FILE

INTERNAL DOCUMENT 266

I.O.S.

Tides, surges and extreme still-water levels at Dover

Graham Alcock and David Blackman

Institute of Oceanographic Sciences
Bidston Observatory
Birkenhead

October 1986

[This document should not be cited in a published bibliography, and is supplied for the use of the recipient only].

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Wormley, Godalming,
Surrey GU8 5UB
(042-879-4141)

(Director: Dr. A. S. Laughton)

Bidston Observatory,
Birkenhead,
Merseyside L43 7RA
(051-653-8633)
(Assistant Director: Dr. D. E. Cartwright)

Crossway,
Taunton,
Somerset TA1 2DW
(0823-86211)
(Assistant Director: M. J. Tucker)

Tides, surges and extreme still-water levels at Dover

Graham Alcock and David Blackman

Institute of Oceanographic Sciences
Bidston Observatory
Birkenhead

October 1986

<u>CONTENTS</u>

		Page
1.	Introduction	1
2.	Data reduction	1
3.	Astronomical tide levels	2
4.	Surge elevations	2
5.	Extreme still-water levels	5
6.	Summary and conclusions	8
7.	References	10

1. Introduction

This report concerns the estimation of extreme still water levels at Dover. Still-water level (swl) is defined here as the observed water level at a location when waves have been averaged out. It contains contributions due to astronomical tides, meteorologically induced surges and mean sea level. A contribution to the surge level may be a steady mean wave set-up due to any wave activity during the period of observation. This may be an important factor in the swl reached at any sea-defence site as the set-up at the shorelines on beaches is about one-fifth of the significant wave height offshore (James 1983).

A long period of carefully edited sea level data has been processed and analysed to yield data and statistics of the astronomical tide, meteorologically induced surge, and mean sea level components at Dover, as well as of the total observed still-water level. Both the Generalised Extreme Value (GEV) and Joint or Combined Probability (JP) methods have been used to compute probabilities of exceedance of extreme levels and hence return frequencies or periods. Estimates of both extreme high and low sea levels have been computed using the JP methods.

2. Data reduction

Hourly values of sea level measured relative to the local tide gauge bench mark were obtained from the stilling well gauge situated on the Inner Harbour side of the Prince of Wales Pier, Western Docks. Hourly values were digitised from analogue charts, from a Lege gauge from 1964 to 1974 and from a Lea gauge from 1975 to 1976. Hourly values were filtered from 15 minute data from a digital Neyrpic gauge in 1977, and from a digital Ott gauge from 1978 to 1985; some gaps were filled with digitised data from analogue charts from a Munro gauge.

Notable gaps, due to tide gauge malfunctions, were 15 days during January/February 1970, 159 days from July to December 1976, 102 days from January to April 1977, and 200 days from January to July 1978.

The records of hourly sea level were rigorously checked and carefully edited using the Tidal Elevation Reduction Package (TERP) suite of computer programs. Previously processed records were brought up to modern standards using this method (Graff and Karunaratne 1980), which consists fundamentally of plotting the surge residuals (i.e. observation minus predicted tide) as a function of time and of examining the plotted values by eye for irregularities. Errors, due principally to datum shifts or irregular timing, were then corrected by referring to the original tide gauge charts. Dubious surges were checked using weather records and other tide gauge records.

At any time (t), the observed sea level (ζ) can be considered as the sum of a tidal component (x), a surge component (y), and a mean level (Z_o) :

$$\zeta(t) = x(t) + y(t) + Z_o \tag{2.1}$$

The edited sea level records were analysed to yield data and statistics of these three components.

3. Astronomical tide levels

The tidal component of the observed record is the coherent part of the sea level that responds directly or indirectly to astronomical forcing. The harmonic method of analysis models the astronomical tide as a finite number, N, of harmonic constituents with an amplitude H and angular speed, σ ,

$$x(t) = \sum_{n=1}^{N} f_n(t)\, H_n \cos(\sigma_n t + V_n + u_n - G_n) \tag{3.1}$$

V is the initial phase at an arbitrary time origin t = 0 and G is the constituent's phase lag with respect to the equilibrium tide, and Greenwich epoch. f and u are slow modulating theoretical functions mostly with the period 18.6y of regression of the lunar nodes. Usually the period of data analysed is chosen to cover maxima and minima of the nodal cycle and hence yield average values for f and u. However, the observed data period covered a nodal cycle and so the actual observed nodal variation could be analysed, using data from 1966 to 1985. The modulation of the principal constituents was found to be smaller in the real tide than in the theoretical tide, because the relationship between a principal constituent and its nodal term was different in shallow water from that assumed in the equilibrium theory, due to tide-tide interactions generated by bottom friction effects (Amin 1985). Therefore, additional constituents were incorporated in the tidal prediction model to allow for the observed modulations.

4. Surge elevations

Hourly values of the meteorologically-induced surge elevations were computed as the difference (the surge residual) between the observed and predicted levels - the mean sea level used was the mean of all the hourly observed values. The probability density function for the surges was generated numerically from the time series using a class interval of 0.10m, and is shown in Figure 1. The p.d.f. has a Normal or Gaussian appearance but there is a positive skewness and longer tails than a Gaussian distribution.

The statistics of the surge distribution were computed in the form of the standard deviation, (0.18m), the coefficients of skewness and kurtosis, (0.412 and 6.64 respectively) and the maximum and minimum surge elevations reached during the observation period (1.59 and -1.45m respectively). The coefficients were defined as follows :

$$\text{k th moment} = \mu_k = \frac{1}{N} \sum_{i=1}^{N} (y_i)^k \tag{4.1a}$$

$$\text{Standard deviation} = \sigma = (\mu_2)^{\frac{1}{2}}$$

where y_i = ith surge elevation, N = total number of observations of surge elevations.

$$\text{coefficient of skewness} = \mu_3^{\,2}/\mu_2^{\,3} \tag{4.1b}$$

$$\text{coefficient of kurtosis} = \mu_4/\mu_2^{\,2},$$

and Sheppard's corrections for grouping were used (Kendall and Stuart 1963).

Skewness is a measure of symmetry and has a value of zero for a symmetrical Gaussian distribution. The positive value obtained indicated that the longer tail of the surge distribution lay towards the positive surge values, i.e. that large positive surges of a given magnitude were more probable than large negative surges of the same magnitude. This reflects the asymmetry in the frequency of extreme atmospheric pressures. The value of skewness is reflected in the maximum and minimum surge elevations, which showed extremes on the positive rather than negative side.

Kurtosis is is a measure of the flattening of a distribution relative to a Gaussian distribution, which has a standard kurtosis value of 3. The surge distribution has a value greater than 3 and is therefore leptokurtic - i.e. more sharply peaked than a Gaussian distribution with greater height and longer tails.

The frequency of surges on a monthly basis was computed, using a class interval of 0.10m, and monthly surge probability distributions are given in Figure 2. As expected, large positive and negative surges are more frequent in the winter months (September to March) when severe meteorological disturbances usually occur. As an example, there was a 1% probability that the observed level at Dover was exceeded by 0.6m in December during the observation period.

Analyses of the amplitude and duration of extreme observed surges at Dover are given in Table 1. The extremes are defined in terms of the standard deviation (σ) of the hourly surge residuals about a zero mean. A rough qualitative rule suggests that extreme positive or negative surges greater than 6σ or 5σ respectively occurred on average once a year. During the major storm surge of 1976 January 3-4 the duration of surge elevation above 3σ was 23 hours, with a maximum hourly surge observed of 1.43m ($>7\sigma$). During the major storm surge of 1983 February 1-2, the duration of the surge elevation above 3σ at Dover was 15 hours with a maximum surge elevation of 1.59m ($>8\sigma$).

Extreme surge elevations were estimated using two methods: by extrapolating a logarithmic curve fitted by least squares to the cumulative distribution of the surge elevations, and by a "peaks over threshold" (POT) technique. A simple POT model (NERC 1975) was used in which the number of exceedances per year of surge elevations (y) greater than a threshold level (y_0) was treated as a Poisson variate whose parameter (λ) was estimated by

$$\hat{\lambda} = M/N \tag{4.2}$$

where M is the number of exceedances in N years of record. The magnitude of the exceedances were treated as an exponential distribution whose parameter (β) was estimated by

$$\hat{\beta} = \bar{y} - y_0 = \sum_{i=1}^{M} \frac{y_i}{M} - y_0 \tag{4.3}$$

where $\bar{y}$ is the mean of the exceedance surge elevations. Then the surge elevation with return period of R years was estimated from

$$y(R) = y_0 + \hat{\beta} \ln \hat{\lambda} + \hat{\beta} \ln R. \tag{4.4}$$

The standard error (S.E.) of the return period surge elevation was computed from

$$(S.E.)^2 = \frac{\beta^2}{\lambda N} \; 1+(\ln \lambda R)^2. \tag{4.5}$$

The POT method was applied to surge events rather than to hourly values by considering the maximum hourly surge elevation in each event determined by the threshold level. A threshold level of 3σ was used, which is the Storm Tide Warning Service (STWS) threshold level for a surge event (Lt.Cdr. J Townsend -

personal communication). This threshold gave frequencies of positive and negative surge events of $25y^{-1}$ and $13.5y^{-1}$ respectively, compared with average frequencies recorded by STWS of 17 and 14.5 per surge season (September to April).

The estimated return period positive and negative surge elevations obtained using the two methods are given in Table 2a-2b respectively, together with the means, which were considered to be the best estimate and which are plotted in Figures 3a and 3b. The standard errors given are those from the POT method.

5. Extreme still-water levels

Two methods have been used to estimate extreme still-water levels : the Generalised Extreme Value (GEV) method and the Joint or Combined Probability (JP) method.

The GEV method involved fitting the cumulative frequency distribution of the 62 annual observed sea level maxima from 1912 to 1984 by a distribution and extrapolating to low probabilities and hence long return period values. The technique used was based on the Jenkinson method used by Lennon (1963) and Suthons (1963) (see also Graff 1981). The series of n annual maxima, $h = h_1$, $h_2 \ldots\ldots h_n$ were ranked in ascending order of magnitude and the cumulative frequency of the mth value was found from

$$P = (2m - 1) / 2n \tag{5.1}$$

The cumulative frequency distribution was fitted, using a maximum likelihood method, by one of a family of extreme value distributions, described by the two- parameter General Extreme Value (GEV) distribution (Jenkinson 1955)

$$h = a(1 - e^{-ky}), \tag{5.2}$$

where a and k are conditional parameters of the distribution calculated from the mean annual maximum and the standard deviations of the annual and biennial maxima, and y is the reduced variate

$$y = -\ln (-\ln P). \tag{5.3}$$

The curves are classified as Fisher-Tippett types 1, 2, 3 (Fisher-Tippett 1928) depending on the curvature, and hence the value of k, since

$$dy / dh = (1 / ak)\exp ky. \tag{5.4}$$

Hence $k=0$, F-T type 1, h has neither an upper nor lower asymptotic limit,

$k<0$, F-T type 2, h has a lower asymptotic limit,

$k>0$, F-T type 3, h has a higher asymptotic limit.

The value of the parameter k was 0.0006 and therefore the best fit distribution was a F-T type 1.

A frequency distribution curve of height, h, against reduced variate, y, or return period was drawn and the value of h for different return periods (rp) read off, the curve being extrapolated if necessary, since, for annual maxima,

$$(rp)^{-1} = 1 - P = 1 - \exp(-e^{-y}), \tag{5.5}$$

noting that the probability, P, is the observed probability of annual maximum $<h$.

The GEV method produces estimates of extreme levels which are unstable and depend critically on the length of data analysed and on the inclusion or exclusion of particular values (Graff 1981, Alcock 1984). For example, a reanalysis of Avonmouth annual maxima by Blackman (1985), using 6 extra annual maxima either unavailable to Graff or rejected by him, increased the previous estimate of the 100y return period level by 0.35m and the 250y level by 0.44m. This lack of stability makes extrapolation to probabilities less than 0.01y (return period > 100y for annual events) very undesirable using this method. Estimates of the extreme levels are given in Table 4, corresponding to specific return periods less than 250 years, as theoretically only estimates for return periods less than four times the data length should be used.

The Joint Probability method is based on the separation of hourly values of swl into tide, surge and msl components. Separate probability distributions for tide and surge were computed (see Sections 2 and 3) and the probabilities of obtaining tide levels and surge elevations combined together to obtain the probability of a particular swl, and hence return period levels.

If P_T and P_S are the probability density functions for tide and surge, then the probability of occurrence of a particular swl (h) was computed as

$$P(h) = \int_{-\infty}^{\infty} P_T(h-y) . P_S(y)dy, \tag{5.6}$$

e.g.

$$P(h=4m) = P_T(T=4m) \times P_S(S=0)+\ldots +P_T(T=0) \times P_S(S=4m). \tag{5.7}$$

From P(h), the probability of exceeding a particular level (H) was computed from the cumulative distribution function

$$Q(H) = \int_H^{\infty} P(h)dh \tag{5.8}$$

and the probability of exposure of a level from

$$R(H) = \int_{-\infty}^{H} P(h)dh. \tag{5.9}$$

The JP method therefore produced extreme statistics in terms of these probabilities of exceeding high levels and of falling below low levels. These were converted into return periods by taking into account the sampling interval (1 hour) i.e.

$$rp = [Q(H) \times 8766]^{-1} \quad \text{or} \quad [R(H) \times 8766]^{-1}, \tag{5.10}$$

where rp is the return period in years and 8766 is the number of hourly samples in 1 year. Pugh and Vassie (1980) have investigated the problems of converting probabilities of instantaneous values into yearly return periods when the samples are not independent, as with hourly swl observations (due to correlation of the surge residuals). They found that the necessary theoretical adjustment to the equation (5.10) was so small compared with the uncertainty associated with statistical sampling that, in practice, it is unnecessary.

The JP method assumes the independence of tide and surge and this was investigated by studying the variance of the surge distributions as a function of tidal level. It is well known from empirical and model studies (Keers 1968, Prandle and Wolf 1978a, 1978b, Wolf 1978) that tide - surge interaction increases down the east coast from Lerwick to Immingham, becomes small at Lowestoft, and increases between Lowestoft and Southend. The interaction between tide and surge is influenced by the effects of various non-linear terms (quadratic friction, shallow water, convective). Wolf (1978) found that while the influence of quadratic friction was greatest - primarily in damping a surge (especially at high water), the influence of the shallow water terms was significant in producing surge amplification on the rising tide by changing the phase speeds of the surge and tide waves.

For Dover, the tide - surge interaction was small, and the extreme estimates were computed assuming complete independence of tide and surge. Therefore the estimates given in Tables 3a, 3b and 4 are the most conservative estimates from the JP method, and have been plotted in Figure 4, relative to mean sea level, which was 0.03m above Ordnance Datum Newlyn for the tidally-analysed period of 1966 to 1985. This value of 0.03m should be added to all estimates relative to msl, to convert them to ODN. ODN itself is 3.67m above Admiralty Chart Datum, therefore this value should be added to all estimates relative to ODN, to convert to ACD.

No allowance has been made in the estimates of extreme levels for any secular trends in mean sea level at Dover, due to local and global long term oceanographic, atmospheric, or geological changes. At Dover, msl trend was 5.2mm per year over the period of 1955 to 1983 (J. Scoffield, personal communication). However the extrapolation of secular trends from only a few decades of msl data is dangerous because of the significant meteorological variations over decadal timescales. Also, U.K. msl data from the 1970s show a coherent fall in sea level - the cause of which is still uncertain (Woodworth, 1986).

Analysis of a composite Sheerness and Southend msl data set from 1916 to 1982 by Woodworth (1986) gives a secular trend of 2.3 $\pm$ 0.2 mm per year. However, there is evidence that rates of rise in global sea level have increased considerably since about 1920, probably owing to the effect of increasing 'greenhouse gases' in the atmosphere (Barnett, 1984). Therefore caution is needed if any value obtained from past msl records is assumed for future trend purposes.

6. Summary and conclusions

Tide gauge observations from 1964 to 1985 at Dover have been analysed to estimate return periods of meteorologically induced surges and still-water levels.

The surge probability distribution function was positively skewed and more sharply peaked than a Gaussian distribution. The maximum positive surge elevation was 1.59 m, during the major storm surge of 1983 February 1-2; the maximum negative surge elevation was -1.45 m, during 1982 November 19; and generally, large positive surges of a given magnitude were more probable than large negative surges of the same magnitude.

Estimates of extreme surge elevations obtained from the cumulative distribution and by a POT method were in fair agreement, and the mean values were used to plot the surge elevation as a function of return period shown in Figures 3a and 3b. It was not considered appropriate to compute return period surge elevations for each month separately, using these statistical methods, because of the lack of adequate data points in some months; but an indication of relative storm surge frequency on a monthly basis is given in Figure 2.

There were only 62 annual observed sea level maxima available for Dover, which meant that extrapolation to return period values greater than 100/250 years was inadvisable. For consistency, estimates of extreme still-water levels using the Joint Probability method have been assumed to be appropriate, and are given in Tables 3a, 3b and 4, and plotted in Figure 4. Complete tide-surge independence has been assumed in computing the JP estimates, thus giving the most conservative estimates for this method.

A secular trend of 5.2 mm per year msl at Dover has been computed but is based on an analysis of only 29 years of data; a value of 2.2 mm per year at Sheerness from 1916 to 1982 may be more indicative of secular trend in the area, but should be treated with caution as an indicator of future trends.

The estimates of surge elevation and still-water level are strictly for the Dover tide gauge site. Spatial distributions of both the spring tidal level amplitude and 50 year extreme positive surge elevation are available for the U.K. continental shelf seas, and are based on observations and hydrodynamic models (Alcock and Flather, 1986). These give contours which are perpendicular to the coast in the Dover Straits, and therefore suggest that the Dover estimates are good approximations to conditions offshore from the Kent coast.

The estimates of still-water level plotted in Figure 4 given relative to mean sea level. 0.03m should be added to convert them to ODN, and a further 3.67m added to convert them to ACD.

7. References

Alcock, G. 1984. Parameterizing extreme still water levels and waves in design level studies. IOS Report No.183.

Alcock, G. and Flather, R.A. 1986. Estimating extreme still-water levels and currents offshore. pp137-152 in, Advances in underwater technology and offshore engineering, Vol.6: Oceanology. London: Graham and Trotman for the Society for Underwater Technology. 486pp.

Amin, M.A. 1985. Temporal variations of tides on the west coast of Great Britain. Geophys. J.R.astr.Soc., 82, 279-299.

Barnett, T.P. 1984. The estimates of "global" sea level change: a problem of uniqueness. J.Geophys.Res., 89, 7980-7988.

Blackman, D.L. 1985. New estimates of annual sea level maxima in the Bristol Channel. Est.Coast and Shelf Scis., 20, 229-232.

Fisher, R.A. and Tippett, L.H.C. 1928. Limiting forms of the frequency distribution of the largest or smallest member of a sample. Procs.Camb.Philos.Soc., 24, 180-190.

Graff, J. and Karunaratne, A. 1980. Accurate reduction of sea level records. Int.Hyd.Rev., 57, 151-166.

Graff, J. 1981. An investigation of the frequency distributions of annual sea level maxima at ports around Great Britain. Est.,Coast. and Shelf Sci., 12, 389-449.

James, I.D. 1983. The effects of wind waves on sea level at the coast. IOS Report No. 155.

Jenkinson, A.F. 1955. The frequency distribution of the annual maximum (or minimum) values of meteorological elements. Q.J.R.Met.Soc., 81, 158-172.

Keers, J.F. 1968. An empirical investigation of interaction between storm surge and astronomical tide on the east coast of Great Britain. Dt.hydrogr.Z., 21, 118-125.

Kendall, M.G. and Stuart, A. 1963. The advanced theory of statistics, 3 Vols. London: Charles Griffen.

Lennon, G.W. 1963. A frequency investigation of abnormally high tidal levels at certain west coast ports. Procs.Instn.Civ.Eng., 25, 451-483.

N.E.R.C. 1975 Flood Studies Report, Vol.I. London: the Council.

Prandle, D. and Wolf, J. 1978a. The interaction of surge and tide in the North Sea and River Thames. Geophys.J.R.astr.Soc., 55, 203-216.

Prandle, D. and Wolf, J. 1978b. Surge-tide interaction in the southern North Sea. In Hydrodynamics of Ests. and Fjords, ed. Nihoul, J.C.J., 161-185. Amsterdam : Elsevier.

Pugh, D.T. and Faull, H. 1983. Tides, surges and mean sea level trends. In Shoreline protection, 59-69. London: Thomas Telford.

Pugh, D.T. and Vassie, J.M. 1980. Applications of the joint probability method for extreme sea level computations. Procs.Instn.Engs. 69, 959-975.

Suthons, C.T. 1963 Frequency of occurrence of abnormally high sea levels on the east and south coasts of England. Procs.Instn.Civ.Engs., 25, 433-450.

Wolf, J. 1978. Interaction of tide and surge in a semi-infinite uniform channel, with application to surge propagation down the east coast of Britain. Appl.math.model., 2, 245-253.

Woodworth, P.L. 1986. Trends in U.K. Mean Sea Level. Marine Geodesy (in Press).

TABLE 1 - Amplitude and duration of observed hourly surges
Dover 1964-1985 Standard deviation, σ , = 0.18m

Duration (hours)	Events less than						Events greater than					
	-7σ	-6σ	-5σ	-4σ	-3σ	-2σ	3σ	4σ	5σ	6σ	7σ	8σ
1 - 4	2	7	15	54	207	1047	384	137	53	21	8	1
5 - 12	0	0	2	7	33	165	92	27	10	0	0	0
12 +	0	0	0	0	0	19	26	4	0	0	0	0

TABLE 2a - Estimated positive surge elevation (metres) at Dover

Return period (years)			
S_1	L.S.	1.22	
	POT (S.E.)	1.01	(0.02)
	mean	1.12	
S_{10}	L.S.	1.53	
	POT (S.E.)	1.35	(0.04)
	mean	1.44	
S_{50}	L.S.	1.74	
	POT (S.E.)	1.58	(0.05)
	mean	1.66	
S_{100}	L.S.	1.83	
	POT (S.E.)	1.68	(0.05)
	mean	1.76	
S_{250}	L.S.	1.95	
	POT (S.E.)	1.82	(0.06)
	mean	1.89	
S_{500}	L.S.	2.04	
	POT (S.E.)	1.92	(0.06)
	mean	1.98	
S_{1000}	L.S.	2.13	
	POT (S.E.)	2.02	(0.07)
	mean	2.08	
S_{2000}	L.S.	2.22	
	POT (S.E.)	2.12	(0.07)
	mean	2.17	

Notes: L.S. = "Least squares fit" method
POT = "peaks over threshold" method
S.E. = standard error from POT method

TABLE 2b - Estimated negative surge elevation (metres) at Dover

Return period (years)			
S_1^-	L.S.	-1.12	
	POT (S.E.)	-0.87	(0.02)
	mean	-1.00	
S_{10}^-	L.S.	-1.50	
	POT (S.E.)	-1.18	(0.04)
	mean	-1.34	
S_{50}^-	L.S.	-1.76	
	POT (S.E.)	-1.40	(0.06)
	mean	-1.58	
S_{100}^-	L.S.	-1.87	
	POT (S.E.)	-1.49	(0.06)
	mean	-1.68	
S_{250}^-	L.S.	-2.02	
	POT (S.E.)	-1.62	(0.07)
	mean	-1.82	
S_{500}^-	L.S.	-2.14	
	POT (S.E.)	-1.71	(0.08)
	mean	-1.93	
S_{1000}^-	L.S.	-2.25	
	POT (S.E.)	-1.80	(0.08)
	mean	-2.03	
S_{2000}^-	L.S.	-2.37	
	POT (S.E.)	-1.90	(0.09)
	mean	-2.14	

Notes: L.S. = "least squares fit" method
POT = "peaks over threshold" method
S.E. = standard error from POT method

TABLE 3a - Return periods for exceedance of specified levels at Dover, from Joint Probability method

Level (metres) above msl	Return period (years)
3.8	1.5
3.9	2.9
4.0	5.8
4.1	11.9
4.2	25.2
4.3	55.5
4.4	128.0
4.5	311.9
4.6	817.5
4.7	2321.3

TABLE 3b - Return periods for exposure of specified levels at Dover, from Joint Probability method

Level (metres) below msl	Return period (years)
3.7	2.0
3.8	4.7
3.9	9.9
4.0	19.7
4.1	38.3
4.2	74.7
4.3	150.4
4.4	320.6
4.5	749.9
4.6	2026.0

TABLE 4 - Extreme levels at Dover for specific return periods

Method (data period, data length)		Return Period (years) 1	10	50	100	250	500	1000	2000
Joint Probability (1964-85, 20.65 years)	High (to msl)	3.74	4.08	4.29	4.37	4.48	4.55	4.62	4.69
	Low (to msl)	-3.60	-3.91	-4.14	-4.25	-4.37	-4.45	-4.53	-4.60
	High (to ODN)	3.77	4.11	4.32	4.40	4.51	4.58	4.65	4.72
	Low (to ODN)	-3.57	-3.88	-4.11	-4.22	-4.34	-4.42	-4.50	-4.57
Extreme Value (maximum likelihood fit) (1912-84, 62 maxima)	High (to ODN) (S.E.)	3.56 (0.03)	4.03 (0.06)	4.36 (0.14)	4.50 (0.18)	4.68 (0.25)	-	-	-

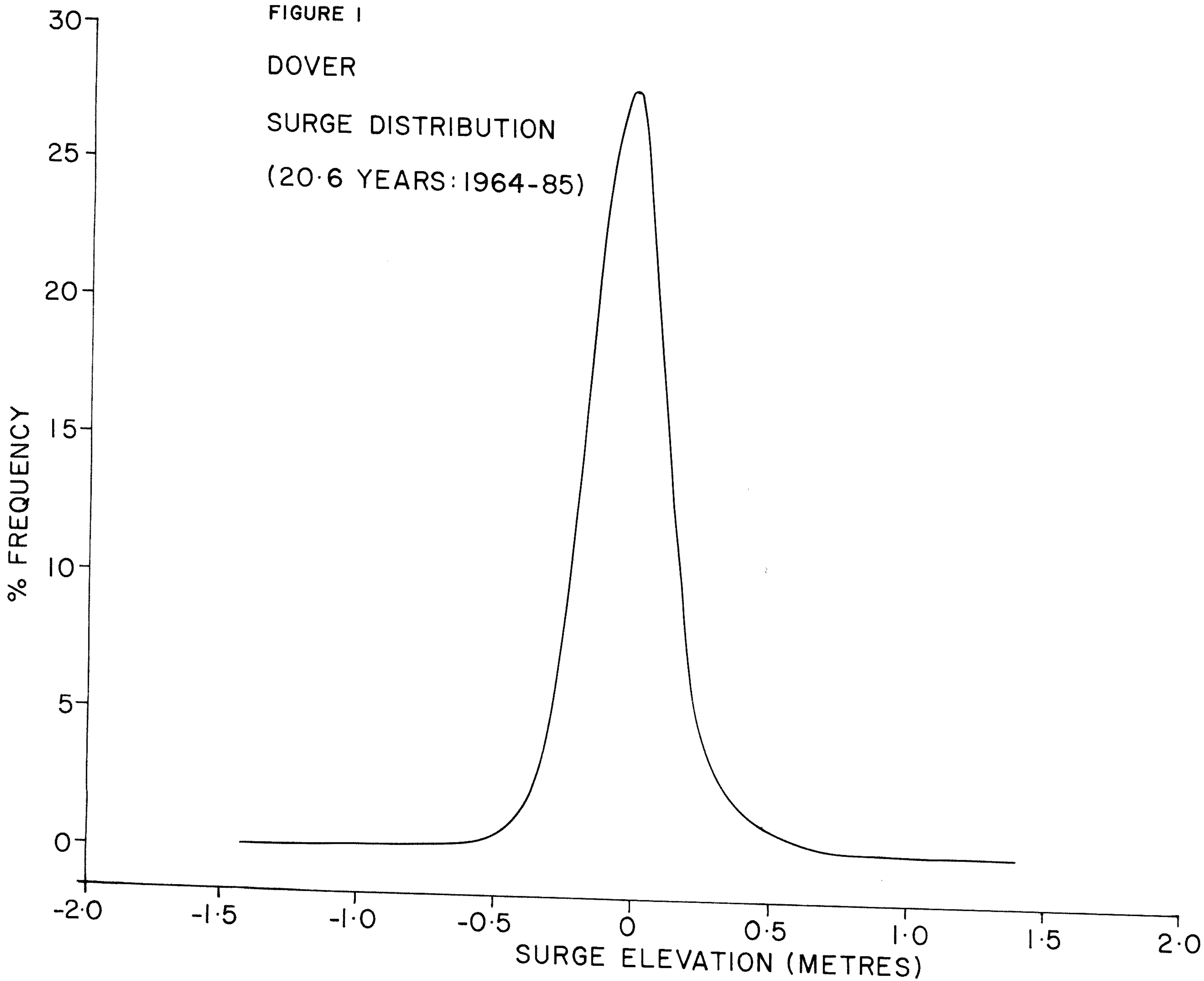
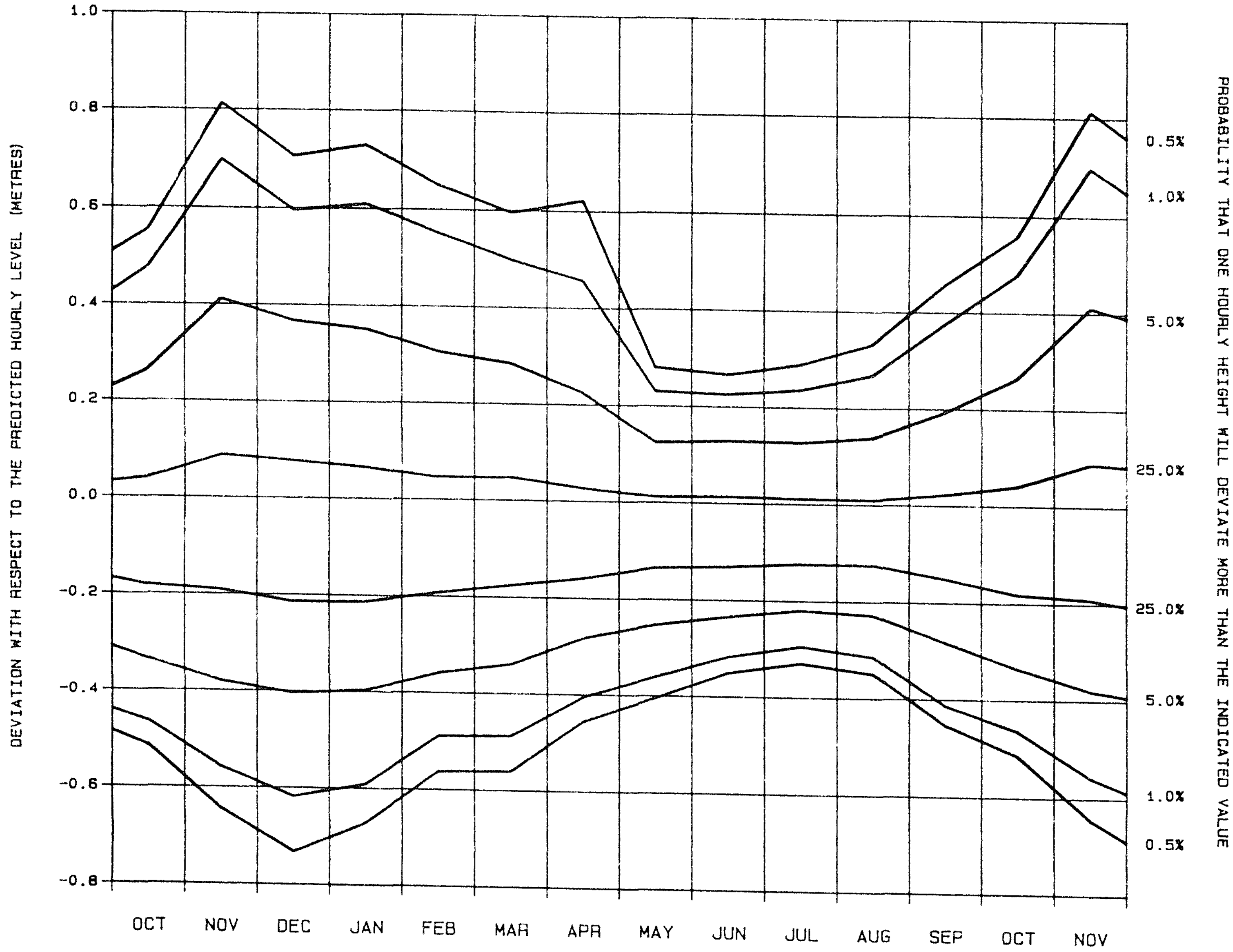


FIGURE 1
DOVER
SURGE DISTRIBUTION
(20·6 YEARS: 1964-85)
% FREQUENCY
30
25
20
15
10
5
0
-2·0
-1·5
-1·0
-0·5
0
0·5
1·0
1·5
2·0
SURGE ELEVATION (METRES)

FIGURE 2 DOVER : MONTHLY SURGE PROBABILITY (1964-1985)



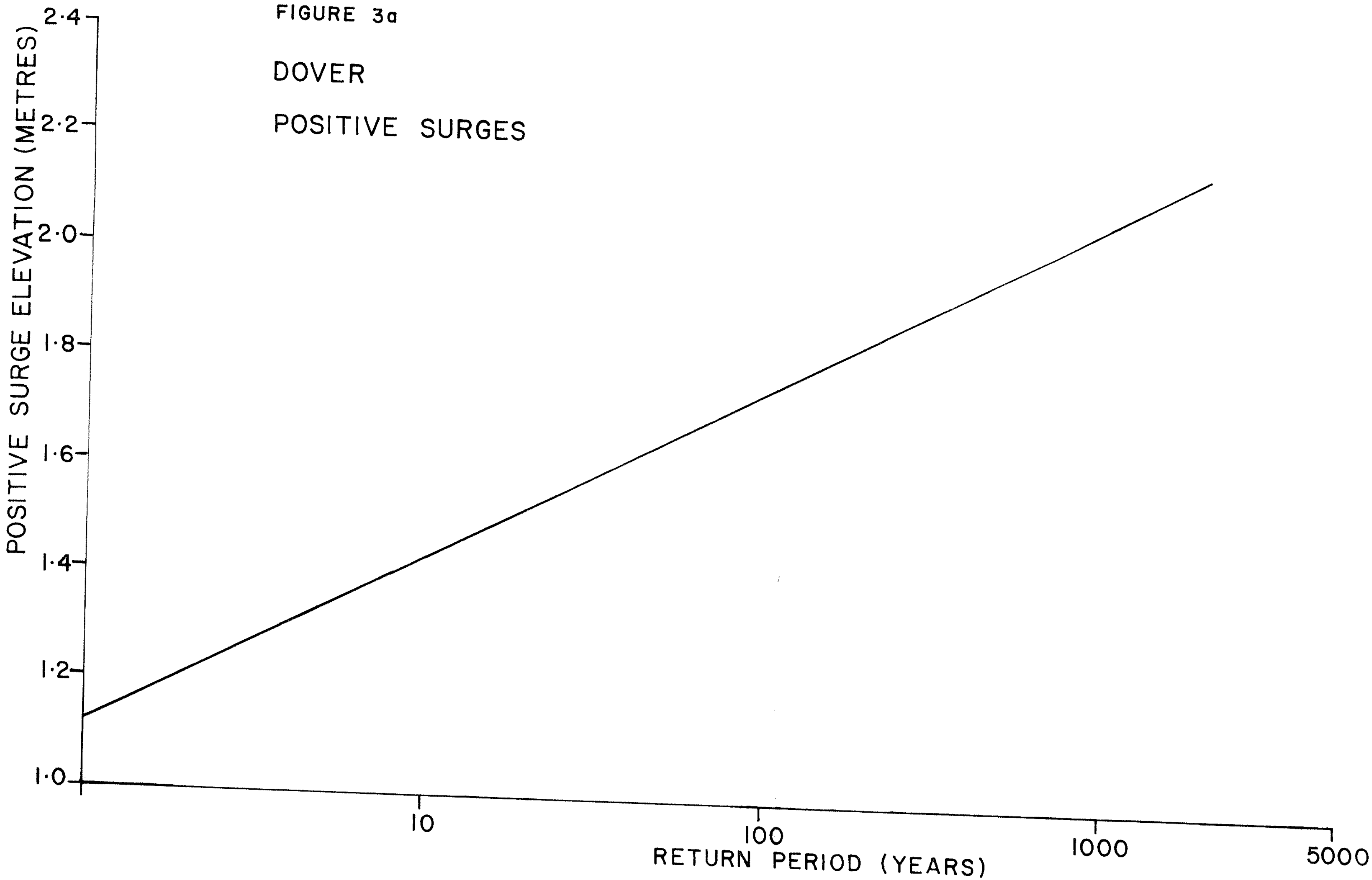


FIGURE 3a
DOVER
POSITIVE SURGES
POSITIVE SURGE ELEVATION (METRES)
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·0
10
100
1000
5000
RETURN PERIOD (YEARS)

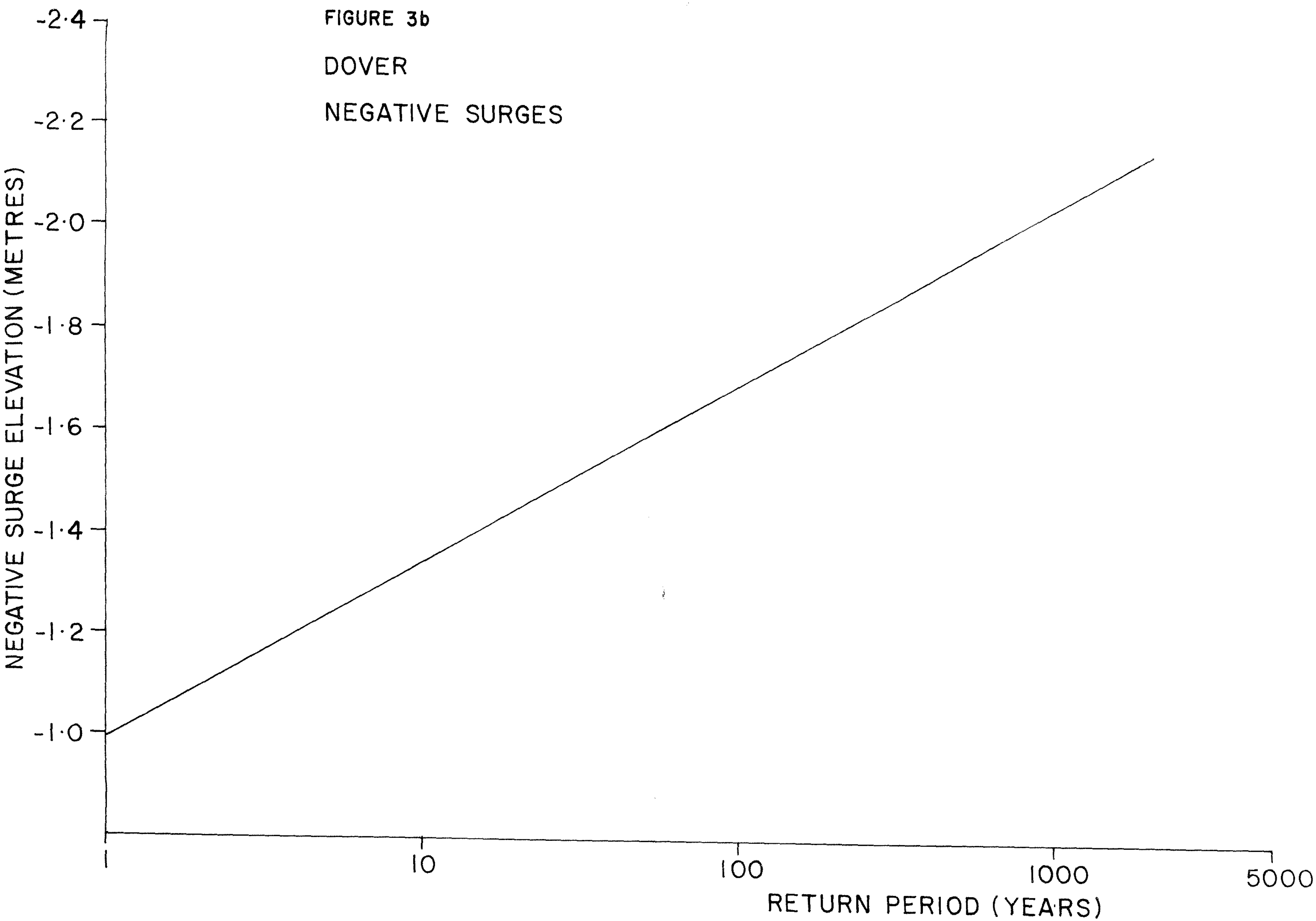


FIGURE 3b
DOVER
NEGATIVE SURGES
NEGATIVE SURGE ELEVATION (METRES)
-2·4
-2·2
-2·0
-1·8
-1·6
-1·4
-1·2
-1·0
1
10
100
1000
5000
RETURN PERIOD (YEARS)

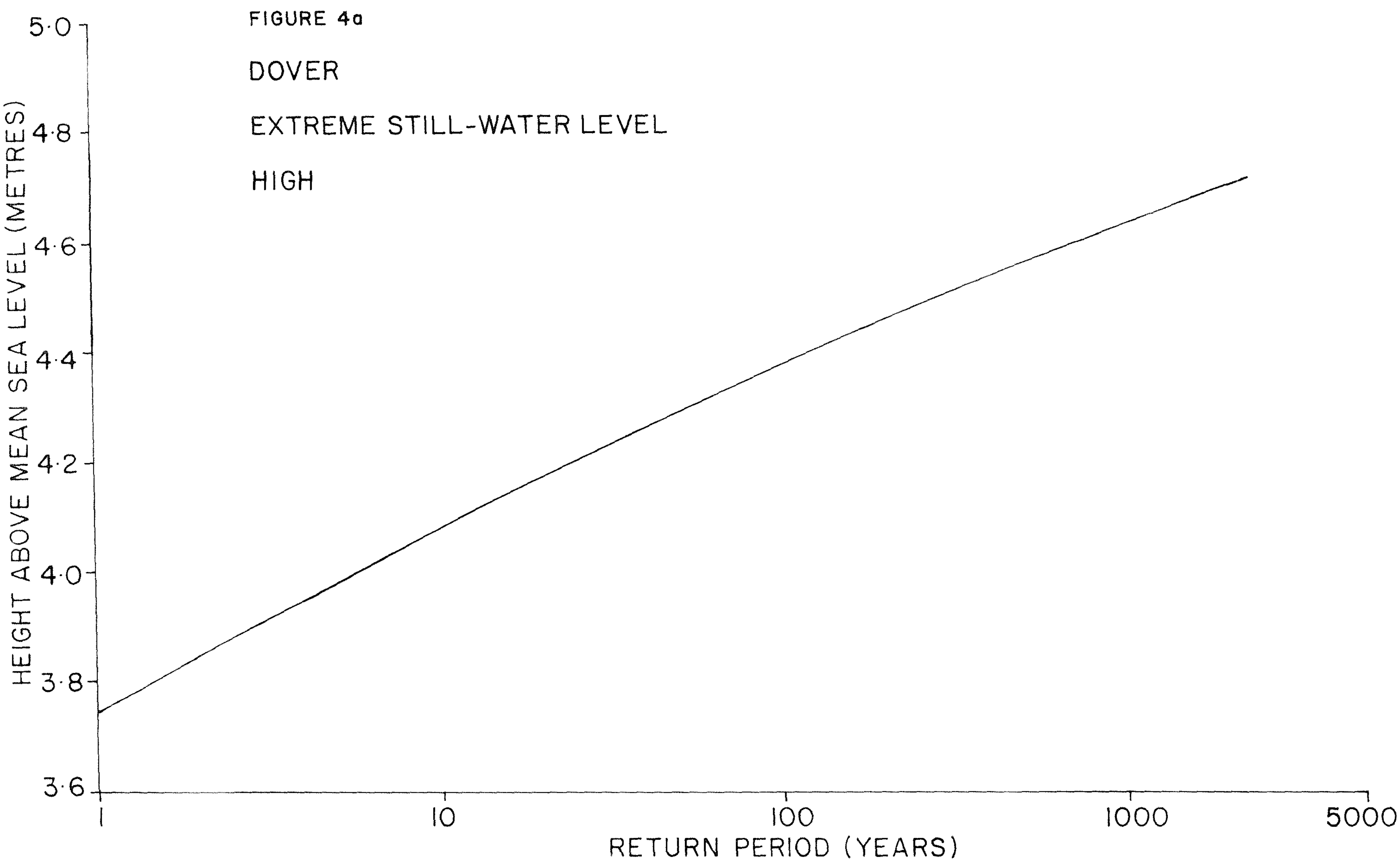


FIGURE 4a
DOVER
EXTREME STILL-WATER LEVEL
HIGH
HEIGHT ABOVE MEAN SEA LEVEL (METRES)
5·0
4·8
4·6
4·4
4·2
4·0
3·8
3·6
1
10
100
1000
5000
RETURN PERIOD (YEARS)

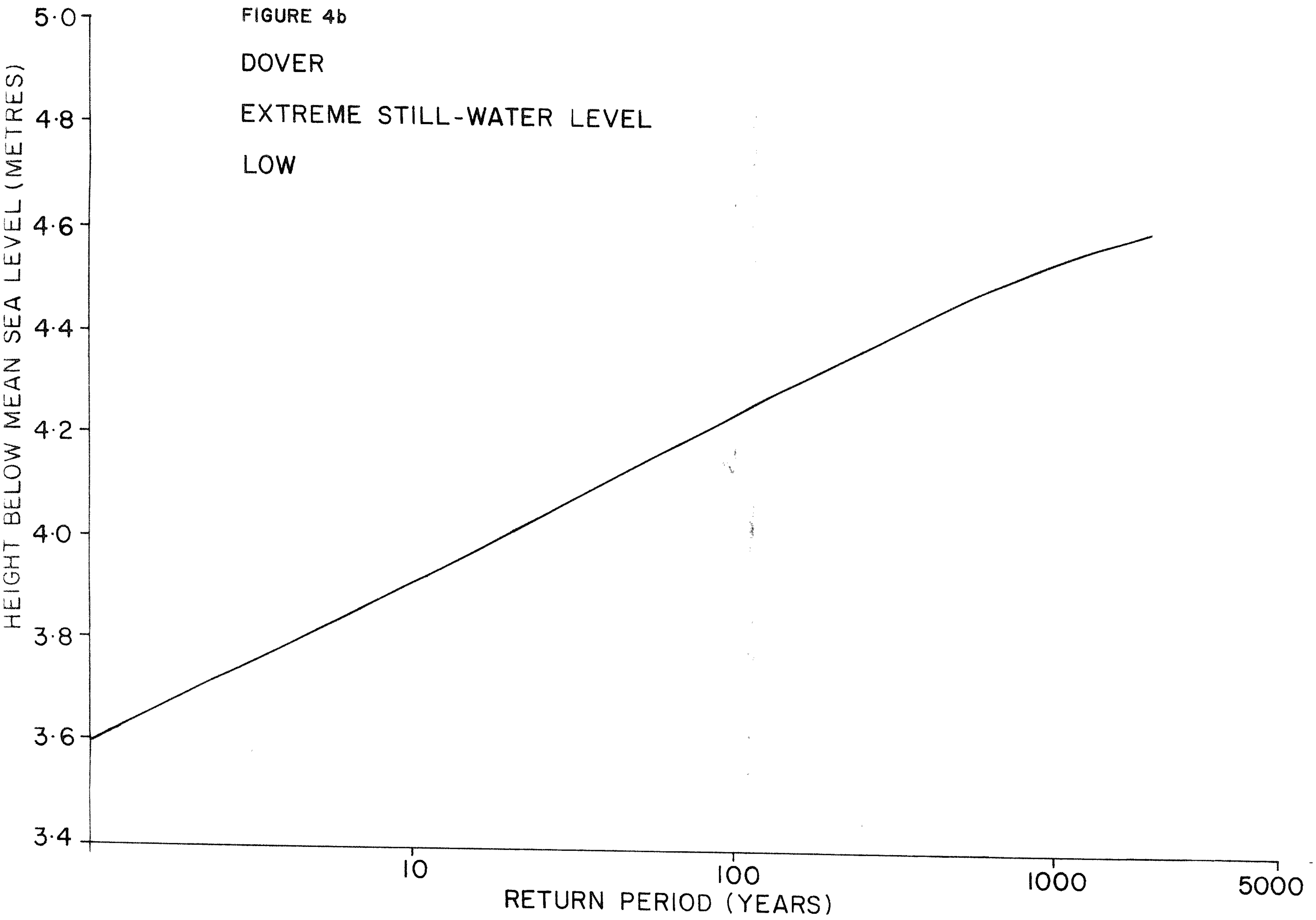


FIGURE 4b
DOVER
EXTREME STILL-WATER LEVEL
LOW
HEIGHT BELOW MEAN SEA LEVEL (METRES)
5·0
4·8
4·6
4·4
4·2
4·0
3·8
3·6
3·4
10
100
1000
5000
RETURN PERIOD (YEARS)