6 October 2021

WRL Ref: WRL2021082 JTC LR20211006

UNSW
Water Research
Laboratory

Mills Oakley on behalf of Sit Family Trust Pty Ltd
Level 7, 151 Clarence Street
Sydney NSW 2000

Attn: Shivi Bhargava and Matt Sonter

sbhargava@millsoakley.com.au ; msonter@millsoakley.com.au

Dear Shivi and Matt,

Coastal Engineer's input/advice regarding cliff erosion, 22c Burran Street, Mosman

Introduction

1. This letter addresses the request for Coastal Engineer's input/advice regarding potential cliff erosion fronting a proposed development at 22c Burran Street, Mosman (Figure 1, Figure 2). Geological assessment and slope stability at the location of the subject property have been undertaken by others (GHD, 2020 and present work by JK Geotechnics).

2. The report has been undertaken by myself, James Carley, Principal Coastal Engineer at the Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney. My CV is attached to this letter. I hold a Master of Engineering Science degree in coastal engineering and have 30 years of experience in coastal engineering; specialising in coastal processes, coastal hazard assessment, sea level rise impacts and coastal structures. I have undertaken approximately 250 coastal engineering consulting projects in all states of Australia and numerous Asian and South Pacific nations. I have served on Engineers Australia's NSW Coastal Ocean and Port Engineering Panel (COPEP) for over 20 years, and am the Chair of Engineers Australia's National Committee for Coastal and Ocean Engineering (NCCOE).

Cliff and wave cut platform fronting site

3. The cliff face at the subject property is predominantly sandstone and is fronted by a wave cut platform (Figure 3, Figure 4). The surface of this platform is approximately 20 m in width. The landward portion of the platform is predominantly armoured with rock boulders from previous cliff face collapses (Figure 4, Figure 5, Figure 6). The rock boulders are highly variable in size, ranging from 0.5 m in places, but typically 1 m, with blocks of more than 3 m in places. The rock boulder apron provides a degree of protection to the base of the cliff from further wave attack over planning periods of 50 to 100 years.

4. Approximately 2.8 m AHD (Australian Height Datum, which is approximately mean sea level), there is a band of siltstone within the sandstone (Figure 7, Figure 8). This siltstone band extends vertically approximately 0.5 to 1 m. The siltstone band is broadly flush with the sandstone cliff face at the northern and southern extremities of the subject site, however, there is an overhang with a small cave in the centre of the subject property's cliff frontage (Figure 7).

5. The presence of vegetation to below the level of the siltstone band indicates that waves reach this band with any force on an infrequent basis – less than once per year.

Historic global sea level

6. Chapman et al (1982) reported on work from Thom and Chappell (1975) which showed that sea level 10,000 years ago was approximately 30 m below present, however, from approximately 6,000 years before present, sea level has remained roughly constant within an envelope of approximately ±1 m.

Estimated cliff erosion at subject property

7. On the assumption that the 20 m wide wave cut platform was formed over the 6000 year duration of this approximately constant sea level, the order of magnitude estimate of cliff erosion is 3.3 mm per year.

Published cliff erosion rates

8. Chapman et al (1982) gave the following commentary on cliff erosion in NSW: *"Rates of cliff erosion are highly variable and actual measurements are virtually non-existent. …cliff retreat is highly erratic, with localized and infrequent rock falls separated by long periods of weathering."*

9. For the purposes of estimating sediment supply to beaches, Chapman et al (1982) suggested an order of magnitude estimate of cliff erosion rates for Sydney to be 5 mm per year.

10. Sunamura (1983) presented a model for cliff recession and collated recession rates from numerous locations around the world. The only Australian locations cited were for limestone at Point Peron near Perth (0.2 to 1 mm per year) and aeolianite at Warrnambool Victoria (14 mm per year). Sunamura also presented results of physical model studies on cliff recession and platform formation.

11. Crozier and Braybrooke (1992) examined sea cliffs on Sydney's northern beaches. Some of these cliffs are shale, which is softer than sandstone. Most sandstone cliffs on Sydney's northern beaches are subject to a higher wave climate than the subject property, which is partially protected due to its location inside Sydney Harbour (Figure 1).

12. They estimated that the average rate of sandstone cliff erosion was 4.3 mm per year, and the maximum was 12.1 mm per year. They also published sandstone erosion rates from a range of sources (not sea cliffs) which ranged from 0.012 mm/year to 4.6 mm per year. However, "fine clayey grained sandstone" at Beacon Hill was observed to erode at 10 to 17.4 mm per year over 15 years.

13. Dragovich (2000) estimated erosion rates of Sydney sandstone in locations with a high salt load to be 1 to 5 mm per year – though this related to dimensioned construction stone rather than sea

cliffs subject to wave action. She also quoted Roy (1983) who estimated that the softer beds near the base of sandstone cliffs in the southern Sydney region were weathering at rates of 2 to 5 mm per year.

Land and building levels

14. Based on the survey data accompanying the DA documents, the land levels on the site in the vicinity of the present and proposed building range from approximately 20 to 25 m AHD. The lowest floor level in the basement of the proposed building is a car stacker at approximately 17 m AHD, well back from the cliff face. The proposed lower ground floor level is approximately 19.5 m AHD. A swimming pool is proposed seaward of the proposed new dwelling.

Present day extreme water levels

15. Water and land levels in this letter are given to Australian Height Datum (AHD) which is approximately mean sea level. Tides are often quoted relative to Chart Datum (CD). For Sydney Harbour 0 m AHD = 0.925 m CD.

16. There have been several credible studies on extreme water levels for Sydney Harbour based on more than 100 years of measurement at Fort Denison. Extreme water levels from all credible studies are within approximately 10 cm of each other. Water levels published in NSW Government (2010) are as follows:

    - Mean High Water Springs (MHWS) – a large high tide: 0.65 m AHD (from MHL Tide Tables 2021)
    - 1 year Average Recurrence Interval (ARI):1.24 m AHD
    - 10 year ARI: 1.35 m AHD
    - 100 year ARI: 1.44 m AHD

Sea level rise

17. The last Intergovernmental Panel on Climate Change (IPCC) report was in 2021. The projections from this for global sea level rise are shown in Figure 9. Local sea level rise for Sydney and other locations may vary from this, but based on my knowledge of numerous studies, projections for NSW have generally been within 0.1 m of the global projections.

18. Future global sea level rise projections relative to 2020 from IPCC (2021) are as follows, noting that IPCC also includes a higher scenario of "*Low likelihood, high-impact storyline, including ice sheet instability processes, under SSP5-8.5*":

    - 40 years, 2060:
        - Low: 0.16 m
        - Mid: 0.24 m
        - High: 0.30 m
    - 80 years, 2100:
        - Low: 0.30 m
        - Mid: 0.50 m
        - High: 0.84 m

Present and future extreme water levels

19. Present and future extreme water levels inclusive of future sea level rise are shown in Table 1. It can be seen that even the 100 year ARI water level with a high sea level rise scenario in 2100 (2.28 m AHD) is still lower than the siltstone band (2.5 to 3.5 m AHD). As discussed below, wave runup may impact the siltstone band at times, but it will not be within the intertidal zone over the next 40 to 80 years.

Table 1: Present and future extreme water levels

	Present	2060	2060	2060	2100	2100	2100
Sea level rise	**-**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**
SLR rel 2020 (m)	0.00	0.16	0.24	0.30	0.30	0.50	0.84
MHWS	0.65	0.81	0.89	0.95	0.95	1.15	1.49
1 year ARI	1.24	1.40	1.48	1.54	1.54	1.74	2.08
10 year ARI	1.35	1.51	1.59	1.65	1.65	1.85	2.19
100 year ARI	1.44	1.60	1.68	1.74	1.74	1.94	2.28

Ocean swell and wave runup

20. Wave runup from ocean swell may occasionally impact the siltstone band, causing increased erosion. Further detailed modelling and calculations are possible to quantify this. As per Figure 5, the existing vegetation extends below the siltstone band, indicating that substantial wave runup to the siltstone band is infrequent, possibly less than approximately once per year. Wave runup events reaching the siltstone band would only persist for a short duration (1 to 2 hours) around the peak of high tide.

21. A profile offshore from the site from the NSW Government's 5 m bathymetric LiDAR survey is shown in Figure 10. This shows that the seabed offshore from the subject property is shallow and gently sloping. It does not drop into deep water. The combination of a shallow and gently sloping seabed with the 20 m wide platform limits the ability of large waves to directly impact the cliff face.

22. An initial approximation for wave runup (R2%, the runup of the highest 2% of waves) against a cliff face is twice the depth limited wave height able to reach the cliff (CEM, 2011). Assuming a breaker index of 1.0 (the wave height divided by the water depth) and a platform elevation of 1.0 m AHD, present day wave runup for a 100 year ARI event would be 2.5 to 3.0 m AHD. This would increase with future sea level rise to about 5 m AHD for 2100 with high sea level rise. Detailed calculations and modelling would be needed to refine these initial approximations. These elevations are far below the lowest portions of land surrounding the existing and proposed houses, but are similar to the siltstone band.

Management of siltstone band

23. Due to the small spatial extent (0.5 to 1 m vertical extent) of the siltstone band, if increased undercutting is observed in the future, structural hardening would be relatively straightforward subject to geotechnical input. It is recommended that ongoing inspections and monitoring of the cliff face and the siltstone band be undertaken at 5 to 10 year intervals.

Summary

24. Within the Sydney region, average sandstone cliff recession rates of 1 to 5 mm per year have been reported. This is consistent with the order of magnitude estimate of 3.3 mm per year for formation of the wave cut platform fronting the cliff at the subject property. These reported average rates need to be interpreted with regard to the episodic nature of cliff collapse events by a geotechnical specialist – that is, many years elapse between major events.

25. The assessment of the stability of the cliff and its management, and the stability of cliff top structures are predominantly a geotechnical and/or structural engineering area, however, coastal engineering input has been provided regarding published cliff erosion rates, extreme water levels and wave runup.

26. No significant coastal engineering hazards have been identified for the subject property, nor are they anticipated to arise due to climate change over the next 40 to 80 years. The portion of the site proposed for building is above the 100 year ARI wave runup level for the next 80 years.

27. The siltstone band in the cliff face is above the 100 year ARI still water level for the next 80 years, but may be subject to wave runup during extreme storms. Due to the small spatial extent of the siltstone band, if increased undercutting is observed in the future, structural hardening would be relatively straightforward, subject to geotechnical input. It is recommended that ongoing inspections and monitoring of the cliff face and the siltstone band be undertaken at 5 to 10 year intervals.

Further information

Thank you for the opportunity to provide this advice. Please contact me should you require further information.

Yours sincerely,

James Carley
Principal Coastal Engineer

Attachment:
CV

References and bibliography

Coastal Engineering Manual (CEM, 2011), US Army Corps of Engineers.

Chapman, DM; Geary, M; Roy, PS and BG Thom (1982), Coastal Evolution and Coastal Erosion in New South Wales, a report prepared for the Coastal Council of New South Wales, Sydney, ISBN 0 7240 6582 2.

Crozier, PJ and Braybrooke, JC (1992), "The Morphology of Northern Sydney's Rocky Headlands, their Rates and Style of Regression and Implications for Coastal Development" , 26th Newcastle Symposium on Advances in the Study of the Sydney Basin.

Dragovich, D (2000), "Weathering Mechanisms and Rates of Decay of Sydney Dimension Sandstone", in Sandstone City, edited by GH McNally and BJ Franklin, Monograph No. 5, Geological Society of Australia, pp. 74-82.

GHD (2020), "Sit Family Trust & O'Connell Street Caddens Unit Trust c/o PBD Architects: 22c Burran Avenue, Mosman Geotechnical Feasibility Assessment" November 2020.

IPCC (2021), Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L.Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

MHL (2021), NSW Tide Tables 2021.

NSW Government (2010), Coastal Risk Management Guide, ISBN 978 1 74232 922 2, DECCW 2010/760, August 2010.

Roy, PS (1983), "Cliff Erosion Rates in the South Sydney Region, Central New South Wales Coast" Geological Survey of NSW Quarterly Notes 50, pp 8-11.

Sunamura, T (1983), "Processes of Sea Cliff and Platform Erosion", in CRC Handbook of Coastal Processes and Erosion, edited by Komar, PD and Moore JR, CRC Press, Boca Raton, Florida, USA.

Thom, BG and Chappell, J (1975), "Holocene Sea Level Relative to Australia" Search, 6, pp 90-93.

Young, RW and RAL Wray (2000), "The Geomorphology of Sandstone in the Sydney Region", in Sandstone City, edited by GH McNally and BJ Franklin, Monograph No. 5, Geological Society of Australia, pp. 55-73.

Figures

Figure 1: Location (Source: Nearmap ©)

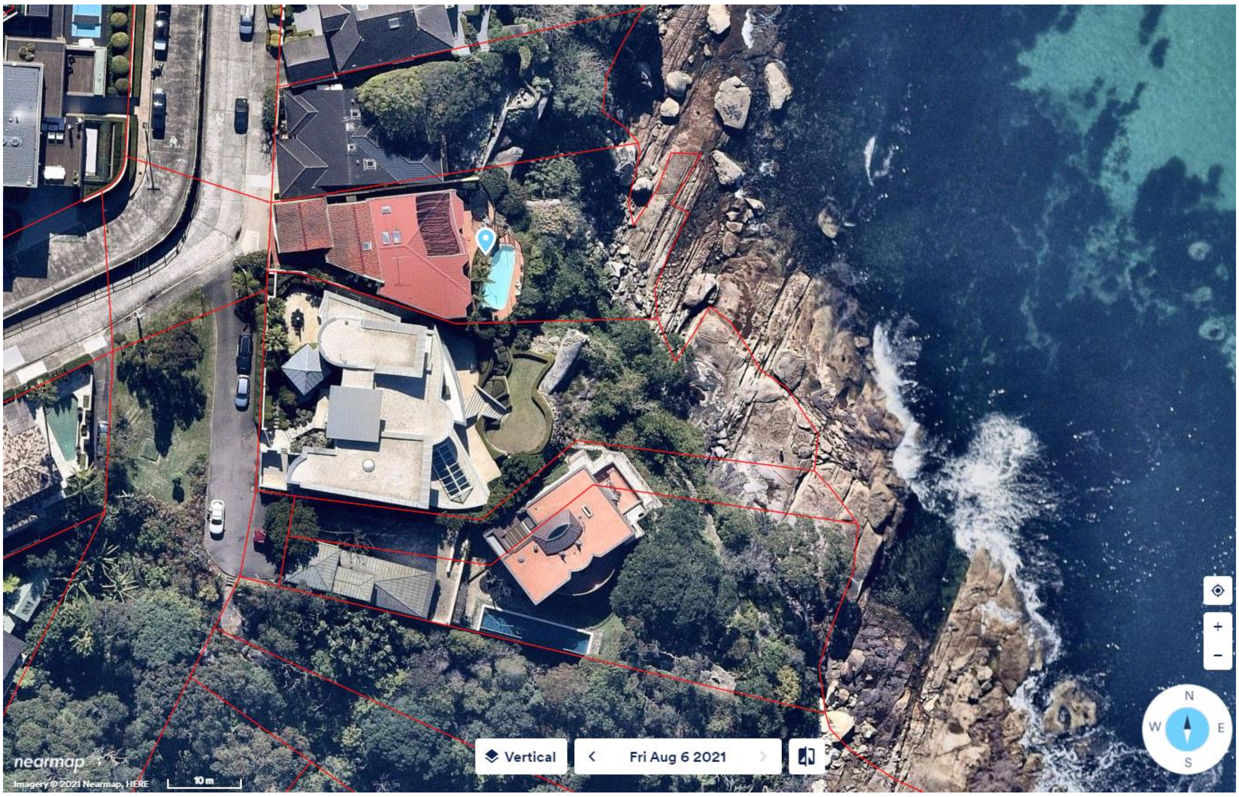

Figure 2: Location closeup (Source: Nearmap ©)

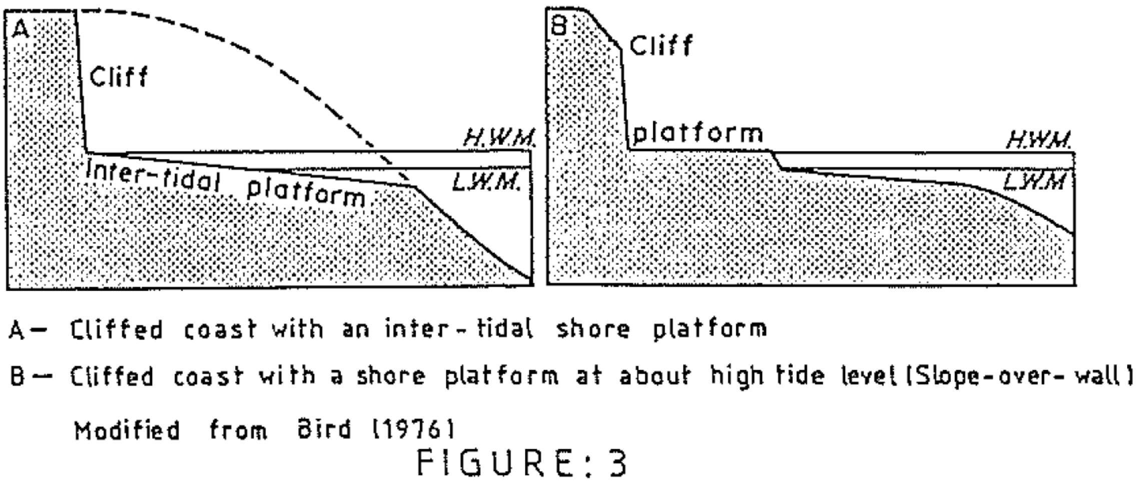

Figure 3: Wave cut platform illustration (Crozier and Braybrooke, 1992)

Figure 4: Oblique aerial view (GHD, 2020)

Figure 5: Vegetation line and armour

Figure 6: Armour at base of cliff

Figure 7: Overhang of siltstone band in middle of site

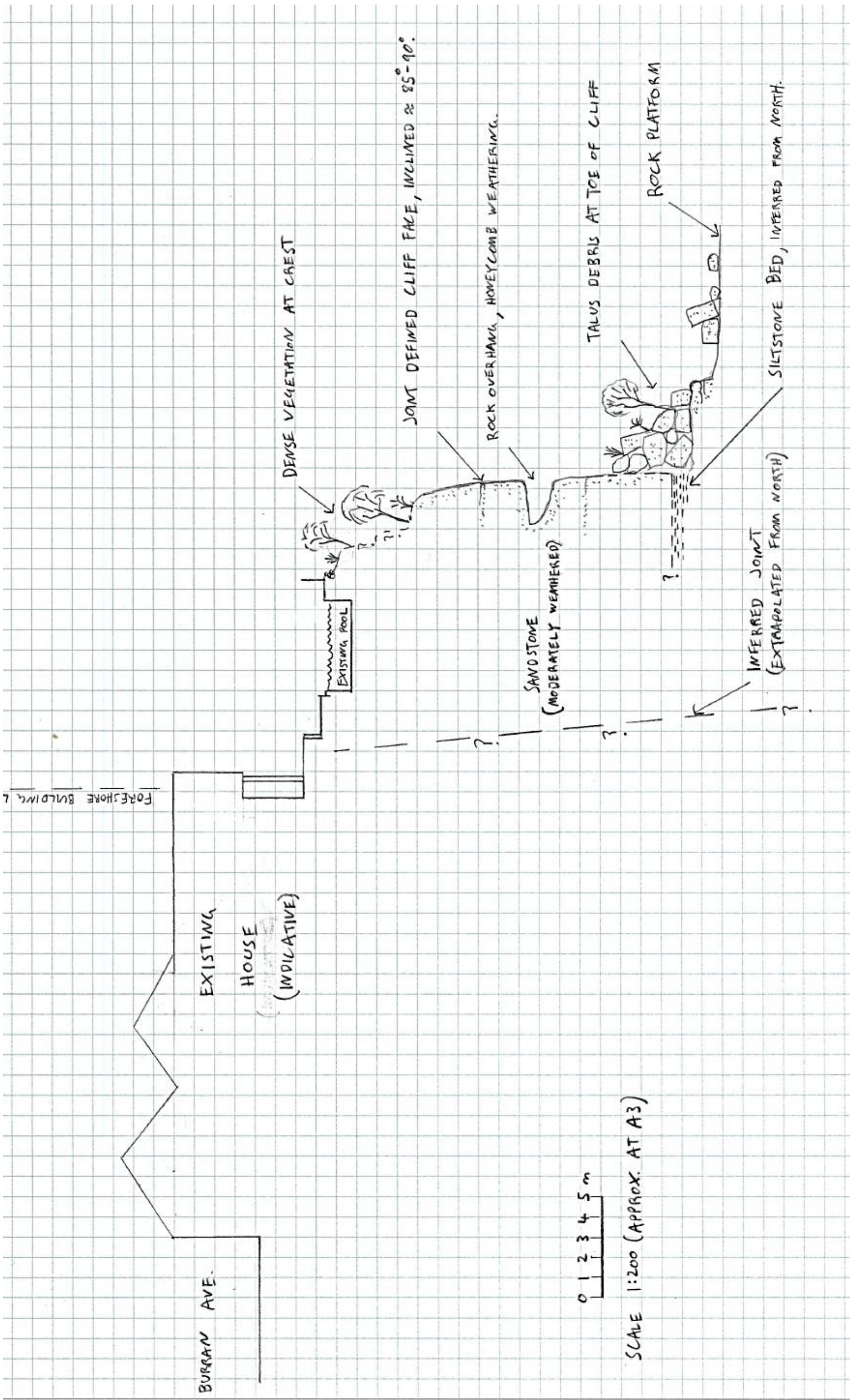

Figure 8: Sketch of cross section (GHD, 2020)

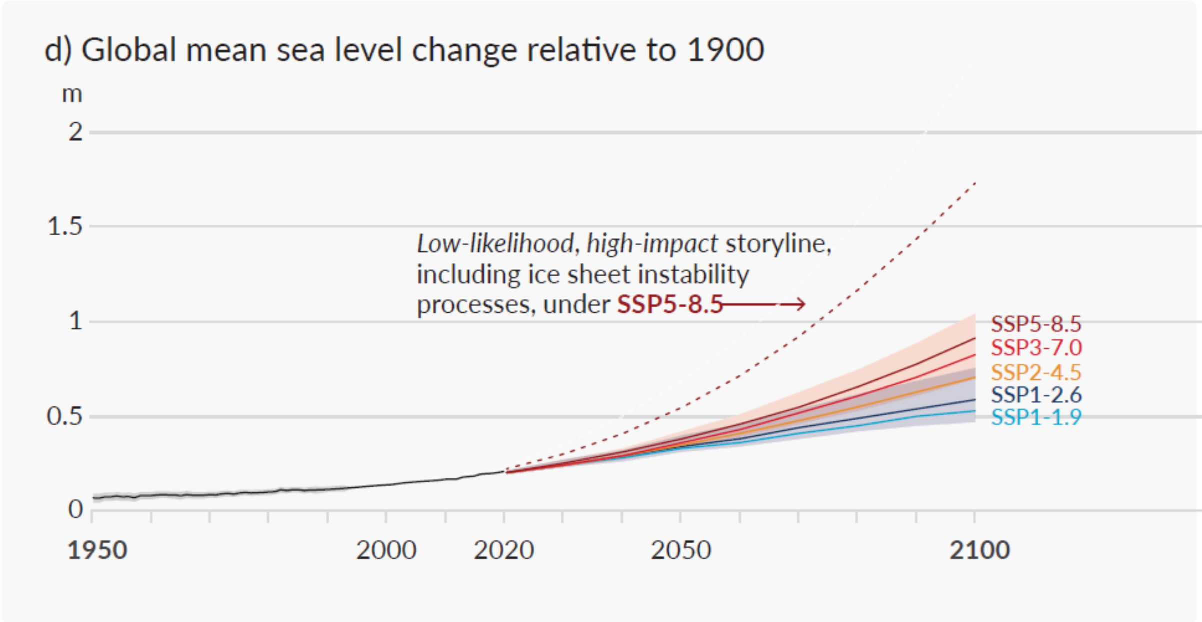

Figure 9: IPCC (2021) global sea level rise projections

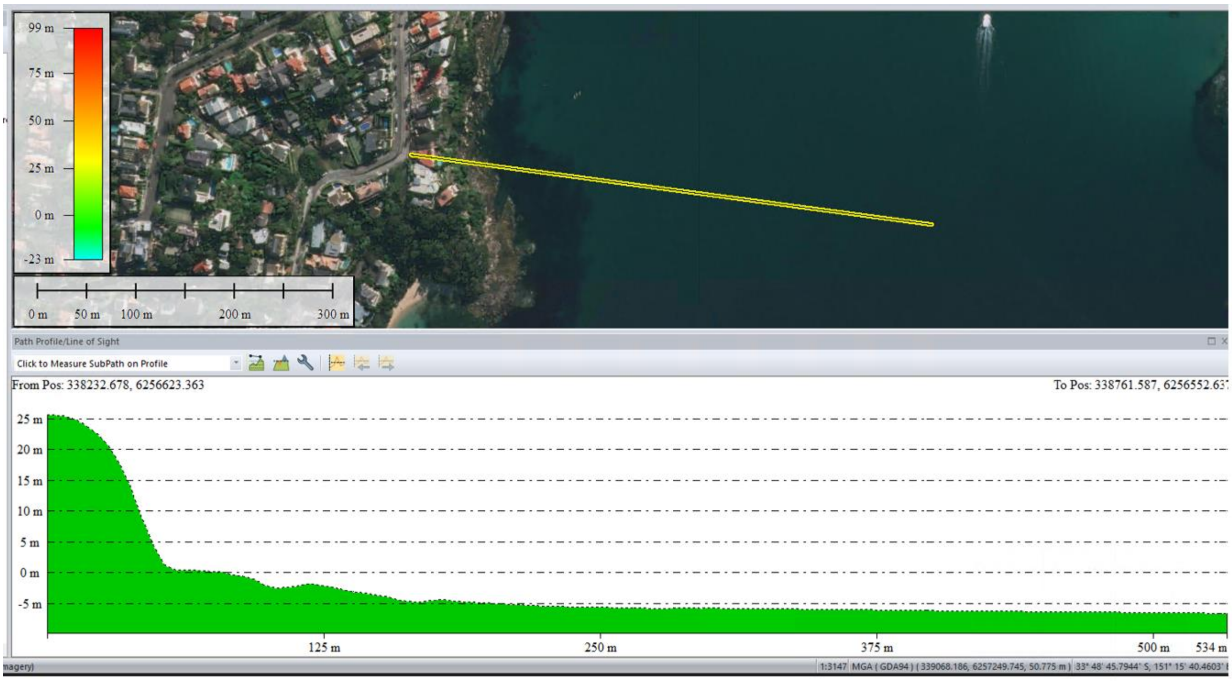

Figure 10: Bathymetric profile offshore from site

UNSW Water Research Laboratory

UNSW SYDNEY

James Carley

Principal Coastal Engineer

James holds a Master of Engineering Science degree in Coastal and Water Engineering and has over 30 years of experience in coastal and water engineering. James has served on Engineers Australia's NSW Coasts Oceans and Port Engineering Panel (COPEP) since 2000 and is Chair of the National Committee on Coastal and Ocean Engineering (NCCOE). Prior to WRL, James worked in the construction industry, including construction and estimating experience for a civil/marine contractor. He is a long term surfer, surf life saver and open water swimmer.

In his time at WRL, James has specialised in coastal processes, coastal hazards and management, and coastal structures. He has undertaken research and provided specialist consulting advice on projects ranging from simple boatsheds to billion dollar ports. His coastal structure experience ranges from conventional rock and concrete structures such as seawalls and breakwaters, to surfing reefs and offshore breakwaters, and structures made from car tyres and geotextiles. Geographically, James has undertaken coastal projects in all states and territories of Australia, New Zealand, the South Pacific, Middle East and South-East Asia.

Applied research led by James in the areas of geotextile coastal structures and beach erosion has been widely used by practising coastal engineers in Australia and New Zealand. Pioneering work on coastal hazard and climate assessment led by James has been used as a template for other sites in Australia. James is frequently engaged as a fair and balanced peer reviewer; and is regularly consulted by government for policy advice on coastal hazard identification and management. He has acted as an expert witness in numerous legal and expert panel proceedings, and regularly presents complex technical information in community and government forums.

Qualifications and affiliations

BBuild, UNSW
MEngSc (Water and Coastal Engineering), UNSW
MIEAust (Member of the Institution of Engineers Australia)
Member of Maritime Panel/NSW Coasts Ocean and Port Engineering Panel (COPEP), Engineers Australia
Member and Chair of National Committee on Coastal and Ocean Engineering (NCCOE), Engineers Australia

Professional history

2014-Current:	Principal Coastal Engineer - UNSW WRL
1992-2013:	Project Engineer/Senior Project Engineer - UNSW WRL
1991-1992:	Builder & MEngSc Student
1990:	Travel & Foreman - Whiteway Group
1988-1989:	Estimator/Engineer - Costain Aust. Ltd
1987:	Estimator - Cordell Estimating
1981-1986:	Student & Duty Manager - Manly Waterworks

Expertise

- Coastal processes
- Coastal structures
- Coastal adaptation
- Estimating and feasibility
- Project management
- Physical modelling
- Ocean pools
- Ocean outfalls

Summary of relevant experience (abbreviated)

Coastal and estuarine studies
1992-2014: Gold Coast QLD
1993: Mauritius sand dredging
1993: Lake Conjola entrance NSW
1994: Port Hacking boat ramps NSW
1994-1995: Lady Robinsons Beach NSW
1995: Point Lillias coastal processes VIC
1995: Point Wilson processes VIC
1995, 2005: Coffs Harbour NSW
1995: Al Mamzar Dubai
1995: Sarawak Malaysia
1995: Map ta Phut Thailand
1995: North Entrance NSW
1995: Oakajee Geraldton WA
1995: Sunset Beach Saudi Arabia
1996: Mine tailings beach profiles
1996: Santubong Malaysia
1997-2000: Bondi Olympic Volleyball NSW
1999-2001: Pindimar, Port Stephens NSW
1999-2001: Brooms Head NSW
1999-2019: Pittwater inundation (>50 sites)
2001-07: Semaphore Park SA
2003: Noosa Beach options QLD
2005: Cook Islands inundation
2005: ANZAC Cove Gallipoli
2005: Coffs Harbour processes NSW
2007: Lakes Beach desalination NSW
2007: Hobart hospital inundation TAS
2007: Yamba coastal monitoring NSW
2007: Clarence Hobart climate change TAS
2007: Turners Beach TAS
2007-08: Byron Bay coastline plan NSW
2007: Port Kembla wave runup, NSW
2008: South Arm highway TAS
2008: New Brighton beach scraping
2008: Wilkinsons Pt climate change TAS
2008: Design setbacks for coastal land VIC
2008: Stanley coastal climate change TAS
2009-10: Coastal processes, Brunei
2009: Beach scraping Roches Beach TAS
2009: St Helens inundation TAS
2009: Byron Shire coastal hazard lines NSW
2010: Tweed Shire coastal hazard lines NSW
2010: NSW wave climate and extremes
2010: Taree & Old Bar coastal hazards NSW
2010: Batemans Bay wave climate NSW
2010: North Palm Beach SLSC hazards NSW
2010: Roches Beach hazard lines TAS
2011: Coastal hazard risk Manly LGA NSW
2011: Beach scraping data New Brighton
2011: Port Fairy wave power VIC
2011: Extreme water levels and waves NSW
2012-13: Port Fairy coastal hazards VIC
2012-13: Probabilistic coastal hazards
2014-16: Byron Bay coastal management
2014: Wave climate Lake Macquarie NSW
2014: Coastal hazards review Kapiti NZ
2015: Lake Macquarie mine subsidence
2016: Freshwater Beach dunes NSW
2018: Eurobodalla NSW
2018: Sandy Beach and Station Beach
2019-21: Fairy Bower overtopping
2019: Okines Beach TAS
2019: Kangaroo Island hazard lines
2020: Great Mackerel Beach NSW
2020-21: Clarkes Beach Byron Bay
2021: Newport SLSC overtopping

Coastal structures/physical modelling
1993-2005: Parallel runway seawall NSW
1994-96: Lady Robinsons groynes NSW
1994: Artificial headlands Brunei
1995: Wirrina Harbour SA
1995-96, 2004-05: Shell Cove NSW
1995-2010: Wave power generators (>10)
1997: Wamberal seawall NSW
1998: Narrowneck reef, Gold Coast QLD
1999-2000: Wave dissipation by wind
1999: Brooms Head revetment NSW
2001: Wave pool feasibility QLD
2001: Semaphore Park sand trap SA
2002-03: Manly seawall NSW
2003-04: Lake Burley Griffin ACT
2004: ‘Eua Tonga breakwaters
2004: Martha Cove breakwaters, VIC
2005: Coffs Harbour expansion, NSW
2005-08: Gorgon Barrow Island, WA
2005: Dalrymple Bay reclamation, QLD
2006: Cook Islands breakwaters
2006: Port Kembla breakwaters, NSW
2006-10: Geotextile walls and groynes
2007: Tyre breakwaters
2007: Scott Reef wave transmission, WA
2007: LNG caisson overtopping
2007: Wyndham Cove VIC
2007-08: Pitcairn Island breakwater
2008: Sir Bani Yas offshore breakwater
2009: Desal intake wave forces VIC
2009: Mornington Pier wave forces VIC
2010: Tutong training walls Brunei
2010: Temporary coastal protection NSW
2010: Detention River geotextile TAS
2010-12: Seawall impacts on beaches
2010: St Kilda breakwater VIC
2010: Portsea geotextle seawall review
2011: Trial groyne for Roches Beach
2011: Abbot Point breakwater QLD
2011: Kingscliff seawall options NSW
2012: Manly LGA seawall risk
2012-13: Artificial reefs for protection review
2012: Review of Roches Beach protection
2012: Groyne options for Kingscliff NSW
2013-15: Interim seawalls Byron Bay
2013: Port Phillip Bay seawalls VIC
2013: Trial groyne design Bambra Reef
2013: Toogoom rock seawall testing QLD
2013: Nambucca Heads SLSC seawall
2013: Scotts Head caravan park NSW
2013: Wonboyn geobag wall NSW
2014: Enhanced surf break Blacksmiths
2014: World Bank Pacific seawalls
2015: Offshore reefs feasibility TAS
2015: Brophys Beach geobags NZ
2015: Kingscliff seawalls NSW
2015: Chatham Islands breakwaters NZ
2015: Ettalong geobag seawall NSW
2016: Bird Island geobags Taren Point
2016: Bruny Island TAS
2016: Low cost Pacific Island structures
2016: Fairy Bower seawall options, Manly
2016: Collaroy-Narrabeen seawalls
2016: Grassy breakwaters King Island
2019: Maroochy geobag groynes
2020: Saltwater Pt indigenous artefacts
2021: Lake Illawarra NSW
2021: Opotiki NZ
2021: Kyowa rock bags
2021: Wamberal seawall NSW
2021: King Island wave scour

Ocean pools
2016: North Curl Curl NSW
2018: Ballina NSW
2019: Hallett Cove SA
2020: Port Macquarie NSW

Ocean outfalls and plumes
1993: Belmont ocean outfall
1993: Bate Bay pollution study
1995: Moa Point STP Wellington NZ
1999: Cronulla ocean outfall NSW
2001: Mangere Manukau pumps NZ
2002: Wollongong ocean outfall NSW
2006: Newport stormwater NSW
2007: Yamba outfall NSW
2017: South Steyne stormwater NSW

Hydraulic physical modelling
1993-99: Prospect water plant NSW
1993-94: Harrington Park lakes NSW
1994: Parrearra development weir QLD
1995: Darling Mills Creek dam NSW
1996: Pilot water filtration plants
1996-2008: Power station filtration (>10)
1997: Trash racks Bankstown NSW
1997: Oil-water separators
1997: Pipe grout pressure testing
1998: Potts Hill reservoir NSW
2000: Tyco flow valves
2002: Kelian pipe plug
2003-04: Eidsvold Weir and fishway QLD
2006: William Slim basin ACT
2007: Springfield Lakes,QLD
2009: Atlantis drainage cells

Estimating and feasibility studies
1988: Gibbergunyah bridges NSW
1988: Manly pier & cove development
1989: Kings Cross tunnel tower NSW

Expert witness
2004: Narrabeen Beach erosion NSW
2005: Parallel Runway seawall NSW
2008: Port Fairy coastal planning VIC
2009-10: Belongil Byron Bay, NSW
2009: Ralphs Bay inundation TAS
2010: Boating accident Farm Cove NSW
2010: Macleay River breakwater, NSW
2013: Beachport breakwater SA
2013-14: Coastal Expert Panel, Kapiti NZ
2014: Port Fairy coastal planning VIC
2015: Belongil interim seawall NSW
20176: Wamberal seawalls
2019: Belongil seawalls NSW
2021: Port Phillip Bay VIC