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14. ABSTRACT
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Hydrologic Aspects of Flood Warning - Preparedness Programs

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Abstract

A reliable flood-threat recognition system is a vital component of a sound flood warning-preparedness program. Fundamental questions associated with the development of a flood-threat recognition system are: what warning times can be achieved, and how reliable will the warnings be? Answers to these questions depend on watershed and storm characteristics, and the flood-threat recognition method being considered. The tradeoff between warning time and warning reliability is illustrated, and methods for estimating warning time are discussed.

Introduction

Flood warning and preparedness programs involve flood-threat recognition, warning dissemination, emergency response and post-flood recovery. The design and implementation of a sound, cost-effective program and the determination of the scope of the program depend substantially on the supporting hydrologic analyses. An important aspect of the hydrologic analyses is the development of a flood-threat recognition system. The analysis includes the evaluation of flood warning times, warning criteria, and the reliability of the warning.

Warning Time and Reliability

The concept of warning time is illustrated in Figure 1 (FIACWD, 1989). As indicated, maximum potential warning time (T_{wp}) is the time from the first indication of precipitation to the time flooding begins. Use of time (T_{wp}) as the actual warning time (T_w) would be totally unreliable because it would indicate that it floods every time it rains. There must be a flood recognition time (T_r) which is the time required for specific warning criteria to indicate flooding is imminent. The criteria could be that a specific amount of precipitation has occurred or that a stream has reached a specified stage. The longer the flood recognition time, the

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warning time. However, one must be aware of the tradeoffs between warning time and warning reliability.

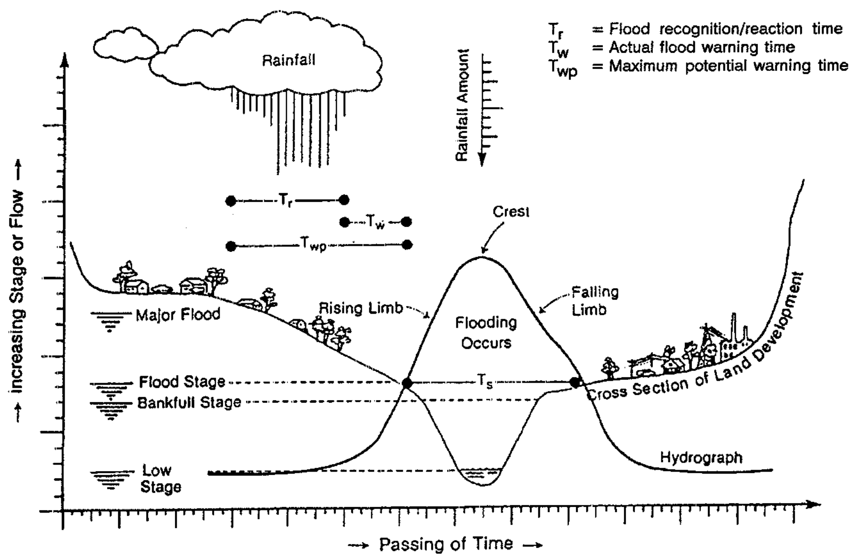

Figure 1. Illustration of Flood Warning Time

Consider Figure 2, which illustrates aspects of reliability. Sets of storm events are labeled {A}, {B}, {C} and {D}, where:

{A} = storm events that cause flooding
{B} = storm events that do not cause flooding
{C} = storm events that cause flooding but for which warnings are not issued
{D} = storm events that do not cause flooding but for which warnings are issued

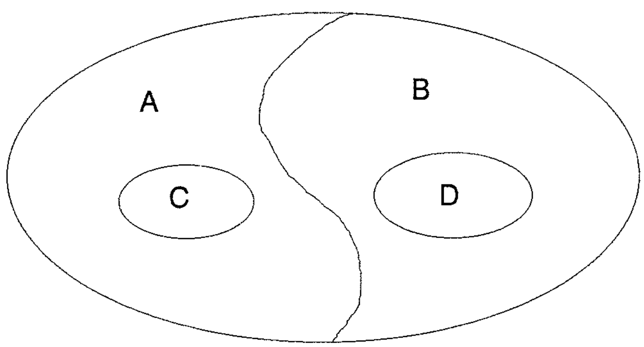

Figure 2. Reliability of Flood Warnings

The goal of a warning system is to minimize both {C} and {D}. Events from {C} can cause damage and loss of life that could possibly be prevented; events from {D} increase the likelihood that future warnings will be ignored. Alternative warning systems will be reflected by different configurations of {C} and {D}. The basis for a warning can range from measured stage at an index gage to results of a rainfall-runoff model that incorporate recent rain data and possibly estimates of future rainfall. Although the more sophisticated warning systems will tend to provide longer lead times, their reliability may not necessarily be greater than that associated with simpler systems. Both warning time and reliability should be evaluated when analyzing alternative warning systems

The tradeoff between lead time (warning time) and warning reliability can be illustrated by considering a simple threshold-stage method of warning, as illustrated in Figure 3. The warning stage is sensed at location A. The primary flood threat is downstream at location B. The problem is to choose a threshold (index) stage for location A such that when that stage is exceeded, a warning for flooding at location B is to be issued. It is desired that the lead time to prepare for the flood threat be as long as possible. The lower the index stage at A, presumably the more lead time will be afforded. However, if the threshold stage is too low, there will be too many false warnings, so that genuine warnings will not be heeded. In terms of Figure 2, as {C} is made smaller, {D} becomes larger.

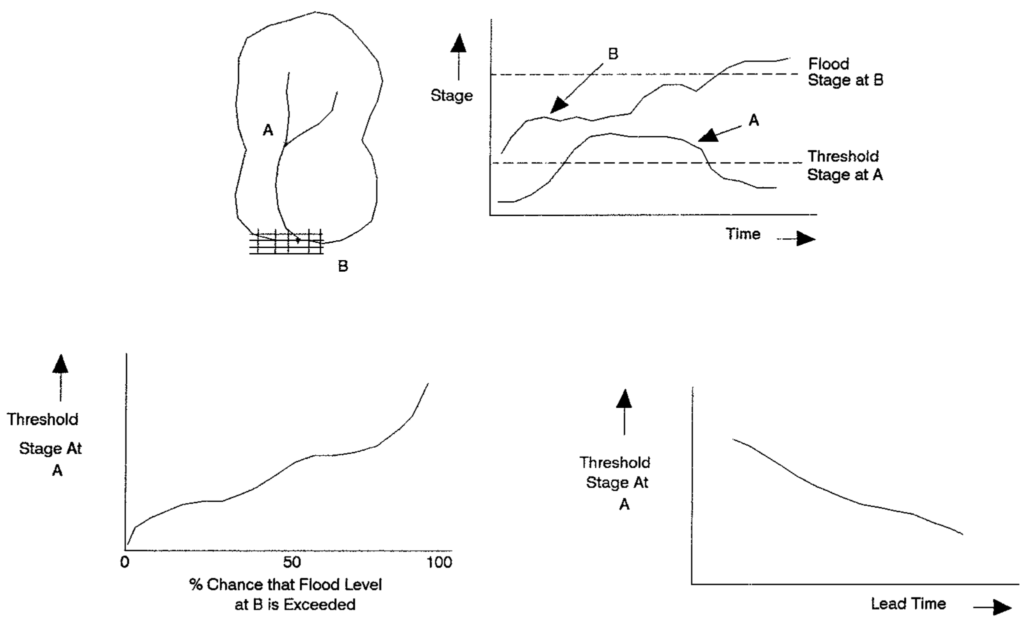

Figure 3. Lead Time Versus Warning Reliability

Illustration of Flood Warning and Reliability

To illustrate the tradeoff between warning time and reliability that is implicit in a flood warning system, consider a situation like that in Figure 3 in which a threshold stage at an index gage is to be used to trigger an alarm that warns of the impending exceedance of flood stage at a damage center. Although most flood warning systems are more sophisticated than this, analysis of a simple system can provide insights that have broader implications.

The basin used in this illustration is part of the Central Great Plains Experimental Watershed near Hastings, Nebraska (USDA, undated). In particular, discharge data collected over a 29-year period (1939-1967) at three gages on the west branch of Beaver Creek were used. The locations are labeled W3, W8 and W11 in Figure 4a. The drainage areas at these locations are very small and warning times will be very short. However, the intent of this analysis is to illustrate concepts rather than a practical design, and the available data is well suited to this purpose.

Assume that location W11 is the damage center for which a warning is to be issued, and that flood stage at W11 corresponds to a discharge of 300 cfs. This discharge was exceeded for 16 events during the 29-year period of record. Locations W3 and W8 will be considered individually as index locations for triggering a warning. That is, when a threshold discharge is exceeded at the index location, a warning is issued. The problem is to determine the threshold discharge to be used, and to assess associated warning time and reliability.

Period-of-record discharge data at a 15-minute interval for the three locations were acquired. The data were processed to determine events that exceed the flood discharge (300 cfs) at W11, and to determine threshold discharge exceedances at W3 and W8. Table

Table 1
Warning Time Analysis for a Threshold Q of 200 cfs at W8

Flood discharge at W11 = 300 cfs.

Date & Time of Flood at W11	Peak Q at W11	Time of Peak Q W11	Thresh. Q at W8 Exceeded?	Time of Exceed. Thresh. Q	Potential Warning Time (hr:min)
12 MAY 44 0315	394	0330	yes	0115	2:00
25 AUG 44 1045	343	1515	yes	1100	-:15
16 JUL 45 2045	333	2100	yes	1745	3:00
9 JUN 49 0030	374	0145	yes	2045 [2]	3:45
20 SEP 50 0115	730	0300	yes	2230	2:45
1 JUL 51 2045	1147	2215	yes	1930	1:15
10 JUL 51 0815	918	0900	yes	0630	1:45
14 JUL 52 0400	1063	0430	yes	0115	2:45
7 JUN 53 1815	680	2000	yes	1745	:30
22 MAY 54 2315	999	0200 [1]	yes	2300	:15
27 MAY 54 0330	325	0345	yes	2345	3:45
15 JUN 57 1730	1459	2115	yes	1215	5:15
29 AUG 57 0045	414	0130	yes	0130	-:45
3 JUL 59 2130	838	2400	yes	2115	:15
27 MAR 60 1645	365	1745	yes	1315	3:30
15 MAY 60 2230	811	0115 [1]	yes	2230	:00

[1] Next day.
[2] Previous day

16 flood events in 29 years
Number of events threshold discharge (200 cfs) was exceeded: 45
Reliability = 16/45 x 100 = 36%

1 illustrates results for a threshold dischage of 200 cfs at W8. The first three columns pertain to the flood event at W11; the last three columns refer to the exceedance of the thresholddischarge at W8. In this illustration, the threshold discharge was exceeded during all 16 flood events. The potential warning time associated with the events is shown in the last column. For two of the events, the time is negative.

As noted at the bottom of Table 1, the threshold discharge was exceeded 45 times during the 29 years of record, which means that a false warning would have been generated 29 times. The realiability of the warning mechanism, that is, the percent of true warnings to total warnings, is 16/45 x 100, or 36 percent. As may be noted from the table, a warning time $\geq$ 1 hour would have been provided for 10 of the 16, or 63 percent of the flood events. A warning time $\geq$ 30 minutes would have been provided for 69 percent of the events. The analysis illustrated in Table 1 was also applied with threshold discharges

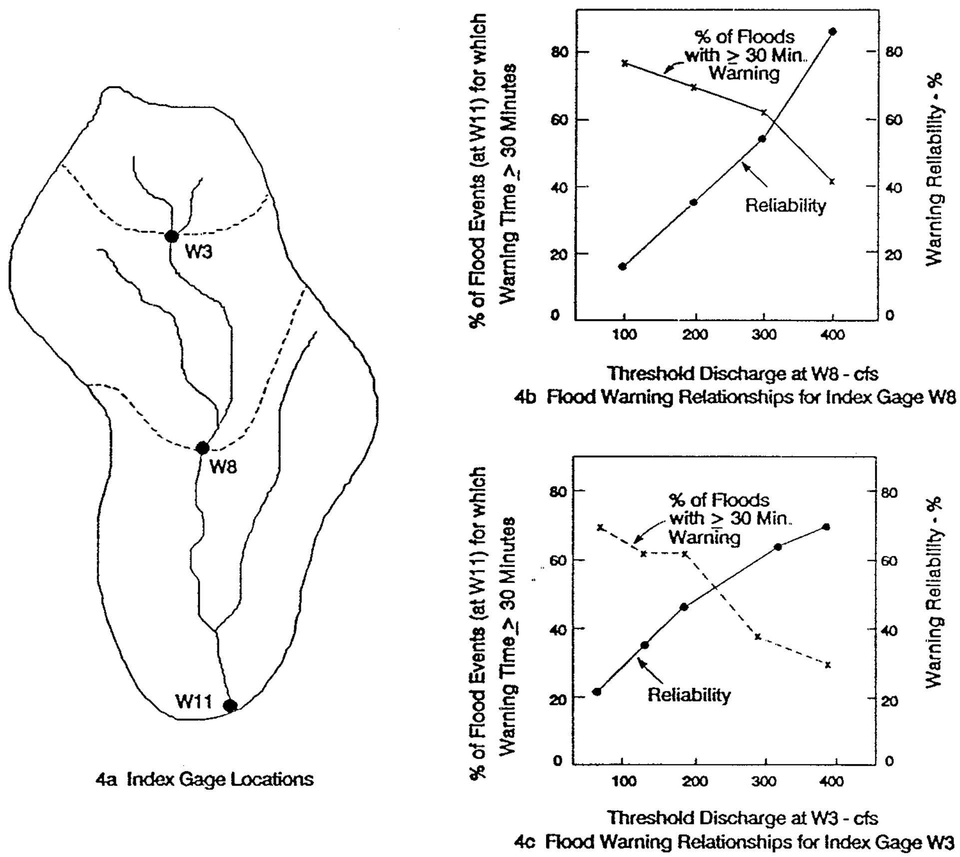

Figure 4. Beaver Creek Watershed

at W8 of 100, 300 and 400 cfs. Figure 4b shows forecast reliability and occurrence of at least a 30-minute warning time, both as a function of threshold discharge at W8. Figure 4c shows results for W3.

The inverse relationship between warning reliability and warning occurrence is readily apparent in Figures 4b and 4c. Suppose that it were desired to have a warning reliability of 70 percent, meaning that 7 out of 10 warnings would be for actual flood events. From Figure 4b, the corresponding threshold discharge at W8 is about 350 cfs and the percent of flood events for which a warning time $\geq$ 30 minutes is provided is 53 percent. That is, a warning time $\geq$ 30 minutes would be provided for only about half the flood events, and 3 out of 10 warnings would be erroneous. These are not very impressive figures, and such a warning system would obviously be far less than adequate.

By comparison, Figure 4c indicates that a 70 percent reliability could be achieved with a threshold discharge of 400 cfs at W3, for which a warning time $\geq$ 30 minutes would be provided for only 31 percent of the flood events. For this level of reliability, index location W8 is the better of the two locations.

Estimation of Flood Warning Time

Flood-threat recognition essentially involves real-time sampling of characteristics of a storm event and forecasting the probable near-term runoff response. The more variability associated with the event being sampled, the more difficulty there is in obtaining an adequate sample and the more uncertain the forecast.

Key variables upon which warning time depends include: (1) spatial variability of precipitation, (2) temporal variability of precipitation, (3) rainfall-runoff response characteristics of the watershed and (4) antecedent soil moisture conditions. Storm rainfall, and consequently warning time, typically exhibit substantial variability. To properly evaluate the potential warning time for a watershed, a set of storms should be analyzed that reflects such variability. Warning time can then be defined in terms of a median value and a standard deviation or some other measure of variability.

Warning time for a specific historical storm event can be estimated using a rainfall-runoff forecast model such as HEC-IF (Peters, 1985). The model accounts for precipitation and streamflow that has occurred up to the specified time-of-forecast and simulates streamflow into the future. Successive times-of-forecast can be evaluated until the simulated future runoff exceeds flood stage. The time between the time-of-forecast and the time when flooding begins represents an estimate of the gross warning time for the event being analyzed. An estimated time for collecting and analyzing real-time data during an actual storm would need to be estimated and subtracted from the gross warning time. If climatological forecasts had indicated a significant probability of future rainfall, such rainfall could be incorporated in the forecast and a longer warning time achieved. However, quantitative estimates of future precipitation are notoriously uncertain.

Ideally the analysis as described would be made for a number of historical events, and the median value and variability of warning determined. If there were no historical precipitation data for the basin, it would be reasonable to transpose rainfall information from within a hydrometeorologically homogeneous region. If no concurrent precipitation and streamflow data were available for a basin, there would, of course, be additional uncertainty associated with lack of data with which to calibrate the rainfall-runoff model.

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