The WFO Hydrologic Forecast System (WHFS) and Flash Flood Forecasting

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1. Introduction

The Weather Forecast Offices (WFOs) of the National Weather Service (NWS) have meteorological and hydrologic forecast responsibility. Flooding , particularly flash flooding, is a very dangerous weather situation where the WFO staff must react quickly and accurately in order to save lives and property. Flash floods ,which can occur in minutes or hours in headwater basins ,are extremely difficult to identify and forecast with reasonable accuracy. Flash floods are loosely defined as floods which crest within six hours of the causative event.

The WFO staff address their hydrologic/flooding responsibilities by monitoring streams, rivers and rainfall. A variety of data sources including observer reports (precipitation and river stages), automated station reports, radar and satellite information as well as output from a variety of meteorological models provide a basis for their evaluations. The WFOs also receive hydrologic support from other NWS offices including River Forecast Centers (RFCs). Based on all the information and data the WFO staff can gather, they then issue a variety of timely hydrologic products including river products, flash flood watches and warnings.

In some situations, the WFOs also need to develop and issue actual headwater crest forecasts . However, the specific model or procedure to do so is not yet available within AWIPS (Advanced Weather Interactive Processing System) and WHFS (WFO Hydrologic Forecast System) . This paper suggests several simplified headwater forecasting techniques which the WFOs could utilize with their present equipment and software in order to make headwater forecasts until the WFO site specific model is available. . It should be noted that WFOs rely on RFCs to provide them with river and crest forecasts for non-headwater rivers and streams. However, headwater forecasts, which usually crest within a few hours of the onset of heavy rainfall, are often not directly forecast by the RFCs due to the rapid onset of flooding.

2. WHFS Description

WHFS is a hydrologic suite of computer software and is part of the AWIPS software system. AWIPS is the standard computer software system which every WFO in the National Weather Service utilizes to present and review data, analyze output from various models, and to prepare and release all public hydrologic products. WHFS itself is presently comprised of three major sections. They are:

Hydrobase- A relational data base which contains all static and dynamic hydrologic data necessary to run WHFS. Real time stage data, precipitation data, flood stages, locations of observing stations, etc. are all examples of the type of data which reside in Hydrobase.

Hydroview- A subsystem which has graphical and tabular display capabilities. Hydroview enables the forecasters to view maps of rivers including locations of forecast points, displays of precipitation in point and areal format, time series of data, dambreak information, tabular displays of hydrologic data, etc.

Riverpro- A subsystem which enables the forecaster to quickly and easily prepare hydrologic products for release to the public.

WHFS is the primary WFO hydrologic display capability which forecasters can utilize to review hydrologic activity in their area of responsibility, determine the severity of possible flooding, and determine the appropriate course of forecast activity. WHFS is a very sophisticated, reliable and valuable part of the WFO forecasters tools. But, WHFS does not yet contain a site specific hydrologic forecast model which would give the WFO forecasters the ability to develop site specific crest forecasts for flashy, headwater locations.

3. Description of Variables

A discussion of WHFS and it's hydrologic capabilities involves understanding some of the variables utilized. Therefore, a few of the more important concepts and variables will be defined here.

Flash Flood Guidance (FFG)- FFG is the amount of rain falling in a given area which will bring small streams in that area (basin, county or zone) up to flood stage. FFG is developed by most RFCs on a daily basis and provided to the WFOs for their use. FFG is based primarily on current soil moisture conditions.

Flood Stage- The height in feet above an arbitrary datum above which a stream or river will begin to leave its natural channel and begin to cause damage and flooding. Each forecast point on a stream or river is assigned a flood stage by the NWS usually in cooperation with local officials.

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Unit Hydrograph- The hydrograph which represents one inch of runoff from a given basin at a given location. Unit hydrograph theory assumes that similar storms over given basins will result in similarly shaped hydrographs.

Hydrograph- A plot of stage or discharge against time for a given location.

Mean Areal Precipitation (MAP)- MAP is the average rainfall over a given area, generally a basin, from a given storm. MAP can be calculated by several different procedures and can be derived from precipitation gage data, radar data or a combination of gage and radar data.

Discharge- Discharge from a river or stream is the volume of water passing a given point over a given time. Generally expressed in cubic feet per second (cfs) and identified as Q.

Ratings-Ratings are a graphical or tabular display of stage (feet) versus discharge (Q) at a given location on a river. Hydrologic models develop forecasts in discharge (Q). However, to issue public forecasts, Q must be converted to stage (feet) and that is done through a rating. Ratings for a given location can vary from season to season and even day to day and must therefore be periodically updated.

API- Antecedent Precipitation Index- An arbitrary index value which represents the soil moisture in a basin. API is used in many hydrologic models as part of the process in determining runoff.

4. Headwater Forecast Technique

If the RFC provides headwater/basin guidance and the WFO has headwater tables, they should be used. Headwater tables have, over the years, proven to be very effective in developing initial headwater forecasts. However, if headwater tables are not available, or if the WFO needs to make headwater type forecasts for other streams using , say county flash flood guidance, then other simple techniques, such as the following, may be considered.

The WHFS is capable of displaying and manipulating a wide range of hydrologic data. With regard to headwater forecasting, WHFS makes several very important calculations. The first calculation is the development of MAP estimates for headwater basins. The MAP analysis is accomplished through a system referred to as the Stage II processor. Stage II is a complex system of algorithms which takes gage reports and radar data and combines them into a best estimate of rainfall over a given basin, zone or county.. In addition, the forecaster can choose to use MAP estimates based on gage data alone or radar data alone. Usually, however, the best estimate of MAP is the gage/radar combination.

WHFS also utilizes FFG provided for headwater basins and counties by the supporting RFC. WHFS then makes a comparison between MAP and FFG for the selected area of concern. This process is called the flash flood monitoring system. WHFS makes the comparison by either a ratio of MAP and FFG or by a difference between MAP and FFG.

One forecasting technique would be to utilize the difference value. If MAP equals FFG, then the difference is zero and the resulting forecast stage should just equal flood stage. If MAP exceeds FFG, then that amount of precipitation exceeding FFG represents additional potential runoff. If a reasonable amount of the excess precipitation is taken as runoff, say .6, and that value is multiplied times the peak Q for the unit hydrograph , then that Q plus the discharge at flood stage would represent the forecast Q. The forecast Q can then be converted to a forecast stage using the stage/discharge relationship. This technique will yield reasonable results at all flows but it depends on the WFO staff having access to the unit hydrograph for the site in question and the unit hydrograph is not available in WHFS. This technique also involves slightly more calculations than the next technique.

A second technique to consider would be the ratio of the two variables, MAP and FFG. If that ratio is 1, that is MAP equals FFG, then, by definition, the resulting headwater hydrograph should just reach flood stage at its peak. If the ratio is less than 1, the resulting hydrograph would peak below flood stage. If the ratio is greater than 1, the resulting hydrograph would exceed flood stage. The forecasting question is how much higher than flood stage would the hydrograph reach if MAP/FFG exceeds 1.

A simplistic assumption could be made that the additional flow above flood stage flow is directly proportional to the MAP/FFG ratio. This assumption is not exactly correct in many cases, but it is possibly close enough for a first cut at most headwater forecasts. For example, if MAP equals 4 inches, and the FFG is 2 inches, then the ratio of the two variables is equal to 2. If we then multiply the flow at flood stage , by the ratio of MAP and FFG , in this example 2, then we have the estimated forecast peak flow for the headwater basin. Once the Q for peak flow is determined, then that Q can be converted to stage in feet by going to the rating for that location. The advantage of this technique is that it is simple and all the information required is in WHFS.

All of the above information, except unit hydrograph information, is available at all times to the WFO forecaster through the WHFS system running continuously at the WFO. Rainfall estimates including MAP values are continuously available for basins as well as zones and counties. FFG displayable for 1, 3 and 6 hour storm values for counties/zones and headwaters are available at least daily in WHFS. It should be noted that not all RFCs provide these FFG values but most do. Flood stage, Q at flood stage, and stage/discharge ratings are available and can be accessed by the forecaster through the WHFS system. Most importantly, the MAP/FFG ratio is continuously available and displayable.

If the entire forecast hydrograph , and not just the peak flow, is desired then the unit hydrograph would have to be available for the forecast point. A forecast hydrograph could be developed in much the same way as outlined above. The technique would be to take the unit hydrograph, multiply all the ordinates by a ratio of Q at flood stage to the Q peak for the unitgraph and then multiply those ordinates by the MAP/FFG ratio. This will then produce a complete forecast hydrograph whose peak equals the peak forecast flow. The advantage of developing a complete forecast hydrograph instead of just the peak flow is that other information can be provided to the user such as crest timing, the time the stream will begin to exceed flood stage and the time the stream will drop below flood stage.

For the examples below, the time to crest averaged 10 hours with a minimum time to crest of 2 hours at Overland Park, KS to 20 hours at Urich and Blairstown, MO. However, in a short fused flash flood situation, just producing a quick forecast of the hydrograph peak Q and stage is valuable. The site specific forecast capability at the WFO through the WHFS is intended to do just that. It is not intended to replace the major river forecast capabilities of the RFCs.

5. Recent Examples

Early to mid June saw significant rainfall in northeast KS and northwest MO. On the 19th of June, some individual precipitation reports in northeast KS totaled nearly 10 inches. The following table (Table 1) utilizes the MAP/FFG ratios from the WHFS at WFO Pleasant Hill, MO . Those ratios were then applied to six individual headwater forecast points utilizing the procedures outlined above. That is, the MAP/FFG ratio was multiplied by the Q at flood stage to get the forecast Q. The forecast Q was then converted to a forecast crest in feet utilizing the stage/discharge rating at each location. Finally, those forecast peak stages were compared to observed peak stages. Flood stages for each location are also noted.

The headwater locations used in this example are Overland Park, KS on Indian Creek, Easton, KS on Stranger Creek, Valley City , MO on the Blackwater River, Blairstown, MO on Big Creek, Urich, MO on the South Grand River and Muscotah, KS on the Delaware River.

Table 1. Examples of Application of Headwater Forecast Technique

Location	Date	MAP/FFG ratio	Q at flood stage (cfs)	Forecast Q (cfs)	Forecast crest (ft)	Observed crest (ft)	Flood Stage (ft)
Overland Park, KS	6/4/01	1.55	2850	4450	13.6	13.6	12
Overland Park, KS	6/6/01	1.24	2850	3550	12.8	14.1	12
Overland Park, KS	6/1/01	1.22	2850	3550	12.7	11.9	12
Easton, KS	6/20/01	5.23	1812	9600	22.0	25.9*	17
Muscotah, KS	6/20/01	2.94	14700	43200	32.7	29.2	27
Valley City, KS	6/20/01	1.64	4375	7200	25.3	27.3	22
Blairstown, KS	6/20/01	1.59	3071	4900	22.2	23.1	20
Urich, MO	6/20/01	1.42	4035	5750	25.0	27.4	24

*record crest

6. Conclusions

There are sound processing and analysis techniques within WHFS. MAP calculations utilize radar and gage data as well as sophisticated data handling and analysis techniques. FFG calculations are updated daily and represent the latest hydrologic situation (runoff potential, soil moisture characteristics, etc) for each headwater basin. All of this information is available and must be used in the most effective manner in order to produce timely and life saving products for the public.

In the eight examples above, forecasts of stage crests were easily and quickly made based on the data currently available within WHFS. The bias for the eight crest forecasts was -.78 feet and the mean absolute forecast error was 1.8 feet. Considering that these were initial forecasts based solely on the MAP/FFG ratios developed by WHFS and that all were short fused flash flood situations, it is felt that the forecasts were acceptable. In the case of

Easton, KS, this was a record flood event. These initial forecasts, based on WHFS analysis, certainly would have given the communities and emergency action officials an early and reasonable understanding of the flooding situation they were dealing with. Initial forecasts would normally be issued for a range of stage (22-24 feet for example) and would not be issued to the nearest tenth of a foot.

It should be noted that a review by Missouri Basin River Forecast Center (MBRFC) has shown that the ratio technique will work reasonably well for dry initial conditions and crests of minor or moderate flooding. However, as crests exceed moderate flooding and approach major or record flooding, the ratio technique underestimates flow. Note in the table, at Overland Park on 6/4, the forecast crest was equal to the observed crest for a minor flood. However, at Easton, KS the forecast crest was about 4 feet below the observed crest which was a flood of record. The flows at the forecast crest were markedly under forecasted.

A lot of assumptions and estimates are made throughout all forecasting processes. Consider that MAP and FFG values are valuable but they are estimates. Stage/discharge ratings are subject to routine change. Flow measurements are subject to error. Assumptions are made as to the length of storm, intensity of the storm and also the location of the storm with regard to the headwater basin. Assumptions are made relating to basic unit hydrograph theory. The purpose of the initial first forecast in a headwater basin for a flash flood situation is to get reasonably close and do it quickly. Therefore, until a site specific model is added to WHFS, the approximate techniques suggested herein may be helpful in many situations.

It should be added that the Missouri Basin RFC in Pleasant Hill, MO has developed a sophisticated, site specific model for use in WHFS, utilizing an API model. It is currently undergoing testing at the Office of Hydrology. This site specific model should be implemented as quickly as possible to complete the WHFS and to provide robust site specific forecasting capability for the WFO forecasters.

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