APPENDIX D

Physical Oceanography

Sydney Harbour Oceanographic Summary

This section presents the results of a desktop study of local physical oceanographic conditions, based on analyses of existing data. The area of interest includes the whole Harbour, with particular emphasis on the Seaward and South Arms where channel dredging and the construction of the terminal are proposed.

1. Oceanographic Overview

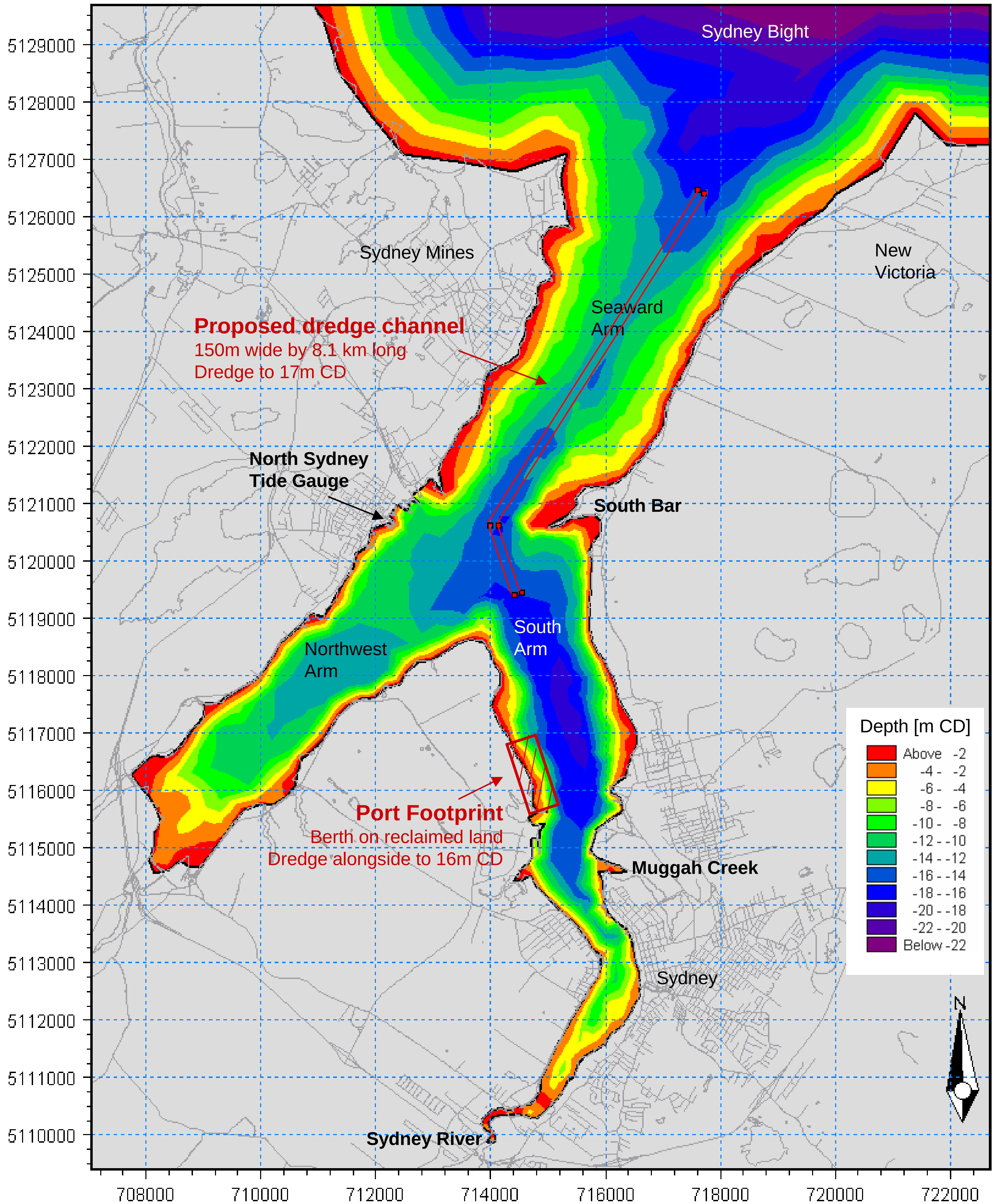
Sydney Harbour is located on the Northeastern Shore of Cape Breton Island and opens onto Sydney Bight, the large body of ocean water east of the Scotian Shelf at the entrance of the Cabot Strait leading into the Gulf of Saint Lawrence. The Harbour's present Y-shape results from the post ice-age drowning of two river valleys, now the 10km-long South Arm and the Northwest Arm joining into the Seaward Arm leading to Sydney Bight. The key oceanographic attributes of the Harbour are its relatively modest freshwater inputs and associated mean estuarine circulation, moderate tidal range, and the presence of a long-period standing wave (or 'seiche') which, when excited by meteorological or large-scale ocean disturbances, generates water level and current oscillations at times larger than tides.

Data sources

Numerous oceanographic studies have been conducted in Sydney Harbour, including, but not limited to, Lane (1988), ASA (1994), Petrie (2001) and Lee (2002). Data and oceanographic interpretations generated for these studies provide a good basis for the present analyses. The Lane study included bottom current meter moorings and concurrent hydrographic observations from August to October 1987 and in January 1988. ASA measured currents and associated hydrography off Muggah Creek in the South Arm in August 1992 and August 1993. As part of the pre-Sydney Tar Ponds Cleanup investigations focussing on the Muggah Creek area, additional analyses of the data were carried out in a comprehensive review of the physical oceanography of Sydney Harbour by DFO scientists (Petrie et al 2001) who also conducted modelling of sediment re-suspension off Muggah Creek. Concurrent to the 2001 study, additional current observations off Muggah Creek in the south Arm were collected by DFO in 2000-2001, and results are presented in the physical oceanographic component of the Toxic Substance Research Initiative (TSRI)-funded study of the Harbour for the Tar Ponds Cleanup (Lee, 2002). References to additional, more specific data sources are included in the following sections.

2. Bathymetry

The bathymetry map shown on Figure 1 is based on navigation chart # 4266 from the Canadian Hydrographic Service (CHS), complemented by 2008 data from a high-resolution bathymetric survey of the proposed dredge channel area. The sill across the Seaward Arm of the harbour has minimum depths in the order of 12 m Chart Datum (CD). The channel deepens again into the South Arm, with depths up to 18 m CD off the proposed container terminal wharf.



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	Base Map and Bathymetry of Sydney Harbour	**Fig. 1**

3. Hydrography and Freshwater Inflows

The density of seawater is determined by its salinity and temperature, the former having the most influence. Temperature and salinity measurements in past studies focus on the South Arm, particularly the area off Muggah Creek. The data shows that the strongest vertical density stratification in the South Arm is encountered between Sydney River and the mouth of Muggah Creek. In this area, less dense (fresher and/or warmer) water overlays layers of denser (saltier and/or colder) water, causing layered currents and affecting the exchange of water between the inlet and the ocean. In the northern half of the South Arm and in the Seaward Arm, the water column is generally well mixed. Overall, hydrographic measurements are generally consistent with that of an estuary where the tidal volume is much greater than the freshwater inflows, causing density stratification to be significant near the head of the inlets (South Arm and Northwest Arm).

There are three major watercourses discharging into Sydney Harbour. Sydney River and Muggah Creek flow into the South Arm, Balls Creek and Leitches Creek flow into the Northwest Arm. There are no long-term flow records for any of these rivers. However, flows can be estimated from measurements at nearby Salmon River (Environment Canada station ID 01FJ001 – watershed area 199 km^2) spanning years 1965 to 1995. The monthly and yearly averages are presented in Table 1. It is estimated that over a tidal cycle, the tidal volume is 104 times the freshwater volume into the harbour, which indicates that the influence of river flows on harbour circulation greatly decreases away from the discharge point and tides, ocean- and meteorologically-driven process would generally prevail.

Table 1 Estimated freshwater inflows into Sydney Harbour –
Source: DFO Classification of Maritime Inlets (Gregory et al 1993)

	Northwest Arm	**Sydney River**	**Muggah Creek**
Watershed area, km^2	151	244	25
Estimated average flows, m3/s			
January	6.8	10.9	1.2
February	5.3	8.5	1.0
March	7.5	12.0	1.4
April	11.7	18.8	2.1
May	7.2	11.6	1.3
June	3.9	6.3	0.7
July	2.6	4.2	0.5
August	2.7	4.4	0.5
September	3.3	5.3	0.6
October	6	9.6	1.1
November	9.5	15.2	1.7
December	9.2	15.2	1.7
Yearly average	*6.3*	*10.2*	*1.2*

4. Water Levels

Water levels in Sydney Harbour are being recorded by a tide gauge in North Sydney, at the site shown on Figure 1. The available digital data starts in 1970. The major components of the total water level are astronomical tide, storm surge, seiche and mean sea level as described in the following paragraphs.

4.1 Astronomical Tide

The local astronomical tide is mixed, mainly semi-diurnal (two high waters and two low waters occurring twice per lunar day), but the diurnal component causes unequal heights. Up-to-date tidal datums and elevations in North Sydney are shown in Table 2.

Table 2 Tidal heights, extremes and mean water level in North Sydney –
Source: 2008 Canadian Tide and Current Tables

	Elevation [metres] relative to	
	Chart Datum	Geodetic Datum
Recorded extreme high water	2.3	1.9
HHWLT	1.5	1.1
HHWMT	1.3	0.9
Mean water level	0.7	0.3
Geodetic datum	0.4	0
LLWMT	0.3	-0.1
LLWLT	0.1	-0.3
Chart datum	0	-0.4
Recorded extreme low water	-0.3	-0.7

4.2. Storm Surge –

Storm surge is due to meteorological effects on sea level, such as wind set-up and low atmospheric pressure, and can be generally defined as the difference between the observed water level during a storm and the predicted astronomical tide (the so-called 'residual' water level). A typical one-year return residual value at North Sydney is between 0.7 and 0.8m (Parkes et al., 1997). Results from more recent analyses of the North Sydney tide gauge data by Bernier and Thompson (2006)[1] indicate that the 100-year return total sea level is about 2.4m CD for a positive storm surge. For this project negative storm surges have to be considered as well because of possible marginal depths with respect to shipping. The 100-year return negative total sea level is about -0.5m below CD. However the potentially adverse impacts of negative storm surges on navigation are expected to decrease with sea level rise (section 4.4). Finally, in Sydney Harbour, the residual during a storm is increased by the effect of a local long-period harbour oscillation called seiche described in the next paragraph.

4.3. Seiche

A seiche is a standing wave caused by a resonance in the harbour that has been disturbed by meteorological effects and/or external large-scale coastal circulation. Analyses of the tide gauge data in the frequency domain indicate that the first resonant mode for the seiche has a period between 120 and 150 minutes. The amplitude of the oscillations as recorded at North Sydney is typically a few centimetres up to near 0.5 m. As an illustration, Figure 2 shows a sample of the tide gauge data during a recent winter storm in December 2007. At the peak of the storm, the recorded water level was 0.8 m above the predicted astronomical tide due to the storm surge and the

[1] Results available on Environment Canada's atmospheric hazards website http://atlantic.hazards.ca

seiche oscillations, which were triggered as the wind speed abruptly increased. The seiche dissipated as the wind died down, to a point where the recorded water level matched the astronomical tide 2 days after the peak of the storm.

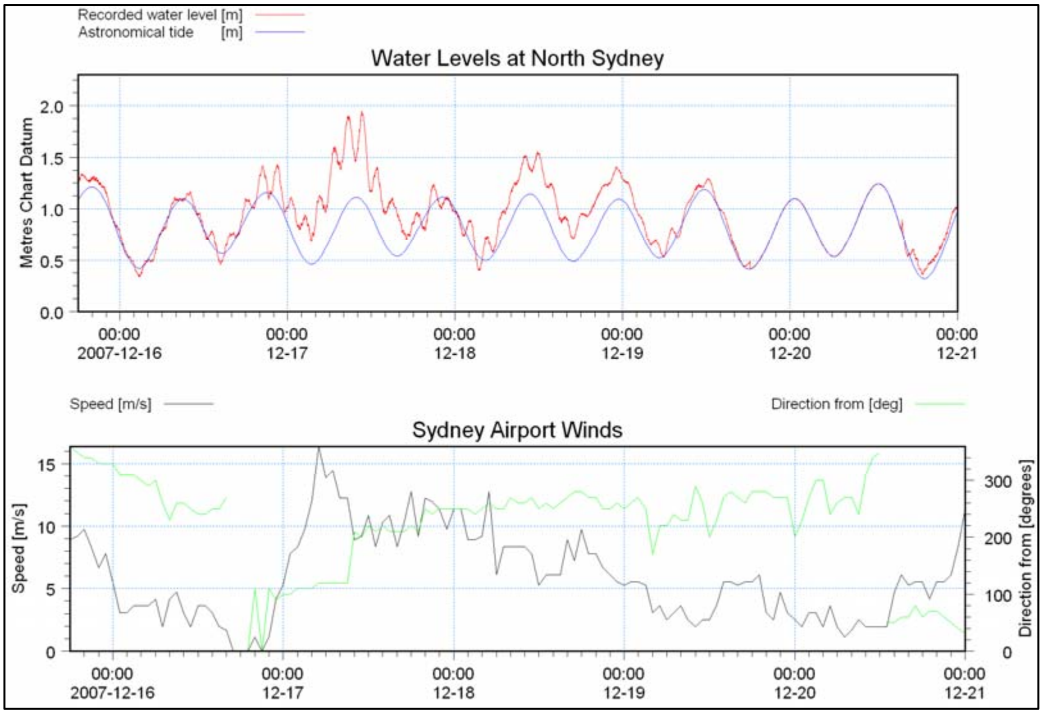


Figure 2 Sample Time Series of Water Levels at North Sydney in December 2007

4.4. Mean Sea Level Rise

<u>Present</u> - The complete time-series of water level observations at North Sydney from 1970 to July 2008 were analysed and show an upward trend in relative mean sea level of about 2.9 mm/year. This value is close to the 3.2 mm/year trend observed in Charlottetown. The relative sea level rise is made of the sum of global and regional sea level rise, plus a contribution -perhaps 0.2 m/century- from crustal subsidence following post-glacial adjustments to changing ice and water loads (McCulloch et al, 2002).

<u>Projections</u> - In their latest fourth assessment report, the Intergovernmental Panel on climate Change (IPCC, 2007) estimate that global sea levels will rise between 0.18 m and 0.59 m by 2099. These estimates exclude local crustal subsidence effects and possible rapid dynamical changes in ice flow, i.e. accelerated melting of polar ice caps. In their assessment of sea level rise impacts on PEI, MacCulloch et al (2002) adopted a total projection of 0.7m relative sea level rise to 2100 in the Charlottetown region (0.5m for global sea level rise plus 0.2 m for crustal subsidence), with an uncertainty of ±0.4 m. It is reasonable to adopt the same value for Sydney, as trends in crustal subsidence and relative sea level rise are relatively similar between the two sites (Peltier 2002).

5. Currents

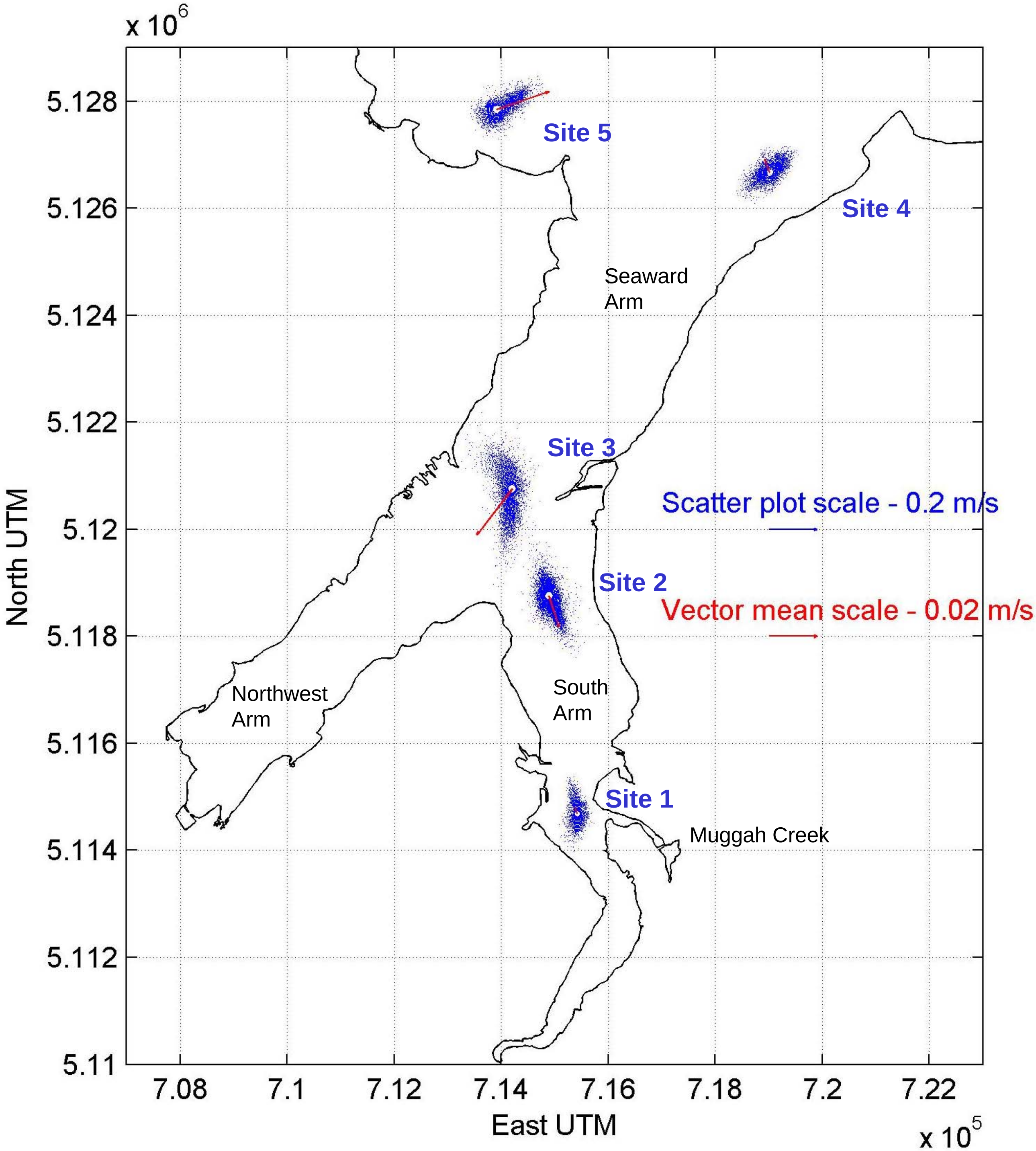
Sydney Harbour is a tidal estuary, in which the density difference between fresh and saline water generally causes a mean seaward surface flow and a mean up-harbour bottom flow that add to the stronger tidal and seiche currents. Currents throughout the harbour are generally weak (in the order of 0.2 m/s or less, decreasing towards the head of the South and Northwest Arms) but increase when winds or large scale oceanic events disrupt or even reverse the mean patterns.

5.1. Bottom Current Sites

Current meter records were obtained from DFO's Ocean Data Inventory. Bottom current meter sites are shown on Figure 3, along with scatter plots of the data and the mean bottom current speed and direction. Within the observation sites, the strongest bottom currents occur in the centre of the harbour off the South Bar in the Seaward Arm (site 3) with typical velocities of 0.2 m/s recorded in the fall of 1987. Then, going up-harbour along the South Arm, the currents become weaker as the tidal prism decreases, with typical velocities of 0.1m/s off Muggah Creek. The mean current along the bottom is up-harbour, with a speed of less than 2 cm/s. Analyses in the frequency domain reveal that there are 3 major components to the currents:

- Low frequency component that includes wind, low frequency sea level variations, and large scale coastal circulation including upwelling (surface water is pushed offshore while bottom water rises against the shore) and down-welling (surface waters are pushed against the shore, forcing bottom waters offshore), which would impact local currents because the harbour depths are well below the thermocline along the coast;
- Semi diurnal tides of period 12.42 hours, which correspond to the principal lunar constituent M2;
- Seiche component of period 1.8 to 2.5 hours.

The relative strength of each component varies spatially. At site 3, the up-harbour tidal prism represented by the Northwest and South Arms causes the tidal component to be the strongest component, while it is much weaker at sites further up the South Arm. The seiche is relatively strong for all sites inside the harbour, but hardly detectable at site 5 outside the harbour. The low frequency component is relatively strong at all sites. Both the seiche and low-frequency currents can at times exceed the tides in the Harbour, as shown on Figure 4 in a time-series plot of data from 1987 at site 3 off South Bar. Higher winds during the first 2 days cause seiche oscillations, combined with a mean up-harbour flow possibly due to the increased freshwater discharge. In contrast, weak winds and reduced river flows during the last 2 days allow the tidal component of the current to prevail.



Site	Dates		Days	Instrument depth, m	Source
	start	end			
1	04/08/1992	02/09/1992	29	10	ASA 1994
2	12/01/1988	27/04/1988	106	13	Lane 1988
3	24/08/1987	31/10/1987	68	13	Lane 1989
4	04/08/1992	02/09/1992	29	9.5	ASA 1994
5	04/08/1992	02/09/1992	29	9	ASA 1994

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Scatter Plots of Existing Bottom Current Datasets

Fig. 3

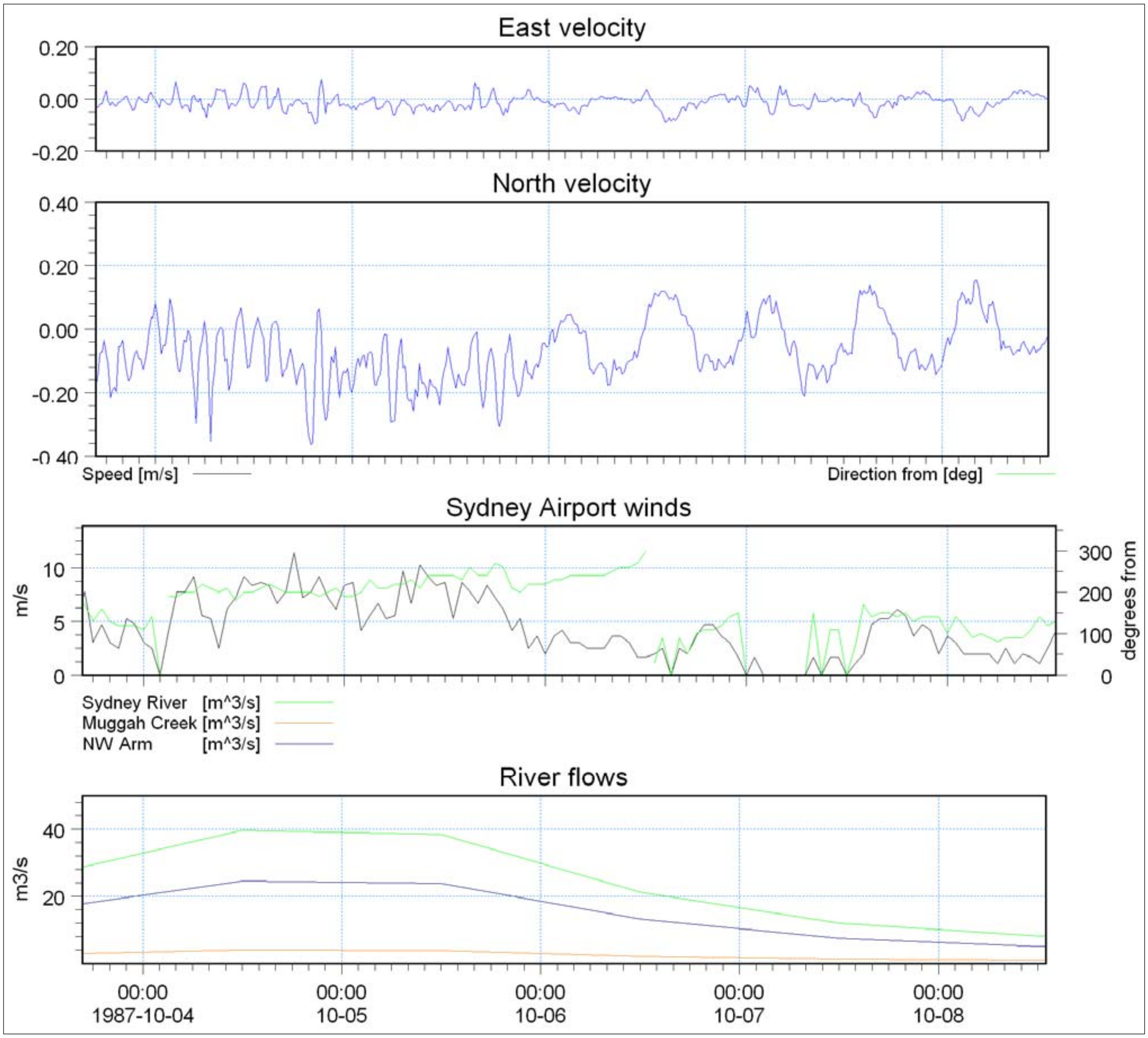


Figure 4 Time-series of bottom currents off South Bar with concurrent wind and estimated freshwater inflows - Source: Lane 1988

5.2. Vertical Structure in the South Arm

Mean currents derived from Acoustic Doppler Current Profiler (ADCP) records off Muggah Creek are consistent with an estuarine-like circulation pattern. The ASA 1993 data shows a seaward mean surface current of 6 cm/s between 0 to 2 m deep. The mean current between 3 and 15m deep is up-harbour with a magnitude range of 0.5 to 2.5 cm/s. It is noted that on several occasions the pattern was reversed. Data from the winter of 2000-2001 collected by DFO shows the instantaneous currents are no stronger than 1993 summer observations by ASA (Lee et al 2002). As for the residual currents, a mean seaward surface value of 0.6 cm/s was observed, and the mean current in the remainder of the water column was up-harbour with a magnitude of 0.5 to 1.5 cm/s. These winter mean values are weaker than during the summer of 1993, likely because of the much reduced freshwater inflows during the winter.

6. Winds

Winds have a large influence on the local current regime, because they excite the seiche and/or cause low frequency water exchange through up- or down-welling. In the winter the influence of winds on the Harbour is at times reduced because of the ice cover. The closest and most comprehensive wind dataset in the area is from Sydney Airport, located approximately 6 km inland from the Atlantic Ocean, and 12 km from the South Arm. The available hourly dataset, recorded at 10m above ground, spans the period 1953 to 2008.

6.1. Directional Statistics

A wind rose representing annual directional statistics is presented in Figure 5 (upper panel). Throughout the year, the most probable wind direction is Southwest, while the strongest wind speeds are distributed over all directions. Monthly wind roses are shown on Figure 6. Southwest winds typically prevail during the summer, while winter months exhibit peaks predominantly from the West between November and January, and also with significant Northerly occurrences in late winter and spring.

6.2. Extreme Values

Return periods for extreme wind speed (5, 10, 50, 100-year) were estimated based on extreme value analyses of the 55 annual maxima in the Sydney Airport data. The final estimates were obtained from the best fitting of two statistical distributions commonly used in such analyses (Weibull and Fisher-Tippett Type 1). Results are presented on Table 3, including directional extremes computed from the subset of annual maxima for each particular direction quadrant. .The N-year return value represents the value that is exceeded on average once every N years.

Table 3 Extreme Return Values for Hourly Average Wind Speed [m/s] at Sydney Airport

Return period, years	Direction				
	All	N	E	S	W
5	22.9	20.5	19.8	21.7	20.1
10	24.4	21.9	21.6	23.5	21.4
50	27.5	24.5	25.4	26.8	24.4
100	28.6	25.4	27.0	28.1	25.7

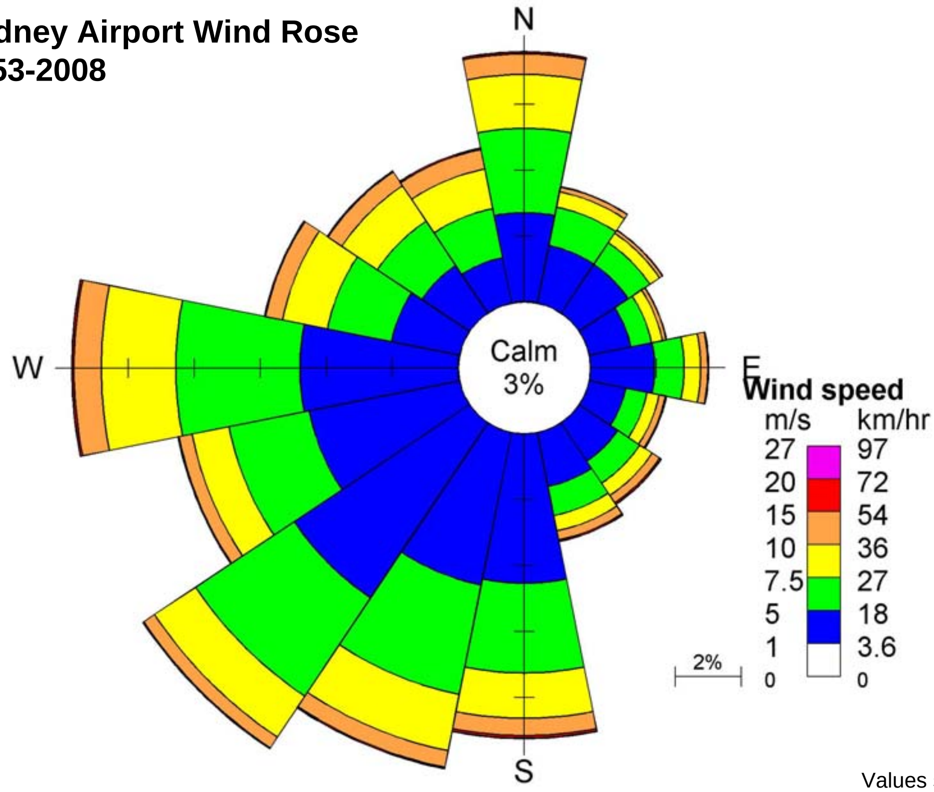
Temporal Variability

Extreme gusts of duration shorter than one hour will exceed the hourly values given in Table 2.3. Environment Canada's online monthly climate statistics (1971 to 2000) at Sydney Airport show maximum instantaneous peak wind observed from the anemometer dials up to 1.66 times the hourly maximum speed. Hourly-to-gust extreme wind speed conversion factors are provided in the Coastal Engineering Manual (USACE 2002) based on the following formula: $WS_t / WS_{hourly} = 1.277 + 0.296 \tanh (0.9 \log_{10} (45/t))$, with t = gust duration in seconds. For example, to convert from hourly speed to 1-second, 30-second and 1-minute gust speed, the factors are 1.54, 1.32 and 1.24 respectively.

Overland vs. Overwater Considerations

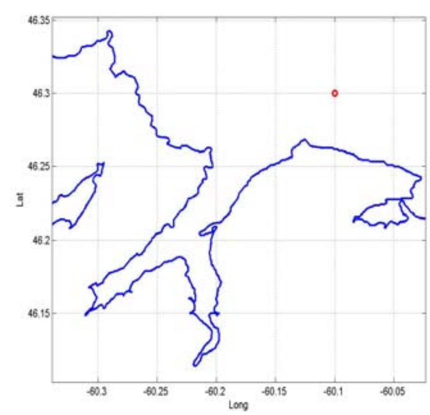
It is cautioned that the overland wind speed at Sydney Airport may be less than over the Harbour which opposes less drag resistance. For use in wave or current models, it is generally recommended to increase the overland wind speed by a factor of 1.2 to better represent overwater wind speeds for fetch distances less than 16km (USACE Coastal Engineering Manual EM II-2-1).

Sydney Airport Wind Rose 1953-2008

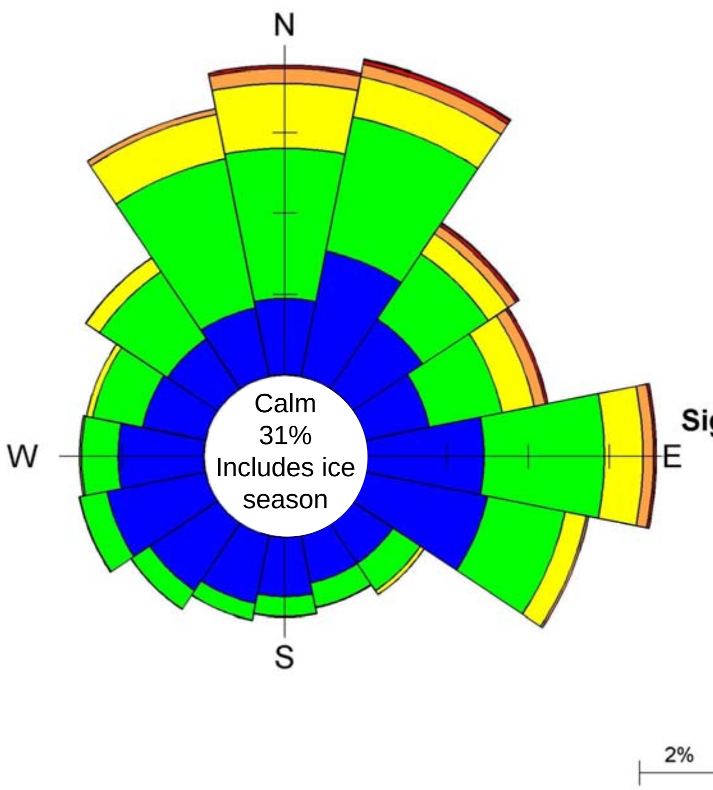


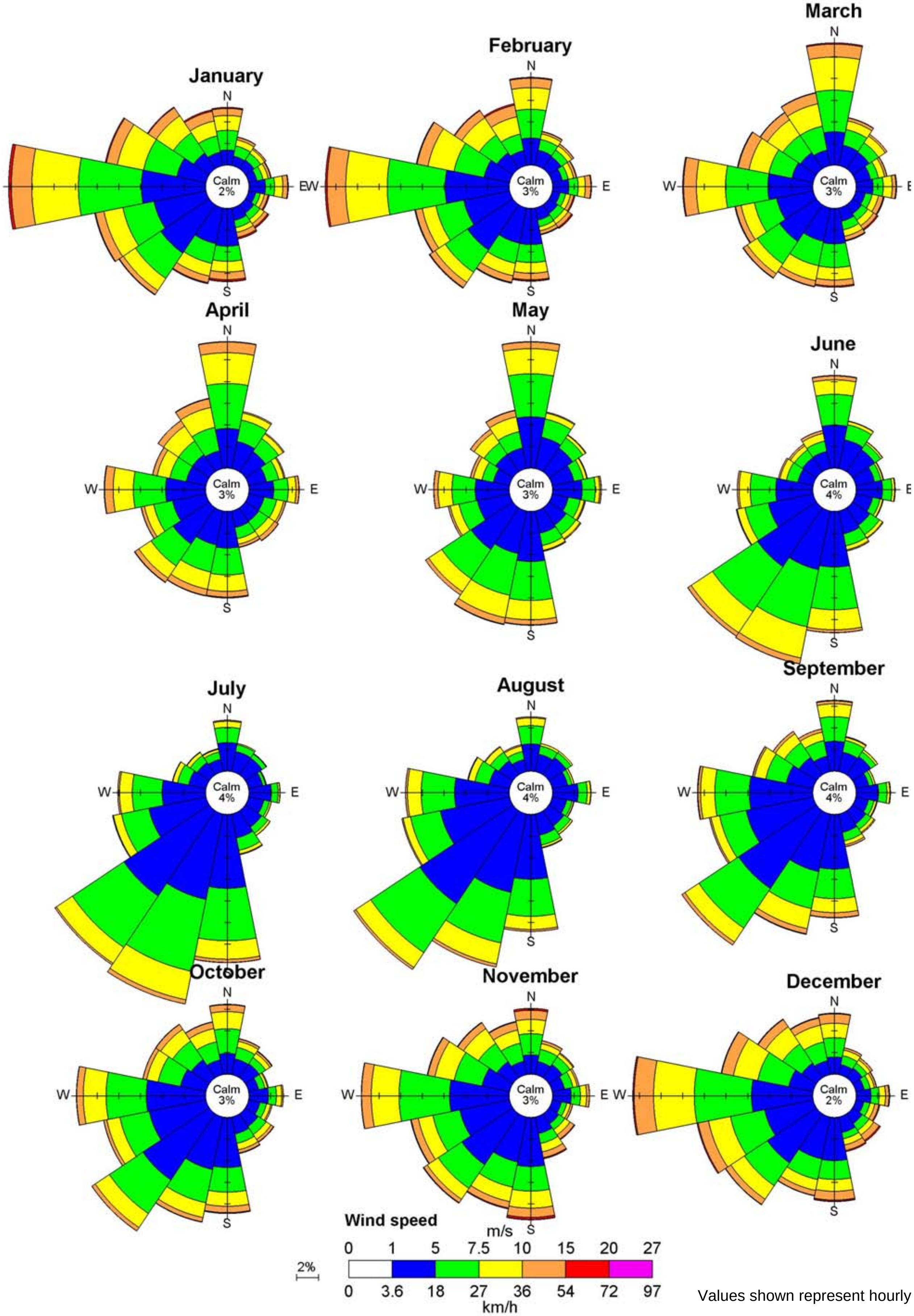
Values shown represent hourly averages.

Offshore Wave Climate



Data source:
'MSC50' hindcast
Gridpoint 10138
46.3N-60.1W
Depth=23.8m
Period: 1/1/1954
to 12/31/2005





Values shown represent hourly averages.

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	Monthly Wind Statistics From Sydney Airport 1953-2008	**Fig. 6**

7. Waves

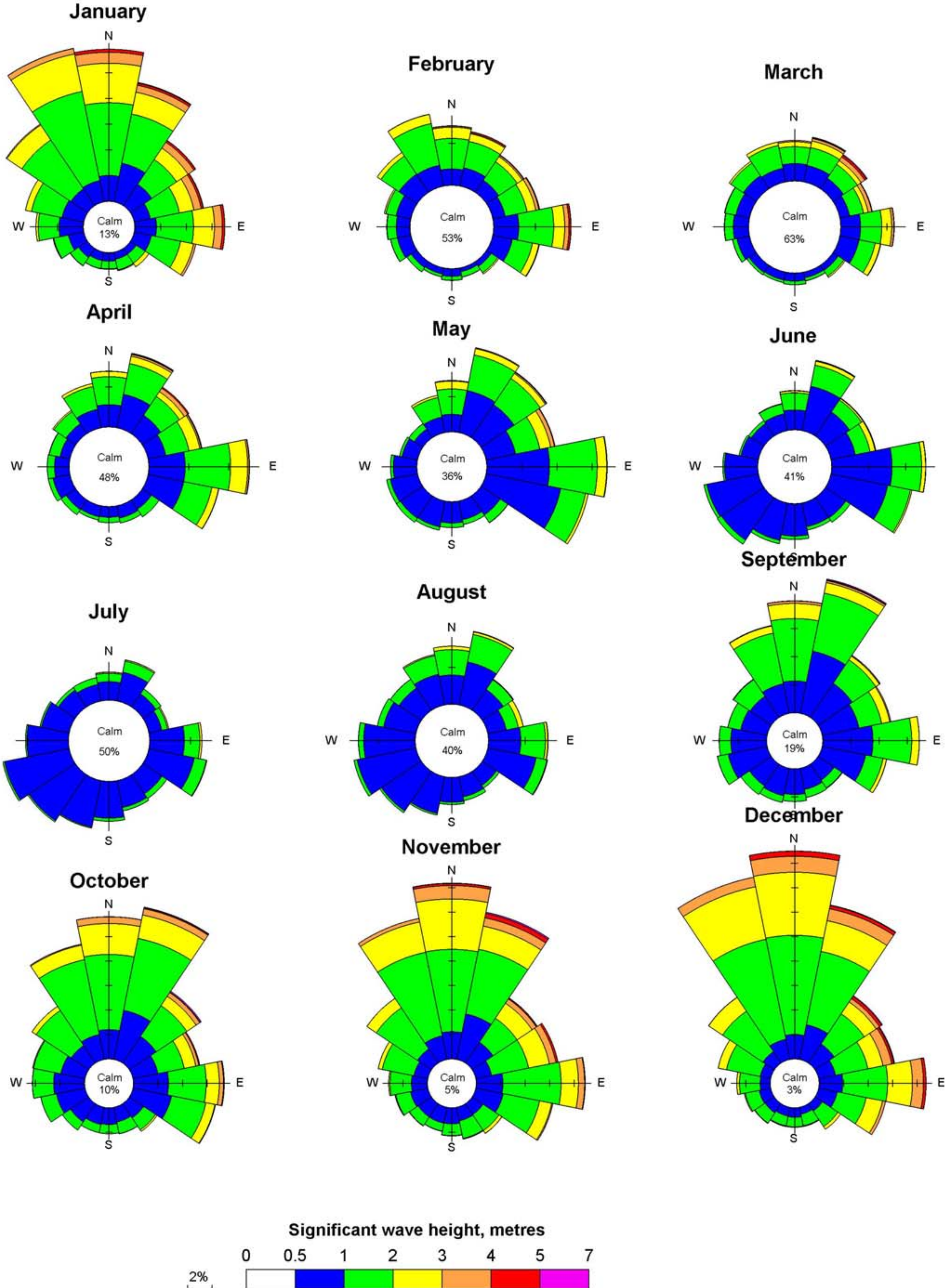
7.1. Data Source

Offshore wave data is available from a recent 50-year wind and wave hindcast referred to as 'MSC50'. The MSC50 hindcast was developed by Oceanweather Inc. and is distributed by Environment Canada (Swail et al., 2006). This dataset spans the period January 1954 to December 2005, and contains hourly time series of wind (speed, direction) and wave (height, period, direction) for the location 46.3N - 61.0W, which is about 5 km Northeast of the harbour mouth. The dataset is a state-of-the art hindcast, i.e., data computed from all existing wind and wave measurements that were re-analysed and input to a 0.1-degree resolution ocean wave growth model that includes the effect of depth and ice cover. Historical ice cover durations in MSC50 were built from high-resolution ice concentration datasets that span the period 1962 to 2005 and supplied to Oceanweather Inc. by the Canadian Ice Service (CIS) branch of Environment Canada. In MSC50, wave heights are set to zero when the local ice cover concentration is over 50%, and the ice edge was allowed to change on a weekly basis. For the present assessment, the MSC50 data were complemented with 2006 and 2007 data acquired from the CIS's online archive.

7.2. Directional Statistics

Yearly directional statistics on significant wave heights[2] on are presented on Figure 5 (lower panel). Due to the situation of Harbour on the Northeastern shore of Cape Breton and the presence of the Cape Breton Highlands land mass to the West, all waves of significant height greater than 2m off Sydney Harbour are from the Northeast quadrant over which they are about equally distributed. Waves under 2m predominantly come from the North. Waves are under 0.5m for 31% of the year, which includes the ice season. The monthly wave statistics are presented in Figure 7. The ice season typically starts into the month of February and ends early April. It is reflected in the statistics for these months, with a low probability of occurrence for any wave height but a high chance of strong waves under unusual open water conditions. In the summer, waves off Sydney Harbour are generally small (Hsig under 1m), because the winds blow predominantly from the land. The strongest wave climate occurs in December and January, when the direction is strongly biased towards the North.

[2] The significant wave height (Hsig) is the common parameter for characterizing the energy in a wave field. Hsig represents the average of the third highest waves over a given time period, and is a good approximation of the 'typical' wave height that would be reported from visual observations. The commonly used wave period parameter is the peak period (Tp) which represents the period of maximum energy in a wave spectrum (i.e., wave energy as a function of frequency band).



Note: calm includes ice season.

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	Monthly Offshore Wave Statistics Source: MSC50 hindcast at 46.3N-60.1W	**Fig. 7**

7.3. Trends

Annual maximum significant wave heights in MSC50 reveal an upward trend of about 0.016 m/year (Figure 8). The data also shows an upward trend in storm frequency, the percentage of significant wave heights over 3 m increasing from less than 1% in the 1950s to nearly 3% (10 days per year) in the mid 2000s. The reasons for the trend are not clear, and could include a combination of climate change, reduction in winter ice cover and cyclical behaviour in storm patterns. The trend cannot not be directly related to a decline in ice cover (even if it is a contributing factor), because many annual wave height maxima from MSC50 occured between September and early January, i.e. before the ice season which typically happens between the end of January and early April.

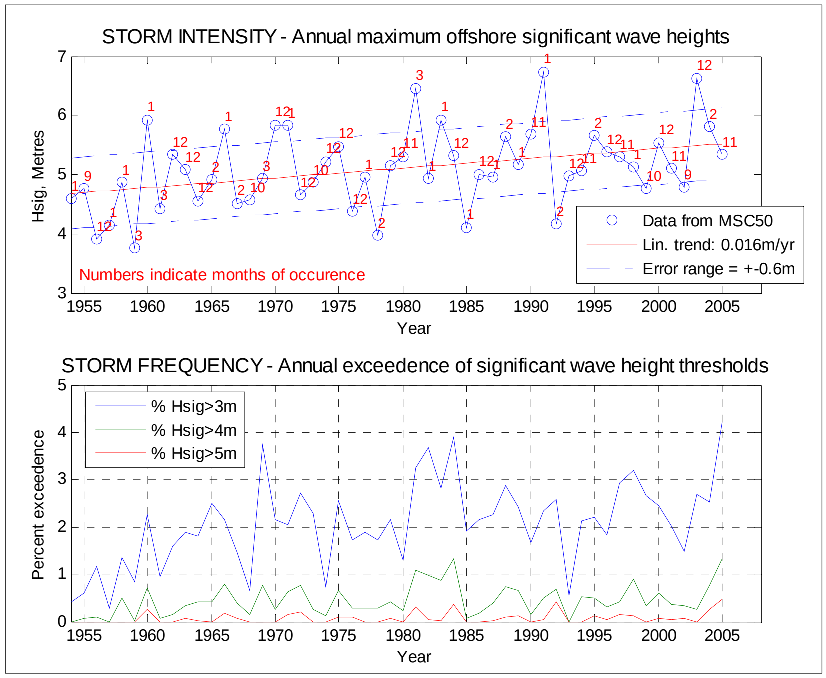

Figure 8 Trends in annual maximum wave heights from MSC50

7.4. Extreme Values

The procedure of extreme value analyses is based on the assumption that the process under investigation is stationary, which is not what trends in the data suggest. As a subjective, conservative correction measure, the population of 52 annual maxima from MSC50 was de-trended to 2008 levels and the extreme value analyses were conducted on the de-trended dataset. The Weibull distribution provided the best correlation to the annual maxima, and was used to derive extreme return values. A most probable peak period was associated to extreme wave heights based on the Hsig-Tp distribution from MSC50. The results are presented in Table 4. It is emphasized that due to the increase in storm frequency and intensity, the statistical N-year return wave height may be greater in the future than its 2008 value.

Table 4 Extreme Return Values for Offshore Significant Wave Heights and Associated Peak Period

Return period, years	Hsig, m	Tp, sec
1	4.8	10.5
5	6.1	10.8
10	6.5	11
50	7.0	11.3
100	7.3	11.5

Note: the 1-year return value cannot be derived using annual maxima. It was estimated separately from a Weibull distribution fitted to a selection of 57 de-trended peaks over 4.7m (the method is referred to as ‘Peak-Over-Threshold’).

7.5. At-Site Modelling

The wave climate inside the Harbour was further investigated using the phase-average spectral wave model SWAN - 'Simulating WAves Nearshore' (Booij et al, 1999, Delft University of Technology, 2006). SWAN is a finite-difference model based on the wave action balance. It is particularly suited for near-shore wave transformations and harbour investigations. Known wave spectra at the boundary are transformed within the bathymetric domain (refraction, shoaling and breaking) as the waves propagate into the Harbour. The model also accounts for local wind-wave growth, and includes the following physics:

- Wave propagation, shoaling, refraction, breaking;
- Wave generation by wind;
- Diffraction around obstacles;
- Dissipation (white-capping, bottom friction and depth-induced breaking);
- Wave-induced set-up; and
- Non-linear wave-wave interactions.

The model was run over a 75m-resolution grid of the harbour. A simulation was performed using the 1-year return offshore wave height and period conditions at high tide (4.8m Hsig – 10.5s Tp), using an associated northerly wind speed of 22m/s. Results are presented in Figure 9. The model predicts significant attenuation at the site. Most of the long-period swell energy refracts and dissipates through breaking along the Seaward Arm's shore. The remainder of the wave energy in the South Arm is primarily wind-generated. The total energy at the proposed terminal site results in a significant wave height of about 1.4m, with a peak period of about 4 seconds. For engineering design purposes, the model was run for using 94 sets of input conditions covering the whole range of potential offshore waves, winds and water level conditions. The outputs at the berth site were used to construct an interpolation table to 'transfer' the wind and offshore statistics to the site, which include the effects of varying wave periods (CBCL Limited 2009).

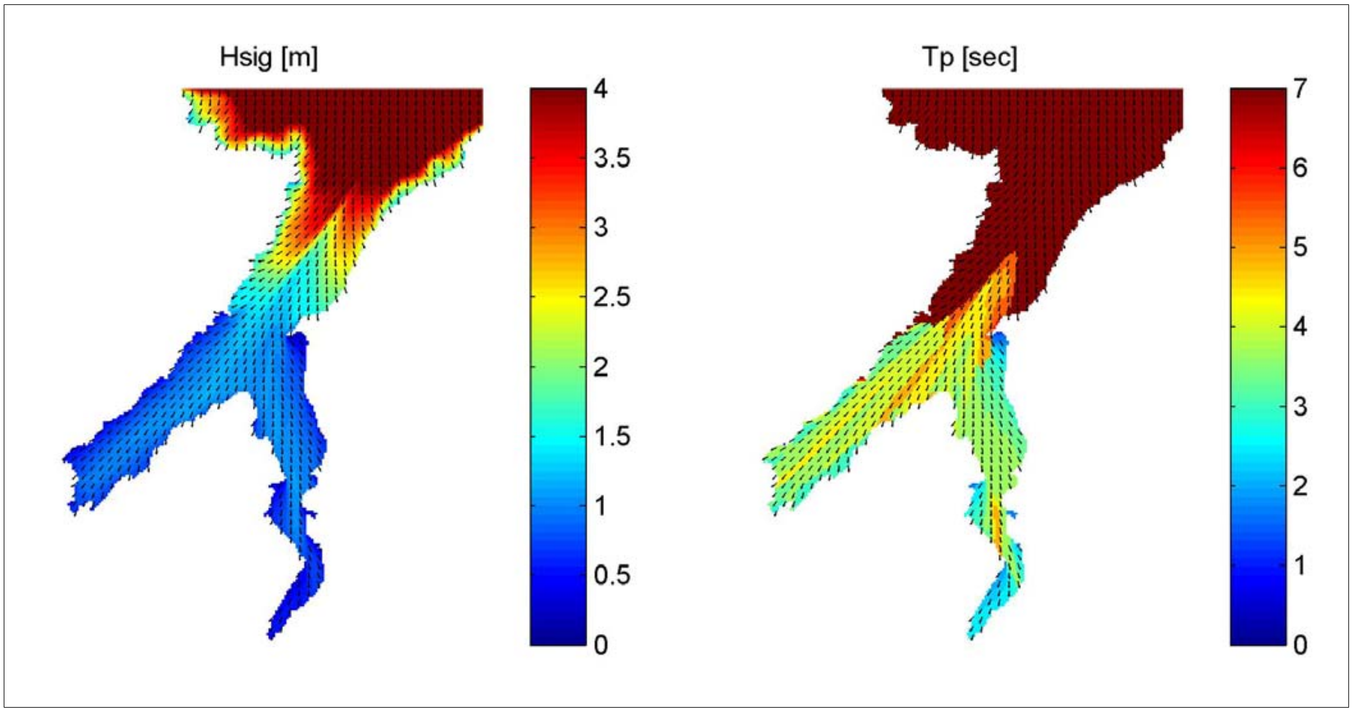

Figure 9 Sample wave model results for the 1-year return offshore wave height, wave period and wind period conditions.

8. Ice Cover duration

Results from climate models indicate that by the year 2045, the Gulf of Saint Lawrence may be free of ice (McCulloch 2002). This is consistent with the downward trend in ice cover in the MSC50 dataset off Sydney, the average duration dropping from 9 weeks in the 1960s to 4 weeks in 2007. The gradual loss of ice cover exposes larger open water areas more frequently to winter winds, which may lead to an increase in the intensity and frequency of wave events.

9. Sediments

9.1. Surficial Sediment Types and Moisture Contents

Recent data were collected at 15 sites along the proposed dredge channel and in the South Arm in January 2008. Both the presence of fines (silt and clay) and the moisture contents decrease seaward as the marine environment becomes more energetic. Surficial sediments in the South Arm exhibit the highest contents of fines, with total sit and clay contents over 80% for the southern-most sites. Sand prevails in the Seaward Arm North of the South Bar. These results are consistent with numerous earlier studies, including Stewart at al (2001) and Lee et al (2002).

9.2. Background Suspended Sediment Concentrations

Suspended sediment (SS) samples were collected by ASA at 8 sites throughout the South Arm and at current meter sites 4 and 5 off New Victoria and Sydney Mines on several occasions in August and December 1992 (Figure 10). All SS concentrations at the top and bottom of the water column were below 10 mg/l, except for two isolated occurrences at the bottom where the sampling mechanism may have stirred up bottom material. The values are typical for lower-energy coastal waters with limited river inputs[3].

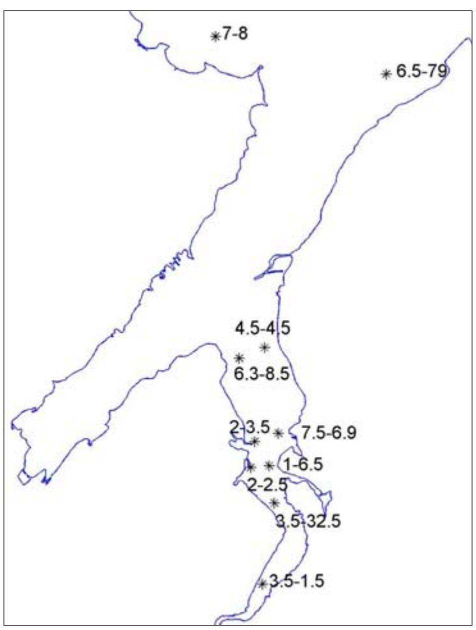

Figure 10 Background maximum suspended sediment concentrations (top-bottom, in mg/l) as measured by ASA (1994).

[3] In contrast, in high-energy estuaries with very active sediment transport such as Saint John Harbour on the Bay of Fundy, SS concentrations are typically in the order of 10 mg/l at the surface to between 50 and 100 mg/l near the bottom

9.3. Sediment Transport

Sediment transport in a coastal inlet results from the combination of two elements: sediment sources and hydraulic energy to disperse it. In Sydney Harbour, both elements are relatively weak. The most important sources include the bluffs along the Seaward Arm and the rivers. Waves gradually erode the exposed bluffs on a storm-by-storm basis, dumping the eroded sediment as their breaking heights decrease along beaches such as South Bar. The South and Northwest Arms are well sheltered and wave-induced longshore transport is minimal there. Sedimentation in sheltered areas mostly comes from riverine deposits, which are limited here by the modest discharge relative to tidal volume. In harbours where tidal inflows carry large suspended sediment loads on each flood tide (as on the Bay of Fundy), significant sedimentation can occur up-harbour at the interface between fresh and salt water. This cannot be the case in Sydney Harbour, as background SS concentrations are generally low. Instead, sediment transport and resulting deposition may occur occasionally during episodes of stronger currents, or strong waves for the Seaward Arm. Petrie at al (2001) used ADCP current data off Muggah Creek to investigate the potential re-suspension and subsequent entrainment of contaminated sediment off Muggah Creek during stronger current events. They conclude that net sediment movement towards the head of the South Arm is expected, which is supported by the physical distribution of pollutants in bottom sediments.

9.4. Sedimentation Rate -

Stewart at al (2001) used surficial bottom sediment samples from 94 stations across the Harbour to conclude that the Harbour is a depositional area, flocculation being an important deposition mechanism. Building on these data and results, a subsequent study of contaminated sediment geochronology was undertaken by Lee et al (2002). The historical record of contaminant inputs was determined by chemical analyses of sediment cores. It appears that cleaner surface sediment deposits have been capping the main inventory of contaminants since the closure in the 1980s of the coke ovens and steel plant that used to discharge toxic effluent into Muggah Creek. Sedimentation rates in the Harbour were estimated between 0.2 and 2 cm/year. Lee notes that the regions closest to Muggah Creek tend to have the highest sedimentation rates.

10. References

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