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Discussion

A new joint probability appraisal of flood risk

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The paper contains an assessment of the joint tidal/fluvial flooding frequency in Cardiff, post-impoundment of the rivers Taff and Ely. The paper is a good example of the application of the technique developed some years ago at the Institute of Hydrology.[8]

A state-of-the-art application is important, as issues related to climate change, and the proper consideration of joint events in coastal areas, are set to increase,[9] and whereas schemes such as Cardiff Bay justify separate studies, smaller schemes need a more generic approach.

The paper makes reference to the use of synthetic time series. Care needs to be exercised with these approaches, especially if the peak-to-peak lag between the tide and fluvial flow is to be considered. The dominance of the large events in such series and the randomness of lags require that the series be run a number of times to include all phases.[10]

The work on the correlation between the tides and rainfall is useful, but does the large size of the Severn tide, coupled with the relatively small size of the more weather-related surge, mean that this lack of correlation may be a local phenomenon?

The paper uses a full hydrodynamic model of the estuary behaviour; given that the retained water behind the barrage is essentially flat, would a reservoir routeing type approach be more reasonable?[11] This could then possibly be coupled to some steady analysis up the river if information is required in those areas. Although the model used is clearly superior, its cost may lead users to discard what might be some important aspects, for example the seasonality of both storms and tides, and the very important lag between the tide and river peaks. The authors refer to the use of hand calculation and interpolation of the results, but it is difficult to judge the extent of their use. The text suggest a cumulative exceedance probability function of tide height with 75 intervals; could the authors indicate the discretisation used for both distributions and the resulting number of combinations contained within Fig. 1? In that context could the authors explain the statement that the horizontal and vertical strips required averaging?

In order to test, for example, a failure scenario at a sluice gate, the approach adopted would require the entire work to effectively be repeated. To develop a 'design approach' it would be useful to see, for example, what events make up a level between 6·9 and 7·1 m. Fig. 2 suggests that by 2100, with a rise in sea level of 0·55 m, the effect on the 1000 return period event is about 0·5 m. This, when viewed with the S shapes of Fig. 1, suggests that the 1 m event is dominated by average rather than extreme events. Some work on unimpounded estuaries, which is a more difficult situation, has previously indicated[12] that such a design approach is feasible.

Authors reply

The authors are grateful to Professor Hughes for his interest in their paper and for his comments, which draw attention to some important issues and to relevant work done at Cardiff University.

The assessment of joint probability for fluvial–tidal interactions goes back several decades, with the work in the late 1960s of Van der Made[13] being an example for the determination of the design flood levels in the Rhine Estuary. However, with the development of computational modelling as a standard tool in recent years, these assessments are feasible in the context of many projects, especially where changing risks from sea level rise or changes in rainfall are important.

It is agreed that care is needed in the use of synthetic time series, particularly in the relative timing of the events. The initial level–duration–frequency analysis work at HR Wallingford[2] addressed this issue by digitising the original flow-gauging charts for the most significant floods, inserting this information in the automatically synthesised flow sequence from mean-daily observations. Certainly sensitivity testing would have been needed had these charts not been available and the flow synthesised from rainfall records.

Professor Hughes conjectures that the lack of correlation tide and rainfall might be a local phenomenon. There is no physical reason for any correlation between astronomic tide-generating forces and rainfall. As explained in the paper, there is likely to be correlation between the atmospheric surge and rainfall from the same weather system; however, the consequent river flow is delayed through hydrological processes, and there is no correlation between surge and flow into Cardiff Bay. This behaviour is to be expected on all catchments where the time of concentration for the river flood exceeds the duration of a surge event and thus is not just of local significance to Cardiff Bay.

It would have been possible to undertake the analysis described in the paper using a reservoir routeing model, provided that included a computation of water level and not just flow rates. The hydrodynamic model ISIS was used partly for convenience as it was already available from other studies complete with the representation of the sluices in the Barrage, but ISIS is also recognised by the Environment Agency as an appropriate tool for flood defence assessments. With the widespread availability of quality-assured hydrodynamic river models within civil engineering consultancies, we see no real need to construct site-specific reservoir routeing codes, at least for investigations of the scale of the one reported in the paper.

The hand interpolation and extrapolation undertaken was in the assessment of the shape of the structure function curves for the Inland Bay, which are given in Fig. 1. Most of the 230 ISIS model results for combinations of tide and river flow were on a grid of 0·5 m in terms of high tide level and 100 m^3/s in terms of peak discharge, with some infilling or coarsening of this grid based upon the initial results obtained. The intention was to provide computations in the area of interest—peak water levels in the bay between 5 m and 9 m OD. The interpolation and extrapolation was necessary to define the structure function at the required water levels (e.g. 7·5 or 8·0 m), as none of the ISIS runs achieved the chosen water levels precisely. Where a required point on the structure function curve lay within the range of computed levels, linear interpolation was used to determine the required condition. Care was taken with the use of extrapolation outside the range of the computations, with additional simulations being undertaken if needed.

The cumulative exceedance probability function (CEPF) for the tidal conditions was based upon the 'countback' approach for levels at 7·3 m or less and a class interval of 0·1 m (that is, the 19624 tides were categorised into bands or classes from 1·6 to 1·7 m, 1·7 to 1·8 m etc.). The higher water levels were likely to contain a surge component, and this was determined from fitting an extreme value distribution to the observed water levels in the Bristol Channel. From a combination of these two sources the CEPF was calculated for each 0·1 m step of tide level from 1·5 m to 7·3 m OD and then as a fitted continuous line on a GEV plot for all higher water levels. For the river flows, the CEPF was developed as a continuous analytic function, which was programmed into the Excel spreadsheet used for the numerical integration of the joint probability. The equation fitted was:

$$Q = 30{\cdot}355x^2 + 60{\cdot}348x$$

where Q is the total peak instantaneous river discharge into the bay and $x = -\log_{10}(\text{CEPF})$. This function was fitted using Excel on the flows assessed as described in Table 2 and had an R^2 coefficient of 0·9996. The nature of the CEPF for tide and river flow and the shape of the structure functions prevented analytic integration from being used to evaluate the joint probability values: thus numerical integration was used. The numerical integration algorithm in Excel gave slightly different results when the 'vertical' strips (that is, parallel to the tide level axis) or 'horizontal' strips (parallel to the discharge axis) were used. The discrepancy was due to the width of strips and numerical quadrature methods chosen. The averaging of the two results was a pragmatic choice to reduce the uncertainty in the end result, but this could also have been achieved (at greater cost) by adjusting the integration method or the width of the strips of the integration.

It is acknowledged that, to test the scenario of a gate failure, the analysis must be repeated, as a gate failure will alter the shape of the structure function for the water level in the Bay. The suggestion that a 'design approach' might be used suggests that the design should focus on a few 'typical' events. This was the approach adopted for the Cardiff Bay Barrage, and the point of the paper is to show the degree of conservatism that this approach gave. The design conditions (approximately 8·0 m OD) were supposed to represent the 100-year flood defence standard, but the reports presented as evidence for the Parliamentary Bill for the Barrage indicated that this was conservative but to an unknown degree. The joint probability appraisal in the paper reveals the degree of conservatism, with the design achieving at least an 8100-year standard for 1990 conditions and at least a 1600-year standard for the sea level rise scenario for 2100. It is our opinion that this type of joint probability appraisal should be undertaken as standard best practice whenever the costs of dealing with uncertainties in the more traditional design approach justify the modest effort required for the work. The work described in the paper took about seven man-weeks of effort to complete with a dedicated PC for the task.

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