The 1974 Storms Revisited: 25 Years Experience in Ocean Wave Measurement Along the South-East Australian Coast

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Abstract

The New South Wales Department of Public Works and Services' Manly Hydraulics Laboratory operates a network of Waverider buoys and water level recorders along the New South Wales east coast. The network comprises seven long-term Waverider stations and 14 ocean tide gauges, providing one of the most comprehensive data sets available anywhere in the world. The network was installed in response to storms in 1974 that resulted in severe damage all along the NSW coast. The MHL wave database now includes 25 years of measured data, with the oldest established water level site at Fort Denison within Sydney Harbour recording data since 1888.

This paper presents an update of the wave data for various stations along the coast. In particular, the more recent analyses of the wave height recurrence data in terms of storm duration are presented and discussed. Recent trends in data collection have seen the installation of directional buoys at two locations, with a third to be installed shortly. The directional data is presented and discussed with comparisons to the previously observed and hindcast wave directions. Variations in the directional distribution from year to year are discussed.

The definitive design storm event in NSW is taken as the 1974 storms, which are generally considered to have a recurrence of 1-in-100 years. The available data from that storm event is considered in terms of the measured wave record to more accurately assess the recurrence for this event. Some comments on the adequacy of the longer-term records are provided.

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1. <u>Introduction</u>

Twenty five years ago severe ocean storms in May-June 1974 ravaged the south-east coast of the Australian mainland (Foster et al. 1975). These storms resulted in extensive damage along the NSW coast. Following these storms, the NSW Government recognised the need for a specialist coastal engineering capability and formed the Coastal Engineering Branch within the then NSW Department of Public Works (PWD). The role of the Department in coastal management was subsequently defined through the *NSW Coastal Protection Act 1979*. In 1996 a reorganisation within the NSW Government saw the role of coastal management divested to the newly formed Department of Land and Water Conservation (DLWC). The responsibility for coastal data collection and archiving remained with the Manly Hydraulics Laboratory (MHL), which was established as a business unit of the new Department of Public Works and Services (DPWS).

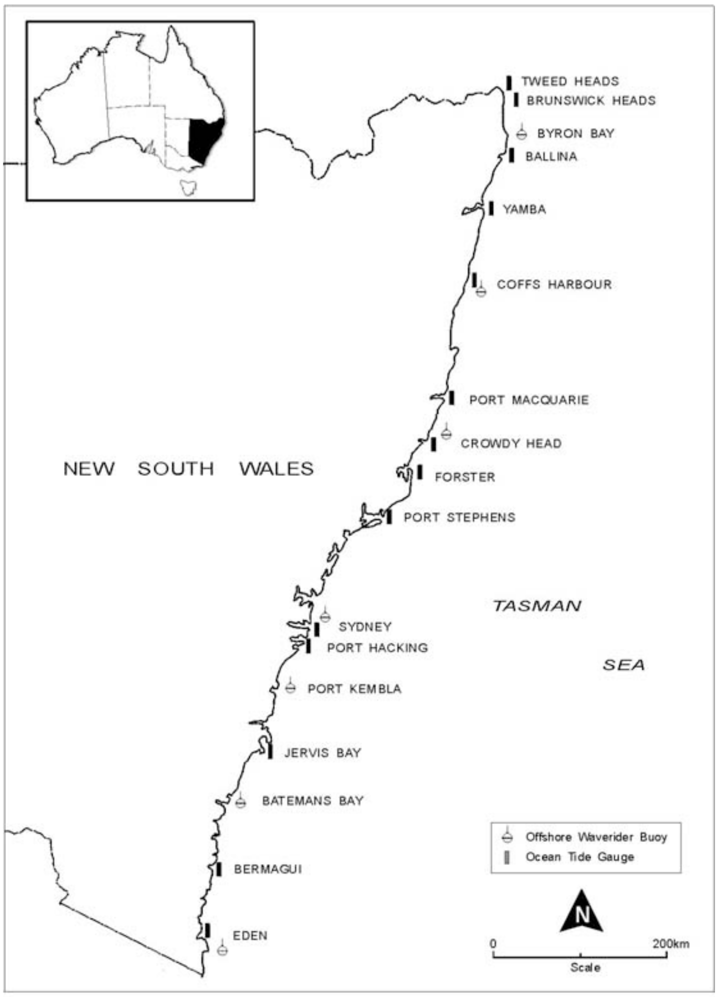

Figure 1. Deep water Waverider and ocean water level stations maintained by the Manly Hydraulics Laboratory in New South Wales

2. The NSW Ocean Data Network

One consequence of the 1974 storms was the recognition of the lack of understanding of the scope and frequency of severe coastal events. The NSW Government committed to the collection of coastal process data for assessment of design conditions and future prediction of shoreline change and coastal impacts. A network comprising seven Datawell Waverider buoys and six ocean tide gauge recorders has been established by MHL for DLWC (Figure 1). Several river entrance gauges are also maintained. The network extends along the 1,000 km NSW coast and provides continuous measurement of wave and water level conditions.

Two long-term Waveriders are also maintained at Newcastle and Botany Bay by the relevant Ports Authority for use in the operation of those ports.

The first continuous tide gauge in NSW was installed at Fort Denison Sydney in 1883. Data prior to 1914 was considered unreliable (Hamon 1987) and a digital composite of data since 1914 to the present has been prepared. Data from other stations along the coast was sporadic until the implementation and subsequent operation by MHL of a continuous network of 14 stations since 1986.

Wave data has been collected continuously at some points along the NSW coast for twenty five years. This has resulted in one of the most comprehensive and long-term data sets available worldwide. In 1992 a directional buoy providing measurement of wave directions at Sydney was added and in 1999 the existing non-directional buoy at Byron Bay was replaced with a directional buoy. A further directional buoy is proposed for Batemans Bay in the near future.

3. The NSW Wave Climate

Records of continuous wave height are collected for 34-minute bursts (2048 x 0.5 sec. intervals) every hour and are analysed at the shore station before transfer of the reduced and selected raw data to MHL early each morning. Data is then quality controlled and archived on MHL's central computer. A zero crossing analysis and spectral analysis are undertaken to determine (amongst other things) the significant wave height (H_s) and peak spectral period (T_{P1}) for each record. Details of the data collection program and summaries of the annual data are published by MHL as annual wave climate summaries (MHL 1999).

The recorded peak spectral wave periods show a good correlation along the coast with the overwhelming dominance of ocean swell conditions. At each station the predominant wave period is in the range 6 seconds to 14 seconds (Figure 2).

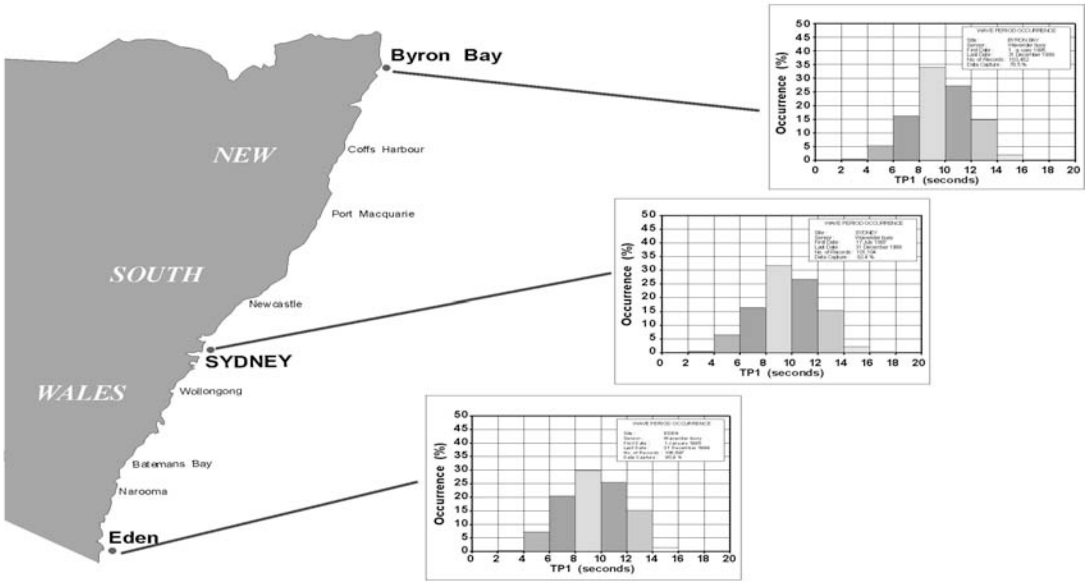

Figure 2. Peak spectral wave period (T_{P1}) for selected NSW stations maintained by MHL

The actual statistics, on spectral peak wave period T_{P1} for each station, (including the duration of records and percentage data capture) are presented for reference in Table 1. The data presented for Sydney is from the non-directional buoy that provides the longer period of record than the directional buoy.

Table 1 Peak Spectral Period Occurrence Table
All stations to 31 December 1999
(Source: Manly Hydraulics Laboratory records)

T_{P1} (sec)	Byron Bay	Coffs Harbour	Crowdy Head	Sydney	Port Kembla	Batemans Bay	Eden
2 3.99	0.395	0.450	0.288	0.565	0.973	0.389	0.259
4 5.99	5.219	5.890	5.151	6.573	6.337	7.162	7.637
6 7.99	16.199	15.149	15.530	16.497	17.616	20.430	19.214
8 9.99	34.022	33.319	32.951	31.658	31.644	29.953	30.135
10 11.99	27.268	28.234	27.359	26.697	24.988	25.402	24.761
12 13.99	14.796	14.877	15.902	15.478	16.033	15.094	15.882
14 15.99	1.881	1.848	2.431	2.105	2.080	1.386	1.871
16 17.99	0.208	0.222	0.370	0.408	0.312	0.179	0.225
18 19.99	0.013	0.011	0.019	0.019	0.018	0.006	0.016
Average T_{P1}	9.58	9.59	9.70	9.57	9.51	9.37	9.44
Start Date	01-Jan-1985	01-Jan-1985	10-Oct-1985	17-Jul-1987	01-Jan-1985	27-May-1986	01-Jan-1985
No. Records	103,452	112,012	108,398	101,105	118,452	108,955	106,597
Capture (%)	78.5	85.0	86.7	92.4	89.9	91.2	80.9

The significant wave height exceedance data for seven stations along the NSW coast is presented in Figure 3. While there is a general coincidence of these data along the coast, there are noticeable differences in the recurrence heights for the lower and higher wave conditions at specific locations. The Sydney Buoy records the highest incidence of higher waves while the Eden buoy has the greatest incidence of lower waves. This may simply reflect the differing data capture rates or the length of record at the individual sites.

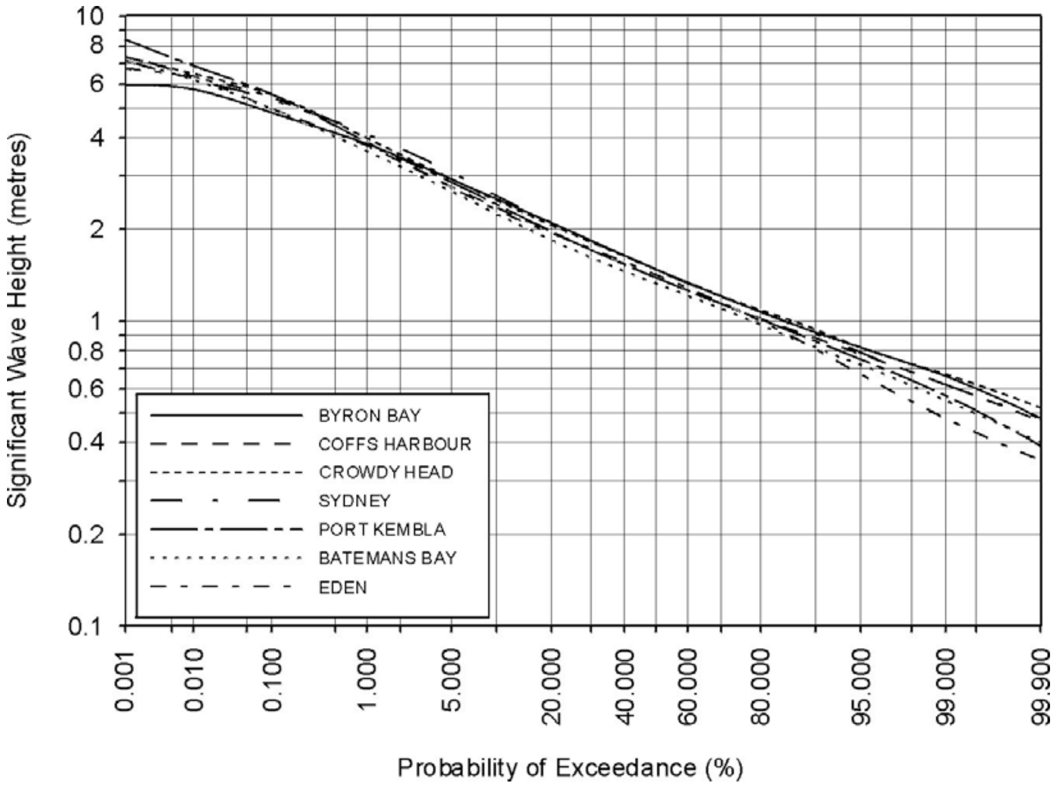

Figure 3. Significant wave height (H_S) exceedance for selected NSW stations maintained by MHL

The wave height exceedance statistics for each site are given in Table 2 for reference. Again the Sydney data is based on the non-directional buoy to maximise the length of record. These data provide the most reliable information for design and sediment transport calculations.

Table 2 NSW Wave Height Exceedance All Stations, All Data to 31 December 1999
(Source: Manly Hydraulics Laboratory records)

Hsig (m)	Byron Bay	Coffs Harbour	Crowdy Head	Sydney	Port Kembla	Batemans Bay	Eden
0.5	99.846	99.807	99.953	99.847	99.481	99.504	98.601
1.0	84.962	81.172	86.468	84.725	80.679	77.758	80.597
1.5	48.908	42.779	48.339	47.988	42.704	37.294	44.339
2.0	23.822	18.720	22.416	23.565	19.111	15.402	18.352
2.5	10.498	7.970	9.896	11.285	8.757	6.651	7.571
3.0	4.333	3.419	4.480	5.631	3.932	2.858	3.406
3.5	1.810	1.554	2.142	2.666	1.786	1.235	1.681
4.0	0.712	0.646	0.990	1.198	0.817	0.532	0.818
4.5	0.252	0.269	0.495	0.474	0.399	0.222	0.404
5.0	0.066	0.100	0.224	0.183	0.211	0.094	0.197
5.5	0.023	0.041	0.108	0.070	0.111	0.040	0.077
6.0		0.024	0.051	0.026	0.063	0.015	0.026
6.5		0.008	0.009	0.004	0.029	0.006	0.003
7.0		0.001	0.003	0.001	0.007	0.002	
7.5					0.003		
8.0					0.002		
Average Hsig	1.63	1.53	1.63	1.64	1.54	1.46	1.53
Start Date	14-Oct-1976	26-May-1976	10-Oct-1985	17-Jul-1987	07-Feb-1974	27-May-1986	08-Feb-1978
No. Records	114,127	125,388	108,398	101,105	134,084	108,955	114,095
Capture (%)	73.1	83.7	86.7	92.4	83.0	91.2	78.7

4. <u>Storm Duration</u>

Past experience along the NSW coast demonstrates the clear link between beach erosion and shoreline damage and the occurrence of high wave conditions with elevated ocean levels. Invariably the foreshore erosion and inundation is maximised when the storm event coincides with a high tide and storm surge. This link is not readily defined.

Considerable effort has been expended in assessing the relationship between storm duration and wave height (Kulmar 1995). For a semi-diurnal tide, the likelihood of coincident wave and high tide increases as the storm duration increases. In general storms with duration in excess of six hours have a high probability of coinciding with the high tide while storms with a short duration (<1 hour) have a reduced probability of coinciding with a high tide.

A plot showing the wave height/duration for storms of various recurrence is shown at Figure 4. This plot is based on all available data for the MHL installations at Byron Bay (23.21 years), Sydney (12.46 years) and Eden (21.89 years). Clearly, in selecting a design wave with a given return period, the duration becomes a significant factor.

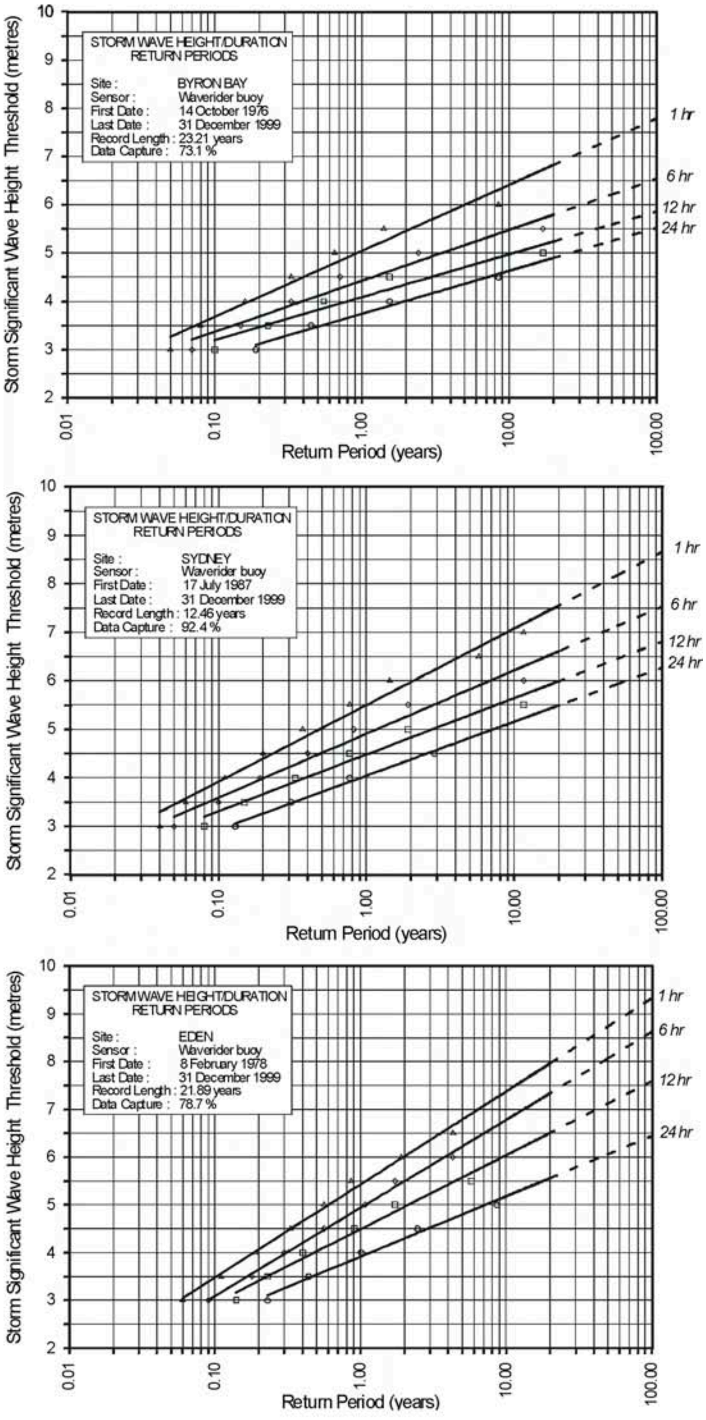

Figure 4. Storm Wave Height (Hsig), Duration and Return Periods for the NSW Coast to 31/12/99
(Source: Manly Hydraulics Laboratory Waverider records, Byron Bay, Sydney and Eden, utilising all available data)

5. Directional Wave Data

MHL is currently upgrading the wave recording system through the installation of direction measuring buoys. A directional buoy has operated at the Sydney offshore station since 1992. The longer-term non-directional buoy has also been retained for comparison and will shortly be removed. A second directional buoy was deployed at Byron Bay in 1999 to replace the long-term buoy at that location. A third directional buoy is planned for Batemans Bay shortly. A summary of the Sydney directional data is presented in Table 3. The duration of this record is 7.8 years and this results in some apparent differences when the data is compared with the longer, non-directional data set from the older Sydney buoy. The correlation between coincident readings from the two buoys is, however, excellent.

Table 3 Offshore Sydney Wave Height Occurrence by Direction
(Source: Manly Hydraulics Laboratory records)

Hsig	**Wave Direction (^{0} True North)**									**TOTAL**
(metres)	**NNE**	**NE**	**ENE**	**EAST**	**ESE**	**SE**	**SSE**	**SOUTH**	**SSW**	
0.00 - 0.49	0.000	0.000	0.002	0.024	0.034	0.056	0.101	0.019	0.002	**0.239**
0.50 - 0.99	0.022	0.377	1.474	1.767	2.105	3.103	5.367	1.263	0.054	**15.531**
1.00 - 1.49	0.069	1.633	4.285	4.638	4.694	6.628	11.427	3.669	0.170	**37.213**
1.50 - 1.99	0.030	1.018	2.587	2.533	2.348	3.919	8.701	3.607	0.148	**24.890**
2.00 - 2.49	0.013	0.247	0.891	0.966	1.173	1.758	4.547	2.673	0.075	**12.344**
2.50 - 2.99	0.002	0.052	0.245	0.282	0.437	0.796	1.855	1.265	0.026	**4.960**
3.00 - 3.49	0.000	0.013	0.103	0.108	0.170	0.387	1.065	0.706	0.017	**2.570**
3.50 - 3.99	0.000	0.004	0.041	0.067	0.097	0.194	0.480	0.288	0.017	**1.188**
4.00 - 4.49	0.000	0.000	0.009	0.039	0.060	0.077	0.232	0.118	0.004	**0.540**
4.50 - 4.99	0.000	0.000	0.006	0.043	0.032	0.052	0.090	0.041	0.000	**0.265**
5.00 - 5.49	0.000	0.000	0.000	0.013	0.030	0.013	0.045	0.024	0.000	**0.125**
5.50 - 5.99	0.000	0.000	0.000	0.009	0.011	0.011	0.039	0.009	0.000	**0.077**
6.00 - 6.49	0.000	0.000	0.000	0.006	0.004	0.002	0.011	0.000	0.000	**0.024**
6.50 - 6.99	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	**0.009**
7.00 - 7.49	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	**0.015**
7.50 - 7.99	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	**0.002**
8.00 - 8.49	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	**0.009**
TOTAL	**0.136**	**3.344**	**9.643**	**10.493**	**11.195**	**16.997**	**33.995**	**13.683**	**0.514**	**100.000**

Site: Sydney Directional Waverider Buoy
Length of Record: 7.81 years 03/03/1992 to 31/12/1999

The wave records that include the directional data have resulted in a significantly different interpretation of the overall wave climate for NSW. In particular the occurrence of waves from the north are absent over the period of record while the NNE direction accounts for only 0.14% of the total occurrence. In contrast the occurrence from the south is approximately 14% with a further 34% from the SSE. The predominant wave climate along the NSW coast is from the south to south-south-east rather than the south-east as usually assumed from the earlier wave hindcast and observed directional data.

It must be noted that the length of record obtained for the Sydney buoy is short and as yet is not adequate to describe fully the long-term wave climate and direction at Sydney. This can be illustrated through comparison of individual years of data as expressed in the wave rose diagrams at Figure 5. The directional occurrence of wave conditions for the calendar year 1999 varied significantly from the longer average directional distribution based on all data (Figure 5 right and left). In particular, there was a significantly higher record of waves from the north-east and east-north-east over 1999. During 1999, beach scour and erosion of the back beach at the southern end of embayments were experienced all along the NSW coast.

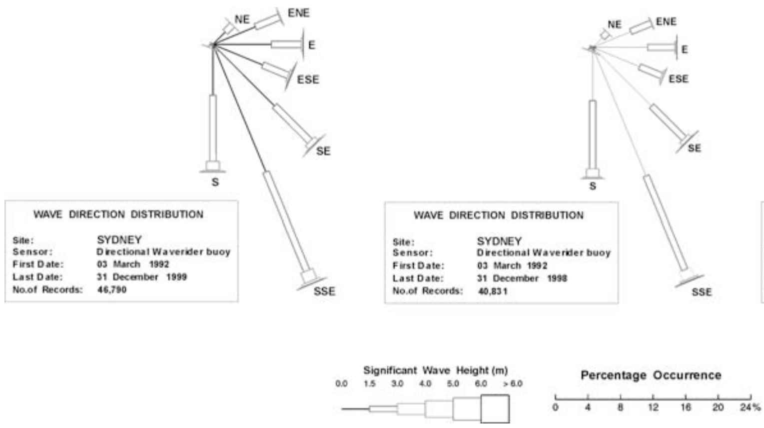

Figure 5. Directional wave roses offshore Sydney showing significant wave height occurrence left: all data 1992 to 1999 centre: all data 1992 to 1998 right: data for 1999 only

Comparison of the (as yet) short record of directional wave data at Byron Bay with longer observed and hindcast wave direction data (PWD 1978) also confirms the more southerly component of the NSW wave climate. In Figure 6 the left hand curve shows the various wave direction data available in 1978 with the adopted directional distribution in bold. This is plotted again on the right hand figure against the recent measured wave directions. Again the observed wave directions significantly overestimate the NE and NNE occurrence while underestimating the occurrence of SSE and S waves.

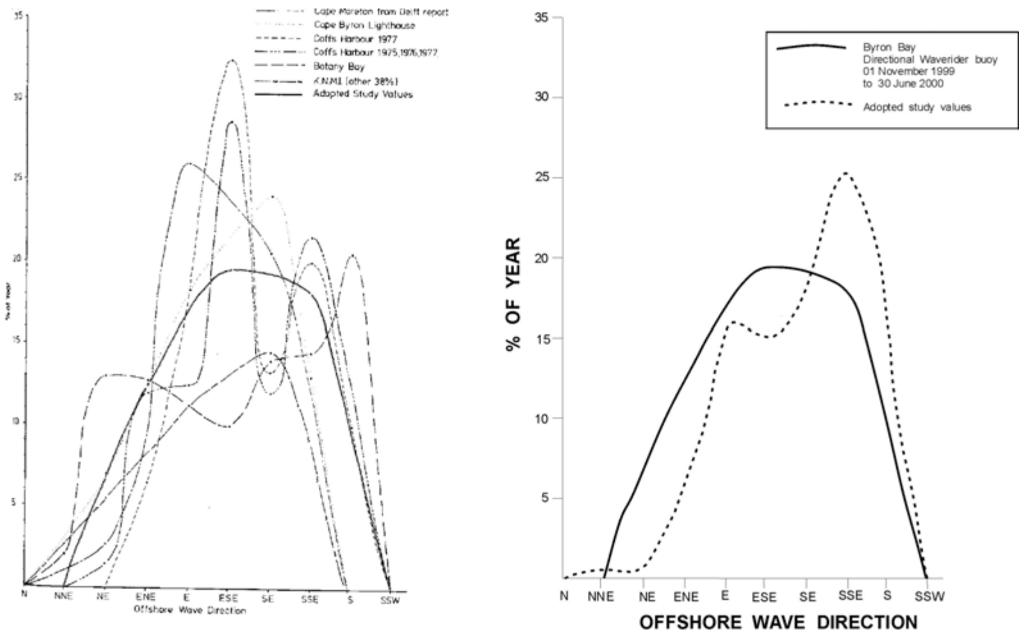

Figure 6. Comparison of observed wave direction data Byron Bay (PWD 1978) with measured directional data from the Byron Bay directional Waverider buoy (eight months data).

6. Storm Ranking

The subsequent assessment of the 1974 storms in NSW (Foster et al. 1975) has provided the basis for the design storm condition in NSW and is commonly assigned a recurrence frequency of 1-in-100 years.

A re-assessment of the return period for this event has been undertaken using the 8 years of Sydney directional wave data (Figure 7). The storm duration and wave heights have been determined from the measured and hindcast data presented in Foster 1975. These height – duration data have then been plotted against the storm wave height duration data, without reference to direction. For the peak significant (1 hour duration) wave height of 9.0 m a return period of approximately 50 years is assessed. For the longer 6-hour duration the return period increases to 70 years while when considered as a 24-hour event the return period is only 20 years. Based solely on wave height and duration, the 1974 storms would more properly be assigned a return interval of 50 years than the 100 years commonly assumed.

The significance of this storm was its coincidence with the highest recorded water level along the NSW coast. There is a direct correlation between the likelihood of such occurrence and the storm duration.

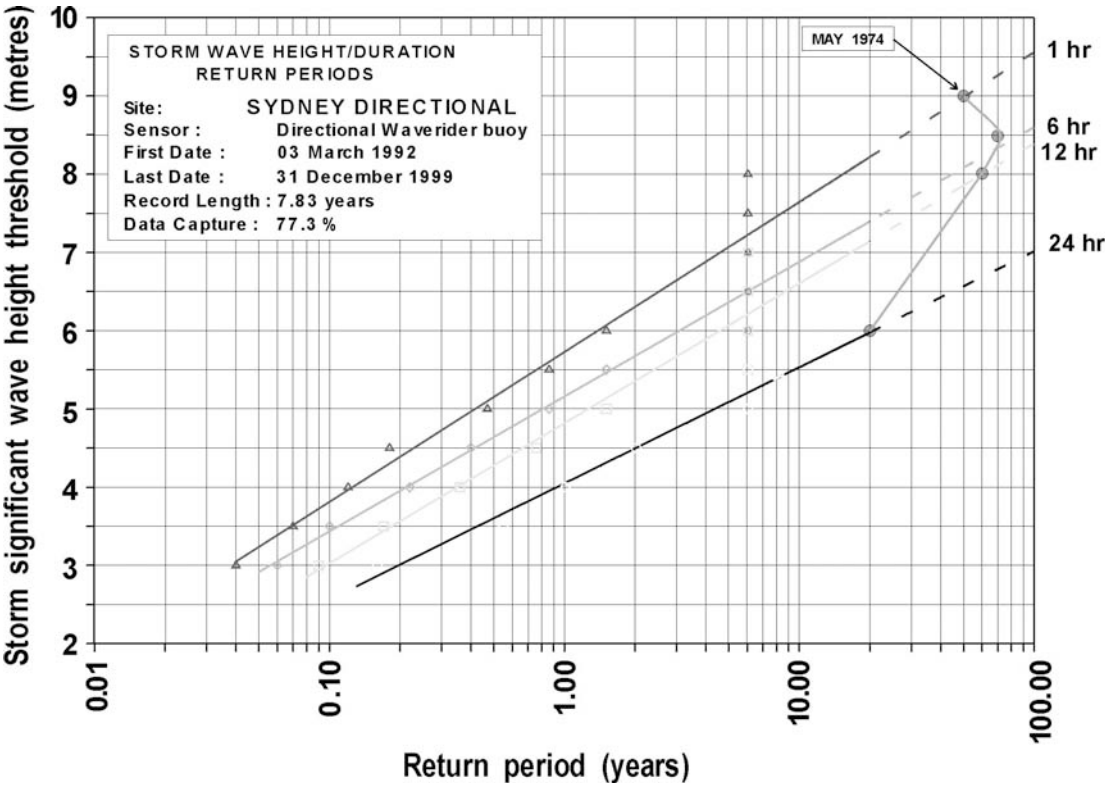

Figure 7. Ranking of H_{sig} for the May 1974 storms against storm duration recurrence data from the Sydney directional Waverider buoy

(Source: Foster et. al. 1975 and Manly Hydraulics Laboratory records)

7. Water Levels

Tides have been measured continuously at Fort Denison in Sydney Harbour for over 100 years. The data for Fort Denison is considered reliable for the period since 1914. These data reflect the astronomical tidal levels as well as anomalies or variations from the predicted tide resulting from storm surge, local effects and other causes (MHL 1992). A recurrence plot for ocean water levels at Sydney (excluding wave effects) is shown at Figure 8 based on a dual probability analysis of predicted tides and measured tidal anomalies from 1914 to 31/12/1999. The datum for the water level measurements is the chart datum of Indian Springs Low Water and equates (approximately) to the zero reading on the Fort Denison tide gauge.

This analysis has not yet included allowance for the measured change in average sea level over the period of record and the effect of this on water level recurrence needs to be considered. The long-term Sydney record includes a measured sea level increase at a rate of about 1.0 mm per annum since 1914 that is included in the analysis, increasing the likelihood of the maximum water levels having been attained over recent years. With a scenario of an accelerated Greenhouse sea level rise over coming decades it is likely that the frequency of occurrence of the higher water levels will become more common with time (Lord and Nalty 1999).

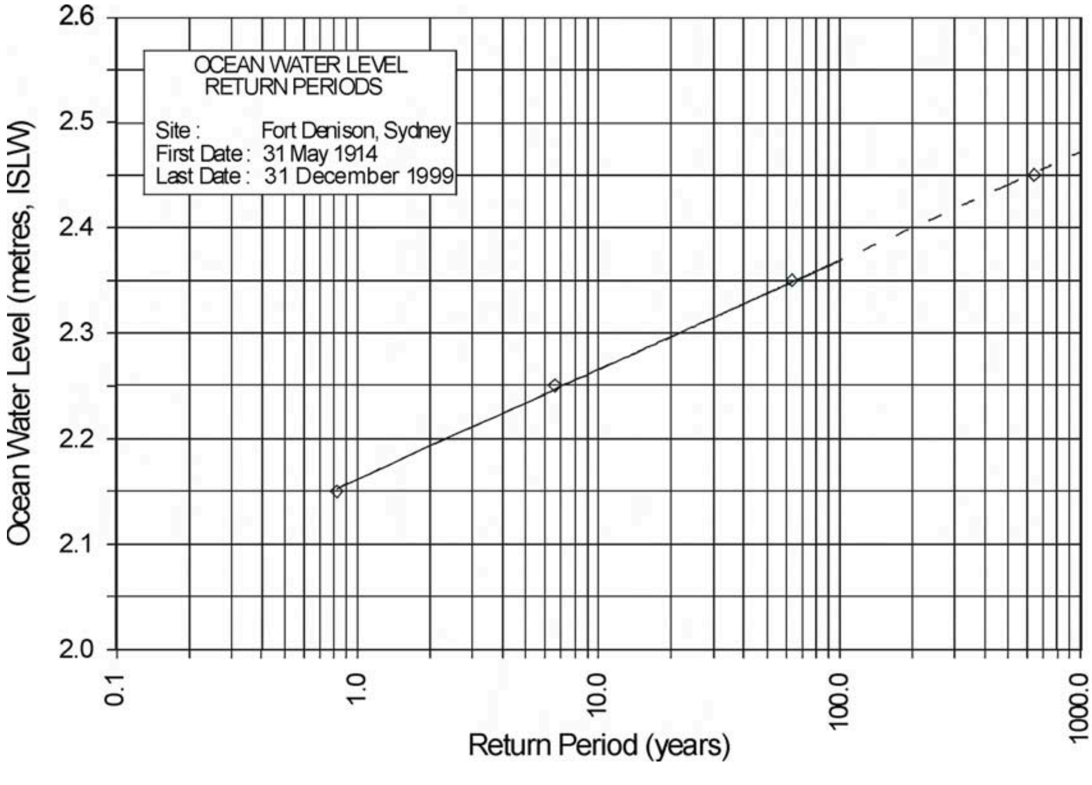

Figure 8. Sydney, NSW, ocean level recurrence based on joint probability analysis 1914 to 1999 utilising all available data
(Source: Manly Hydraulics Laboratory records)

These Sydney data are now augmented with shorter measurements at other stations maintained by MHL along the NSW coast (Figure 1).

8. Longer-Term Variations in Wave Height

Discussion and presentations at the 27th ICCE in Sydney (Komar pers. comm.) included data suggesting an increase in wave heights over a timescale of several decades along the Oregon coast of the USA, based on long-term wave data records. The tentative link to El Nino–La Nina cycles was raised as a possible contributing factor. The data presented were based on the average winter wave height in a location where a strong seasonal trend in wave climate is observed.

A seasonal trend does not exist within the NSW wave records with severe storm events liable to occur at any time during the year. To test the long-term trend in wave heights, analysis of the records from three stations (Byron Bay, Sydney and Eden) was undertaken. The average value of the significant wave height on an annual basis has been plotted for these stations (Figure 9 and Table 4). Caution is required in including the early data from Byron Bay and Eden due to changes in the buoy location at Eden and low data recovery in the earlier years at Byron Bay. The impact of the significantly higher measured wave conditions in 1999 also tends to bias the line of fit (least squares regression) to the data. Based on the more reliable recordings of the last 15 years, an increase in average wave height of 5 mm/yr to 7 mm/yr is assessed at all sites. However this may be an overestimate resulting from the annual variability in the average wave heights. Analysis of these data does not confirm any significant increase in the wave heights over the period of record. Additional records are required before a change in average or storm wave conditions could be concluded.

Table 4 Annual average wave heights (H_{sig}) and annual average 10% exceedance wave heights (H_{10}) for Byron Bay, Sydney and Eden
Source: Manly Hydraulics Laboratory records

Year	Byron Bay			Sydney			Eden		
	Hsig (m)	H_{10} (m)	Data (%)	Hsig (m)	H_{10} (m)	Data (%)	Hsig (m)	H_{10} (m)	Data (%)
1977	1.45	-	79	-	-	-	-	-	-
1978	1.47	-	72	-	-	-	-	-	-
1979	1.53	-	70	-	-	-	1.02	-	76
1980	1.55	-	56	-	-	-	1.15	-	92
1981	1.34	-	41	-	-	-	1.23	-	59
1982	1.48	-	65	-	-	-	1.03	-	64
1983	1.53	-	53	-	-	-	1.19	-	91
1984	1.64	-	62	-	-	-	1.51	-	48
1985	1.54	1.94	29	-	-	-	1.66	2.10	46
1986	1.63	2.05	68	-	-	-	1.55	1.96	62
1987	1.69	2.13	92	-	-	-	1.53	1.95	58
1988	1.76	2.21	71	1.68	2.11	99	1.65	2.10	83
1989	1.78	2.24	66	1.70	2.14	99	1.82	2.32	83
1990	1.74	2.19	89	1.66	2.08	100	1.73	2.19	91
1991	1.55	1.94	86	1.52	1.91	89	1.64	2.06	98
1992	1.67	2.10	71	1.61	2.02	90	1.75	2.21	90
1993	1.63	2.05	86	1.52	1.90	98	1.52	1.91	88
1994	1.59	2.00	86	1.61	2.02	93	1.64	2.06	91
1995	1.65	2.07	99	1.69	2.12	97	1.69	2.13	75
1996	1.61	2.01	93	1.56	1.95	91	1.62	2.04	82
1997	1.60	2.01	86	1.54	1.93	84	1.66	2.10	98
1998	1.75	2.19	76	1.70	2.13	86	1.75	2.20	83
1999	1.92	2.41	84	1.81	2.27	85	1.74	2.20	90
Avg. All Data	1.62	-	73	1.63	2.05	92	1.53	-	78
Avg. 1985-99	1.68	2.11	79	-	-	-	1.67	2.11	81

Note: Data % is total annual data capture rate

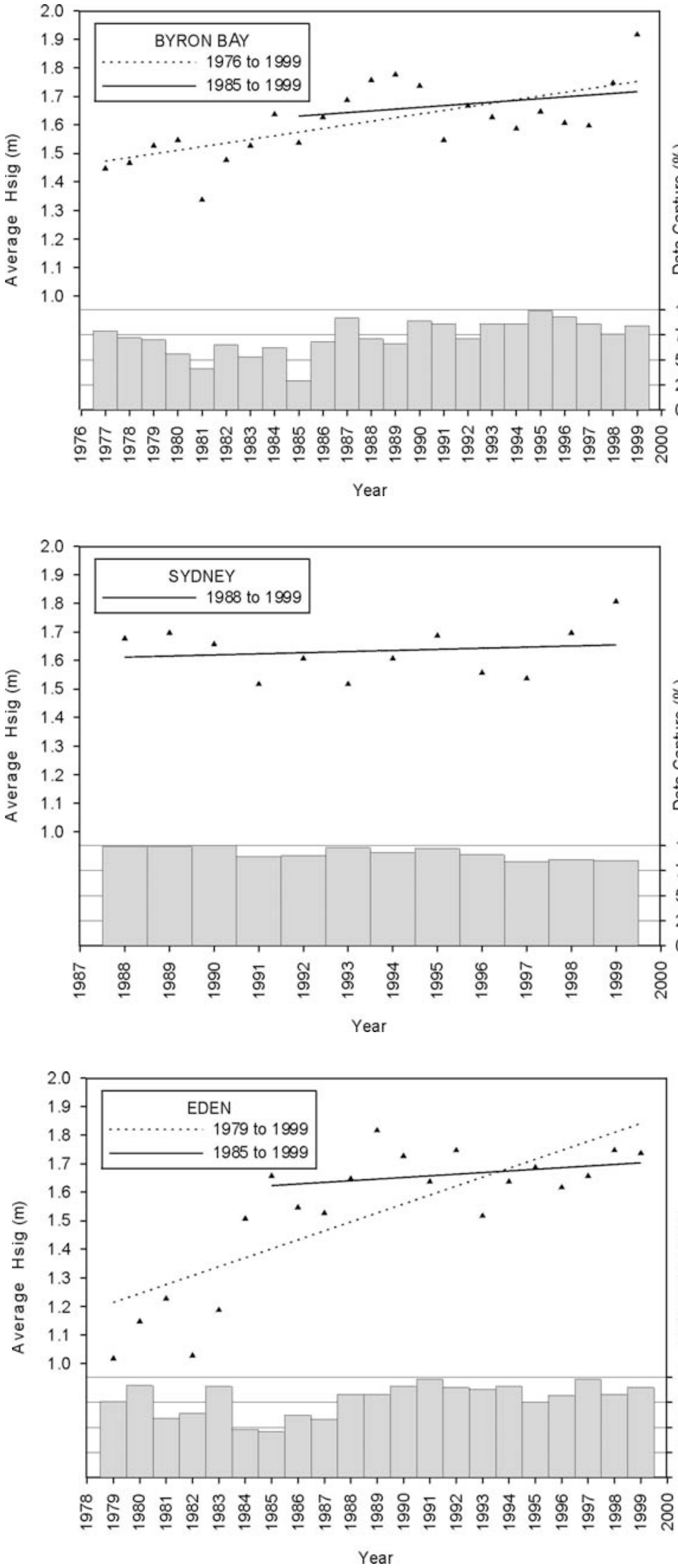

Figure 9. Annual increase in wave height (H_{sig}) for Byron Bay, Sydney and Eden Waverider buoys
Source: Manly Hydraulics Laboratory records

9. Conclusions

The NSW coastal data program is maintained by the NSW Department of Public Works and Services, Manly Hydraulics Laboratory (MHL) with funding provided by the NSW Department of Land and Water Conservation. The network collects detailed information on wave and ocean water levels, with reliable records for waves extending over 25 years and for water levels over 100 years. The ongoing program provides one of the most comprehensive data sets available anywhere in the world.

The paper presents the long-term wave exceedance statistics for seven stations along the NSW coast. The storm duration statistics for three key sites are also presented, highlighting the effect of duration on the selection of design wave conditions.

Water level is a significant factor in combination with storm waves, influencing the extent of coastal damage. Long-term measured water level data for Sydney NSW are presented from 1914. The likely contribution to extreme water levels from past sea level rise can now be addressed. The impact of predicted Greenhouse sea level rise on water level recurrence can be assessed.

The 1974 storms have been used as the basis for coastal design and prediction of foreshore change along the NSW coast over the past 25 years. They are commonly adopted as the 1-in-100-year recurrence event. The known storm parameters and estimated recurrence have been re-assessed in terms of the more recent long-term recorded data incorporating both wave duration and direction statistics. Significantly, the impact of storm duration on recurrence suggests that the recurrence frequency of this event is more common than previously assumed with the recurrence varying from 1-in-20 years to 1-in-70 years for the peak wave height/durations considered. However, the recurrence of this event when considered in conjunction with ocean water levels may still be significantly less. The water level associated with this storm event (concurrent tide and storm surge) is the highest recorded for the NSW coast. With the scenario of even a modest Greenhouse sea level rise the frequency of occurrence of these extreme water levels will become much more common.

Recent literature and presentations at the 27th ICCE in Sydney raised the spectre of a general increase in winter wave heights over a timescale of several decades along the west coast of the USA, possibly linked to El Nino–La Nina cycles. Analysis of the NSW wave data does not indicate any significant increase in the wave heights over the period of record although, if anything, the trend is upwards. Using only the more reliable recordings of the last 15 years along the NSW coast, an increase in average wave height of 5 mm/yr to 7 mm/yr is assessed at all sites. However the annual variations in the average wave heights and the occurrence of a higher than average wave climate for the 1999 calendar year suggest that this trend may be an overestimate. Longer reliable records are required before any conclusion could be drawn of a change in average or storm wave conditions.

10. References

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