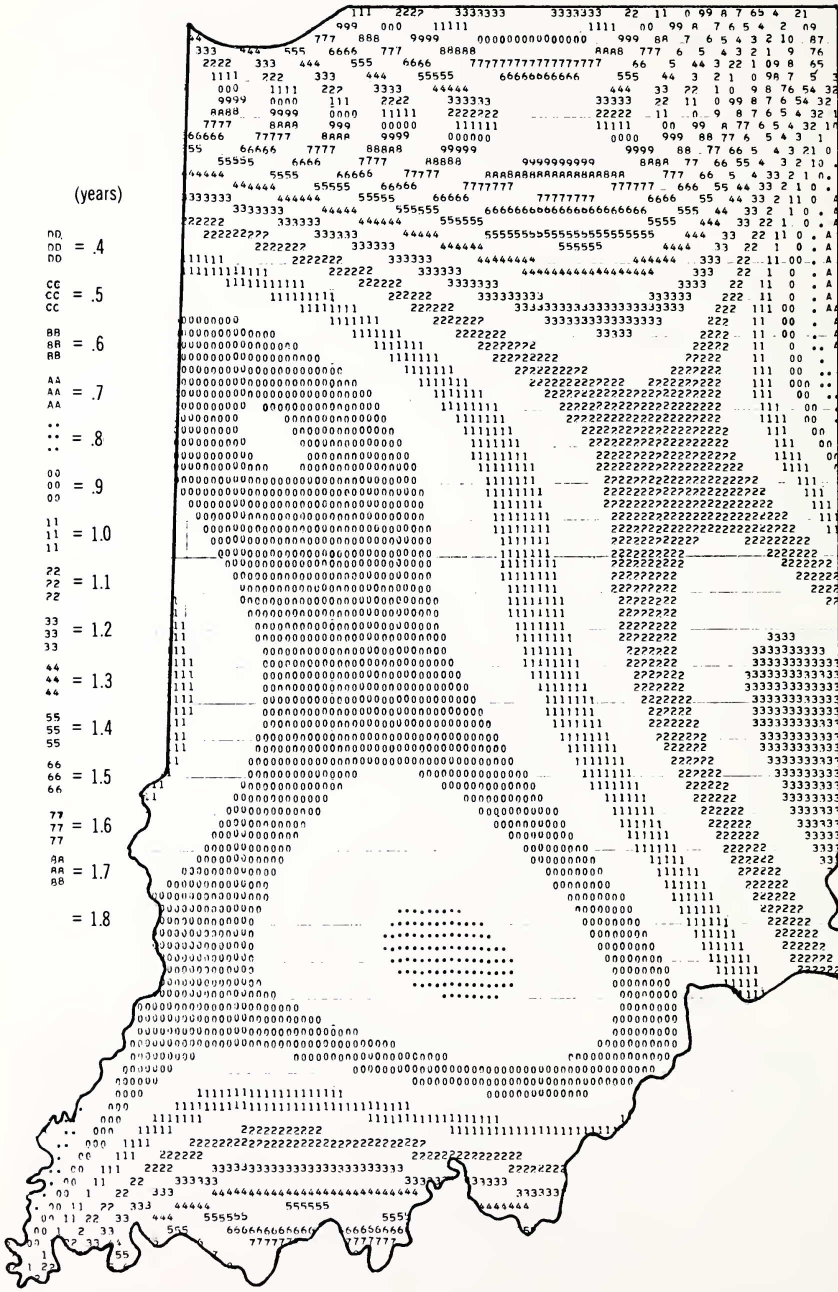

FIGURE 2. *Fourth - degree trend surface of RI Q_b*

The first-degree equation (RI Q_b = 1.812-0.003x-0.235y) fits a plane to the spatial data. Although this surface only explains 23 per cent of the data variation, it demonstrates the distinct south to north increase in RI Q_b. This is indicated by the fact that the y-coefficient (-0.235), representing north to south distance, is two orders of magnituted greater than the x-coefficient (-0.003), representing west to east distance.

The fourth-degree surface (Fig. 2) accounts for 66 per cent of the variation. The most prominent feature of the quartic surface is the pronounced minimum in south-central Indiana. RI Q_b increases in every direction from this point. A secondary minimum occurs along the northern half of the state's eastern border with Ohio. The steepest reliable gradient on the map is in the north-central part of the state where the surface attains its distinct maximum. To the north of the maximum and again in the southwest portion of the map, the surface equation generates meaningless values because of a lack of data points in these areas. It should be noted that the output of the routine is not the value of RI Q_b at a specified location but only the trend of the data within the specified region (10). This phenomenon is evidenced by non-correspondence between the values in Figure 1 and those in Figure 2.

Analysis of Variance

The south to north increase in RI Q_b suggests the possibility that bankfull discharge may be related to the variable effect of repeated glaciations in different parts of the state. It appears that RI Q_b is inversely proportional to time elapsed since glaciation and the number of repeated glaciations and directly proportional to thickness of glacial materials. A direct test of these hypotheses is impractical due to the difficulty of obtaining a single numerical value characteristic of these glacial variables for each gaging station. However, a

REGION	NO. OF DATA POINTS	MEAN RI Q_b
Northern Lake and Moraine	7	2.00
Tipton Till Plain	28	1.23
Illinoian Glacial	16	1.11
Unglaciated	5	1.02

Figure 3. *Glacial regions and analysis of variance statistics*

satisfactory surrogate for the necessary glacial measures is available in the form of Indiana's major physiographic regions. Significant differences in RI Q_b between glacially determined physiographic regions would indicate the two are related. Analysis of variance is the appropriate test for such differences.

Four regions are employed in the analysis of variance×the Northern Lake and Moraine Region, the Tipton Till Plain, the Illinoian Glacial Region, and the Unglaciated Region (Fig. 3).

The analysis of variance yields significant F-test results at the 99 per cent confidence level. The results indicate that RI Q_b variation within glacial regions is significantly less than RI Q_b variations between regions. Thus, the null hypothesis is rejected and the hypothesis that RI Q_b and glacial parameters are related is strengthened. The increase from south to north is again apparent.

Correlation Analysis

The results obtained in the preceding section may be spurious if the two variables are only related to each other by means of a third variable. One such potential confounding variable is precipitation which also varies along the north-south axis of the state. Correlations are calculated to test this possibility and to indentify morphometric variables related to RI Q_b. Five morphometric drainage basin characteristics, a measure of soil conditions, and an index of precipitation are employed in the correlation analysis (Table 1). These data were obtained from Davis (3).

Two of the variables are significantly correlated with RI Q_b at the 95 per cent confidence level: drainage density and watershed relief. Two additional variables are significant at the 99 per cent confidence level: precipitation index (mean annual precipitation - average annual evapotranspiration - water equivalent of annual snowfall) and soil runoff coefficient (ratio of the volume of rainfall to the total volume of runoff occurring after the inception of runoff).

TABLE I. *Correlation Analysis Statistics*

Independent Variable	No. of Data Points	Correlation with RI Q_b	F-Ratio Significance Level
Channel Slope	54	-0.03	Not Significant
Drainage Area	56	-0.16	Not Significant
Channel Length	54	-0.23	Not Significant
Precipitation Index	41	-0.44	0.01
Drainage Density	20	-0.44	0.05
Watershed Relief	54	-0.48	0.05
Soil Runoff Coefficient	21	-0.73	0.01

Graphs of RI Q_b as a function of each of the significant variables illuminate the nature of the relationships. The graphs display strikingly similar characteristics: (1) a significant overall inverse relationship with RI Q_b; (2) a marked overlapping of the spatially clustered values of the Unglaciated Region, Illinoian Glacial Region and the Tipton Till Plain; (3) a separate spatial distribution for the Northern Lake and Moraine Region: and (4) a tendency toward regional variability in the response of RI Q_b. Within certain regions the relationships seem random and in several cases a region displays an orthogonal relationship to the overall trend. The tendency toward randomness and orthogonality increases from south to north (i.e. prevalent in the Northern Lake and Moraine Region and the Tipton Till Plain and not found in the Illinoian Glacial Region and the Unglaciated Region). These results indicate that RI Q_b is more closely related to some undiscovered regional mix of variables represented by the glacially defined regions than to any of the independent variables tested.

Conclusions

The uniform frequency of flooding of about 1-2 years, first postulated by Wolman and Leopold (12), is essentially confirmed by the modest range (0.9 to 3.9 years) and the mean of 1.26 years obtained for Indiana streams. However, spatial analysis shows significant differences between glacially defined regions. Specifically, the results show a consistent increase in mean RI Q_b from a low value of 1.0 year in the Unglaciated Region through 1.1 years in the Illinoian Glacial Region and 1.2 years in the Tipton Till Plain to a high value of almost 2.0 years in the Northern Lake and Moraine Region.

Correlation analysis indicates precipitation index, drainage density, relief and soil runoff coefficient to be significantly related to the frequency of bankfull flow. However, these correlations are not entirely convincing due to the inconsistency of the relationships from one glacial region to another. The correlation results are much more consistent for the Unglaciated Region and the Illinoian Glacial Region than for the more recently glaciated Tipton Till Plain and Northern Lake and Moraine Region. The significantly correlated variables may be reliable determinants of RI Q_b only for streams that have reached a state of quasi-equilibrium. As many authors have suggested (12, 9, 14), a uniform frequency of flooding may be the end result of the balance achieved between the erosive effect of the water and the resistance to erosion provided by the channel material. The dramatic changes accompanying glaciation could obviously disturb such a quasi-equilibrium. The retreat of the glaciers would be followed by a refractory period during which the streams must readjust to a new regime. According to this view, the Unglaciated Region and the Illinoian Glacial Region have had sufficient time since glaciation to achieve a relatively uniform frequency of flooding whereas the Tipton Till Plain and the Northern Lake and Moraine Region have not.

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