APPENDIX 4

Geotechnical Hazard Assessment – Cliffs and Bluffs (SCE 2010)

SHIRLEY CONSULTING ENGINEERS PTY. LTD.
CONSULTING & FORENSIC ENGINEERS

DIRECTOR:
A F SHIRLEY BE(Hons.), FIEAust, CPEng(Civil), M.CIRCEA, RPEQ
ASSOCIATE:
D P WILLOWS BE(Hons.), MIEAust, CPEng(Civil)

895 PACIFIC HIGHWAY
PYMBLE, NSW 2073
PO BOX 439, PYMBLE NSW 2073

ABN 65 001 224 728

Phone: (02) 9449 5577
Fax: (02) 9449 5136
www.shirley.net.au

Report on the Geotechnical Issues associated with the Coastline Hazard Management Study

[CPA # 170951]

for the Wyong Shire Council

undertaken by SCE as a sub-consultant to

UMWELT (Australia) Pty Ltd

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EXECUTIVE SUMMARY & CONCLUSIONS

This report summarises & describes the additional investigations undertaken by Shirley Consulting Engineers Pty Ltd *[SCE]* during 2009 / 2010 to assess the various geotechnical hazards associated with the 'bluff areas' of the coastline within the Wyong Shire Council area. The work follows previous studies and hazard assessments of various parts of the coastline by SCE in 1996 / 97 & in 2004, and the availability of much improved topographic data on the area from LiDAR scanning in 2007; the work is also part of a comprehensive study of the Wyong coastline by SCE in association with two other consulting groups (viz: Umwelt Australia Pty Ltd and SMEC Australia Limited *[SMEC]*).

The work was required as a result of increasing concern by the Council as to the effects of climate change & sea level rise *[SLR]* on the land areas close to the coastline, and the need for the formulation of appropriate policies to respond to the potential recession of the coastline within the Council's area.

In summary, the various investigations and studies undertaken have resulted in the following conclusions being reached:

Likely Extent of Bluff Recession [2100]

Refer Section 5 of this report

C1. The historical data obtained during the latest work, in association with the previous studies, indicates that over the past 130 years [viz: over 1878 to 2007], the bluff areas have recessed landward by the following amounts:

a) Rock cliff bluffs; typically 10 to 15 m, with local extremes of up to 26 m.

b) Indurated sand bluffs; 30 to 33 m.

C2. SCE observation of the coastline over approximately 30 years has indicated very significant recession of both the rock cliff bluffs and the indurated sand bluffs, with a number of major rock falls and landslips within the coastline recession zone being observed at various times by SCE.

C3. Geotechnical modelling of the bluff area recession processes over the next 93 years [viz: to 2100] indicates that without any significant climate change or SLR, it is likely that the areas within the coastline recession zone will recess further landward by the following amounts:

c) Rock cliff bluffs; typically 7 to 11 m, with local extremes of up to 19 m.

d) Indurated sand bluffs; 22 to 24 m.

C4. Geotechnical modelling of the bluff area recession processes assuming the probable effects of climate change, and the SLR stated in the current NSW government policy [viz: a SLR of 400 mm by 2050 & 900 mm by 2100], the land areas within the coastline recession zone will, ignoring possible local extremes, recess landward as follows:

Years	**Predicted Landward Recession – post 2007** (m)		
	Rock Cliff Bluffs [no dykes]	Rock Cliff Bluffs [dykes present]	Indurated Sand Bluffs
2007 - 2050	5 to 6 m	6 to 7 m	12 to 18 m
2050 - 2100	6 to 8 m	7 to 9 m	20 to 25 m
Total: 2007 - 2100	**11 to 14 m**	**13 to 16 m**	**32 to 43 m**

Geotechnical Hazards / Hazard Zones

Refer Section 7 of this report

C5. Within the study area, and landward of the coastline recession zone and the hazard lines defined in this report, there are a number of areas of geotechnical hazard [termed *'geotechnical hazard zones'*]; these zones require more detailed investigation and the development of appropriate planning instruments, to ensure the long-term safety / surety of future development within these geotechnical hazard zones.

Note: These areas are primarily at Toowoon Bay, Bateau Bay & southwards, Norah Head and Noraville.

C6. Within the study area, and landward of some of the hazard lines determined by SMEC [viz: the 'Dune Stable Foundation Zone'], there are some geotechnical hazard zones which require more detailed investigation, and the development of appropriate planning instruments to ensure the safety, and long-term surety of future development within these geotechnical hazard zones.

Note: These areas are primarily at Bateau Bay, Toowoon Bay, Blue Bay & Noraville.

C7. As the methodology for dealing with the geotechnical hazards referred to in conclusions C5 & C6 are beyond the scope of this report, it is important that:

a) The extent & type of the geotechnical hazards be more accurately defined / identified.

b) Appropriate policies, procedures and planning controls be developed to control development within the areas of identified geotechnical hazard.

Implications of Predicted Recession for Development & Public Infrastructure

Refer Sections 6, 7 & 8 of this report

C8. The amount of bluff recession predicted by the work indicates that:

c) Presently, **38 buildings** are within the Immediate High hazard zone and thus affected in a significant way by bluff recession. In addition, part of the land associated with these dwellings is being destabilised by bluff recession.

d) By 2050, at least **64 buildings** will be within the Immediate High hazard zone and thus affected in a significant way by bluff recession. In addition, part or all of the land associated with these dwellings will be destabilised by bluff recession.

e) By 2100, at least **93 buildings** will be within the Immediate High hazard zone and thus affected in a significant way by bluff recession. In addition, part or all of the land associated with these dwellings will be destabilised by bluff recession.

C9. The current 'relatively fast' rate of bluff recession is a major factor to be considered with any development on the land areas within the coastline recession zone.

C10. It is very important that appropriate planning and development controls be implemented on both public and private land [including National Park areas], if major economic losses are not to arise from unsuitable development.

C11. Public infrastructure [e.g. stormwater drainage, sewage systems, roads, etc.] within the coastline recession zone **must** be designed to take into account the various bluff recession processes, if the infrastructure is to have a life expectancy appropriate to the particular facility.

C12. It is preferable for any new public infrastructure to be located landward of the 2100 ‘Low’ hazard line.

Planning Controls & Risk Based Hazard Classification System

Refer sub-section 6.1 & Section 8 of this report

C13. It is important that appropriate development controls be rapidly developed and implemented, to ensure that future development within the coastline recession zone and geotechnical hazard zones are planned / built with a reasonable life expectancy.

C14. It is preferable that a 'three-dimensional' planning control be implemented in the bluff areas of the coastline recession zone; this three-dimensional planning control should:

a) Apply to the land areas between the ‘Immediate High’, and the ‘Low’ hazard lines.

b) Take into account the specific details of the proposed development, as well as the detailed topography / geology of the area identified between the defined ‘Immediate High’ and ‘Low’ hazard lines.

C15. It is desirable that the current separate hazard classification systems for the bluff areas, and beach / sand dune areas, be rationalised into a common 'risk based' hazard classification system. It is also preferable that the 'risk based' classification system adopt the landslide risk management principles suggested by the Australian Geomechanics Society.

Scope of Report

Refer Section 10 of this report

This report is limited to documentation of the potential future recession of the bluffs in the coastline recession zone, general identification of the geotechnical hazards in close proximity to the coastline recession zone and a restricted study of the historic recession; as such, it does not include detailed comments on other matters such as, public infrastructure, control of slope stability / geotechnical hazards, public safety, etc.

The report also does not extend to comments / advice on the hazards associated with the recession of the beach / sand dune areas between the coastal bluffs and the geotechnical hazards immediately landward of the beach / sand dune areas.

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TECHNICAL APPENDIX

Geological notes, photographs, explanatory sketches on bluff recession, bluff recession & hazard classification tables, hazard line maps and historical data / information.

1. INTRODUCTION

As a part of a head contract with the Wyong Shire Council *[Council],* Umwelt (Australia) Pty Ltd *[Umwelt]* requested Shirley Consulting Engineers Pty Ltd *[SCE]* to undertake various geotechnical and historical studies of the coastline and bluff areas in the Wyong Shire. The coastline study area extends from Yumbool Point in the south, to Hargraves Beach, Noraville in the north and includes areas such as Toowoon Bay, The Entrance and Cabbage Tree Harbour *[CTH].*

The work was carried out in accordance with SCE's letter of offer to Umwelt dated 22 August 2009, with the contract formally commencing 21 October 2009. The bulk of the work was undertaken in the period December 2009 to May 2010.

Whilst the team leader for the project was an Associate of the firm [David Willows], the work has been subject to regular overview / input from a director of SCE [Andrew Shirley - the principal author of this report]; in addition, much of the geology and recession analysis was undertaken by a senior civil & geotechnical engineer employed by SCE [Simon Fagg].

It is also noted that:

1. The present work follows previous studies of the coastline by SCE in 1996 / 1997, and in 2004. In addition, the CTH area was studied separately, and in significant detail, during 2007 & 2008 following the severe storm event of June 2007.
2. Whilst an extensive 'draft report' on the "Geotechnical Studies and Identified Hazards" was prepared by SCE in October 2004 [R1], as the hazard zones / lines then determined were of limited accuracy, and the current climate change debate / public concern only commencing, the draft report was never adopted as Council policy.

   Note: The principal reason for the limited accuracy of the hazard zones / lines determined in 2004 was the accuracy of the contour map information [from photogrammetry] then available; more accurate information has however been provided for the latest work as a result of LiDAR scanning of the coastline in early 2007.
3. As a result of increased concerns about climate change and the likely extent of sea level rise *[SLR]*, the New South Wales government formulated a policy in October 2009 which specified that planning within the various local government areas should take into account a SLR of 400 mm by 2050, and 900 mm by 2100, as compared to 1990 levels.

   Note: In line with the technical consensus in 2004, the SCE 2004 report assumed a SLR of 250 mm by 2050.
4. This report should be read in conjunction with the related reports in the coastal management strategy study by SMEC Australia Limited *[SMEC]* and Umwelt.

The purposes of the work, and related matters, are described in the following sub-sections.

1.1 Scope of Study & Purposes of Work

Whilst the overall coastline study area extends from Yumbool Point in the south, to Hargraves Beach, Noraville in the north, during the project inception meeting and other discussions it was agreed that:

1. The hazard line definition work by SCE would be confined to the bluff areas of the coastline.
2. 'Accurate' hazard lines [viz: ± 2m, but preferably to ± 1m] were only required in areas where there was existing development / residential construction. The hazard lines in other areas could have a lower level of accuracy.

3. The geotechnical hazards just beyond the coastline recession zone, but within the study area, would only be generally identified, with the detailed definition of the hazards being the subject of later work.

In light of the above, the purposes of the studies undertaken can be summarised as follows:

a) To evaluate the likely historical extent of bluff recession that has occurred within the coastline recession zone.

b) To formulate / identify the likely mechanisms of bluff recession that are presently occurring within the coastline recession zone.

c) To predict the possible / likely future recession of the bluff areas, both with and without climate change / SLR.

d) To produce a series of maps illustrating the various hazard lines / zones identified by the work with an accuracy of better than ± 2m, but preferably to ± 1m.

   Note: In National Parks and similar areas, an accuracy of ± 5m was considered to be sufficient.

e) To identify the various geotechnical issues associated with the identified hazards, to enable the development of appropriate policies / strategies to take into account such issues.

1.2 Documents & Data

To assist in the work, Umwelt provided copies of detailed contour data of the coastline recession zone developed from LiDAR aerial scanning, as well as aerial photographs of the study area. In addition:

a) SCE made use of the extensive information [both photographic, field plans and maps] that had been acquired during the previous coastal studies, as well as during the design processes for the Toe Drainage Structure *[TDS]* at Cabbage Tree Harbour *[CTH].*

b) SCE obtained independently from various libraries, local sources and government agencies, a number of historical documents, booklets and plans.

c) Umwelt provided a copy of the draft version of the SMEC main report on the Wyong Coastal Study [R8] on 3 March 2010.

   Note: Whilst the SMEC report primarily addresses the hazard lines in the beach / sand dune areas of the study area, it also includes some information on the area geology & bluff areas.

It is also noted that during the field operations, both for the current and previous work, a number of discussions took place with local residents as to their observations of the coastline; in addition, members of the Council's staff made available to SCE a number of photographs taken during severe storm events at CTH.

1.3 Abbreviations

To assist in the reading of this report, the following abbreviations have been used in the text:

Name or Term	Abbreviation
Wyong Shire Council	**Council**
Umwelt Australia Pty Ltd	**Umwelt**
SMEC Australia Limited	**SMEC**

Name or Term	Abbreviation
NSW Department of Environment, Climate Change & Water	**DECCW**
Shirley Consulting Engineers Pty Ltd [Consulting & Forensic Engineers]	**SCE**
Australian Geomechanics Society	**AGS**
Cabbage Tree Harbour [also known as Cabbage Tree Bay]	**CTH**
Proposed Toe Drainage Structure at CTH	**TDS**
Sea Level Rise	**SLR**
The currently predicted changes in storm severity, storm frequency & wave actions in response to the likely changes in the climate, whether naturally occurring or man-induced.	**climate change**
A storm event equivalent to the currently assessed 1 in 15 year storm event based on the currently available records.	**severe storm event**
The coastal area of the Wyong Shire from Yumbool Point to Noraville which is subject to coastal recession. Whilst this area includes the land area above & immediately landward of the various cliffs / bluffs forming the coastline, it does NOT include the land areas that may be subject to geotechnical & stability issues within the project 'study area'. **Note:** The beach and sand dune areas associated with the coastline are also not included in the areas reported on by SCE; these areas are the subject of advice from SMEC.	**coastline recession zone**
Coastal cliffs [especially steep & precipitous cliffs], steep rock & weathered rock slopes, headlands, indurated & cemented sand coastal slopes.	**bluff**
Land areas within the project 'study area' that may be subject to geotechnical & stability issues beyond the area subject to coastline recession processes.	**geotechnical hazard zone**
Land areas where the coastline recession processes involve a consideration of both the bluff recession processes, and the beach / sand dune recession processes.	**combined bluff / beach / dune zone**
Building structures, including residential & commercial buildings / dwellings, surf clubs, garages & carports, toilet blocks, etc. **Note:** Minor structures such as garden sheds, gazebos are not included in the definition of 'buildings'.	**buildings**
Deposited Plans [from land title searches / information].	**DP or DPs**
Draft report [by SCE] on geotechnical studies and identified hazards for the Wyong Shire Coastline : 11 October 2004 [R1].	**SCE 2004 report**
Note: The bluff area hazard classification system, together with the definitions of the various hazard lines, is provided in Tables D1 & D2 in the Appendix.	

The Technical Appendix has also been divided into a number of sections separated by index tabs referred to as Tab A, Tab B, ….; an index to the Technical Appendix is provided at the end of the report text. In addition, to facilitate referencing of the photographs presented in the Appendix, the various photographs are referred to as [P1], or [P1 & P2], etc. Likewise, the various historical extracts / researched documents included in the Appendix [Tab F] are referred to as Document FA, Document FB, etc.

1.4 Correlation to SCE 2004 report

As this report is to be read in conjunction with the SCE 2004 report issued in October 2004, it is to be noted that:

a) The results of the additional work undertaken in the latest study has resulted in Sections 7, 9 & 10 of the SCE 2004 report being superseded.

b) Sub-section 9.1 of the SCE 2004 report has been expanded in Section 6 of this report; sub-sections 9.2 & 9.3 of the SCE 2004 report have also been largely superseded by Section 6 of this report.

c) As a result of the 2009 NSW government policy in relation to SLR, Section 7 of the SCE 2004 report has been superseded by Section 4 of this report.

d) The SLR of 250 mm assumed in the SCE 2004 report is no longer applicable; the SLR assumed in this report is 400 mm by 2050, and 900 mm by 2100 from 1990 levels.

e) The various bluff recession mechanisms presented in the drawings included in the Appendix to the SCE 2004 report have been further developed and simplified in line with the additional work undertaken during the course of the study. The currently applicable mechanisms are described on the 'Hazard Line Relationships' drawings included in the Appendix [Tab C].

f) The 1:25,000 scale geological map presented in the Appendix to the SCE 2004 report has been upgraded by the latest work; the new 1:10,000 scale geological map is included in the Appendix to this report [Tab A].

The relevant differences between the SCE 2004 report and this report are summarised in the following Table 1.

TABLE 1 : COMPARISON SCE 2004 to SCE 2010

SCE 2004 Section	Title	Applicable	Replaced / Expanded by SCE 2010	
		Y / N	Section	Title
4	Identified Coastal Stability Issues.	Y	3.1	Geology & Extent of Coastline Recession Zone.
5 & 6	Regional & Engineering Geology.	Y	3.1	Geology & Extent of Coastline Recession Zone.
7	SLR	N	4	SLR & Climate Change
9	Hazard Classification System.	N	6 & 7	Bluff Recession Hazard Zones & Lines. Geotechnical Hazard Zones.
10	Hazard Maps & Specific Area Reports.	Y	8.2	Hazard Zones : Need for 3d Model.

TABLE 1 : COMPARISON SCE 2004 to SCE 2010

		Applicable	Replaced / Expanded by SCE 2010	
Appendix Tab B	Geological Map 1:25,000	N	Appendix Tab A	Geological Map 1:10,000 Geological Notes
Appendix Tab D	Hazard Line Mechanism Drawings	N	Appendix Tab C	Hazard Line Relationships [viz: recession mechanisms] - Sketch Diagrams.

2. WORK UNDERTAKEN

Whilst the work undertaken as part of this study was necessarily limited by Council's budget, the investigation & analysis work has been extensive, with the work involving:

a) Attendance at planning meetings, discussions with the other consultants engaged on the project [viz: SMEC & Umwelt], and informal meetings with Phillip Watson & Neil Kelleher of DECCW.

b) Detailed compilation and review of the provided LiDAR data, aerial photographs, 2004 fieldwork results / draft report and other information.

c) The preparation of a number of topographic / geological cross sections in geotechnically relevant areas, assessment & analysis of the likely geology in the various parts of the study area, and the formulation of geotechnical models at many locations along the coastline recession zone.

d) Review of the 2004 bluff recession mechanisms, and development / simplification of these mechanisms to include the additional information from both the 'ground truthing' fieldwork, and the LiDAR data.

e) The preparation of a series of diagrams to illustrate the way in which the hazard lines are predicted from the determined coastline recession mechanism.

f) Development of a modified version of the previously determined hazard classification system for the bluff areas within the coastline recession zone presented in the SCE October 2004 report, to allow for:

   - the SLR, and associated climate change, for the time periods specified by the NSW government policy [viz: 2050 & 2100];
   - a 'risk management' approach to the bluff area hazard lines / zones that is compatible with the 2007 AGS guidelines on landslide risk management.

g) The preparation of hazard lines determined from a consideration of the historical recession, as well as the likely current and future bluff recession taking into account SLR and the probable effects of climate change.

h) The delineation of the various 'geotechnical hazard zones' beyond the area subject to coastline recession processes, but within the project 'study area', that may be subject to geotechnical & stability issues

i) The preparation of an updated geological map of the study area.

The details of the work undertaken at each stage of the project is set out in Table 2. In addition, some details of the historical searches, bluff recession mechanisms and associated hazard assessment are set out in the following sub-sections.

TABLE 2 : WORK UNDERTAKEN AT EACH PROJECT STAGE

Date(s)	Project Stage	Work Undertaken
9 January 2006 to 30 June 2009	Preliminary work following 2004 draft coastline hazard management study.	Preliminary work for updated coastline hazard management study. Ongoing advice on coastline bluff hazard management. Discussions regarding the scope and methodology of the update work.
29 April 2009	Project planning meeting with consulting team.	David Willows [SCE] & Chris Adamantidis [SMEC] attended a meeting with Umwelt in the Umwelt Toronto office. Review of project scope, LiDAR information and computing models.
12 June 2009	Project inception meeting.	Inception meeting with Wyong Council DECCW, Umwelt & SMEC. Discussions & general agreements regarding the project and timeframes.
30 October 2009	Planning meeting SCE & Umwelt.	Discussions regarding the use of LiDAR data & computing systems. Project timeframes & anticipated completion dates / milestones.
16 October 2009 to 19 November 2009	Initial office assessment of bluff recession hazard mechanisms.	Cross section preparation from LiDAR & aerial photographs. Meeting with Phillip Watson (DECCW) regarding mechanisms.
20 November 2009 to 22 December 2009	Office assessment of bluff recession mechanisms. Set up for fieldwork.	Develop hazard mechanisms, review geology units and development of geology maps for internal analysis. Initial assembly of fieldwork maps.
23 December 2009 to 22 January 2010	Office assessment of bluff recession mechanisms. Set up for fieldwork.	Further development of hazard mechanisms, and internal geology maps. Assembly of fieldwork maps.
22 January 2010 to 22 February 2010	Fieldwork, draft hazard lines & draft report.	Determine draft hazard lines on maps based on bluff recession mechanisms. Undertaking of ground truthing fieldwork to confirm geology, assumptions & other information.
25 February 2010	Draft report – summary.	Summary of draft report prepared for discussion with Umwelt / Council.
3 March 2010	Council meeting.	Meeting at Council's Offices with Council, Umwelt, SMEC to discuss the preliminary results of the various studies / investigations and content of draft report.

TABLE 2 : WORK UNDERTAKEN AT EACH PROJECT STAGE

Date(s)	Project Stage	Work Undertaken
10 March 2010	Initial 'draft version' of SCE report.	Finalisation of draft report content and provision of the initial draft to Umwelt for inclusion in a draft version of the overall project report.
1 April 2010	Council & DECCW meeting.	Meeting at Council's Offices with Council, Umwelt & DECCW [N Kelleher] to discuss the project generally and work required to complete the project.
13 May 2010	Consultants / Council meeting.	Meeting at SCE's Offices with Council, Umwelt & SMEC to finalise the scope of the report and resolve the various consultant interface issues.

2.1 Historical Searches & Data

As the various detailed SCE site observations in the area during the period 1974 to 2010 indicated that the amount of bluff recession that had occurred in the vicinity of CTH was substantially more than is usually recognised by the geotechnical community, extensive research was carried out on the likely historical recession of the coastline recession zone.

To this end, a number of historical documents on the area were obtained from the Council's libraries, and other sources, which resulted in the compilation of many maps, photographs and diagrams including:

a) Detailed maps of the CTH & Noraville area dating from 1878, and relevant DPs.

b) Detailed 'large-scale' contour maps of the area [developed both by land-based survey and from aerial photogrammetry] that had been previously obtained by SCE during work / investigations for a number of private clients.

c) Photographs and paintings of former buildings and development within the coastline recession zone [e.g. at Hargraves House at Noraville].

Note: Some of the most relevant documents are included in the Appendix [Tab F].

As a result, it was possible to reasonably assess the actual amount of bluff recession that has occurred over the study area / coastline recession zone since the late 19th century using computer-aided overlay techniques, and the software Google Earth.

In addition, the severe erosion that has been occurring at CTH, in combination with the now mainly destroyed drainage manifold installed in 2002 and detailed 'land based' topographic surveys of the area, enabled reasonably accurate measurement of the amount of recession that has occurred at CTH since 2002.

It is however to be especially noted that as the historical research carried out has not been exhaustive, it would be beneficial to undertake further research on the history of bluff recession to improve the accuracy of the modelling included in this study. To this end it would be useful to persons undertaking any future studies to be provided with:

- the available aerial photographs from 1941 onwards;
- full access to Council's library resources.

In addition, it is likely that the various local historical societies and other government departments, may well have additional historical information that would significantly improve the currently available historical data / maps.

2.2 Analysis & Hazard Assessment

As a critical output from the studies was the formulation of maps indicating the various hazard zones, the study area was divided into a number of individual 'map areas' [see Drawing No. BM001A1 : Appendix Tab A]; within these 'map areas', the various recession mechanisms currently occurring were assessed. During this work, a number of areas of 'geotechnical hazard' were identified that were either close to, or immediately behind the coastline recession zone. The approximate extent of the geotechnical hazard zones is delineated on the 2007 hazard line maps [ref. Drawings No. BM001G1-G6 and G9-G12 in Appendix Tab E].

Note: In order for the geotechnical hazard zones to be accurately defined, it would be necessary for the current cadastral information to be accurately related to the LiDAR contour data.

Subsequently, topographic sections through areas considered to be 'typical' of the recession mechanisms occurring within an area were prepared, and the subsurface conditions / geology inferred in the office.

Later, the geological / topographic sections were checked during the ground truthing fieldwork in February 2010, with the fieldwork being specifically designed to ensure that the various bluff recession mechanisms reasonably represented the geological conditions and bluff recessionary processes observed in the area.

It is also to be noted that:

1. Although the very significant influence of dykes on the coastline recession had been previously recognised, during the course of the ground truthing fieldwork it was discovered that a 'dyke induced' recession mechanism was one of the principal mechanisms of bluff recession in the vicinity of Noraville and Jenny Dixon beach.

2. After assembly of all the field and other data, the various bluff recession mechanisms occurring in the various areas were modelled & assessed, the various hazard line plans developed and this report prepared.

3. In this report only the Immediate High, and Low hazard lines have been defined on the maps; this has been done to enable later definition of the Medium / High hazard line for a particular lot, as a part of the detailed investigation & planning processes for a particular development [see Section 6, particularly sub-section 6.2].

4. The issues associated with the geotechnical hazard zones beyond the coastline recession zone are discussed in Section 7.

3. COASTLINE RECESSION ZONE CONDITIONS & GEOLOGY

As noted in sub-section 1.3, the term 'coastline recession zone' has been used in this report to describe the various cliffs / bluffs forming the coastline, and the land areas immediately above and landward of the coastline that are likely to be subject to coastal recession during the period to 2100.

The term 'coastline recession zone' does however NOT include the land areas that may be subject to geotechnical & stability issues within the study area that are beyond the areas subject to coastal recession. The areas subject to geotechnical & stability issues are termed 'geotechnical hazard zones', and briefly commented on in Section 7.

In light of the foregoing, the various aspects of the coastline recession zone, and study area geology are discussed in the following sub-sections.

3.1 Geology & Extent of Coastline Recession Zone

As the various coastline stability issues, regional & engineering geology were described in detail in Sections 4, 5 & 6 of the SCE 2004 report, a detailed description of the coastline recession zone conditions, stability issues and engineering geology is not provided in this report. Suffice to note in this report that:

a) The coastline recession zone geotechnical studies extend from Yumbool Point in the south, to Hargraves Beach in the north.

b) The various bluff areas studied within the coastline recession zone of the Wyong Shire are identified on the study area locality plan [Drawing No. BM001A1 : Tab A].

c) Reasonably detailed geological maps [viz: 2x A3 maps at 1:10,000 scale] of the study area have been included in the Appendix [Tab A].

   Note: Whilst these 1:10,000 scale maps are based on larger scale mapping by SCE in the area over many years, because no detailed drilling has been carried out, there may be a number of inconsistencies / inaccuracies in the maps.

The relevant geological formations encountered over the bluff areas of the study area are described in the geological legend on Drawing No. BM001A3, and summarised in Table 3.

TABLE 3 : GEOLOGICAL FORMATIONS

Abbreviation	Description
Qhs	High Level Aeolian Sands
Qpa	Indurated / Cemented Sands
Rnt	Terrigal Formation
Rnp	Patonga Claystone
Rnu	Tuggerah Formation
Rnm	Munmorah Conglomerate
Jv	Igneous Dykes

To assist in the appreciation of the various properties of these formations, some geological notes on the formations are included in the Appendix [Tab A].

In relation to the igneous dykes within the study area [ref: geological maps - Drawings No. BM001A4 & A5], the following are also noted:

a) There are a large number of dykes.

b) The dykes typically trend approximately 30° & 315° off both the north / south direction, and the east / west direction.

c) The bedrock on either side of the dykes has been extensively fractured and altered by the intrusion processes.

d) Seepage along the fracture planes associated with the dykes is common.

e) The dykes have a significant influence on the pattern of coastal recession [P9 & P10].

3.2 Interfaces between Bluff Areas & Beach / Sand Dune Areas

As noted in Section 1, the study area comprises an extensive proportion of the Council's coastline including both the bluff areas [viz: cliffs and indurated sand slopes], as well as beaches and sand dune areas. However, as the assessment of the hazard lines for the beach & sand dune areas was a task assigned to SMEC, the interfaces between the hazard lines assessed by SCE, and those assessed by SMEC are indicated on the 2007 bluff area hazard line drawings included in the Appendix [Tab E].

It is also to be noted that:

a) In some locations, the coastline recession processes are complex and involve a consideration of both the way in which the beach & sand dune areas recess, as well as the geotechnical characteristics of the bluff areas that form part of the particular area. These areas have been identified on the drawings as 'combined bluff / beach / dune zone', and require more detailed studies by SMEC / SCE to resolve the appropriate hazard classification and recession mechanisms.

b) A number of 'geotechnical hazard zones' have been identified on the 2007 bluff area hazard line drawings, with these zones being behind the hazard lines determined by both SCE & SMEC; in these areas, there are a number of geotechnical issues relating to the land, with these issues including slope stability, soil erosion, soil pipes and shrink / swell clay materials.

   Note: In some locations, SCE has determined a geotechnical hazard zone where SMEC has indicated that the land is a 'Dune Stable Foundation Zone'.

3.3 LiDAR Contour Data

Whilst the LiDAR contour data provided was far more representative of the steeply sloping landform forming the bluff areas than the photogrammetry used to compile the hazard lines in 2004, during the course of the analytical and ground truthing fieldwork undertaken by SCE, the following became apparent:

a) The provided LiDAR contours had some significant errors in particular locations [e.g. at Roslyn Place, Noraville], with the errors being principally in areas of dense vegetation and where there were overhangs in the cliffs / bluffs.

b) In some locations [e.g. gullies & drainage lines], the LiDAR contour information was not representative of the landform.

In view of the above, the process of determining the hazard lines for the bluff areas also included the application of 'engineering judgement' [viz: smoothing and adjustment based on local knowledge and experience in the area] to the analytically determined hazard line recession mechanisms based on the LiDAR data.

3.4 Cadastral Information

During the course of the fieldwork for this study and in 2004, it became apparent that when the cadastral information was overlain on the provided contour information, there were a number of inconsistencies between the cadastral overlay, the contour information and site observations. As such, in preparing the various hazard lines and determining the extent of the geotechnical hazard zones, the following has been assumed:

- the contour information was the most accurate;
- the position of the cadastral information may not be accurate.

The effect of these assumptions on the accuracy of the hazard lines presented on the drawings in the Appendix [Tab B] is discussed in sub-section 6.5.

4. SEA LEVEL RISE & CLIMATE CHANGE

As a background to the bluff area hazard recession mechanisms described in Section 5, some comments on SLR and climate change are included in the following sub-sections, because:

a) It is considered self-evident that SLR is one of the responses to the climate change that is currently occurring [whether man induced, or natural].

b) Increased sea levels will increase the rate of bluff recession due to a reduction in the protection to the bluffs provided by the 'wave platform', as well as erosion of the soft bedrock seams exposed immediately above the existing wave platforms.

c) As bluff recession is also a function of the storms that occur along the coastline, an important consideration in the assessment of the future bluff recession is whether or not it is likely that there will be an increased frequency of severe storm events during the next 90 years [i.e. to 2100].

4.1 Sea Level Rise

In light of the NSW government policy on SLR benchmarks [R2], the various comments made in relation to SLR in Section 7 of the SCE 2004 report are no longer applicable, with the following reflecting the current situation:

a) The NSW government policy on SLR is consistent with the current engineering and geotechnical consensus that climate change is occurring in Australia [R7].

b) Measurements of the changes in sea level around Australia over the last 90 years suggest that the rate of rise has been about 1 mm / year, or about 0.1 m over 100 years [R4]. In recent times [viz: since 1990], the rate of SLR appears to be about 2 to 3 mm / year [R9].

c) Global warming from human activity may well be a significant cause for the increasing rate of SLR.

In view of the above, the 2050 & 2100 hazard lines have adopted the benchmark SLR of 400 mm by 2050, and 900 mm by 2100; the actual mechanism by which SLR affects the rate of coastline recession for the bluff areas is discussed in sub-section 5.5.

4.2 Climate Change & Severe Storm Events (Storminess)

An important consideration in the prediction of future bluff recession is whether the historic rate of recession will continue into the future, or whether there will be an increased rate of recession. In this regard, the following are to be noted:

a) The majority of bluff recession occurs during storm events, with the more severe storm events often causing extensive bluff recession. Severe storm events can also induce an extreme sea level event.

b) If there are more severe storm events over the next 90 years, than has occurred over the past 100 years, then it is very probable that the rate of bluff recession over the next 90 years will be faster than over the past 100 years.

Note: From a coastal recession point of view over the next 90 years, it is important to consider events that occur at intervals of 1 in 10 to 1 in 15 years, rather than the extreme 1 in 250, or 1 in 1000 year events.

c) Whilst a technical consensus has not yet been fully achieved on the issue of whether or not there will be an increased frequency of severe storm events [or storminess], a number of authors have suggested that there will be increased 'storminess' over the next 90 years based on studies of the 'extremes' of sea levels and storms [R4, R6 & R10].

d) As there has been a *"decrease in the average recurrence interval [ARI] by factors of about 3 for extreme sea levels from the pre-1950 period to the post-1950 period"* [R4], it is likely that there has been an increased frequency of severe storm events after 1950, which is most probably related to a combination of long-term cyclic weather patterns, and climate change.

Note: Whilst some have suggested that this may be the result of the period prior to 1950 being somewhat drier than the post-1950 period, others suggest [e.g. R6] that it is more likely that there will be an increased frequency of severe storm events as a result of climate change.

e) In the recent assessment of the Hunter Region and Central Coast of NSW [Blackmore & Goodwin : R10 - 2009], the authors concluded in their ‘Executive Summary’ to R10:

> *"Storm frequency is projected to increase during autumn and winter with an associated increase in extreme sea levels."*

And again on page 73:

> *“Hence, we can only conclude that the increase in monthly frequency of ST1 will be accompanied by an increase in the frequency of extreme maritime storm events along the NSW coast.”*

In view of the above, and although the science is not currently ‘fully settled’, it was considered ‘appropriately conservative’ to assume that there would be increased storminess over the next 90 years, with a resultant increased rate of bluff recession.

Note: The increased rates of recession assumed in this report are set out Section 5 [Tables 5 & 6].

5. BLUFF AREA COASTLINE RECESSION MECHANISMS

As the determination of the recession mechanism operating in a particular area of the coastline recession zone is fundamental to the formulation of the hazard lines, attention is firstly drawn to the comments in sub-section 9.1 of the SCE 2004 report.

In addition, and by way of expansion of the comments in sub-section 9.1 of the SCE 2004 report, the mechanism actually operating in a particular area [both in this, and the previous studies] was assessed from a combination of:

1. A consideration of the joints, fractures and seams within the bedrock strata.
2. The extent of weathering of the bedrock strata [including the igneous dykes] observed in the various bluff areas.
3. The various rock falls & rock litter observed during field inspections.
4. Site observations & mapping of the various surficial soil slope failures occurring in both the indurated sand bluff areas, as well as the weathered bedrock bluff areas.

5. Review of land-based photography & topographic surveys obtained over the years by SCE, and other historical sources.

   Note: Some of the photographs and maps obtained / used by SCE as background for the historical recession are included in the Appendix [Tab F].

Whilst the bluff area historical recession, methodology for evaluating the current bluff recession mechanism, and the prediction of future recession are described in the following sub-sections, the following are noted:

a) During the course of the fieldwork many geotechnical and land stability hazards just beyond the coastline recession zones reported on by SCE & SMEC were identified; the approximate extent of the hazards identified by SCE [viz: geotechnical hazard zones] is indicated by the purple dashed lines / hazard areas on the 2007 hazard line drawings [Appendix : Tab E].

b) Some comments on the geotechnical hazard zones are provided in Section 7.

c) The beach / sand dune areas of the coastline recession zone have been excluded from the SCE work as they have been reported on separately by SMEC [R8]. Some of these areas are indicated by the khaki hatching on the hazard line drawings included in the Appendix [Tab E].

d) The present studies have not delineated the hazard lines in the combined bluff / beach / dune zones [ref: red hatched areas on the hazard line drawings in Appendix Tab E], due to the complexity of the relevant issues.

   Note: The combined bluff / beach / dune zones are commented on in sub-section 8.2.

5.1 Historical Recession Record

As noted in sub-section 2.1, the historical record for coastline recession was determined from a study of the various available maps and photographs obtained during the course of both this study, and previous investigations. It is however especially to be noted that the historical search of documents was not an 'exhaustive' search, and without the benefit of the aerial photography undertaken in the early 1940s & subsequently.

As such, it is likely that the accuracy of the historical recession record could be improved by an 'exhaustive' search, during which all of the documents & maps available in the various governmental archives, libraries and photographs were considered and assessed. In addition, it is possible that particular persons within the local historical societies may have additional information to that already provided by them to SCE.

Whilst the results of this historical recession review are set out in Table B4 of the Appendix [Tab B] and summarised in the following Table 4, it is also noted that:

a) A substantial headland near Ada Avenue was reported to have disappeared into the sea in the early 1970s [and possibly during the 1974 major storm event].

b) The various dykes exposed within the bluff areas / wave platforms can initiate a very large rock block failure of the bluff area.

c) SCE photographs over time have revealed a number of large rock block failures within the headland areas.

d) By reference to the SMEC report [R8] and other data, it is likely that over the historical period studied [viz: 1878 to 2007, but chiefly between 1920 to 2007]:

- 30 significant storm events occurred that had a 'significant wave height' in excess of 6.0 m;
- 6 severe storm events occurred with a 'significant wave height' in excess of 7.5 m;
- the 1974 storm event was most probably a 1 in 60, or 1 in 70 year event and caused major coastal recession in the Central Coast area.

e) Some of the measured historical recession [ref: Table B4 in Appendix Tab B] is likely to have been the result of the removal of rock from the headland areas, and / or beachfront areas, as a result of quarrying activities in the late 19th & early 20th centuries, or removal by individuals for building / other purposes.

TABLE 4 : RECORDED HISTORICAL RECESSION [typical values]

Abbreviation	Description	Distance / Number of Joint Sets [per 100 years]
Qpa	Indurated / Cemented Sands	30 – 33 m
Rnp	Patonga Claystone	5 – 7 joint sets / 10 – 15 m
Rnu	Tuggerah Formation	1 – 2 joint sets / 4 – 8 m
Rnu	Tuggerah Formation – affected by dykes	3 – 4 joint sets / 10 – 16 m

5.2 Prediction of Bluff Recession – Geological Principles

To predict the likely extent of bluff recession into the future, it is firstly necessary to establish the geological processes of recession by which the bluff is likely to recess; in this regard, the various field observations / office analysis indicated that there are essentially five bluff recession mechanisms occurring within the study area [Table B1 : Appendix Tab B]. These recession mechanisms are also illustrated on:

- Drawings No. BM001G21, G22 & G23 [Appendix Tab C];
- the various photographs included in the Appendix [Tab B];

with the approximate 'plan extent' of the mechanisms being indicated on the 2007 hazard line drawings included in the Appendix [Tab E]. The mechanisms are also described in Table B3.

The analytical work also revealed that there were a number of 'subsidiary' potential recession mechanisms for the coastline that could occur as a result of **either:**

- removal of the current protection to the bluff area by the beach / sand dune area, **or**
- instability as a result of the geotechnical hazards in the bluff area itself.

As a consequence, the principal mechanisms set out in Table B1 have been subdivided into a number of 'subsidiary mechanisms' [e.g. B2, B3] which are described in Table B2 [Appendix Tab B].

It is also noted that:

a) In contrast to the recession of a beach / sand dune area, bluff recession is NOT recoverable with time; as such, severe storm events destroy the coastline and permanently remove the land into the sea.

b) Because of the more extensive site observations, and additional factual / historical data now available, the geometric relationships for the various recession mechanisms set out in the SCE 2004 report have been simplified in the latest work.

c) The mechanisms and associated geometric relationships are described more fully in sub-section 5.3.

5.3 Bluff Recession Mechanisms – Geometric Relationships

In light of the geological principles set out in sub-section 5.2, the various geometric relationships to predict the recession of the bluff areas were developed, with these relationships being set out in diagrammatic form on Drawings No. BM001G21, G22 & G23 [Appendix Tab C].

In addition, and following analysis of the recession mechanisms generally applicable to each area, the 'present day' [viz: 2007] hazard lines determined in section, were transferred onto the contour plans; later, engineering judgement was applied to the locations of the hazard lines to account for localised variability in the surface topography, coastal slope & geology.

It is also noted that the recession mechanism diagrams are an evolution of the diagrams presented in the SCE 2004 report, with the hazard line recession mechanism drawings introducing the concepts of:

a) An 'equivalent friction angle' [**Φ**] - a parameter analogous to the angle of internal friction of a soil / fractured rock to provide a geometric basis to the formulation of the hazard lines.

b) An 'angle of influence' [**Θ**] of the coastline recession processes [which is related to the well-established differential between the horizontal and vertical stresses in the sedimentary rocks of the Sydney Basin.

Notes:

1. Extensive measurements within the bedrock strata of the Sydney Basin has indicated that the lateral stresses in fresh rock are typically 3 to 4 times the vertical stress; however, near the coastline, the lateral stresses have been found to have been relieved by the coastal recession process, with consequent significant opening of the pre-existing bedrock joints.
2. As the Tuggerah Formation bedrock strata is very 'stiff' by comparison to the Patonga Claystone, the majority of the high lateral stresses in the Patonga Claystone have been relieved well away from the coastline, whereas significant lateral stresses exist in the Tuggerah Formation close to the coastline.

In the formulation of the relationships illustrated on the recession diagrams and described in Table B3, the following assumptions were made on the basis of extensive experience in the soil and rock types present in the study area:

i) The recession mechanisms will differ in accordance with the geological formation encountered in the particular area.

ii) The 'angle of influence' [**Θ**] for the Tuggerah Formation where the lateral stresses are fully relieved is 70° [to the horizontal], and 45° where the stresses have only been partly relieved.

iii) The typical spacing of joints in the Tuggerah Formation and Munmorah Conglomerate is approximately 4 m.

Note: SCE field observations indicate that the joint spacing varies between 2 and 5 m.

iv) The typical spacing of joints in the Patonga Claystone is about 2 m.

v) Within the coastline recession zone, the recession mechanisms in the bedrock are dominated by erosion of softer seams and the undercutting / failure of rock blocks undermined by the seam erosion [P5, P6 & P7], except for the areas where igneous dykes are present.

vi) Where igneous dykes are present, the principal recession mechanism is weathering of the dyke and the immediately associated fractured / jointed rock; the weathering processes then gives rise to a major rock block failure [P8, P9 & P10].

vii) The principal recession mechanism in indurated sand is one of a surficial slope failure, induced by weathering of the underlying indurated sand over time, in combination with severe undercutting and water / wave erosion of the material at the toe of the slope during a severe storm event [P1 & P2].

Note: In some areas [e.g. at The Entrance : P3 & P4], the surficial soil failure has also been aggravated by the emplacement of fill materials.

5.4 Prediction of Bluff Recession - Comparisons to Historical Observation

Another important factor in the prediction of bluff recession, is **the rate** at which the recession is expected to occur. In this regard, the following are noted:

a) Whilst investigators used to adopt the geological principle that *"the past is the guide to the future"* [i.e. the rate at which things happened in the past is the rate at which it will happen in the future], it is now recognised that natural geological processes are not 'continuous', but rather a series of significant [sometimes catastrophic], events.

b) For the reasons discussed in sub-section 4.2, it is unlikely that the rate of recession over the past 100 years has been 'linear' because of the differences in storminess & SLR in the pre-1950 period, as compared to the post-1950 period.

c) It is very probable that the recession rate over the next 90 years, will be greater than the average rate determined from the historical record because of the benchmark SLR increase, in combination with the likely increase in storminess.

In view of the above, in the development of the 2050 & 2100 hazard lines, it has been assumed that the bluffs will recess at a rate in excess of the rate indicated by historical observations [ref: sub-section 5.1].

Note: The way in which the SLR and increased storminess affects the bluff recession rate is discussed in sub-section 5.5.

5.5 Effect of Climate Change & SLR on Bluff Recession

As it is likely that the rate of bluff recession will be in excess of the rate indicated by the historical record [ref: sub-section 5.4], in the development of the hazard lines for 2050 & 2100, it was necessary to formulate an objective process by which the increased rate of recession could be assessed. In addition, and as it is likely that the rate of historical recession has not been uniform, it was also necessary to formulate a methodology by which a prediction could be made of the likely rate of recession over the next 40 years [viz: to 2050], and over the following 50 years [viz: to 2100].

In view of the above, to formulate an approach to the rate of bluff recession that is related to the historical record, geology and the effects of climate change / SLR, the following assumptions were made in relation to predictions of the rate of bluff recession up to 2100:

a) The SLR will be in accordance with the NSW government policy [R2].

b) The SLR will cause many of the presently existing wave platforms to become permanently inundated by the sea, thus exposing the many soft seams near the base of the various cliffs to erosion and softening by water.

c) The higher sea levels resultant from SLR at the base of the cliffs will initiate more extensive undermining of the various potentially unstable rock blocks, and result in an increased rate of bluff recession as compared to the current historical rate of recession.

d) Post 2010, it is likely that the frequency of severe storm events will be greater than the long-term average since 1900; associated with this increased frequency of storms will be somewhat higher 'significant wave heights' [R6], and thus an increased 'wave attack' to destabilise the bluffs.

e) Beyond 2050, the frequency of severe storm events will most probably increase further, with an associated rise in sea levels [due to both SLR and storms], and additional wave attack on the cliff bluffs.

f) A substantial proportion of the bluff recession occurs during times of severe storm events, and is related to the frequency of severe storm events, when:

   - significant erosion of the toe of indurated sand slopes can occur;
   - potentially unstable rock blocks within a bluff can become dislodged from the action of higher water levels & strong waves.

In light of the foregoing, the 2050 & 2100 hazard lines have been developed on the basis of an increased rate of recession over the historical rate of recession; the postulated rates of recession are set out in sub-section 5.6.

5.6 Bluff Recession - Assumed Recession Rates

Whilst the latest work by SCE was undertaken in 2009 / 2010, the work utilised the latest available accurate contour data on the area [viz: the LiDAR data] which was acquired in early 2007. As such, it was necessary to establish the bluff recession rates prior to 2007 on the basis of the historical record, and post 2007 on the basis of an increased rate of recession related to the historical record, SLR & climate change.

However, as a 'quantitative' correlation between SLR, frequency of severe storm events, etc., would require observation and measurement of the bluff, SLR & severe storm events over many years / decades, the following assumptions were made to enable predictions to be made as to the future bluff recession rates:

a) The rate of recession post-1950 is increasing, and greater than the rate of recession prior to 1950.

b) The rate of recession post-2007 is likely to be in excess of the rate between 1950 & 2007.

c) The rate of recession will increase over a similar timeframe to the SLR and the increases in storminess; thus, as the predicted increase in SLR is an exponential curve, the rate of recession induced by SLR will also be an exponential curve.

d) Rather than there being 2.5 severe storm events [viz: 1 in 15 year events] over the next 40 years [i.e. to 2050], there will be three severe storm events.

e) Post 2050, there will be five severe storm events rather than the three severe storm events predicted on the basis of current storm frequency.

f) Whilst the effect of SLR post 2010 and prior to 2050 is very limited [and probably equivalent to one extra significant, but not severe, storm event], the likely effect of the SLR post 2050 would be similar to one additional severe storm event.

Thus, the likely effect of the combined increased storminess and SLR on bluff recession is as follows:

- post 2010 and prior to 2050, one extra severe storm event over the number of events that would have occurred in the late 20th century;
- post 2050 and prior to 2100, three extra severe storm events over the number of events that would have occurred in the late 20th century.

In addition to the foregoing, the recession rate of a particular coastal bluff is dependent on:

1. The particular bedrock formation / soil type cropping out in the particular bluff.
2. The softness of the various seams within the bedrock strata.
3. The pre-2007 development of undercuts in the bluffs as a result of water inundation & wave action.
4. Long-term thermal effects and chemical weathering of the strata.

A consideration of all the above issues led to the development of a series of exponential curves reflecting the rate of recession based on the above assumptions [ref: Figure B5 in Appendix Tab B]; the resultant postulated increases in bluff recession rate are set out in the following Tables 5 & 6.

TABLE 5 : POSTULATED FUTURE BLUFF RECESSION RATES [rock areas]

Years	Recession Rate	Average Increase for Period	Likely Range of Increase for Period
1900 – 2007	Historic Average over 1900 – 2007 *[Base Value]*	-	-
2007 – 2050		5%	0% to 10%
2050	110% of Base Value	-	-
2050 – 2100		15%	10% to 20%
2100	120% of Base Value	-	-

TABLE 6 : POSTULATED FUTURE BLUFF RECESSION RATES
[indurated sand areas]

Years	Recession Rate	Average Increase for Period	Likely Range of Increase for Period
1900 – 2007	Historic Average over 1900 – 2007 *[Base Value]*	-	-
2007 – 2050		10%	5% to 15%
2050	120% of Base Value	-	-
2050 – 2100		35%	25% to 50%
2100	150% of Base Value	-	-

6. HAZARD LINE MAPS

To enable presentation of the various hazard line maps, the study area was subdivided into a number of individual map sheets on which the various hazard lines are presented; these hazard line maps are included in Tab E of the Appendix. An index to the individual map sheets is also provided on Drawing No. BM001A2 [Tab A].

Whilst the various aspects of the hazard classification system used, and the methodology for determining the 2007, 2050 & 2100 hazard line maps themselves, are discussed in the following sub-sections, the following are to be especially noted:

1. Whilst the maps were prepared at a scale of 1:2000 [A1 size], for convenience of presentation in this report, the maps in the Appendix are presented at a scale of 1:4000 [A3 size].
2. There are three sets of hazard line maps, with each individual series of hazard line maps representing the current day [viz: 2007] hazards, and for the hazards predicted to arise by 2050 & 2100.
3. The recession mechanism diagrams presented in Tab B of the Appendix are based on the current day [viz: 2007] situation.
4. The 2007 series of maps also show the extent of the various geotechnical hazard zones, and interfaces with the work performed by SMEC.

6.1 Hazard Classification System

Although the AGS has published extensive guidelines on landslide risk management and hazard zoning, to date the geotechnical community has not agreed on a common classification system for the coastline recession zone.

As such, it has been necessary for SCE to develop an appropriate classification system; the developed system is presented in the Appendix [Tab D] and discussed in the following paragraphs.

Note: The first 'risk based' bluff area classification system was developed by SCE for the Gosford City Council at Copacabana in 1993.

The delineation of the coastline recession zone into a number of areas of equivalent 'hazard' is a complex task, with the methods that are applicable to the classification of hazards in beach / sand dune areas [viz: the SMEC *"Dune Stability Schema"* as suggested by Nielsen & Poulos (R5)], being very different to the system needed to classify the bluff areas where the substrata is predominantly fractured & weathered bedrock and soil.

In addition:

1. The extensive amount of indurated & cemented sands in the study area add additional complexity because these materials tend to act as a 'weak rock' from a slope stability point of view, and as a 'cemented sand' from an erosion point of view.
2. The publication of comprehensive Landslide Risk Management guidelines by the AGS [R3] in 2000, 2002 & 2007, and SCE's experience, indicates that the Nielsen & Poulos classification system (R5) is not appropriate to bluff areas.

   Note: The AGS guideline on 'Landslide Risk' [viz: Geoguide LR7] is included in Appendix [Tab D].

Whilst a hazard classification system similar to the Gosford City Council system was used by SCE in the 1997 study, and continued in the 2004 study, a further modification of the classification system has been developed, and is described in Tables D1 & D2 in the Appendix [Tab D].

Note: The latest hazard classification system embraces an annual probability approach to the hazard classification of the coastline recession zone to provide compatibility to the current AGS guidelines.

Further, and to assist in the appreciation of the instability processes associated with the bluff areas, the AGS 'geoguides' entitled Landslides [LR2], Landslides in Soil [LR3], Landslides in Rock [LR4], Landslide Risk [LR7] and Coastal Landslides [LR10] are also included in the Appendix [Tab D].

6.2 Bluff Area Hazard Lines & Maps

As the study brief required the preparation of a number of hazard lines to identify / separate the various land areas subject to hazard / recession due to coastal processes, a series of hazard lines have been drawn on the various hazard maps for the years 2007 [present], 2050 & 2100 [see the various hazard line drawings in the Appendix – Tab E].

These hazard line maps were generated by a consideration of the recession mechanism applicable to each area [based on the geological sections], and the initial 2007 hazard lines plotted onto the contour plans at the various section locations. Subsequently, the plan locations of the various hazard lines were analysed and engineering judgement applied to the location of the hazard lines to account for:

- any localised variability in the surface topography / coastal slopes;
- knowledge obtained during the various site inspections and ground truthing fieldwork.

Whilst the various assumptions made in the preparation of the hazard lines are described in sub-section 6.4, the following are to be noted in relation to the lines & maps:

a) The methodology for determining the 2050 & 2100 hazard lines is described in sub-section 6.3.

b) The maps only present the Immediate High and Low hazard lines for each of the selected years because the definition of the High / Medium hazard line to an accuracy of better than 1 m, requires much more accurate topographic and geotechnical data than is currently available, or could be obtained at reasonable cost.

   Note: In Table B3 [Appendix Tab B] the line defining the boundary between the Immediate High hazard line and the adjacent area is termed the Immediate High / High & Medium hazard line.

c) The generally steep topography of the bluff areas suggests that a two-dimensional approach to the identification of areas of equivalent hazard could unnecessarily sterilise significant areas of valuable land against development over the next 100 years.

d) As the interface between the High & Medium hazard zones is in reality, a three-dimensional surface rather than a two-dimensional line at the existing ground surface, it is necessary to have a knowledge of both the proposed development as well as the geological and topographic features, to correctly define the High / Medium hazard interface.

In view of the foregoing, the hazard line drawings presented in the Appendix [Tab E] do not define the boundary between the High and Medium hazard areas, so that this line can be defined at a later stage and as a part of any particular site development works.

In this regard, it is likely that an appropriate 'planning control' can be developed [e.g. along the lines of Figure D3 in the Appendix] to define the High / Medium hazard line for a particular site. It is also envisaged that the 'planning control' would incorporate a requirement for the person / organisation proposing the development to establish:

- the detailed topography and geological strata at a particular site;
- the three-dimensional interface by reference to a diagram in the planning control [e.g. Figure D3].

6.3 Hazard Line Maps : Methodology for 2050 & 2100 Hazard Lines

As discussed in the introductory paragraphs in Section 5, the bluff area hazard lines & maps included in the Appendix [Tab E] were developed on the basis of the current recession mechanisms operating in a particular area, in combination with the geological principles and historical recession record [see sub-sections 5.1 & 5.2].

In relation to the methodology for determining the 2050 & 2100 hazard lines, these hazard lines were determined in the following manner:

a) The 2007 hazard lines were reviewed with particular regard to the propensity for any localised area to recess at a rate potentially faster than the average historical bluff recession rate.

b) The average 'median rate of bluff recession' was ascertained for the period from Figure B5.

c) The amount of the bluff recession for the selected period [viz: 2007 to 2050, or 2050 to 2100] was then calculated by reference to the median rate included in Figure B5.

d) The 2007 hazard lines were then 'stepped back' landward by the calculated amount of bluff recession, and the new hazard line plotted on the relevant hazard line map.

Subsequently, the 2050 & 2100 hazard lines were reviewed for consistency and the potential for localised areas to recess more / less than the average 'median rate of bluff recession'; afterwards, the final lines indicated on the drawings included in the Appendix [Tab D] were established.

6.4 Assumptions Underlying Hazard Maps / Lines

The various hazard lines shown on the hazard line maps included in the Appendix [Tab D] have been determined on the basis of the following:

a) A SLR of 400 mm between 1990 & 2050.

b) A SLR of 500 mm between 2050 & 2100.

c) The historical rate of recession for the various geological formations as set out in the Appendix [viz: Table B4 – Appendix Tab B].

d) An increased rate of recession over the previously observed historical rate of recession.

   Note: The increased rate assumed is the average value set out in Tables 4, 5 & 6 [see sub-sections 5.1 & 5.4].

It is also to be especially noted that the increase in recession rate assumed for the purposes of determining the hazard lines is likely to be towards the 'lower bound' of the possible increase in recession rate.

Note: An indication of the presently considered possible range of variations in the rate of recession is indicated on Figure B5 in the Appendix [Tab B]. This figure also illustrates the likely rates of recession [in metres / 100 years] for the various geological formations present within the study area.

6.5 Likely Accuracy of Hazard Lines

As noted in sub-section 3.3, the various field observations indicated some inconsistency between the locations of property boundaries and the provided LiDAR contour information. As such, when preparing the hazard lines it was assumed that the LiDAR contour information was correct, and that the 'cadastral information' was incorrect with respect to the contour information.

Despite the above, in areas where SCE had noted some significant discrepancies in the LiDAR contour information, the locations of the hazard lines were established on the basis of field observations / local experience, and other ground survey work.

In regard to the likely accuracy of the Low & Immediate High hazard lines, the ground truthing fieldwork has indicated that the plan locations of the hazard lines is likely to be at least within ± 2m of the true location, and possibly within ± 1m in many areas.

6.6 Hazard Line Maps : 2007 (present day)

The hazard lines produced for the present-day conditions are indicated on Drawings No. G1 to G6 and G9 to G12 in the Appendix [Tab E]. In relation to these hazard line maps, the following are noted:

i) The drawings also indicate the 'geotechnical hazard zones', and the 'combined bluff / beach / dune zones' which require further detailed investigations and study.

ii) The combined bluff / beach / dune zones are located at Bald Street, CTH and Pebbley Beach where the coastline recession processes involve a consideration of both beach / sand dune recession, and rock / bluff issues [see sub-section 8.2].

iii) If in the future, the beach / sand dune area is removed / eroded from in front of some of the steeper land / bluff areas, then coastal processes may commence to destabilise the steeper land / bluff areas beyond the current coastline recession zone.

6.7 Hazard Maps / Lines : 2050

The hazard line maps produced for the predicted conditions that will potentially exist in 2050 are indicated on Drawings No. G102 to G106 and G109 to G112 in the Appendix [Tab E].

The 'present day' hazard lines noted in sub-section 6.6 have been omitted from this series of drawings for clarity.

6.8 Hazard Maps / Lines : 2100

The hazard lines maps produced for the predicted conditions that will potentially exist in 2100 are indicated on Drawings No. G202 to G206 and G209 to G212 in the Appendix [Tab E].

The 'present day' hazard lines noted in sub-section 6.6 have been omitted from this series of drawings for clarity.

6.9 Properties & Buildings affected by Hazard Lines

A review of the various bluff area hazard lines and hazard zones has indicated that the following numbers of buildings / lots are affected by the various hazard zones:

TABLE 6 : LOTS / BUILDINGS AFFECTED BY IMMEDIATE HIGH HAZARD LINE

[Excludes any lots / buildings in hazard areas advised on by SMEC]

Maps	Currently Affected		Number Affected by 2050		Number Affected by 2100	
	Lots	Buildings	Lots	Buildings	Lots	Buildings
G4, G104, G204	9	7	9	7	9	12
G5, G105, G205	20	11	26	21	26	23
G6, G106, G206	11	10	26	20	31	33
G10, G110, G210	0	0	0	1	0	1
G11, G111, G211	11	4	12	6	14	9
G12, G112, G212	18	6	19	9	20	15
Totals:	**69**	**38**	**92**	**64**	**100**	**93**

Notes:
1. The numbers in the various columns represent the numbers of current [viz: 2007] buildings, at the time period stated and includes the lots / buildings from the previous time period.
2. Because of the cadastral error issues [ref: sub-section 3.4], the actual number of lots in the above table may also be in error.
3. The numbers in the various columns do NOT include any lots / buildings in areas of 'geotechnical hazard' beyond the coastline recession zone, or in the combined bluff / beach / dune zones.

7. GEOTECHNICAL HAZARD ZONES

During the course of the study, a number of areas of 'geotechnical hazard' were identified that were immediately landward of the coastline recession zone. The locations of these geotechnical hazard zones are indicated on the 2007 hazard line drawings [Appendix Tab E]. In relation to these geotechnical hazard zones the following are to be noted:

a) Many of the geotechnical hazard zones are located immediately behind the beach / sand dune areas being reported on by SMEC.

b) The geotechnical hazards are primarily landslip & soil erosion.

c) The various hazards may have a serious impact on development.

In view of the foregoing, it is important that appropriate policies and procedures be developed to identify and control the development within these areas.

Whilst advice on these areas of geotechnical hazard is beyond scope of the current work, some information on the various risks posed by these geotechnical hazard zones is included in the AGS GeoGuides included in the Appendix [Tab D].

8. IMPLICATIONS

In light of the identified hazard mechanisms, likely landward recession of the bluff areas [particularly in the areas of indurated sand], and current 'two-dimensional' method of defining the hazard lines, the studies undertaken to date have a number of implications for the way in which the hazard lines are to be finalised, and the planning controls defined for the bluff areas.

As such, the various implications of the work are briefly discussed in the following sub-sections; the conclusions from the implications are presented in the 'Executive Summary'.

8.1 Hazard Zones : Need for 3d Model

As discussed in sub-section 6.2, a two-dimensional model [viz: hazard lines on a plan] for defining a hazard zone is inappropriate because of its potential to sterilise the areas of land that could be used for building and other purposes for many years. In this regard, the following are noted:

a) The projection of bluff recession lines of 'influence' to the surface to define the hazard zone cannot consider the possibility of a building development with a basement level.

b) As bluff recession is a three-dimensional process, whilst the land at the natural surface can be potentially unstable, at depth the land may be suitable for the founding of buildings and other works.

c) From a geotechnical engineering point of view, the founding of a building structure below potentially unstable material is a common solution to the construction of structures in areas subject to instability.

d) **If,** Council continued to adopt its present policy of not permitting new development in areas of Immediate High hazard, and

established a mechanism that requires the provision of geotechnical & engineering advice for any development between the Immediate High and Low hazard lines in accordance with strictly defined parameters [e.g. as suggested in Figure D3 : Appendix Tab D],

then, currently usable land would not be sterilised, and the responsibility for the development would lie with the persons / organisations planning the development.

8.2 Combined Bluff / Beach / Dune Zone

As noted in sub-section 3.2, in some areas of the study area [i.e. Bald Street, CTH and part of Pebbley Beach], the hazard lines have currently not been determined by SMEC and / or SCE because:

a) The areas are affected by a combination of the bluff recession mechanism and the beach / sand dune recession mechanism.

b) The determination of the relevant hazard lines is a technically complex matter requiring the import of both SMEC & SCE.

In view of the above, to enable the hazard lines to be defined in the combined bluff / beach / dune zone, it is necessary for additional investigations to be undertaken in these areas and the hazard lines defined in accordance with an agreed classification system.

8.3 Planning Controls

As the bluff recession processes are a major factor in the consideration of any development on land areas within the coastline recession zone, it is very important that appropriate planning controls be implemented on both public and private land, if major economic losses are not to arise from unsuitable development. In addition:

a) As the current DCP governing development in the coastline recession zone [viz: DCP 77] is technically flawed, and does not appropriately address the various geotechnical and engineering issues associated with development in the coastline recession zone, it is important that this DCP be revised, and / or other suitable planning control implemented at an early date.

b) Whilst the Immediate High and Low hazard lines presented on the various drawings included in the Appendix [Tab E] can be regarded as reasonably 'accurate' [viz: within ± 2m] with respect to the LiDAR contour data generally, the inconsistencies between the LiDAR data and other ground survey information should be resolved prior to implementation of the planning control.

c) As it is preferable that the definition of the High / Medium hazard line [between the Immediate High and Low hazard lines] be undertaken at the time that development is proposed on an individual lot, it is necessary for Figure D3 [Appendix Tab D] to be refined and developed.

   Note: In many respects the concepts in Figure D3 are similar to the Nielsen & Poulos diagram that forms the basis of the SMEC hazard classification system.

d) As a part of the detailed High / Medium hazard line definition, the detailed topography and geology of an individual lot should be determined.

e) As there is an ambiguity as to whether or not the current DCP 77 covers the geotechnical hazard zones determined by the investigations to date, it is important that an appropriate planning control be developed to cover any future works / development planned in the areas within the 'geotechnical hazard zones'.

In regard to the planning control itself, it is considered very desirable that the hazard classification system for both the bluff areas, and beach / sand dune areas of the coastline be either the same, or at least a 'risk based' classification system that is compatible with the current AGS guidelines.

8.4 Public Infrastructure & Parks

The current studies have indicated that some of the public infrastructure constructed over the past 30 to 50 years has not adequately taken into account the very serious land stability and coastal recession issues in the study area. As a consequence, a significant amount of public infrastructure [particularly stormwater drainage & sewer systems] now needs to be reconstructed, and well ahead of the usual 'service life' of the infrastructure.

Examples of the premature deterioration of drainage & sewer works exist at CTH, Bateau Bay and The Entrance; in addition, there is a continuing issue with sewer pumping station at Toowoon Bay. Further, some of the infrastructure in National Park areas [e.g. carparks, public look-outs, toilet blocks / buildings, fences, pipelines, etc.] were noted to be very vulnerable to geotechnical hazards and coastal recession.

As a consequence, the public infrastructure must be designed to take into account the various recession processes occurring in the coastline recession zone, if the infrastructure [e.g. stormwater drainage, sewage systems, roads, buildings, etc.] is to have a life expectancy appropriate to the particular facility.

9. RECOMMENDATIONS

In light of the work undertaken to date, in conjunction with the various implications disclosed by the work, the following recommendations are made:

R1. Additional studies be undertaken co-jointly by SMEC & SCE to determine the coastline hazard mechanisms, hazard classification and applicable hazard lines, in the land areas identified in this study as being 'combined bluff / beach / dune zones'.

R2. Appropriate 'planning controls' be formulated to enable 'lot by lot' definition [at the time of development consent]. of the Medium / High hazard lines in the various bluff areas between the Immediate High & Low hazard lines.

R3. Detailed surveys be carried out in those land areas where inconsistencies have been noted between the LiDAR data, and other ground survey information, to resolve the inconsistencies and confirm the hazard line locations.

R4. The inconsistencies between the supplied cadastral data and LiDAR contour data, be resolved as a part of any additional investigations, and the formulation of the planning controls for the study area.

R5. Additional historical research be undertaken to refine the extent of historical recession, and improve the accuracy of the currently predicted recession.

R6. Additional investigations be undertaken into the various geotechnical hazard zones identified by this study to establish the type and extent of geotechnical hazards existent in the various areas. Subsequently, an appropriate policy / planning control be developed to control any future development within the geotechnical hazard zones.

10. REPORT LIMITATIONS & QUALIFICATIONS

It is to be noted that this draft report, and its various conclusions / recommendations is:

1. Based on a limited amount of investigation and analyses and for the use of the Client [viz: Umwelt (Australia) Pty Ltd], and the Wyong Shire Council in accordance with generally accepted consulting practices. No other warranty, expressed or implied, is made as to the professional advice included in this report.
2. Limited to the documentation of the geotechnical hazards in the coastline recession zone & the related recession of the coastal cliff bluffs; as such, it does include detailed comments on matters such as public infrastructure, slope stability / geotechnical hazards beyond the coastline recession zone or public safety.

At the Client's request, the report does not extend to comments / advice on the hazards associated with the recession of the beach / sand dune areas between the coastal bluffs.
Note: For information on the above, reference should be made to the reports by Umwelt & SMEC.

In addition, the following are noted:

3. Whilst a number of geotechnical hazards are identified on the maps in the Appendix to this report, these hazard areas have only been generally identified; as such, it is necessary for accurate cadastral information [with respect to the land contours] to be obtained and the geotechnical hazard zones refined as a part of the development of the detailed planning control.
4. This 'Limitations' section is to be read in conjunction with the notes headed 'SCE Engineering Reports : Information and Limitations' in the Appendix.
5. This report has not been prepared for purposes other than those stated in the Introduction to this report, nor for use by parties other than the Client, its consulting advisers and the Wyong Shire Council. As such, it may not contain sufficient information for purposes of other parties, or for other uses.

SHIRLEY CONSULTING ENGINEERS PTY LTD

Reviewed By

A F Shirley
BE(Hons.), FIEAust, CPEng(Civil), M.CIRCEA, RPEQ [4904]
Senior Consultant

David Willows
BE(Hons.), MIEAust, CPEng(Civil)
Associate

Encl. Technical Appendix

SCE ENGINEERING REPORTS : INFORMATION AND LIMITATIONS

1. Limited Scope of Report

The report to which this information sheet is attached is a 'limited scope' report; this information sheet should also be read in conjunction with the 'Report Limitations' section of the report prepared by SCE.

The report has been prepared for the Client stated in the report, for the specific purposes stated in the 'Introduction' section of the report. The 'scope of work' undertaken to enable the preparation of the report was also limited to that defined in Shirley Consulting Engineers Pty Ltd *[SCE]* Letter of Offer, and any subsequent variations agreed to by the Client. As a consequence, the report may not have addressed all of the engineering and / or geotechnical issues at the site.

Where the SCE report is a 'geotechnical report', the report is also subject to the limitations and accuracy of the information gained from a limited amount of site mapping, geological research & subsurface investigation. The geotechnical report should thus be regarded as an 'interpretive' document of limited accuracy. Geotechnical reports are also limited by the amount / accuracy of information provided by a Client, and / or the extent of information available at the time of writing the report.

2. Report for a Specific Purpose and/or Client

The report has been prepared to address the specific needs of a specific Client at a specific site, and usually for a specific project or development; as such, the report should not be used for other projects on the same site, neither should the report be used by persons other than the Client named in the report without prior permission from SCE.

3. The Report can be Misinterpreted

Engineering & geotechnical reports are technical documents that often require specialist knowledge to understand and interpret. As such, there may be occasions where further elucidation of some parts of the report may be required for some Clients or third parties. Geotechnical engineering is also a 'less exact' science than other engineering disciplines [e.g. structural engineering].

In view of the above, some Clients / design professionals can misinterpret some parts of a report and the implications of a particular engineering or geotechnical issue, and so prepare a design that is not suited for the site. Problems can also arise when design professionals develop their plans / designs for a particular project without reference to SCE; this is because the design professional will not be fully aware of the technology & thinking behind the various recommendations in the report.

It is thus recommended that SCE work with the other design professionals on the project during the planning and construction stages.

4. Substrata / Subsurface Conditions

The subsurface conditions predicted in a geotechnical report should be regarded as an 'interpretation' of the substrata, rather than a detailed, or specific prediction.

Also, where the subsurface conditions predicted in the report are based on site observations, surface mapping and the general geology of the area without a detailed site investigation, the actual subsurface conditions may vary significantly from those predicted in the report.

Where a detailed site investigation has been undertaken [e.g. test pits, boreholes, drilling, etc.] to establish the subsurface conditions, the predicted subsurface conditions still have a 'margin of error' despite the detailed work.

This 'margin of error' comes about because the prediction is based on an 'interpretation' of the materials that are likely to exist under the ground between the discrete sampling points [viz: the test pits / boreholes] or other subsurface probing.

In the event that the subsurface conditions encountered during the course of construction appear to be significantly different from those expected from the information contained in the report, then it is important that the Client immediately notify SCE, and request SCE to advise on the apparent difference, or anomaly.

5. Construction Issues

As many construction problems / failures arise from a misunderstanding of a site's geotechnical & engineering issues, it is prudent for both the report's recommendations and the predicted subsurface conditions to be confirmed by SCE during the course of the construction processes. Further, where the actual subsurface conditions are different to those predicted, SCE can provide advice on the design changes required as a result of the different subsurface conditions.

Where a Client decides to use a different geotechnical engineer [or allied professional] to undertake the construction review process rather than SCE, significant difficulties [and associated cost issues] can arise with the interpretation of site conditions. This is because SCE [as the author of the original report], is more likely to have a fuller understanding of the site's substrata and its potential effects on the construction processes.

SCE also consider that a Client should be wary of accepting geotechnical advice from non-geotechnical professionals [e.g. civil engineers, structural engineers, etc.], or engineering advice from non-engineers [e.g. engineering geologists].

6. Site Contamination and Environmental Issues

SCE reports do not usually provide information on the findings, conclusions, or recommendations about potentially hazardous materials occurring at a site; this is because the equipment, techniques and personnel used to undertake environmental studies and exploration differ substantially from those used in geotechnical and civil engineering studies.

As site contamination from any source can create major problems, should a Client suspect that the site has any contamination, then it is prudent for the Client to engage a specialist environmental consultant to advise on the possible site environmental and contamination issues.

7. Reproduction of Information

Where the information contained in a geotechnical report prepared by SCE is to be provided for contract or tender purposes, SCE recommends that ALL the information contained in the report [including the written text and any appendix material] be made available to potential tenderers / contractors. SCE also strongly advises against a Client being selective about the geotechnical information to be provided to third parties.

Where a Client considers that some sections of a report are not relevant to a third party in a particular situation, then it may be appropriate for SCE to prepare an especially edited document for the third party.

INDEX TO TECHNICAL APPENDIX

SCE ENGINEERING REPORTS : INFORMATION AND LIMITATIONS

TAB A : Geological Notes, Reference List & Locality Plans

LIST OF GEOLOGICAL NOTES

Abbreviation	Description
Qpa	Indurated / Cemented Sands
Rnp	Patonga Claystone
Rnu	Tuggerah Formation
Rnm	Munmorah Conglomerate

List of References.

Drawing No. BM001A1 : Study Area Locality Plan

Drawing No. BM001A2 : Study Area Map Index Sheet

Drawing No. BM001A3 : Study Area Geological Map – Geological Legend

Drawing No. BM001A4 : Study Area Geological Map – South [1: 10,000]

Drawing No. BM001A5 : Study Area Geological Map – North [1: 10,000]

TAB B : Recession Mechanism Tables & Photographs

Table B1	Summary of Bluff Recession Mechanisms
Table B2	Recession Models – Current Processes & Locations Within Study Area
Table B3	Hazard Line Relationships
Table B4	Historical Recession
Figure B5	Postulated Recession Graph
Plates P1 to P14	Illustrative Photographs of Recession Mechanisms

TAB C : Hazard Line Relationships [viz: recession mechanisms]
[Presented in Generic Form on various sections]

Mechanism	Mechanism Sketch Diagram / Drawing	Mechanism Description	Applicable Geology
A	BM001G21	Indurated Sands	Qpa, Qhs
B & C	BM001G22	Soil & Fill Creep on Slopes Rock Block Differential Weathering	Rnp, Rnu, Qhs, Qhmf
D & E	BM001G23	Dyke Induced Rock Recession Instability of Weathered Rock Slope	Rnu, Rnp, Qhs

TAB D : Bluff Area Hazard Classification System, Mechanisms & Landslide Risk Notes

Table D1	Bluff Area Hazard Classification System *[related to AGS guidelines]*
Table D2	Bluff Area Hazard Line Definitions
Figure D3	Possible Method of Defining the Medium / High Hazard Interface, on a Lot by Lot basis

AGS Australian Geoguides

LR2 : Landslides; LR3 : Landslides in Soil; LR4 : Landslides in Rock;
LR7 : Landslide Risk; LR10 : Coastal Landslides

TAB E : Hazard Line Drawings

Drawings No. BM001G1-G6 & G9 to G12 1:4000 [reduced scale] hazard lines 2007 [present day]
Drawings No. BM001G102-G106 & G109 to G112 1:4000 [reduced scale] hazard lines 2050
Drawings No. BM001G202-G206 & G209 to G212 1:4000 [reduced scale] hazard lines 2100

Note: The 1:4000 scale drawings [viz: A3 size] produced in the hard copy version of the report appendix were originally compiled at a scale of 1:2000 [viz: A1 size]. The electronic version of the ‘full size’ drawings is included on the DVD attached to back cover of the report.

TAB F : Background Information

Document	Description	Date(s)
FA	Extract from 1:4,000 Orthophoto Map [U3697-3] of Bateau Bay	Photo 23/09/1985
FB	Bateau Bay history; extract from “Down Memory Lane” by Robyn Stewart and Lynne Webster, page 108.	2007
FC	Survey plan of Long jetty, Toowoon Bay and Blue Bay area. Plan of Portion MP14, County of Northumberland, Parish of Tuggerah	July 1888
FD	Survey Plan of The Entrance and Blue Bay area. Plan of Portion MP8, County of Northumberland, Parish of Tuggerah	26 June 1890
FE	Comparison of photos of The Entrance Baths. Stinson Vol 4, page 84 SCE photo dated 2009.	Early 1900’s and 2009
FF	Plan of Norah Head area. Plan of the Village of Norah, Parish of Wallarah, County of Northumberland.	1878 to 1942
FG	Comparison of photos of Cabbage Tree Harbour. Extract from Stinson Vol 5, pp 121 SCE photo dated 2007	Circa 1920? 5/12/2007
FH	Comparison of photos of Cabbage Tree Harbour. Extract from Stinson Vol 4, pp 123 SCE photo dated 2010	Circa 1920 - 1950 2010
FI	Traced survey plan of Hargraves Homestead Extract from Stinson Vol 4, pp 116	1867

GEOLOGICAL NOTES ON THE PATONGA CLAYSTONE

The Patonga Claystone (Rnp) comprises the uppermost portion of the Clifton Sub-Group. This group of rocks belongs to the lower part of the widespread Narrabeen Group and are of Early Triassic Age [250 to 240 Million Years before present].

This sequence crops out from Lake Macquarie in the north and thickens toward its southern outcrop limits near Wamberal and Wyong. The Patonga Claystone, together with the underlying Tuggerah Formation (Rnu), form distinctive 'red beds' consisting of interbedded sandstones, siltstones and claystones. These sediments were deposited by meandering streams flowing from the northwest, with the Patonga Claystone comprising fine-grained over bank deposits. The rock units are generally thinly to very thinly bedded, with low angles [about 1°-2°] of dip to the south and west.

In the field, the Patonga Claystone is generally characterised by relatively thin [1.25m to 2m thick] surficial soils underlain by very deeply and extremely weathered bedrock of low bearing capacity. The extremely weathered bedrock of the Patonga Claystone is also visually very similar to the overlying residual soil [stiff red / brown mottled silty clay].

The susceptibility of the strata to weathering and the lack of the thick sandstone beds typically result in the formation of relatively featureless slopes without obvious outcrop. Examples of the typical terrain formed by weathering of the Patonga Claystone are below The Entrance Road near Wamberal, and the coastal slopes at Crackneck and Yumbool Point, south of Bateau Bay, New South Wales.

Common geotechnical problems encountered in sites underlain by the Patonga Claystone include:

- Landslip Areas.
- Erosion prone soils.
- Soil Creep.
- Shrink / swell movement of foundation strata.

Areas of particular concern are where the Patonga Claystone outcrops on sloping ground, where the weathering of the claystone results in a highly plastic clay soil that loses strength when wet.

Strong seepage flows are a characteristic of the junction of the Patonga Claystone with the overlying Terrigal Formation; as such, areas of landslip and soil creep are common near this interface. Local areas of minor seepage within the Patonga Claystone have also been observed and emanate from the ground surface as springs or seeps. There is also a general seepage path along the base of the colluvial soil horizon. The groundwater is generally saline and unsuitable for domestic or stock purposes.

Sources: R. Uren, Geol Surv. N.S.W. Bull. 26.
SCE Job Files

GEOLOGICAL NOTES ON THE TUGGERAH FORMATION

The Tuggerah Formation (Rnu) overlies the Munmorah Conglomerate and is exposed in the headland and cliff areas at Norah Head, Noraville, Jenny Dixon Beach and Cabbage Tree Harbour. The Formation also outcrops in the rock platforms at The Entrance, Blue Bay and Toowoon Point.

The Tuggerah Formation is part of the Triassic age Narrabeen Group that underlies the chocolate / brown claystone formation known as the Patonga Claystone. The rock unit generally consists of a lithic sandstone, with minor constituents of red / brown and grey / green claystone, siltstone and minor conglomerate & pebbly bands. The sandstones are typically lithic, with a very low percentage of detrital quartz, the majority of which is of volcanic origin. The main cementing agent of the Formation is calcite, rather than siderite, and this water soluble cement can give rise to localised porous zones within the bedrock.

Where significant siltstone / claystone bands occur within the Tuggerah Formation, at the level of the 'wave / tide zone' [e.g. at the Roslyn Place headland at Noraville], extensive undercutting of the bluff area can occur and so lead to very vulnerable cliff overhangs which are capable of sudden failure.

In addition, weathering [due to groundwater seepage, wave / wind action, etc.] of the regular joints within the massive sandstones comprising the Formation commonly lead to very large rock block failures from exposed parts of the headland. Examples of such large rock falls can be seen on the beach areas below the headlands near Macquarie Street, Cabbage Tree Harbour and the headlands near Hargraves Street, Roslyn Place & Ada Avenue at Noraville.

Effect of Dykes / Igneous Activity

Igneous activity is widespread in the Wyong / Tuggerah Lake area and where igneous dykes have intruded into the sandstones of the Tuggerah Formation, extensive zones of fracturing and open rock joints are to be expected. Such dyke structures can significantly affect the parent bedrock properties, and allow much higher rates of groundwater seepage, erosion and weathering to occur within the zone of influence of the dyke. Rapid rates of cliff line recession and rockfall are usually associated with the increased groundwater infiltration and bedrock erosion in the vicinity of an igneous dyke intrusion.

Coastal Recession Processes

In bluff areas where the Tuggerah Formation is exposed, large rock block overhangs develop and unstable rock blocks fall from the cliff face, the pre-existing horizontal stresses within the rock mass are released and lateral strain of the rock mass occurs. This lateral strain then causes opening of the rock joints behind the cliff face, with the amount of opening depending on the distance behind the rock face. Thus, where structures are located within the 'zone of influence' of the cliff, the potential for opening of joints behind a cliff face is an important factor in footing design.

The engineering implications of the foregoing in consideration of site development in areas underlain by the Tuggerah Formation are thus:

a) Where the Tuggerah Formation occurs, the cliff / headland can be stable for many years [perhaps hundreds of years] with virtually no recession; then a sudden and large scale recession takes place as a result of a large rock block failure.

b) Within the 'zone of influence' of the cliff face / headland, the opening of the rock joints behind the cliff face can cause damage to footing systems not designed to take account of lateral strain.

GEOLOGICAL NOTES ON THE MUNMORAH CONGLOMERATE

The Munmorah Conglomerate is a largely lithic to quartz-lithic, medium to very coarse grained sandstone and granule to pebble conglomerate.

The Munmorah Conglomerate was formed by coarse detritus from the nearby New England Fold Belt being transported & deposited as a large alluvial fan complex. This detritus prograded south-westwards over the sandy and silty coastal outwash sediments now known as the Dooralong Shale.

The unit ranges in thickness from 50 m to 120 m and underlies much of the elevated land within the Morisset / Lake Macquarie. At Chain Valley Bay, borehole data indicates a unit thickness of about 115 m; also, at Norah Head the strata dips locally to the south-west at between 1° and 2°.

The majority of the Munmorah Conglomerate is typically a conglomerate [viz: pebbly sandstones, fine to medium grained sandstones and some siltstones]. The sandstones and conglomerates commonly grade into one another and exhibit lateral and vertical textural variations. Clast sizes range up to 25 mm and consist of subrounded to subangular red and brown jasper, green chert and lithic fragments, black, grey and white quartzite and white claystone and siltstone. The unit also has some minor bands of siltstone / claystone.

The members of the conglomerate are described as follows:

Conglomerate member

The conglomerate is usually consistently fresh and medium strong, to strong. Further, whilst the typical unconfined compressive strength of the rock is between 10 and 50 MPa, in places rock strengths of up to 70 MPa can be expected. The amount of pebbles within the conglomerate also varies greatly, with some parts of the conglomerate having very few pebbles, whilst other parts being predominantly pebbles with very little sandy clay matrix.

Siltstone / claystone member

By contrast to the conglomerate member, the siltstone / claystone member is relatively soft rock [viz: typical UCS < 10 MPa] and deteriorates rapidly upon exposure.

The Munmorah Conglomerate is underlain by the Dooralong Shale & the Newcastle coal measures.

Source:

R. Uren, in C. Herbert and R. Helby 1976, Geol. Surv. of N.S.W. Bull 26, pp. 162 to 168.

GEOLOGICAL NOTES ON CEMENTED / INDURATED SANDS [Qpa]

These notes have been prepared to assist in the understanding of the cemented and indurated sands occurring on the east coast of NSW, in particular the northern Sydney basin. These notes also provide information on the geological formation processes, some engineering properties and some of the typical issues that need to be considered when dealing with these sands.

Note: Whilst the terms 'cemented' and 'indurated' sand are often used interchangeably [as the formation processes and properties are generally similar], the differences between the two types of sand are important, and can give rise to significant differences in field performance and engineering treatment.

1. Geological Formation

Both the 'cemented' and 'indurated' sands of the NSW coastline were deposited during the Pleistocene age [about 10,000 to 1.78 million years ago] and form the inner barrier system of a large proportion of the coast. The sands were typically deposited by beach ridge progradation during the last inter-glacial period [viz: at the high sea level]. After deposition, the sand materials were altered to form either 'Cemented', or 'Indurated' sands as follows:

a) *Cemented Sands:* the sediments remain relatively undisturbed for a long period of time and under high pressure from overburden soils; due to the high pressure, cementation occurs of the individual grains. The sediments formed by this environment are termed 'cemented' sediments [typically sands and silts].

b) *Indurated Sands:* marine regression allowed the formation of lagoon systems providing a source of iron and organic mineral rich waters, or humic acids. Along with high pressures from the overburden soils, these waters then leached through the sand barriers resulting in the precipitation of iron and other organic minerals through the sand material. These minerals give the sand a reddish brown to yellow brown colour, which often leads to them being described as a 'coffee rock' [or similar]. This leaching process usually results in 'bands' or 'indurated' layers forming within the sands.

2. Problems with Indurated Sands

As indurated sands gain their strength from the precipitation of leached minerals, groundwater flows or exposure of the sand surface results in these minerals being dissolved; as a consequence, indurated sand areas that are below the water table are much weaker than dry indurated sand areas. Also, as the bonding of the sands is typically weak, dry 'indurated' sands are typically friable.

An additional issue with the friability of the sand is that differential water flows through the sand mass can cause the formation of 'pipes' through the sand mass. These 'pipes' can leave sections of the indurated sand having the appearance of a 'sponge'. This 'sponge' then creates localised porous zones, which in turn allow increased groundwater flows and the transportation of sand and other particles through the sand mass.

3. Engineering Properties

In engineering terms, 'cemented' and 'indurated' sands above the water table typically exhibit high cohesion values [viz: >25 kPa and up to 100 kPa] and high angles of internal friction [typically > 40°]. However, below the water table, the strength of an indurated sand becomes less because of a reduction in the 'cohesion' to typically 5 to 20 kPa.

Also, whilst indurated sands can exhibit a high strength that typically results in solid foundation material, the presence of 'soil pipes', or 'sponge' like materials in some areas can cause any 'point loads' on the material to collapse the 'sponge' and so cause the groundwater flows through the sand mass to be re-arranged.

Source:

Chapman et al 1982 'Coastal Evolution and Coastal Erosion in New South Wales' Coastal Council of New South Wales.

LIST OF REFERENCES

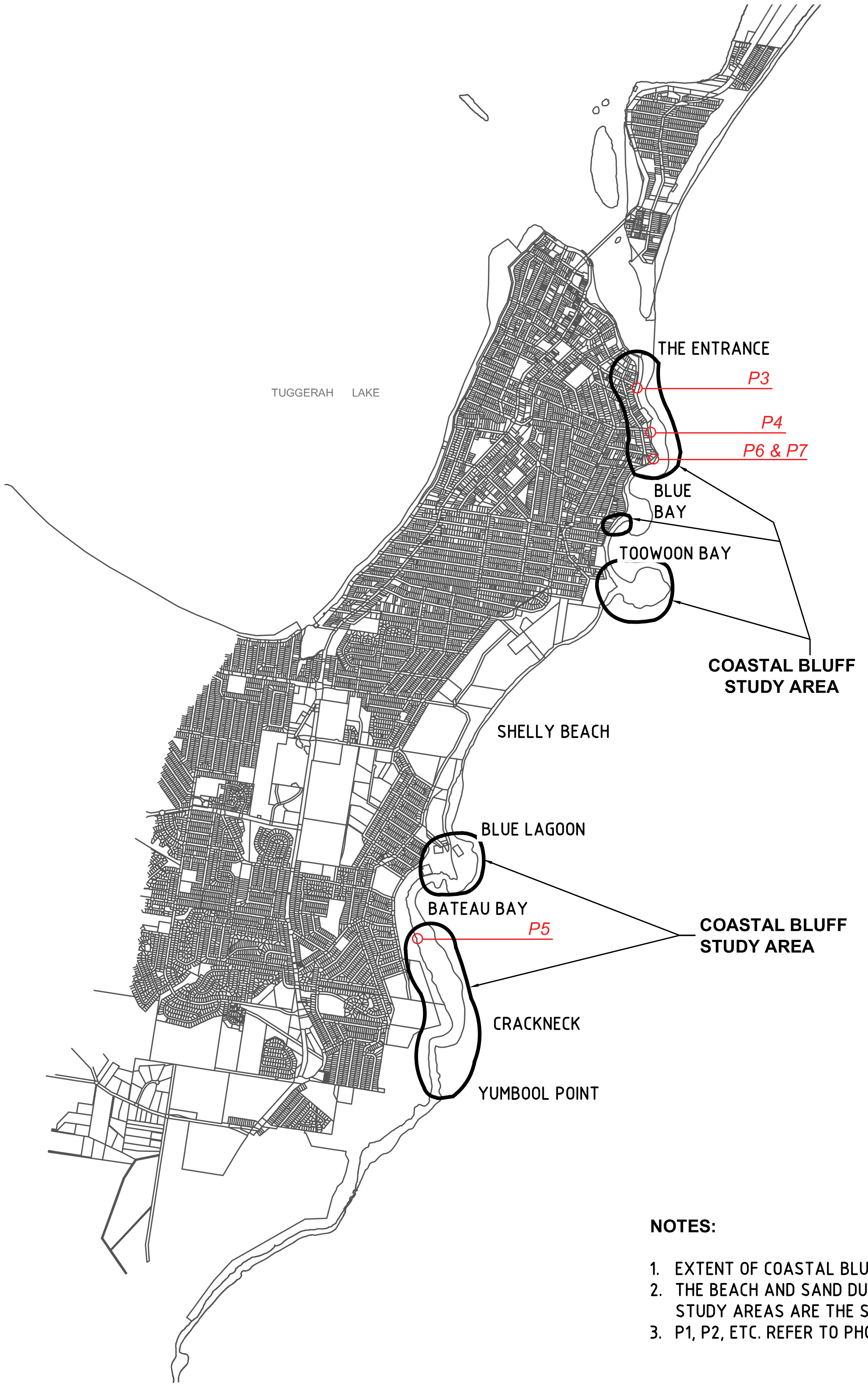
Reference No.	Title	Author
R1	Draft report on geotechnical studies and identified hazards for the Wyong Shire Coastline	SCE [11 October 2004]
R2	Draft Coastal Risk Management Guide: incorporating SLR benchmarks in coastal risk assessments.	DECCW [February 2009]
R3	Landslide Risk Assessment Guidelines : [March 2007].	Australian Geomechanics Society
R4	Sea-level rise around the Australian coastline and the changing frequency of extreme sea-level events.	John A Church, John R Hunter, Kathleen L McInnes, Neil J White [July 2006]. Aust. Met. Mag. 55 (2006) 253-260.
R5	Dune Stability Considerations for Building Foundations. Referred to by SMEC as a "*Dune Stability Schema*"	Nielsen, Lord & Poulos Vol. CE34 No. 2 June 1992.
R6	Projected Changes in Climatological Forcing for Coastal Erosion in NSW.	McInnes et al [CSIRO & DECC] August 2007.
R7	Engineers Australia Policy on Climate Change & Energy – April 2008	Engineers Australia
R8	Wyong Coastal Hazard Study : Main Report [Draft] SMEC Project No. 3001053	SMEC Australia Pty Ltd
R9	Sydney Harbour Sea Level Rise Vulnerability Studies.	Phil Watson, Doug Lord and Cath Snelgrove [2009].
R10	Report No. 3: Climate Change Impact on the Hunter, Lower North Coast and Central Coast of NSW [2009].	HCCREMS K L Blackmore & Ina D Goodwin.
Note: There are many other references included in the SCE 2004 report in relation to the sources of the geotechnical information that form the technical basis of this report.		

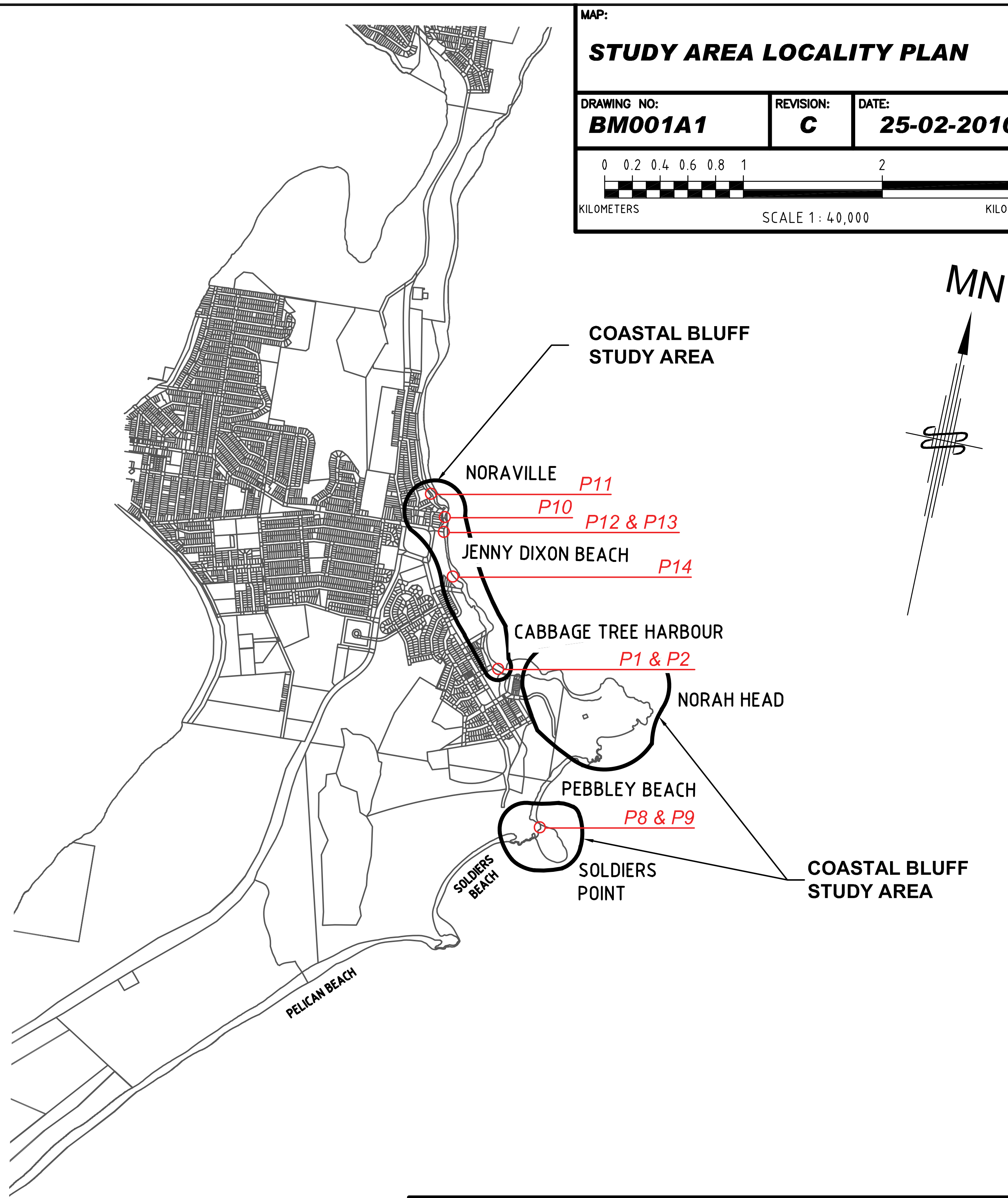
MAP:

STUDY AREA LOCALITY PLAN

DRAWING NO:	REVISION:	DATE:
BM001A1	C	25-02-2010

SCALE 1 : 40,000 (KILOMETERS)





NOTES:

1. EXTENT OF COASTAL BLUFF STUDY AREAS ARE APPROXIMATE ONLY.
2. THE BEACH AND SAND DUNE AREAS WITHIN THE IDENTIFIED COASTAL BLUFF STUDY AREAS ARE THE SUBJECT OF ADVICE / REPORT BY SMEC.
3. P1, P2, ETC. REFER TO PHOTOS IN THE REPORT.

TITLE:

COASTLINE HAZARD MANAGEMENT STUDY
WYONG SHIRE COUNCIL

FIELDWORK: **DPW / HM**
DRAWN: **WH**

This plan is to be read in conjunction with Shirley Consulting Engineers Pty Ltd Geotechnical Report No.

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PTY LTD ABN 65 001 224 728
CONSULTING & FORENSIC ENGINEERS

895 PACIFIC HIGHWAY
PYMBLE NSW 2073
Ph (02) 9449 5577

P.O. BOX 439
PYMBLE NSW 2073
Fax (02) 9449 5136

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TITLE:

STUDY AREA MAP INDEX SHEET
COASTLINE HAZARD MANAGEMENT STUDY
WYONG SHIRE COUNCIL

DRAWING NO: **BM001A2**

REV: **B**

NORAVILLE
G12, G112, G212

CABBAGE
TREE HARBOUR
[CTH]
G11, G111, G211

NORAH
HEAD
G10, G110, G210

PEBBLEY BEACH (NOT REPORTED ON BY SCE)

SOLDIERS
POINT
G9, G109, G209

THE ENTRANCE TO TUGGERAH BEACH (NOT REPORTED ON BY SCE)
G7 AND G8 ARE NOT USED

KARAGI
POINT
G6, G106, G206

BLUE
BAY
G5, G105,G205

TOOWOON
BAY
G4, G104, G204

SHELLY BEACH AREA (NOT REPORTED ON BY SCE)

BATEAU
BAY
G3, G103, G203

CRACKNECK
G2, G102, G202

YUMBOOL
POINT
G1

NOTES:

1. G1, G2 ETC. REFER TO 'PRESENT DAY' HAZARD LINES MAPS BM001G1 TO BM001G12 [VIZ: 2007].
2. G102, G103 ETC. REFER TO '2050' HAZARD LINES MAPS BM001G102 TO BM001G112.
3. G202, G203 ETC. REFER TO '2100' HAZARD LINES MAPS BM001G202 TO BM001G212.

REVISION	DATE	DETAILS	CHECKED
B	10-03-2010	ADJUSTED NOTES AND MAP NAMES	AFS
A	25-02-2010	INITIAL ISSUE	AFS

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CLIENT: **WYONG SHIRE COUNCIL**

DRAWN: **WH**

CHECK: **AFS**

DATE: **24-2-2010**

MAP:
STUDY AREA GEOLOGICAL MAP - GEOLOGICAL LEGEND

DRAWING NO:	REVISION:	DATE:
BM001A3	**A**	**10-05-2010**

LEGEND

Graphical Symbol	Geology Symbol	Formation	Age	Lithology	Depositional Environment or form
	Qha	-	Quaternary (Holocene)	Gravel, Sand Silt, Clay	Alluvium and swamp
	Qhs	-	Quaternary (Holocene)	Quartz Sand	High level aeolian sand, forming thin cover over bedrock
	Qhd	-	Quaternary (Holocene)	Quartz Sand	Dune, Landslide debris and Holocene barrier
	Qhb	-	Quaternary (Holocene)	Quartz sand	Beach and Holocene Barrier
	Qhmf	-	Quaternary (Holocene)	Rock, Sediment, Concrete etc.	Man made fill
	Qha	-	Quaternary (Holocene)	Sand, Silt and Clay	Estuarine
	Qpa	-	Quaternary (Pleistocene)	Indurated and Cemented Sand	Dune and Pleistocene
	Rnt	Terrigal Formation	Early Triassic	Lithic-quartz to quartz sandstone, siltstone, minor sedimentary breccia, claystone and conglomerate	Meandering alluvial
	Rnp	Patonga Claystone	Early Triassic	Red-brown and grey-green claystone and siltstone, grey siltstone and laminite, fine lithic sandstone.	Alluvial plain, channel and lacustrine.
	Rnu	Tuggerah formation	Early Triassic	Lithic sandstone, red-brown and grey-green claystone and siltstone, grey siltstone and laminite, rare conglomerate.	Alluvial channel, plain and lacustrine.
	Rnm	Munmorah conglomerate	Early Triassic	Conglomerate, pebbly sandstone, sandstone, grey-green and grey siltstone and claystone	Alluvial Fan

? ——•——•——•—— ? DYKES (POSITION INFERRED)

——•——•——•—— DYKES (POSITION ACCURATE)

TITLE:
COASTLINE HAZARD MANAGEMENT STUDY
WYONG SHIRE COUNCIL

FIELDWORK: **DPW / HM**
DRAWN: **WH**

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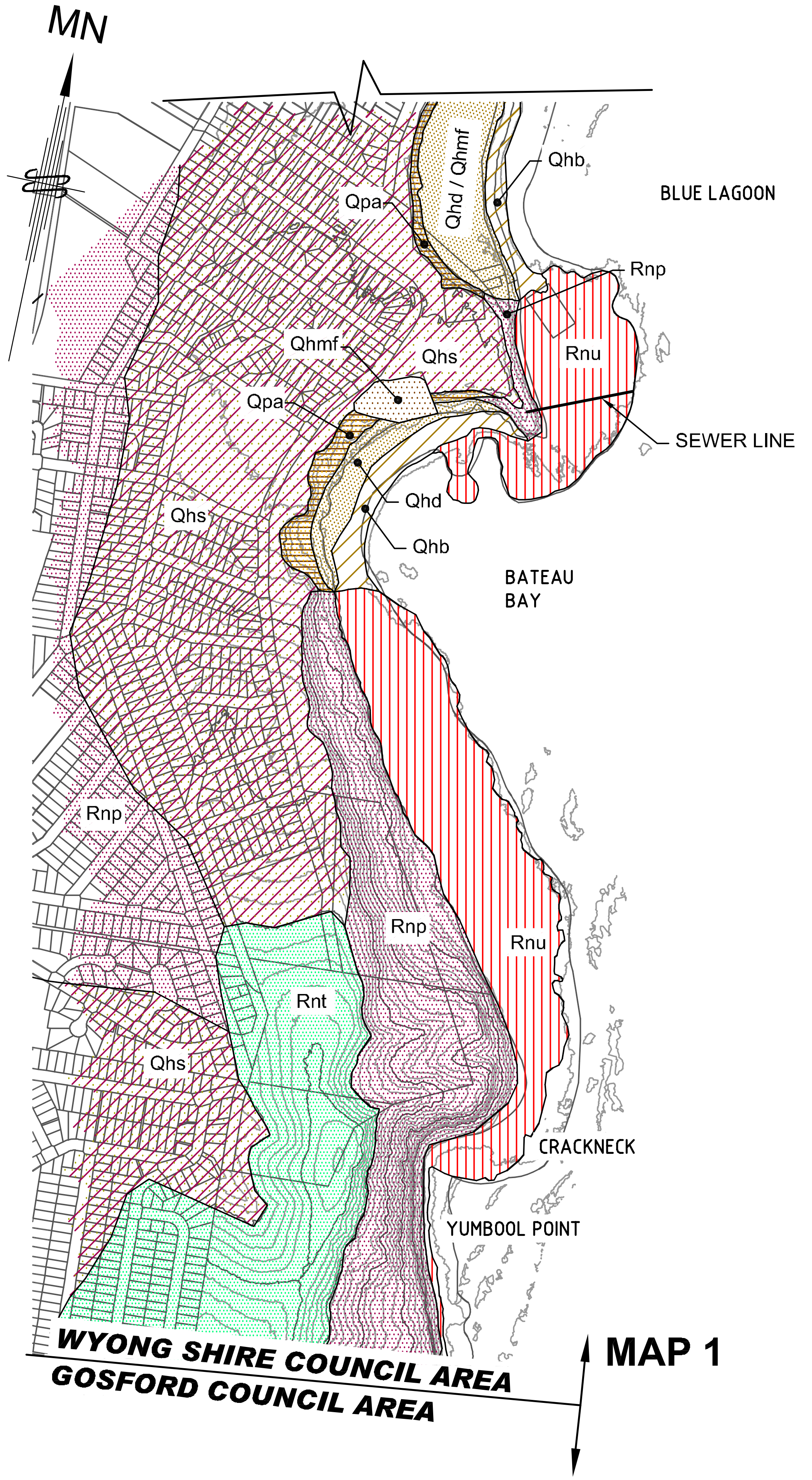

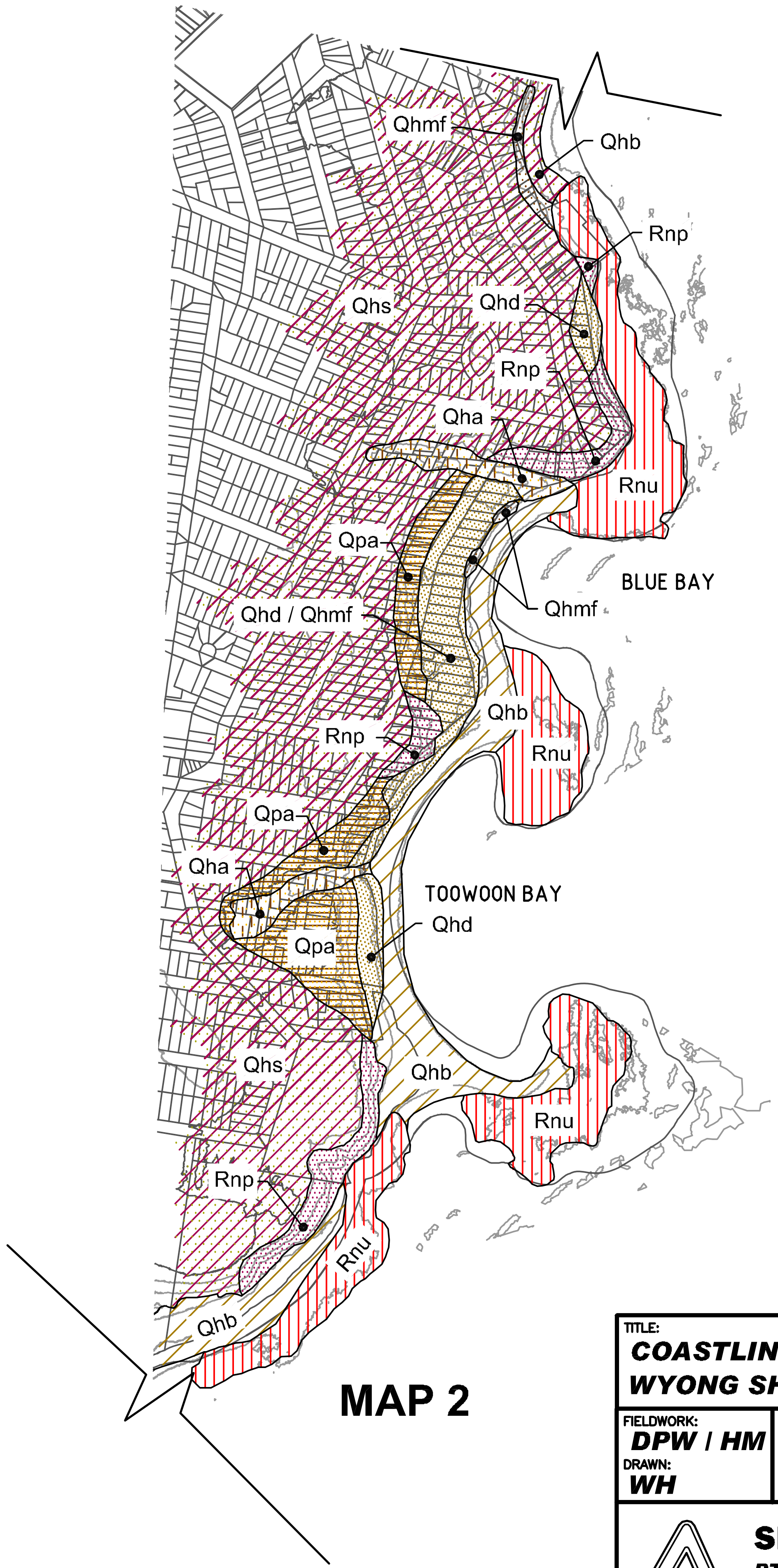

MAP:

STUDY AREA GEOLOGICAL MAP - SOUTH

DRAWING NO:	REVISION:	DATE:
BM001A4	**A**	**10-05-2010**

METRES 0 10 20 40 600 METRES

SCALE 1 : 10,000 @ A3

TITLE:

COASTLINE HAZARD MANAGEMENT STUDY
WYONG SHIRE COUNCIL

FIELDWORK: **DPW / HM**

DRAWN: **WH**

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CONSULTING & FORENSIC ENGINEERS

895 PACIFIC HIGHWAY
PYMBLE NSW 2073
Ph (02) 9449 5577

P.O. BOX 439
PYMBLE NSW 2073
Fax (02) 9449 5136

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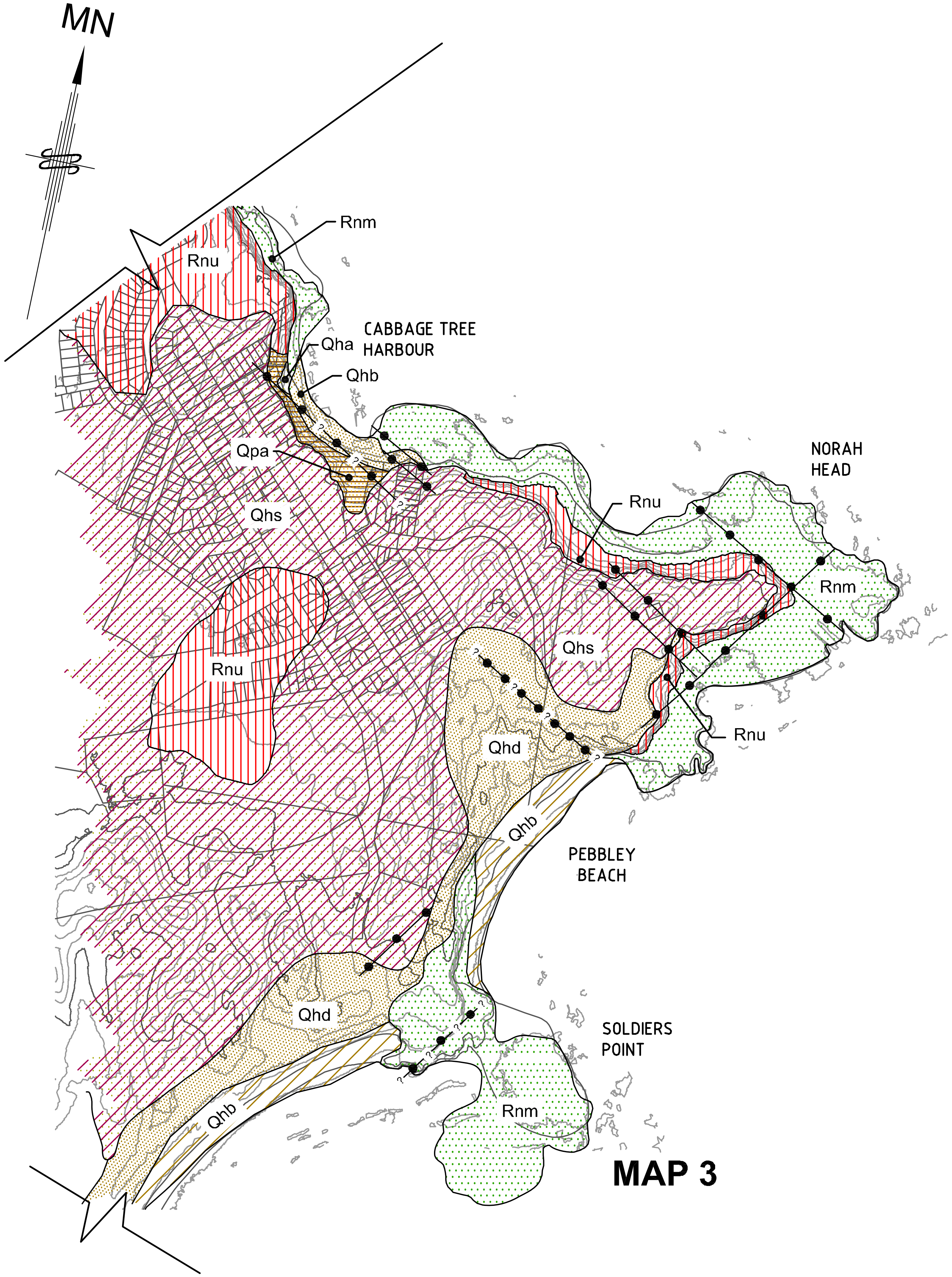
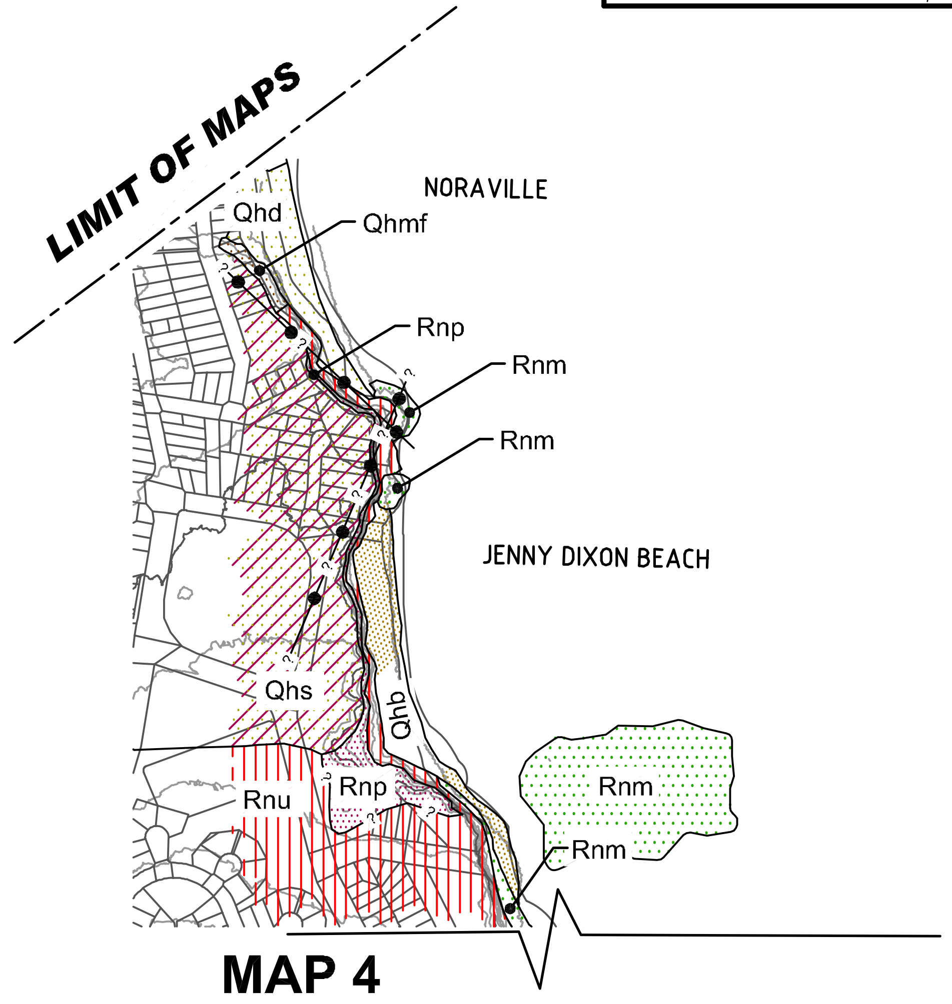
MAP:
STUDY AREA GEOLOGICAL MAP - NORTH

DRAWING NO:	REVISION:	DATE:
BM001A5	**A**	**10-05-2010**

METRES 0 10 20 40 600 METRES
SCALE 1 : 10,000 @ A3





TITLE:
COASTLINE HAZARD MANAGEMENT STUDY
WYONG SHIRE COUNCIL

FIELDWORK: **DPW / HM**
DRAWN: **WH**

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