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Thresholds for estuarine compound flooding using a combined hydrodynamic–statistical modelling approach

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S1. Description of method for DEM generation

A number of sources were combined to generate the land elevation data required to build the model, including (a) seabed bathymetry, (b) land elevations and (c) location and heights of existing flood defences.

a. Seabed bathymetry for the Menai Strait, Conwy Bay and the mouth of the Conwy estuary extending upstream to the Conwy Bridge were obtained from marine Digital Elevation Models (DEMs) distributed by OceanWise (https://www.oceanwise.eu/) and made available through Digimap (https://digimap.edina.ac.uk/). These marine DEMs consist of bed elevations measured with single- and multibeam sonar sensors and converted into raster tiles of 1 Arc Second horizontal resolution. They are referenced to the WGS 1984 coordinate system and the recorded bathymetry is referenced to the local Chart Datum (CD) at Llandudno.
b. The majority of land elevations for this catchment (73%) have been surveyed by Natural Resources Wales (NRW) using Light Detection and Ranging (Lidar) technology through a series of aerial surveys spanning multiple years. The composite-derived Digital Terrain and Surface Models (DTMs and DSMs, respectively) were obtained from Digimap. The raster tiles have 1 m resolution, are projected to the British National Grid (OSGB36) and the elevations are referenced to the national Ordnance Survey vertical datum at Newlyn (OD) with a ± 0.15 m RMSE accuracy. The difference between DTMs and DSMs is that the former represents earth terrain and as such has all 'above-surface' features (e.g. vegetation, human-made structures) removed, which are included in the latter. Elevation data for the remaining land areas not covered by the Lidar-based composites (27%) were extracted from the Ordnance Survey OS Terrain 5 m DTM also available through Digimap. This lower-resolution dataset has national coverage and consists of elevation data obtained from multiple sources including airborne Lidar, photogrammetry and field surveys. The data are provided as raster tiles of 5 m resolution projected to OSGB36 with elevations referenced to OD.
c. Locations and heights of flood defences were obtained from the NRW data catalogue (https://datamap.gov.wales/). These data consist of vector shapefiles projected to the British National Grid with polylines detailing the location of flood defences including information on the type of defence (e.g. wall, embankment) and the height of the crest above the terrain in metres.

All spatial data outlined above were imported into ArcGIS Pro 3.0 and processed to generate the model domain. The domain topography was based on the marine DEM, Lidar DTM and OS Terrain 5m DTM. The Lidar DSM data was used to check and, where necessary, augment the flood defences vector database, described below and Figure S1.

a. Individual raster files pertaining to the various datasets outlined above were mosaiced into a single raster tile and resampled to 5 m resolution using a bilinear interpolation method.
b. The marine DEM was projected to OSGB36 and converted from the Llandudno CD to OD, by subtracting the offset between the two datums as documented by the National Tidal and Sea Level Facility (https://ntslf.org/tides/datum) using $Elevation_{OD} = Elevation_{CD} - 3.85$ m.
c. Where marine DEM, Lidar DTM and OS Terrain 5 m DTM overlaid each other, they were masked accordingly so that only a single elevation would correspond to each unique location of the model domain. Specifically, for areas that are permanently underwater the marine DEM was prioritised with Lidar DTM and OS Terrain 5 m DTM used to fill any potential gaps. Conversely, for land areas, the Lidar DTM was prioritised with OS Terrain 5 m DTM used to fill any potential gaps.
d. To generate a continuous surface, the raster data from all sources were mosaiced into a single raster and then converted to points with each unique raster cell being represented by a single point. These point data were then interpolated into a continuous surface that covered the complete extent of the model domain. The topo to raster interpolation method was

used with the resulting surface having a resolution of 20 m. A 20 m resolution was chosen because it was found that it retains a good level of domain detail while keeping the computational cost of model simulations to an acceptable level.

e. The vector polylines representing flood defences were manually checked against the Lidar DSM datasets to identify existing flood defences that had not been incorporated yet into the NRW databases. These were manually digitised with the crest height estimated from the DSM elevations.

f. The augmented vector polylines were converted to polygons by applying a buffer of 20 m and then to rasters of 20 m resolution which were subsequently added to the surface created earlier (step d) thus generating a final model domain of continuous surface elevations including existing flood defences.

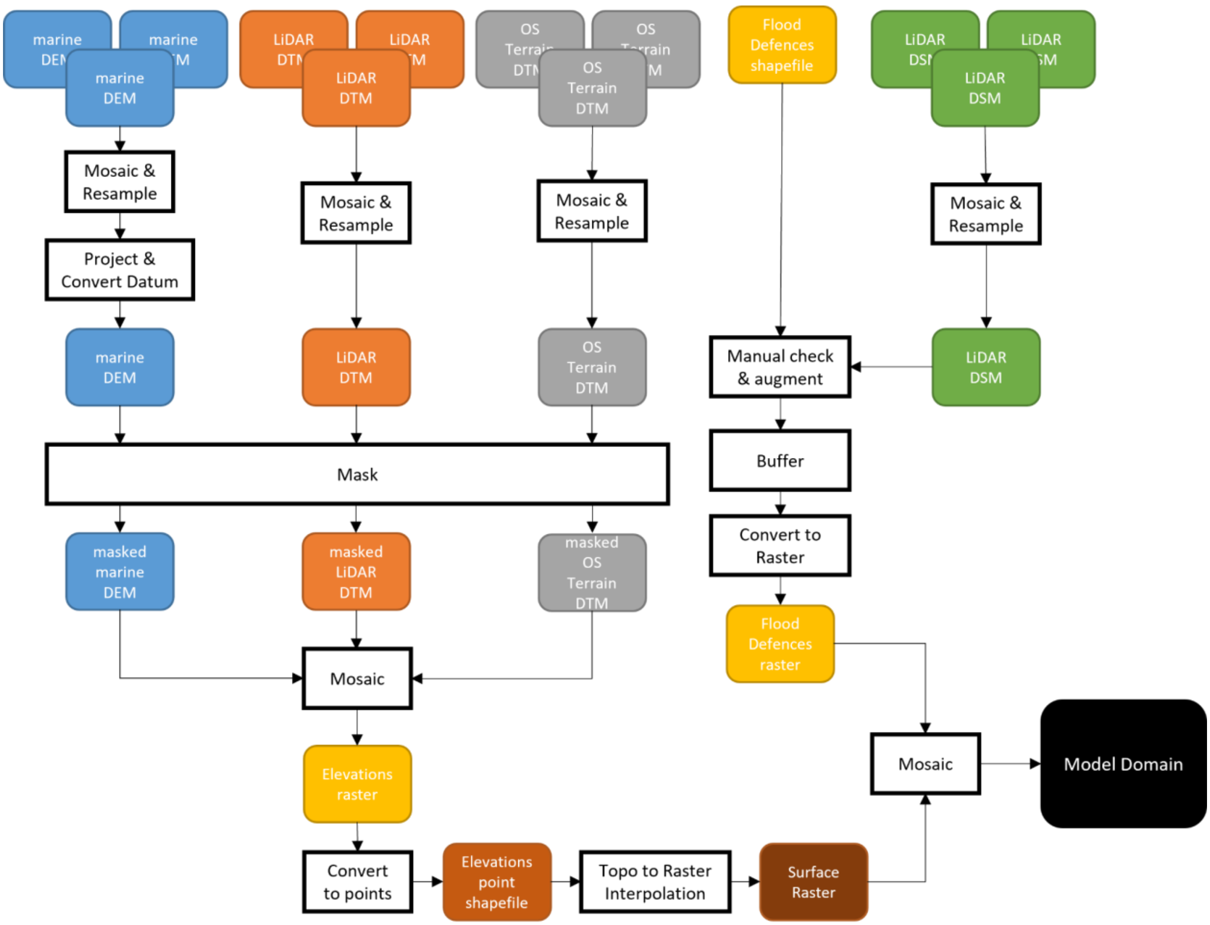

Figure S1: Flowchart summarising the steps undertaken to generate the model domain.

The resulting model domain surface was capable of representing floodplain elevations, heights of flood defences and marine elevations but lacks accurately representing the elevations of the riverbeds. These regions are not covered by the marine DEM and in the procedure described above had to be estimated from the Lidar DTM data. However, Lidar is not well suited to estimating inundated topography because of light refraction effects when crossing the boundary of two media (i.e. air and water) and also because of suspended matter within the water column. Therefore the river channels appeared shallower in the resulting surface, requiring a correction for the riverbed elevations that was the focus of the calibration procedure (Section 2.4.2).

The following equation was used to calculate RMSE scores for flood peaks, which is a widely used metric for evaluating model performance:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}, \quad (1)$$

where N is the number of data points, y(i) is the i-th measurement, and $\hat{y}(i)$ is its corresponding prediction.

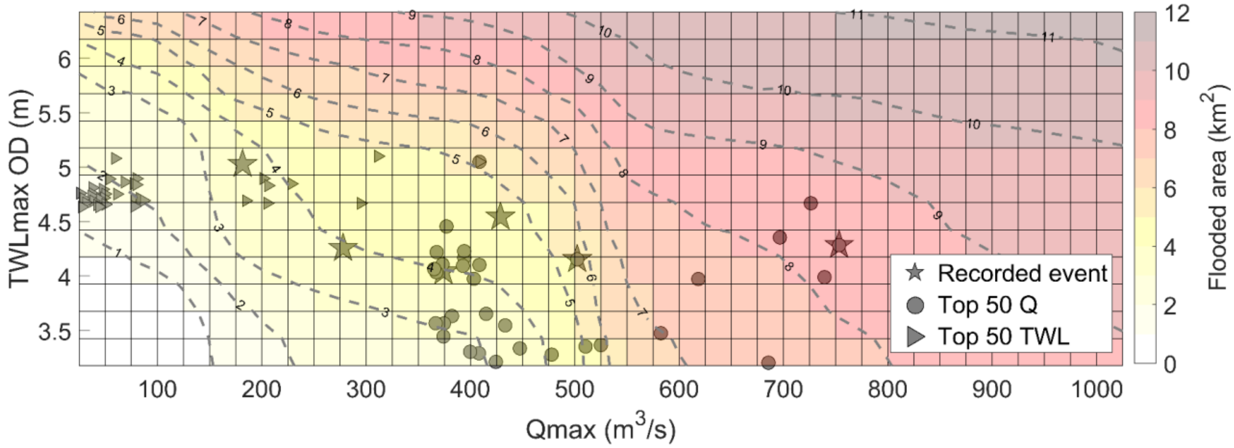

Figure S2: Results from Scenario-3: MAX SURGE, -3 HOUR LAG. *Coloured surface represents modelled FloodArea exceeding the baseline areal threshold, from combinations of 520 Q and TWL (tide + min surge) scenarios with a –3 hour time lag (peak river is 3 hrs before peak HW). The 12 contours link common flooded area values. Shapes indicate the magnitude of river discharge and total water level (tide + surge) for recorded flood events (stars), top 50 most extreme TWL (triangles) and Q (circles).*

The icons used in Figures 9 and 10 relate to TWL-dominant, extreme compound, moderate compound, and river-dominant scenarios in the parameter space, identified in Figure S3. The icons indicate the scenarios referred to within the context of the parameter space.

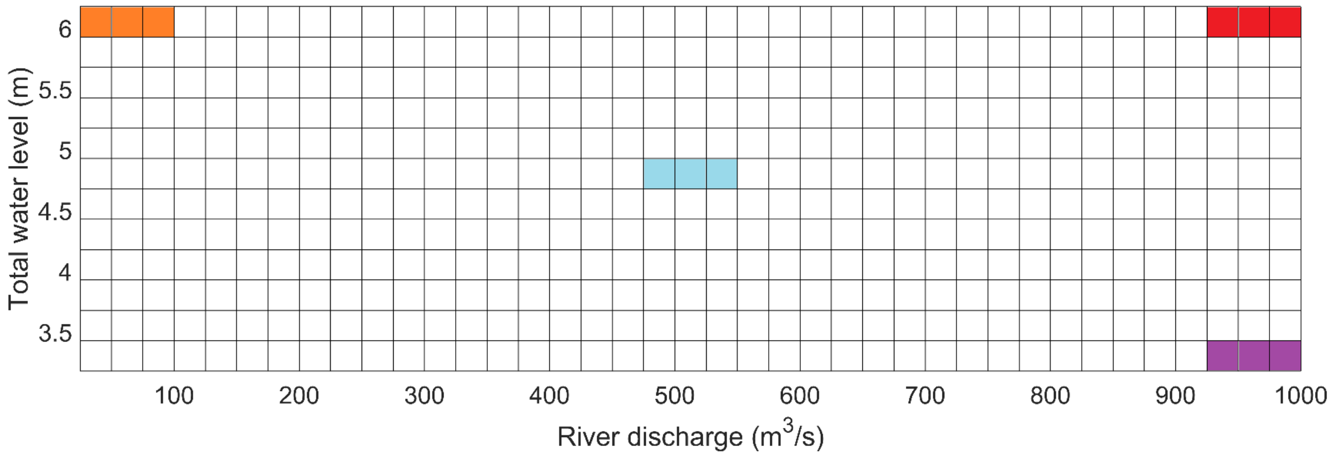

Figure S3: Four cases across the TWLmax:Qmax parameter space: (a) TWL-dominant ($Q_{1\text{-}3}TWL_{13}$) - orange; (b) extreme compound ($Q_{38\text{-}40}TWL_{13}$) - red; (c) moderate compound ($Q_{19\text{-}20}TWL_{7}$) - blue; and (d) river-dominant ($Q_{38\text{-}40}TWL_{1}$) - purple.