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the East Anglian Coast.
Second Report.

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East Coast Extreme Levels

1. Introduction

Estimates of N-year return values of extreme sea levels due to tide and surge at 5 east coast sites were presented by Alcock and Blackman (1985). Two statistical methods were used: the General Extreme Value (GEV) method using annual maxima, and the Joint Probability (JP) method using hourly observations of astronomical tide and meteorological surge.

Differences in estimates of return values using the two methods are given in Table 1. Note that the difference between the estimates of the 250 year return values at Sheerness is 0.29m, not 0.40m as given in MAFF memo 5/RAD/267 of 15 March 1985. (0.40m was erroneously obtained by subtracting the JP estimate to mean sea level from the GEV estimate to ODN).

Immingham and Walton show good correlation between the estimates over return periods from 10 to 250 years but the other sites do not. The JP estimates are lower than the GEV estimates if our model of interaction is taken into account - assuming no interaction would give estimates greater than those from the GEV method.

The comparison of Lowestoft's estimates is made more complicated because of the questionable validity of the 1953 annual maximum (it is a "visual" estimate), and its impact on the GEV method - if it is excluded, the estimates from the two methods are in good agreement. The 1953 annual maximum at Harwich is also visually estimated.

Our JP estimates are generally lower than "existing" estimates based on extreme value techniques. One question is: how good or reliable are the extreme value estimates - are we using them as an erroneous yardstick? The JP curves do seem to flatten out quickly compared with the GEV curves, giving short return periods for the 1969, 73, 76 events and very long return periods for the 1953 events (as measured by the estimated observations, except at Immingham).

2. Sensitivity and reliability of the GEV method and estimates

It is difficult to compute standard errors (s.e.) of the return value estimate for the method which fits the extreme value distribution to the data using a "least-squares technique". Standard errors using a "maximum likelihood" technique are given in Table 2 together with the estimates of return values themselves - s.e. using least squares are unlikely to be less than using max. likelihood. The opportunity has been taken to use recent annual maxima at Immingham, Lowestoft and Sheerness. The Immingham and Sheerness estimates are those with no trend removed and therefore are not strictly comparable with those contained in Tables 9a and 9e of Alcock and Blackman. The incorporation of significant trends in the GEV method, using max. likelihood, has been done, but estimates depend significantly on the base year and trend used.

For each site, standard errors increase for longer return periods. For a specific return period, standard errors increase as the number of annual maxima used decrease, e.g. for the 100 year return value, smaller s.e's are 0.16m, 0.13m for Immingham, Sheerness (64, 136 annual maxima), largest is 0.71m for Walton (11 maxima); illustrating the sensitivity of the estimates to data length. Note that 1 s.e. indicates a 60% chance of the true value lying within ± 1 s.e. of the mean estimates; an approximate 95% confidence interval is given by the mean ± 2 s.e.; eg for Sheerness, the 100 year return value estimated from the GEV method has a 95% chance of lying 0.26m either side of the mean value of 4.30m.

The estimated mean values from least squares and max. likelihood do not differ significantly for Immingham, Lowestoft and Sheerness because the same type of distribution fits the data using the different techniques (shown by the sign of the parameter k). However, there are differences for Harwich and Walton because the distribution curve changes from Fisher-Tippett 2 to FT1 at Harwich, and from FT3 to FT2 at Walton, giving smaller or larger estimates, respectively, for max. likelihood compared with least squares. For these 2 sites, the type of distribution fitted is therefore sensitive to the fitting technique. For Sheerness, the distribution curve changes from FT2 (nearly FT1) to FT1, giving smaller estimates. For this site, the distribution type fitted is sensitive to either the fitting technique, inclusion of extra data, or both.

3. Reliability of outlying data

Discarding or downweighting an outlier of questionable validity and refitting the distribution to the rest of the data could well give a better estimate. Table 9b of Alcock and Blackman gives the results of including or omitting the 1953 visually estimated annual maxima at Lowestoft. Omitting the value gives an 100y return value of 2.87m compared with 3.33m, i.e. a difference of 0.46m; which is less than 2 s.e's (=0.91m) from the original estimate. The statistical conclusion would be that the outlier does not have an excessive influence on the estimates and can be safely left in. This illustrates the uncertainty of the method - the reliability of the 100y estimate is expressed by a 95% confidence interval of nearly 1 metre!

A "censoring" technique has been used on the Lowestoft annual maxima data of 1953-83. Basically the method assumes that the largest value in the annual maxima series lies somewhere above the largest reliable annual maxima (that of 1983) but the actual value is not known. The resulting estimates are given in Table 2 - the differences between the estimates of the return values are still less than 1 s.e. The method has been extended to incorporate trends or variation, using regression models, but the estimates depend on the base year and trend used.

A further illustration of the uncertainty of the GEV method is given by noting that, for Sheerness, the difference in estimates of the 100y and 250y return value is the same as the s.e. of the 250y value (4.50m - 4.30m = 0.20m, s.e. of 250y value = 0.19m) - note that this is for the data set with the lowest standard errors.

4. Adequacy of the surge distribution used in the JP method

The JP method uses a limited population of surges which is a subset of the true population.

a) One question is whether the observed surge data set contains the highest historic surge recorded at the site. We can estimate the surge component of the highest observed annual maxima (which may have been outside the hourly observation period used), and see if that surge value is within the observed surge distribution (Table 3):

	Immingham	Lowestoft	Harwich	Walton	Sheerness
Ann max year	1953	1953	1953	1973	1953
and surge (m)	1.95	2.41	2.32	1.38	2.16
Observation period	1964-81	1970-82	1967-76	1967-78	1965-75
surge (m)	1.83	2.05	2.24	2.21	2.26

TABLE 3: Surge component of highest recorded annual max level and highest surge of JP data set.

At all sites except Walton and Sheerness, the observed surge distribution does not contain the surge component of the highest recorded annual maximum. The surge population can be extended by adding "artificial" surges and this was done at Lowestoft by adding hourly surges extracted from Roger Flather's numerical model of the 1953 surge. The 100-year return value increased by 0.39m. This augmentation of the surge population using modelled hindcast or predicted surges needs further investigation. In fact, this is the basis of the method adopted in the U.S.A. for extreme level estimation (Dendrou et al 1985).

b) Is it more appropriate to use subsets of the surge population?

Several approaches to limit the surge population were tried for Sheerness; assuming no interaction in order to retain as many data points as possible.

i) Only surges from the storm surge "season" September to April, were used, together with the full tide distribution. Because of the difficulties of converting the results into return period (because of the sampling frequency associated with this and the other methods below), the exceedance probabilities have been used for comparisons.

Using the storm surge season population, the probability of a level being exceeded was only a factor of about 1 to 2 different (larger) from the probability using the full set of surges. In fact the surge probability distribution was not altered much at the tails; only 1 or 2 large surges being removed.

ii) A subset of surges was used which consisted of the hourly surge nearest to the time of each High Water plus surges ± 3 hours either side, together with the corresponding hourly tides.

The probability of each total level was a factor of about 1.5 to 3 smaller than using the corresponding surges from the total surge population. The inference is that the largest surges occur outside the HW ± 3h time band, but this needs a surge classification according to time. (The maximum surge occurring in the HW ± 3h band was 2.07m, compared with the maximum of the total population of 2.26m in 1969, also 2.25m in 1968).

iii) Only surges above certain threshold were used, together with the full tide distribution. Using a threshold of 1.0m, the probability of each total level was a factor of about 300 smaller than the corresponding probability with the total surge population. A threshold of 1.5m gave probabilities about 2000 smaller than those with the total population.

The difficulty with this method is the selection of the appropriate threshold level to be used: the two examples above are respectively 4.3 and 6.5 times the standard deviation of the surge population. An adequate population of independent data is needed.

5. Conversion of probabilities to return period values

Pugh and Vassie (1980) used results from Cartwright (1958) to show that the theoretical adjustment to be made in converting hourly values to annual values was not significant; but this assumption may not be valid because Cartwright's theory ignores several higher terms in an expansion series which may be significant - a research student is currently investigating this problem.

6. The determination and modelling of tide-surge interaction

We determined the degree of tide-surge interaction at a site using a simple test based on the surge variance as a function of tide level. More rigorous criteria are probably needed to determine the interaction. Once determined, it may be better to model the interaction using tide-surge bands according to sample size and not simply according to a finite width of the tidal bands. Both these points are being investigated.

7. Other methods

We have used a peaks over threshold (POT) method for surges, and are investigating it for still water levels. The problem in using this method is the choice of an appropriate threshold, so that an adequate set of independent data is obtained. The monthly maximum still water levels may be appropriate.

We intend to test an exceedance probability (EP) method (J Middleton and K Thompson, personal communication) which is based on an extension of the exceedance theory originally developed by Rice (1954) to study noise in electrical circuits. It is claimed that the EP method should overcome the main deficiency of the JP method: the assumption of independence of both tide and surge data over the sampling interval of one hour. In the EP method, the appropriate independence time is obtained from the statistics of the sea levels. This method may also more adequately deal with sites, such as Lowestoft, where the surge component dominates the tide component.

8. Conclusions

The GEV method produces extreme level estimates which are dependent on the type of distribution fitted; this is sensitive to the fitting technique and data length.

Standard errors are generally large for the East Anglian sites, increase for longer return periods, and depend on data length.

Series containing doubtful annual maxima data can be treated using a censoring technique.

The uncertainty of the GEV method is graphically illustrated by the Sheerness estimates, from the longest data set. The difference between the 100-year and 250-year estimates is less than the standard error of the 250-year estimates.

For the JP method, the augmentation of the observed surge population using modelled surges needs further investigation.

Using subsets of observed surges accentuates the problem of converting probabilities into return periods because of the sampling frequency used.

For Sheerness, use of a storm surge "season" subset did not alter the probabilities greatly.

The results using a subset of surges occurring up to 3 hours either side of High Water indicated that the largest surges at Sheerness occur outside that time band.

Using a subset of surges above a certain threshold increases the estimates but selection of the appropriate threshold is subjective.

The conversion of probabilities to annual return periods is a problem for any data set using data sampled for less than 1 year.

Better methods of determining and modelling tide-surge interaction are needed.

Alternative techniques to the GEV and JP methods, eg POT and EP methods, need investigation.

9. References

Alcock, G. and Blackman, D.T. 1985. "Tide, surge and extreme still water levels along the East Anglian coast". IOS Internal Report No.230.

Dendrou, S.A., Moore, C.I. and Myers, V.A. 1985. "Application of storm surge modelling to coastal flood rate determinations". Marine Technology Society, 19(2), p42-50.

Rice, S.O. 1954. "The mathematical analysis of random noise" pp133-294 in Noise and Stochastic processes, Ed. N. Wax. Dover, New York.

	Return Period (years)				
	10	25	50	100	250
Immingham	-0.02	-0.02	-0.01	0.00	0.01
Lowestoft					
inc. 1953 data	-0.05	-0.19	-0.32	-0.47	(-0.73)
exc. 1953	0.08	0.05	0.02	-0.01	(-0.06)
Harwich	0.02	-0.11	-0.21	-0.32	(-0.49)
Walton	0.09	0.08	(0.07)	(0.06)	(0.03)
Sheerness	0.05	-0.03	-0.08	-0.15	-0.29

TABLE 1: Differences (JP-GEV) in extreme level estimates (metres).

Note: Bracketed figures indicate that the GEV estimates are unreliable because of short data length.

				Return period (years)				
			K	10	25	50	100	250
Immingham	(1920-81,62)	LS	0.112	4.42	4.56	4.65	4.75	4.85
(1920-83, 64 ann max)		ML	0.063	4.44	4.61	4.72	4.84	4.97
			(0.096)	(0.06)	(0.09)	(0.12)	(0.16)	(0.22)
Lowestoft	(1953-81,29)	LS	-0.089	2.59	2.87	3.09	3.33	3.68
	(1953-83,31)	ML	-0.100	2.61	2.91	3.15	3.41	3.78
			(0.132)	(0.14)	(0.24)	(0.35)	(0.49)	(0.73)
	(1953-83,31)	ML	-0.068	2.58	2.86	3.07	3.30	3.61
	censored		(0.152)	(0.14)	(0.24)	(0.35)	(0.48)	(0.72)
Harwich	(1926-76,51)	LS	-0.045	3.10	3.34	3.53	3.72	3.98
	(1926-76,51)	ML	0.003	3.10	3.32	3.49	3.66	3.88
			(0.083)	(0.08)	(0.12)	(0.17)	(0.22)	(0.31)
Walton	(1968-79,11)	LS	0.049	3.12	3.22	3.30	3.37	3.46
		ML	-0.178	3.13	3.30	3.45	3.61	3.86
			(0.385)	(0.14)	(0.29)	(0.47)	(0.71)	(1.17)
Sheerness	(1819-1978,133)	LS	-0.017	3.80	4.01	4.17	4.33	4.54
	(1819-1983,136)	ML	0.003	3.79	4.00	4.15	4.30	4.50
			(0.058)	(0.05)	(0.07)	(0.10)	(0.13)	(0.19)

TABLE 2: Extreme levels (metres to ODN) using GEV method
LS = least squares fit
ML = max. likelihood fit

Note: Bracketed figure is standard error.