Application of Velocity Measurements in Flood Warning Systems

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1. Introduction

Warning systems are designed to provide us with high quality data, inform us of critical events, and send alerts in a timely manner. To set up an appropriate Infrastructure (Figure 1) for this to be made possible, it is necessary to choose a sensor with proper frequency, accuracy and precision to collect the appropriate parameters, so that the data can be transformed into useful information to interested parties. This paper describes how continuous velocity and flow data monitoring at a hydrometric station can be used as a predictor of future critical conditions of eminent flooding.

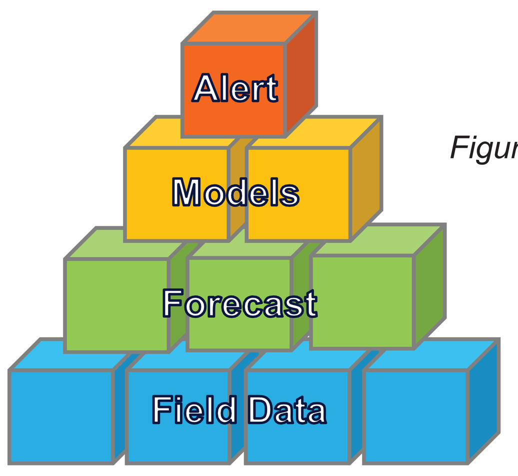


Figure 1. Schematic of the components in a Warning System

2. Limitations of the Stage – Discharge Curve

The stage- discharge curve is a commonly used tool worldwide, to predict future flow conditions based on the water level (elevation). However, there is a vast amount of research that has been done in this area and it suggests that the stage-discharge curve has got its own limitation and does not account for an accurate prediction. Therefore, practical limitations to the use of the stage-discharge curve are, for example:

1. Most curves in use today are drawn from measurements obtained mostly during normal flow conditions. Consequently, a one-to-one relationship between the stage and the flow is often assumed as valid for the whole range of flow in the section. This gets compounded because the data collected during floods, which are necessary for accurate development of key curves, are precisely those with the lowest accuracy and reliability (Fenton and Keller, 2001)

2. The effect of the flood water velocity is not properly considered (it is assumed that the flow is a function of stage). It is possible to observe significantly different flow rates at the same level in a single flood simply depending on when the measurements are made (figure 2).

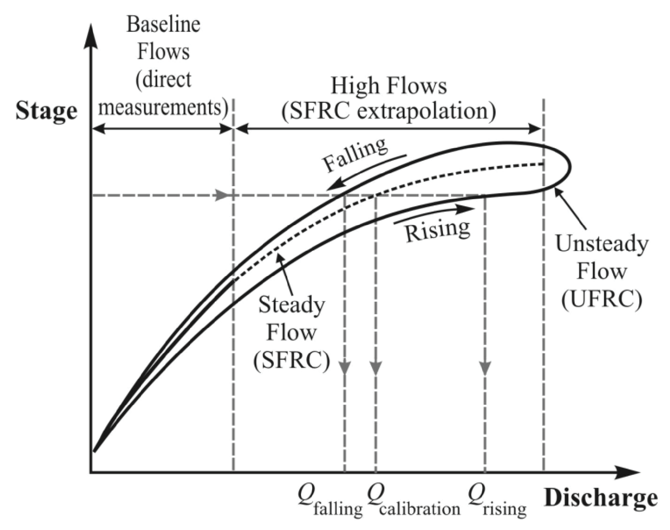


Figure 2. Conceptual example of stage - discharge "in the loop", where two different flow rates for the same water level may be observed depending on when during same event, the measurements are made.

Modificade Muste et al. (2011).

3. Velocity Measurement

Because of the limitations of the earlier mentioned stage – discharge curve it is desirable in many cases to expand the measurements relative to two (or more) parameters, thus creating a more capable means to predict the flow rates in the future. One of the parameters used in this process is the water velocity (Chow, 1959; Rantz et al, 1982a;. Chen and Chiu, 2002; Cheng et al., 2004). For open channels, one of the more effective and efficient technology for measuring velocity is the Doppler effect, due to ease of use, ability to measure velocity profiles, and the flexibility it allows to be installed in various applications and river of various sizes.

Currently, the two most common configurations of Velocity measurements in river flow applications are done using Acoustic Doppler profilers either on the river banks/sides (eg. SonTek SL) or bottom mounted profilers (eg. SonTek IQ). Both types of configurations allow for continuous measurement of velocity profiles and are illustrated in Figure 3 below.

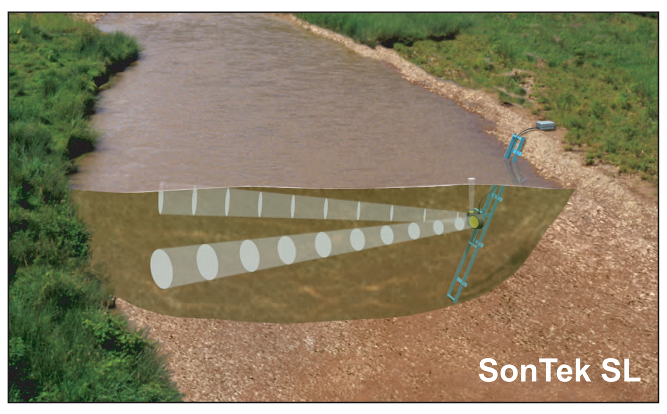
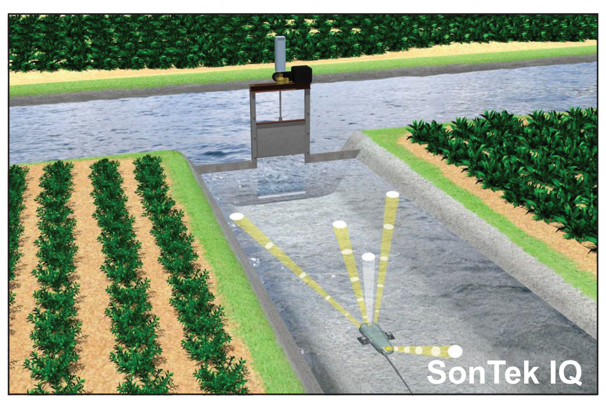
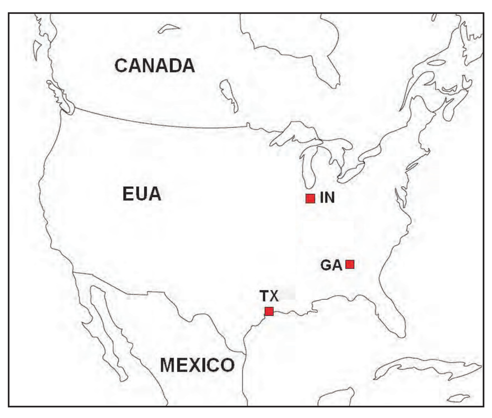


Figure 3. Illustrations of the two most typical configurations of the Acoustic Doppler meters to measure velocity in open channels (lateral, left); (bottom mount, right).



4. Case Study

The velocity of water in a river section is a parameter that is frequently regarded as the best predictor of future conditions. Here we present data from three floods in rivers in the United States that illustrate this. The three stations are located in the states of Georgia (GA), Texas (TX) and Indiana (IN), and cover a variety of conditions. The three positions are part of the hydro-meteorological network of the United States Geological Survey (USGS) and contains an extensive historical series (several decades) of flow and stage data measured every 15 minutes. Then measurements of the flow velocity are also made using Acoustic Doppler sensors at the same sampling rate as the stage data is measured.



USGS
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Figure 4: Map showing the location of the three positions presented in this paper.

Georgia Findings

The GA measurement station is located in a section whose flow is controlled by the Jim Woodruff Dam, located approximately 47 km downstream of the station. A continuous measuring Acoustic Doppler profiler, model SL1500, is installed in one of the bridge supports, as can be seen in Figure 5a. As shown in the data plot in Figure 5b during the flood of 2009, at the station in GA, peak stage and speed are relatively aligned, but the velocity data clearly shows the pulse of the river during the flood, probably due to the backwater effect. During this period of approximately four days if you look at only the stage data, you wouldn't get a good picture of the flow.

Identifier	Basin (km^2)	Mean Width (m)	Mean Stage (m)	Maximum Historical Stage (m)	Maximum Historical Flow (m^3/s)
GA	6.941	102	2,2	9,28 on 24/Sep/2009	2.172 on 24/Sep/2009

Figure 5a. Map and photo of the station at GA. Arrow indicates direction of flow

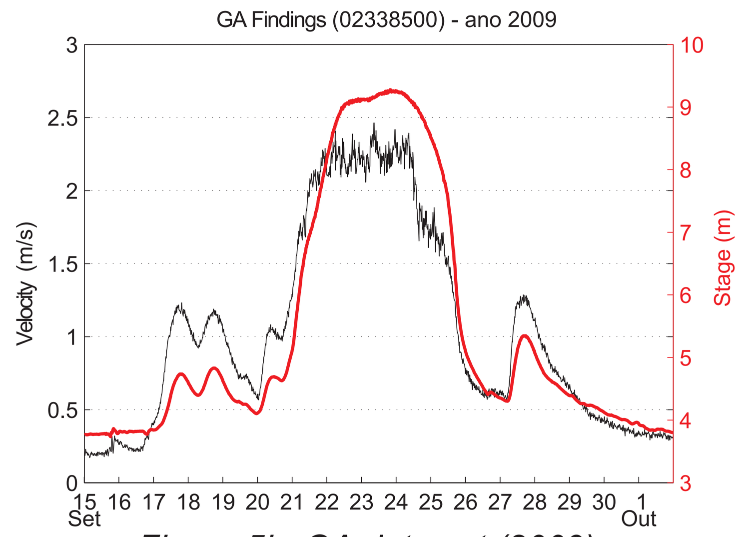

Figure 5b: GA data set (2009)

Texas Findings

This site features a section with a shallow navigation channel set. The station is equipped with a Doppler Velocity Profiler, Model SL500 (Figure 6a, dir.). It is possible to observe the effect of tidal elevation and velocity in this position, allowing the flow to be reversed (negative flow). In terms of warning about flooding during this historic event the maximum speed was observed at 06: 15h on 19th Oct, but the maximum level over 60 hours (2.5 days) was observed at 11:30 on 22nd Oct. In this case, the Velocity data could have been used to alert the city of Beaumont (with a population of 120,000), located 13 km downstream of the station, more than two days in advance of the growing level of the Neches River, when the river was still 1.5 m below the maximum level.

Identifier	Basin (km^2)	Mean Width (m)	Mean Stage (m)	Maximum Historical Stage (m)	Maximum Historical Flow (m^3/s)
TX	25.353	128	0,9	3,58 on 22/Oct/2006	2.713 on 21/Oct/2006

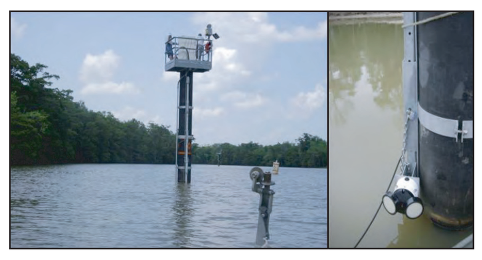

Figure 6a. Map and photo TX position. Arrow indicates direction of the flow

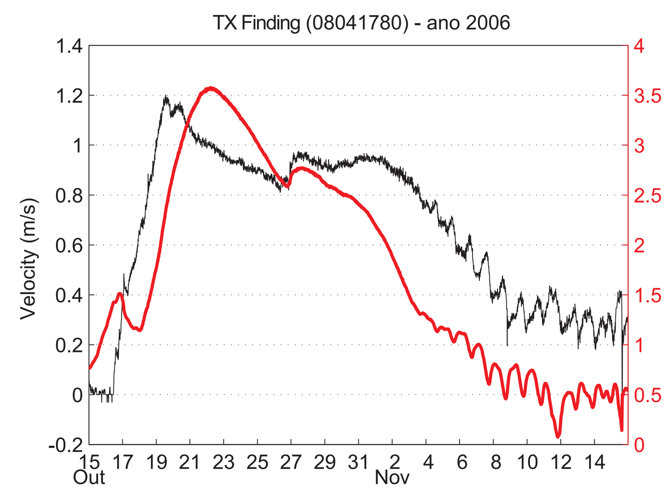

Figure 6b. TX data set (2006)

Indiana Findings

This station is at a third order tributary of the Mississippi River and the observed average speeds are below 0.3 m/s. It is subjected to frequent flooding caused not only by seasonal rainfall, but also by the melting of snow/ice within the basin during the spring. The measurement of velocity and flow calculation at this station are made by an Acoustic Doppler Profiler (SonTek model SL1500). Figure 7b shows three flood occurrences at this station. In each of the flooding, the maximum speed was observed over 12 hours in advance, respectively before the maximum stage. It is interesting to note that in this station, the higher the maximum stage, lesser the time between the peak velocity and the peak stage measured, thus illustrating the importance of an early warning system that can help decision makers to act in a timely manner.

Identifier	Basin (km^2)	Mean Width (m)	Mean Stage (m)	Maximum Historical Stage (m)	Maximum Historical Flow (m^3/s)
IN	1.163	24	1,4	7,44 on 14/Jun/1958	184 on 07/Feb/2008

Figure 7a. Map and photo of IN station. Arrow indicates direction of the flow

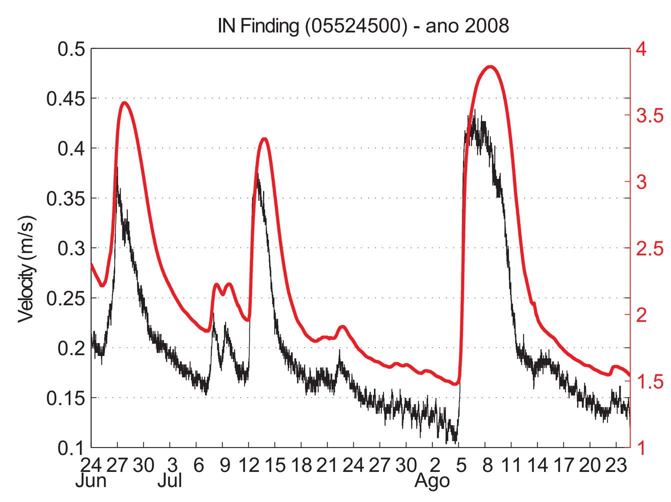

Figura 7b. TX data set (2006)

5. Conclusion

Several factors are required for the flood warning system to have the desired impact and be able to warn the population off an imminent risk. This work showed the importance of these parameters, i.e. The velocity of water in a measuring section continuously and illustrated its application at 3 stations in American rivers. As presented, velocity data are better predictors of risk conditions than just the stage data. Although using the traditional stage – discharge relation produces acceptable estimates of future conditions during periods of normal flow, it has limited usage in cases of floods, and can generate significant errors in extreme cases. The addition of velocity data to stage - discharge curve allows an improvement in the prediction of future conditions. Additionally, in specific cases of floods, knowledge of speed in a section allows the generation of alerts on levels reaching maximum values several hours (or even days) in advance, reducing the risk that the population is at.

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