Geomorphology and Floods

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Introduction

One of the most difficult problems facing the hydrologist and the hydraulic engineer in flood-protection work is the determination of the magnitude of peak discharges and the shape of flood hydrographs. These are essential to the design of flood-protection structures, including levees, floodwalls and reservoirs, for the determination of channel sizes and bridge openings, and for the establishment of house-floor elevations in urban developments.

The Surface Water Division of the United States Geological Survey maintains throughout Indiana and the Nation a network of stream-flow measuring stations, at which are recorded continuously river stages. By means of current-meter discharge measurements stage-discharge relations are developed and from these and the stage record the discharge hydrographs are computed. The problem is to extrapolate these records to streams on which there are no records, by a study of precipitation patterns, geomorphologic characteristics of the watersheds and statistical evaluations of flood frequency.

Chronology of Flooding

When precipitation occurs over a watershed a part is absorbed into the ground, a part is retained on the surface in puddles and ponds, and a part is intercepted by vegetation surfaces and the soil, to be evaporated during and following the storm. That part of the precipitation which is in excess of these demands finds its way into the streams and, if sufficiently large, produces a flood. This excess is referred to here as the runin.

During the progress of a storm the rate of runin increases to a maximum and then decreases at or shortly after the end of the storm. As the water flows over the ground surface and into the rills and small streams and thence to the larger creeks and finally down the main stream a part is retained as storage within the channels, to flow out after the peak. According to the equation of continuity

Rate of runin = Rate of outflow + Rate of change in channel storage

The rate of runin is primarily a function of the pattern of precipitation, with some modification by the geomorphologic characteristics of the watershed, the rate of change in channel storage is entirely modified by the geomorphologic characteristics of the stream channels. If it is possible to determine this latter relation, the data now being collected at stream-flow measuring stations may be extrapolated to ungaged areas and the characteristics of the flood hydrograph determined.

Illustrative Streams

Three Indiana streams of widely diverse geomorphologic characteristics have been selected to illustrate these effects on the flood hydrograph.

The Yellow River watershed above Plymouth drains the northeast portion of the Steuben Morainal Lake Section. Poorly drained muck areas, lakes, kames, kettles, and eskers are common features. The surface drainage is very poorly developed, is dendritic, and is augmented by man-made ditches. The stream valleys are very young in age, having only recently been uncovered by the ice. The main tributaries exhibit narrow flood plains with very gently sloping valley walls and with relief not in excess of 30 feet. Shallow groundwater storage is very large.

The Raccoon Creek watershed above Mansfield drains a portion of the low, undulating Wisconsin Tipton Till Plain, which is broken with occasional morainic hills. The headwater creeks in southeastern Montgomery County flow mainly in Wisconsin glacial drift, occasionally crossing a bedrock outcrop. In Putnam and Parke Counties the bedrock exposures are much more frequent. The stream is in part preglacial, for which reason its valley width is most erratic. Raccoon Creek carried the outflow from glacial melting and undoubtedly experienced great floods during the severe storms which raged along the edge of the retreating ice. As a result, the valley is filled with coarse sand and gravel. Shallow groundwater storage is sizable, particularly along the upper reaches.

The Laughery Creek watershed above Farmers Retreat drains the east half of Ripley County, which lies in the southeast section of the Dearborn Upland. This creek and its larger tributaries are entrenched into Ordovician and Silurian limestones and shales. Impervious Illinoian glacial till overlies the bedrock and forms a relatively flat upland surface which extends out as long spurs overlooking the principal tributaries. The tributary streams are narrow, steep and V-shaped. The streams undulate back and forth between the narrow valley walls on shallow, coarse alluvium which covers the bedrock of the valley floor. There is practically no groundwater storage within the watershed.

Characteristics of the Flood Hydrographs

In Fig. 1 are shown the watershed outlines and channel slopes for the selected streams. It will be noted that the Yellow River is relatively wide as compared to its length, while Raccoon and Laughery Creeks are longer and narrower. The drainage areas are—Yellow River above Plymouth, 284 square miles; Raccoon Creek above Mansfield, 240 square miles; Laughery Creek at Farmers Retreat, 248 square miles. The average watershed falls are—Yellow River, 4 feet per mile; Raccoon Creek, 7 feet per mile; Laughery Creek, 8 feet per mile.

In Fig. 2 are shown time-intensity graphs of precipitation, runin, and outflow for intense storms over each of the three basins. The top graph gives the rainfall intensity, in cubic feet per second over the watershed, computed from data of the U. S. Weather Bureau. The middle graph shows the rate of runin, in cubic feet per second, computed by the equation of continuity. The lower graph shows the discharge past the gaging station, or the outflow from the basin at that point, also in cubic feet per second.

Attention is called to the following salient features: The precipitation rate over the Yellow River watershed during the flood of October 1954 reached a maximum of approximately 130,000 cubic feet per second. This was reduced by losses and modified by the geomorphological characteristics of the watershed to a maximum runin of 40,000 cubic feet per

FIG. 1

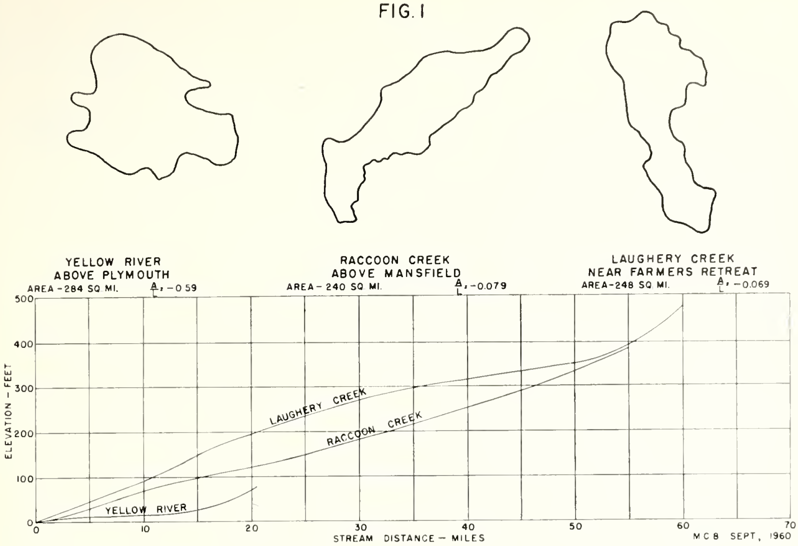

Figure 1

second. This was, in turn, greatly modified by the effects of channel storage, reducing the peak discharge at the gaging station to a mere 5,390 cubic feet per second.

In June 1957 the Raccoon Creek watershed was struck by a storm which had a maximum intensity of 140,000 cubic feet per second. This was modified by watershed characteristics to a maximum runin rate of approximately 110,000 cubic feet per second, which was in turn reduced to an outflow of 38,400 cubic feet per second by channel storage.

In January 1959 the Laughery Creek watershed experienced a severe storm. The maximum precipitation rate was 60,000 cubic feet per second, as a one-hour average. The maximum runin was over 100,000 cubic feet per second, which, in relation to the rainfall rate, seems somewhat anomalous. This will require further study. The peak outflow was 47,800 cubic feet per second.

The foregoing clearly shows the geomorphologic effects on the modification of storm precipitation. The losses were relatively small, varying from 0.9 inch in the Yellow River watershed to 1.3 inches in the Laughery Creek watershed. The channel storage, on the other hand, was much larger for Yellow River, than for either Raccoon or Laughery Creeks.

Geomorphologic Factors

The principal geomorphologic factors which modify the flood discharges of streams are the watershed area and shape, average watershed fall, the convexity or concavity of the basin, and the surficial geology. Curves of relation (Fig. 3) have been developed between peak discharge, watershed area, and watershed fall for several flood determinations on streams in central Indiana, made during the floods of May 1956 and May

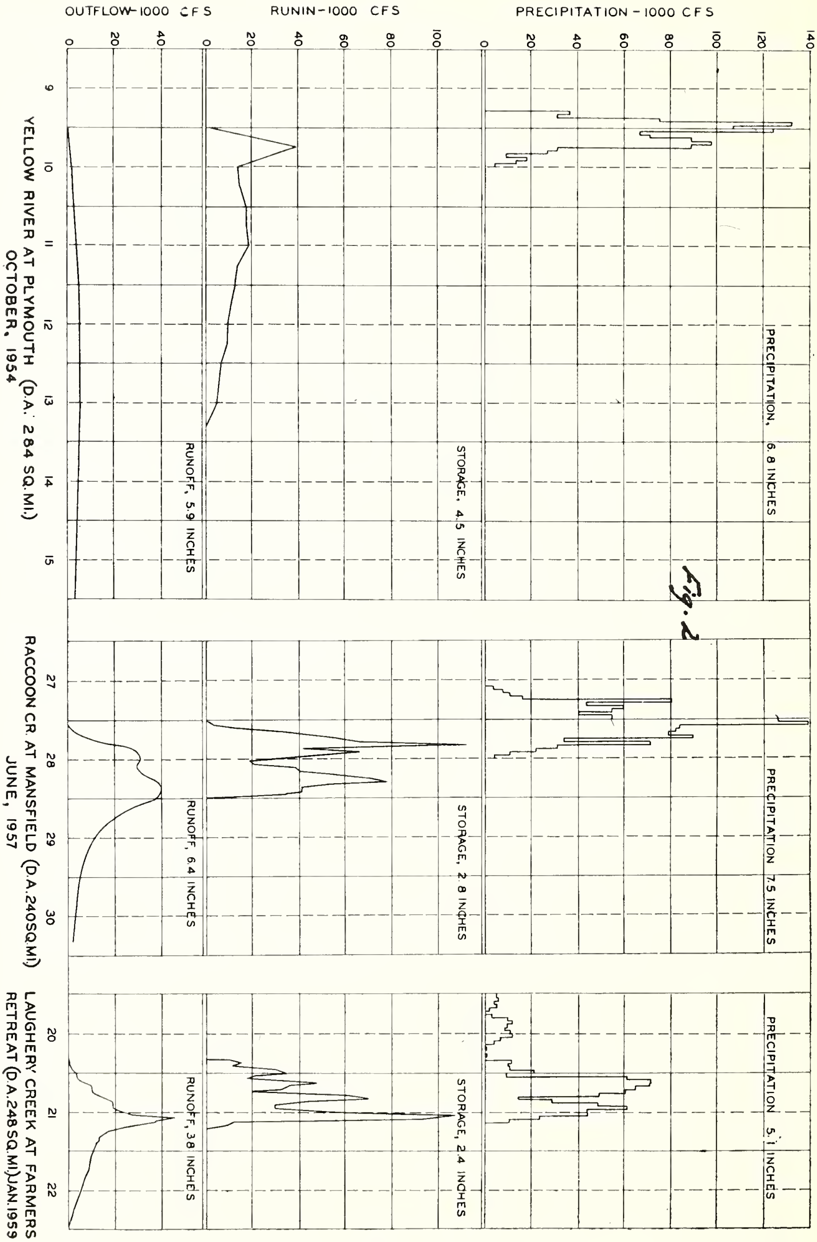

Figure 2

and June 1957. These have been very helpful in determining peak discharges for ungaged areas.

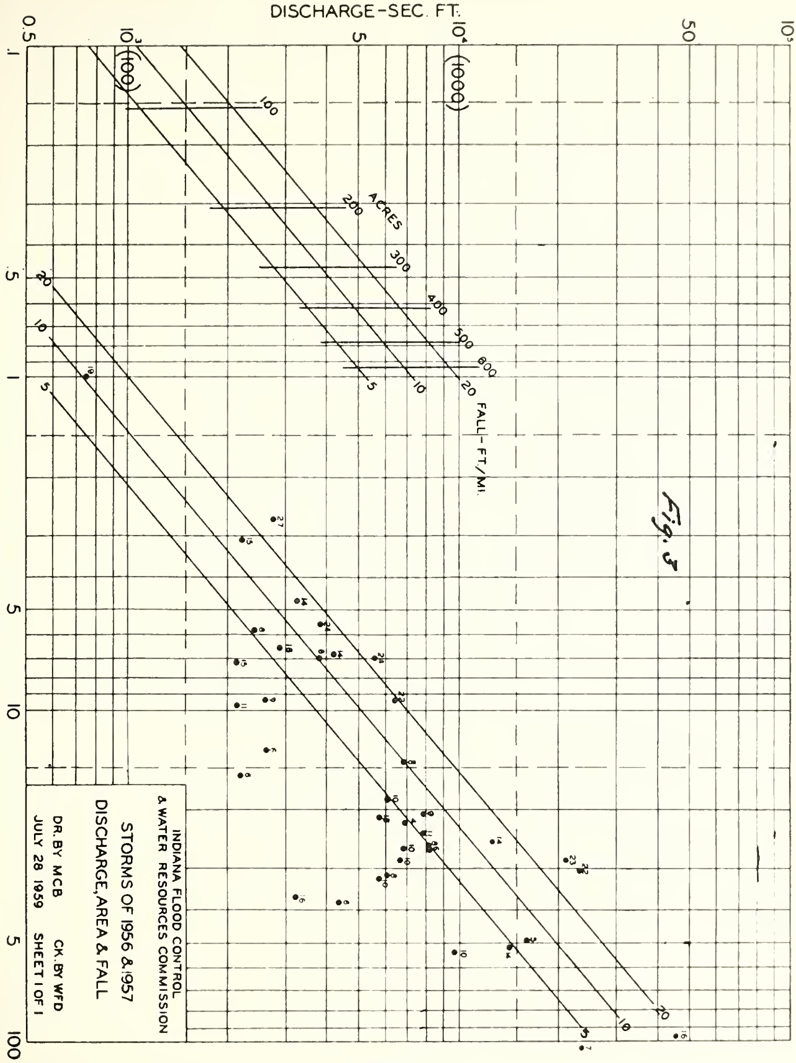

Figure 3

Studies are underway to develop dimensionless relationships between watershed falls, area, length, and shape, and the discharge characteristics of runoff, time to peak discharge, peak discharge, and the shape of the hydrograph.