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Extreme Sea Levels for Section 105 Surveys

Final Report

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CONTRACT

This report describes work commissioned by The Environment Agency under Order N°. 200000112 of 6th April 1998. The Agency's representative for the contract was Tim Palmer and the work was carried out by Jeremy Benn, Craig Robson, Jane Ellis and Dr Paul Garrad of Jeremy Benn Associates Ltd, with support from Dr Andrew Metcalf of the University of Newcastle upon Tyne.

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EXECUTIVE SUMMARY

This report summarises work undertaken to calculate extreme sea levels at 10 sites around the North West coast of the UK. The methods adopted include (i) the Spatial Revised Joint Probability Method (SRJPM) described by Dixon and Tawn (1997), and (ii) a General Extreme Value (GEV) distribution fitted to the annual maximum data by the method of maximum likelihood (GEV-MLE) and by probability weighted moments (GEV-PWM).

A comparison of these 3 methods of estimation with those by Graff (1981) and Coles and Tawn (1990) suggest that the SRJPM overestimates levels at most locations, and that the GEV-MLE distribution provides the best fit to the data and hence for estimating extreme sea levels. Thus on the basis of the GEV-MLE distribution, the return periods of the extreme events of Feb 1990 and Feb 1997 have been calculated, as have those for the Operation Neptune flood warning levels, at selected sites.

The results suggest that the SRJPM is inaccurate at many locations and, to provide extreme sea levels for sites without tide gauges such as the Ribble estuary, the SRJPM method has been revised using the GEV-MLE estimates presented in this report. Dixon and Tawn (1997) suggest revisions using local data should be undertaken by revising the 1-year level based on a 6 or preferably 12 month period of hourly tidal data. However, it is considered that revising the 1-year level would influence the origin of the relationship between return period and sea levels and not the slope of the relationship which is shown to be inaccurate at many locations. Consequently the SRJPM has been revised by recalculating the return period adjustment factors at relevant nodes in the area by accounting for the GEV-MLE estimates at selected locations.

The original and revised nodal return period weightings have been used to calculate and compare extreme sea levels at each measurement site and also for an unmonitored site in the Ribble estuary. The results suggest that the SRJPM and the revised SRJPM do not accurately predict extreme sea levels at all monitoring sites and thus the use of the SRJPM at sites without recorded data may also be inaccurate. It is therefore suggested that, at unmeasured sites, the weighted distance from 2 adjacent sites with a sufficiently long period of record should be used to interpolate extreme sea levels. It is considered that this would provide results with greater accuracy than the SRJPM.

This report includes a methodology for interpolation of the calculated extreme sea levels to other sites in the area.

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ABBREVIATIONS

Abbreviation	Definition
AMAX	Annual maximum tidal data as a series
AODN	Above Ordinance Datum Newlyn
GEV	General Extreme Value Distribution – a distribution or curve fitted to extreme event data
MDM	Model Distance Metric
MLE	Maximum Likelihood Method – a method of fitting a GEV distribution to data
PWM	Probability Weighted Moments– a method of fitting a GEV distribution to data
SRJPM	Spatial Revised Joint Probability Method – an empirical method of estimating extreme sea levels around the coast of the UK as detailed by Dixon and Tawn (1997)

1 INTRODUCTION

1.1 Study Brief

The study requirements are set out in Section 2 of the Environment Agency North West Region (the Agency) specification of 5 March 1998 which is given in Appendix F. These requirements have been refined slightly as a result of the meeting with the Agency's Tim Palmer on 28 April 1998 but form the basis of the current study. The requirements can be divided into a number of separate tasks as detailed below;

Task 1: Obtain the appropriate data from the Proudman Oceanographic Laboratory (POL) and/or other organisations to fulfil the project requirements. For each site confirm the chart datum and identify any conflicts.

Task 2: Compute extreme sea levels for 10 selected sites (Appendix A of Specification) and 12 Return Periods using the Spatial Revised Joint Probability Method (SRJPM) described in Dixon and Tawn (1997)[1]. The required return periods (defined in Appendix B of the Specification) are the 1, 5, 10, 20, 25, 50, 75 100, 150, 200, 500 and 1,000 year events.

Task 3: Using the annual maximum data (AMAX) for each site collated in Task 1, compute extreme sea levels for the 10 specified sites and the 12 return periods detailed above using extreme distribution/frequency analyses. The calculation of extreme levels should adopt the methodology described in Graff (1981)[2] and Coles and Tawn (1990)[3]. These fit a relationship to the data using the General Extreme Value distribution (GEV) fitted (i) by the method of Maximum Likelihood (MLE) and (ii) by Probability Weighted Moments (PWM).

Task 4: Compare the extreme sea level results from the 2 methods detailed above (i.e. Tasks 2 and 3), and those given in Graff (1981)[2] and Coles and Tawn (1990)[3].

Task 5: Produce a robust and consistent set of extreme sea levels for the specified locations and return periods.

Task 6: Calculate the return periods of the high tides of 26/2/90 and 10/2/97.

Task 7: Calculate the return periods of the Operation Neptune flood warning levels of 5.5m and 6.0m AOD at Gladstone Dock, Liverpool and compute equivalent levels at Heysham, Workington, Llandudno and Fleetwood for these return periods.

Task 8: Recommend a standard methodology for interpolating extreme sea levels between the 10 locations. This method should take account of the recent work described in Dixon and Tawn (1997)[1]. A full worked example of this method should be included for the mouth of the Ribble estuary.

[1] Dixon and Tawn (1997). Estimates of Extreme Sea Conditions, Final Report; Spatial Analyses for the UK Coast. Proudman Oceanographic Laboratory, June 1997.

[2] Graff (1981). An investigation of the frequency distributions of annual sea level maxima at ports around Great Britain. *Estuarine, Coastal and Shelf Science*, **12**, 389-449.

[3] Coles and Tawn (1990). Statistics of coastal flood prevention. *Phil Trans R Soc Lond., Series A*, **332**, 457-476.

Task 9: Recommend a standard methodology to take account of sea level rise and its effect on extreme levels. This method should take account of the reference to sea level rise in MAFF (1993)[4] and Dixon and Tawn (1997)[1]. A worked example of this methodology should be given for Liverpool (Gladstone Dock) in the years 2025 and 2050.

Task 10: Produce report and other outputs detailing the data used, studies undertaken and results produced.

[4] MAFF (1993). Project Appraisal Guidance Notes. Publication No. PB1214. MAFF Publications, London.

2 METHODOLOGY

2.1 Task 1: Obtain Data

Annual maximum tide level (AMAX) data were obtained for the 10 sites identified in Appendix A of the Specification (Table 1) from the Proudman Oceanographic Laboratory (POL). The Environment Agency have also provided data from 2 tide gauges it operates as part of the RCS flood warning network at Howley Weir and Arpley Pier on the Mersey. These data are available as a mixture of Hydrolog and RCS archive data and will be of most use in the analysis of the recent (Feb 1990 and Feb 1997) events (Task 6).

As detailed in Table 1, the National A-class tide gauge sites are at Workington, Heysham, Liverpool (Princes Pier, until 1983), Liverpool (Gladstone Dock, since 1991) and Llandudno and data for these sites has been provided directly by POL. The data for Silloth, Barrow, Fleetwood, Hilbre Island and Eastham Dock were obtained by POL from the appropriate harbour authority. The grid references of the National tide gauge sites are known to the nearest tenth of one second of latitude and longitude and each site can therefore be accurately located. The grid references of the other stations are taken from the Admiralty tide tables and, as these are provided to the nearest minute of latitude/longitude, these positions are less accurately defined. The location of all gauges is shown on Figure 1 whilst the organisations consulted and data obtained are detailed in Table 2.

The POL and EA tide level data were obtained in hard copy format and all data provided to m AODN. A summary of the available information is detailed in Table 3 whilst a chronological listing of the data is given in Appendix A. As requested by the Agency, a listing of the data in order of magnitude is also given in Appendix B.

The chart datum are identified in Table 1 – no conflicts were identified.

2.2 Task 2: Extreme Sea Levels Using SRJPM

The extreme sea levels for each of the required 10 sites (Table 1) have been calculated using the Spatial Revised Joint Probability Method (SRJPM) described in Dixon and Tawn (1997). The results, presented in Table 4, are limited to the return periods provided by Dixon and Tawn. A summary of the methodology and all calculations are presented in Appendix C.

These estimates are based on the 1-year tide level provided by Dixon and Tawn (ibid. Table 8.4). Dixon and Tawn suggest that, where possible, this 1-year level estimate should be improved at each site by using recorded hourly tidal data. This requires a minimum of 1 to 6 months of winter period hourly tide and surge data at each site although preferably, to avoid seasonal bias and reduce sampling variation, a complete year of hourly tidal data should be obtained for each site.

However, due to the high cost (£600 per station-year) of the hourly data we have, as agreed with the Agency, not purchased the hourly data from POL at this stage. It is considered that the 1-year levels provided by Dixon and Tawn are sufficiently accurate (ibid. Figure 8.18) to obviate the need for this additional and expensive data, to calculate the 1-year level. Only at a later stage would we consider analysis of the hourly data if the results from the currently available AMAX series show that there would be benefit in doing so.

2.3 Task 3: Extreme Sea Levels Using Frequency Analysis

Using the annual maximum (AMAX) data collected in Task 1, the extreme sea levels for the 10 sites specified in Table 1 have been calculated for 12 return periods (defined in Appendix B of the Specification) using the methodology described by Graff (1981) and Coles and Tawn (1990). The required return periods are the 1, 5, 10, 20, 25, 50, 75 100, 150, 200, 500 and 1,000 year events.

These 2 methodologies use the General Extreme Value distribution (GEV), fitted by the method of Maximum Likelihood (GEV-MLE) and by Probability Weighted Moments (GEV-PWM) respectively, to put an equation through the annual maximum data. No adjustment for trend with time was or has been made. For the GEV distribution the probability of an annual maximum value x being less than any value X is given by a 3 parameter equation;

$$F(x>X) = \exp\left(-\{1-k(X-u)/a\}^{1/k}\right)$$

Where u, a and K are constants. The parameters of the distributions for each of the 10 stations have been derived using the WINFAP programme and these parameters are given in Table 5.

The Extreme Sea Levels calculated using the GEV–MLE and GEV-PWM methods are detailed in Table 6 although due to the small number of data points at Llandudno, it was not possible to fit a MLE distribution to these data.

The Standard Errors (SE) of the 2 GEV distributions at various return periods are detailed in Table 7. This indicates that there is a marginally lower SE with the GEV-MLE distribution than the GEV-PWM and thus this should be adopted as the best estimate of extreme sea levels at most sites. The exception is Hilbre Island although for consistency it is recommended that the GEV-MLE distribution is adopted for all sites except Llandudno where there is insufficient data to fit such a distribution.

2.4 Task 4: Comparison of Extreme Sea Level Estimates

2.4.1 *Previous Estimates*

The extreme sea level estimates detailed in Graff (1981) and Coles and Tawn (1990) are given in Tables 8 and 9 respectively.

2.4.2 *SRJPM and 1998 Frequency Analyses*

Estimates of extreme sea levels have therefore been derived by;

- the SRJPM method described in Section 2.2,
- the Frequency analyses using data up to 1997 described in Section 2.3, and
- estimates derived by Graff (1981) and Coles and Tawn (1990) detailed in Section 2.4.1.

A comparison of extreme sea levels calculated by each of these methods is given in Appendix D and shown on Figures 2 to 11 for each of the 10 sites. These figures also show the data plotted using the Gringroten plotting position.

2.4.3 *Comparison and Discussion of Estimates*

Llandudno (Figure 2). Due to the lack of annual maximum data (only 4 years of AMAX data are available) it was not possible to fit a suitable GVE-MLE distribution to these data; more than 4 years of data are required.

The GVE-PWM curve shows a large departure from the SRJPM estimates. In other extreme value distributions (eg flood studies) the GEV curve is stated as being valid to a return period of 2N, where N is the number of years of record, which suggests that extension to a return period of 8 years only is valid. It is suggested that, due to the lack of adequate data, a comparison between estimates cannot be adequately made at this location.

Hilbre Island (Figure 3). Apart from the 1-year return period, the GEV frequency analyses exceed those from Graff and from Coles and Tawn, and are presumably due to a rise in sea level in the intervening 18 year period and due to additional data being available. The SRJPM overestimates levels at all return periods above the 1-year event and exceed the GEV-MLE 95% confidence limits.

Eastham Dock (Figure 4). Apart from the 1-year estimate, the SRJPM shows a reasonable fit to the 1998 frequency analyses for flood return periods up to the 100-year event. Above this level the SRJPM overestimate the tide levels predicted by the GEV fitted distributions.

Liverpool - Gladstone Dock (Figure 5), Liverpool - Princes Pier (Figure 6), Fleetwood (Figure 7), Barrow (Figure 9) and Workington (Figure 10). For each of these sites the SRJPM significantly overestimates the estimates derived from the other methods across the full range of return periods (Figure 5, 6, 7, 9 and 10) and exceed the GEV-MLE 95% confidence limits. At Workington the GEV-PWM estimates are based on only 6 years of AMAX data. As detailed above for Llandudno, in other extreme value distributions (eg flood studies) the GEV curve is stated as being valid to a return period of 2N, where N is the number of years of record. This suggests that extension to a return period of 12 years only is valid and that, due to the lack of adequate data, a comparison between estimates cannot be adequately made at this location.

Heysham. (Figure 8). Both the Coles and Tawn (1990) estimates and SRJPM overestimate those given by Graf and the 2 GEV distributions. The SRJPM exceeds all estimates apart from Coles andTawn.

Silloth (Figure 11). The SRJPM significantly underestimates the levels derived from the other methods across the full range of return periods.

Due to the variability of high tides on the UK west coast being large relative to the variability of surge levels, the SRJPM was considered by Dixon and Tawn to be superior to both annual maxima and r-largest analysis methods, provided at least 5-10 years of hourly observed tides were available.

The results (Figure 2-11) suggest the SRJPM does not provide a good fit to the recorded data. In view of the under and overestimate of the SRJPM, it is suggested that the GEV-MLE distribution should be used to estimate extreme tide levels at these sites.

2.5 Task 5: Consistent Set of Extreme Sea Levels

The study brief requires a robust and consistent set of extreme sea levels for the specified locations and return periods. In view of the under and overestimate of the SRJPM, as detailed in section 2.4, it is suggested that the GEV-MLE distribution should be used to estimate extreme tide levels at these sites. The recommended adopted values are given in Table 10.

2.6 Task 6: High Tides of 26/2/90 and 10/2/97

Using the GEV equation detailed in section 2.3, and the parameters detailed in Table 5, the return periods of the high tides of 26/2/90 and 10/2/97 (provided in Appendix A) have been calculated for each site where tide level data is available (Table 11).

2.7 Task 7: Operation Neptune Flood Warning Levels

Using the GEV-MLE parameters derived (Table 5) the Return Periods of the Operation Neptune flood warning levels of 5.5m and 6.0m AOD at Gladstone Dock, Liverpool have been calculated (Table 12).

The equivalent levels for these return periods at Heysham, Workington, Llandudno and Fleetwood have been calculated by rearranging the GEV equation given in section 2.3 and are shown in Table 13.

2.8 Task 8: Interpolating Extreme Sea Levels

The brief requires a methodology for interpolating extreme sea levels between the 10 locations to be recommended, and such a method should take account of the recent work described in Dixon and Tawn (1997). A full worked example of applying the SRJPM method is detailed in Appendix C and the brief requires a worked example, using SPJPM, for the mouth of the Ribble estuary.

However, for the reasons detailed in section 2.4.3, it is considered that the SRJPM may not be appropriate and has been shown to be inaccurate at these locations. It is recommended that the SRJPM method be revised before being adopted and applied to other sites on the north west coast of the UK.

2.8.1 Revised SRJPM

In order to provide extreme sea level estimates for the Ribble estuary and other unmonitored sites, the SRJPM method has been revised using the GEV-MLE estimates presented in this report (Table 6). Such revisions using local data can be undertaken by revising the 1-year level based on 6 or preferably 12 month period of hourly tidal data. However, it is considered that such revisions would influence the origin of the relationship between return period and sea level and not the slope of the relationship which is shown to be inaccurate at many sites (Figures 2 to 11). Consequently the SRJPM has been revised by recalculating the return period adjustment factors at relevant nodes in the area by accounting for the GEV-MLE estimates at the selected locations.

The GEV-MLE estimates (Table 6) are adjusted by initially removing the datum adjustment factor and the node estimates then calculated from these site estimates and the distance weightings. Two approaches have been adopted (i) extrapolating from a node through a site to the next node of interest assuming a linear relationship, and (ii) interpolating between 2 sites to a node of interest between them. It was found that extrapolation, particularly where more than 1 site exists between 2 nodes, resulted in large error of estimation (i.e. more than 1metre). Hence interpolation to a node between 2 or more sites has been adopted.

Due to lack of data at Llandudno (only 4 years), and hence a poor GEV distribution, this site was removed from the analyses and it was thus not possible to recalculate weightings for nodes 62 and 63. These are assumed to be as given in Dixon and Tawn. The revised return period estimates at node 64 are based on the weightings and levels at the one site to the west; Hilbre Island and three sites to the east; Eastham, Gladstone Dock and Princes Pier. For each return period the sea level at node 64 was calculated as a weighted distance value between the GEV-MLE estimates at Hilbre and at Eastham, Gladstone and Princes Pier. The adopted value was then taken as the mean of these three estimates. The weightings for node 65 are taken as the mean of 9 estimates, with 3 sites to the south and 3 sites to the north. The weightings for node 66 are extrapolated from node 65 and the three sites to the north; Barrow, Heysham and Fleetwood, there being no measurement sites between nodes 66 and 67 to allow for interpolation. The weightings for nodes 67 and 68 are calculated using simultaneous equations for Workington and Silloth. These revised nodal estimates are shown in Table 14.

The revised return period adjustment factors are then calculated by removing the 1-year level specified by Dixon and Tawn and assuming a zero trend adjustment (i.e. a base year of 1990). These give the revised nodal estimates or return period adjustments (Table 15) equivalent to Tables 8.1 to 8.3 in Dixon and Tawn (1997).

On this basis the SRJPM has been used to recalculate extreme sea level estimates (Table 16) based on the revised return period adjustment factors (Table 15). A comparison of the GEV-MLE, the original SRJPM and revised SRJPM estimates (Table 17) suggests some improvement is made, as would be expected given that a separate validation data set is not available, but variability does exist. These comparisons are also shown on Figures 12 to 20.

In summary, due to the discrepancy between the GEV and SRJPM methods, the return period adjustment factors have been revised to recalculate extreme sea levels estimates, and whilst some improvement is made a large degree of variability does exist.

2.8.2 *Estimates for the Ribble Estuary*

The original and revised nodal return period weightings have been used to calculate extreme sea levels for a site in the Ribble estuary (Table 18). The methodology is given in Appendix E.

Compared to adjacent sites; Fleetwood to the north and Eastham, Gladstone and Princes Pier to the south, the results suggest that the revised SRJPM yields more accurate results than the unadjusted SRJPM (Table 19). This suggests that there is little benefit in using the SRJPM over using weighted distance estimates from adjacent tidal stations with a sufficiently long period of record.

It is therefore recommended that the GEV-MLE estimates and weighted distance factors to unmonitored sites be used in preference to the SRJPM or revised SRJPM and estimates for the Ribble estuary are given in Table 19.

2.9 Task 9: Sea Level Rise

It is required to recommend a standard methodology to take account of sea level rise and its effect on extreme sea levels. This method should take account of the reference to sea level rise in MAFF (1993) and Dixon and Tawn (1997). A worked example of this methodology should be given for Gladstone Dock in the years 2025 and 2050.

In July 1989 MAFF announced a strategy to respond to the Greenhouse effect, embracing the use of current predictions of sea level rise in reviewing existing standards for coastal defences. The Inter Governmental Panel on Climate Change (1990)[5] offered predictions of global sea level rise for various scenarios, of which the 'IPCC best estimate trend' is accepted as the most appropriate at this time. Predictions are also available of earth crustal movements in the UK. More recent estimates (Climate Change Impacts Review Group, 1996)[6] indicate a global sea level rise of 19cm by the 2020s (i.e. 7.6 mm/yr) and 37cm by the 2050s (i.e. 6.7mm/yr). However, these estimates make no allowance for any regional differences which may arise from isostatic rebound and crustal movements.

The combination of the IPCC 1990 predictions has been accepted by MAFF (1993) as forming the best basis of allowances for the appraisal of coastal defences and is based on Environment Agency regions (Table 20). This suggests a sea level rise of 4.0 mm/year for the EA-NW region. Dixon and Tawn (1997) also provide estimates

[5] The Inter Governmental Panel on Climate Change (1990). Houghton, J. T., Jenkins, G. J., & Ephralms, J. J. (1990). Climate Change: the IPCC Scientific Assessment. Cambridge University Press: Cambridge.

[6] Climate Change Impacts Review Group, (1996). Review of the Potential Effects of Climate Change in the United Kingdom. Second Report, prepared for the Department of the Environment. HMSO. London: 247 pp.

of the rate of increase in sea level at each of the nodes around the UK (Table 21) which are provided to greater resolution than the MAFF estimates. The Dixon and Tawn estimates have been used.

The increase in sea level at Liverpool (Gladstone Dock) by 2025 and 2050 (Table 22) follow the same approach as detailed in Appendix D, with the adjustment figure in Table D4 altered to those figures given in Table 21.

2.10 Task 10: Reporting

This report has been produced in Microsoft Word format, which can be converted to WordPerfect format data files as required by the Agency. In addition to the deliverables stated in the specification we are also pleased to provide the following additional outputs:

- Provision of the data in both MapInfo and Arc/Info format.
- The majority of the data analyses has been undertaken using bespoke Excel spreadsheets and these are provided.

3 CONCLUSIONS AND RECOMMENDATIONS

Extreme sea levels at 10 sites around the NW coast of the UK have been calculated by various methods. These methods include;

- The Spatial Revised Joint Probability Method (SRJPM) described by Dixon and Tawn (1997), and
- A General Extreme Value (GEV) distribution fitted to the annual maximum data by the method of maximum likelihood (GEV-MLE) and by probability weighted moments (GEV-PWM).
- A summary of estimates by Graff (1981) and Coles and Tawn (1990)

A comparison of these methods of estimation suggest that the SRJPM overestimates levels at most locations, and that the GEV-MLE distribution provides the best fit to the data and for estimating extreme sea levels. Extreme sea levels have therefore been derived for all sites using the parameters from this GEV-MLE distribution. The return periods of the extreme tidal events of Feb 1990 and Feb 1997 have therefore been calculated, as have those for the Operation Neptune flood levels at selected sites.

This SRJPM method is shown to be inaccurate at several locations in the Northwest. To apply this method to sites without tidal gauges (e.g. Ribble estuary) 2 options to revise the SRJPM method were considered. These include;

- Revisions to the 1-year level based on 6 or preferably 12 month period of hourly tidal data
- Revisions to the return period adjustment factors at each node by considering the GEV-MLE estimates at the selected locations.

In view of the different slope of the SRJPM estimates compared to the GEV values, it was considered that changing the 1-year level would have a minimal impact on the estimate values. The SRJPM method was therefore revised using the GEV-MLE estimates to derive return period adjustment factors and whilst some improvement is gained over the unadjusted SRJPM method, in view of the limited number of measurement sites such revisions cannot be recommended for application to un-measured sites. It is suggested that extreme sea levels at unmeasured site be taken as the weighted distance mean of measurements at two adjacent sites where a sufficient period of record exists. Such an approach has been adopted for the Ribble Estuary.

The original and revised nodal return period weightings have been used to calculate and compare extreme sea levels at each measurement site and also for an unmonitored site in the Ribble estuary. The results suggest that the SRJPM and the revised SRJPM do not accurately predict extreme sea levels at all monitoring sites. It is therefore suggested that, at unmeasured sites, the weighted distance from 2 adjacent sites with a sufficiently long period of record should be used to interpolate extreme sea levels from GEV-MLE estimates. It is considered that this would provide results with greater accuracy than the SRJPM.

A methodology for interpolation of the calculated extreme sea levels to other sites in the area is included.

TABLES

Table 1 Location of Tide Gauges

Location	UK A-Class Tide Gauge	Gauge Datum (m above Newlyn)	Grid Reference	Latitude	Longitude
Llandudno	✓	-3.85	SH 7857 8320	53° 19' 53.4" N	03° 49' 25.2" W
Hilbre Island		-4.93	SJ 1837 8905	53° 23' 30.0" N	03° 13' 39.3" W
Eastham Lock		-4.93	SJ 3672 8042	53° 19'N	02° 57'W
Liverpool - Gladstone Dock	✓ (since 1991)	-4.93	SJ 3249 9525	53° 26' 57.9" N	03° 01' 00.0" W
Liverpool - Princes Pier	✓ (until 1983)	-4.93	SJ 3363 8983	53° 24' 03.0" N	02° 59' 54.0" W
Fleetwood		-4.90	SD 3435 4906	53° 56' N	03° 00' W
Heysham	✓	-4.90	SD 4025 6015	54° 02' 01.3" N	02° 54' 44.5" W
Barrow		-4.75	SD 2154 6781	54° 06'N	03° 12'W
Workington	✓	-4.20	NX 9896 2953	540 39' 02.2" N	03° 33' 58.2" W
Silloth		-4.40	NY 1016 5334	54° 52'N	03° 24'W

Table 2 Organisations Consulted for Tidal data

Organisation	Data Made Available
Proudman Oceanographic Laboratory	AMAX data at 10 sites detailed in Table 1
Environment Agency – North West	AMAX data at 2 sites
Harbour Authorities	Peak tide levels for events of 26/2/90 and 10/2/97 at Fleetwood, Barrow in Furness and Silloth.

Table 3 Available Annual Maximum Tide Level Data

Location	Period of Record	No of Complete Years of Record
Llandudno	1994 – 1997	4
Hilbre Island	1854 – 1907 1956 – 1981 1990 1997	82
Eastham Lock	1956 – 1970 1974 – 1977 1990 1997	21
Liverpool - Gladstone Dock	1956 – 1970 1973 – 1977 1989 – 1997	29
Liverpool - Princes Pier	1941 – 1983 1990 1997	45
Fleetwood	1930 – 1931 1935 – 1962 1965 – 1973 1975 – 1983 1985 – 1990	54
Heysham	1940 – 1941 1943 – 1952 1959 – 1969 1971 – 1972 1974 – 1997	49
Barrow	1920 – 1923 1962 – 1967 1970 – 1978	19
Workington	1992 – 1997	6
Silloth	1928 – 1934 1940 – 1958 1965 – 1978	40

Table 4 Tide Levels (to m AODN) calculated using SRJPM (Dixon and Tawn, 1997) with base year of 1990

	Return Period (Years)								
Site	1	10	25	50	100	250	500	1000	10000
Llandudno	4.132	4.511	4.664	4.748	4.901	5.054	5.138	5.261	5.673
Hilbre Island	4.777	5.219	5.395	5.508	5.684	5.861	5.975	6.120	6.626
Eastham Lock	5.522	6.062	6.282	6.418	6.638	6.865	7.005	7.191	7.821
Gladstone Dock	5.523	6.063	6.283	6.420	6.640	6.866	7.006	7.193	7.823
Princes Pier	5.526	6.067	6.287	6.423	6.643	6.870	7.010	7.197	7.827
Fleetwood	5.681	6.224	6.444	6.584	6.804	7.034	7.174	7.364	8.011
Heysham	5.671	6.215	6.435	6.575	6.795	7.025	7.165	7.355	8.001
Barrow	5.633	6.181	6.401	6.541	6.761	6.991	7.131	7.321	7.963
Workington	5.231	5.674	5.835	5.935	6.102	6.269	6.373	6.514	7.002
Silloth	5.237	5.683	5.850	5.950	6.122	6.293	6.399	6.547	7.045

Table 5 Parameters of Fitted GEV Distributions

Site	No Years Data	Fitting Procedure	GEV Parameters		
			U	a	k
Llandudno	4	GEV-PWM	4.651	.023	-.831
Llandudno	4	GEV-MLE	Fitting failure		
Hilbre Island	82	GEV-PWM	4.878	.244	.073
Hilbre Island	82	GEV-MLE	4.876	.235	.047
Eastham Lock	21	GEV-PWM	5.797	.196	.118
Eastham Lock	21	GEV-MLE	5.807	.201	.192
Liverpool – Gladstone Dock	29	GEV-PWM	5.318	.214	.047
Liverpool – Gladstone Dock	29	GEV-MLE	5.327	.221	.117
Liverpool – Princes Pier	45	GEV-PWM	5.412	.221	.022
Liverpool – Princes Pier	45	GEV-MLE	5.415	.218	.028
Fleetwood	54	GEV-PWM	5.592	.227	.307
Fleetwood	54	GEV-MLE	5.590	.221	.279
Heysham	49	GEV-PWM	5.788	.190	.081
Heysham	49	GEV-MLE	5.787	.185	.064
Barrow	19	GEV-PWM	5.418	.144	-.150
Barrow	19	GEV-MLE	5.423	.143	-.133
Workington	6	GEV-PWM	5.031	.291	.222
Workington	6	GEV-MLE	5.050	.246	.247
Silloth	40	GEV-PWM	5.676	.290	.164
Silloth	40	GEV-MLE	5.677	.286	.159

Table 6 Extreme Sea Levels (m AODN) by GEV–MLE and GEV-PWM methods (= fitting failure)**

		Return Period (Years)											
Site	**Method**	**1**	**5**	**10**	**20**	**25**	**50**	**75**	**100**	**150**	**200**	**500**	**1000**
Llandudno	PWM	4.63	4.72	4.80	4.94	5.01	5.32	5.60	5.86	6.36	6.83	9.36	13.06
	MLE	**	**	**	**	**	**	**	**	**	**	**	**
Hilbre	PWM	4.22	5.22	5.38	5.53	5.57	5.71	5.78	5.83	5.90	5.95	6.10	6.20
	MLE	4.27	5.22	5.38	5.53	5.57	5.71	5.79	5.85	5.92	5.98	6.14	6.26
Eastham Lock	PWM	5.24	6.07	6.19	6.29	6.32	6.41	6.46	6.49	6.54	6.57	6.66	6.73
	MLE	5.18	6.07	6.17	6.26	6.29	6.36	6.40	6.42	6.45	6.47	6.53	6.57
Gladstone Dock	PWM	4.76	5.63	5.78	5.91	5.95	6.08	6.15	6.20	6.27	6.32	6.47	6.58
	MLE	4.70	5.63	5.76	5.88	5.92	6.02	6.08	6.11	6.16	6.20	6.30	6.37
Princes Pier	PWM	4.86	5.74	5.90	6.05	6.10	6.24	6.32	6.38	6.46	6.52	6.70	6.83
	MLE	4.86	5.73	5.89	6.03	6.08	6.22	6.30	6.35	6.43	6.48	6.65	6.78
Fleetwood	PWM	4.77	5.86	5.96	6.03	6.05	6.11	6.13	6.15	6.17	6.18	6.22	6.24
	MLE	4.82	5.86	5.96	6.04	6.06	6.11	6.14	6.16	6.19	6.20	6.24	6.27
Heysham	PWM	5.27	6.06	6.18	6.29	6.32	6.42	6.48	6.52	6.57	6.61	6.72	6.79
	MLE	5.30	6.05	6.18	6.29	6.32	6.43	6.49	6.53	6.58	6.62	6.74	6.82
Barrow	PWM	5.12	5.66	5.80	5.96	6.01	6.18	6.29	6.37	6.49	6.58	6.90	7.17
	MLE	5.13	5.66	5.80	5.94	5.99	6.15	6.25	6.33	6.44	6.52	6.80	7.04
Workington	PWM	4.09	5.40	5.55	5.66	5.70	5.79	5.84	5.87	5.91	5.93	6.01	6.06
	MLE	4.22	5.36	5.48	5.57	5.59	5.67	5.70	5.73	5.76	5.78	5.83	5.87
Silloth	PWM	4.81	6.06	6.22	6.36	6.40	6.51	6.57	6.61	6.67	6.70	6.80	6.87
	MLE	4.82	6.06	6.22	6.35	6.39	6.51	6.57	6.61	6.66	6.70	6.81	6.88

Table 7 Standard Errors of GEV Distributions (lowest SEs in italics), ** = fitting failure.

		Return Period (Years)											
Location	**Method**	**1**	**5**	**10**	**20**	**25**	**50**	**75**	**100**	**150**	**200**	**500**	**1000**
Llandudno	PWM	**	**	**	**	**	**	**	**	**	**	**	**
	MLE	**	**	**	**	**	**	**	**	**	**	**	**
Hilbre Island	*PWM*	*0.10*	*0.04*	*0.06*	*0.08*	*0.08*	*0.11*	*0.13*	*0.15*	*0.17*	*0.19*	*0.25*	*0.30*
	MLE	0.09	0.04	0.06	0.08	0.09	0.12	0.15	0.16	0.19	0.21	0.28	0.35
Eastham Lock	PWM	0.17	0.07	0.08	0.11	0.12	0.15	0.18	0.20	0.23	0.25	0.32	0.38
	MLE	*0.18*	*0.06*	*0.07*	*0.08*	*0.09*	*0.11*	*0.13*	*0.14*	*0.16*	*0.17*	*0.21*	*0.24*
Gladstone Dock	PWM	0.14	0.07	0.09	0.12	0.14	0.18	0.22	0.24	0.28	0.31	0.42	0.51
	MLE	*0.15*	*0.06*	*0.08*	*0.10*	*0.11*	*0.15*	*0.17*	*0.19*	*0.21*	*0.23*	*0.30*	*0.35*
Princes Pier	PWM	0.11	0.06	0.08	0.11	0.12	0.17	0.20	0.22	0.26	0.29	0.39	0.48
	MLE	*0.11*	*0.06*	*0.08*	*0.11*	*0.12*	*0.17*	*0.20*	*0.22*	*0.26*	*0.29*	*0.39*	*0.47*
Fleetwood	PWM	0.17	0.04	0.04	0.05	0.05	0.06	0.07	0.07	0.08	0.09	0.10	0.11
	MLE	*0.15*	*0.04*	*0.04*	*0.04*	*0.05*	*0.05*	*0.06*	*0.07*	*0.07*	*0.08*	*0.09*	*0.10*
Heysham	PWM	0.10	0.04	0.06	0.08	0.08	0.11	0.13	0.15	0.17	0.18	0.24	0.29
	MLE	*0.09*	*0.04*	*0.06*	*0.08*	*0.08*	*0.11*	*0.13*	*0.15*	*0.17*	*0.19*	*0.24*	*0.29*
Barrow	PWM	0.09	0.08	0.12	0.19	0.21	0.33	0.41	0.48	0.59	0.68	1.02	1.36
	MLE	*0.08*	*0.07*	*0.11*	*0.18*	*0.21*	*0.31*	*0.39*	*0.45*	*0.55*	*0.63*	*0.94*	*1.24*
Workington	PWM	0.55	0.15	0.18	0.22	0.24	0.30	0.34	0.38	0.42	0.45	0.56	0.63
	MLE	*0.62*	*0.13*	*0.14*	*0.19*	*0.20*	*0.27*	*0.32*	*0.35*	*0.40*	*0.43*	*0.53*	*0.61*
Silloth	PWM	0.19	0.07	0.08	0.10	0.11	0.14	0.16	0.18	0.20	0.22	0.28	0.32
	MLE	*0.16*	*0.06*	*0.08*	*0.09*	*0.10*	*0.13*	*0.14*	*0.16*	*0.17*	*0.19*	*0.23*	*0.27*

Table 8 Extreme Sea Level Results (m AODN) from Coles and Tawn (1990); base year of 1990

	Return Period (Years)			Start	End	No
Location	10	100	1000	Year	Year	Years
Llandudno	-	-	-	-	-	-
Hilbre Island	5.51	5.78	5.96	1854	1981	80
Eastham Lock	6.43	6.48	6.49	1956	1977	19
Liverpool - Gladstone Dock	6.08	6.21	6.30	1956	1977	20
Liverpool - Princes Pier	6.10	6.24	6.31	1941	1977	37
Fleetwood	6.01	6.21	6.30	1930	1983	48
Heysham	6.13	6.93	8.13	1940	1984	36
Barrow	5.79	6.39	7.30	1920	1978	19
Workington	-	-	-	-	-	-
Silloth	6.23	6.69	7.08	1928	1978	39

Table 9 Extreme Sea Level Results (m AODN) from Graff (1981); base year of 1978

	Return Period (Years)							Start	End	No
Location	1	5	10	20	50	100	250	Year	Year	Years
Llandudno	-	-	-	-	-	-	-	-	-	-
Hilbre Island	4.88	5.19	5.31	5.44	5.58	5.69	5.78	1854	1977	76
Eastham Lock	5.81	6.03	6.09	6.19	6.25	6.31	6.38	1956	1977	19
Liverpool - Gladstone Dock	5.31	5.59	5.72	5.81	5.94	5.97	6.06	1956	1977	20
Liverpool - Princes Pier	5.38	5.69	5.81	5.88	6.00	6.09	6.19	1941	1977	37
Fleetwood	5.56	5.88	5.94	6.01	6.09	6.13	6.19	1930	1978	43
Heysham	5.78	6.06	6.19	6.28	6.44	6.53	6.66	1940	1977	29
Barrow	5.38	5.69	5.81	5.94	6.09	6.25	6.44	1920	1978	19
Workington	-	-	-	-	-	-	-	-	-	-
Silloth	5.69	6.06	6.22	6.34	6.47	6.56	6.69	1928	1978	40

Table 10 Recommended Extreme Sea Levels (m AODN) using GEV–MLE method (Llandudno = GEV-PWM)

	Fitting	Return Period (Years)											
Site	Method	1	5	10	20	25	50	75	100	150	200	500	1000
Llandudno	PWM	4.63	4.72	4.80	4.94	5.01	5.32	5.60	5.86	6.36	6.83	9.36	13.06
Hilbre	MLE	4.27	5.22	5.38	5.53	5.57	5.71	5.79	5.85	5.92	5.98	6.14	6.26
Eastham Lock	MLE	5.18	6.07	6.17	6.26	6.29	6.36	6.4	6.42	6.45	6.47	6.53	6.57
Gladstone Dk	MLE	4.70	5.63	5.76	5.88	5.92	6.02	6.08	6.11	6.16	6.20	6.30	6.37
Princes Pier	MLE	4.86	5.73	5.89	6.03	6.08	6.22	6.30	6.35	6.43	6.48	6.65	6.78
Fleetwood	MLE	4.82	5.86	5.96	6.04	6.06	6.11	6.14	6.16	6.19	6.20	6.24	6.27
Heysham	MLE	5.30	6.05	6.18	6.29	6.32	6.43	6.49	6.53	6.58	6.62	6.74	6.82
Barrow	MLE	5.13	5.66	5.80	5.94	5.99	6.15	6.25	6.33	6.44	6.52	6.80	7.04
Workington	MLE	4.22	5.36	5.48	5.57	5.59	5.67	5.70	5.73	5.76	5.78	5.83	5.87
Silloth	MLE	4.82	6.06	6.22	6.35	6.39	6.51	6.57	6.61	6.66	6.70	6.81	6.88

Table 11 Return Periods of the High Tides of 26/2/90 and 10/2/97 (* = not possible to extrapolate distribution)**

Location	26/2/90		10/2/97	
	Tide Level (m AODN)	Return Period (Years)	Tide Level (m AODN)	Return Period (Years)
Llandudno	-	-	5.100	31.2
Hilbre Island	5.970	191.8	5.650	36.3
Eastham Lock	6.390	70.0	6.070	5.0
Liverpool - Gladstone Dock	6.040	58.0	5.890	21.1
Liverpool - Princes Pier	6.220	49.8	6.290	71.1
Fleetwood	6.200	194.7	6.500	***
Heysham	6.270	17.9	6.390	39.2
Barrow	5.950	20.6	6.350	107.7
Workington	-	-	5.589	23.9
Silloth	5.900	2.84	6.600	93.0

Table 12 Return Periods for Operation Neptune Flood Levels at Liverpool (Gladstone Dock)

Location	5.5m AODN	6.0m AODN
Liverpool - Gladstone Dock	2.81 years	43.67 years

Table 13 Flood Levels (m AODN) at selected sites for Operation Neptune Return Periods at Liverpool (Gladstone Dock)

	Return Period (Years)	
Location	2.81 years	43.67 years
Llandudno	4.68	5.26
Fleetwood	5.75	6.11
Heysham	5.94	6.41
Workington	5.23	5.65

Table 14 Return Period Estimates (m AODN) at each Node based on interpolation with station records

	Return Period (Years)					
Node	10	25	50	100	500	1000
62	4.230	4.380	4.460	4.610	4.840	4.960
63	4.940	5.110	5.220	5.390	5.670	5.810
64	5.298	5.482	5.615	5.746	6.019	6.131
65	5.764	5.909	6.010	6.108	6.323	6.416
66	5.828	5.936	6.011	6.090	6.254	6.326
67	4.040	4.052	4.067	4.061	3.998	3.989
68	7.419	7.705	7.902	8.080	8.473	8.601

Table 15 Revised Return Period Adjustments (m)

	Return Period (Years)					
Node	**10**	**25**	**50**	**100**	**500**	**1000**
63	0.430	0.600	0.710	0.880	1.160	1.300
64	0.138	0.322	0.455	0.586	0.859	0.971
65	0.364	0.509	0.610	0.708	0.923	1.016
66	0.348	0.456	0.531	0.610	0.774	0.846
67	-0.980	-0.968	-0.953	-0.959	-1.022	-1.031
68	2.429	2.715	2.912	3.090	3.483	3.611

Table 16 Extreme Sea Level estimates (m AODN) based on revised SRJPM

	Return Period (Years)					
Site	**10**	**25**	**50**	**100**	**500**	**1000**
Hilbre Island	5.440	5.622	5.752	5.888	6.162	6.278
Eastham Lock	5.653	5.823	5.946	6.065	6.319	6.425
Liverpool – Gladstone Dock	5.651	5.822	5.944	6.064	6.318	6.423
Liverpool – Princes Pier	5.645	5.816	5.939	6.059	6.313	6.419
Fleetwood	5.998	6.132	6.226	6.318	6.519	6.606
Heysham	6.007	6.137	6.228	6.319	6.514	6.599
Barrow	6.038	6.155	6.236	6.320	6.495	6.572
Workington	5.480	5.590	5.670	5.730	5.830	5.870
Silloth	6.220	6.390	6.510	6.610	6.810	6.880

Table 17 Comparison of estimates (m AODN)

		Return Period (Years)					
Location	**Method**	**10**	**25**	**50**	**100**	**500**	**1000**
Hilbre Island	MLE	5.38	5.57	5.71	5.85	6.14	6.26
	SRJPM	5.22	5.40	5.51	5.68	5.97	6.12
	R-SRJPM	5.440	5.622	5.752	5.888	6.162	6.278
Eastham Lock	MLE	6.17	6.29	6.36	6.42	6.53	6.57
	SRJPM	6.06	6.28	6.42	6.64	7.00	7.19
	R-SRJPM	5.653	5.823	5.946	6.065	6.319	6.425
Gladstone Dock	MLE	5.76	5.92	6.02	6.11	6.3	6.37
	SRJPM	6.06	6.28	6.42	6.64	7.01	7.19
	R-SRJPM	5.651	5.822	5.944	6.064	6.318	6.423
Princes Pier	MLE	5.89	6.08	6.22	6.35	6.65	6.78
	SRJPM	6.07	6.29	6.42	6.64	7.01	7.20
	R-SRJPM	5.645	5.816	5.939	6.059	6.313	6.419
Fleetwood	MLE	5.96	6.06	6.11	6.16	6.24	6.27
	SRJPM	6.22	6.44	6.58	6.80	7.17	7.36
	R-SRJPM	5.998	6.132	6.226	6.318	6.519	6.606
Heysham	MLE	6.18	6.32	6.43	6.53	6.74	6.82
	SRJPM	6.21	6.43	6.57	6.79	7.16	7.35
	R-SRJPM	6.007	6.137	6.228	6.319	6.514	6.599
Barrow	MLE	5.8	5.99	6.15	6.33	6.8	7.04
	SRJPM	6.18	6.40	6.54	6.76	7.13	7.32
	R-SRJPM	6.038	6.155	6.236	6.320	6.495	6.572
Workington	MLE	5.48	5.59	5.67	5.73	5.83	5.87
	SRJPM	5.67	5.84	5.94	6.10	6.37	6.51
	R-SRJPM	5.480	5.590	5.670	5.730	5.830	5.870
Silloth	MLE	6.22	6.39	6.51	6.61	6.81	6.88
	SRJPM	5.68	5.85	5.95	6.12	6.40	6.55
	R-SRJPM	6.220	6.390	6.510	6.610	6.810	6.880

Table 18 Extreme sea levels (m AODN) for a site in the Ribble estuary

	Return Period (Years)						
	10	**25**	**50**	**100**	**250**	**500**	**1000**
SRJPM	6.073	6.293	6.430	6.650	6.877	7.017	7.204
Revised SRJPM	5.634	5.806	5.930	6.051	6.147	6.306	6.413

Table 19 Average Extreme Sea Levels (m AODN) for the Ribble Estuary based on GEV-MLE estimates and the average of 9 interpolations (3 sites to the north, 3 sites to the south)

	Return Period (Years)											
Location	1	5	10	20	25	50	75	100	150	200	500	1000
Eastham Lock	5.18	6.07	6.17	6.26	6.29	6.36	6.40	6.42	6.45	6.47	6.53	6.57
Gladstone Dk	4.70	5.63	5.76	5.88	5.92	6.02	6.08	6.11	6.16	6.20	6.30	6.37
Princes Pier	4.86	5.73	5.89	6.03	6.08	6.22	6.30	6.35	6.43	6.48	6.65	6.78
Ribble	4.98	5.83	5.96	6.07	6.11	6.21	6.27	6.31	6.37	6.41	6.53	6.62
Fleetwood	4.82	5.86	5.96	6.04	6.06	6.11	6.14	6.16	6.19	6.20	6.24	6.27
Heysham	5.30	6.05	6.18	6.29	6.32	6.43	6.49	6.53	6.58	6.62	6.74	6.82
Barrow	5.13	5.66	5.80	5.94	5.99	6.15	6.25	6.33	6.44	6.52	6.80	7.04

Table 20 Regional Rates of Relative Sea Level Rise allowing for global warming and crustal movements.

EA Region	Allowance (mm/year)
Anglian Thames Southern	6.0
North West North East	4.0
Remainder	5.0

Table 21 Sea Level trends by 2025 and 2050

Node	Trend (mm/year)	Adjustment by 2025 (m)	Adjustment by 2050 (m)
62	3.06	0.1071	0.1836
63	3.07	0.1075	0.1842
64	3.11	0.1089	0.1866
65	3.07	0.1075	0.1842
66	2.63	0.0921	0.1578
67	2.11	0.0739	0.1266
68	0.34	0.0119	0.0204

Table 22 Predicted Sea Levels (m AODN) at Liverpool (Gladstone Dock)

	Return Period (Years)								
Year	1	10	25	50	100	250	500	1000	10000
1990	5.523	6.063	6.283	6.420	6.640	6.866	7.006	7.193	7.823
2025	5.631	6.171	6.391	6.528	6.748	6.974	7.114	7.301	7.931
2050	5.708	6.248	6.468	6.605	6.825	7.051	7.191	7.378	8.008

FIGURES

Key

- Extreme Sea Level Data Locations
- Environment Agency North West Region Office
- Environment Agency Regional Boundary
- Environment Agency Area Boundary

ENVIRONMENT AGENCY NORTH WEST REGION

Extreme Sea Levels for Section 105 Surveys

Figure 1: General Location Plan

JBA
Jeremy Benn Associates
Consulting Engineers

Figure 2 Extreme Sea Level Estimates - Llandudno

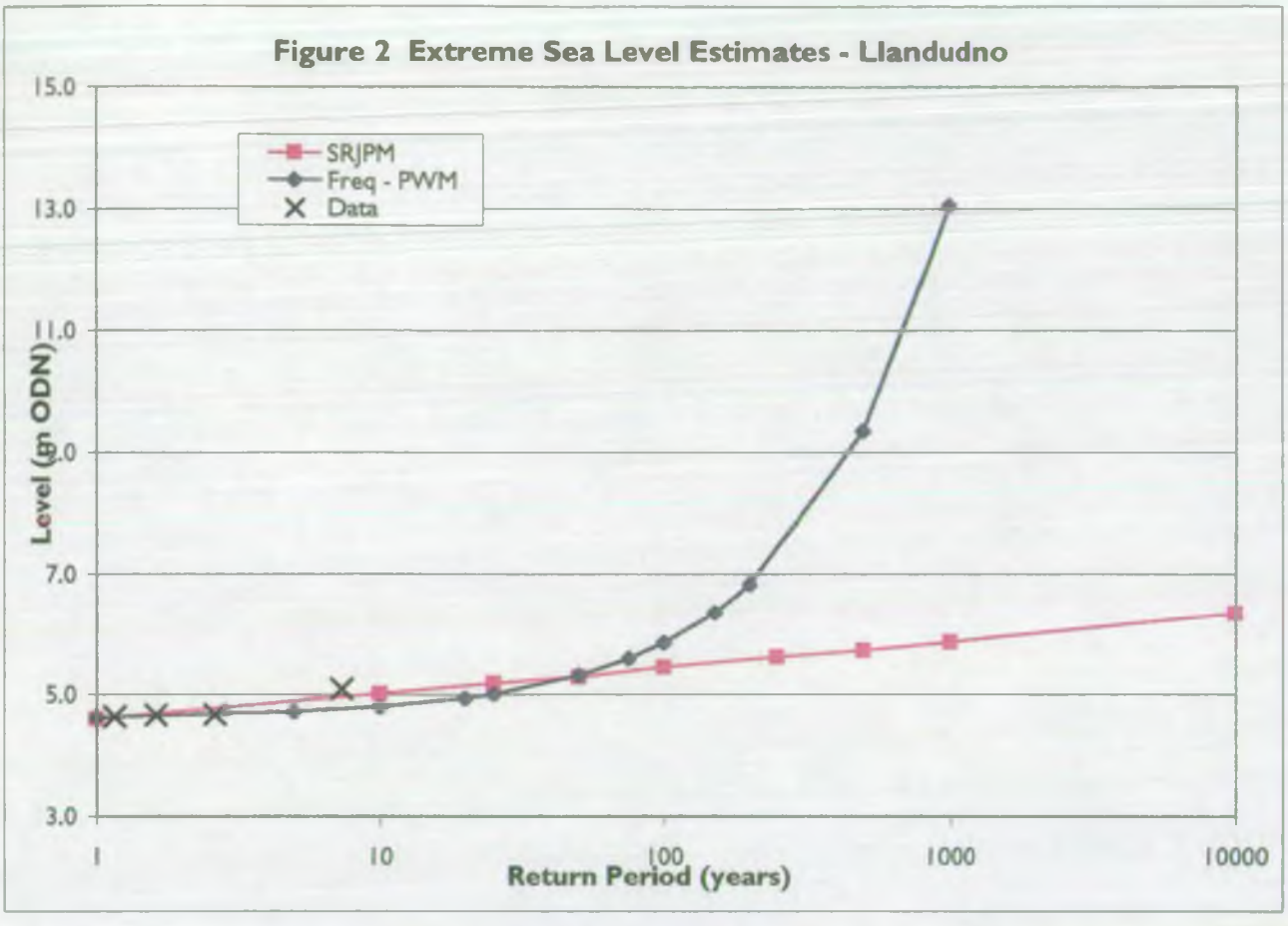


Figure 3 Extreme Sea Level Estimates - Hilbre Island

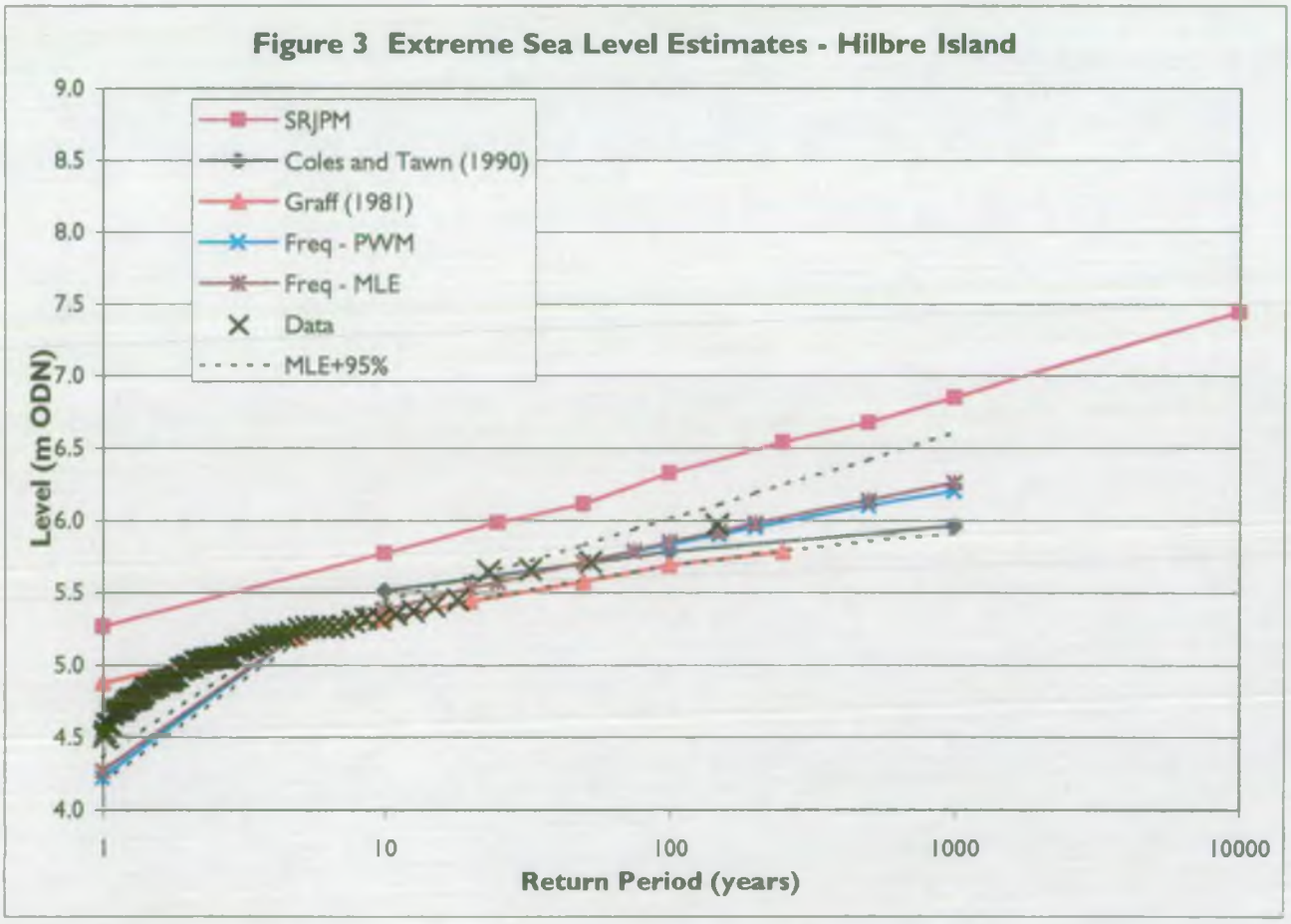


Figure 4 Extreme Sea Level Estimates - Eastham Dock

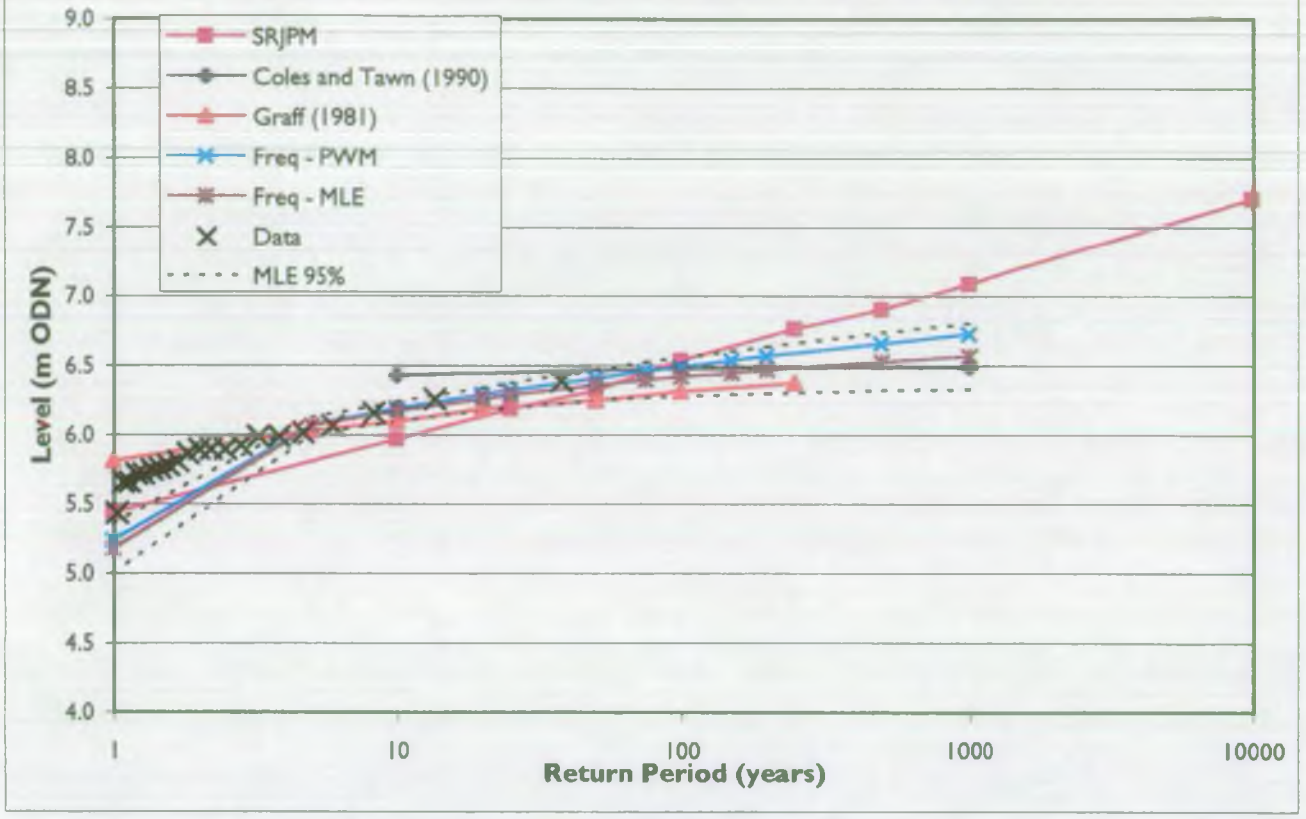


Figure 5 Extreme Sea Level Estimates - Liverpool Gladstone Dock

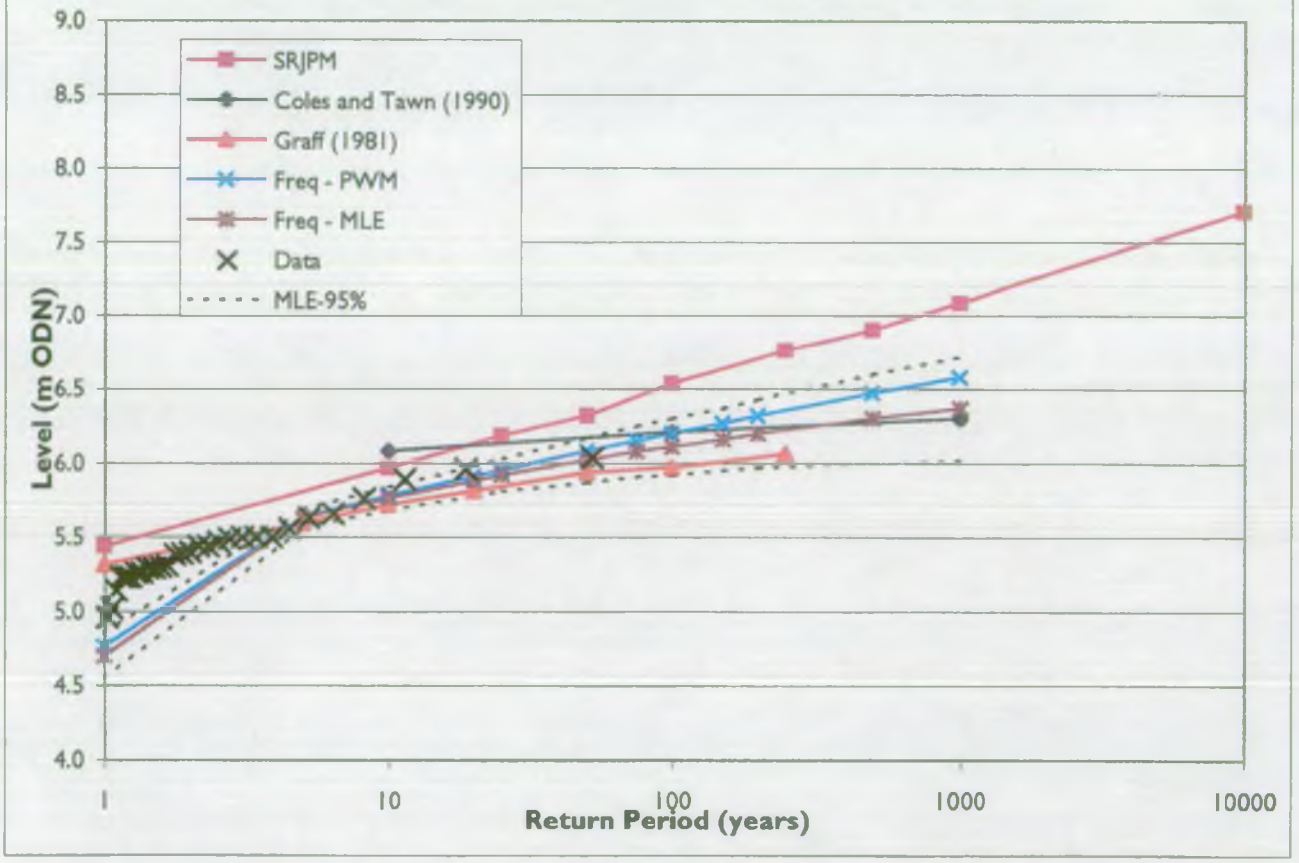


Figure 6 Extreme Sea Level Estimates - Liverpool Princes Pier

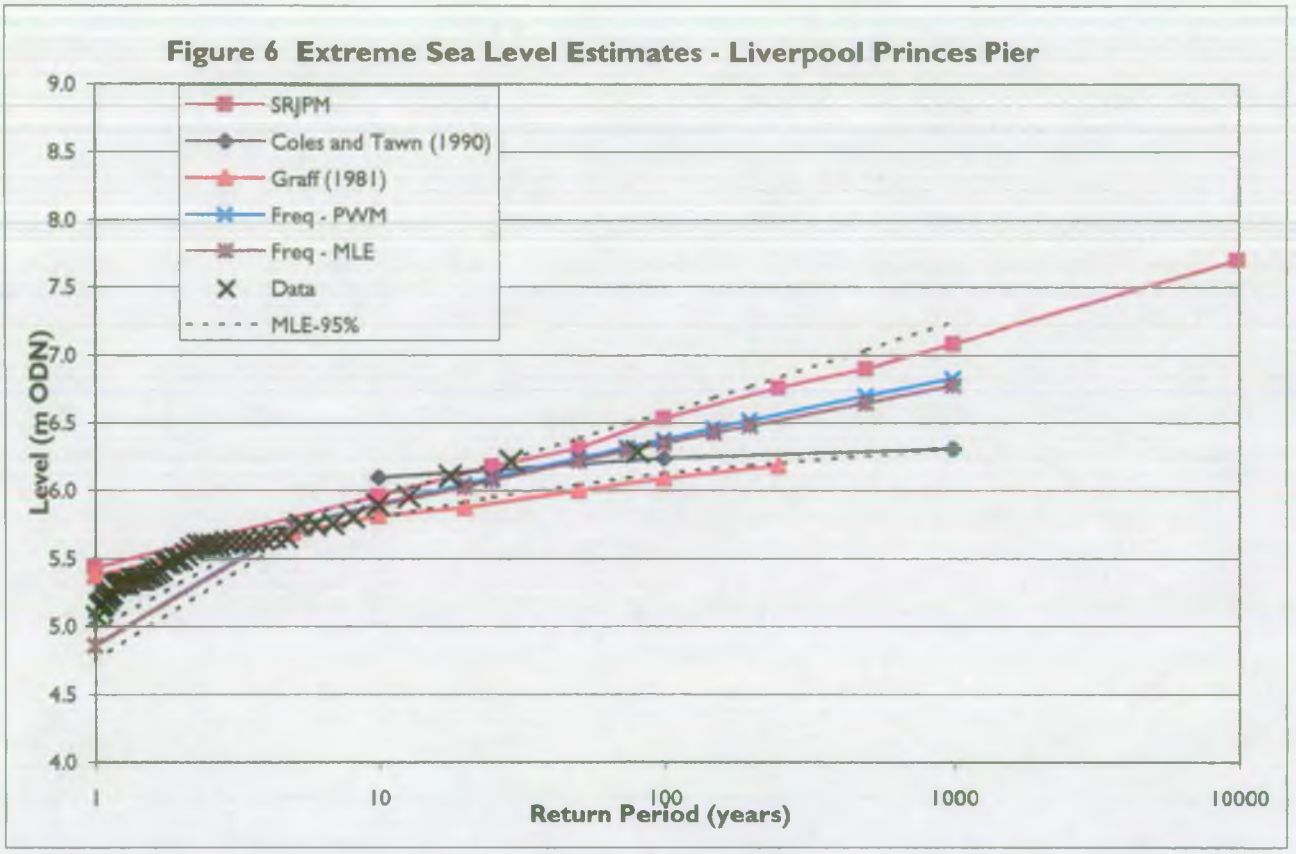


Figure 7 Extreme Sea Level Estimates - Fleetwood

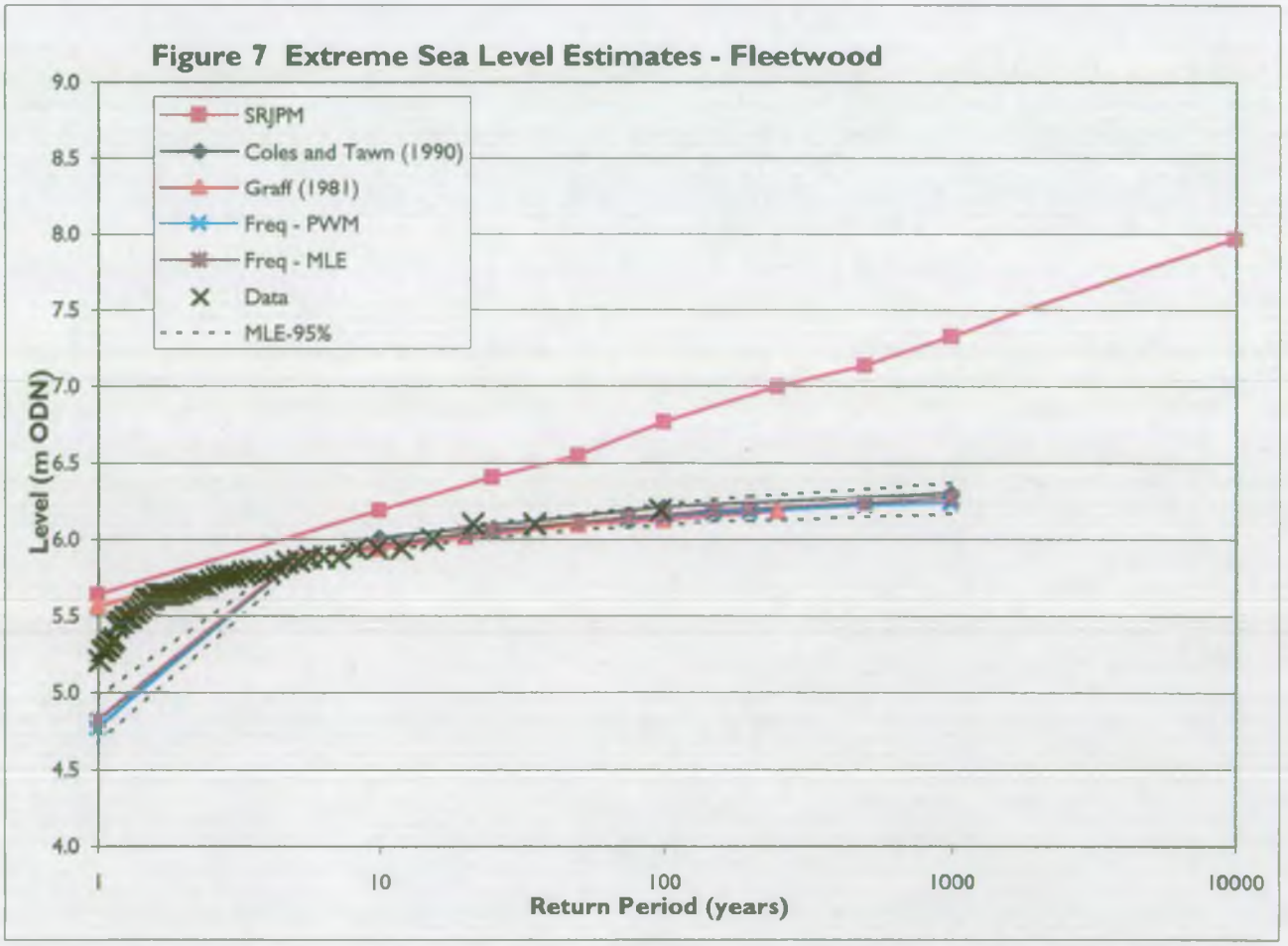


Figure 8 Extreme Sea Level Estimates - Heysham

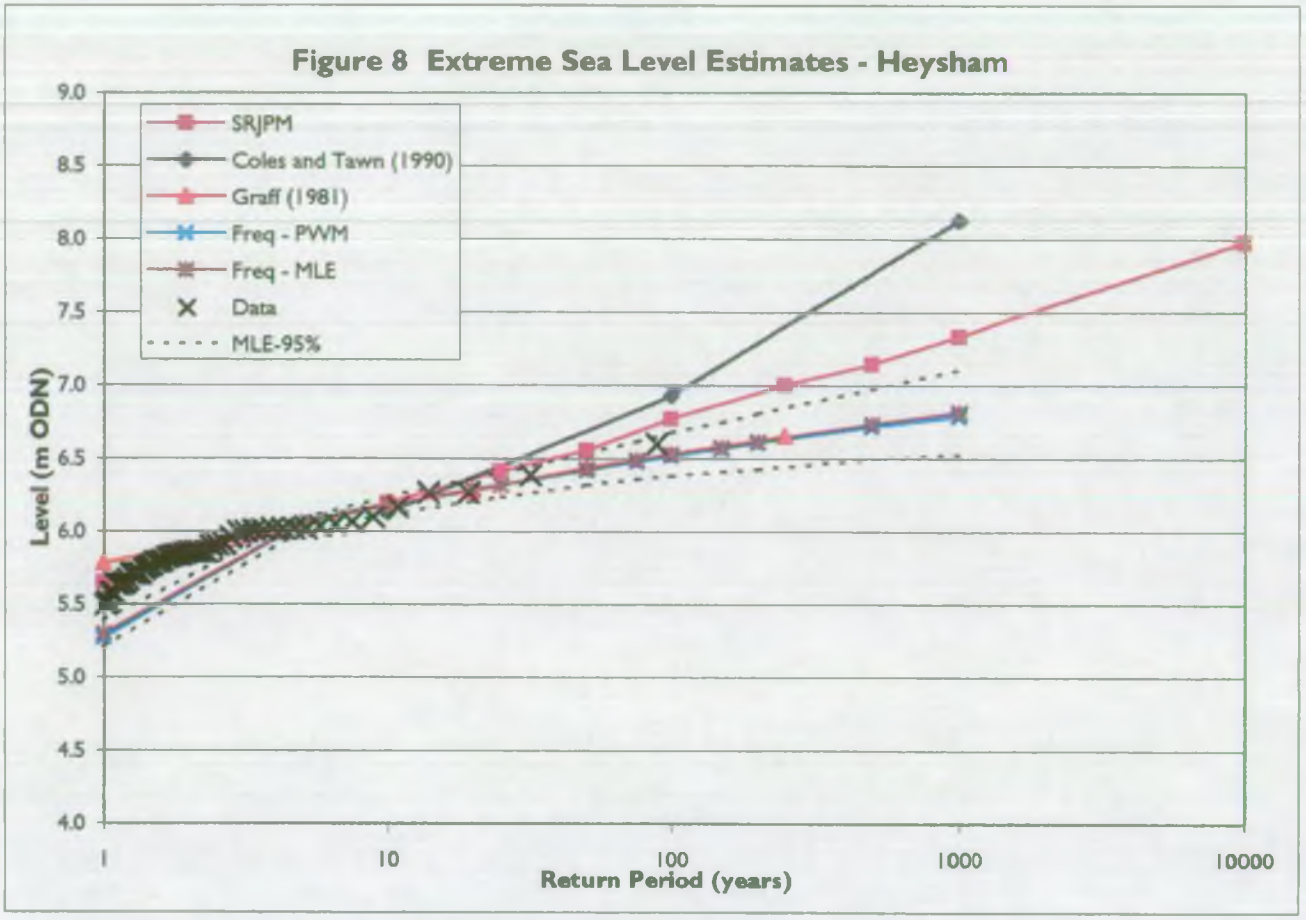


Figure 9 Extreme Sea Level Estimates - Barrow

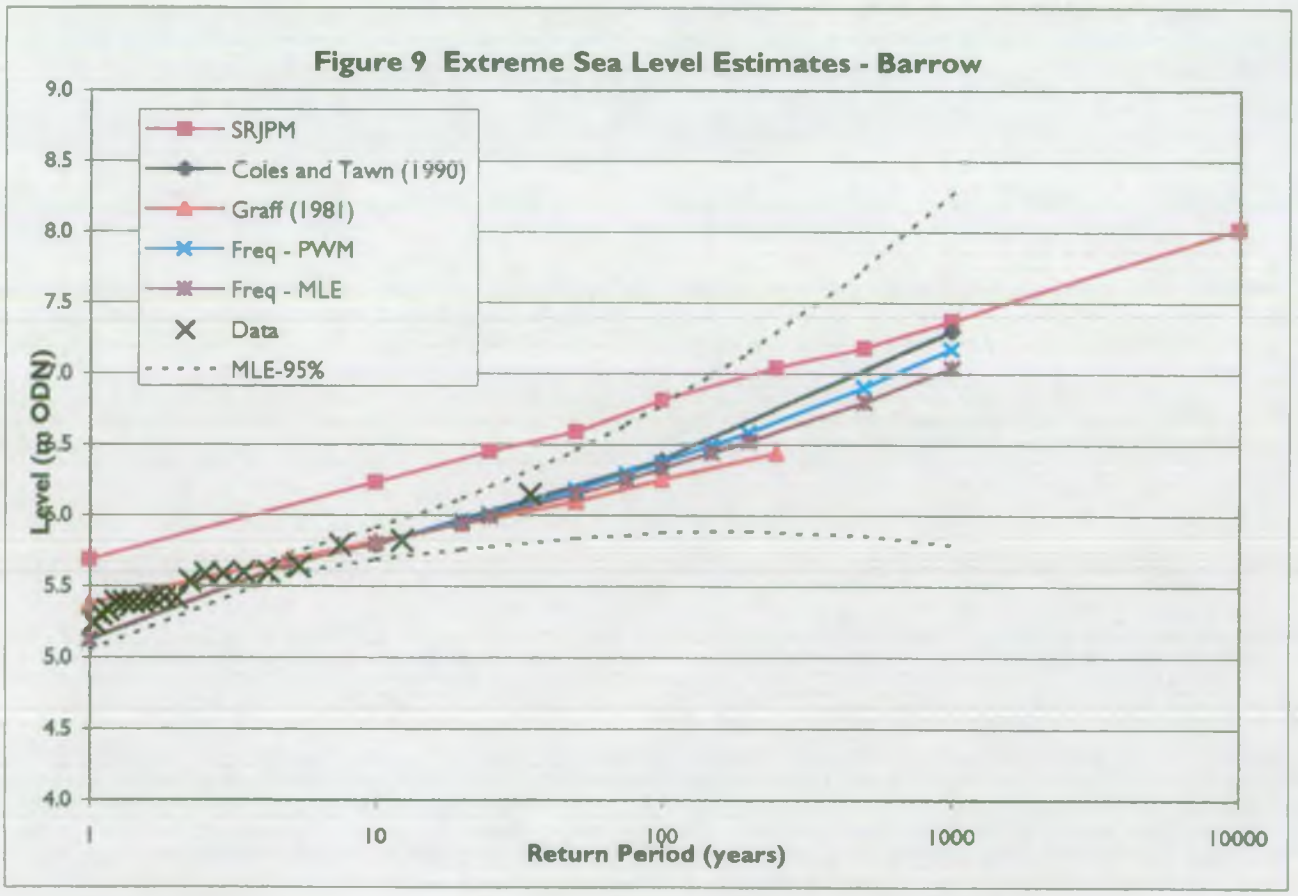


Figure 10 Extreme Sea Level Estimates - Workington

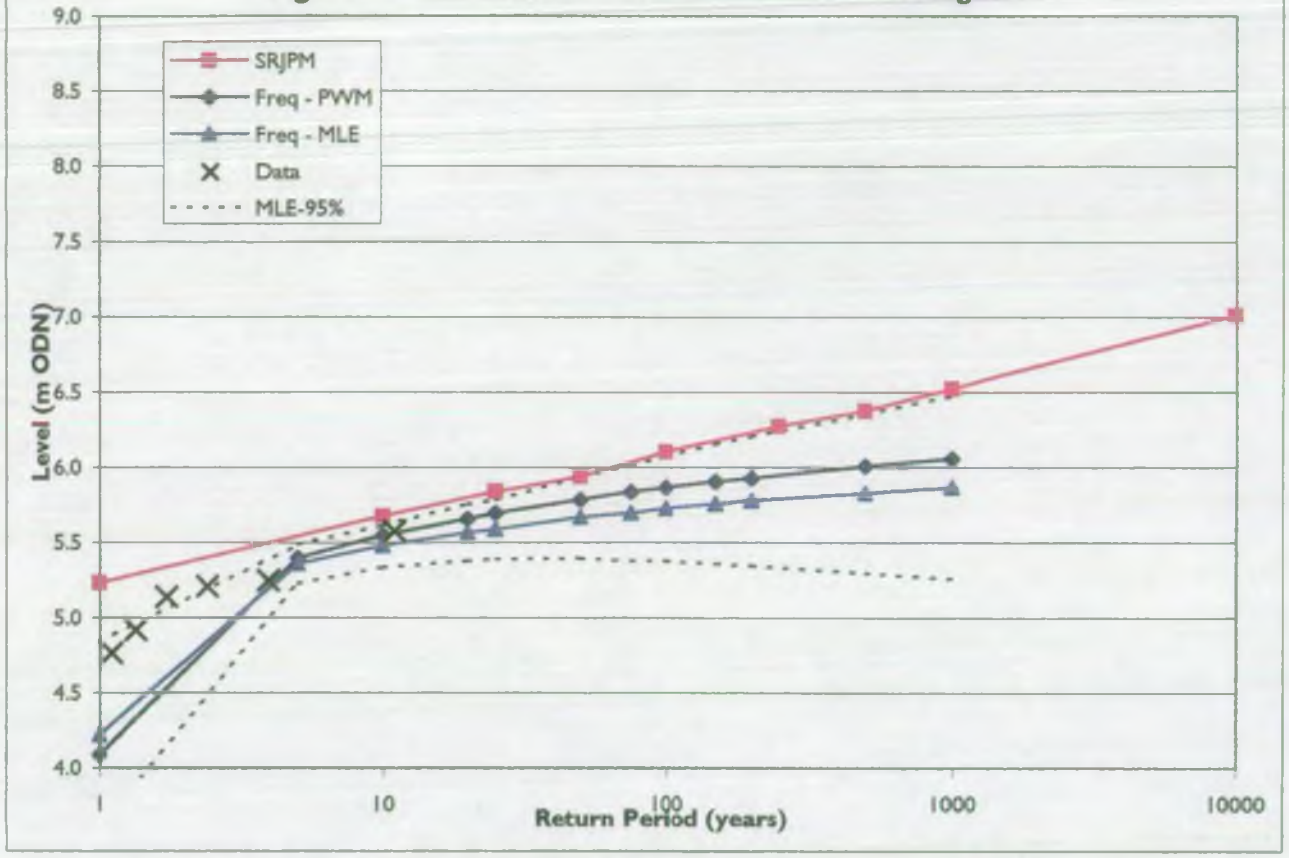


Figure 11 Extreme Sea Level Estimates - Silloth

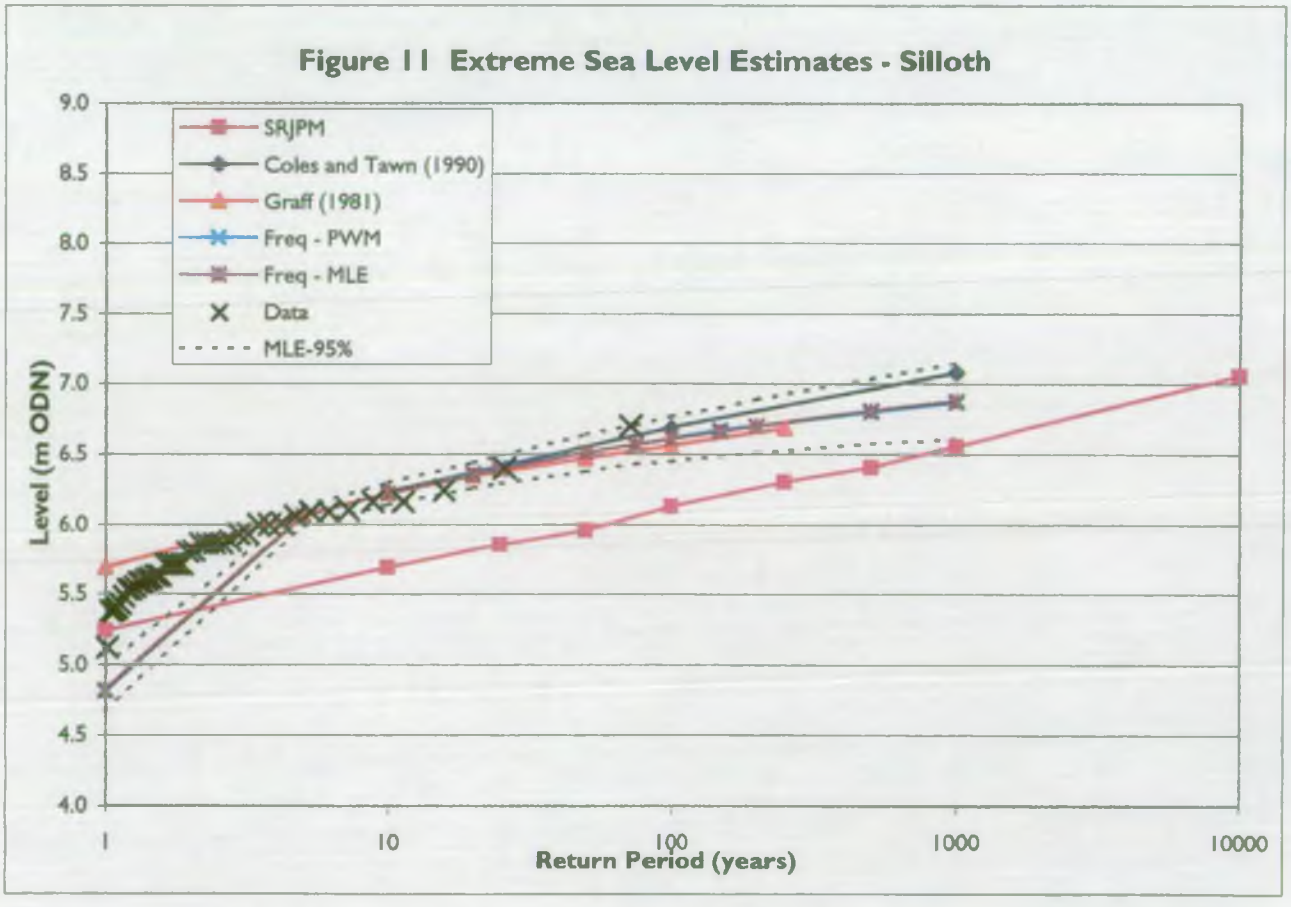


Figure 12 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Hillbre Island

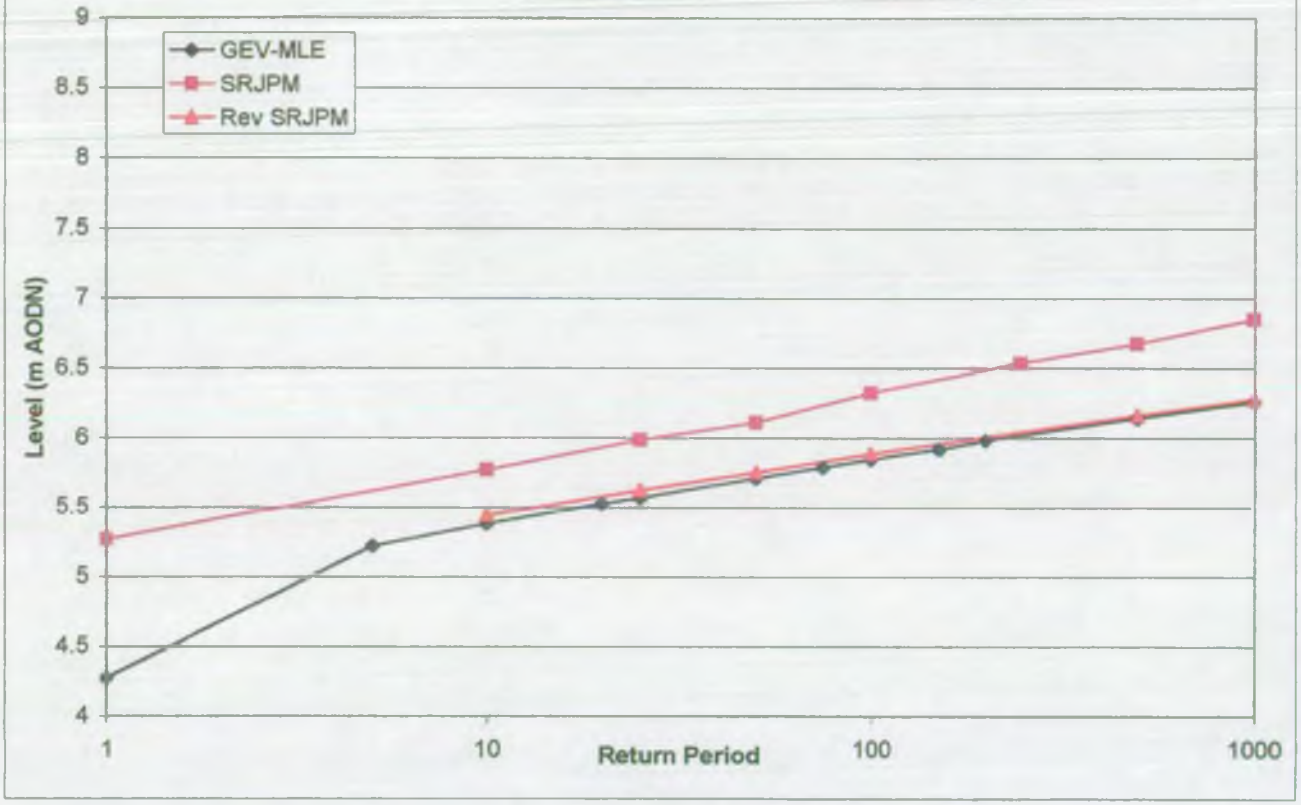


Figure 13 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Eastham

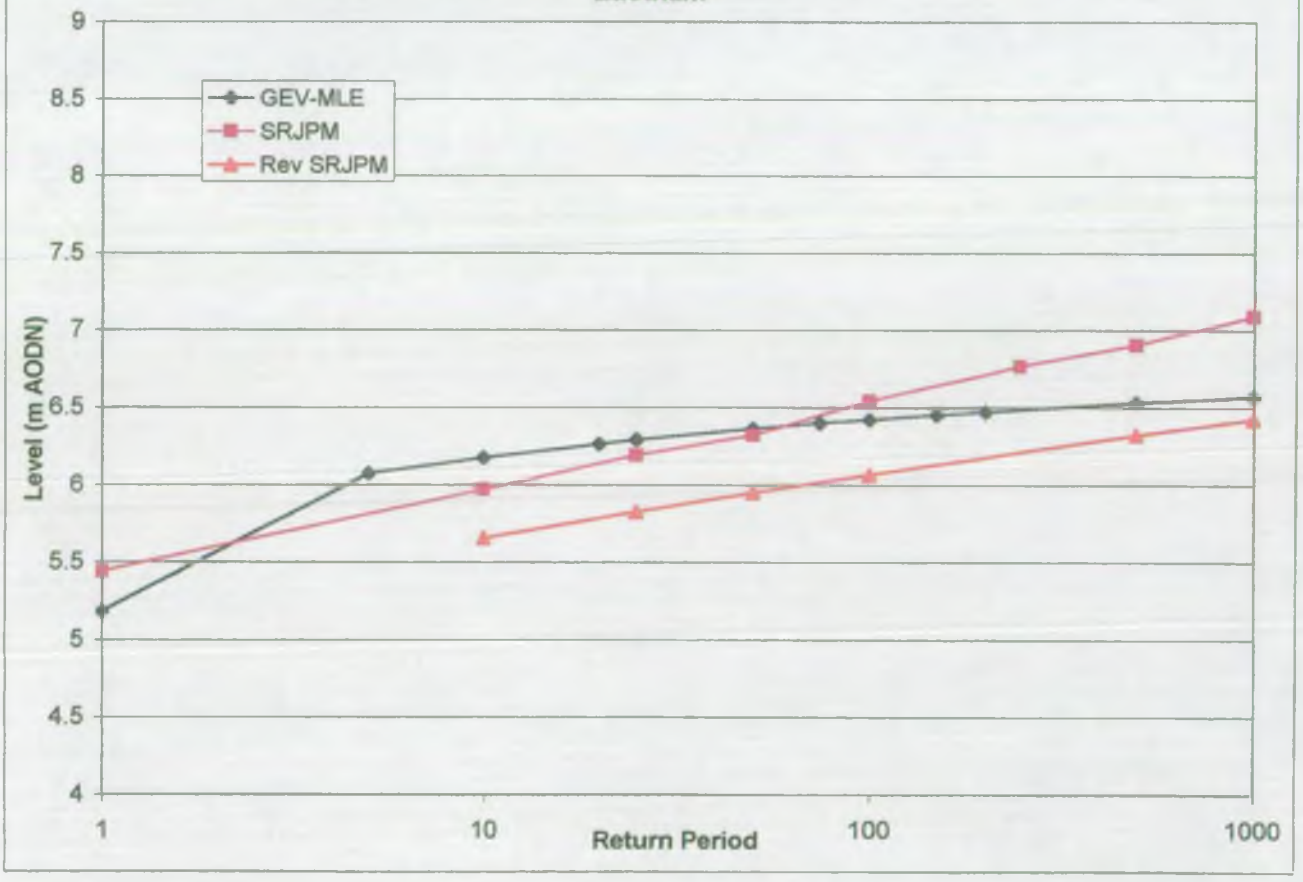


Figure 14 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Liverpool - Gladstone Dock

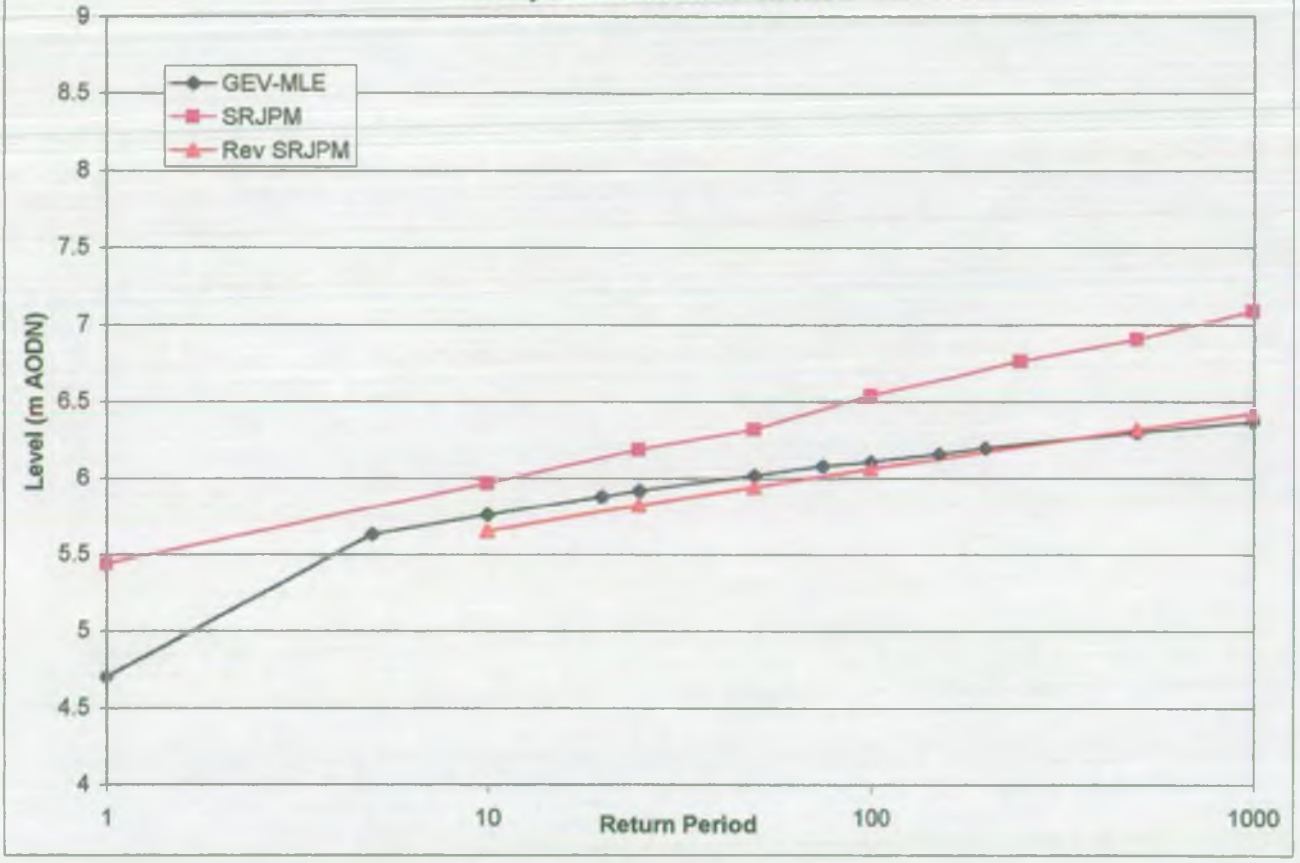


Figure 15 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Liverpool - Princes Pier

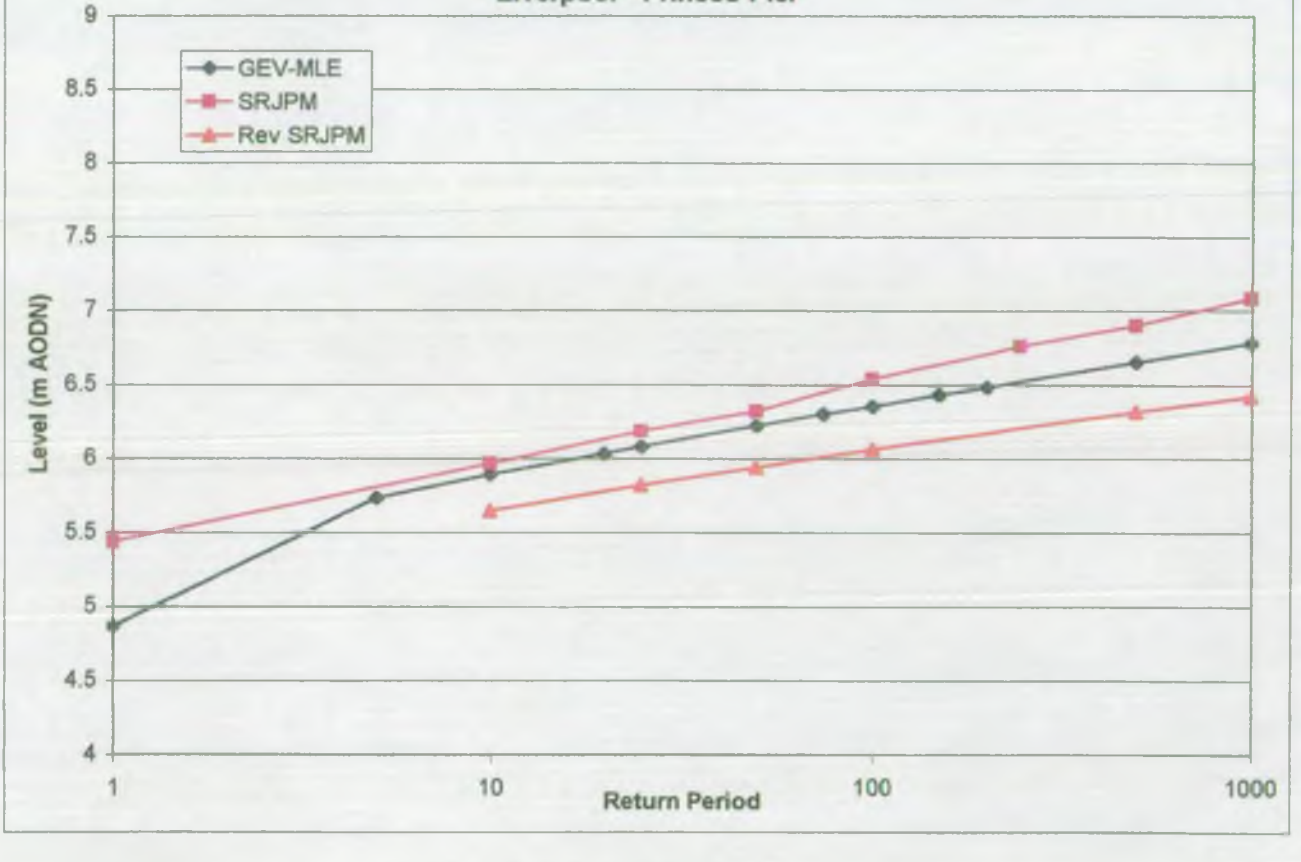


Figure 16 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Fleetwood

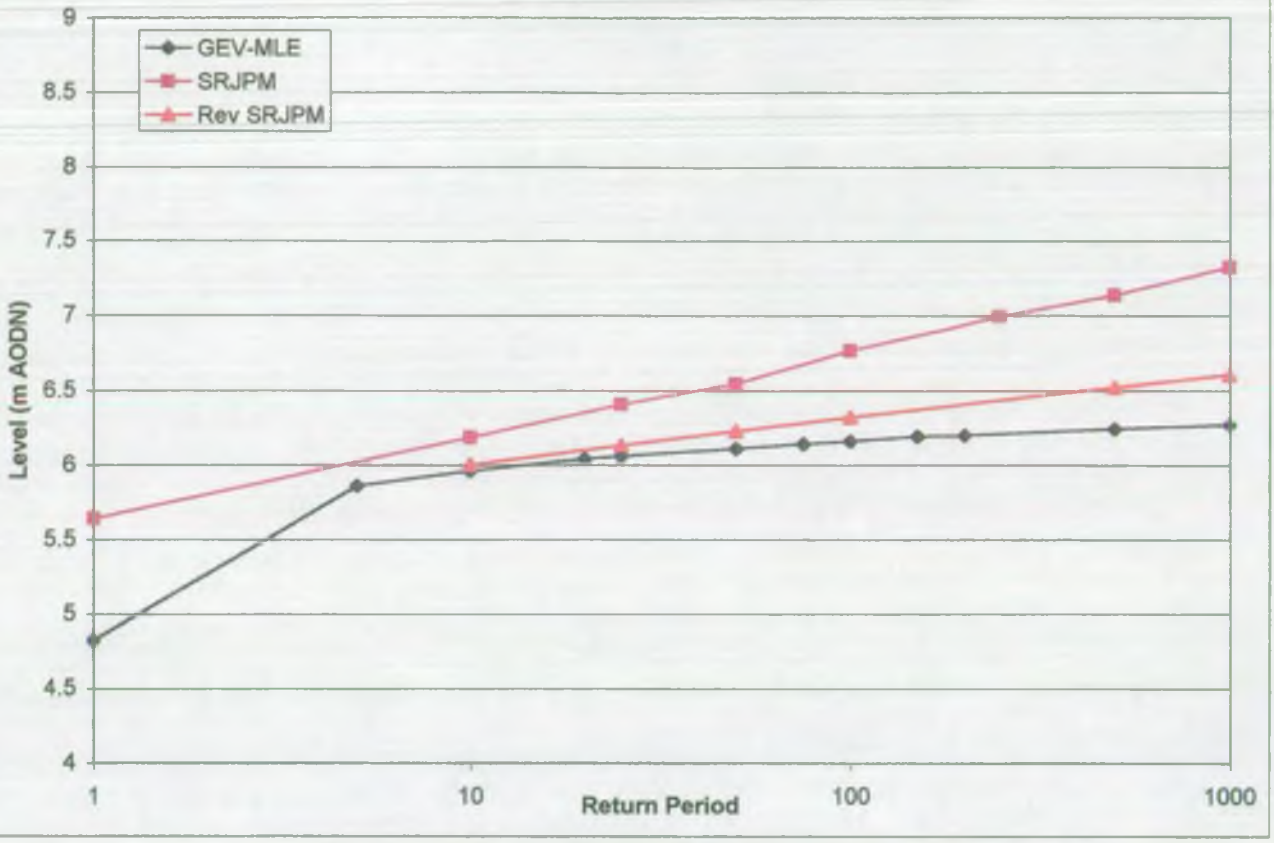


Figure 17 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Heysham

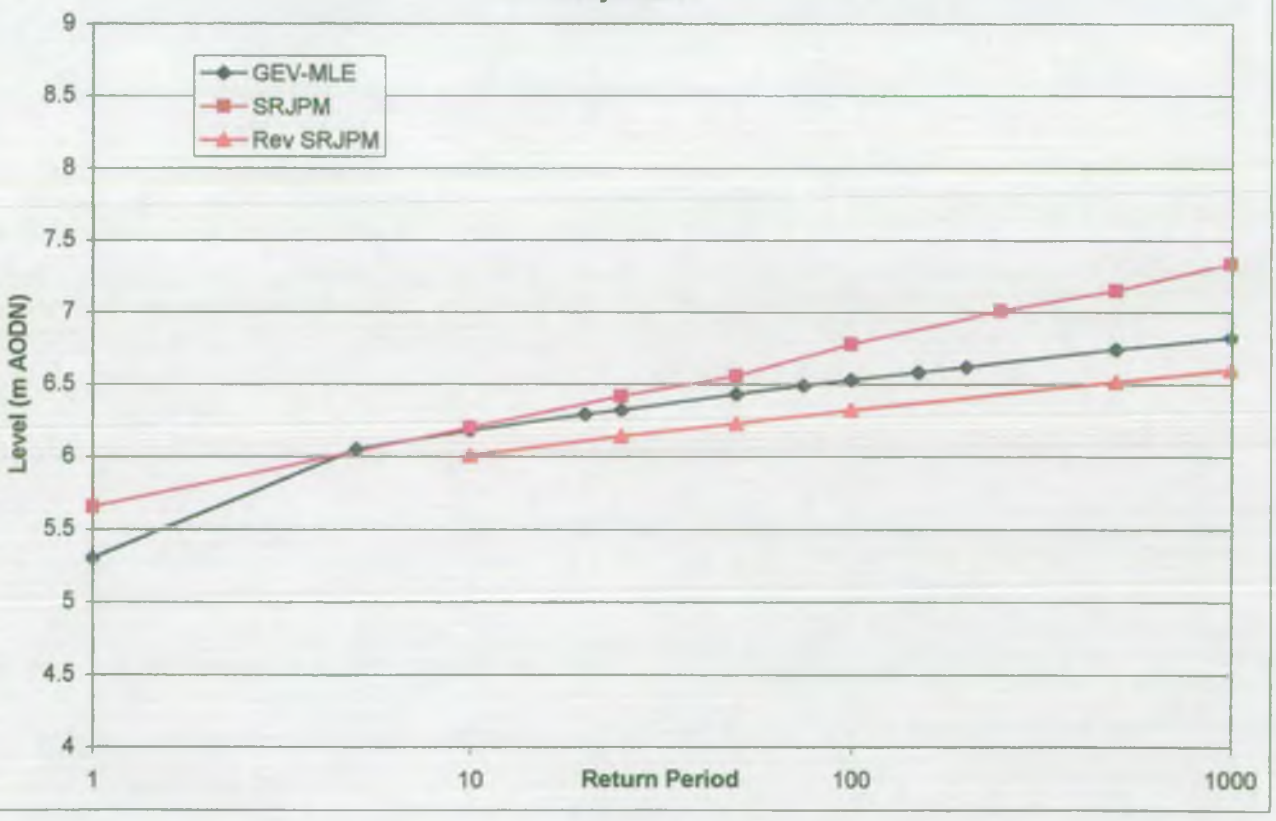


Figure 18 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Barrow

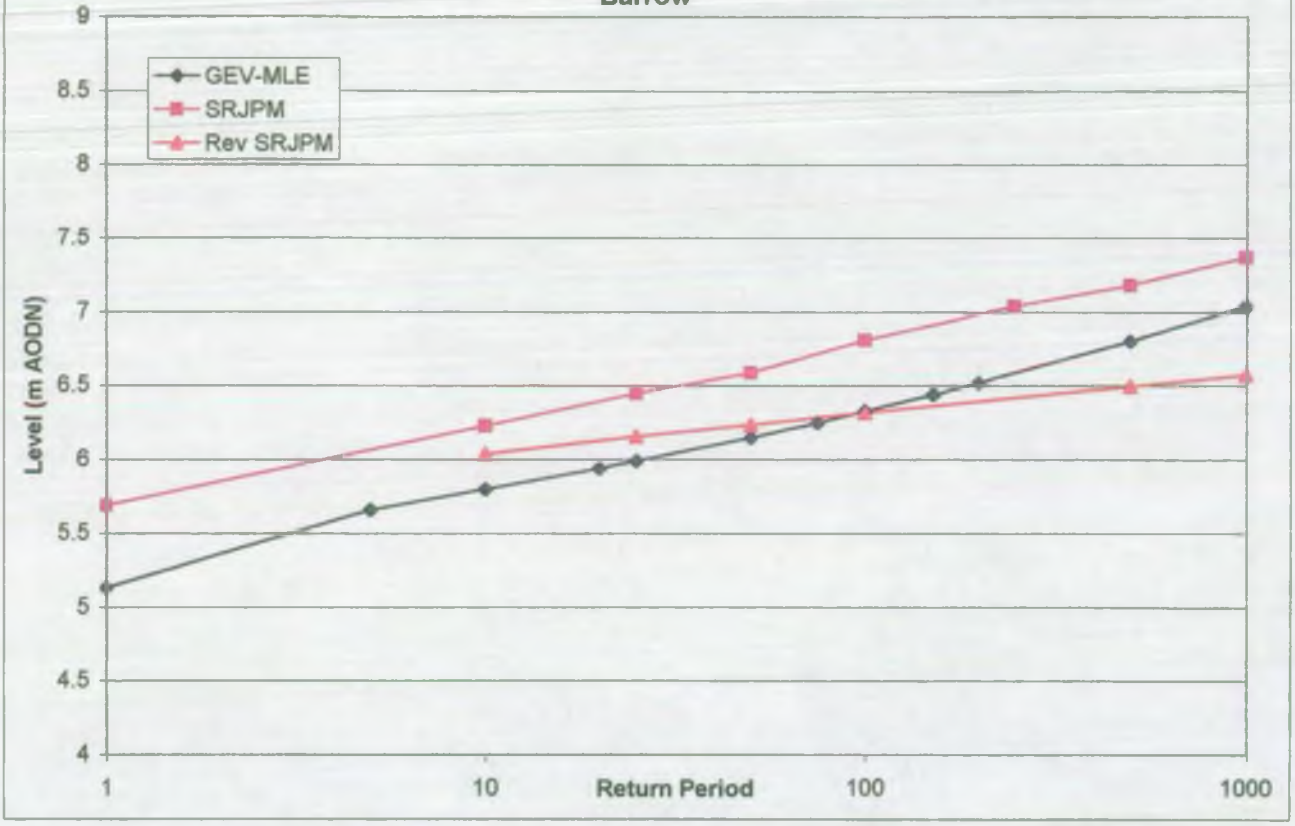
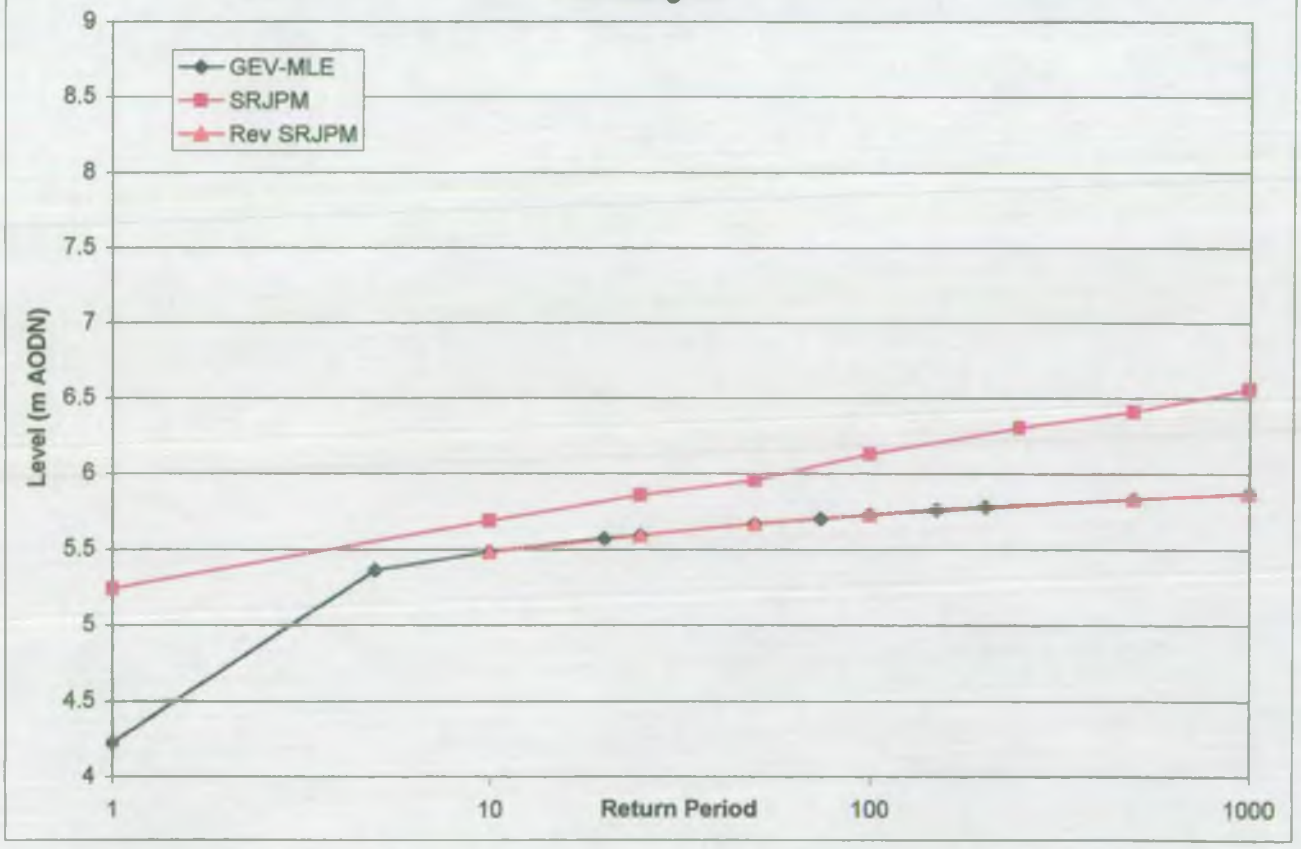


Figure 19 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Workington



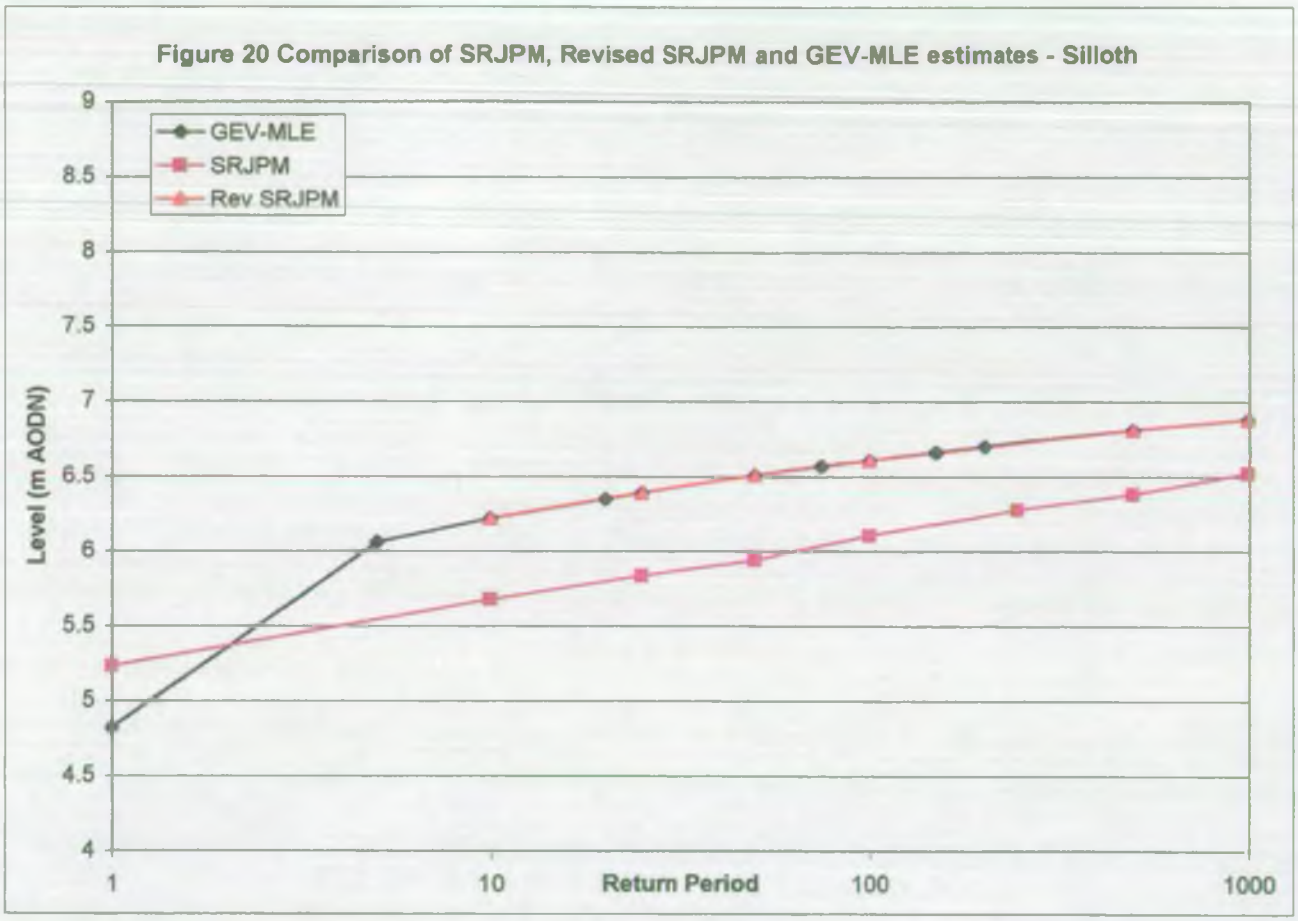


Figure 20 Comparison of SRJPM, Revised SRJPM and GEV-MLE estimates - Silloth
GEV-MLE
SRJPM
Rev SRJPM
Level (m AODN)
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
1
10
Return Period
100
1000

APPENDICES

APPENDIX A: Tidal Data in Chronological Order

Table A1 Annual Maximum Data in Chronological Order – Llandudno

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1994	4.640
1995	4.680
1996	4.670
1997	5.100

Table A2 **Annual Maximum Data in Chronological Order - Hilbre Island**
NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1854	4.760
1855	4.890
1856	4.890
1857	4.690
1858	4.760
1859	4.990
1860	5.020
1861	4.860
1862	4.970
1863	4.890
1864	5.120
1865	5.200
1866	5.040
1867	4.590
1868	4.740
1869	5.200
1870	5.040
1871	4.590
1872	4.660
1873	5.450
1874	4.990
1875	4.810
1876	4.690
1877	4.690
1878	4.840
1879	4.840
1880	4.690
1881	5.070
1882	5.200
1883	5.370
1884	4.760
1885	5.040
1886	4.860
1887	4.740
1888	4.690
1889	4.840
1890	4.840
1891	5.170
1892	4.890
1893	4.590
1894	4.510
1895	4.920
1896	5.120
1897	4.920
1898	4.790
1899	5.350
1900	4.660
1901	4.710
1902	4.890
1903	4.690
1904	4.970
1905	5.220
1906	4.760

Year	Level (m AODN)
1907	4.540
1908	-99.999
1909	-99.999
1910	-99.999
1911	-99.999
1912	-99.999
1913	-99.999
1914	-99.999
1915	-99.999
1916	-99.999
1917	-99.999
1918	-99.999
1919	-99.999
1920	-99.999
1921	-99.999
1922	-99.999
1923	-99.999
1924	-99.999
1925	-99.999
1926	-99.999
1927	-99.999
1928	-99.999
1929	-99.999
1930	-99.999
1931	-99.999
1932	-99.999
1933	-99.999
1934	-99.999
1935	-99.999
1936	-99.999
1937	-99.999
1938	-99.999
1939	-99.999
1940	-99.999
1941	-99.999
1942	-99.999
1943	-99.999
1944	-99.999
1945	-99.999
1946	-99.999
1947	-99.999
1948	-99.999
1949	-99.999
1950	-99.999
1951	-99.999
1952	-99.999
1953	-99.999
1954	-99.999
1955	-99.999
1956	5.050
1957	5.660
1958	5.020
1959	5.320
1960	5.140
1961	5.260
1962	5.200

Year	Level (m AODN)
1963	5.260
1964	5.050
1965	5.020
1966	5.050
1967	5.320
1968	4.900
1969	4.990
1970	5.140
1971	5.110
1972	4.770
1973	4.770
1974	5.260
1975	5.410
1976	5.260
1977	5.710
1978	5.060
1979	5.250
1980	5.270
1981	5.300
1982	-99.999
1983	-99.999
1984	-99.999
1985	-99.999
1986	-99.999
1987	-99.999
1988	-99.999
1989	-99.999
1990	5.970
1991	-99.999
1992	-99.999
1993	-99.999
1994	-99.999
1995	-99.999
1996	-99.999
1997	5.650

Table A3 Annual Maximum Data in Chronological Order - Eastham Dock

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1956	5.660
1957	5.870
1958	5.990
1959	5.720
1960	5.660
1961	5.780
1962	5.900
1963	5.930
1964	5.750
1965	5.900
1966	6.020
1967	5.900
1968	5.990
1969	5.440
1970	5.720
1971	-99.999
1972	-99.999
1973	-99.999
1974	5.810
1975	5.760
1976	6.260
1977	6.160
1978	-99.999
1979	-99.999
1980	-99.999
1981	-99.999
1982	-99.999
1983	-99.999
1984	-99.999
1985	-99.999
1986	-99.999
1987	-99.999
1988	-99.999
1989	-99.999
1990	6.390
1991	-99.999
1992	-99.999
1993	-99.999
1994	-99.999
1995	-99.999
1996	-99.999
1997	6.070

Table A4 **Annual Maximum Data in Chronological Order - Liverpool Gladstone Dock**
NOTE: -99.999 denotes missing data

Year	Level (mAODN)
1956	5.230
1957	5.500
1958	5.630
1959	5.290
1960	5.230
1961	5.440
1962	5.380
1963	5.440
1964	4.960
1965	5.260
1966	5.260
1967	5.500
1968	5.470
1969	5.230
1970	5.660
1971	-99.999
1972	-99.999
1973	5.140
1974	5.500
1975	5.560
1976	5.760
1977	5.960
1978	-99.999
1979	-99.999
1980	-99.999
1981	-99.999
1982	-99.999
1983	-99.999
1984	-99.999
1985	-99.999
1986	-99.999
1987	-99.999
1988	-99.999
1989	5.490
1990	6.040
1991	5.310
1992	5.020
1993	5.400
1994	5.290
1995	5.300
1996	5.390
1997	5.890

Table A5 **Annual Maximum Data in Chronological Order - Liverpool Princes Pier**

NOTE: -99.999 denotes missing data

Year	Level (mAODN)
1941	5.300
1942	5.320
1943	5.400
1944	5.420
1945	5.600
1946	5.070
1947	5.170
1948	5.250
1949	5.600
1950	5.370
1951	5.470
1952	5.150
1953	5.320
1954	5.630
1955	5.500
1956	5.350
1957	5.650
1958	5.530
1959	5.470
1960	5.350
1961	5.380
1962	5.630
1963	5.600
1964	5.320
1965	5.570
1966	5.500
1967	5.660
1968	5.660
1969	5.320
1970	5.630
1971	5.350
1972	5.200
1973	5.230
1974	5.750
1975	5.760
1976	5.960
1977	6.110
1978	5.350
1979	5.620
1980	5.600
1981	5.750
1982	5.810
1983	5.900
1984	-99.999
1985	-99.999
1986	-99.999
1987	-99.999
1988	-99.999
1989	-99.999
1990	6.220
1991	-99.999
1992	-99.999
1993	-99.999

Year	Level (m AODN)
1994	-99.999
1995	-99.999
1996	-99.999
1997	6.290

Table A6 **Annual Maximum Data in Chronological Order - Fleetwood**

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1930	5.640
1931	5.490
1932	-99.999
1933	-99.999
1934	-99.999
1935	5.820
1936	5.610
1937	5.270
1938	5.880
1939	5.760
1940	5.670
1941	5.300
1942	5.490
1943	5.940
1944	5.790
1945	5.640
1946	5.270
1947	5.520
1948	5.430
1949	5.730
1950	5.610
1951	5.850
1952	5.610
1953	5.700
1954	5.940
1955	5.460
1956	5.640
1957	5.940
1958	5.760
1959	5.790
1960	5.580
1961	5.880
1962	5.700
1963	-99.999
1964	-99.999
1965	5.520
1966	5.640
1967	6.190
1968	5.880
1969	5.550
1970	5.760
1971	5.490
1972	5.330
1973	5.640
1974	-99.999
1975	5.210
1976	5.790
1977	6.100
1978	5.460
1979	5.650
1980	5.700
1981	5.750
1982	5.300

Year	Level (m AODN)
1983	6.100
1984	-99.999
1985	5.650
1986	5.350
1987	5.685
1988	5.785
1989	5.856
1990	6.000

Table A7 Annual Maximum Data in Chronological Order – Heysham

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1940	5.710
1941	6.170
1942	-99.999
1943	6.020
1944	5.860
1945	6.020
1946	5.710
1947	5.710
1948	5.710
1949	6.020
1950	5.860
1951	6.020
1952	5.860
1953	-99.999
1954	-99.999
1955	-99.999
1956	-99.999
1957	-99.999
1958	-99.999
1959	5.790
1960	5.580
1961	6.040
1962	5.910
1963	5.850
1964	5.640
1965	5.580
1966	5.670
1967	6.070
1968	5.790
1969	5.520
1970	-99.999
1971	5.640
1972	5.640
1973	-99.999
1974	6.000
1975	6.000
1976	6.100
1977	6.600
1978	5.650
1979	5.860
1980	5.840
1981	5.800
1982	5.500
1983	6.270
1984	5.840
1985	5.760
1986	5.820
1987	5.900
1988	6.010
1989	6.050
1990	6.270
1991	5.740
1992	5.920

Year	Level (m AODN)
1993	6.010
1994	5.770
1995	5.830
1996	5.960
1997	6.390

Table A8 **Annual Maximum Data in Chronological Order - Barrow**

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1920	5.390
1921	5.410
1922	5.390
1923	5.590
1924	-99.999
1925	-99.999
1926	-99.999
1927	-99.999
1928	-99.999
1929	-99.999
1930	-99.999
1931	-99.999
1932	-99.999
1933	-99.999
1934	-99.999
1935	-99.999
1936	-99.999
1937	-99.999
1938	-99.999
1939	-99.999
1940	-99.999
1941	-99.999
1942	-99.999
1943	-99.999
1944	-99.999
1945	-99.999
1946	-99.999
1947	-99.999
1948	-99.999
1949	-99.999
1950	-99.999
1951	-99.999
1952	-99.999
1953	-99.999
1954	-99.999
1955	-99.999
1956	-99.999
1957	-99.999
1958	-99.999
1959	-99.999
1960	-99.999
1961	-99.999
1962	5.590
1963	5.540
1964	5.330
1965	5.390
1966	5.420
1967	5.790
1968	-99.999
1969	-99.999
1970	5.640
1971	5.390
1972	5.240

Year	Level (mAODN)
1973	5.300
1974	5.420
1975	5.820
1976	5.600
1977	6.150
1978	5.600

Table A9 **Annual Maximum Data in Chronological Order - Workington**

NOTE: -99.999 denotes missing data

Year	Level (mAODN)
1992	5.210
1993	5.250
1994	5.140
1995	4.920
1996	4.770
1997	5.580

Table A10 **Annual Maximum Data in Chronological Order – Silloth**
NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1928	5.860
1929	5.480
1930	5.930
1931	5.710
1932	5.580
1933	5.120
1934	6.240
1935	-99.999
1936	-99.999
1937	-99.999
1938	-99.999
1939	-99.999
1940	5.710
1941	5.610
1942	6.090
1943	5.930
1944	5.860
1945	5.810
1946	5.380
1947	6.010
1948	5.550
1949	5.860
1950	5.710
1951	6.160
1952	5.530
1953	5.710
1954	6.060
1955	5.400
1956	5.530
1957	5.880
1958	6.160
1959	-99.999
1960	-99.999
1961	-99.999
1962	-99.999
1963	-99.999
1964	-99.999
1965	5.580
1966	5.630
1967	6.700
1968	5.860
1969	5.430
1970	6.090
1971	5.630
1972	5.380
1973	5.600
1974	6.000
1975	6.100
1976	5.800
1977	6.400
1978	6.000

Table A11 **Annual Maximum Data in Chronological Order – Mersey (Howley Weir)**

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1956	6.640
1957	6.770
1958	6.490
1959	6.700
1960	6.490
1961	6.700
1962	6.640
1963	6.720
1964	7.390
1965	6.950
1966	6.920
1967	6.800
1968	7.000
1969	-99.999
1970	6.800
1971	6.340
1972	6.240
1973	6.440
1974	6.640
1975	6.490
1976	6.900
1977	6.950
1978	6.340
1979	6.290

Table A12 **Annual Maximum Data in Chronological Order – Mersey (Arpley Pier)**
NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1964	6.240
1965	6.900
1966	6.230
1967	6.450
1968	6.500
1969	-99.999
1970	6.750
1971	6.390
1972	6.290
1973	6.450
1974	6.900
1975	-99.999
1976	7.200
1977	6.940
1978	-99.999
1979	6.380

APPENDIX B: Tidal Data in Magnitude Order

Table B1 **Annual Maximum Data in Magnitude Order - Llandudno**

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1997	5.100
1995	4.680
1996	4.670
1994	4.640

Table B2 **Annual Maximum Data in Magnitude Order - Hilbre Island**
NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1990	5.970
1977	5.710
1957	5.660
1997	5.650
1873	5.450
1975	5.410
1883	5.370
1899	5.350
1959	5.320
1967	5.320
1981	5.300
1980	5.270
1961	5.260
1963	5.260
1974	5.260
1976	5.260
1979	5.250
1905	5.220
1865	5.200
1869	5.200
1882	5.200
1962	5.200
1891	5.170
1960	5.140
1970	5.140
1864	5.120
1896	5.120
1971	5.110
1881	5.070
1978	5.060
1956	5.050
1964	5.050
1966	5.050
1866	5.040
1870	5.040
1885	5.040
1860	5.020
1958	5.020
1965	5.020
1859	4.990
1874	4.990
1969	4.990
1862	4.970
1904	4.970
1895	4.920
1897	4.920
1968	4.900
1855	4.890
1856	4.890
1863	4.890
1892	4.890
1902	4.890
1861	4.860

Year	Level (m AODN)
1886	4.860
1878	4.840
1879	4.840
1889	4.840
1890	4.840
1875	4.810
1898	4.790
1972	4.770
1973	4.770
1854	4.760
1858	4.760
1884	4.760
1906	4.760
1868	4.740
1887	4.740
1901	4.710
1857	4.690
1876	4.690
1877	4.690
1880	4.690
1888	4.690
1903	4.690
1872	4.660
1900	4.660
1867	4.590
1871	4.590
1893	4.590
1907	4.540
1894	4.510
1908	-99.999
1909	-99.999
1910	-99.999
1911	-99.999
1912	-99.999
1913	-99.999
1914	-99.999
1915	-99.999
1916	-99.999
1917	-99.999
1918	-99.999
1919	-99.999
1920	-99.999
1921	-99.999
1922	-99.999
1923	-99.999
1924	-99.999
1925	-99.999
1926	-99.999
1927	-99.999
1928	-99.999
1929	-99.999
1930	-99.999
1931	-99.999
1932	-99.999
1933	-99.999
1934	-99.999

Year	Level (m AODN)
1935	-99.999
1936	-99.999
1937	-99.999
1938	-99.999
1939	-99.999
1940	-99.999
1941	-99.999
1942	-99.999
1943	-99.999
1944	-99.999
1945	-99.999
1946	-99.999
1947	-99.999
1948	-99.999
1949	-99.999
1950	-99.999
1951	-99.999
1952	-99.999
1953	-99.999
1954	-99.999
1955	-99.999
1982	-99.999
1983	-99.999
1984	-99.999
1985	-99.999
1986	-99.999
1987	-99.999
1988	-99.999
1989	-99.999
1991	-99.999
1992	-99.999
1993	-99.999
1994	-99.999
1995	-99.999
1996	-99.999

Table B3 Annual Maximum Data in Magnitude Order - Eastham Dock

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1990	6.390
1976	6.260
1977	6.160
1997	6.070
1966	6.020
1958	5.990
1968	5.990
1963	5.930
1962	5.900
1965	5.900
1967	5.900
1957	5.870
1974	5.810
1961	5.780
1975	5.760
1964	5.750
1959	5.720
1970	5.720
1956	5.660
1960	5.660
1969	5.440
1971	-99.999
1972	-99.999
1973	-99.999
1978	-99.999
1979	-99.999
1980	-99.999
1981	-99.999
1982	-99.999
1983	-99.999
1984	-99.999
1985	-99.999
1986	-99.999
1987	-99.999
1988	-99.999
1989	-99.999
1991	-99.999
1992	-99.999
1993	-99.999
1994	-99.999
1995	-99.999
1996	-99.999

Table B4 **Annual Maximum Data in Magnitude Order - Liverpool Gladstone Dock**
NOTE: -99.999 denotes missing data

Year	Level (mAODN)
1990	6.040
1977	5.960
1997	5.890
1976	5.760
1970	5.660
1958	5.630
1975	5.560
1957	5.500
1967	5.500
1974	5.500
1989	5.490
1968	5.470
1961	5.440
1963	5.440
1993	5.400
1996	5.390
1962	5.380
1991	5.310
1995	5.300
1959	5.290
1994	5.290
1965	5.260
1966	5.260
1956	5.230
1960	5.230
1969	5.230
1973	5.140
1992	5.020
1964	4.960
1971	-99.999
1972	-99.999
1978	-99.999
1979	-99.999
1980	-99.999
1981	-99.999
1982	-99.999
1983	-99.999
1984	-99.999
1985	-99.999
1986	-99.999
1987	-99.999
1988	-99.999

Table B5 Annual Maximum Data in Magnitude Order - Liverpool Princes Pier

NOTE:--99.999 denotes missing data

Year	Level (m AODN)
1997	6.290
1990	6.220
1977	6.110
1976	5.960
1983	5.900
1982	5.810
1975	5.760
1974	5.750
1981	5.750
1967	5.660
1968	5.660
1957	5.650
1954	5.630
1962	5.630
1970	5.630
1979	5.620
1945	5.600
1949	5.600
1963	5.600
1980	5.600
1965	5.570
1958	5.530
1955	5.500
1966	5.500
1951	5.470
1959	5.470
1944	5.420
1943	5.400
1961	5.380
1950	5.370
1956	5.350
1960	5.350
1971	5.350
1978	5.350
1942	5.320
1953	5.320
1964	5.320
1969	5.320
1941	5.300
1948	5.250
1973	5.230
1972	5.200
1947	5.170
1952	5.150
1946	5.070
1984	-99.999
1985	-99.999
1986	-99.999
1987	-99.999
1988	-99.999
1989	-99.999
1991	-99.999
1992	-99.999

Year	Level (m AODN)
1993	-99.999
1994	-99.999
1995	-99.999
1996	-99.999

Table B6 **Annual Maximum Data in Magnitude Order - Fleetwood**

NOTE:--99.999 denotes missing data

Year	Level (m AODN)
1967	6.190
1977	6.100
1983	6.100
1990	6.000
1943	5.940
1954	5.940
1957	5.940
1938	5.880
1961	5.880
1968	5.880
1989	5.856
1951	5.850
1935	5.820
1944	5.790
1959	5.790
1976	5.790
1988	5.785
1939	5.760
1958	5.760
1970	5.760
1981	5.750
1949	5.730
1953	5.700
1962	5.700
1980	5.700
1987	5.685
1940	5.670
1979	5.650
1985	5.650
1930	5.640
1945	5.640
1956	5.640
1966	5.640
1973	5.640
1936	5.610
1950	5.610
1952	5.610
1960	5.580
1969	5.550
1947	5.520
1965	5.520
1931	5.490
1942	5.490
1971	5.490
1955	5.460
1978	5.460
1948	5.430
1986	5.350
1972	5.330
1941	5.300
1982	5.300
1937	5.270
1946	5.270

Year	Level (mAODN)
1975	5.210
1932	-99.999
1933	-99.999
1934	-99.999
1963	-99.999
1964	-99.999
1974	-99.999
1984	-99.999

Table B7 Annual Maximum Data in Magnitude Order – Heysham

NOTE: -99.999 denotes missing data

Year	Level (mAODN)
1977	6.600
1997	6.390
1983	6.270
1990	6.270
1941	6.170
1976	6.100
1967	6.070
1989	6.050
1961	6.040
1943	6.020
1945	6.020
1949	6.020
1951	6.020
1988	6.010
1993	6.010
1974	6.000
1975	6.000
1996	5.960
1992	5.920
1962	5.910
1987	5.900
1944	5.860
1950	5.860
1952	5.860
1979	5.860
1963	5.850
1980	5.840
1984	5.840
1995	5.830
1986	5.820
1981	5.800
1959	5.790
1968	5.790
1994	5.770
1985	5.760
1991	5.740
1940	5.710
1946	5.710
1947	5.710
1948	5.710
1966	5.670
1978	5.650
1964	5.640
1971	5.640
1972	5.640
1960	5.580
1965	5.580
1969	5.520
1982	5.500
1942	-99.999
1953	-99.999
1954	-99.999
1955	-99.999

Year	Level (m AODN)
1956	-99.999
1957	-99.999
1958	-99.999
1970	-99.999
1973	-99.999

Table B8 Annual Maximum Data in Magnitude Order - Barrow

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1977	6.150
1975	5.820
1967	5.790
1970	5.640
1976	5.600
1978	5.600
1923	5.590
1962	5.590
1963	5.540
1966	5.420
1974	5.420
1921	5.410
1920	5.390
1922	5.390
1965	5.390
1971	5.390
1964	5.330
1973	5.300
1972	5.240
1924	-99.999
1925	-99.999
1926	-99.999
1927	-99.999
1928	-99.999
1929	-99.999
1930	-99.999
1931	-99.999
1932	-99.999
1933	-99.999
1934	-99.999
1935	-99.999
1936	-99.999
1937	-99.999
1938	-99.999
1939	-99.999
1940	-99.999
1941	-99.999
1942	-99.999
1943	-99.999
1944	-99.999
1945	-99.999
1946	-99.999
1947	-99.999
1948	-99.999
1949	-99.999
1950	-99.999
1951	-99.999
1952	-99.999
1953	-99.999
1954	-99.999
1955	-99.999
1956	-99.999
1957	-99.999

Year	Level (m AODN)
1958	-99.999
1959	-99.999
1960	-99.999
1961	-99.999
1968	-99.999
1969	-99.999

Table B9 **Annual Maximum Data in Magnitude Order – Workington**

NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1997	5.580
1993	5.250
1992	5.210
1994	5.140
1995	4.920
1996	4.770

Table B10 **Annual Maximum Data in Magnitude Order – Silloth**
NOTE: -99.999 denotes missing data

Year	Level (mAODN)
1967	6.700
1977	6.400
1934	6.240
1951	6.160
1958	6.160
1975	6.100
1942	6.090
1970	6.090
1954	6.060
1947	6.010
1974	6.000
1978	6.000
1930	5.930
1943	5.930
1957	5.880
1928	5.860
1944	5.860
1949	5.860
1968	5.860
1945	5.810
1976	5.800
1931	5.710
1940	5.710
1950	5.710
1953	5.710
1966	5.630
1971	5.630
1941	5.610
1973	5.600
1932	5.580
1965	5.580
1948	5.550
1952	5.530
1956	5.530
1929	5.480
1969	5.430
1955	5.400
1946	5.380
1972	5.380
1933	5.120
1935	-99.999
1936	-99.999
1937	-99.999
1938	-99.999
1939	-99.999
1959	-99.999
1960	-99.999
1961	-99.999
1962	-99.999
1963	-99.999
1964	-99.999

Table B11 **Annual Maximum Data in Magnitude Order – Mersey (Howley Weir)**

NOTE: -99.999 denotes missing data

Year	Level (mAODN)
1964	7.390
1968	7.000
1965	6.950
1977	6.950
1966	6.920
1976	6.900
1967	6.800
1970	6.800
1957	6.770
1963	6.720
1959	6.700
1961	6.700
1956	6.640
1962	6.640
1974	6.640
1958	6.490
1960	6.490
1975	6.490
1973	6.440
1971	6.340
1978	6.340
1979	6.290
1972	6.240
1969	-99.999

Table B12 **Annual Maximum Data in Magnitude Order – Mersey (Arpley Pier)**
NOTE: -99.999 denotes missing data

Year	Level (m AODN)
1976	7.200
1977	6.940
1965	6.900
1974	6.900
1970	6.750
1968	6.500
1967	6.450
1973	6.450
1971	6.390
1979	6.380
1972	6.290
1964	6.240
1966	6.230
1969	-99.999
1975	-99.999
1978	-99.999

APPENDIX C: Example of SRJPM Method

The SRJPM approach is a 6 step procedure as detailed in the following sections. All calculations are included on an Excel spreadsheet.

1. Identify Adjacent Nodes

The 10 locations and the adjacent nodes are identified from Dixon and Tawn (ibid Figures 8.10 to 8.17), with the latitude, longitude and MDM of the nodes extracted from Dixon and Tawn (ibid Table 4.1). These are identified in Table C1. MDM is the Model Distance Metric defined by Dixon and Tawn (1997) and refers to clockwise distance around the UK coastline (to the nearest 12km) from a point near Wick and is based on the World Vector Shoreline compiled by the US Defence Mapping Agency.

Table C1 Location of Nodes and Points of Interest

Location	MDM node	MDM distance metric (km)	Latitude (° N)	Longitude (° E)
	62	3090	53.23	-4.15
Llandudno			53.31	-3.82
	63	3103	53.33	-3.77
Hilbre Island			53.38	-3.28
	64	3144	53.39	-3.21
Eastham Lock			*53.35*	*-2.95*
Liverpool - Gladstone Dock			*53.45*	*-3.02*
Liverpool - Princes Pier			*53.41*	*-3.00*
	65	3211	53.85	-3.06
Fleetwood			53.97	-3.03
Heysham			54.03	-2.91
Barrow			54.10	-3.20
	66	3305	54.17	-3.25
	67	3358	54.51	-3.64
Workington			54.65	-3.57
Silloth			54.96	-3.40
	68	3448	54.86	-3.76

italics = estimated

2. Calculate the Weighting between Points of Interest and Adjacent Nodes

Dixon and Tawn adopted a visual assessment of the relative distance between the nodes adjacent to the sites of interest and hence derived weightings. For this study the difference in Latitude and Longitude is calculated from the point of interest to each of the 2 adjacent nodes using an Excel spreadsheet. By using the Pythagorous theorem and assuming 1' of latitude is equal to 1 Nautical Mile (NM), the distance between the required location and each of the 2 adjacent nodes can be calculated.

In the example (Table C2) the distance from Llandudno to node 62 is 20.231 NM and 3.346 NM to node 63. On this basis a weighting factor has been calculated, being the ratio of the distance between the 2 adjacent nodes. Thus for Llandudno, node 62 has a weighting of 0.858 and node 63 a weighting of (1-0.858) or 0.142. On this basis the distance metric can be calculated (Table C2).

Table C2 Calculation of Node Weightings

Site	Node	Latitude (° N)	Longitude (° E)	Pre Node Distance (NM)	Post Node Distance (NM)	Weighting Factor	Model Distance Metric (km)
	62	53.23	-4.15				
Llandudno		53.31	-3.82	20.231	3.346	0.858	3101.2
	63	53.33	-3.77				
Hilbre Island		53.38	-3.28	29.354	4.441	0.869	3138.6
	64	53.39	-3.21				
Eastham Lock		*53.35*	*-2.95*	15.784	30.717	0.339	3166.7
Liverpool - Gladstone Dock		*53.45*	*-3.02*	12.146	24.140	0.335	3166.4
Liverpool - Princes Pier		*53.41*	*-3.00*	12.657	26.644	0.322	3165.6
	65	53.85	-3.06				
Fleetwood		53.97	-3.03	7.181	17.828	0.287	3238.0
Heysham		54.03	-2.91	14.140	21.847	0.393	3247.9
Barrow		54.10	-3.20	17.192	5.161	0.769	3283.3
	66	54.17	-3.25				
	67	54.51	-3.64				
Workington		54.65	-3.57	9.529	17.120	0.358	3390.2
Silloth		54.96	-3.40	30.600	22.418	0.577	3409.9
	68	54.86	-3.76				

italics = estimated

This approach can be confirmed by comparing the distance metric for nodes provided in Table 4.1 of Dixon and Tawn with the calculated distance using Pythagorous as detailed above. Table C3 indicates differences between the 2 estimates and is assumed to be due to the resolution of the MDM nodes to the nearest 12km in Dixon and Tawn (1997).

Table C3 Comparison of Pythagorous Approach with Model Distance Metric of Nodes

Node	MDM (km)	Latitude (° N)	Longitude (° E)	Distance (km) using Pythagorous	Difference in MDM (km)
62	3090	53.23	-4.15		
				25.273	13
63	3103	53.33	-3.77		
				36.169	41
64	3144	53.39	-3.21		
				31.851	67
65	3211	53.85	-3.06		
				24.389	94
66	3305	54.17	-3.25		
				33.622	53
67	3358	54.51	-3.64		
				24.351	90
68	3448	54.86	-3.76		

3. Extract Relevant Data from Dixon and Tawn

For each of the Nodes, look up basic data in Tables provided in Dixon and Tawn;

- The 1-year Level
- Return period adjustment
- Trend and hence calculate adjustment with time, in this case from 1990
- Datum Addition to correct MSL to either ACD or ODN.

These values for each node are given in Table C4. These tables are included in an Excel spreadsheet, allowing the values for each node to be looked up directly.

Table C4 Basic Data from Dixon and Tawn Tables

Node	Distance (km)	1-Year Level (MSL)	Return Period Adjustment								Trend (mm/yr)	Trend Adjust	Datum Adjust
			Return Period (Years)										
			10	25	50	100	250	500	1000	10000			to ODN
62	3090	3.86	0.37	0.52	0.60	0.75	0.90	0.98	1.10	1.50	3.06	0	0.18
63	3103	4.51	0.43	0.60	0.71	0.88	1.05	1.16	1.30	1.79	3.07	0	0.18
64	3144	5.16	0.52	0.74	0.87	1.09	1.31	1.45	1.63	2.24	3.11	0	0.19
65	3211	5.40	0.55	0.77	0.91	1.13	1.36	1.50	1.69	2.33	3.07	0	0.21
66	3305	5.48	0.54	0.76	0.90	1.12	1.35	1.49	1.68	2.33	2.63	0	0.23
67	3358	5.02	0.45	0.63	0.73	0.91	1.09	1.20	1.36	1.88	2.11	0	0.23
68	3448	4.99	0.44	0.59	0.69	0.85	1.01	1.11	1.24	1.71	0.34	0	0.23

4. Calculate Return Period Levels for Each Node

The return period extreme level is then the sum of the 1-year level, the Return Period adjustment and the trend adjustment (Table C5). As Dixon and Tawn gives only selected return period adjustments, it is not possible to calculate tide levels for other Return Periods without interpolation.

Table C5 Return Period Extreme Sea Levels (MSL) at Nodes

	Return Period (Years)								
Node	1	10	25	50	100	250	500	1000	10000
62	3.860	4.230	4.380	4.460	4.610	4.760	4.840	4.960	5.360
63	4.510	4.940	5.110	5.220	5.390	5.560	5.670	5.810	6.300
64	5.160	5.680	5.900	6.030	6.250	6.470	6.610	6.790	7.400
65	5.400	5.950	6.170	6.310	6.530	6.760	6.900	7.090	7.730
66	5.480	6.020	6.240	6.380	6.600	6.830	6.970	7.160	7.810
67	5.020	5.470	5.650	5.750	5.930	6.110	6.220	6.380	6.900
68	4.990	5.430	5.580	5.680	5.840	6.000	6.100	6.230	6.700

5. Calculate Return Period Tide Levels for Required Sites

Apply weighting factors previously derived to calculate the return period levels for sites between each of 2 nodes (Table C6).

Table C6 Calculated Levels (MSL) at Nodes and Sites

		Node Weighting		Return Period (Years)								
Site	Node	i	i+1	1	10	25	50	100	250	500	1000	10000
	62			3.860	4.230	4.380	4.460	4.610	4.760	4.840	4.960	5.360
Llandudno		0.858	0.142	3.952	4.331	4.484	4.568	4.721	4.874	4.958	5.081	5.493
	63			4.510	4.940	5.110	5.220	5.390	5.560	5.670	5.810	6.300
Hilbre Island		0.869	0.131	4.595	5.037	5.214	5.326	5.503	5.680	5.794	5.939	6.445
	64			5.160	5.680	5.900	6.030	6.250	6.470	6.610	6.790	7.400
Eastham Lock		0.339	0.661	5.319	5.858	6.078	6.215	6.435	6.662	6.802	6.988	7.618
Liverpool - Gladstone Dock		0.335	0.665	5.320	5.860	6.080	6.216	6.436	6.663	6.803	6.990	7.620
Liverpool - Princes Pier		0.322	0.678	5.323	5.863	6.083	6.220	6.440	6.667	6.807	6.993	7.624
	65			5.400	5.950	6.170	6.310	6.530	6.760	6.900	7.090	7.730
Fleetwood		0.287	0.713	5.457	6.000	6.220	6.360	6.580	6.810	6.950	7.140	7.787
Heysham		0.393	0.607	5.449	5.992	6.212	6.352	6.572	6.802	6.942	7.132	7.779
Barrow		0.769	0.231	5.418	5.966	6.186	6.326	6.546	6.776	6.916	7.106	7.748
	66			5.480	6.020	6.240	6.380	6.600	6.830	6.970	7.160	7.810
				5.020	5.470	5.650	5.750	5.930	6.110	6.220	6.380	6.900
Workington		0.358	0.642	5.001	5.444	5.605	5.705	5.872	6.039	6.143	6.284	6.772
Silloth		0.577	0.423	5.007	5.453	5.620	5.720	5.892	6.063	6.169	6.317	6.815
	67			4.990	5.430	5.580	5.680	5.840	6.000	6.100	6.230	6.700

6. Adjust to ODN

Using the weighted datum adjustment factor (Table C4) correct all levels (Table C6) to m AODN (Table C7).

Table C7 Levels to ODN (m AODN)

	Return Period (years)								
Site	1	10	25	50	100	250	500	1000	10000
Llandudno	4.132	4.511	4.664	4.748	4.901	5.054	5.138	5.261	5.673
Hilbre Island	4.777	5.219	5.395	5.508	5.684	5.861	5.975	6.120	6.626
Eastham Lock	5.522	6.062	6.282	6.418	6.638	6.865	7.005	7.191	7.821
Gladstone Dock	5.523	6.063	6.283	6.420	6.640	6.866	7.006	7.193	7.823
Princes Pier	5.526	6.067	6.287	6.423	6.643	6.870	7.010	7.197	7.827
Fleetwood	5.681	6.224	6.444	6.584	6.804	7.034	7.174	7.364	8.011
Heysham	5.671	6.215	6.435	6.575	6.795	7.025	7.165	7.355	8.001
Barrow	5.633	6.181	6.401	6.541	6.761	6.991	7.131	7.321	7.963
Workington	5.231	5.674	5.835	5.935	6.102	6.269	6.373	6.514	7.002
Silloth	5.237	5.683	5.850	5.950	6.122	6.293	6.399	6.547	7.045

APPENDIX D: Comparison of Extreme Sea Level Estimates

Table D1 Extreme Sea Level Estimates (m AODN) – Llandudno (** = fitting failure)

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
			(1994-1997)	(1994-1997)	
1		-	4.63	**	4.13
5		-	4.72	**	
10	-	-	4.80	**	4.51
20		-	4.94	**	
25			5.01	**	4.66
50		-	5.32	**	4.75
100	-	-	5.86	**	4.90
150			6.36	**	
200			6.83	**	
250		-			5.05
500			9.36	**	5.14
1000	-		13.06	**	5.26
10000					5.67

Table D2 Extreme Sea Level Estimates (m AODN) - Hilbre Island

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
	(1854-1981)	(1854-1977)	(1854-1997)	(1854-1997)	
1		4.875	4.22	4.27	4.780
5		5.187	5.22	5.22	
10	5.51	5.312	5.38	5.38	5.218
20		5.437	5.53	5.53	
25			5.57	5.57	5.395
50		5.575	5.71	5.71	5.508
100	5.78	5.687	5.83	5.85	5.684
150			5.90	5.92	
200			5.95	5.98	
250		5.781			5.861
500			6.10	6.14	5.975
1000	5.96		6.20	6.26	6.120
10000					6.626

Table D3 Extreme Sea Level Estimates (m AODN) - Eastham Lock

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
	(1956-1977)	(1956-1977)	(1956-1997)	(1956-1997)	
1		5.812	5.24	5.18	5.522
5		6.031	6.07	6.07	
10	6.43	6.093	6.19	6.17	6.062
20		6.187	6.29	6.26	
25			6.32	6.29	6.282
50		6.250	6.41	6.36	6.418
100	6.48	6.312	6.49	6.42	6.638
150			6.54	6.45	
200			6.57	6.47	
250		6.375			6.865
500			6.66	6.53	7.005
1000	6.49		6.73	6.57	7.191
10000					7.821

Table D4 Extreme Sea Level Estimates (m AODN) - Liverpool Gladstone Dock

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
	(1956-1977)	(1956-1977)	(1956-1997)	(1956-1997)	
1		5.312	4.76	4.70	5.523
5		5.594	5.63	5.63	
10	6.08	5.719	5.78	5.76	6.063
20		5.812	5.91	5.88	
25			5.95	5.92	6.283
50		5.937	6.08	6.02	6.419
100	6.21	5.969	6.20	6.11	6.639
150			6.27	6.16	
200			6.32	6.20	
250		6.062			6.866
500			6.47	6.30	7.006
1000	6.30		6.58	6.37	7.193
10000					7.823

Table D5 Extreme Sea Level Estimates (m AODN) - Liverpool - Princes Pier

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
	(1941-1977)	(1941-1977)	(1941-1997)	(1941-1997)	
1		5.375	4.86	4.86	5.526
5		5.687	5.74	5.73	
10	6.10	5.812	5.90	5.89	6.067
20		5.875	6.05	6.03	
25			6.10	6.08	6.287
50		6.000	6.24	6.22	6.423
100	6.24	6.094	6.38	6.35	6.643
150			6.46	6.43	
200			6.52	6.48	
250		6.187			6.870
500			6.70	6.65	7.010
1000	6.31		6.83	6.78	7.197
10000					7.827

Table D6 Extreme Sea Level Estimates (m AODN) - Fleetwood

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
	(1930-1983)	(1930-1978)	(1930-1990)	(1930-1990)	
1		5.562	4.77	4.82	5.681
5		5.875	5.86	5.86	
10	6.01	5.937	5.96	5.96	6.224
20		6.012	6.03	6.04	
25			6.05	6.06	6.444
50		6.094	6.11	6.11	6.584
100	6.21	6.125	6.15	6.16	6.804
150			6.17	6.19	
200			6.18	6.20	
250		6.187			7.034
500			6.22	6.24	7.174
1000	6.30		6.24	6.27	7.364
10000					8.011

Table D7 Extreme Sea Level Estimates (m AODN) - Heysham

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
	(1940-1984)	(1940-1977)	(1940-1997)	(1940-1997)	
1		5.781	5.27	5.30	5.671
5		6.062	6.06	6.05	
10	6.13	6.187	6.18	6.18	6.215
20		6.281	6.29	6.29	
25			6.32	6.32	6.435
50		6.437	6.42	6.43	6.575
100	6.93	6.531	6.52	6.53	6.795
150			6.57	6.58	
200			6.61	6.62	
250		6.656			7.025
500			6.72	6.74	7.165
1000	8.13		6.79	6.82	7.355
10000					8.001

Table D8 Extreme Sea Level Estimates (m AODN) - Barrow

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
	(1920-1978)	(1920-1978)	(1920-1978)	(1920-1978)	
1		5.375	5.12	5.13	5.633
5		5.687	5.66	5.66	
10	5.79	5.812	5.80	5.80	6.181
20		5.937	5.96	5.94	
25			6.01	5.99	6.401
50		6.093	6.18	6.15	6.541
100	6.39	6.250	6.37	6.33	6.761
150			6.49	6.44	
200			6.58	6.52	
250		6.437			6.991
500			6.90	6.80	7.131
1000	7.30		7.17	7.04	7.321
10000					7.963

Table D9 Extreme Sea Level Estimates (m AODN) - Workington

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
			(1992-1997)	(1992-1997)	
1		-	4.09	4.22	5.231
5		-	5.40	5.36	
10	-	-	5.55	5.48	5.674
20		-	5.66	5.57	
25			5.70	5.59	5.835
50		-	5.79	5.67	5.935
100	-	-	5.87	5.73	6.102
150			5.91	5.76	
200			5.93	5.78	
250		-			6.269
500			6.01	5.83	6.373
1000	-		6.06	5.87	6.514
10000					7.001

Table D10 Extreme Sea Level Estimates (m AODN) - Silloth

Return Period (Years)	Coles and Tawn	Graff	PWM	MLE	SRJPM
	(1928-1978)	(1928-1978)	(1928-1978)	(1928-1978)	
1		5.69	4.81	4.82	5.237
5		6.06	6.06	6.06	
10	6.23	6.22	6.22	6.22	5.683
20		6.34	6.36	6.35	
25			6.40	6.39	5.850
50		6.47	6.51	6.51	5.950
100	6.69	6.562	6.61	6.61	6.122
150			6.67	6.66	
200			6.70	6.70	
250		6.687			6.293
500			6.80	6.81	6.399
1000	7.08		6.87	6.88	6.546
10000					7.045

APPENDIX E: Application of SRJPM Method to the Ribble Estuary

As detailed in Appendix C, the SRJPM approach is a 6 step procedure and this has been applied to a location at the mouth of the Ribble estuary as detailed below. All calculations are included on an Excel spreadsheet.

1. Identify Adjacent Nodes

The locations of the point in the Ribble Estuary and the 2 adjacent nodes are identified from Dixon and Tawn (Figures 8.10 to 8.17), with the latitude, longitude and MDM of the adjacent nodes extracted from Dixon and Tawn (Table 4.1). These are identified in Table E1 where MDM is the Model Distance Metric defined by Dixon and Tawn (1997).

Table E1 Location of Nodes adjacent to Ribble Estuary

Location	MDM node	MDM distance metric (km)	Latitude (° N)	Longitude (° E)
	64	3144	53.39	-3.21
River Ribble Estuary			53.72	-2.93
	65	3211	53.85	-3.06

2. Calculate the Weighting between Points of Interest and Adjacent Nodes

Dixon and Tawn adopted a visual assessment of the relative distance between the nodes adjacent to the sites of interest and hence derived weightings. For this study the difference in Latitude and Longitude is calculated from the point of interest to each of the 2 adjacent nodes using Pythagorous' theorem and assuming 1' of latitude is equal to 1 Nautical Mile (NM). The distance between the required location and each of the 2 adjacent nodes is thus calculated.

In the example (Table D2) the distance from the Ribble estuary to node 64 is 25.685 NM and 11.034 NM to node 65. On this basis a weighting factor has been calculated, being the ratio of the distance between the 2 adjacent nodes. Thus for the Ribble Estuary, node 64 has a weighting of 0.699 and node 65 a weighting of (1-0.699) or 0.301. On this basis the distance metric can be calculated (Table E2).

Table E2 Calculation of Node Weightings

Site	Node	Latitude (° N)	Longitude (° E)	Pre Node Distance (NM)	Post Node Distance (NM)	Weighting Factor	Model Distance Metric (km)
	64	53.39	-3.21				
River Ribble		53.72	-2.93	25.685	11.034	0.699	3190.9
	65	53.85	-3.06				

3. Extract Relevant Data from Dixon and Tawn

For each of the Nodes, look up basic data in Tables provided in Dixon and Tawn;

- The 1-year Level
- Return period adjustment
- Trend and hence calculate adjustment with time, in this case from 1990
- Datum Addition to correct MSL to either ACD or ODN.

These values for each node are given in Table E3. These tables are included in an Excel spreadsheet, allowing the values for each node to be looked up directly.

Table E3 Basic Data from Dixon and Tawn Tables

Node	Distance (km)	1-Year Level (MSL)	Return Period Adjustment								Trend (mm/yr)	Trend Adjust	Datum Adjust
			Return Period (Years)										
			10	25	50	100	250	500	1000	10000			To ODN
64	3144	5.16	0.52	0.74	0.87	1.09	1.31	1.45	1.63	2.24	3.11	0	0.19
65	3211	5.4	0.55	0.77	0.91	1.13	1.36	1.5	1.69	2.33	3.07	0	0.21

4. Calculate Return Period Levels for Each Node

The return period extreme level is then the sum of the 1-year level, the Return Period adjustment and the trend adjustment (Table E4). As Dixon and Tawn gives only selected return period adjustments, it is not possible to calculate tide levels for other Return Periods without interpolation.

Table E4 Return Period Extreme Sea Levels (MSL) at Relevant Nodes

	Return Period (Years)								
Node	1	10	25	50	100	250	500	1000	10000
SRJPM									
64	5.160	5.680	5.900	6.030	6.250	6.470	6.610	6.790	7.400
65	5.400	5.950	6.170	6.310	6.530	6.760	6.900	7.090	7.730
Adjusted SRJPM									
64		5.298	5.482	5.615	5.746	5.84834	6.019	6.131	
65		5.764	5.909	6.010	6.108	6.18848	6.323	6.416	

5. Calculate Return Period Tide Levels for Ribble Estuary

Apply weighting factors previously derived to calculate the return period levels for the site between each of 2 nodes (Table E5).

Table E5 Calculated Levels (MSL) at Nodes and River Ribble Estuary

SRJPM		Node Weighting		Return Period (Years)								
Site	Node	i	i+1	1	10	25	50	100	250	500	1000	10000
	64			5.160	5.680	5.900	6.030	6.250	6.470	6.610	6.790	7.400
River Ribble		0.699	0.301	5.328	5.869	6.089	6.226	6.446	6.557	6.813	7.000	7.631
	65			5.400	5.950	6.170	6.310	6.530	6.760	6.900	7.090	7.730
Adjusted SRJPM												
	64				5.298	5.482	5.615	5.746	5.848	6.019	6.131	
River Ribble					5.634	5.806	5.930	6.051	6.147	6.306	6.413	
	65				5.764	5.909	6.010	6.108	6.188	6.323	6.416	

6. Adjust to m AODN

Using the weighted datum adjustment factor (Table E3) correct all levels (Table E5) to m AODN (Table E6).

Table E6 Levels to m AODN for River Ribble Estuary

	Return Period (years)								
Site	1	10	25	50	100	250	500	1000	10000
SRJPM	5.532	6.073	6.293	6.430	6.650	6.877	7.017	7.204	7.835
Revised SRJPM		5.634	5.806	5.930	6.051	6.147	6.306	6.413	

APPENDIX F: Specification

EXTREME SEA LEVELS FOR SECTION 105 SURVEYS

SPECIFICATION

TABLE OF CONTENTS

1. OBJECTIVES

The project objective is to produce a consistent set of extreme sea levels for varying return periods at various locations along the coastline of the North West Region of the Environment Agency. The calculation of these levels should use the best available and most up to date data and knowledge.

2. REQUIREMENTS

The successful Consultant will be required to:

- Obtain the appropriate data from Proudman Oceanographic Laboratory or other organisations to fulfill the project requirements.

- Compute the extreme sea levels for the locations specified in Appendix A and the return periods specified in Appendix B using the Spatial Revised Joint Probability Method (SRJPM) given in Dixon and Tawn (1997)

- Compute the extreme sea levels for the locations specified in Appendix A and the return periods specified in Appendix B from the annual maxima (AMAX) data for each site. The calculation of these levels by this method should take note of the previous methodology used especially that described in Graff (1981) and Coles and Tawn (1990).

- Compare the extreme sea level results from the two methods stated above, and also those from Graff (1981) and Coles and Tawn (1990).

- Produce a robust and consistent set of extreme sea levels for the specified locations and return periods.

- Calculate the return periods of the high tides on 26 February 1990 and 10 February 1997

- Calculate the return periods of the Operation Neptune flood warning levels of 5.5m AOD and 6.0m AOD at Gladstone Dock, Liverpool, and compute the equivalent levels at Heysham, Workington, Llandudno and Fleetwood for these return periods

- Recommend a standard methodology for interpolating extreme sea levels between locations specified in Appendix A. This method should take account of the recent work described in Dixon and Tawn (1997). A full worked example of this method should be included for the mouth of the Ribble Estuary.

- Recommend a standard methodology to take account of sea level rise and its effect on extreme levels. This method should take account of the references to sea level rise in MAFF (1993) and Dixon and Tawn (1997). A worked example of this methodology should be given for Liverpool (Gladstone Dock) in the years 2025 and 2050.

- Produce a report and other outputs detailing the data used, studies undertaken and results produced.

3. PROJECT OUTPUTS

3.1 Report

The report shall detail the data used, the studies undertaken and results produced. The Agency shall be supplied with two draft copies and eight final copies of this report in hard copy. The report shall also be supplied as the appropriate word-processor and other computer files on 3½" floppy disk or CD. The report must be sufficient to explain the data and methologies used and the results obtained and shall include:

- a map showing the locations for which sea levels have been calculated
- graphs of level against return period for each location
- tables of level against return period for each location
- listings of the annual maxima for each location
- worked examples as required in project requirements
- calculation sheets (included as appendices as appropriate)
- a table of the differences between Ordnance Datum and Chart Datum at each location

3.2 Computer Files

The Consultant shall supply the following computer files on 3½" floppy disk or CD:

- sufficient wordprocessor and other files to reproduce the entire report. The format of these files shall be agreed with the Agency.
- an ASCII text file detailing the location name, latitude (to the nearest second), longitude (to the nearest second), National Grid Reference (to the nearest 10m), difference in metres between Chart datum and Ordnance Datum at this location and the calculated extreme sea levels. The fields shall be of a fixed length and each location shall form one line of the file.
- an ASCII text file for each location detailing the annual maxima for that site. The fields to be included are date, time and level. The file should contain a header of the location name and its filename should be a shortened version of the location name. The fields shall be of a fixed length.

4. PROJECT MANAGEMENT

4.1 Agency's Representative

The Agency's representative for this project will be Tim Palmer.

4.2 Programme

The programmed length of the project is ten weeks including allowances of four weeks for data delivery and two weeks for the Agency to comment on the draft report.

4.3 Progress Reporting

Progress should be reported on a fortnightly basis in the form of a short written report transmitted by fax or email.

4.4 Meetings

A meeting to discuss the Agency's comments on the draft report will be held.

5. PAYMENT

The project cost shall be paid as a single lump sum invoice for all consultancy fees, other fees and expenses. The cost of data from third parties (eg Proudman Oceanographic Laboratory) shall be re-imbursed at cost. The estimate of these third party data costs submitted with the Consultant's quotation will be treated as a target cost and should not be exceeded without prior permission from the Agency. Copies of the third party invoices shall be submitted as proof of these costs. The invoice shall be submitted on delivery of the final reports.

6. QUOTATION

The Consultant shall submit a quotation for the project containing the following items:

- a single fixed cost for all consultancy fees, other fees and expenses
- a price per additional copy of the final report (The fixed price should include the production of the specified number of reports)
- an estimate of cost of data from third parties
- a brief statement outlining the intended methodology and any other relevant points

a brief statement outlining the proposed project staffing (including approximate total number of staff hours and the approximate number of hours that each individual staff member will work)

- the relevant staff CVs
- a brief programme outlining the start date, end date, date of issue of draft reports and other key dates.

The Consultant may submit alternative quotations provided that this in addition to a quotation submitted in the format specified above.

7. TERMS AND CONDITIONS

The contract for this project shall be under the Agency's standard terms and conditions. Copies of these are available from Chris Roberts, Procurement Manager at the Agency's Warrington office.

8. REFERENCES

Coles, S G and Tawn, J A. (1990). Statistics of coastal flood prevention. *Phil. Trans. R. Soc. Lond., A,* **332**, 457-476

Dixon, M J and Tawn, J A. (1997). *Estimates of Extreme Sea Conditions: Spatial Analyses for the UK Coast*. Proudman Oceanographic Laboratory Internal Document No 112

Graff, J. (1981). An investigation of the frequency distributions of annual sea level maxima at ports around Great Britain. *Estuarine Coastal Shelf Sci.*, 12, 389-449

MAFF. (1993). *Project Appraisal Guidance Notes*. Publication no PB1214. MAFF Publications, London

APPENDIX A - LOCATIONS

Silloth
Workington †*
Barrow
Heysham†
Fleetwood
Hilbre Island
Liverpool - Princes Pier
Liverpool - Gladstone Dock †
Eastham Lock
Llandudno†*

† Location of UK A-Class Tide Gauge
* Location not included in Graff (1981)

'ENDIX B - RETURN PERIODS

in	1	year
	5†	years
	10	
	20†	
	25	
	50†	
	75	
	100	
	150†	
	200†	
	500	
	1000	

† Return period for indicative standard of protection (for tidal flooding) from MAFF (1993)

APPENDIX C - DATA USED IN PREVIOUS STUDIES

	Annual Maxima used in Graff (1981)		Annual Maxima used in Coles and Tawn (1990)		Hourly data used in Dixon and Tawn (1997)	
	Range of Years	Number of Years	Range of Years	Number of Years	Range of Years	Number of Years
Silloth	1928-1978	20	1928-1978	20		
Workington					1992-1993	2
Barrow	1920-1978	19	1920-1978	19		
Heysham	1940-1977	29	1940-1984	36	1964-1990	21
Fleetwood	1930-1978	43	1930-1983	48		
Hilbre Island	1854-1977	76	1854-1981	80		
Liverpool - Princes Pier	1941-1977	37	1941-1977	37		
Liverpool - Gladstone Dock	1956-1977	20	1956-1977	20	1991-1993	3
Eastham Lock	1956-1977	19	1956-1977	19		
Llandudno						

ENVIRONMENT AGENCY

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