# An assessment of the hazard posed by storm surges in the Tamar Estuary

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A flood hazard assessment for a storm surge with a recurrence interval of 10 000 years has been developed for the Tamar Estuary. The method involved extrapolation of storm surge levels from Devonport tidal gauge data covering a 12 year period, (1991-2002), and extrapolating the data to produce an extreme still water level prediction for a 1 in 10 000 year event. This level was then incorporated into LiDAR (Light Detection and Ranging) elevation data to produce a hazard map showing areas of the Tamar Estuary at risk from storm surges. The method of combining storm surge levels within elevation data is a useful tool which can be used to inform planning, allow assessment of possible remediation schemes and to assess the likely impact of a given event on areas prone to storm surges.

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## Introduction

Floods are the most frequent natural hazard in the world constituting 32 percent of natural disasters (Smith, 1992). Human settlement of low lying coastal areas and river valleys, due to their increased fertility and industrial importance has made them susceptible to the risk posed by flooding. The main causes of flooding are those due to atmospheric hazards, both rainfall, snowmelt and storm surges. The most hazardous floods are those caused by storm surges (McGuire *et al.*, 2002).

The study area constitutes a section of the Tamar Estuary called the Hamoze, a few miles to the east of Plymouth, Devon. The major settlements are Devonport, Stonehouse and Millbay in Devon and Torpoint in Cornwall. The main infrastructure is residential with some small industrial sites, the continental ferry port at Millbay and a dockyard at Devonport. All these areas are built close to the waterfront and occupy low lying areas considered to be at risk from storm surges. Figure 1 shows the study area where LiDAR (Light Detection and Ranging) elevation data were available.

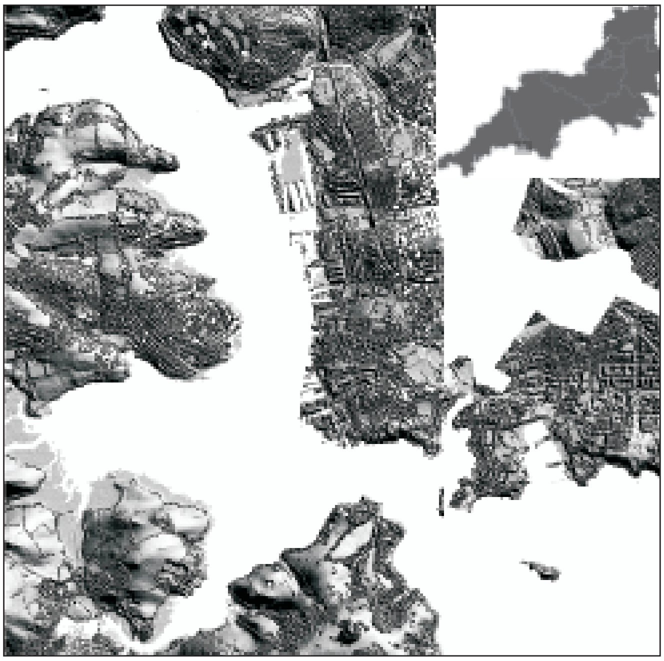

***Figure 1.*** *Sunshaded LiDAR digital elevation model of the Tamar Estuary.*

## Hazard

The hazard examined in this study is that posed by a storm surge with a return period of 1 in 10 000 years. This was estimated using historical tidal gauge records from Devonport for the period 1991-2002 and extrapolated to the required return period. In addition to storm surge level it was also necessary to analyse the tidal ranges that were likely to occur. This was calculated using a tidal prediction software package; POLTIPS-3 provided by Proudman Oceanographic Laboratory (POL) ( POLTIPS-3 User guide (2003)). Adding the storm surge height and astronomical tidal range gave an extreme water level for various return periods. These water heights were then incorporated into elevation data to show areas that are likely to be flooded for a specific return period. The first hazard assessment shows areas that would be flooded if the event occurred today.

An additional hazard is that posed by rising sea level. Recent sea rise predictions by the Environment Agency (2002) and Huthance (2003), were used to produce a hazard assessment for a 1 in 10 000 year event incorporating the likely sea level rise over the next 100 years. The effect of wave action which would depend on local topography, and the additional wave height would give on the overall extreme water level has not been included within the scope of this study.

## What is a storm surge ?

Law (1998) defined a storm surge as a change in sea level caused by meteorological conditions rather than astronomical causes. A simple representation of the water levels observed at a given location can be represented by the formula:

$$X(t) = Z_o(t) + T(t) + S(t)$$

Where: $X(t)$ = observed level
$Z_o(t)$ = mean sea level
$T(t)$ = tidal component (gravitational)
$S(t)$ = meteorological surge component (Pugh 1987).

This formula can be rearranged to define the term storm surge:

$$S(t) = X(t) - Z_o(t) - T(t).$$

This shows that a storm surge is the difference between the observed and the predicted water levels (Pugh, 1987).

## Method

The analysis of storm surges in the Tamar Estuary required two data sets. The first is the actual recorded tidal gauge data that gives sea level heights for the area. This data set not only records the predicted level but also contains a component of meteorological conditions that occurred at the time of recording. The second data set is the predicted tidal heights. This is generated using a tidal prediction software package called POLTIPS version 3 supplied by POL. The parameters are set to predict tidal heights at hourly intervals for the given periods for each port generating yearly predictions as a text file. The observed and predicted levels are subtracted to give the residual storm surge level. Yearly data was sorted to locate the maximum storm surge, giving the 12 maximum storm surges for the period 1991-2002. This method differs from that used by the Environment Agency (2002) which uses observed levels only to make a prediction and did not separate out the meteorological and astronomical components.

## Producing a prediction for a 1 in 10 000 year event

The probability of a rare event of high magnitude can be ascertained by determining the recurrence interval of that event, given by the formula:

$$\text{Recurrence Interval } RI = \frac{n+1}{m}$$

Where: n = the number of ranks
m = the rank of the individual event (highest = 1)
(Bryant, 1997)

All the events in a given time series are ranked in magnitude from highest (1) to lowest (12), and the recurrence interval is then calculated for each event. The surge level was then plotted against the Recurrence Interval on probability paper as shown in Figure 2.

## Extreme water levels

Extreme water levels are the combination of 3 heights, namely, the highest astronomical tide, the 10 000 year storm surge event and global sea level change. The highest astronomical tide was taken as 3.00 m. This is calculated using the 1 year storm surge level taken from Figure 2 and the yearly maximum predicted tide height extracted from POLTIPS-3. This level matches that used by Proudman Oceanographic Laboratories and the Environment Agency in their tidal predictions, (Dixon and Tawn, 1997; Environment Agency, 2002). Combined isostatic and eustatic were assumed to be + 5 mm/yr as recommended by the Environment Agency (Environment Agency, 2002).

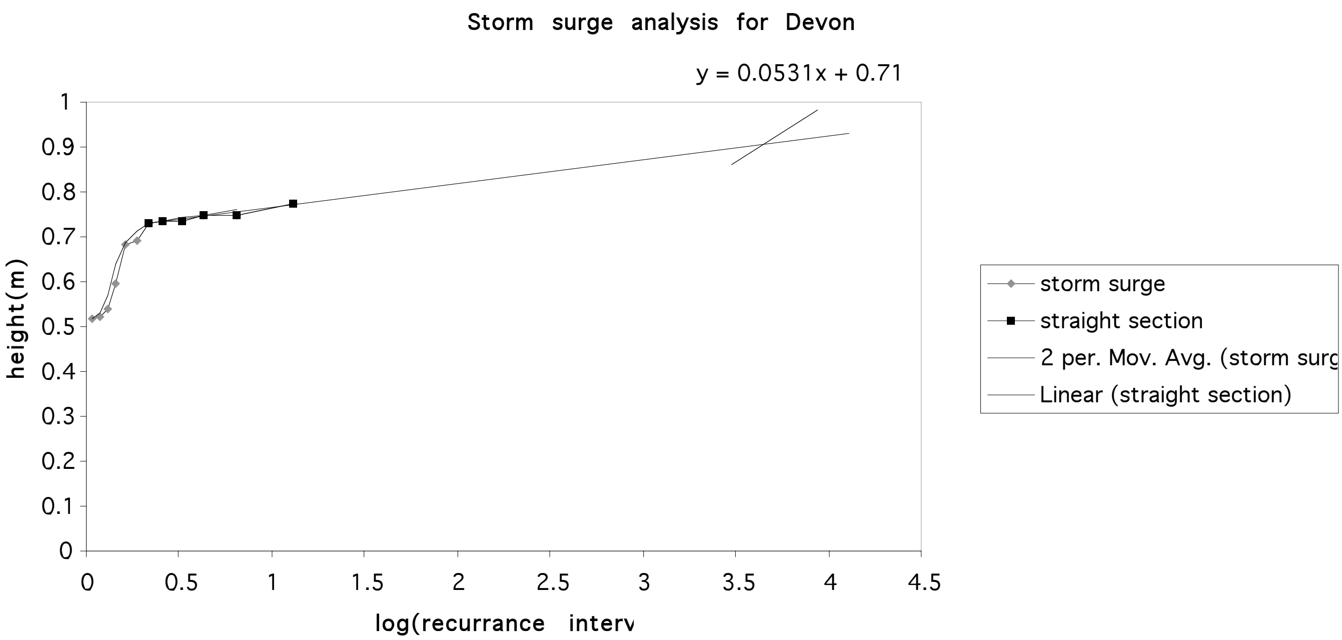


***Figure 2.*** *Storm surge analysis for Devonport with trend line to extrapolate a 10 000 year recurrence interval.*

## Results

Figure 2 shows the plot of $\log_{10}$ recurrence interval against storm surge height. It can be seen that the upper section approximates to a straight line. This section was extrapolated to produce the prediction for storm surge events up to 1 in 10 000 years. These results are shown in Table 1 and Table 2. The extreme water level for Devonport for the present day, given a 1 in 10 000 year event was estimated to be 3.92 m. The same magnitude event occurring in 100 years time, incorporating the predicted increase in sea level rise of 5 mm per year for 100 years, gave an estimated extreme water level of 4.42 m.

| **Recurrence interval (years)** | **Storm surge height (m)** |
|---|---|
| 10 | 0.7643 |
| 100 | 0.8174 |
| 1000 | 0.8705 |
| 10 000 | 0.9236 |

***Table 1.*** *Storm surge heights for various recurrence intervals for Devonport taken from Figure 2.*

| Return period | 1:10 | 1:100 | 1:1000 | 1:10 000 |
|---|---|---|---|---|
| 1 year return period | 3.00 | 3.00 | 3.00 | 3.00 |
| Storm surge elevation | 0.76 | 0.82 | 0.87 | 0.92 |
| Extreme water levels | 3.76 | 3.82 | 3.87 | 3.92 |

***Table 2.*** *Extreme water levels for different recurrence intervals for Devonport (heights are in metres above Ordnance Datum Newlyn.*

## Production of a hazard and risk map for the study area

To produce a hazard map for the Tamar Estuary three data sets were required, the first being elevation data, the second being information on the infra-structure and, finally, the extreme water levels for a 1 in 10 000 year event. To combine this information the following 6 steps were carried out (Holden, 2003): (1) Import of LiDAR data into Ermapper software. (2) Rectification of each tile to Ordnance Survey coordinate system. (3) Stitching of individual tiles into one image covering the whole study area. (4) Visual validation of data and correction of small errors within LiDAR data. (5) Calculation of areas within the elevation range at risk from the predicted storm surge. (6) Production of hazard maps.

## Hazard assessment

Overlaying the 3.92 m extreme water level and the LIDAR elevation data as outlined above produces a present day hazard map of the area that will be inundated due to a 1 in 10 000 year event (Figure 3a). The hatched area of the sun-shaded elevation data delineates the area liable to flooding. Several areas are residential areas and industrial areas. Figure 3(b) is a hazard map incorporating 100 years of sea level giving a total extreme water level of 4.42 m above the ordnance datum Newlyn. The impact of sea level rise can be seen by comparing Figure 3(a) and 3(b), revealing the increased extent of flooding due to a 0.50 m rise in extreme water level. No account of flow obstructions including flood defences has been taken into account with this study. This is the next stage of detail and would require more complex hydraulics and further ground survey and truthing. The Environment Agency has carried out this work around the SW coastline to specifically include the effect of defences for their flood map. This study has been for a lesser return period of 1 in 200 years or 0.5% but could equally be applied to other return periods.

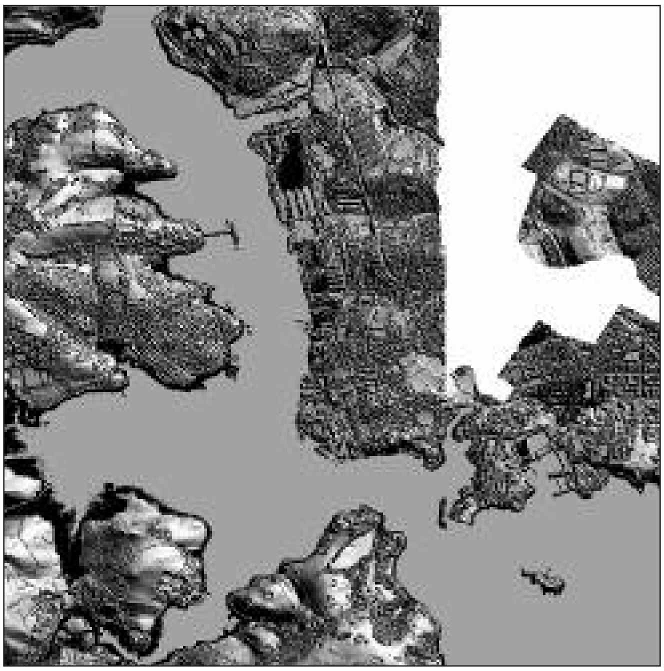

***Figure 3a.*** *Sunshaded digital elevation model with areas at risk from 3.92 metre storm surge event shown as a hatched area.*

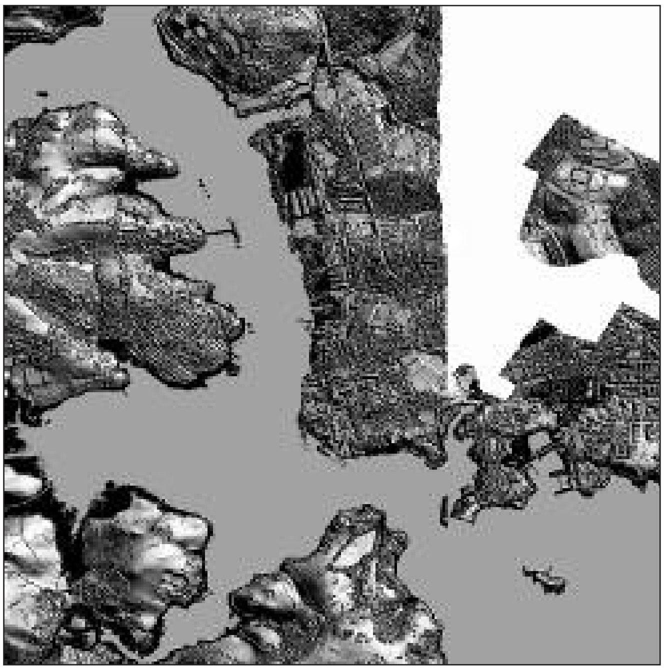

***Figure 3b.*** *Sunshaded digital elevation model with areas at risk from 4.42 metre storm surge event shown as a hatched area.*

## Limitations

The limited data set available (12 years) means that extrapolation to a 1 in 10 000 year event may exaggerate any errors within the method and limits the accuracy of the prediction. Extracting yearly maximum storm surge levels from the data set assumes that only one large storm surge event occurs each year. Where two events of similar magnitude occur in any one year, the slightly smaller event is excluded from the statistical model.

## Conclusions

Once a prediction of an extreme sea level has been produced it is a straightforward and quick process to produce a hazard assessment for the areas likely to be affected by flooding. Although only an event with a probability of 1 in 10 000 years was used in this instance, it is possible to model other events and include other sea level change scenarios to assess sensitivity. The method used is relative easy, is not time consuming, and produces informative hazard maps. This geographic information system could be used in planning guidance, in identifying developed areas potentially at risk from flooding and also in the assessment of remediation schemes. Although the prediction of storm surge levels was based on a very small data set, it is felt that the results closely match other studies, such as those carried out by Devonport Management Ltd, Proudman Oceanographic laboratory and the Environment Agency.

## Acknowledgements

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