Effect of Main-Channel Orientation on Flood Peaks for Streams in Ohio

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ABSTRACT

Flood data from 205 unregulated rural drainage basins ranging in size from 0.012 to 5,993 mi^2 were analyzed to determine whether main-channel orientation had any effect on flood peaks. No significant effect on flood peaks was found for unregulated rural streams in Ohio except for steep basins (main-channel slope > approximately 1 percent) that flow in nearly the same direction as the prevailing storm movement (<20-degree deviation). These basins in general produce higher flood peaks than those predicted by the U.S. Geological Survey regional regression equations for Ohio.

Numerous studies (1-12) have addressed the fact that storm patterns affect peak runoff rates for small drainage basins. Abraham et al. (13) and Masch (14) showed that storms traveling in the same direction as the main-channel flow of the basin produce flood peaks of shorter duration and greater magnitude than storms traveling directly opposite the flow of the main channel. This effect is normally increased with an increase in the ratio of length to drainage area of the basins. For most areas of the United States there is a prevailing direction of rainstorm movement (15,16). Considering the foregoing, it would be reasonable to question whether streams flowing in the same direction as the prevailing direction of storm movement would have significantly different flood peaks than streams flowing in the opposite direction.

Previous studies (17-20) that developed peak-runoff prediction equations for ungauged and unregulated rural basins in Ohio have not addressed the effect of drainage-basin orientation on floods. The latest report by Webber and Bartlett (20), based on data from 215 gauging stations, presents predictive equations for flood peaks with recurrence intervals of 2, 5, 10, 25, 50, and 100 years for five separate geographic areas of the state (see Figure 1). Basin characteristics that had a significant effect on discharge for all five geographic areas were drainage area and main-channel slope. Basin characteristics that had a significant effect on discharge for one or more but not all five areas were surface storage, average basin elevation, and average annual precipitation.

Because there is a prevailing direction of rainstorm movement in Ohio generally from west to east except along Lake Erie, this study was undertaken to determine whether drainage-basin orientation had any effect on peak-runoff rates for unregulated rural streams in Ohio. If possible with available data, a quantitative relationship was to be developed and an adjustment factor provided for the existing predictive equations. Thus an improved estimate of flood flows would be provided to the designers of hydraulic structures.

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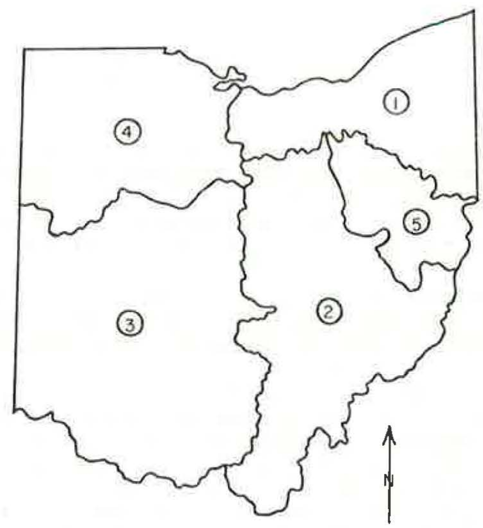

FIGURE 1 Geographic areas of Ohio for U.S. Geological Survey flood-prediction equations.

DATA DEVELOPMENT

The 215 unregulated gauged sites used by Webber and Bartlett (20) to develop their predictive equations were used as the data base for this study. Ten stations were dropped from the data base because a large percentage of their basin areas was in forest, which tends to attenuate flood peaks. Drainage areas for these streams ranged from 0.012 to 5,993 mi^2. Peak-flow data developed from station records by Webber and Bartlett with methods described in Water Resources Council (WRC) Bulletin 17B (21) were used as the observed station flood peaks for this study. Although an additional 7 years of records were available on some stations used by Webber and Bartlett, most of these stations with additional record length were already long-term ones. Therefore, it was believed that the 10-fold or greater increase in study cost to reestablish estimated station flood peaks was not warranted for this study. This increase in cost would have been even more infeasible if several methods of flood peak estimation were used at each station as recommended by Wallis and Wood (22).

Gauging-station record lengths used by Webber and Bartlett are as follows:

Record Length (years)	No. of Stations
15 or less	45
16-25	35
26-35	66
36-45	26
>45	33

Most of the stations with short-term records that had not been discontinued before the report were discontinued after its publication (20). The Ohio Department of Transportation (ODOT) currently has a research contract with the Water Resources Division, U.S. Geological Survey (USGS), to perform an update of the report by Webber and Bartlett that will include additional data on strip-mined, forested, and northwest Ohio basins. The station flood estimates will also be updated. Predicted flood peaks were generated by using the equations developed by Webber and Bartlett from the basin characteristics listed in that report.

In order to quantify drainage-basin orientation for this study, the main-channel orientation angle of each drainage basin was initially developed as shown in Figure 2. A main-channel vector was constructed from a point on the main channel located at 85 percent of the total main-channel distance from the gauging station to a point at 10 percent of the distance from the gauging station. The angle (from 0 to 180 degrees measured north or south) between this vector and a vector running due west to east was defined as the main-channel orientation angle for the basin. The 85 and 10 percent points were selected because they are the stream distances commonly used in determining main-channel slope and mean basin elevation in the USGS regression equations used by numerous states for flood estimates. If initial data analyses provided quantifiable relationships between channel orientation angle and flood peaks, other means of defining the angle were to be studied. Channel orientation angles were determined for the data sites by using topographic maps with scales ranging from 1:2,400 to 1:625,000. The scale of map selected was that most convenient for the size of drainage area for each basin.

DATA ANALYSES

The ratios of previously defined observed flood peaks to predicted flood peaks for Q_{10}, Q_{25}, Q_{50}, and Q_{100} were computed for each station. The flood peaks Q_2 and Q_5 were not considered because ODOT does not use floods of these frequencies in the design of hydraulic structures. These ratios were compared initially with both main-channel orientation angles and the cosines of these angles by using several linear and log-linear regression relations. The cosine of the angle was initially selected because it was thought to be the most representative of the theoretical relationship between orientation angle and flood ratios. If initial analyses provided quantifiable results, other measures of angle were to be studied. Comparisons were done for the total data set and several subsets based on drainage area:

Drainage Area Size (mi²)	No. of Sites
All areas	205
1,000 or less	191
>1,000	14
300 or less	151
>300	54
100 or less	105
>100	100
30 or less	76
>30	129

The ratios of observed 25-year flood peaks to predicted 25-year flood peaks for basins of 30 mi² or less are plotted against main-channel orientation angles in Figure 3.

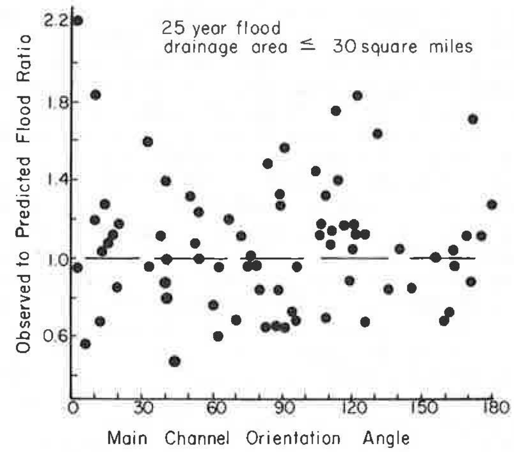

FIGURE 3 Observed to predicted flood ratios for basins with drainage areas 30 mi² or less.

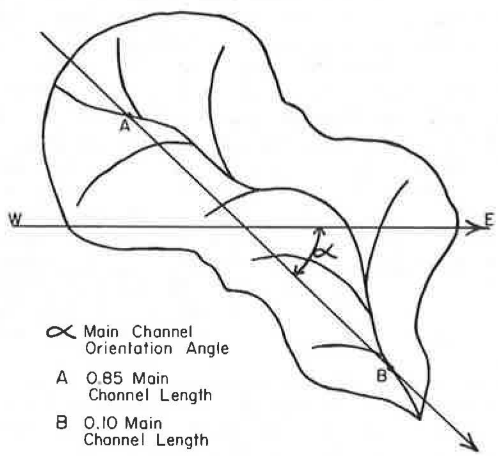

FIGURE 2 Main-channel orientation angle.

Results of the regression analyses showed that there was no significant relation between the ratio of observed flood peaks to predicted flood peaks and main-channel orientation for any combination of drainage area data set and recurrence interval.

Because channel orientation was not considered by Webber and Bartlett, there was some question whether the geographic breakdown of the state or the variables used in the predictive equations in that report could have accounted for any effect of channel orientation. In order to determine whether there was any bias in stream-channel orientation among the geographic areas considered by Webber and Bartlett, chi-square analyses were performed on the channel orientation data.

The main-channel orientation angles were divided into three groups for each geographic area: west to east-flowing (angle ≤ 45 degrees), east- to west-flowing (angle ≥ 135 degrees), and north- to south- and south- to north-flowing (angle between 45 and 135 degrees). The number of stations in each group for each geographic area was as follows:

Geographic Area	No. of Stations by Flow Direction: E to W	N to S and S to N	W to E
1	4	26	6
2	2	28	17
3	23	37	15
4	11	16	6
5	4	7	3

There were significant differences at the 99 percent confidence level in the number of streams in each orientation-angle category among the geographic areas. Geographic Area 2 had significantly more west- to east-flowing streams than the other areas and Geographic Area 1 had significantly more south- to north-flowing streams than the other areas.

Because of this bias it was decided to rerun the stepwise regression analysis for Q_{10} through Q_{100} previously performed for the statewide data set by Webber and Bartlett. The independent variables for channel orientation angle and cosine of that angle were included with those variables found to have a significant effect on floods in that study. Results showed that neither channel orientation angle nor the cosine of that angle had any significant effect on floods for any recurrence interval. Therefore, any bias in main-channel orientation angle among different geographic areas shown by Webber and Bartlett did not affect the results of that study.

A possible explanation for the lack of effect of channel orientation on flood magnitudes for the data sets studied is the large difference in the response time of the rural basin to a rainfall event and the time it takes the rainstorm to cross the basin. Rainstorms that produce flood peaks on most drainage areas in Ohio travel at approximately 35 to 45 mph (or approximately 50 to 65 ft/sec). This rate of storm movement produces a rather short storm travel time across the basin. The average velocity of flood flows in most natural channels in Ohio is in the range of 5 to 10 ft/sec. The rate of flood wave movement is even less than this. A difference in the two travel times of approximately one order of magnitude would create an actual condition very close to the idealized case of "uniform rainfall" across the basin. In such a case main-channel orientation would be of little consequence.

In order to test whether main-channel orientation might affect peak flows in basins with faster response times, a data subset of basins with main-channel slopes of 50 ft/mi (approximately 1 percent) or greater was analyzed. This included 31 basins that ranged in size from 0.012 to 14.0 mi². The ratios of observed 25-year flood peaks to predicted 25-year flood peaks for these basins are plotted against main-channel orientation angles in Figure 4.

The same regression analyses performed on the drainage-area data set and subsets shown at the beginning of this section were applied to the data for the foregoing 31 basins. Results of the regression analyses showed that there was no significant relation between flood-peak ratios and main-channel orientation for these basins with steeper main-channel slopes.

Although no regression relation could be developed for the entire range of main-channel orientation angle, observation of Figure 4 and similar plots for Q_{10}, Q_{50}, and Q_{100} showed that 5 of the 6 basins with main-channel orientation angles <20 degrees had ratios of observed to predicted floods

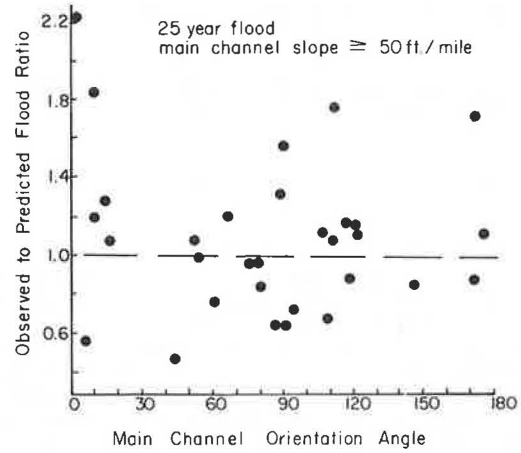

FIGURE 4 Observed to predicted flow ratios for basins with main-channel slopes 50 ft/mi or greater.

>1.0, whereas only 13 of the remaining 25 basins had ratios >1.0. Chi-square analyses comparing these 6 basins with the other 25 basins in this data set showed with 80 percent confidence that this difference could not have occurred randomly.

Considering the foregoing finding, the plots of flood ratio versus angle for the data sets used by Webber and Bartlett (shown in the section on data development) were tested to compare ratios of basins with main-channel orientation angles $\leq$20 degrees with ratios from basins with angles >20 degrees. This comparison was also made for a data set composed of 33 basins with drainage areas <15.0 mi² and channel slopes <50 ft/mi. There was no significant difference between ratios for basins with angles >20 degrees and those with angles $\leq$20 degrees for any of these data sets.

These findings indicate that main-channel orientation angle has no effect on flood peaks except for steep (main-channel slope approximately 1 percent or greater) basins with orientation angles $\leq$ approximately 20 degrees. These basins appear to have significantly larger observed flood peaks than those predicted by Webber and Bartlett. The mean value of observed to predicted 25-year flood ratios for these six basins was 1.36. However, insufficient data exist to develop any reliable quantifiable relationship or to determine whether the ratio of basin length to drainage area or other factors affect the relationship.

Although it was beyond the scope of this study, an examination of existing stream-flow data on gauged sites in neighboring states (Pennsylvania, West Virginia, Kentucky, etc.) should be made. Steep basins with orientation angles $\leq$ approximately 20 degrees with sufficient years of record should be added to the six Ohio basins to form a larger data set. At this point an update of estimated gauging-station flood peaks could be made at stations where there are significant increases in record lengths from those used in existing estimates. This data set, it is hoped, would produce a quantifiable adjustment factor for existing flood-peak prediction models. If such is not the case, new gauging stations would be required to expand the set of stations.

Floods for urbanized areas that have much faster basin response times may also be affected by channel orientation. However, at this time data were not available to investigate floods from urban basins in Ohio.

CONCLUSION

Main-channel orientation had no significant effect on flood peaks for unregulated rural streams in Ohio except for steep (main-channel slope > approximately 1 percent) basins that flow in nearly the same direction as the prevailing storm movement (<20-degree deviation). These basins produce higher flood peaks than those predicted by USGS regional regression equations as given by Webber and Bartlett (20) by an average of 36 percent for 25-year floods.

RECOMMENDATIONS

The effect of basin orientation on urban flood peaks in Ohio should be investigated when data become available.

Additional rural basins in and around Ohio with steep main-channel slopes and flow directions with small deviations from prevailing storm movement should be studied to more precisely quantify the effect of direct channel alignment with prevailing storm movement. Adjustment of prevailing storm movement from due west to east should be made based on geographic location, and the effect of basin length-to-width ratio should be considered.

At those sites where failure of the hydraulic structure to adequately convey flood flow is critical, an increase in the flood peaks predicted by the USGS regression equations should be made on those basins with main-channel slopes >50 ft/mi and main-channel orientation angles <20 degrees.

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