Future Directions for Wave Data Collection in New South Wales

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Abstract
The NSW Waverider buoy network was developed in response to a series of destructive storms in 1974. The resulting wave database now has four stations with over 25 years of record and one site at Sydney with over 12 years of directional data. A summary of the data, including information from three directional buoys, is included in the paper for reference by coastal designers and managers. Ultimately, the information of most interest for coastal management in NSW relates to the inshore wave conditions. At present inshore wave data are mostly inferred by numerical transfer rather than through direct measurement. Given constraints on program funding, one future option may be to reduce the effort on deepwater wave data collection while increasing the collection of selected inshore data. Such a change would need confidence in the adequacy of a reduced number of offshore stations to describe significant events on a state-wide basis. In this paper a preliminary assessment of the accuracy of interpolating the wave conditions at one buoy location using the data from adjacent buoys is presented.

1 Introduction

The NSW Department of Commerce's Manly Hydraulics Laboratory (MHL) maintains a network of seven Datawell Waverider buoys along the NSW coastline for the NSW Department of Infrastructure, Planning and Natural Resources. The development of the network has been documented in earlier publications, including Webb (1983), Webb and Kulmar (1989), Kulmar (1995) and MHL (2003).

The NSW Waverider buoy network was developed in response to storms in 1974 that resulted in severe damage to coastal structures and beaches all along the 1,200 km NSW coastline. The MHL wave database now includes four stations with over 25 years of data and one station off Sydney with over 12 years of directional wave data.

Updates of previously published wave climate and storm duration information are presented in the paper. The latest analysis of data from three Directional Waverider buoys is also presented and the results discussed. The results of a site comparison study that examined the accuracy of interpolating the wave conditions at one buoy location using the data from adjacent buoys is included. Options for future directions of wave data collection in NSW are discussed in the paper.

2 The NSW Wave Data Network

The locations of the NSW Waverider buoys are shown in Figure 1. To provide deepwater data the buoys are typically moored in a water depth of over 70 m, between 6 and 12 km from the shoreline.

Since 1986, in an effort to routinely catalogue the data captured by the Waverider network, annual wave climate summaries are published by MHL (1986–2004). The network presently comprises four non-directional and three directional buoys as detailed in Table 1.

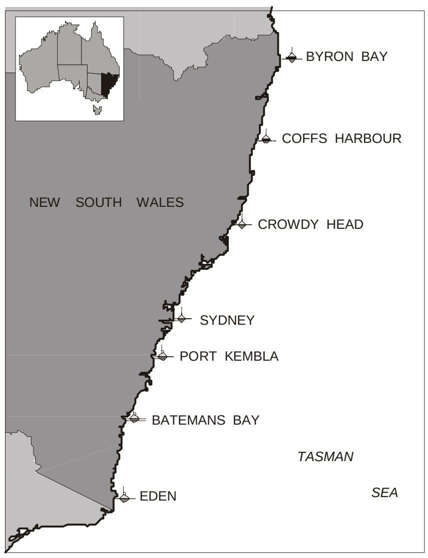

Figure 1 NSW Deepwater Waverider buoy stations maintained by Manly Hydraulics Laboratory

Table 1 NSW Waverider buoy stations – December 2004

Wave Data Station	Date Site Commissioned	Directional Buoy Deployed
Byron Bay	14-Oct-1976	26-Oct-1999
Coffs Habour	26-May-1976	-
Crowdy Head	10-Oct-1985	-
Sydney	17-Jul-1987	03-Mar-1992
Port Kembla	07-Feb-1974	-
Batemans Bay	27-May-1986	23-Feb-2001
Eden	08-Feb-1978	-

3 The NSW Wave Climate

3.1 General

Information on the NSW wave climate was last published in Lord and Kulmar (2000). Since then an additional four years of data from the seven Waverider buoy stations is available for analysis. Summaries of significant wave height (Hsig) exceedance, spectral peak period (TP1) occurrence and wave direction distributions are presented in the following subsections.

3.2 Wave Height

Wave height exceedance for the seven stations is presented in Table 2 and for Byron Bay, Sydney and Eden is plotted in Figure 2. In general, for Hsig < 4 m there is a similar exceedance distribution for all sites except Batemans Bay. For Hsig > 4 m there is some variation in the distribution. This may be explained by the loss of storm data due to equipment failure, differing data capture rates or length of record at individual sites. Table 2 indicates that the exceedance distribution is noticeably lower at Batemans Bay than the other sites. This may be the result of the movement of the wave generating systems off the NSW south coast, and requires investigation. This feature has been apparent since early analysis of the Batemans Bay record and is reflected by the lower average Hsig than all the other stations.

Table 2 Wave Height Exceedance for all Stations to December 2004

Hsig (m)	Byron Bay	Coffs Harbour	Crowdy Head	Sydney	Port Kembla	Batemans Bay	Eden
0.5	99.868	99.938	99.941	99.771	99.801	99.307	99.765
1.0	85.524	84.092	85.684	83.124	82.783	76.386	89.297
1.5	49.794	45.765	47.306	46.385	44.649	36.510	51.766
2.0	24.933	20.877	21.946	22.195	20.576	15.136	21.651
2.5	11.343	8.998	9.789	10.123	9.514	6.385	8.950
3.0	4.671	3.957	4.398	5.162	4.273	2.716	3.978
3.5	1.949	1.777	2.096	2.567	1.927	1.180	1.912
4.0	0.783	0.719	0.937	1.299	0.871	0.514	0.930
4.5	0.272	0.298	0.443	0.670	0.426	0.201	0.469
5.0	0.069	0.114.	0.197	0.330	0.212	0.075	0.209
5.5	0.019	0.048	0.090	0.157	0.101	0.030	0.081
6.0		0.024	0.041	0.060	0.048	0.011	0.022
6.5		0.009	0.007	0.027	0.017	0.004	0.003
7.0		0.001	0.002	0.014	0.008	0.001	0.001
7.5				0.006	0.003		
8.0				0.005	0.002		
Average Hsig	1.65	1.58	1.62	1.61	1.58	1.44	1.65
Start Date	14-Oct-1976	26-May-1976	10-Oct-1985	03-Mar-1992	07-Feb-1974	27-May-1986	08-Feb-1978
Record (years)	28.23	28.62	19.24	11.84	30.91	18.61	26.91
No. Records	142,000	164,021	145,059	86,595	171,794	148,537	152,809
Capture (%)	71.5	84.6	86.0	82.7	83.5	91.0	80.6

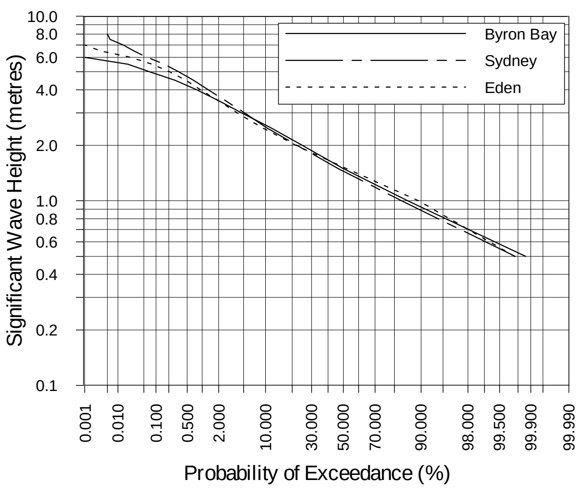

Figure 2 Byron Bay, Sydney and Eden Significant Wave Height Exceedance – All Data to December 2004

3.3 Wave Period

The occurrence of TP1 is presented in Table 3 and displays a good correlation along the NSW coast. The distribution for Byron Bay, Sydney and Eden is shown graphically in Figure 3. Ocean swell with TP1 > 6 seconds dominates the record, with the average for all stations between 9 and 10 seconds. The incidence of TP1 > 16 seconds is less than 1% at all stations. There is, however, a variation in the Sydney distribution for the 8 to 9.99 and 10 to 11.99 second grouping bins when compared to the other sites. It is believed that this is an artefact of the spectral analysis undertaken on board the Directional Waverider buoy that distributes energy slightly differently to the analysis undertaken for the non-directional buoys.

Table 3 Wave Period Occurrence for all Stations to December 2004

TP1 (sec)	Byron Bay	Coffs Harbour	Crowdy Head	Sydney	Port Kembla	Batemans Bay	Eden
2 → 3.99	0.404	0.429	0.301	0.353	0.924	0.401	0.260
4 → 5.99	5.492	5.879	5.201	5.702	6.035	6.955	7.569
6 → 7.99	16.005	15.475	15.289	15.492	17.017	20.330	19.309
8 → 9.99	34.185	33.744	32.731	24.037	31.913	30.271	31.325
10 → 11.99	27.168	28.026	27.833	36.302	25.600	25.785	24.320
12 → 13.99	14.742	14.399	15.853	14.160	15.871	14.733	15.127
14 → 15.99	1.796	1.824	2.382	3.415	2.307	1.341	1.865
16 → 17.99	0.199	0.215	0.387	0.469	0.310	0.176	0.208
18 → 19.99	0.011	0.010	0.023	0.069	0.023	0.007	0.016
Average TP1	9.57	9.57	9.71	9.83	9.57	9.36	9.41
Start Date	14-Oct-1976	26-May-1976	10-Oct-1985	03-Mar-1992	07-Feb-1974	27-May-1986	08-Feb-1978
Record (years)	28.23	28.62	19.24	12.84	30.91	18.61	26.91
No. Records	142,000	164,021	145,059	86,595	171,794	148,537	152,809
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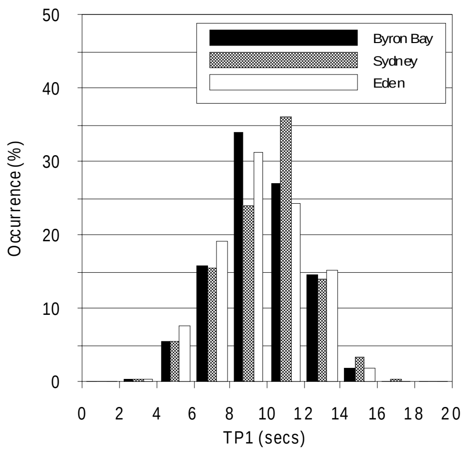

Figure 3 Byron Bay, Sydney and Eden Peak Spectral Period Occurrence – All Data to December 2004

3.4 Storm Duration

Coastal managers are often concerned with the influence of storm events on beach erosion and shoreline damage. Foreshore erosion and inundation increase when a storm coincides with a high tide and storm surge. For the semi-diurnal tides that occur along the NSW coast, the probability of the coincidence of storm waves and high tide increases as the storm duration increases.

In general, storms with a duration greater than six hours have a high probability of coinciding with a high tide. Therefore, the development of a storm history database for each deepwater Waverider station provided the opportunity to generate storm wave height/duration curves. For the storm history database, the duration of a storm event is defined as the time in hours that Hsig exceeds 3 m. Updated storm wave height/duration curves for Byron Bay, Sydney and Eden, previously published in Lord and Kulmar (2000), are presented as Figure 4. The lower storm wave heights and associated return periods at Byron Bay may be explained by the lower data recovery achieved at this station. It is known that over the history of the Byron Bay record several severe storm events were not recorded due to equipment failure and buoy loss.

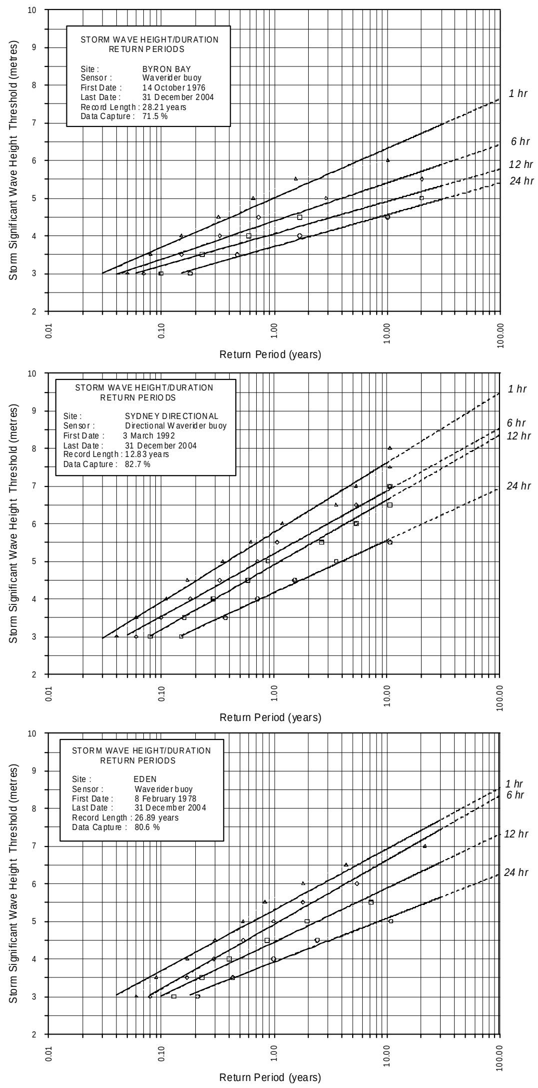

Figure 4 Storm Wave Height (Hsig) Duration and Return Periods for Byron Bay, Sydney and Eden to December 2004

3.5 Wave Direction

The NSW Waverider buoy network now includes three directional buoys. Since the first directional buoy was commissioned off Sydney in March 1992 the Byron Bay (October 1999) and Batemans Bay (February 2001) sites have been upgraded through the deployment of Directional Waverider buoys.

Results of the analysis of the Sydney directional database have been previously published in Kulmar (1995) and Lord and Kulmar (2000). Kulmar (1995) examined the first two years of Sydney directional data and compared the results with two long-term datasets based on daily observed and hindcast direction estimates and a coincident observed dataset. Kulmar's (1995) early analysis concluded that the buoy measurements differed from the then widely accepted observed and hindcast distributions. The buoy data displayed a significantly stronger bias, particularly during storms, from the SSE and south directions than was estimated from the observed and hindcast data sets. The difference between buoy measured directions and early observed data for Byron Bay was confirmed in Lord and Kulmar (2000) who concluded that observed wave directions significantly overestimated the NNE and NE occurrence while underestimating the SSE and south directions. The additional four years of Sydney and Byron Bay directional data have confirmed these preliminary results.

A summary of the directional distributions based on hourly directional records for the Byron Bay, Sydney and the more recently commissioned Batemans Bay directional buoy is provided in Table 4. These results suggest that directional distributions for the NSW north, central and south coast regions differ with significant variation in the occurrence of waves from the NNE, NE, SE and south. Longer record lengths at all stations will be required to improve confidence in these results.

Table 4 Wave Direction Occurrence for Directional Waverider Buoys to December 2004

Wave Direction	Byron Bay	Sydney	Batemans Bay
N	0.000	0.000	0.000
NNE	3.615	0.077	0.003
NE	2.414	3.130	2.223
ENE	4.659	8.930	9.095
E	11.941	11.090	11.794
ESE	13.633	10.118	10.630
SE	19.453	16.002	24.554
SSE	28.286	30.956	33.675
S	14.581	18.724	7.579
SSW	0.742	0.663	0.235
Avg Dir	130.0	134.9	130.6
Start Date	26-Oct-1999	03-Mar-1992	23-Feb-2001
Record (yrs)	5.19	12.84	3.85
No. Records	29,127	86,595	30,227
Capture (%)	64.3	82.7	89.5

An update of the more detailed Sydney wave height and direction distribution published in Lord and Kulmar (2000) is presented in Table 5.

Table 5 Sydney Wave Height Occurrence by Direction to December 2004

Start Date: 03-Mar-1992 **End Date:** 31-Dec-2004 **Record:** 12.84 years **No. Records:** 86,595 **Capture:** 82.7%

Hsig (metres)	Wave Direction (° True North)									TOTAL
	NNE	NE	ENE	EAST	ESE	SE	SSE	SOUTH	SSW	
0.00 → 0.99	0.02	0.43	1.27	1.71	1.87	3.20	5.75	1.96	0.08	16.48
1.00 → 1.99	0.06	2.34	6.44	7.53	6.39	9.74	18.20	9.91	0.41	61.13
2.00 → 2.99		0.35	1.08	1.46	1.52	2.35	5.27	5.03	0.13	17.19
3.00 → 3.99		0.01	0.11	0.29	0.24	0.51	1.29	1.39	0.04	3.89
4.00 → 4.99			0.03	0.08	0.08	0.15	0.31	0.33		0.98
5.00 → 5.99				0.02	0.02	0.05	0.10	0.09		0.27
6.00 → 6.99							0.02	0.01		0.04
7.00 → 7.99							0.01			0.01
TOTAL	0.08	3.13	8.93	11.09	10.12	16.00	30.96	18.73	0.66	100.00

4 Site Data Comparison

4.1 Preamble

There are two critical issues relevant to the continuation of the present level of offshore data collection along the NSW coast:

- whether the data adequately define the extreme events for design purposes; and
- whether the existing data are adequate to define the long-term wave climate at various locations along the coast.

Ultimately, the information of most interest for coastal management in NSW relates to the inshore wave conditions. At present inshore wave data are inferred by numerical transfer rather than through direct measurement. Some measurements of inshore wave conditions are available, however most inshore deployments are short-term for site specific projects and unfortunately do not find their way into the long-term database.

Given the current fiscal constraint, one future option may be to reduce the effort on deepwater wave data collection while increasing the collection of selected inshore data to improve and verify transfer coefficients. Such a change would require confidence in the accuracy of a reduced number of offshore stations to describe significant events on a state-wide basis. The accuracy of interpolating the wave conditions at one buoy location using the data from adjacent buoys was examined in MHL (2003) and Sanderson (2003). The results of these studies are discussed briefly in the following subsections.

4.2 Statistical Comparison

All available data for a common record length of over 16 years from three adjacent Waverider stations (Byron Bay, Coffs Harbour and Crowdy Head) was used in the study (MHL 2003). The distance between the Byron Bay and Coffs Harbour buoys is approximately 180 km and from Coffs Harbour to the Crowdy Head buoy is 170 km. The three datasets were analysed to generate a direct statistical comparison by computing the average, standard deviation, maximum and minimum values for a range of wave parameters. Exceedance and occurrence analyses were also undertaken and more rigorous coincident difference distributions between each site combination for several wave parameters were generated.

The statistical comparison found that the three long-term data sets agreed favourably. However, the coincident difference analysis showed that there is often a significant difference in wave data recorded simultaneously at Byron Bay, Coffs Harbour and Crowdy Head. As expected, considerably more variation in data was displayed between Byron Bay and Crowdy Head than between the adjacent Byron Bay–Coffs Harbour and Coffs Harbour–Crowdy Head comparisons.

4.3 Covariance and Lagged Correlations

To explore the relationship between the Byron Bay, Coffs Harbour and Crowdy Head stations in more detail and to develop a suitable methodology for further comparison studies, covariance and lagged correlations during three storm events were examined by Sanderson (2003). The main findings of this study were:

- averaging over the duration of a storm Hsig varied smoothly along the Waverider buoy network suggesting it is possible to interpolate between Waverider sites
- improvements in cross-correlations going from separation scales of 180 km to 360 km are minor
- probability density functions of wave height and period may or may not vary along the NSW coast. This issue should be determined definitively before making decisions about whether to reduce or increase the spatial resolution of offshore Waverider buoy measurements
- it remains to be seen whether or not measurements of wave direction will enable better translation of wave field measurements from one Waverider buoy site to the next
- the analysis of the three storms undertaken to date needs to be repeated for a range of wave conditions in order to assess all the implications of reducing the spatial resolution of the NSW offshore Waverider buoy network.

5 Future Directions

The results of the Waverider site comparison studies documented in MHL (2003) and Sanderson (2003) clearly indicate that more comprehensive research is required before a decision to reduce the existing effort on deepwater wave data collection can be reached. Such a study will require the application of the methodology developed by Sanderson (2003) over a range of wave conditions over the entire spatial range of the Waverider buoy network since hourly data records were introduced in 1984.

Results of Sanderson's (2003) storm event analysis suggest the measurement of wave direction will enable better translation of wave field measurement from one Waverider buoy site to another. However, at present Sydney is the only Waverider buoy station with what would be considered a long-term measured wave direction dataset (greater than 10 years). Whilst directional buoys have been deployed at Byron Bay (5 years) and Batemans Bay (4 years) these datasets do not span a sufficient period to describe the directional wave climate at both locations. Therefore, further study on both the importance of wave direction measurement and at what locations along the NSW coast is required. Such research, for example, may conclude that an upgrade of one or two existing non-directional stations to directional buoys (while removing the remaining non-directional buoys) is warranted to better describe the directional wave climate along the NSW coast.

The use of alternative technology such as remote sensing and numerical wave models to augment the existing Waverider buoy network is also worthy of consideration in any rationalisation of NSW wave data collection. Data from such sources may be incorporated in the existing wave database to 'patch' data missing due to Waverider system downtime and provide supplementary information at inshore locations of interest.

It is important that the impact on users of the existing wave data, particularly those with near real-time access, is considered before any change in direction on wave data collection in NSW is implemented. Therefore, further research on a range of issues is required before the effort on deepwater wave measurement can be confidently redirected to selected inshore locations.

6 Benefits of Wave Data Collection

The NSW deepwater Waverider buoy network has collected over 160 station years of wave data since the first station was established in 1974. As such, it represents one of the world's most comprehensive wave data sets. The MHL wave database is a valuable asset of the NSW Government. Over the years the data has been extensively used in coastal investigations, design and management. More recently near real-time data is available to the community via the internet and is utilised by the Bureau of Meteorology and SES in coastal water forecasts and storm warnings. In the future the database will provide baseline data to monitor possible changes in the NSW wave climate due to future climatic change.

7 Acknowledgements

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