

# Integrating streamflow prediction and data into an operational system – the example of flood warning

Jim Elliott  
*Water Division, Bureau of Meteorology*

## Introduction

The aim of this paper is to discuss the issues associated with transforming the predictive capacity of some form of natural process modeling into an operational system. This is done through the example of flood warning, which involves using streamflow prediction modeling to forecast future flood levels and to use that forecast information to provide a flood warning service. There are considerations in this example that are peculiar to flood forecasting and warning, but the aim is to use flood warning as a case study to illustrate the need for an integrated approach when transforming any predictive modeling capacity into an operational system.

## An operational system for flood warning

An operational system is essentially an information system designed to support the operation of a particular business. In the case of flood warning, it is the system that supports the production and dissemination of warning and other flood information aimed at reducing the damaging impacts of floods. A schematic of the Bureau of Meteorology operational flood forecasting system is shown in Figure 1. This system supports the transformation of data and other inputs into products that

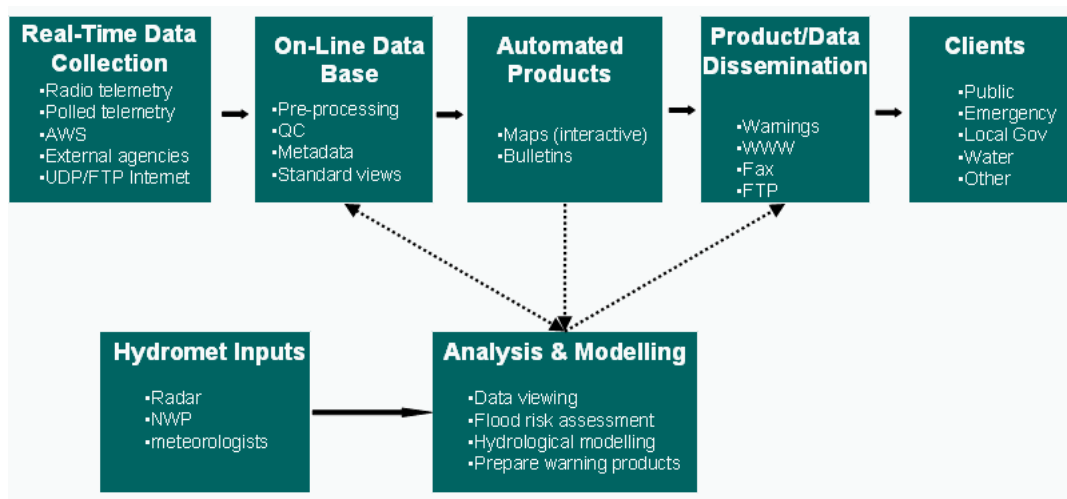


Fig. 1. Schematic of Bureau of Meteorology Operational Flood Forecasting System

contribute to this damage reduction, by providing agencies and people at risk with advance information about future flood conditions. An obvious requirement of a flood warning system is to be able to accurately predict future flood conditions with sufficient lead time to enable effective protection action to be taken. Clearly streamflow prediction and the data required to operate the prediction model are key technical inputs to an effective system; but they are not **the**

system. Streamflow prediction must work in harmony with all other system components in an integrated way if the objectives of the operational system are to be achieved efficiently and effectively. Some of the influences that have shaped this integration for the Bureau operational flood forecasting system are discussed in the following in terms of a number of general characteristics of many operational systems in order to illustrate this point.

## **System purpose**

The outcome to be achieved from the system should be kept in clear view. What is the system trying to achieve? Who are the target group and what do they need from the system? In the case of flood warning the aim is to reduce the risk to loss of life and property damage by providing information both directly to those at risk, as well as to agencies involved in flood emergency management. Accurate streamflow predictions are crucial some of the time during an event, but not at others. For example long lead time, but uncertain forecasts can be very helpful in the early stages of an event when the benefits of being prepared early can outweigh the cost should the flood not eventuate. Flash flood warning is another example when effective warning response will only require a *flood* or *no flood* prediction rather than specific levels of flooding. This is not saying that accurate streamflow predictions are not important, but by focusing more on the outcome from (or purpose of) the system, their relative importance in the context of other components of the operational system can be better assessed.

## **Output products**

What output products does the system need to produce to achieve the outcome? The product needs to match the requirements of the recipient (response agency, public) and may not always require a precise streamflow prediction. Although the current forecasting system does routinely produce forecast streamflow hydrographs, the more common output product is a worded warning message based on this hydrograph; often with some interpretation and indication of degree of certainty. Much less commonly, the hydrograph can be shared with selected clients judged to be able to interpret it appropriately. The issue of uncertainty is relevant here too, as it is not clear that warning clients are yet able to fully utilize the quantitative information on uncertainty being generated by modern prediction systems. The choice, and investments to be made in the streamflow prediction component needs to take consideration of this range of needs.

## **Data issues**

The primary data inputs to the flood forecasting and warning system are rainfall and river level observations collected through the real-time data collection network. This network utilizes a range of technologies and cooperative arrangements and the assimilation of these data into a useable data set is a significant component of an operational flood forecasting system. This data set must serve the needs (timeliness, format, etc) of the streamflow prediction system used as well as other operational products. The issues involved with integrating these data into an operational system include dealing with missing data, interpolating data into regular intervals, blending multiple data streams from a single site, voiding obviously erroneous data, etc. Some of this can be done immediately prior to, and during a flood event, but data preparation must be as up-to-date as possible to enable the system to go operational with as little delay as possible. Much of this can be automated but not all, and so the system needs to provide the capability for users to intervene in order to adjust data in particular situations.

## **Model issues**

While there is a wide choice of models available for streamflow prediction, the characteristics of the flood warning problem make some more suited to the task than others, and the operation of the model needs to be integrated with other characteristics of the operational system. As indicated above, the warning requirement can be such that a refined model may not be justified to achieve the system outcome and care should be taken not to over-model. Simple models can give perfectly adequate results in many cases and have the advantage that users can more readily relate to a model built on simple concepts, which can facilitate user-intervention during critical stages of certain events in order to “correct” the model. While objective updating techniques can be used here, the ability to inject the experience of the operator through manual adjustments to the model can often be superior.

Ideally the modelling system should be set up so that on-line verification is supported such as to provide an objective basis for considering when to implement new or improved models. It is important that such a verification system be designed around performance statistics that best match the use of the model output in the warning context. For example the normal model evaluation statistics for streamflow simulation that focus on overall hydrograph reproduction are less relevant for flood forecasting, where the ability to forecast the rising limb or the exceedance of particular thresholds can be most important. The ability of the system to offer users a choice of models can be an advantage, particularly where it is found that certain models work best in particular flood situations.

Forecasting models need to operate at incremental time steps to match the way the data becomes available rather than in a “simulation” mode more common for hydrological models. Many research models are not developed in this mode and so some modification may be necessary before the model can be integrated into the operational system. Re-calibration (or verification) of the model after each event is necessary to ensure the information from each new event is “captured” in the model. To facilitate this, the Bureau system is set up so that calibration is undertaken in the same “system” that is used operationally. This ensures that the model calibration is adjusted in a manner consistent with its proposed operation.

## **Operational and user requirements**

The circumstances under which the system needs to be operated needs to be considered. Does the demand for outputs from the system follow a regular predictable pattern, or is it random? For a flood warning system, the demand is unpredictable and so the system must be in a constant state of readiness. This requires that data must be continually up to date and the streamflow prediction model ready to operate at the required time interval to match the flooding pattern.

The requirements of system users are also an important input to the system design. In the case of flood forecasting, the system has many users in all of the national forecasting offices of the Bureau. As discussed above, the requirement to operate the system is not always predictable and so a web-based design has been followed so that users can access the system from home as well as the office. Remote operation allows the forecaster to be able to respond to a quickly developing situation as well as monitoring a flood situation remotely when conditions are suitable. Having the same “national” system in all forecasting offices means that users moving between offices when (for example) workloads in one part of the country are particularly high, can become productive more quickly.

## **Other inputs and interactions**

In the case of flood forecasting, inputs of meteorological forecasts are critical at both the early developing stages of a flood as well as during the event. Although confidence in the quality of rainfall forecasts from numerical weather modeling systems is increasing, this input can still be quite qualitative and the operational system must be designed to make best use of the information in this form. The current system does this by providing for the sensitivity of the flood forecast to different meteorological forecasts to be tested in order to evaluate the impact of the uncertainty before issuing the warning. Increasingly meteorological forecasting involves more quantitative information on uncertainty and the streamflow prediction system needs to be structured such that this information can be sensibly used. As discussed above, whether or not the ultimate clients can utilise the detail in this information is another issue.

## **Feedback**

Most operational systems have some form of feedback. In the case of flood forecasting this includes the observations of flood levels that are used to adjust or update the streamflow prediction model in order to improve its performance for later forecasts. Feedback from response agencies in terms of the relationship between current flood levels and whether critical threshold levels (eg. levee over-topping) are being approached is also important, as this can provide more specific accuracy and timeliness targets for the streamflow prediction model at that particular time of the event. Observations in the field can also prove invaluable during an event as a check that automated observation systems are functioning correctly.

## **Support and maintenance**

The support and maintenance required for operational systems depends on its role and the consequences of outages. This aspect is often overlooked and under funded. In the case of flood forecasting, clearly the emergency nature of the operation of the system means that a robust system is required. This is not just confined to considerations such as IT infrastructure and its support, but includes building in features such as redundant data inputs and flows and choosing streamflow prediction models that are robust to missing data or work adequately with degraded data inputs. Maintenance of the metadata that supports the overall operation of the system is also important. Experience with the current flood forecasting operational system is that the effort required to maintain the integrity of the data inputs, metadata, responding to system configuration changes etc significantly outweighs the effort involved in streamflow prediction model calibration and maintenance.

## **Conclusion**

Building an effective operational system involves many more considerations than just the operation of some form of prediction model. Issues such as the overall outcome expected from the system, its operating environment, characteristics of the operators and operations, data inputs and the level of operational robustness expected are also critical. Some of the influences of these factors on the design and development of the Bureau's operational flood forecasting system have been discussed as a case study to illustrate this point.