COASTAL ZONE CONJUNCTIVE FLOOD MODELLING

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Abstract

The paper draws attention to the need for coastal zone flood analysis and mapping to be based on a conjunctive approach which combines the annual probabilities or average return intervals (ARIs) of storm events on catchments (meteorologic) discharging against essentially *unknown* sea conditions (primarily astronomic). As a first step, the local conjunctive probabilities of exceedence of flood levels throughout the flood-prone zone need to determined. A broad methodology to achieve this through a ‘Monte Carlo’ approach of couching a hydrodynamic model within a stochastic shell is described. This allows the undertaking of a large set of ‘flood scenario trials’ against a randomly selected starting-point (and subsequent) sea level condition from a long record. As a second step, the local probabilities of exceedence then need to be combined with the annual exceedence probabilities (AEPs) of the storm events to obtain the conjunctive probability of exceedence or its inverse, the conjunctive ARI. Storm event categorisation is typically in terms of intensity, duration and frequency (IDF) which means that pre-selection of both ARIs and storm durations must be made for rainstorm intensities to be uniquely defined. A storm duration analysis must then be carried out to complete the analysis.

Key Words: ARI storm-events (meteorologic), tidal levels (astronomic), conjunctive flood analyses, hydrodynamic modelling

1 Introduction

Coastal zone flood modelling requires the combining of storm-event runoff (the upstream boundary condition) with the ‘unknown’ sea level (the downstream boundary condition) against which the upland floodwaters discharge.

Rising sea levels associated with climate change brings the need for such conjunctive flood modelling into sharp focus. The spotlight is now on realistic coastal zone flood mapping and no longer is it sufficient to produce flood maps simply nominating the storm-event Average Return Interval (ARI) with the annotated qualifier of perhaps an assumed ‘high’ or ‘mean’ sea-level. Risk analysis, the value of coastal real-estate and the propensity for litigation demands a more rigorous analysis.

The presentation illustrates a procedure whereby hydrodynamic modelling is used to construct local probabilities for all levels of inundation in the flood-prone zone by the carrying out of numerous Monte Carlo trials. This places a huge demand on the accuracy, robustness and speed of the hydrodynamic model computations which are no longer ‘single shot’ runs. The conjunctive analysis of combining storm-event probabilities with the local probabilities for all levels throughout the flood-prone zone is then required.

Rainstorm events are typically categorised with three parameters; intensity, duration and frequency (IDF). This indicates that a further analysis must enter into the overall procedure, that of a duration analysis. This then allows the determination of flood contours carrying return intervals without qualification.

Use of the procedure is shown for the MFP Barker Inlet Coastal Wetlands in Adelaide and for the tidal wetlands and flood channels of Sydney’s Olympic site at Homebush Bay.

2 The Approach

Consulting briefs for coastal zone flood studies typically recognise a hydrologic component to determine flood hydrographs off catchments and the need for some, generally unspecified, sea level to be used as a downstream boundary condition. This might take the form of a full tidal signal or one that is attenuated by e,g. a beach berm at the mouth of an estuary or perhaps a severe bridge section. In any event, the industry has long recognized an elusive component.

The two occurrences of rising sea level and present-day readily accessible computational power provide impetus for the following conjunctive approach to coastal zone flood modelling as an appropriate means of addressing this *'unknown'*.

Figure 1 schematizes the prototype problem.

Hydrologic model

A hydrologic catchment model is required to turn rainfall into runoff (high enough up in the catchment to be outside the tidal influence) for a range of representative frequencies (ARIs) and storm durations.

Hydrodynamic model within stochastic shell

A hydrodynamic model is then required to route the resulting flood through the flood-prone zone using a downstream (seaward) boundary condition. This boundary condition is obtained by randomly entering a long (10's of years) sea level record to yield the starting-point and subsequent time-series of sea level against which the flood discharges. Such a procedure constitutes a Monte Carlo trial of which several hundred need to be carried out so that, by tallying exceedence (i.e. number of times a particular level is reached), for all chosen representative levels at all chosen representative sites (grid locations) the local relative frequencies of exceedence can be determined. These relative frequencies tend towards the conjunctive local probability as the number of Monte Carlo trials is increased. [A complete Monte Carlo statistical experiment comprising 5 ARIs, 4 storm durations and the carrying out of say 500 trials per combination, would constitute 10,000 trial routings.]

Conjunctive annual probability of exceedence

Taking the sea level and the meteorological storm events as independent, the conjunctive annual probability of exceedence for each chosen level is determined by the product rule for the probability of simultaneous occurrence of independent events.

Duration analysis

To complete the conjunctive analysis, a duration analysis (undertaken by the Bureau of Meteorology) is required on a long rainfall record to provide information on the way in which the storm durations are correlated. This allows the flood-level versus conjunctive ARI curves for all chosen durations to be combined into a final envelope curve.

A note on the choice of hydrodynamic model

Given the central role of the hydrodynamic model as a representation of the physical situation, it is worth commenting further on the need for its accuracy, robustness and speed in the context of this paper. A one-dimensional channel network model with facility for floodplain storage is generally favoured over a two-dimensional model. There are three fundamental reasons for this.

- First, flood flows are generally directional following flood channels and spilling onto floodplains as overbank flow with the associated momentum transfer in the transverse direction being considerably less than in the main channel direction. (Where it is of interest a local two-dimensional model can be used.)

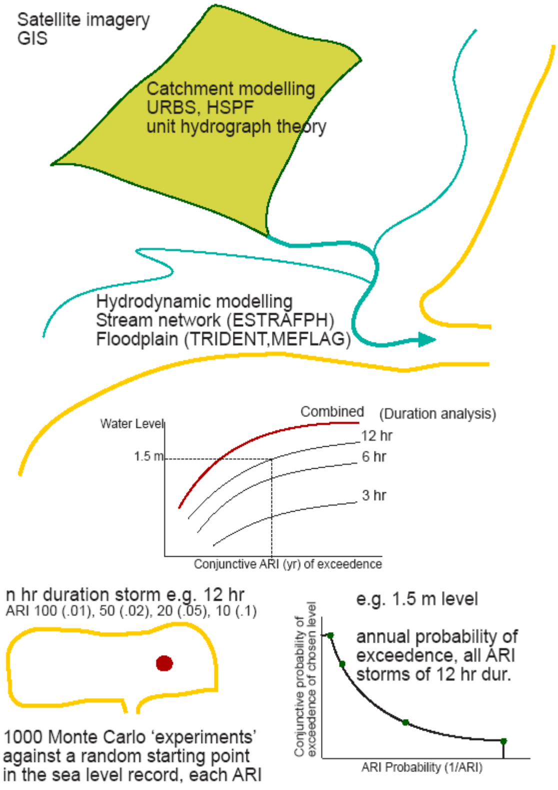
- Second, a one-dimensional model is better suited to the implementation of in-line hydraulic controls (via rating curves) which are of paramount importance.

- Third, in a one-dimensional model, defined by cross-sections, the difficult task of implementing a moving boundary does not arise. This is in sharp contrast to a two-dimensional model where a moving boundary can cause run instability.

Mapping

Just as the flood investigation would start with the land contours in the flood-prone zone as a layer in GIS, the flood mapping also proceeds as a layer in GIS through the plotting of the flood contour for any chosen conjunctive ARI.

Fig 1 Approach to conjunctive coastal zone flooding
(You don't know what the sea is doing when the upland flood hits!)



3 Illustrations

Case 1 MFP Barker Inlet Coastal Wetlands

The MFP Barker Inlet Coastal Wetlands were designed as the receiving waterbodies for the drainage from Adelaide's northern suburbs (4500 ha). Being located adjacent to North Arm Creek (of the Port River Waterways), the wetland system was designed as a freshwater and marine water system for biodiversity (Fig 2). A conjunctive analysis for wetland flood levels was undertaken.

The approach outlined above was implemented, this time using ILSAX as the urban hydrologic model and a simple two-basin routing as the dynamic model.

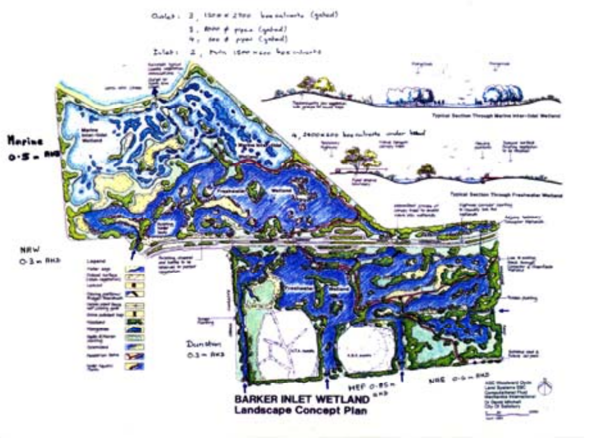


Fig 2 Barker Inlet Wetland – Landscape Concept Plan

As indicated, the wetlands were schematized as a two-basin system, this being a quite reasonable representation (Fig 3) allowing emphasis to be placed on the ratings for the hydraulic controls (a culvert system, a sharp-crested weir with a second set of culverts, a dividing bund as a submerged broad-crested weir and an ungated inflow/outflow aperture in the sea wall).

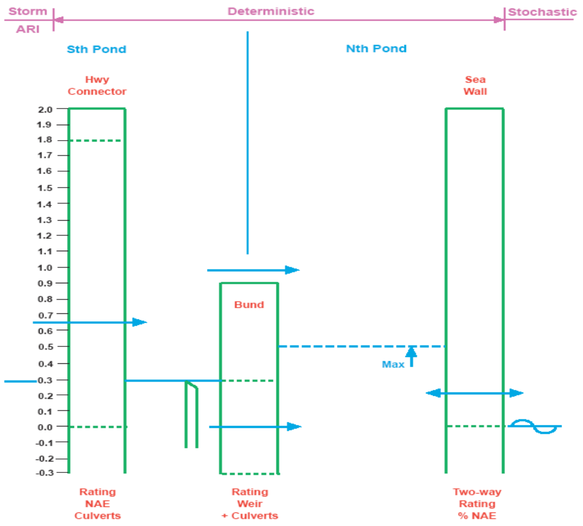


Fig 3 Schematic of two-basins with control structures

The following figure shows the results of the analysis for the individual storm durations and their combination as an envelope curve.

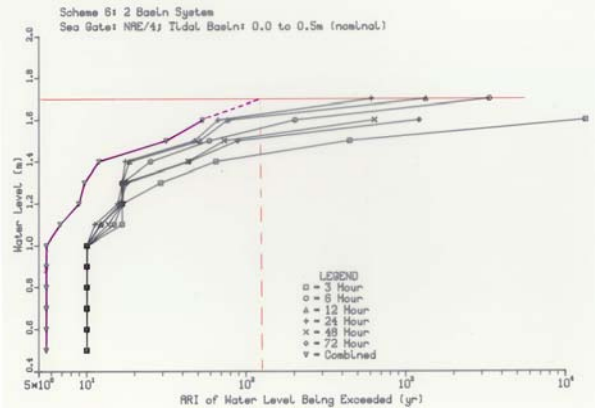


Fig 4 Water level vs conjunctive ARI for specific config.

The analysis allowed the design of the wetlands and control structures to proceed with particular interest in the sizing of the ungated aperture in the sea wall. With this sea-gate sized as 1/4th the capacity of the first culvert system through the highway connector, the 1.7 m water level was shown to have in excess of a 100 year level of protection. With the sea-gate sized as 1/6th the highway connector culvert capacity, the level of protection dropped to about 50 years.

Case 2 Sydney Olympic Site – Homebush Bay

In a similar manner, the tidal wetlands and floodways for the 2000 Olympic site at Homebush Bay was designed with the aid of hydrodynamic modelling to test design options as they arose. With acquisition of the adjacent Newington naval depot, the flood capacity of the tidally influenced Haslams Creek, was enhanced by construction of a floodway adjacent to the Olympic Village and known as the Newington freshwater wetlands and floodway as in the figure below.

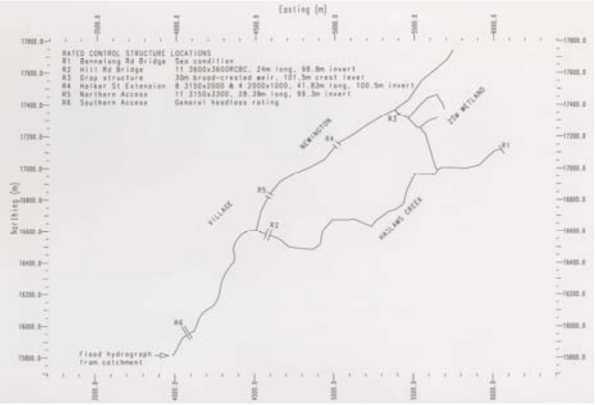


Fig 5 Schematic of waterways and control structures – Homebush Bay

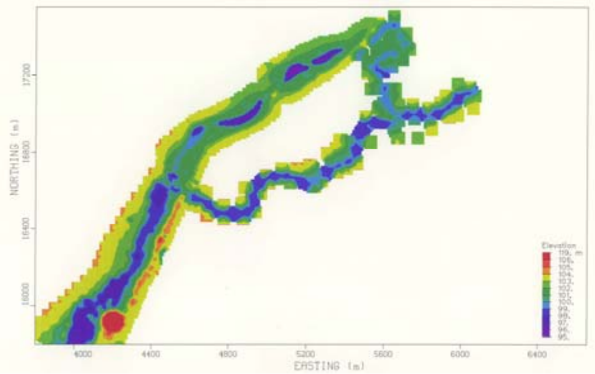


Fig 6 Bathymetry of the Homebush Bay waterways

The need for a conjunctive flood investigation arose to address the question of the level of protection that the final site configuration afforded to the 'short-out' level of the 2SM radio antenna (level 1.67 m AHD). In this case, continuing use was made of the full hydrodynamic channel network model ESTRAFPH (ESTuary River And Flood Plain Hydrodynamics) developed by Computational Fluid Mechanics.

The model was configured to the bathymetry of the site as shown in Fig 6 with 99 cross-sections and with emphasis placed on the determination of the ratings for the 6 hydraulic controls structures shown in Fig 5.

ESTRAFPH is based on the renown Preissmann 4-point operator and retains an accurate, fast and diagonally dominant system solver for dendritic and multiply-connected channel systems. It proved entirely suitable for the conjunctive analysis undertaken on a DEC 4/166 Alpha Server.

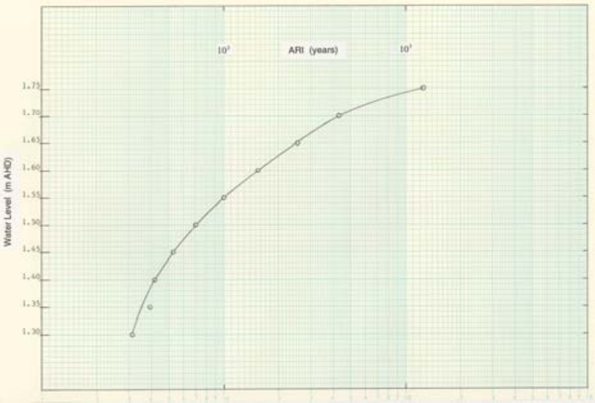


Fig 7 Conjunctive ARIs for 2SM site – Homebush Bay

The conjunctive ARI level of protection for the 2SM short-out level was found to be 300 yrs.

4 Concluding Remarks

The resulting water level vs conjunctive ARI envelope curves obtained through a conjunctive approach to flood analysis as outlined above and over the domain of interest are the basis for the flood mapping of iso-probability flood contours given as conjunctive ARIs. They incorporate the combined effect of storm event ARIs (all durations) and the ‘unknown’ sea condition that catchment runoff discharges against. They need no qualification.

The approach outlined is computationally intensive and is seen to place a huge demand on a hydrodynamic model set to run over thousands of Monte Carlo trials within a stochastic shell. This places a focus on the numerical algorithm employed and the preference to preserve a diagonally symmetric system solver even for dendritic and multiply-connected channel systems which naturally produce sparse systems. It is the solution algorithm which influences the accuracy, robustness and speed of the hydrodynamic model.

A limitation in the analysis is the assumed independence between the sea levels and the meteorological storm events. This would not be a limitation if just tidal levels were generated and used in a conjunctive analysis since astronomic and meteorologic events are independent.

It is the use of an actual sea level record that introduces the limitation to the assumption since such a record contains the effect of high & low pressure cells and storm surge effects. This indicates the need for a further analysis to determine the correlation between, for example, storm surge effects and rainstorm events. A knowledge of this correlation would then allow a further adjustment of probabilities in perhaps much the same way as the correlation between storm durations is utilised in apportioning their contributing probabilities.