NOTICE OF FILING

Details of Filing

Document Lodged:	Expert Report
Court of Filing	FEDERAL COURT OF AUSTRALIA (FCA)
Date of Lodgment:	3/08/2023 3:22:18 PM AEST
Date Accepted for Filing:	3/08/2023 3:22:22 PM AEST
File Number:	VID622/2021
File Title:	PABAI PABAI & ANOR v COMMONWEALTH OF AUSTRALIA
Registry:	VICTORIA REGISTRY - FEDERAL COURT OF AUSTRALIA

SEAL OF THE FEDERAL COURT OF AUSTRALIA

Registrar

Important Information

This Notice has been inserted as the first page of the document which has been accepted for electronic filing. It is now taken to be part of that document for the purposes of the proceeding in the Court and contains important information for all parties to that proceeding. It must be included in the document served on each of those parties.

The date of the filing of the document is determined pursuant to the Court's Rules.

REPORT

Expert Report of Stuart Bettington

Pabai & Anor v Commonwealth of Australia (VID622/2021)

Client:

Reference: PA3434-RHD-AU-ZZ-RP-C-0001

Status: Final/01

Date: 3 August 2023

Royal HaskoningDHV
Enhancing Society Together

HASKONING AUSTRALIA PTY LTD.

Level 10 Suite B
333 Ann Street
Brisbane 4000
Australia
Water & Maritime

[redacted] **E**
royalhaskoningdhv.com **W**

Document title:	Expert Report of Stuart Bettington
Subtitle:	Pabai & Anor v Commonwealth of Australia (VID622/2021)
Reference:	PA3434-RHD-AU-ZZ-RP-C-0001
Your reference	VID622/2021
Status:	Final/01
Date:	3 August 2023
Project name:	Pabai v Commonwealth
Project number:	PA3434
Author(s):	Stuart Bettington
Drafted by:	Stuart Bettington
Checked by:	
Date:	
Approved by:	
Date:	

Classification
Open

Royal HaskoningDHV

Table of Contents

Table of Tables

Table of Figures

Appendices

Royal HaskoningDHV

1 Introduction

Stuart Bettington, through Haskoning Australia Pty Limited, a company of Royal HaskoningDHV (RHDHV), has been retained by Uncle Pabai and Uncle Paul Kabai (Applicants) to act as an independent expert in the matter of Pabai & Anor v Commonwealth of Australia, VID622/2021 (Proceeding).

Uncle Pabai and Uncle Paul Kabai (Applicants) are being represented by Phi Finney McDonald (Legal Representative) and have provided a retainer for Stuart Bettington via a letter dated 1st June 2023 (refer Appendix A) and a letter of instruction dated 21st June 2023 (refer Appendix B) and further instructions dated 4th July 2023 (refer Appendix C).

The letters of instruction from Phi Finney McDonald dated 21st June 2023 and 4th July 2023 request a response to the questions outlined in the following sections.

In preparing this report Stuart was assisted by Mr. Paul Prenzler (a Principal Coastal Engineer) who checked the report. Notwithstanding the opinions expressed in this report are those of Stuart Bettington.

1.1 Statement of experience for Stuart Bettington

Letter of Instruction question A:

A. Introduction

1. Please describe your academic qualifications, professional background, and experience in the field of coastal engineering, and any other training, study, or experience that is relevant to this brief (you may wish to do so by reference to a current curriculum vitae).

In answering questions 2-15, please adopt the following assumptions:

i. As at 2023, global mean sea level has increased by approximately 21cm when compared with global mean sea level at 1900 (the Baseline).

ii. *'Extreme sea level event' means:*

> *An event involving different phenomena (such as storm surges, high tides etc.) combining to result in relatively rare and temporary (usually a few days or less) increases (or decreases) in sea level height above (or below) what is normally expected.*

iii. *Your answers are to be given by reference to each of the following islands within the Torres Strait:*
   a. Saibai;
   b. Boigu;
   c. Poruma; and
   d. Warraber.
   (Mapped Islands)

Response:

I have received the following academic qualifications:

- Bachelor of Engineering (Civil) with Honours from the University of NSW in 1990; and,
- Master in Engineering Science (Water) from the University of NSW in 1994.

Currently, I retain recognised professional status confirmed by my registration as:

- Professional Member of the Institution of Engineers Australia (College of Civil Engineers) since 1995
- Registered Professional Engineer Queensland (RPEQ)
- National Professional Engineering Register (NPER-3)

Since graduation I have worked as a Civil Engineer within academic institutions, state government agencies and international consulting engineering firms. With over 30 years of experience in coastal and maritime engineering, I have practised coastal and maritime engineering across every state in Australia and internationally across the Pacific and Asia. Of specific relevance to this report, I have over 12 years of experience in the Torres Strait delivering hazard assessments including in respect of foreshore erosion, inundation and flooding and navigation. I have also undertaken extensive design in the Torres Strait including seawalls, flood barriers, dredging and marine infrastructure such as jetties, pontoons, breakwaters and barge ramps.

As part of my ongoing contribution to the industry and as a demonstration of continuing professional development I am on the organising committee for the Australasian Coasts and Ports Conferences and have written numerous peer reviewed technical papers. Examples include:

- 'Morphology and Harbour Siltation at Cape Ferguson', 2023 Australasian Coasts and Ports Conference, Sunshine Coast.
- 'Climate Change Impacts on Reef Top Islands', 2022 International Conference on Coastal Engineering, Sydney.
- 'Morphology of Reef Top Islands and Impacts of Climate Change', 2021 Australasian Coasts and Ports Conference, Christchurch.
- 'A Guide to the use of Geographical, Geological and Ecological Features to Support Coastal Engineering Design ', 2019 Australasian Coasts and Ports Conference, Hobart.
- 'Coastal Engineering Solutions for Remote Island Communities', 2017 Australasian Coasts and Ports Conference, Cairns.
- 'Adaptation to Climate Change in Design - SH16 Causeway Upgrade', 2015 Australasian Coasts and Ports Conference, Auckland.
- 'Adaptation to coastal erosion and marine inundation on Torres Strait Islands', 2013 Australasian Coasts and Ports Conference, Sydney.

My current role is as a Technical Director at the internationally recognised Dutch consulting engineering company, Royal HaskoningDHV, located in their Brisbane office. In this role, I provide technical oversight to work undertaken by the large coastal and maritime teams in Australia, the Pacific region and South East Asia and undertake all aspects of project delivery from site inspections, approvals design and documentation, construction supervision and project management. Areas of practice include coastal processes, dredging, ocean outfalls, environmental considerations and adaptation, breakwater or revetment design, piling, flood assessment and mitigation, and the collection and analysis of coastal data. In recent years I have developed considerable expertise in tropical and remote coastal and marine works.

Prior to joining Royal HaskoningDHV, I led the ANZ coastal engineering team in the large US consultancy firm AECOM for 11 years. Before this I worked as a Senior Engineer in another large US consultancy firm, KBR, for 9 years undertaking a wide range of coastal and maritime projects. I have also held positions as Senior Engineer in the Queensland Government on the Tweed River Entrance Sand Bypassing Project gaining experience in coastal processes, dredging, construction and contract implementations and at the Queensland Government Hydraulics Laboratory managing physical modelling

Royal HaskoningDHV

projects. I commenced my career at the UNSW's Water Research Laboratory where I spent 7 years. A more detailed listing of my experience is provided in Appendix D.

1.2 Islands of Interest (Mapped Islands)

In relation to the Mapped Islands, I provide the following as a summary of my knowledge of the Torres Strait Islands and the climatic conditions of interest to this report.

The Torres Strait, located between Cape York and Papua New Guinea (PNG) has over 200 islands, as shown in Figure 1. Nineteen (19) of the islands are inhabited and play a vital role in border security and support the varied customs of the communities.

Although all the communities in the Torres Strait are threatened by the impacts of climate change, with ecological system health, erosion and flooding issues all exacerbated, this report will primarily focus on just four islands referred to as the *Mapped Islands*. These islands are presented in Figure 1 and are listed below:

a. Boigu

b. Saibai

c. Poruma (Coconut)

d. Warraber (Sue)

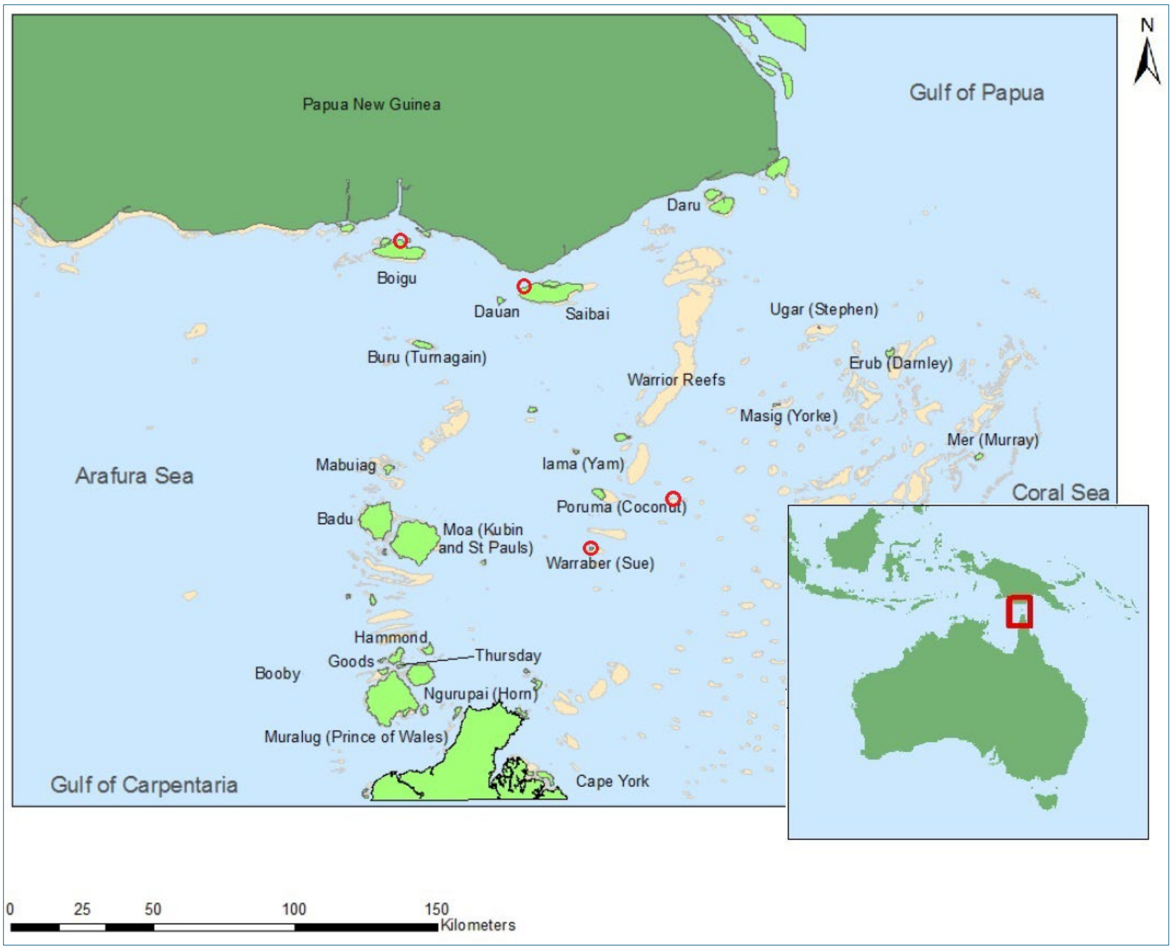


Figure 1 Torres Strait Locality Map

1.3 Climate and its Impact on the Torres Strait

In examining the climate range risks it is important to understand the existing climate as this impacts the underlying coastal processes that are occurring in the Torres Strait.

Most obviously the Torres Strait is tropical with an average water temperature of approximately 28°C (AIMS Weather Station on Thursday Island refer Duce 2010). Combined with generally clean low nutrient waters it is a region ideal for corals. These corals, the reefs they build, and the sediments they produce are the building blocks for much of the Torres Strait islands.

Despite being located in the tropics its proximity to the equator means that the occurrence of tropical cyclones in the region is not common, as seen in Figure 2. This is critical in understanding the relative importance of non-cyclonic drivers in coastal processes and extreme water levels in the Torres Strait.

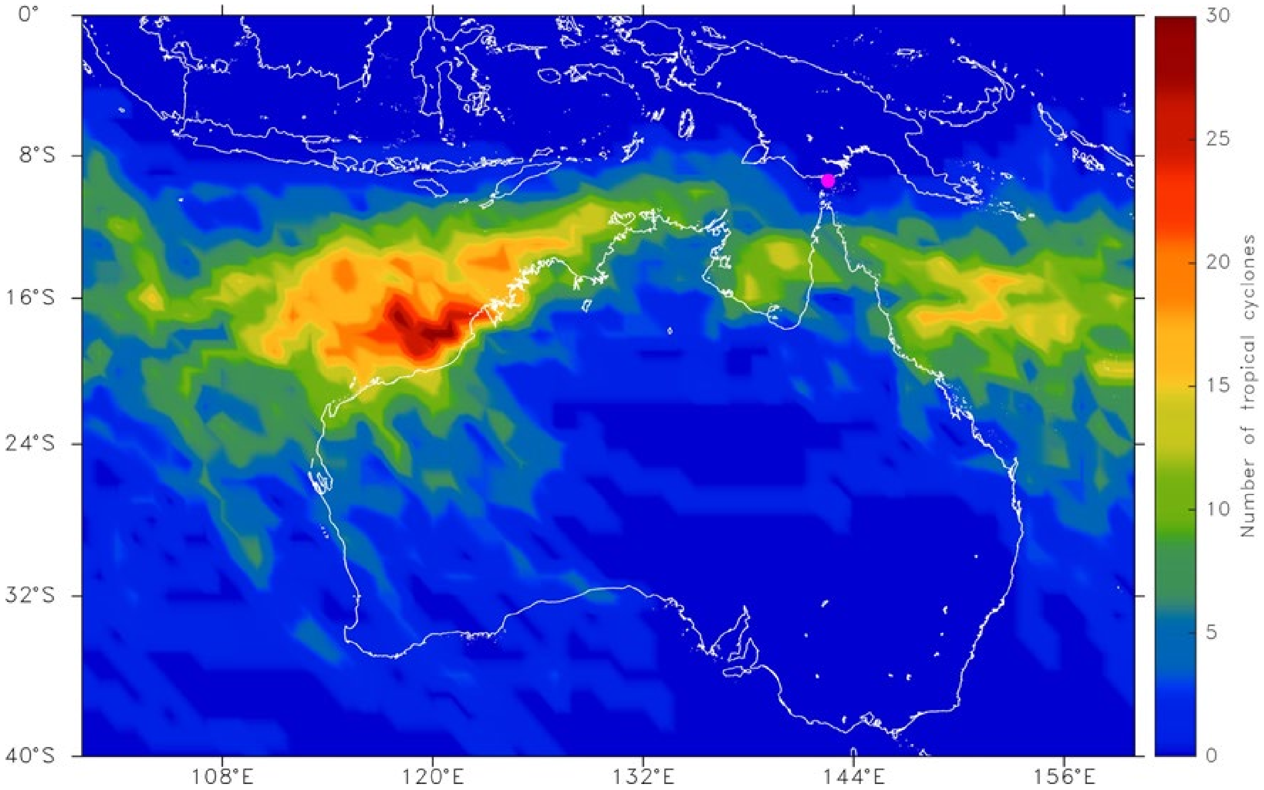


Figure 2 Number of tropical cyclones in the South Pacific Ocean since 1970.

A key climatic feature of the Torres Strait is the distinct seasons that drive the region's coastal processes. In traditional cultures, these are described in relation to key issues linked to food and transport as seen in **Figure 3**. There are different versions of this calendar around the Torres Strait however they all have the same basic seasonal drivers:

- Kerker Sager (April to September) – Strong south-easterly winds
- Naigai (October to November) – Weak winds
- Kuki (December to March) – Storms with winds from west to north-west

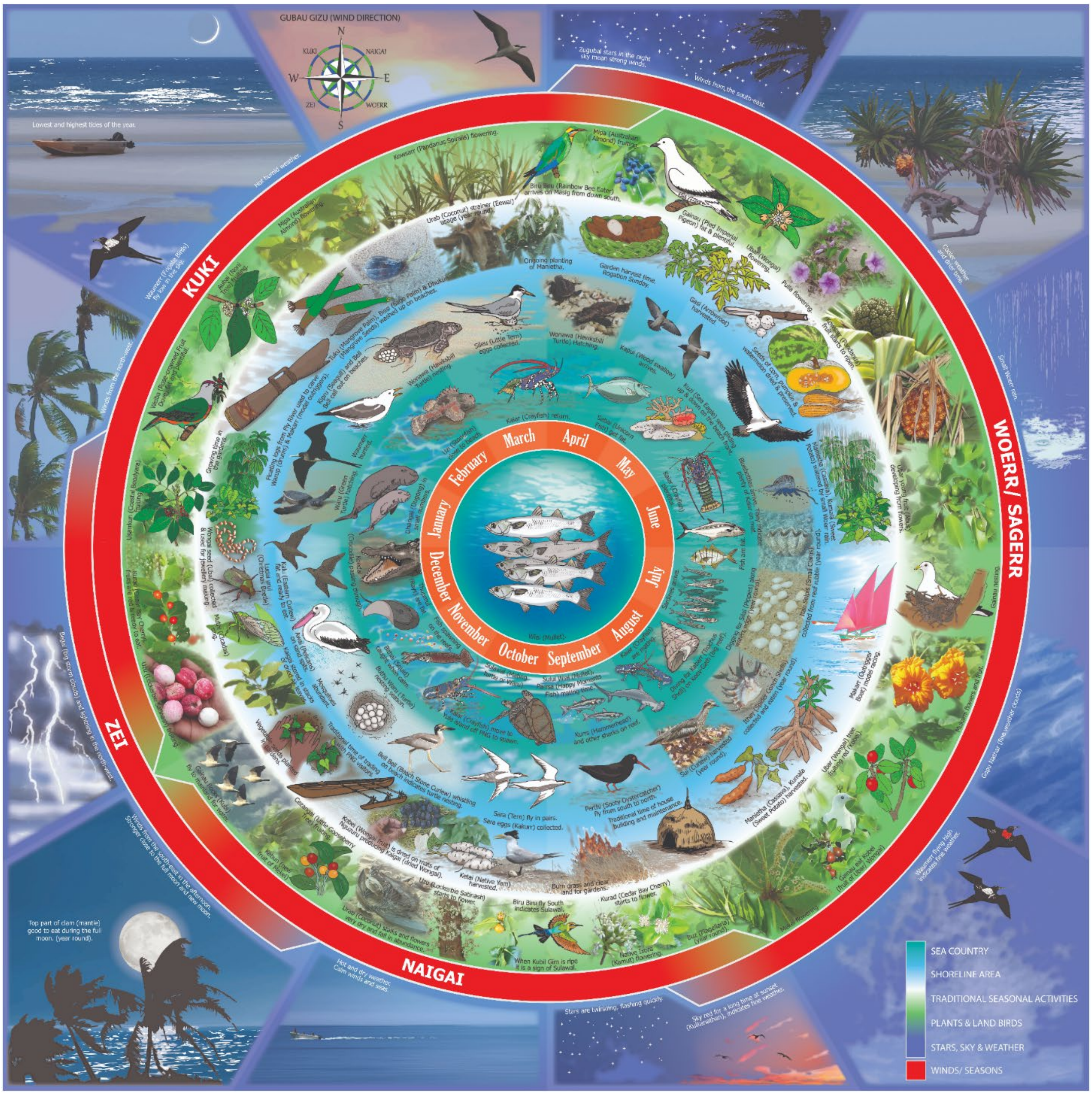


Figure 3 Islander Seasonal Calendar with months in the inner ring and weather depicted in the outer ring (Erub Island ref. BoM))

In terms of coastal process, the focus is on the distinct seasonal winds and associated weather:

i. Dry season (7 to 8 months from April to November) – Dominated by sustained south-easterly winds (refer **Figure 4**). It is noted that wind intensity diminishes towards the end of the dry season and wind speeds reduce though the wind direction remains south-easterly.

ii. Wet season (3 to 4 months from December to March) – Dominated by variable winds from west through north-westerly to north (refer **Figure 5**).

These seasonal winds and the associated waves and currents that the winds produce drive many of the coastal processes in the Torres Strait. Due to their duration and consistency the dry season south-easterly conditions are dominant, however, the shorter wet season is typically associated with the more dramatic marine impacts such as flooding in the communities and high seas.

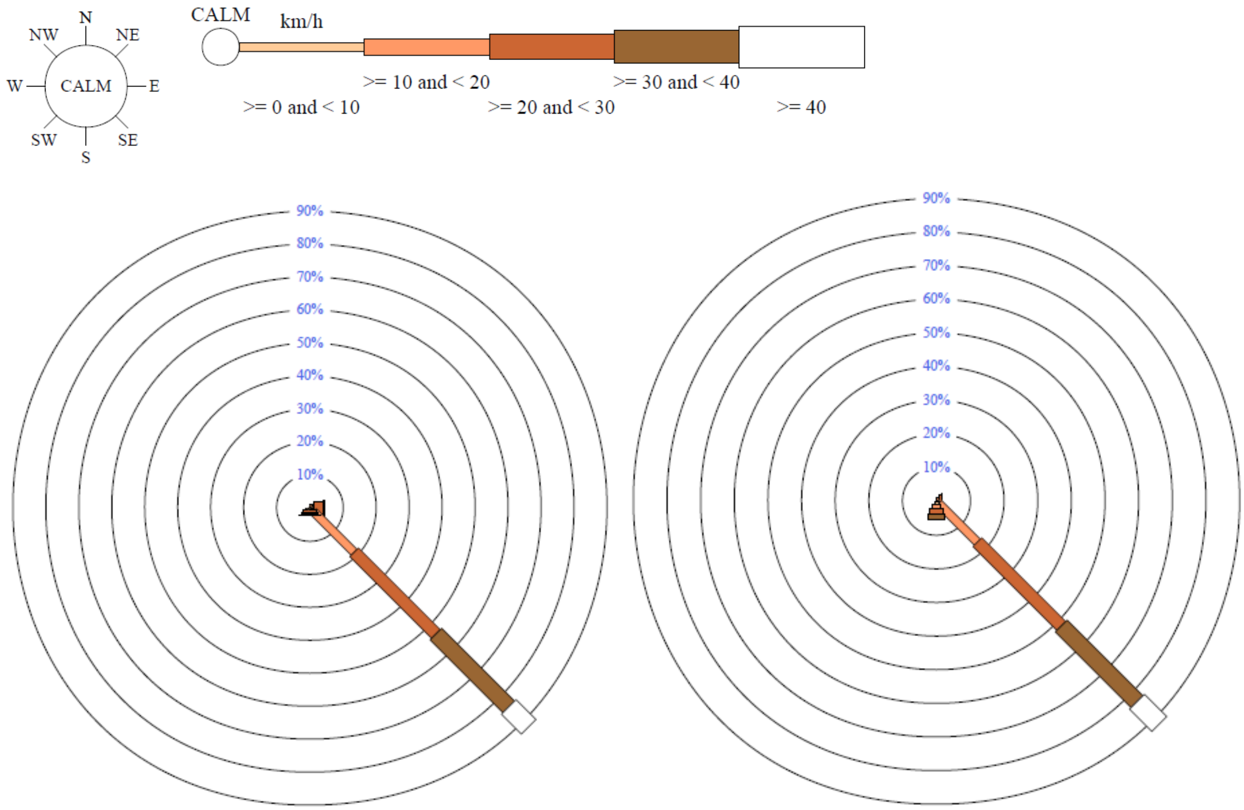


Figure 4 Wind Roses for Poruma for July (Dry Season); 9am left, 3pm right (BoM)

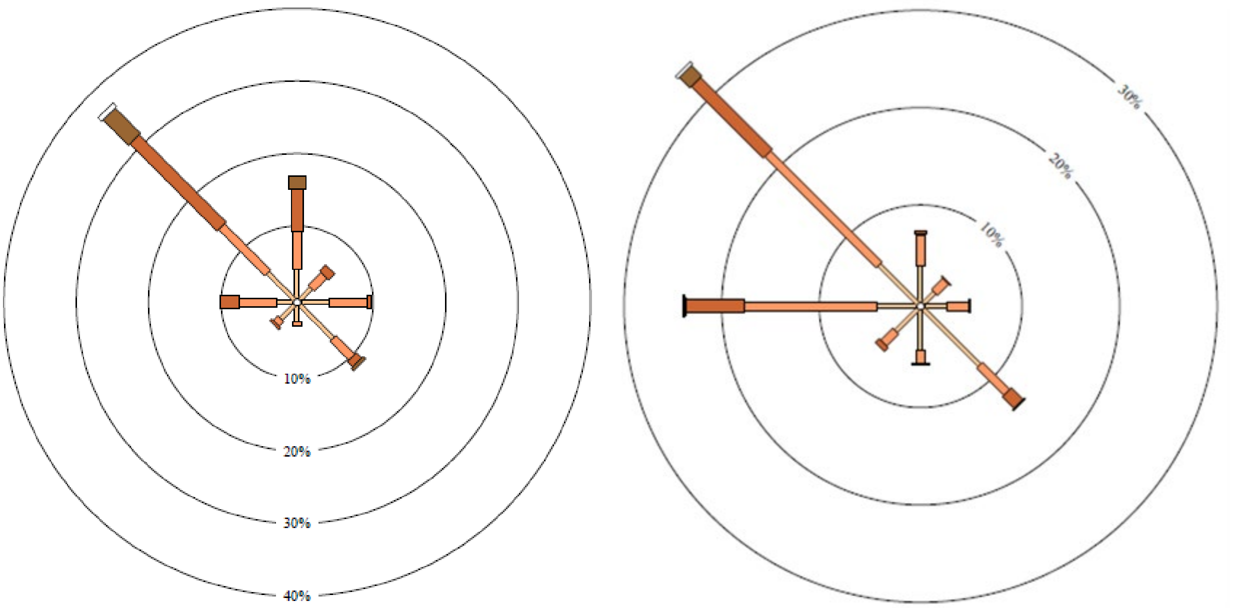


Figure 5 Wind Roses for Poruma for January (wet season) top - 9am left, 3pm right (BoM)

2 Extreme Sea Level Events

Letter of Instruction question B:

B. Extreme Sea Level Events

2. Please draft maps showing the level of flooding and inundation on each of the Mapped Islands that would be caused by the following:
   a) an extreme sea level event that had a '1 in 100 year' frequency as at the Baseline (**Baseline Event**);
   b) an extreme sea level event that has a '1 in 100 year' frequency as at 2023 (**Current Event**); and
   c) an extreme sea level event that causes a temporary increase in sea level sufficient to flood 50% of the township on each of the Mapped Islands (**Township Inundation Event**).

3. In relation to a Township Inundation Event, please discuss:
   a) what would have been the frequency of that event on each of the Mapped Islands as at the Baseline; and
   b) what is the current frequency of that event on each of the Mapped Islands?

Response:

Ocean water levels impacting an island are comprised of various inputs. These include:

- Tides;
- Meteorological influences (waves, wind and atmospheric pressure); and
- The mean sea level that is impacted by climate change induced sea level rise.

2.1 Tides

Tides are driven by the gravitational pull of celestial bodies (sun, moon, etc.) lifting water levels. This results in tidal waves moving around the globe. The Torres Strait is a shallow and narrow passage that connects the Coral Sea and beyond to the Pacific Ocean with the Arafura Sea and beyond to the Indian Ocean. As the tides travel from east to west through this region strong currents are generated with tides changing rapidly. Tides across the Torres Strait vary from semi-diurnal tides in the east to diurnal tides in the west. Tide ranges (Lowest to Highest Astronomical Tides) vary from 3.5 m at Mer to 4.7 m at Boigu. The tidal planes for the islands of interest are presented in Table 1 and Table 2.

Table 1 Tidal Planes Diurnal Tides (sourced MSQ Torres Strait Tide Tables 2022 and Australian Hydrographic Services 2019)

Tidal Plane	Boigu (m MSL)	Saibai (m MSL)
Highest astronomical Tide (HAT)	2.42	2.02
Mean Higher High Water (MHHW)	1.31	1.10
Mean Lower High Water (MLHW)	0.41	0.32
Mean Sea Level (MSL)	0.00	0.00
Mean Higher Low Water (MHLW)	-0.41	-0.32
Mean Lower Low Water (MLLW)	-1.31	-1.07
Lowest Astronomical Tide (LAT)	-2.26	-1.84

Table 2 Tidal Planes Semi Diurnal Tides (sourced MSQ 2022 Torres Strait Tide Tables and Australian Hydrographic Services 2019)

Tidal Plane	Poruma (m MSL)	Warraber (m MSL)
Highest astronomical Tide (HAT)	2.27	2.13
Mean High Water Springs (MHWS)	1.16	1.06
Mean High Water Neaps (MHWN)	0.27	0.17
Mean Sea Level (MSL)	0.00	0.00
Mean Low Water Neaps (MLWN)	-0.27	-0.17
Mean Low Water Springs (MLWS)	-1.16	-1.06
Lowest Astronomical Tide (LAT)	-2.28	-2.05

With tidal ranges in the order of 4 m the most important single contributor to extreme water levels is the tides. Further, because the tides are linked to the movement of celestial bodies the largest tides of the year typically occur during December and February, coinciding with the wet season in the Torres Strait.

2.2 Meteorological Influences

Meteorological water level anomalies refers to the impact of wind, barometric pressure and waves on the water levels. These are seen as water levels either above or below forecast water levels (tidal influenced) and occur at a minor scale most of the time. Large anomalies are linked to extreme water levels when the combined influence of a large tide and significant anomaly combine to drive water levels beyond the maximum tidal range (LAT to HAT). The most dramatic anomalies are up, raising water levels above HAT.

In most areas, these meteorological anomalies are minor during ambient weather, with large anomalies linked only to extreme weather events such as cyclones. During these extreme weather events, these extreme water levels are called storm surges. In the Torres Strait meteorological water level anomalies are also common every wet season during otherwise ambient weather conditions.

2.2.1 Storm Tides

A study into storm tides, based on cyclonic events has been undertaken for the Torres Strait Regional Authority (TSRA), ref. SEA 2011. This study has been relied on to assess storm tide impacts. The explanation provided herein for storm tides is largely taken from that study.

Storm tides are the combined impacts of storm surge, reef top wave setup, and tide. The various elements of storm tide water levels during extreme events are presented in **Figure 6**.

Storm surge is the elevated water level that occurs when barometric pressure and wind combine to push up water. The storm surge is the water level above tidal forecast immediately offshore from the coast. This was considered in the assessment using hydrodynamic modelling tools. Storm surge is combined with the tides in a Monte Carlo assessment to obtain water levels surrounding islands. The study comprised simulation of 10,000 years of possible cyclone tracks to develop a robust relationship for storm surge levels.

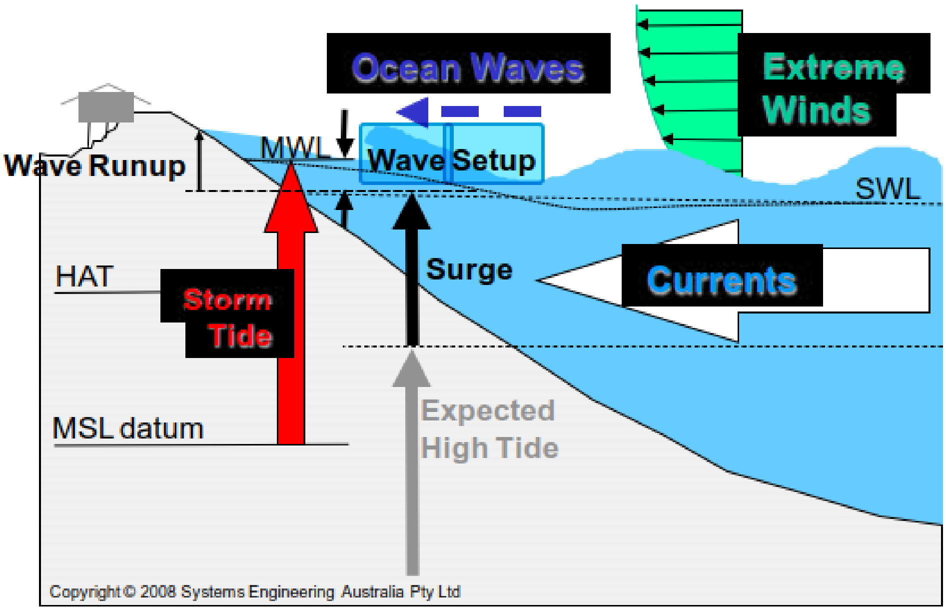


Figure 6 Storm Tide Schematic

In the Torres Strait, islands are surrounded by shallow reefs. When waves break onto the reef edge a flux of water onto the reef drives wave setup on the reef top, which is a key contributor to storm tide levels. Reef top wave setup is described in the following equation (refer Gourlay 1997) and is schematically presented in **Figure 7**.

$$\bar{\eta}_r = \frac{3 \times K_p \times g^{1/2} \times H_0^2 \times T}{64 \times \pi \times (\bar{\eta}_r + h_r)^{3/2}}$$

Where K_p is a variable influenced by the slope of the reef rim profile, refer to **Figure 8**. With a tan(α)≈0.1 the adopted K_p is 0.4.

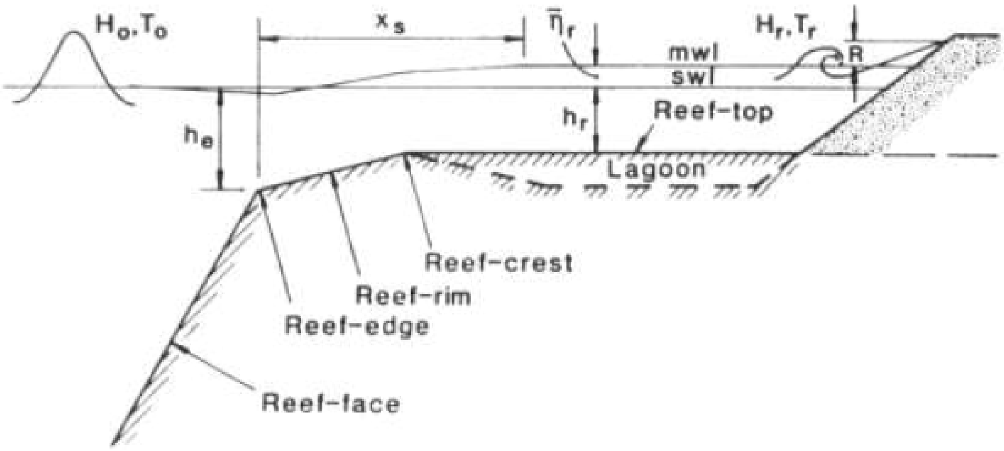


Figure 7 Reef top wave setup schematic

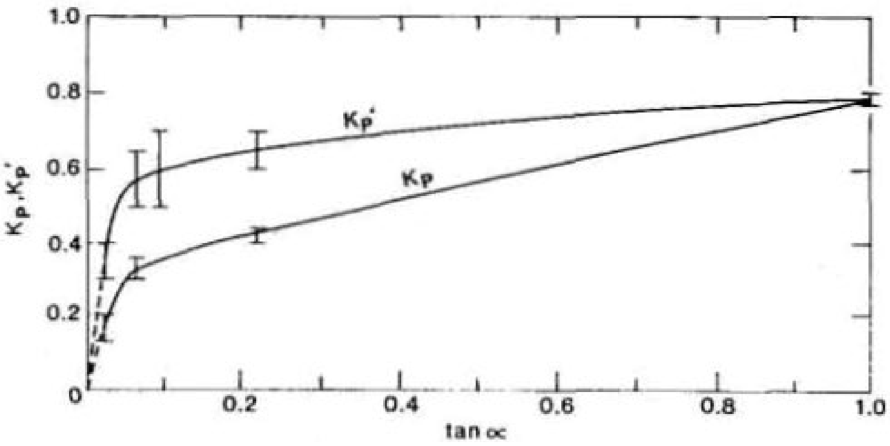


Figure 8 Reef profile factor (Gourlay 1997)

The results of the cyclonic storm tide assessments are presented in **Table 3**.

Table 3 Storm tides, including wave setup from

Average recurrence interval (ARI years)	Boigu Storm tide (m MSL)	Saibai Storm tide (m MSL)	Poruma Storm tide (m MSL)	Warraber Storm tide (m MSL)
HAT	2.42	2.02	2.27	2.13
10 years	2.53	2.14	2.47	2.53
25 years	2.61	2.19	2.51	2.61
50 years	2.65	2.22	2.55	2.65
100 years	**2.67**	**2.26**	**2.56**	**2.67**
500 years	2.72	2.35	2.60	2.72

Note that the likelihood of an extreme event occurring is described here as Average Recurrence Interval (ARI). This describes the average number of years for a water level to be reached or exceeded once. That is to say over a 50 year period a 50 year ARI event would be exceeded once on average, however, it may not occur at all or it may occur a number of times in any 50 year period. An alternative way to describe this is that a 50 year ARI event has a 2% chance of being exceeded in any given year.

It is important to note that this storm tide study is based on cyclonic events and forecast tides only. This study did not fully consider non-cyclonic water levels variation that occur across the region. This has meant that the levels forecast in this study are an underestimate of the conditions that are experienced on site. In assessing the extreme water levels in this report an additional lift has been added to the design storm tide, as described below.

2.2.2 Regional Non-Cyclonic Water Level Anomalies

Based on lived experience and measured water levels in Torres Strait, significant water level anomalies regularly occur in this region. The scale of these anomalies is unusual compared to most coastal areas and is linked to the wet season. These meteorologically influenced water level events regularly lead to flooding in communities across the Torres Strait, as seen in **Table 4**. It is noted that this list of observed events is not exhaustive but does demonstrate that levels exceeding forecast are common.

Table 4 Some of the recently observed flooding due to abnormally high-water levels in non-Cyclonic (ambient) conditions

Event	Observation	Impact
Iama 2006	Still Water Level ~0.7m above HAT	
Warraber 2006	Still Water Level ~0.2m above HAT	
Boigu date unknown (likely January 2009)	Still Water Level ~0.3m above HAT	 
Saibai January 2009	Still Water Level ~0.3m above HAT	 
Saibai 2010	Still Water Level ~0.2m above HAT	
Saibai January 2018	Still Water Level ~0.4m above HAT	
Iama January 2018	Still Water Level ~0.6m above HAT Flooding linked to wave action (overtopping) combined with high water	
Poruma Feb 2019	Still Water Level ~0.1m above HAT	

Event	Observation	Impact
Iama January 2023	Still Water Level ~0.2m above HAT	 

Note: Photos sourced from community, supplied for various studies undertaken for TSIRC. These photographs have been used as they are the only record of these events available on the islands

Data sets for three years of the water levels in the Torres Strait is presented in **Figure 9.** This record reveals that the significant anomaly events are linked to the wet season (north-westerly winds). However, beyond this their timing and scale are random. Further, the data reveals that these events occur with variable spatial intensity and a pattern of behaviour that is consistent with anecdotal observations of flooding events during non-cyclonic events, represented in **Table 4**.

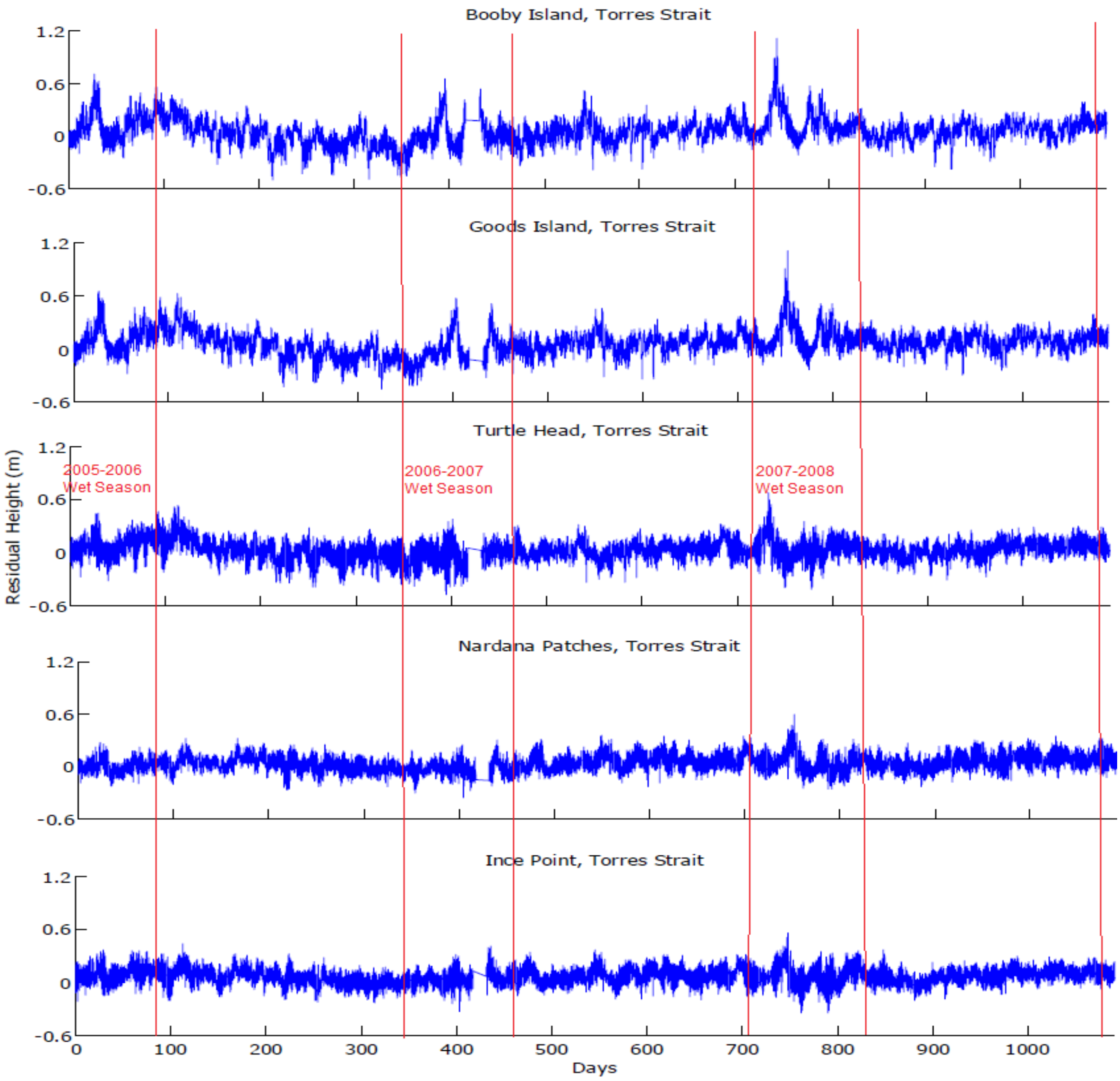


Figure 9 Residual tide height derived from observed less predicted water levels for 3 years from 2006 to 2008 (refer Ribbat 2012)

By contrast with Table 4 the captured data presented in Figure 9, though reliable, is for islands that are not the Mapped Islands.

A significant event that occurred in January 2009 was captured at Goods Island and is presented in **Figure 10**. This reveals an anomaly lasting for more than a week, driving a peak water level of 0.4 m above the Highest Astronomical Tide (HAT) nearly 1 m above the forecast tide level. This event is seen in the flooding images for Saibai and Boigu in 2009 (refer **Table 4**).

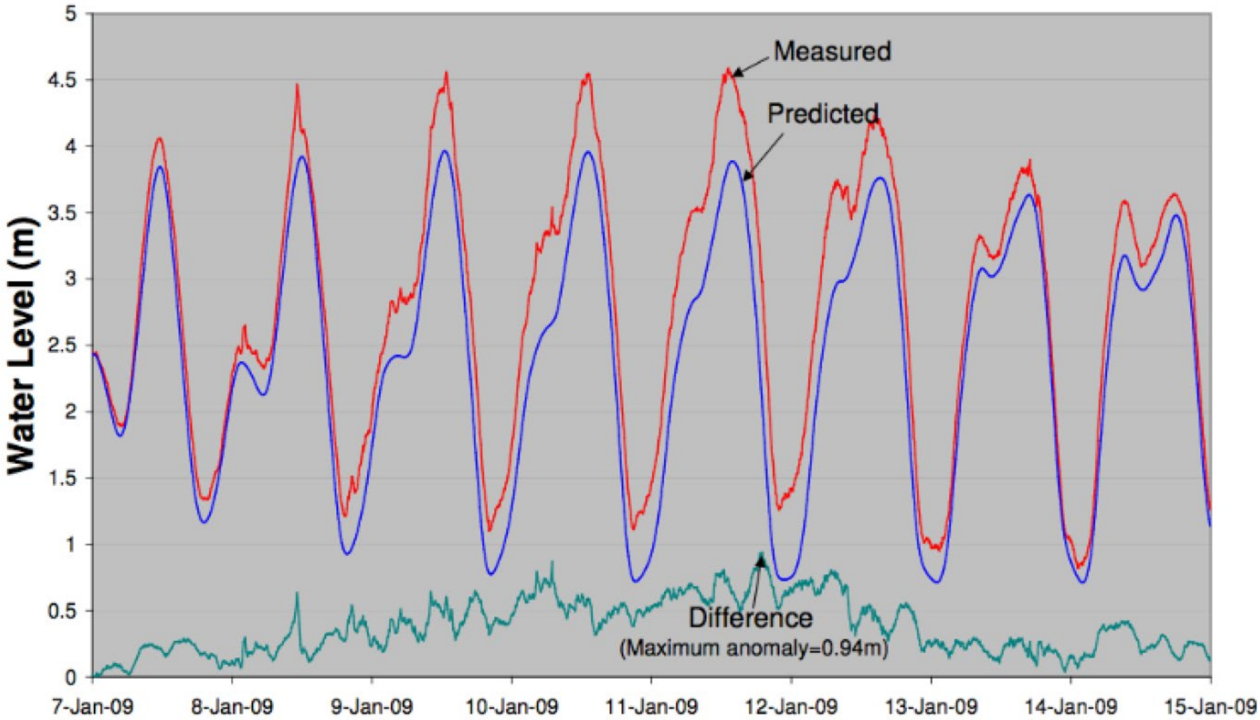


Figure 10 Goods Island Water Levels January 2009 with peak level 0.4 m above HAT (refer Table 4 for images of flooding)

The driving mechanism of these non-cyclonic anomalies has not been fully resolved, and as such they are not forecast. Similarly, the potential scale and frequency of the events are not defined. Based on available data, it is the author's assessment that the processes are strongly influenced by sustained stiff north-westerly (wet season) winds blowing across the shallow waters of the Arafura Sea, to the west of the Torres Strait. This wind drives surface waters into the Gulf of Carpentaria where, due to the shallow water depths, return flow is hampered driving a northerly flow of water along the western side of Cape York. When this mass of water reaches the Torres Strait, water banks up and this drives non-cyclonic water level anomalies.

2.2.3 Adopted Extreme Water Levels

The storm tide assessment presented in **Section 2.2.1** does not include allowance for the regional water level anomalies described in **Section 2.2.2**. As a result the extreme water levels presented in **Table 3** are approximately the same level as some of the resent observed inundation events during non-cyclonic conditions as seen in **Table 4**.

To address the short comings in the storm tide assessment a modest level of regional lift has been added to the water levels. The geography of sandy coastlines in the tropics can capture historic storm tide levels, with dune lines formed under overtopping waves. This effect has been well documented on the

Queensland coast with historic dune crest created by extreme storm tides with an Average Recurrence Interval of approximately 500 years ARI. The dunes on Warraber (refer Figure 24) are a good example of this process and have been used to assist in determining the scale of regional lift that should be applied to the storm tides. The adopted lift levels are:

- 0.1 m added to 25 year ARI Storm Tide;
- 0.2 m added to 50 year ARI Storm Tide;
- 0.3 m added to 100 year ARI Storm Tide; and,
- 0.5 m added to 500 year ARI Storm Tide.

The inclusion of a water level lift with the storm tide gives the adopted extreme water levels presented in **Table 5**.

Table 5 Adopted Extreme Water Levels Relative to Mean Sea Level

Average recurrence interval (ARI years)	Boigu Storm tide (m MSL)	Saibai Storm tide (m MSL)	Poruma Storm tide (m MSL)	Warraber Storm tide (m MSL)
HAT	2.42	2.02	2.27	2.13
10 years	2.53	2.14	2.47	2.53
25 years	2.71	2.29	2.61	2.71
50 years	2.85	2.42	2.75	2.85
100 years	**3.07**	**2.56**	**2.86**	**2.97**
500 years	3.22	2.85	3.10	3.22

It is important to remember that these extreme events incorporate tides, regional water level lifts, storm surge and reef top wave set-up. Because of the strong tidal influence the duration of the high water levels is short-lived, a few hours at most. The influence of regional lift and tides mean that very similar water levels could occur over a few days (refer **Figure 10**), leading to several separate flooding events in very short succession.

2.2.4 Historic Sea Level Rise

The extreme water levels described above are related to Mean Sea Level (MSL). To understand how these events relate to the land we need to describe them relative to a land based datum. For this assessment we have adopted Australian Height Datum (AHD), a commonly used datum in Australia. For the Torres Strait the level of AHD relative to MSL was measured in 2010 (refer Maritime Safety Queensland 2010). The relationship in levels is presented in **Table 6**.

For this assessment a baseline date of 1900 has been adopted for original conditions. Between 1900 and 2023 global sea levels have risen by 0.21 m. Since 2010 global sea levels have been rising at 3.4 mm per year (total = 0.04 m), refer NASA 2023. Based on this the adopted values for Mean Sea Level (MSL) relative to Australian Height Datum (AHD) for our refence dates are presented in **Table 6**.

Table 6 Mean Sea Level (MSL) relative to Australian Height Datum (AHD) for different dates

Horizon	Boigu (m AHD)	Saibai (m AHD)	Poruma (m AHD)	Warraber (m AHD)
MSL in 1900 (Base Line)	0.66	0.55	0.19	0.30
MSL in 2010	0.83	0.72	0.36	0.47
MSL 2023 (Present Day)	0.87	0.76	0.40	0.51

2.3 Impact of Extreme Water Level Events on Communities

2.3.1 Baseline (1900) Extreme Water Level Impacts

Applying the above datum conversions (**Table 6**) with the extreme sea levels (**Table 5**) the baseline (1900) extreme sea levels were derived as seen in **Table 7** and **Figure 11**.

Table 7 Baseline (1900) Extreme Water Levels Relative to AHD

Average recurrence interval (ARI years)	Boigu Storm tide (m AHD)	Saibai Storm tide (m AHD)	Poruma Storm tide (m AHD)	Warraber Storm tide (m AHD)
HAT	3.08	2.57	2.46	2.43
10 years	3.19	2.69	2.66	2.83
25 years	3.37	2.84	2.80	3.01
50 years	3.51	2.97	2.94	3.15
100 years	**3.73**	**3.11**	**3.05**	**3.27**
500 years	3.88	3.40	3.29	3.52

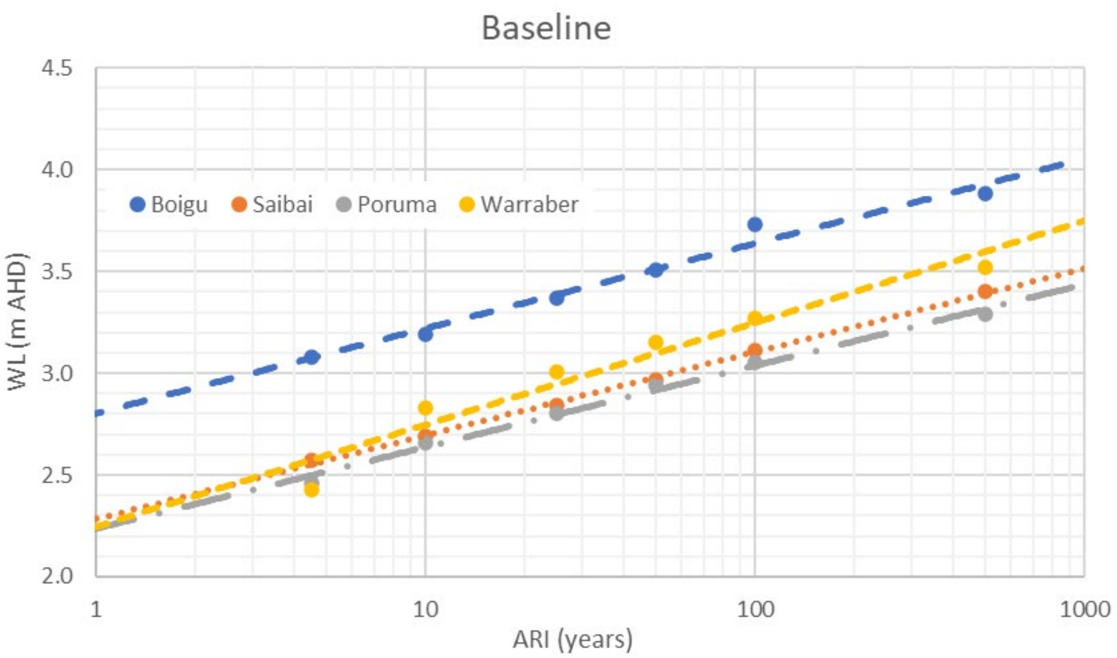


Figure 11 Baseline Extreme Water Levels (Note HAT assumed to be a 4.5 year ARI event)

As identified previously the 100 year ARI event is commonly adopted for acceptable risk of flooding in the broader community. This flood level for baseline conditions has been mapped for the four communities and is presented in **Figure 12** to **Figure 15**.

The results reveal that even for the baseline conditions the mud island communities of Saibai and Boigu were vulnerable to marine flooding events. Due to this underlying vulnerability houses on these islands are raised (on stilts). On Poruma and Warraber the baseline flooding risks are more in line with broader community expectations in mainland Australia (above 100 year ARI flooding).

2.3.2 Current (2023) Extreme Water Level Impacts

The extreme sea levels for the current conditions (2023) are presented in **Table 8**. The 100 year floods for these events are mapped and presented in **Figure 16** to **Figure 19**.

As with the baseline conditions the mud islands are severely impacted by a 100 year ARI event with current ocean levels, while the cays experience less frequent flooding issues.

Table 8 Current (2023) Extreme Water Levels Relative to AHD

Average recurrence interval (ARI years)	Boigu Storm tide (m AHD)	Saibai Storm tide (m AHD)	Poruma Storm tide (m AHD)	Warraber Storm tide (m AHD)
HAT	3.29	2.78	2.67	2.64
10 years	3.40	2.90	2.87	3.04
25 years	3.58	3.05	3.01	3.22
50 years	3.72	3.18	3.15	3.36
100 years	**3.94**	**3.32**	**3.26**	**3.48**
500 years	4.09	3.61	3.50	3.73

2.3.3 Township Inundation Event (~ 50% of community flooded)

Township inundation events have been defined as when 50% of the community is flooded. This flooding level for each township was defined based on visual assessment of the flood mapping, as seen in **Figure 20** to **Figure 23**. The adopted levels for this inundation event are presented in **Table 9**.

Table 9 Township Inundation Event Water Levels Relative to AHD with Baseline and Current Frequency of Exceedance

	Boigu	Saibai	Poruma	Warraber
~50% of township flooded (m AHD)	3.4	2.8	3.6	3.5
Baseline Frequency (years)	25	25	>500	500
Current Frequency (years)	10	5	>500	100

Frequency of occurrence on the Mud Islands (Boigu and Saibai)

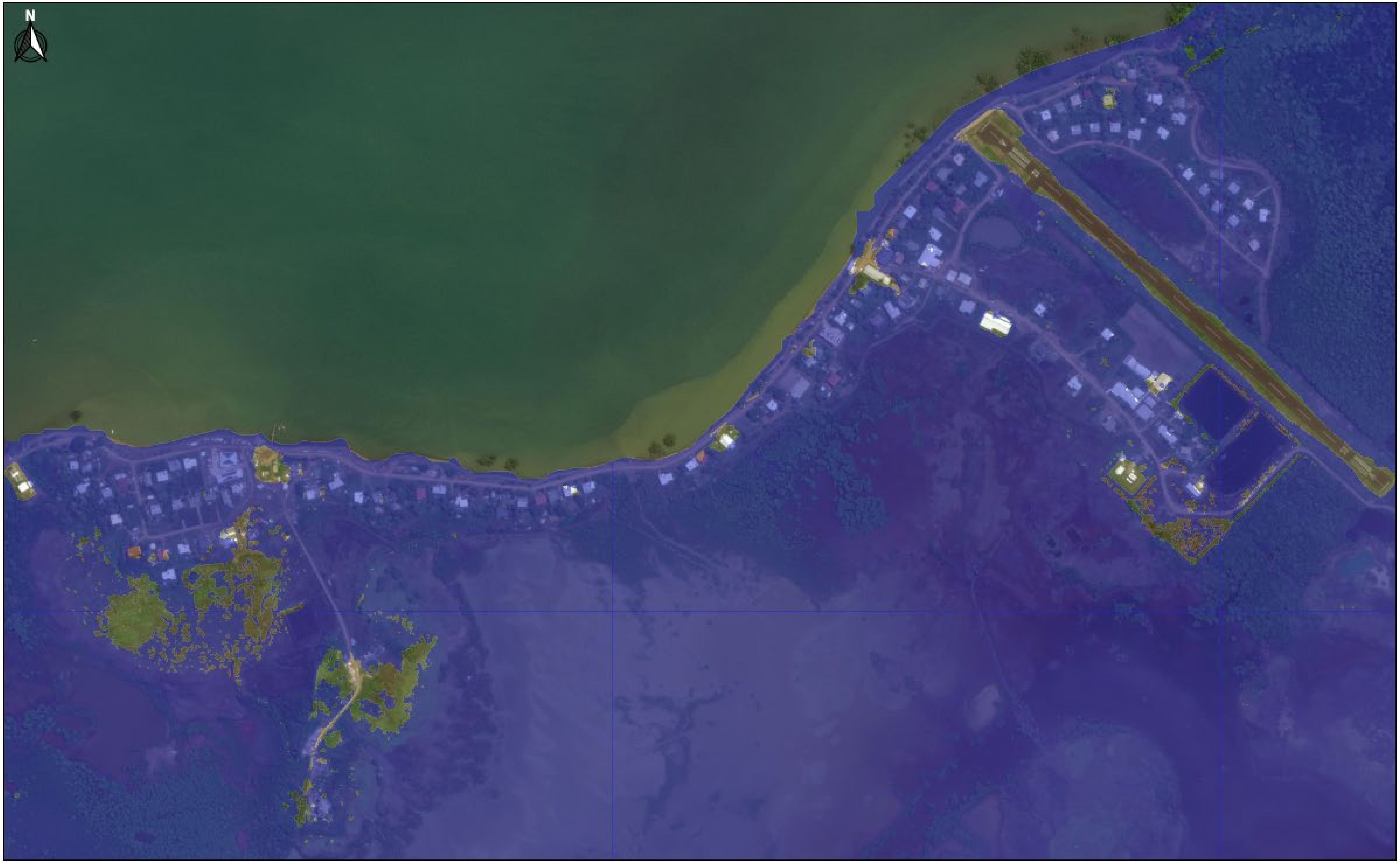
As seen in Table 9 the Mud Islands township inundation events were approximately 25 year ARI events in the base line conditions (1900). This frequency of flooding with suitable adaptation, such as houses on silts, is a frequency of event that communities could manage.

For water levels today, the event has now become a 5 to 10 year average recurrence interval event. This increasing frequency is seen anecdotally in the number of flood events presented in **Table 4**. This frequency represents a significant increase in issues for the community.

Frequency of occurrence on the Cays (Poruma and Warraber)

The township inundation level events on the cays are rare. With baseline water levels the event frequency 500 years or greater. For current conditions the level of risk has increased with a 100 year event now able to flood Warraber, but Poruma, remains rare at approximately 500 years ARI.

Figure 12 Boigu Baseline (1900) 100 year ARI flood



NOTES
Baseline (1900) 100 Year ARI Flood on Saibai = 3.11m AHD
Level Datum: AHD
Meridian: MGAz54

SAIBAI BASELINE (1900) 100 YEAR ARI FLOOD
1:5000 (A3)

50 0 50 100 150 200 250 m
1:5000 (A3) 1:2500 (A1)

Figure 13 Saibai Baseline (1900) 100 year ARI flood

NOTES
Baseline (1900) 100 Year ARI Flood on Poruma = 3.05m AHD
Level Datum: AHD
Meridian: MGAz54

PORUMA BASELINE (1900) 100 YEAR ARI FLOOD
1:6000 (A3)

100 0 100 200 300 m
1:6000 (A3) 1:3000 (A1)

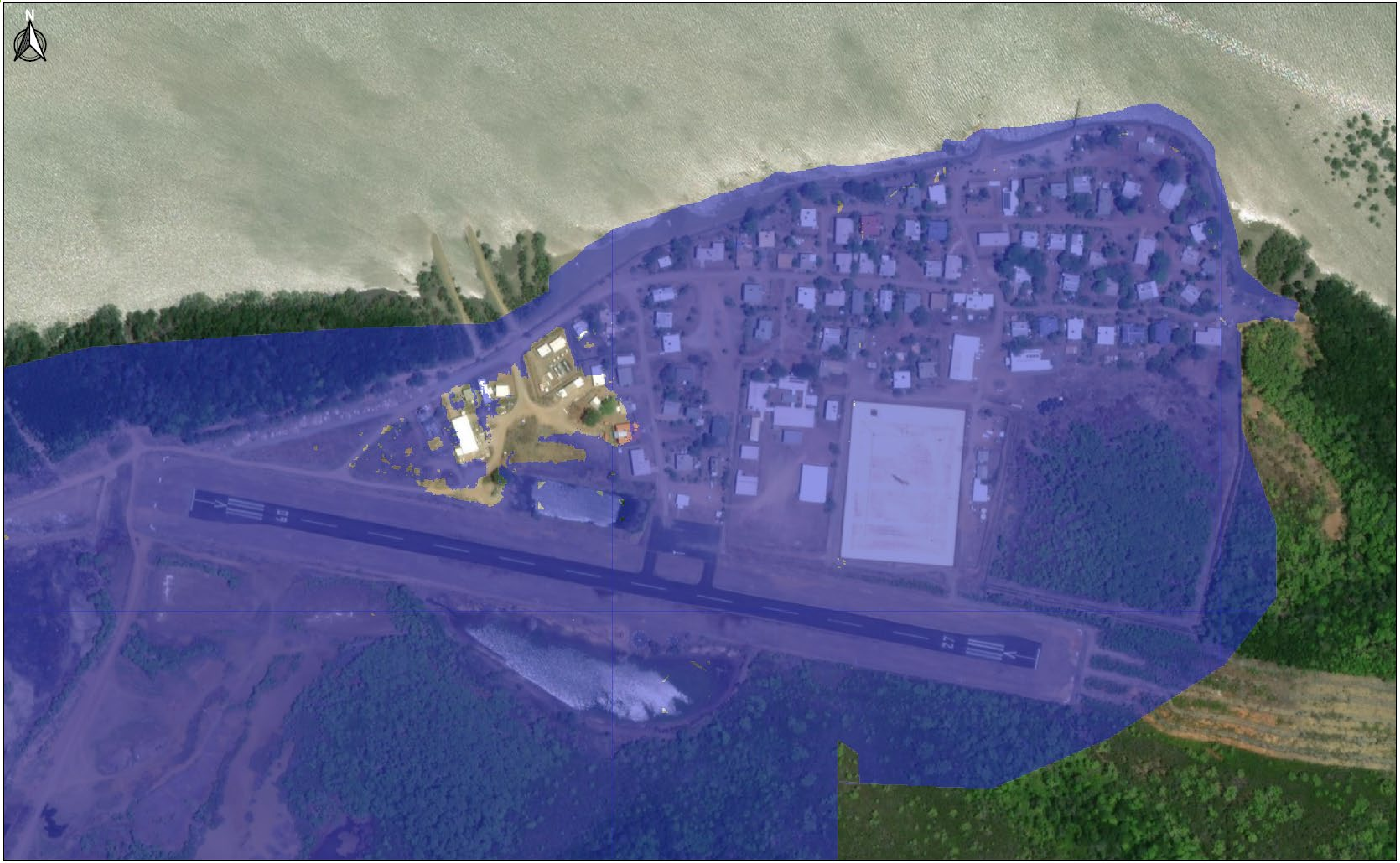
Figure 14 Poruma Baseline (1900) 100 year ARI flood

NOTES
Baseline (1900) 100 Year ARI Flood on Warraber = 3.27m AHD
Level Datum: AHD
Meridian: MGAz54

WARRABER BASELINE (1900) 100 YEAR ARI FLOOD
1:4000 (A3)

40 0 40 80 120 160 200 m
1:4000 (A3) 1:2000 (A1)

Figure 15 Warraber Baseline (1900) 100 year ARI flood



NOTES
Current (2023) 100 Year ARI Flood on Boigu = 3.94m AHD
Level Datum: AHD
Meridian: MGAz54

BOIGU CURRENT (2023) 100 YEAR ARI FLOOD
1:3000 (A3)

40 0 40 80 120 160 m
1:3000 (A3) 1:1500 (A1)

Figure 16 Boigu Current (2023) 100 year ARI flood

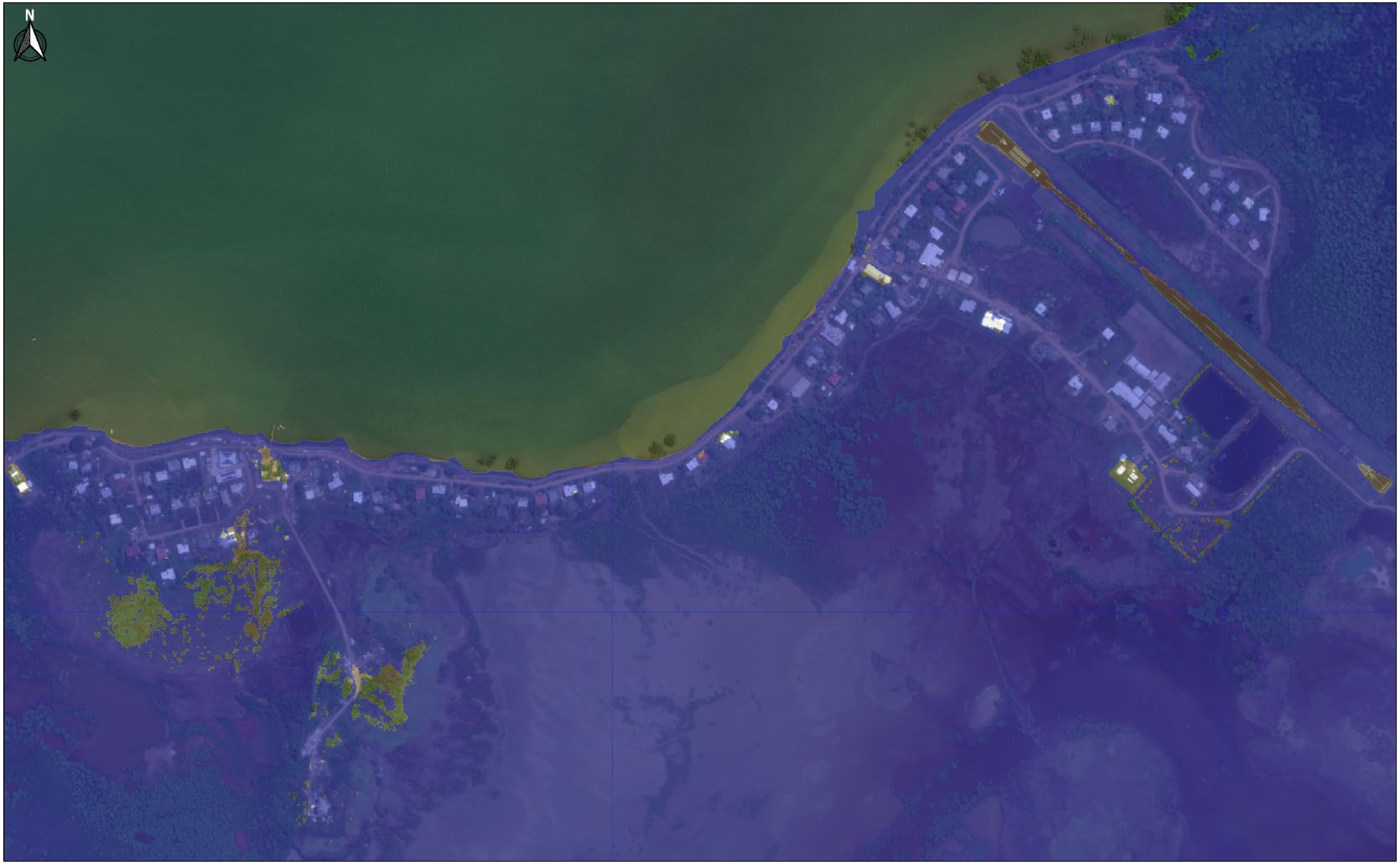


Figure 17 Saibai Current (2023) 100 year ARI flood

NOTES
Current (2023) 100 Year ARI Flood on Poruma = 3.26m AHD
Level Datum: AHD
Meridian: MGAz54

PORUMA CURRENT (2023) 100 YEAR ARI FLOOD
1:6000 (A3)

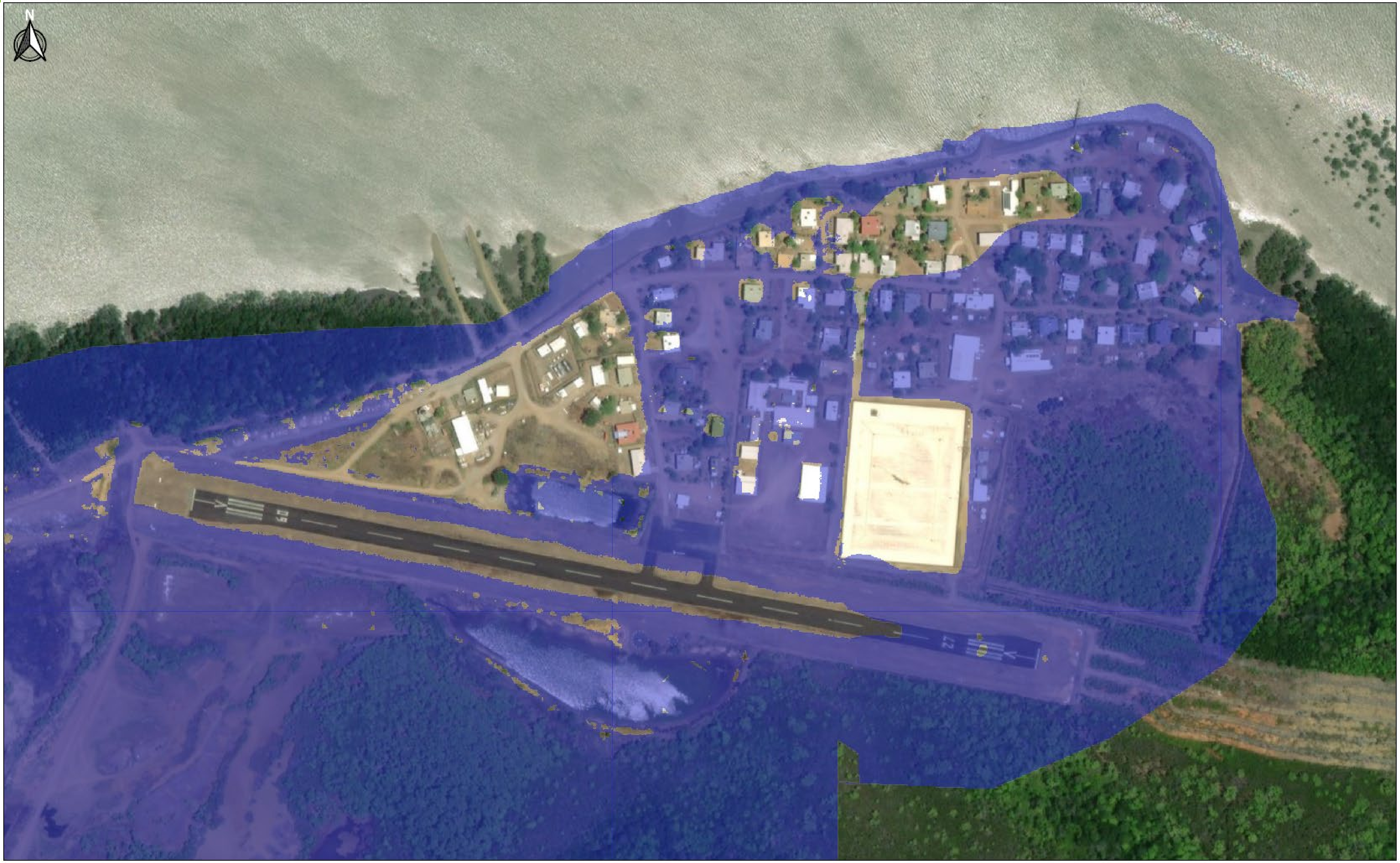
Figure 18 Poruma Current (2023) 100 year ARI flood

NOTES
Current (2023) 100 Year ARI Flood on Warraber = 3.48m AHD
Level Datum: AHD
Meridian: MGAz54

WARRABER CURRENT (2023) 100 YEAR ARI FLOOD
1:4000 (A3)

40 0 40 80 120 160 200 m
1:4000 (A3) 1:2000 (A1)

Figure 19 Warraber Current (2023) 100 year ARI flood

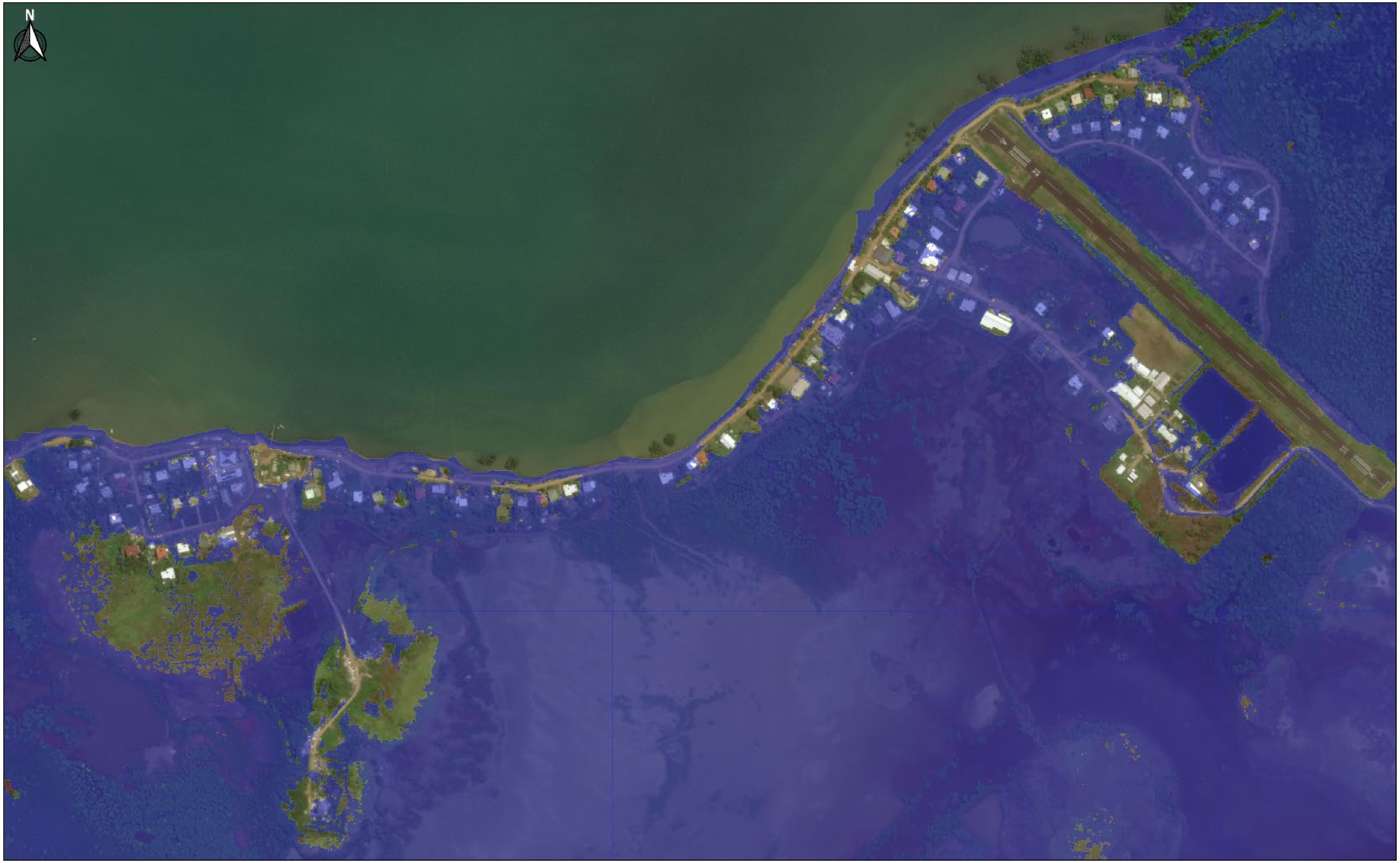


NOTES
Township Inundation Event for Boigu
(50% of community flooded) = 3.4m AHD
Level Datum: AHD
Meridian: MGAz54

BOIGU TOWNSHIP INUNDATION EVENT
(50% OF COMMUNITY FLOODED)
1:3000 (A3)

40 0 40 80 120 160 m
1:3000 (A3) 1:1500 (A1)

Figure 20 Boigu Inundation Event 3.1 m AHD (50% flooded)

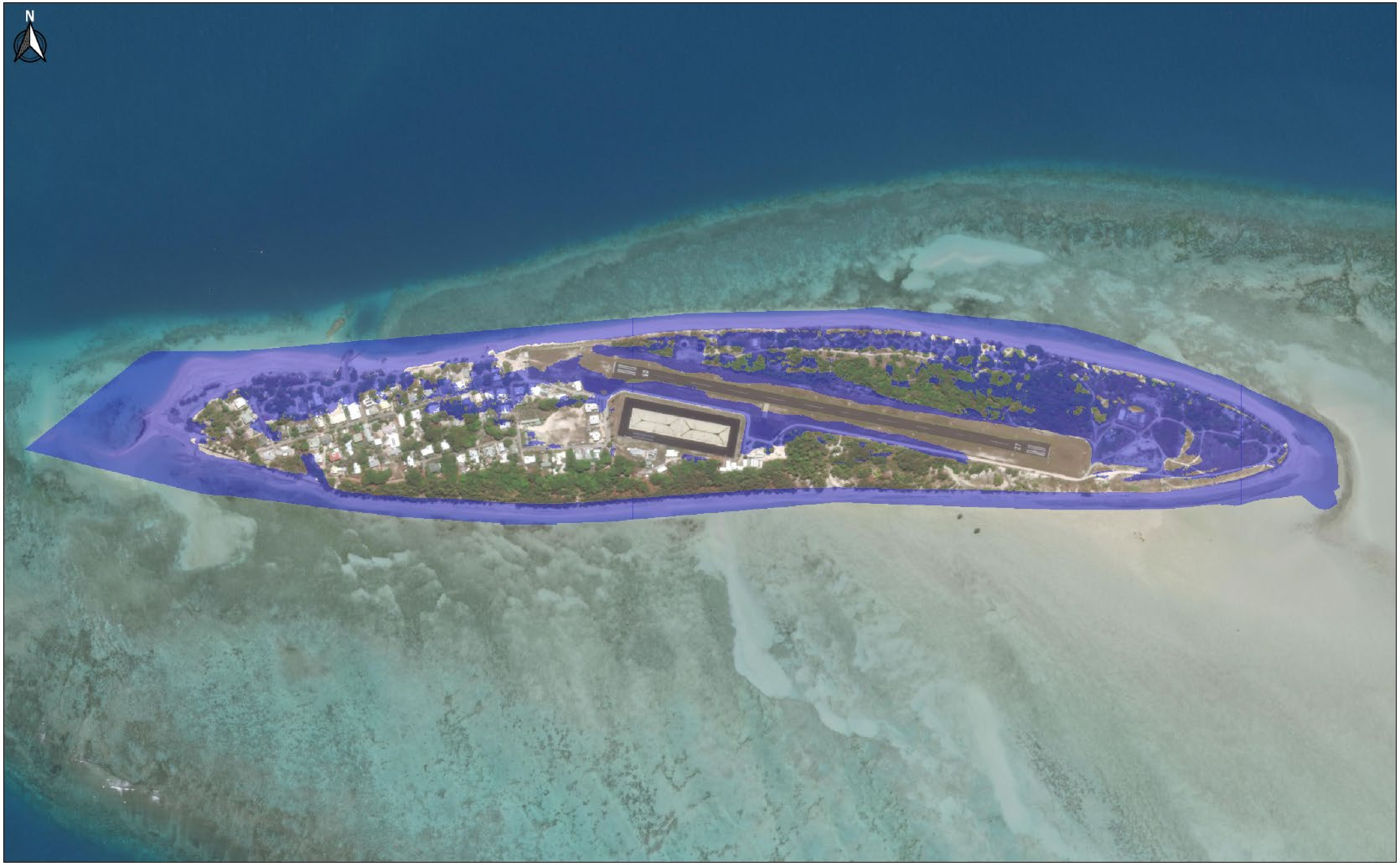


NOTES
Township Inundation Event for Saibai
(50% of community flooded) = 2.80m AHD
Level Datum: AHD
Meridian: MGAz54

SAIBAI TOWNSHIP INUNDATION EVENT
(50% OF COMMUNITY FLOODED)
1:5000 (A3)

50 0 50 100 150 200 250 m
1:5000 (A3) 1:2500 (A1)

Figure 21 Saibai Inundation Event 2.9 m AHD (50% flooded)



NOTES
Township Inundation Event for Poruma
(50% of community flooded) = 3.60m AHD
Level Datum: AHD
Meridian: MGAz54

PORUMA TOWNSHIP INUNDATION EVENT
(50% OF COMMUNITY FLOODED)
1:6000 (A3)

100 0 100 200 300 m
1:6000 (A3) 1:3000 (A1)

Figure 22 Poruma Inundation Event 3.6 m AHD (50% flooded)

NOTES
Township Inundation Event for Warraber
(50% of community flooded) = 3.5m AHD
Level Datum: AHD
Meridian: MGAz54

WARRABER TOWNSHIP INUNDATION EVENT
(50% OF COMMUNITY FLOODED)
1:4000 (A3)

40 0 40 80 120 160 200 m
1:4000 (A3) 1:2000 (A1)

Figure 23 Warraber Inundation Event 3.7 m AHD (50% flooded)

3 Climate Change Impacts in the Torres Strait

Letter of Instruction question C:

C. Climate change impacts in the Torres Strait

4. Please describe the geological features and coastal processes of the different kinds of islands in the Torres Strait (including, but not limited to, each of the Mapped Islands).
5. By reference to the features and processes described in your answer to question 4, please:
   a) explain how the combination of sea level rise and extreme sea level events impacts each of the Mapped Islands (for example, by causing/increasing coastal erosion, salination of soil/water and any other relevant impact) (**climate change impacts**); and
   b) describe what other drivers (if any) may cause/increase the climate change impacts on the Mapped Islands (for example, coral bleaching, loss of mangrove habitat, etc.).
6. Please explain the interactions (including reinforcing feedbacks, if any) between each of:
   a) the climate change impacts identified in your answer to question 5(a) above;
   b) the drivers identified in your answer to question 5(b), above; and
   c) the frequency and severity of extreme sea level events.
7. Please describe the climate change impacts on each of the Mapped Islands today, including increases (if any) in the rates of change that have been observed since the Baseline.

Response:

3.1 Geological Background

Over geological timeframes sea levels have been highly variable. During the last glacial period during the Pleistocene epoch sea levels were approximately 120 m lower than present day sea levels and the Torres Strait was a land bridge between Cape York and Papua New Guinea. The last glacial period ended approximately 11,700 years ago (start of the current Holocene epoch) and sea levels rose and stabilised at current day levels approximately 8,000 years ago.

The islands in the Torres have been formed through a range of geological processes. These differences impact on the vulnerability of the island communities to inundation and erosion issues, and the nature of the engineering solutions that can be adopted. The islands of Torres Strait can be classified into the following broad groups:

- Coral Cays or sand islands
- Rock Islands that can be split into:
  - Continental or
  - Volcanic
- Mud islands

3.1.1 Coral Cays (Sand Islands)

One of the key building blocks for the Torres Strait islands is the fringing coral reefs. Corals of the Torres Strait require a hard strata such as rock or old reef as a foundation. The growth of coral upward is limited by exposure, with reef growth halted at approximately mean low water level. The reefs platforms we see today have formed since the water levels stabilised and represent thousands of years coral growth.

The communities of Poruma, Warraber and Masig are on Coral Cays. These islands are formed on reef platforms from sand created from the shells of living creatures such as the coral. Living coral on the reef edge generates approximately 5 kg to 20 kg of sand per square meter annually. This carbonate based sand accumulates on the reef platform and under the influence of marine forces (waves and currents). This reef top sand can be raised up to form an island by the waves and currents.

Because they are built up by marine forces these Coral Cay islands are low, with the level of the cays broadly matching the level of extreme marine inundation events (cyclones) that flood over the islands and deposit sand. This process to raise the ground level is relatively slow and younger islands or younger parts of an island are lower, having been exposed to less severe marine inundation events. Analysis of island age undertaken (Duce et al 2010) revealed that the oldest parts of Warraber are higher than the younger parts of the island. This impact on island formation is presented in **Figure 24**.

The shape, size and location of these islands on the reef platform reflect a dynamic stability between the various met-ocean forces driving sediment transport and the sand supply. Because of dominant south easterly winds and waves in the Torres Strait these islands are found on the northwest corners of the reef platforms as seen in **Figure 25** and **Figure 26**. The size of the island is tied to the balance between an ongoing supply of sand from the reef edged and sand being washed off the platform. If this balance is disturbed the dynamic stability is lost.

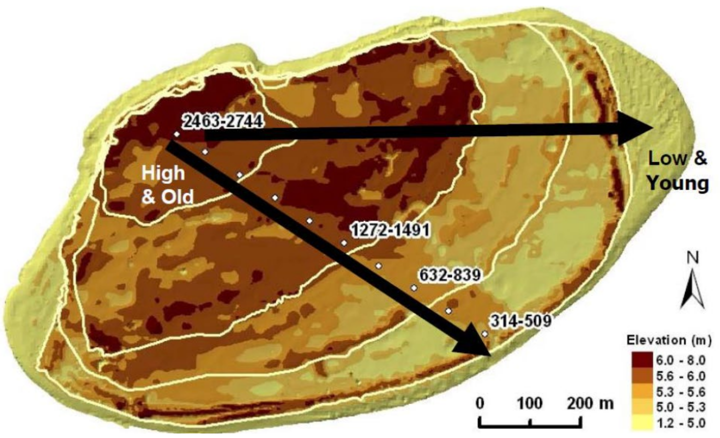


Figure 24 Analysis of Warraber growth and elevation compared with age

Figure 25 Warraber located on the north-west corner of the reef platform

Figure 26 Poruma located on the north-west corner of the reef platform

The loose beach sand circulates around the islands driven by the seasonal waves. Sand is pushed towards the north-western parts of the islands during the 9 months of south-easterlies in the dry season. During the shorter north-westerly season sand is pushed to the south-eastern end of the islands.

Disturbances to the balance in the sediment transport regimes causes erosion pressures. There is evidence that this also leads to an increased rate of sand lost off the reef platform and more widespread erosion issues. The key drivers of disturbance to the system due to anthropogenic (human caused) impacts are:

- Direct interruption to sediment transport caused by construction of the marine infrastructure (dredge channels and causeways).
- Changes to reef top morphology due to increased water depths linked to sea level rise.
- Loss of sand supply due to loss of coral vigour caused by:
  - Coral bleaching linked to increased water temperatures
  - Increased water nutrients (pollution) from island sewage and runoff

Because of the geological origins of the cays the communities on these islands (including Warraber and Poruma) are particularly vulnerable to coastal erosion (refer **Figure 27**) and marine inundation issues, both anticipated to worsen with sea level rise.

A common feature with the carbonate sands is beach rock, a weak limestone that is produced when the calcium carbonate saturated groundwater evaporates under the beach and the calcium carbonate solidifies, binding the beach material together. The beach rock takes time to form and increases in thickness and strength over time.

Where the beach rock exists it acts to control erosion and is vital to island stability (a natural seawall). Prominent beach rock formations exist on the inhabited cays, including Poruma (refer **Figure 28**) and Warraber. It is recognised that the extensive lengths of exposed beach rock is an indication of abnormal morphologic conditions.

Figure 27 Erosion undermining mature trees on south-west coast or Poruma (February 2018)

Figure 28 Exposed beach rock formation on the south coast of Poruma

An informative example of how dynamic cays are and the impact beach rock has on coastal movements is found on Halfway Island (25 km west of Poruma). This island is uninhabited and so provides a good refence for conditions where direct anthropogenic impacts (e.g. water pollution of marine works) are not an issue. As seen in **Figure 29**, the beach rock anchors the island, acting to resist the dominant south easterly waves. Beach rock can also be helpful in revealing where the island's beaches were located during pre-historic periods.

Analysis of satellite data allows the coastline movements in this remote location to be captured over a 30 year period. The recent coastal locations, presented in **Figure 30**, reveal that the island is experiencing dramatic changes. It demonstrates that although beach rock can anchor the island it does not prevent significant coastal erosion and accretion occurring in areas not protected. This level of coastline change and the significant beach rock exposure on the south coast are indications of changing reef top conditions, compared to prehistoric conditions that formed the island.

Figure 29 Exposed Beach Rock on Halfway Island reveals pre-historic foreshore alighnments and erosion pressures today

Figure 30 Satellite imagery of Halfway Island coastline revealing dramatic island movement (Source Digital Earth Australia).

3.1.2 Rock Islands

These islands are formed on rock outcrops around which coral reef platforms develop. Associated with the reef platform carbonate sand is produced. As with the cays sand movement is controlled by marine forces, with islands exposed to the dominant south-east conditions seeing sand accumulate on the north-west side of the rocky outcrop. The sand accumulation around the rocky outcrops forms flat land that is preferred for housing. As with the cays this low flat land created by marine forces is vulnerable to erosion and flooding.

The rocky islands have been split into continental and volcanic islands for the purpose of assessing the impact of geological origin on the islands. However, the differences are not significant when assessing risks and outcomes. The threats for these islands are primarily related to the communities' desire to occupy the low flat sandy areas that are vulnerable to erosion and flooding.

3.1.2.1 Continental Islands

Continental islands are formed around high ground that was part of the Australian mainland prior to the end of the last glacial period, when sea levels rose to their current levels. In the Torres Strait these islands are found in the western Torres Strait, forming a string of islands off the tip of Cape York. These include the inhabited islands Horn, Thursday, Prince of Wales, Keriri (Hammond), Badu, Mabuiag, Moa (Kubin and St. Paul), Iama and Dauan.

The rocky parts of the island are typically granite with mild (weathered) slopes. These islands are often relatively large in area, though the vegetation is dominated by open woodlands. The islands have fringing reefs and the sand from the reefs creates coastal flats at locations around the islands. Despite the sand presence much of the coastline is not particularly accessible with rocky foreshores in exposed areas. The preference historically has been to site many of the communities on the limited coastal flats. As such, despite the high ground, many of the community assets are vulnerable to erosion and flooding, as seen in **Figure 31** and **Figure 32**.

Figure 31 Iama is a continental island with the community sited on low lying sand deposits on the north side of the island

Figure 32 Mabuiag is a large continental island, with the community largely confined to the low flat sandy land on the west coast

3.1.2.2 Volcanic Islands

Volcanic islands are, as the name suggests, based on dormant volcanic peaks that have risen from the sea floor. This type of island is found scattered across the eastern Torres Strait and include the inhabited islands of Mer, Erub and Ugar.

Due to the volcanic origin the rock in these islands is basalt, that degrades to rich soils, with native vegetation often including rainforest. The volcanic islands are typically steep sided and much of the coastline is rocky. As with the continental islands parts of the community located on the sand flats are vulnerable to erosion and flooding. The community on Mer is one of the most vulnerable of the volcanic islands with most of the assets located on the flats as seen in **Figure 33**.

Figure 33 Mer and Dowar (distant) with the Mer community largely located on sand flats along the north coast

3.1.3 Mud Islands

In the far north of the Torres Strait, close to the coastline of Papua New Guinea (PNG), there are a number of low expansive mud islands. These islands are located on old reef platforms; however, the coral communities are inactive or at the very least significantly reduced due to smothering by sediments from the nearby PNG rivers. The sediments on these islands are largely sourced from the river discharges. This material deposits below the water levels and has resulted in large areas of intertidal wetlands and in particular mangroves that dominate these islands. Unlike sand islands the process to deposit the mud requires calm conditions and so the mechanism to build up land is largely limited by high tide levels resulting in most land being below the Highest Astronomical Tide (HAT).

With no active reef system there is a limited amount of granular material available on these islands. As seen in **Figure 34**, this granular material forms beaches and small dunes that are raised above the bulk of the island by waves at high tide, penetrating through fringing mangrove forests. This limited "high" ground is where the communities of Saibai and Boigu are located as seen in **Figure 35** and **Figure 36**.

The land the communities is on, though raised above the wetlands, is still low when compared to the extreme tides in the region. These communities regularly experience flooding from abnormally high tides. Further the very limited land available is vulnerable to erosion, particularly when mangroves are cleared from the foreshore (clearing undertaken historically).

Figure 34 Boigu Island cemetery had a natural foreshore with a beach developed behind a mangrove forest (not coral sand).

Figure 35 Sabai community is confined to a narrow strip of "high" ground

Figure 36 Boigu seen from over the island with mangrove forests surrounding the community.

3.2 Impacts of Climate Change

3.2.1 Erosion (reef top morphology)

As discussed previously the location and shape of sand formations (cays and sand build ups around rock islands) are controlled by the reef top wave and currents that drive morphological processes. Most of the energy from the sea is blocked at the reef edge, with currents blocked and waves breaking and dissipating much of the energy. As sea levels rise the depth of water over the reef increases, allowing more energy onto the reef top. This results in changes to morphological process on the reef and alters the long term balance.

The impact of sea level increases on reef top morphology has been analysed (refer Bettington, 2021). This analysis on the impact of increasing sea level on foreshore sand transport rates on Poruma revealed that the annual transport rates have increase as seen in **Figure 37**. These analysis consider the two seasons and found that the increased longshore transport rate for the dominant south easterly conditions was greater than the increase for the wet season north westerly conditions, resulting in a loss of balance that drives erosion of the islands.

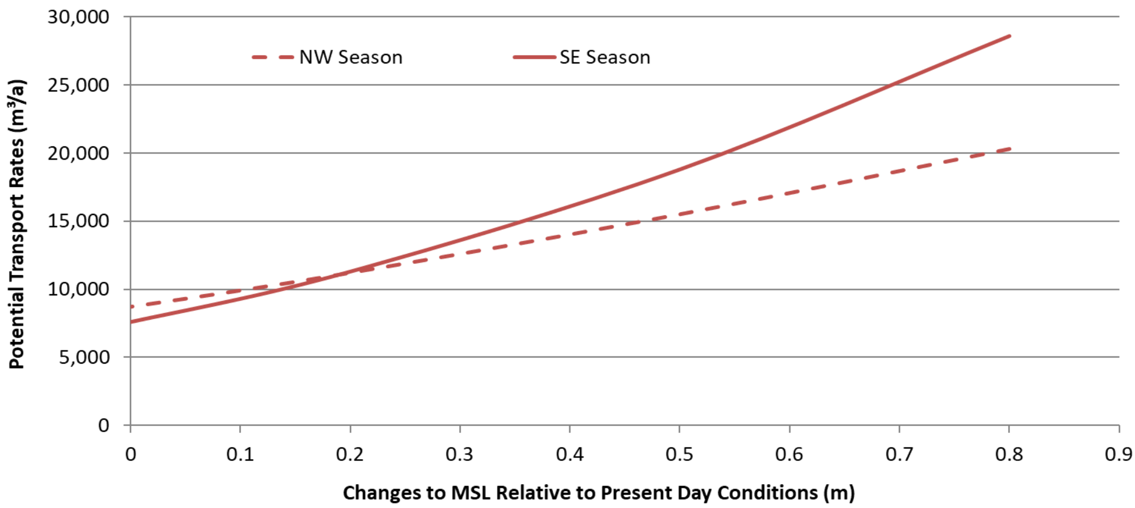


Figure 37 Changes in longshore sand transport rates with sea level rise on Poruma – note the overall increase in sediment transport as energy levels increase with rising seas, but the balance is lost significantly greater increases in SE conditions over NW conditions.

Apart from the increased erosion being driven by the direct changes seen in **Figure 37**, the additional transport is anticipated to diminish the volume of sand on the reef platform. As sand is washed of the reef platform this will act to increase the depth of water over the central parts of the reef. Ultimately while this feedback will worsen conditions slightly, reef edge levels will not be impacted.

As sea levels rise above baseline the energy on the reef top will drive changes to the sand distribution, with a long term trend towards sand being increasingly washed off the platform and lost to the system. Recent changes to the coastline on Poruma and Warraber reveal the dramatic changes that are possible (refer **Figure 38** and **Figure 39**).

Figure 38 Foreshore locations captured over 30 years reveal significant changes in the foreshore location on Poruma's western end as a result of an imbalance in morphological processes. Note north and south coasts anchored by beach rock.

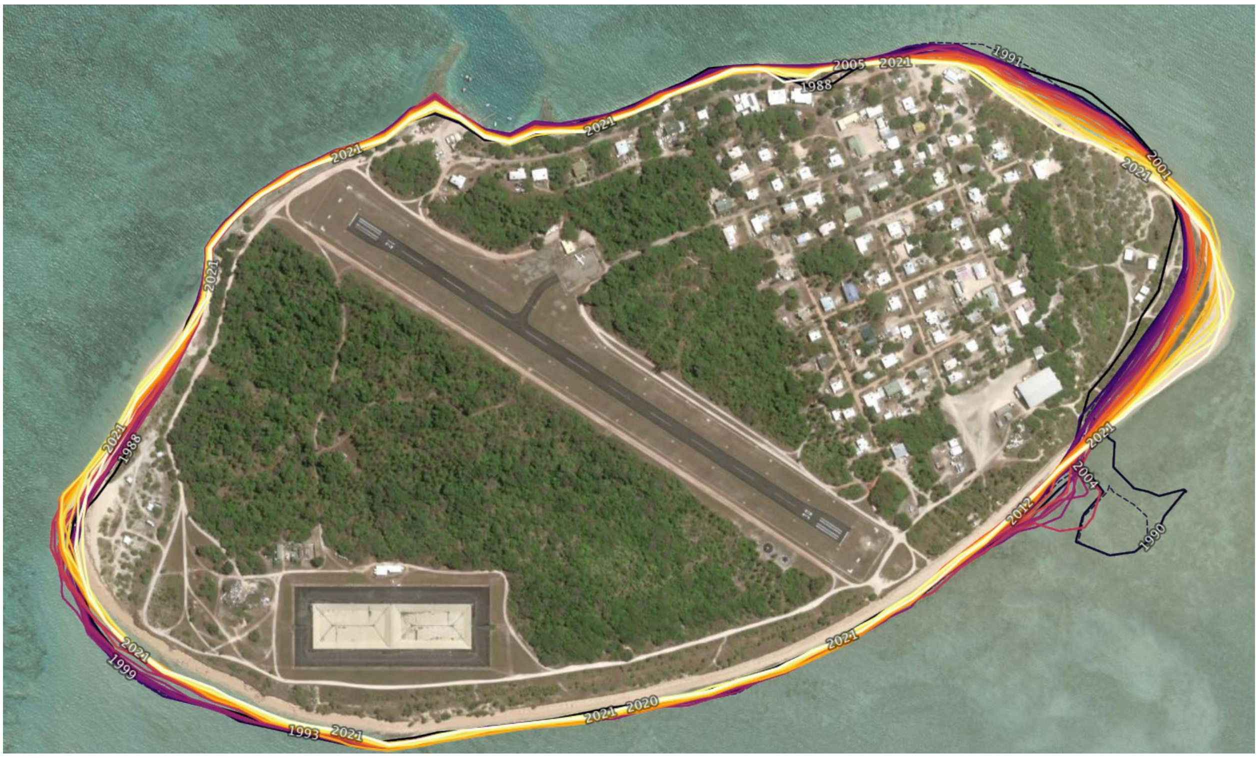


Figure 39 Satellite images over the last 30 years reveal that Warraber's eastern and western ends are experiencing erosion and accretion, with beach rock stabilising the north coast.

Ultimately if the morphological processes are severely out of balance the erosion pressure on the islands is relentless and islands can be lost. Examples of this, from Tuvalu, are presented in **Figure 40** and

Figure 41 where recent erosion linked to severe Tropical Cyclone Pam has had dramatic impacts on the islands.

Figure 40 An island in Tuvalu severely impacted by erosion with beach rock formations left isolated, unable to halt erosion

Figure 41 A separate island in Tuvalu was lost, with beach rock rubble (formed in the island), left to mark the location.

It is noted that the erosion issue will be most dramatically felt on the coral cays but is also an issue for sedimentary foreshores of the rock islands.

On the mud islands foreshores are extremely vulnerable to erosion but the morphology on these islands is impacted by both changing reef top energy and the presence or otherwise of mangroves. As a result the assessment of the issue is a more complicated problem than the relatively simple morphological balance described above, but no less severe. If mangroves sheltering the coast are lost, either through clearing or die back because of changes in tidal regime due to sea level rise, erosion will occur.

3.2.2 Flooding

The coral cays, mud islands and sand deposits around the rock islands are vulnerable to marine flooding. During flooding sediments are carried onto the land by the storm and deposited, slowly raising ground levels. The mud islands and the younger sand deposits are lowest and most vulnerable to flooding as seen in **Figure 42**. The depth and frequency of flooding is the critical issue. A common refence for acceptable flooding frequency is greater than 100 years ARI (i.e. a 1% chance of occurrence annually).

Conditions today in the Torres Strait vary considerably. Most of the land on the cays and around rock island is above the 100 year ARI flood level, though some land is currently vulnerable (refer **Figure 18** and **Figure 19**). The mud islands are much more severely impacted by flooding today. As seen in **Figure 16** and **Figure 17** the mud island communities today are completely flooded in a 100 year ARI event. For the Torres Strait communities the frequency of inundation is the critical issue.

As sea levels rise the frequency and severity of flooding events is likely to increase. As a broad guide 100 year ARI event is a tolerable flood frequency, but once this is exceeded the issue then becomes what frequency is a tipping point for liveability.

Figure 42 Flooding on Saibai in December 2009

3.2.3 Groundwater contamination

The pattern of settlement in the Torres Strait was linked to availability of fresh water on the islands. The islands with communities all had fresh groundwater that could be accessed via wells or springs through bad droughts. Until recently the fresh groundwater was the primary source of water for the communities, with septic overflow feeding much of the extracted water back into the island. In recent decades all islands have had sewage systems installed and the water supply secured with surface dams and desalination plants.

Saltwater intrusion from the ocean is persistent with high tides forcing sea water through the foreshores. However, because freshwater is less dense than saltwater within the sandy soils of the islands a freshwater lens exists. This freshwater is vital to the island's vegetation, with trees drawing on the water during the dry season. Depending on the rainfall and water extraction (e.g. wells) the size of the freshwater lens will expand/deepen or shrink/narrow.

If the freshwater lens is replaced by seawater the water table will no longer support terrestrial vegetation. The freshwater lens can be replaced by saltwater if:

- There is a severe drought, and the freshwater is exhausted (possibly made worse with water extraction).
- When seawater swamps the island and enters from above (e.g. marine flooding event) and contaminates the lens.

It is recognised that in areas that have experienced groundwater contamination, salt tolerant vegetation is found with coconuts and beach almonds being common. In areas above regular inundation the vegetation is more terrestrial. As sea levels rise the groundwater contamination events will increase in frequency and intensity with higher still water levels driving higher tides and greater frequency of flooding events. As this happens the vegetation on the islands will experience die back with salt tolerant vegetation taking over from terrestrial vegetation and in areas with severe contamination even salt tolerant vegetation will not survive.

Because modern water supply for potable water on the islands relies on dams and desalination plants groundwater contamination will not extinguish water supply. However, contamination of the groundwater would result in the character of the islands changing as the vegetation dies back, impacting continued habitation. This will also impact gardens and cropping that occurs on the islands.

3.2.4 Coral Bleaching

Coral reefs are the building block of the Torres Strait islands, both physically and culturally. These ecosystems provide the reef platforms and sand for the islands plus a vital habitat for the fisheries. As sea levels rise, if the natural systems are able to adapt, they will require healthy coral reefs that can respond and grow. If the reefs are not healthy Torres Strait communities, particularly those located on cays have a bleak future.

Coral bleaching occurs when water temperatures are higher than normal, leading corals to expel symbiotic microalgae that give corals their colour and protection from the sun. If coral bleaching is severe enough the corals die. In the Torres Strait coral bleaching events typically occur during years with lower than normal wet season cloud cover (El Nino events). An example of a severe bleaching event in the Torres Strait that occurred in the 2015/16 wet season (a severe El Nino) is seen in **Figure 43**.

To recover from bleaching events coral systems need to be healthy and require time. With climate change, the warming of the waters and potential changes to intensity and frequency of El Nino years coral bleaching is becoming more common and severe. Without sufficient respite from bleaching events the vigour of reefs is diminished and ultimately survival of the corals is threatened.

As addressed previously, bleaching of the coral directly impacts the production of sand and the ability to respond to sea level rise.

Figure 43 Coral bleaching seen as white/pale patches, captured in March 2016 after a severe bleaching event in the Torres Strait

3.2.5 Wetland and Mangrove Extent

Across the Torres Strait there are extensive intertidal wetland ecosystems, dominated by mangrove forests. The mud islands, in particular, are vast intertidal wetlands with extensive mangrove forests and very limited areas raised above tidal inundation. Mangroves are also common on protected foreshores of the rock islands, and some mangroves can be found around the cays. The mangroves are an important species, especially when they become a forest. They have numerous impacts on the islands, including:

- Trapping and stabilising fine sediments in the calm waters inside root systems, allowing silts and muds to build up (refer **Figure 44**).
- Sheltering foreshores from seasonal waves, helping to stabilise dunes and beaches (refer **Figure 34** and **Figure 44**).
- Acting as a habitat for a vast array of marine life that sustain fisheries.
- Moderating the peak flood levels in the wetlands, with the short lived marine flood events significantly higher on the coast than in wetlands.

Figure 44 Mangroves on the foreshore of Boigu (looking to sea from the "high" sand dune)

Although mangroves are an aggressive colonising species, they need the right conditions to grow. To establish mangroves need:

- A mild wave and current climate for seedlings to take root; and,
- Mangroves occupy very specific zones within the tidal range and will only grow in those zones. Note that different species have different tolerances.

Once established the mature mangrove trees can tolerate larger waves and currents and even some erosion or accretion. This is relevant in the Torres Strait where the seasons give respite from waves for several months, allowing mangroves seedlings time to take root.

The vast forests on the mud island provide a graphic display of the niche nature of mangroves, as seen in **Figure 45**, where the various species of mangroves occupy different zones within the upper parts of the tidal range. If the tidal regime is altered mangroves outside the tolerable tide range will initially not colonise and ultimately die. An example of mangrove die back due to altered tides is seen in **Figure 46**.

As sea levels rise the tidal regime will change and mangroves will be impacted with altered colonisation and die back. This process will cause significant disruption, leading to erosion of land shielded by mangroves and a likely loss in health of the fisheries.

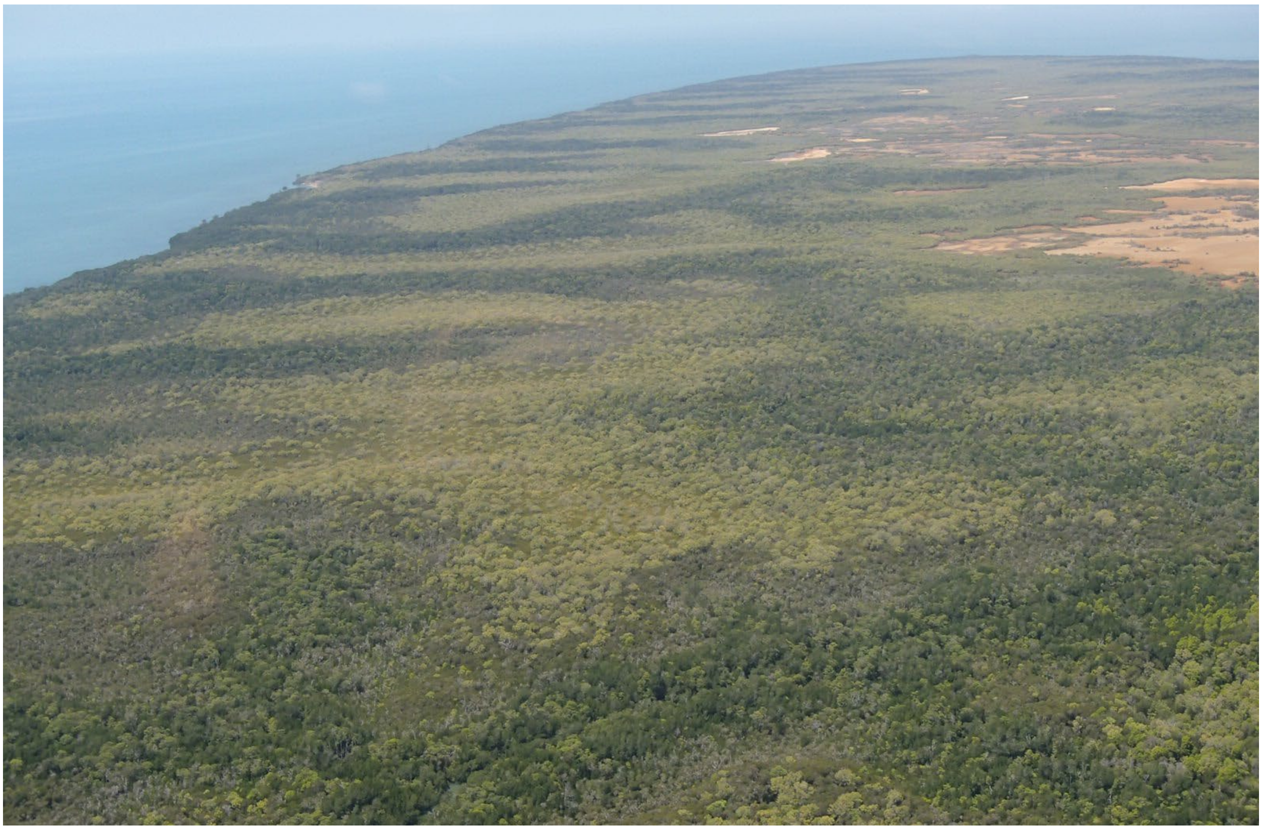


Figure 45 Vast mangrove forests on Boigu – note at least 3 different species of mangrove (shades of green) occupy different tidal zones between roughly MSL and a Higher High Water, with salt pans at the top of the tidal range

Figure 46 Mangrove die back in the Gulf of Carpentaria due to altered tidal levels (El Nino event led to 0.4 m dip in sea levels)

3.3 Impacts of Climate on Warraber and Poruma (Cays)

For the coral cays the critical climate change impacts of concern are:

- Erosion due to changed reef top morphology;
- Increase frequency of flooding, especially on younger (newer) parts of these islands;
- Contamination of groundwater impacting terrestrial vegetation; and,
- Coral bleaching and the resultant loss of coral vigour impacting both the supply of sediment and the health of the fisheries.

3.4 Impacts of Climate Change on Boigu and Saibai (Mud Islands)

For the mud islands the impacts of climate change are different to the other islands in the Torres Strait due to their low profile and the resultant importance of mangroves, and lack of a coral reef. The Impacts of concern are:

- Regular flooding and inundation;
- Loss of mangroves:
  - Erosion;
  - Increased storm tide ingress into wetlands; and,
  - Loss of fisheries and other hunting;
- Contamination of groundwater is an issue, impacting vegetation.

It is important to recognise that mangroves forests moderate tidal movements into the wetlands, leading to peak water levels within the wetlands that are appreciably lower than those on the coast. This moderating effect is due to water moving through the mangroves, especially the roots that provide a dense tangle close to the ground, the same effect that moderates waves. As water levels rise above the roots the passage through mangroves is made easier. Thus, as sea levels rise this moderating effect will be diminished as sea levels rise above the root tangle. If the mangrove is also suffering a loss of vigour due to the water level changes this will see a reduction in tree numbers and again an easier passage through the mangroves. As such it is anticipated that the mangrove forests of Saibai and Boigu could experience even more dramatic decline than the simple water level would indicate due to the feedback impacts on water levels within the mangroves.

4 Future Impacts

Letter of Instruction question D:

D. Future impacts

2050 Projections

*In answering questions 8-11, please use the projected sea levels for the following Shared Socioeconomic Pathways (**SSPs**) as used by the Intergovernmental Panel on Climate Change (**IPCC**):*

- *i) SSP 1-1.9: assume that sea levels in the Torres Strait in 2050 will be 34cm higher than at the Baseline;*
- *ii) SSP 1-2.6: assume that sea levels in the Torres Strait in 2050 will be 36cm higher than at the Baseline; and*
- *iii) SSP 3-7.0: assume that sea levels in the Torres Strait in 2050 will be 38cm higher than at the Baseline.*

(2050 Projections)

8. Adopting the 2050 Projections, what would be the expected frequency of a Township Inundation Event on the Mapped Islands under each of the SSPs? In answering this question, please identify and explain any differences in expected frequency between the Mapped Islands.
9. In relation to SSP 1-2.6 only, please draft maps showing the flooding and inundation levels on each of the Mapped Islands that would be caused by an extreme sea level event having a frequency of 1 in 100 years as at 2050.
10. Please describe the impact of HAT tides on Saibai at 2050 under each of the SSPs listed above.
11. Please discuss how the 2050 Projections under each SSP will affect:
    a) the climate change impacts identified in your answer to question 5(a), above; and
    b) the rate of change of those climate change impacts.

2100 Projections

In answering questions 12-15, please use the projected sea levels for the following SSPs as used by the IPCC:

- *i) SSP 1-1.9: assume that sea levels in the Torres Strait in 2100 will be 56cm higher than at the Baseline;*
- *ii) SSP 1-2.6: assume that sea levels in the Torres Strait in 2100 will be 62cm higher than at the Baseline; and*
- *iii) SSP 3-7.0: assume that sea levels in the Torres Strait in 2100 will be 87cm higher than at the Baseline.*

(2100 Projections)

12. Adopting the 2100 Projections, what would be the expected frequency of a Township Inundation Event on the Mapped Islands under each of the SSPs? In answering this question, please identify and explain any differences in expected frequency between the Mapped Islands.
13. In relation to SSP 1-2.6 only, please draft maps showing the flooding and inundation levels on each of the Mapped Islands that would be caused by an extreme sea level event having a frequency of 1 in 100 years as at 2100.
14. Please describe the impact of HAT tides on Saibai at 2100 under each of SSPs
15. Please discuss how the 2100 Projections under each SSP will affect:
    a) the climate change impacts identified in your answer to question 5(a), above; and
    b) the rate of change of those climate change impacts.

Response:
For the assessment of future sea level rise impacts the Intergovernmental Panel on Climate Change (IPCC) forecasts have been adopted. Scenarios adopted are SSP 1-1.9, SSP 1-2.6 and SSP 3-7.0, which are low to mid-level emission scenarios. The adopted sea level rises and implication for Mean Sea Level (MSL) relative to Australian Height Datum (AHD) are presented in **Table 10.**

Table 10 Mean Sea Level (MSL) relative to Australian Height Datum (AHD) for various time horizons and climate change scenarios

Horizon	SLR (m)	Boigu (m AHD)	Saibai (m AHD)	Poruma (m AHD)	Warraber (m AHD)
MSL in 1900 (Base Line)	*0.00*	*0.66*	*0.55*	*0.19*	*0.30*
MSL in 2050 SSP 1-1.9	0.34	1.00	0.89	0.53	0.64
MSL in 2050 SSP 1-2.6	0.36	1.02	0.91	0.55	0.66
MSL in 2050 SSP 3-7.0	0.38	1.04	0.93	0.57	0.68
MSL in 2100 SSP 1-1.9	0.56	1.22	1.11	0.75	0.86
MSL in 2100 SSP 1-2.6	0.62	1.28	1.17	0.81	0.92
MSL in 2100 SSP 3-7.0	0.87	1.53	1.42	1.06	1.17

4.1 2050 Projections

Applying mean sea level datum conversions presented in **Table 10** to the 2050 projections for various scenarios provides the resultant high water levels that are presented in **Table 11** to **Table 13**. Note that the tidal limit of Highest Astronomical Tide (HAT), exceeded nominally less often than once a year, and the average higher tides (MHHW or MHWS), a level exceeded nearly every month, are included as lower bound flood levels for assessing frequency of flooding events. A plot of water level recurrences for the mid-level forecast (SSP 1-2.6) is presented in Figure 47.

Table 11 2050 SSP 1-1.9 (SLR = 0.34m) Projections for Water Levels Relative to AHD

Recurrence Interval (ARI years)	Boigu (m AHD)	Saibai (m AHD)	Poruma (m AHD)	Warraber (m AHD)
MHWS/MHHW	2.31	1.99	1.69	1.70
HAT (~4.5 year[1])	3.42	2.91	2.80	2.77
10 years	3.53	3.03	3.00	3.17
25 years	3.71	3.18	3.14	3.35
50 years	3.85	3.31	3.28	3.49
100 years	**4.07**	**3.45**	**3.39**	**3.61**
500 years	4.22	3.74	3.63	3.86

[1] Note that the ARI assigned to HAT is below the theoretical recurrence interval for HAT (~18.5 years) but includes the influence on regional water level lifts in defining the frequency of recurrence.

Table 12 2050 SSP 1-2.6 (SLR = 0.36m) Projections for Water Levels Relative to AHD

Recurrence Interval (ARI years)	Boigu (m AHD)	Saibai (m AHD)	Poruma (m AHD)	Warraber (m AHD)
MHWS/MHHW	2.33	2.01	1.71	1.72
HAT (~4.5 year)	3.44	2.93	2.82	2.79
10 years	3.55	3.05	3.02	3.19
25 years	3.73	3.20	3.16	3.37
50 years	3.87	3.33	3.30	3.51
100 years	**4.09**	**3.47**	**3.41**	**3.63**
500 years	4.24	3.76	3.65	3.88

Table 13 2050 SSP 3-7.0 (SLR = 0.38m) Projections for Water Levels Relative to AHD

Recurrence Interval (ARI years)	Boigu (m AHD)	Saibai (m AHD)	Poruma (m AHD)	Warraber (m AHD)
MHWS/MHHW	2.35	2.03	1.73	1.74
HAT (~4.5 year)	3.46	2.95	2.84	2.81
10 years	3.57	3.07	3.04	3.21
25 years	3.75	3.22	3.18	3.39
50 years	3.89	3.35	3.32	3.53
100 years	**4.11**	**3.49**	**3.43**	**3.65**
500 years	4.26	3.78	3.67	3.90

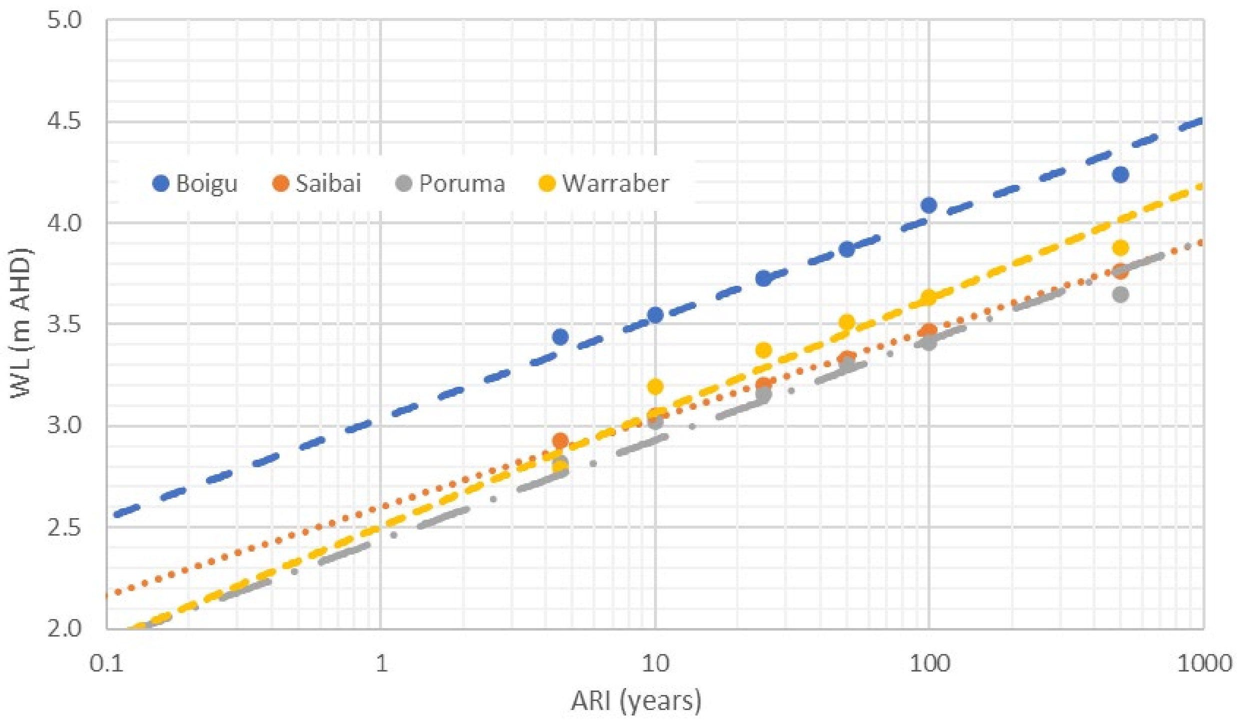


Figure 47 SSP 1-2.6 2050 Extreme Water Levels (Note assume HAT is a 4.5 year and MHWS is 0.05 year ARI event)

4.1.1 Impact of the 100 year ARI Flood in 2050

For reference the 100 year ARI event for scenarios SSP1-2.6 has been plotted on the communities, as seen in **Figure 48** to **Figure 51**. These figures reveal that for the mud islands the entire community will be flooded by this event. For the cays the 100 year flood events are now starting to flood significant land areas, though still has only minor impacts on Poruma.

4.1.2 Township Flooding Events in 2050

The frequency of Township Flooding Events, when 50% of the community is flooded, are presented in **Table 14**.

Table 14 Township Inundation Event Water Levels Relative to AHD with 2050 Frequency of Exceedance

	Boigu	Saibai	Poruma	Warraber
~50% of township flooded (m AHD)	3.4	2.8	3.6	3.5
SSP1-1.9 2050 Frequency (years)	5	3	250	60
SSP1-2.6 2050 Frequency (years)	4	2.5	200	50
SSP3-7.0 2050 Frequency (years)	3	2	150	40

Under 2050 sea level rise scenarios the Mud Islands are facing a situation where township flooding events will be occurring several times per decade. On the Cays the township flooding remains below the community standard 100 year ARI.

4.1.3 Impact of HAT in 2050

In 2050, Highest Astronomical Tide (HAT) will become a township flooding event for both Saibai and Boigu. On the Cays the tides will largely remain out of the community area.

4.1.4 Other Impacts in 2050

The other identified impacts were coastal erosion, habitat impacts (coral bleaching and mangrove die back), and groundwater contamination.

Erosion

The erosion assessment for the cays (refer **Figure 37**) shows that the sediment transport regime on the reef top of Poruma will have become 50% more intense and will be out of balance, with an excess of transport potential towards the northwest in the order of 2,500 m^3/year. Something similar will be occurring on Warraber. Effectively the islands will be experiencing more severe erosion and there will be a significant trend for the overall sand budget to be depleted.

For the mud islands the impacts on mangroves and increased energy will make erosion issues worse, though due to the complex nature of the problem no calculations to quantify the issue exist.

Habitat Impacts

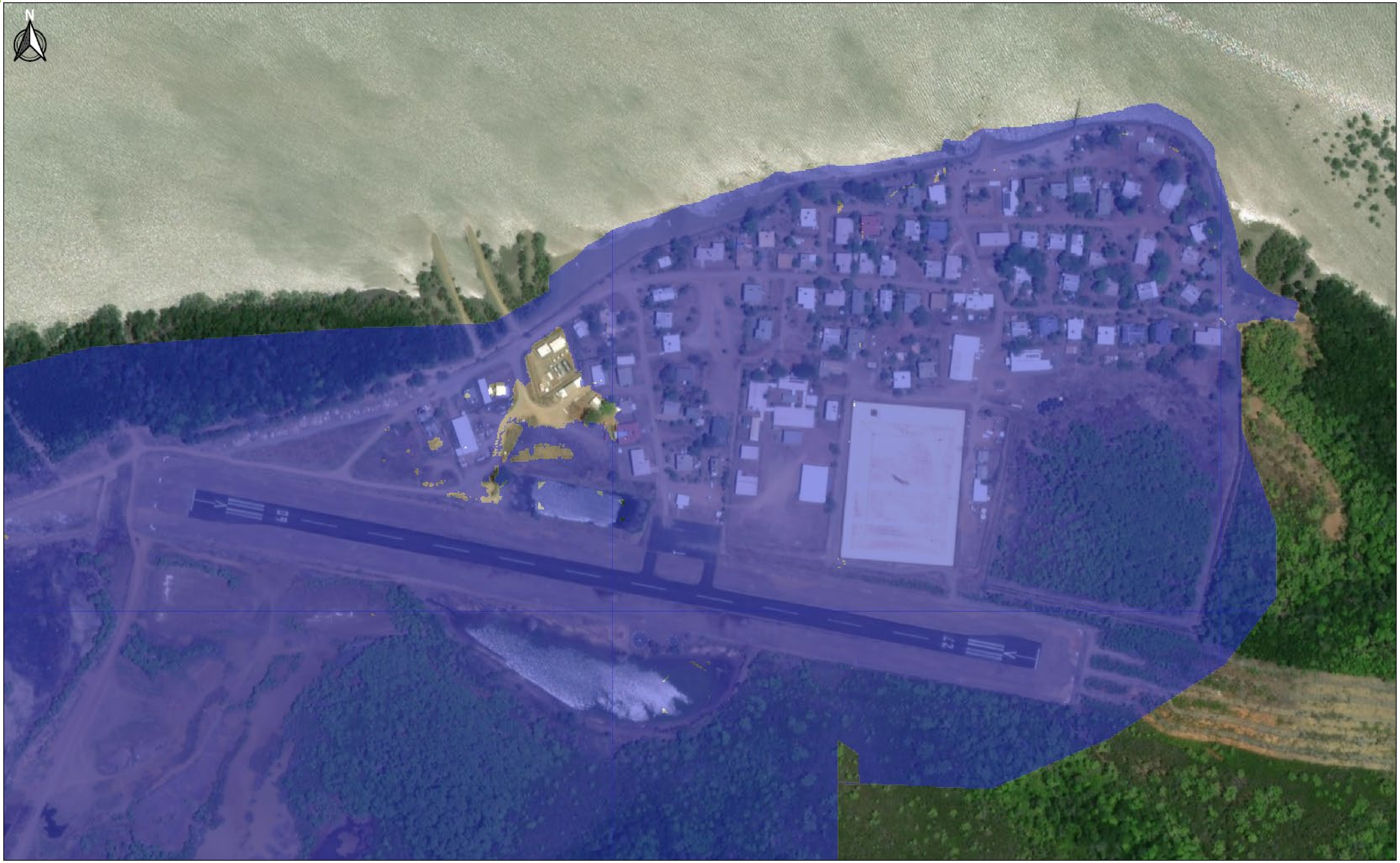
The habitat impacts are far more subjective, with systems being adaptive and hopefully resilient, but impacts based on the forecast changes can be expected:

- With a sea level 0.36 m higher than baseline it is likely that mangrove forests will be seeing changes, with mangroves at the lower part of their traditional tidal range not replacing or even dying, leading to loss of foreshore mangrove protection.

- Coral bleaching is expected to become more frequent and severe, with the overall health of the reef anticipated to be diminished. The loss of reef vigour would contribute to the expected sand availability issues on reef platforms.

Groundwater Contamination

The groundwater on the low mud islands will now be severely impacted with tidal waters able to flood much of the land. It is likely that large parts of Saibai and Boigu will not be able to sustain terrestrial trees, with mangroves able to survive in many lower parts of the community.



NOTES
2050 SSP 1-2.6 (SLR = 0.36m) 100 Year
ARI Flood on Boigu = 4.09m AHD
Level Datum: AHD
Meridian: MGAz54

BOIGU 2050 SSP 1-2.6 (SLR = 0.36m) 100 YEAR ARI FLOOD
1:3000 (A3)

40 0 40 80 120 160 m
1:3000 (A3) 1:1500 (A1)

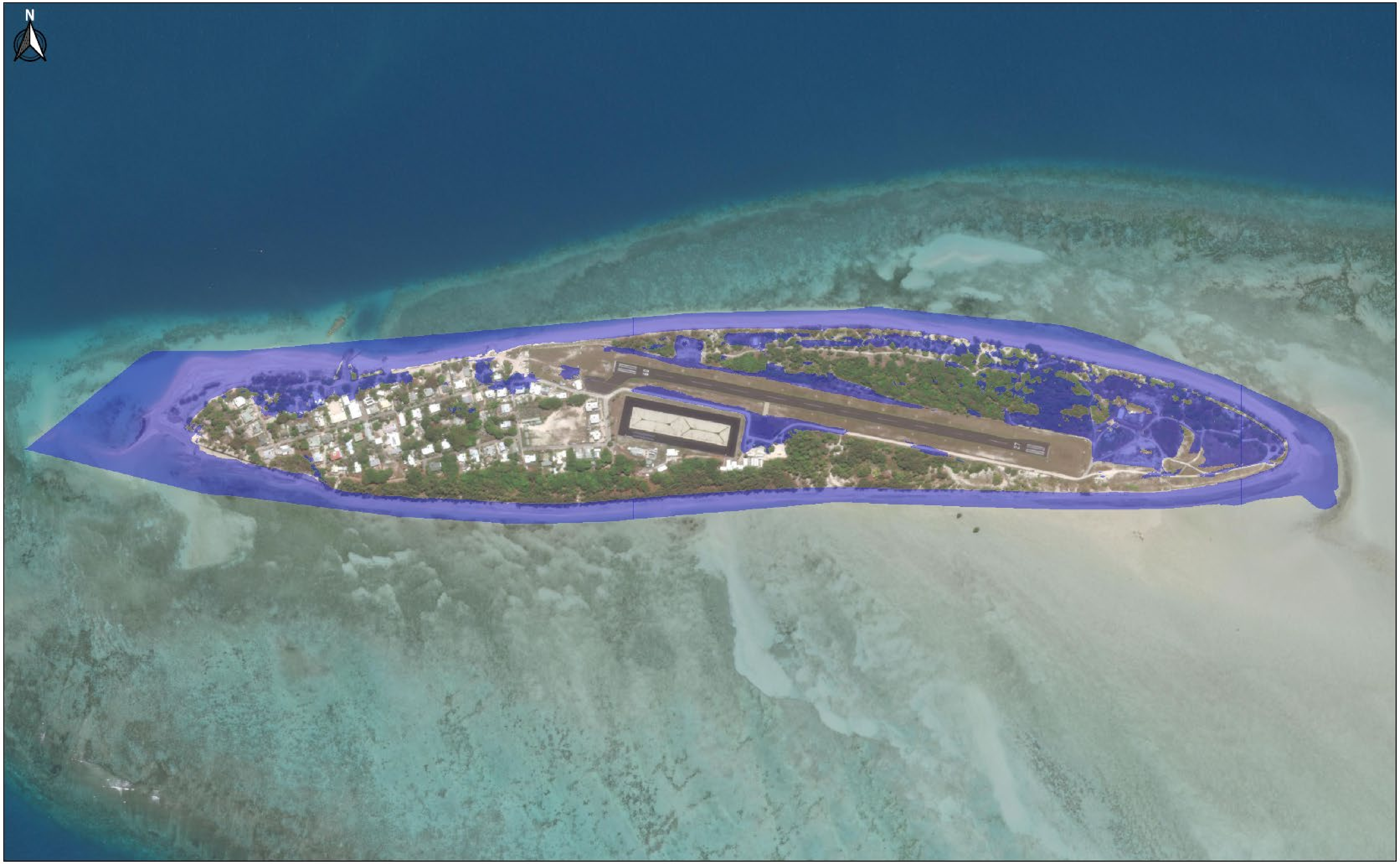
Figure 48 Boigu 2050 SSP 1 – 2.6 100 year ARI flood

NOTES
2050 SSP 1-2.6 (SLR = 0.36m) 100 Year
ARI Flood on Saibai = 3.47m AHD
Level Datum: AHD
Meridian: MGAz54

SAIBAI 2050 SSP 1-2.6 (SLR = 0.36m) 100 YEAR ARI FLOOD
1:5000 (A3)

50 0 50 100 150 200 250 m
1:5000 (A3) 1:2500 (A1)

Figure 49 Saibai 2050 SSP 1 – 2.6 100 year ARI flood



NOTES
2050 SSP 1-2.6 (SLR = 0.36m) 100 Year
ARI Flood on Poruma = 3.41m AHD
Level Datum: AHD
Meridian: MGAz54

PORUMA 2050 SSP 1-2.6 (SLR = 0.36m) 100 YEAR ARI FLOOD

1:6000 (A3)

100 0 100 200 300 m

1:6000 (A3) 1:3000 (A1)

Figure 50 Poruma 2050 SSP 1 – 2.6 100 year ARI flood

NOTES
2050 SSP 1-2.6 (SLR = 0.36m) 100 Year ARI
Flood on Warraber = 3.63m AHD
Level Datum: AHD
Meridian: MGAz54

WARRABER 2050 SSP 1-2.6 (SLR=0.36m) 100 YEAR ARI FLOOD
1:4000 (A3)

40 0 40 80 120 160 200 m
1:4000 (A3) 1:2000 (A1)

Figure 51 Warraber 2050 SSP 1 – 2.6 100 year ARI flood

4.2 2100 Projections

Applying mean sea level datum conversions presented in **Table 10** the 2100 projections for various scenarios the resultant high water levels are presented in **Table 15** to **Table 17** with the SSP 1-2.6 levels also plotted in **Figure 52**. Note that the tidal limit of Highest Astronomical Tide (HAT), exceeded nominally less often than once a year, and the average higher tides (MHHW or MHWS), a level exceeded a few times per month, are included as lower bound flood levels for assessing frequency of flooding events.

Table 15 2100 SSP 1-1.9 (SLR = 0.56m) Projections for Water Levels Relative to AHD

Recurrence Interval (ARI years)	Boigu (m AHD)	Saibai (m AHD)	Poruma (m AHD)	Warraber (m AHD)
MHWS/MHHW	2.53	2.21	1.91	1.92
HAT (~4.5 year)	3.64	3.13	3.02	2.99
10 years	3.75	3.25	3.22	3.39
25 years	3.93	3.40	3.36	3.57
50 years	4.07	3.53	3.50	3.71
100 years	**4.29**	**3.67**	**3.61**	**3.83**
500 years	4.44	3.96	3.85	4.08

Table 16 2100 SSP 1-2.6 (SLR = 0.62m) Projections for Water Levels Relative to AHD

Recurrence Interval (ARI years)	Boigu (m AHD)	Saibai (m AHD)	Poruma (m AHD)	Warraber (m AHD)
MHWS/MHHW	2.59	2.27	1.97	1.98
HAT (~4.5 year)	3.70	3.19	3.08	3.05
10 years	3.81	3.31	3.28	3.45
25 years	3.99	3.46	3.42	3.63
50 years	4.13	3.59	3.56	3.77
100 years	**4.35**	**3.73**	**3.67**	**3.89**
500 years	4.50	4.02	3.91	4.14

Table 17 2100 SSP 3-7.0 (SLR = 0.87m) Projections for Water Levels Relative to AHD

Recurrence Interval (ARI years)	Boigu (m AHD)	Saibai (m AHD)	Poruma (m AHD)	Warraber (m AHD)
MHWS/MHHW	2.84	2.52	2.22	2.23
HAT (~4.5 year)	3.95	3.44	3.33	3.30
10 years	4.06	3.56	3.53	3.70
25 years	4.24	3.71	3.67	3.88
50 years	4.38	3.84	3.81	4.02
100 years	**4.60**	**3.98**	**3.92**	**4.14**
500 years	4.75	4.27	4.16	4.39

Royal HaskoningDHV

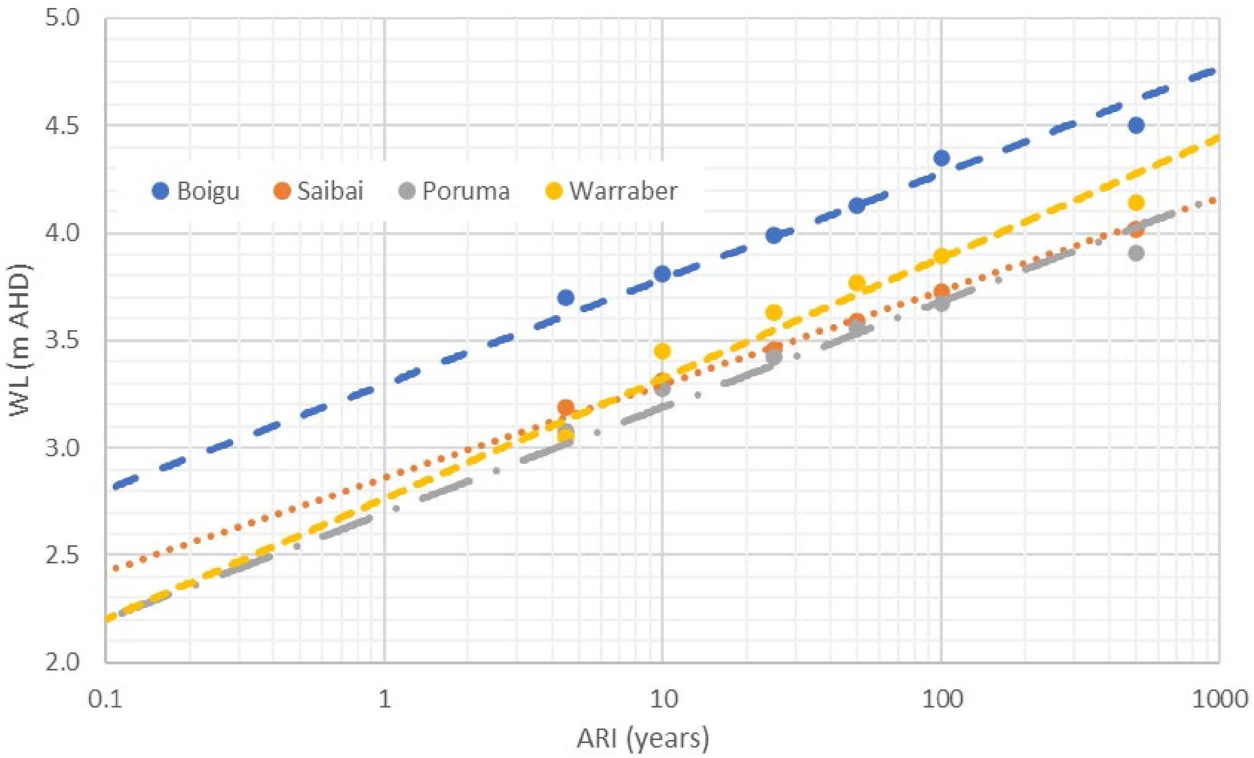


Figure 52 SSP 1-2.6 2100 Extreme Water Levels (Note assume HAT is a 4.5 year and MHWS is 0.05 year ARI event)

4.2.1 Impact of the 100 year ARI Flood in 2100

For reference the 100 year ARI event for scenarios SSP1-2.6 has been plotted on the communities, as seen in **Figure 53** to **Figure 56**. These figures reveal that for the mud islands the entire community will be flooded by this event. For the cays the 100 year flood events are now a significant issue.

4.2.2 Township Flooding Events in 2100

The frequency of Township Flooding Events, when 50% of the community is flooded, are presented in **Table 18**.

Table 18 Township Inundation Event Water Levels Relative to AHD with 2100 Frequency of Exceedance

	Boigu	Saibai	Poruma	Warraber
~50% of township flooded (m AHD)	3.4	2.8	3.6	3.5
SSP1-1.9 2100 Frequency (years)	2	1	100	20
SSP1-2.6 2100 Frequency (years)	1.5	0.7	70	15
SSP3-7.0 2100 Frequency (years)	0.5	0.2	20	7

Under 2100 sea level rise scenarios the mud Islands are facing a situation where township flooding events will be occurring several times per year. This effectively means that by 2100 the communities of Sabai and Boigu are within the normal tidal range. Worsening the flooding situation on the mud islands is the expected diminution of the mangroves, leading to elevated water levels on both sides of the community.

On the cays the township flooding becomes an issue, with flooding frequency now below the community standard 100 year ARI.

4.2.3 Impact of HAT in 2100

For the mud islands the communities are flooded by the Highest Astronomical Tide (HAT). This effectively means most of the township will now be flooded by tides alone.

The highest astronomical tide on Warraber will flood some of the lower lying houses, but flooding on Poruma still remains limited.

4.2.4 Other Impacts in 2100

For the other identified impacts of erosion, habitat impacts (coral bleaching and mangrove die back), and groundwater contamination are now being severely impacted.

Erosion
The erosion assessment for the cays (refer **Figure 37**) shows that the sediment transport regime on the reef top of Poruma will have become 100% more intense and will be out of balance, with an excess of transport potential towards the northwest in the order of 5,000 m^3/year. Something similar will be occurring on Warraber. Effectively the islands will be experiencing extreme erosion pressure and many parts of the sand budget of the reef top will be close to exhausted.

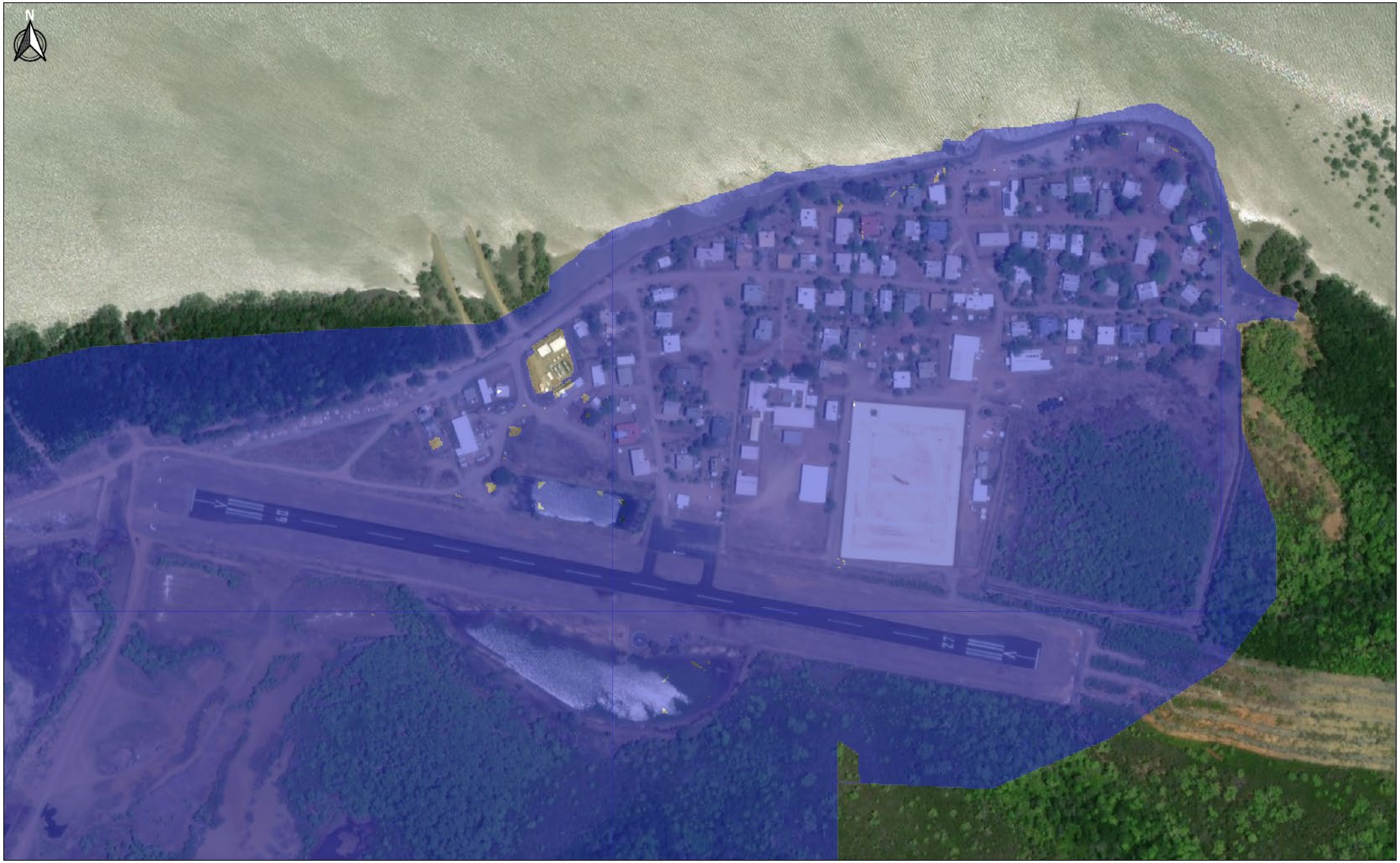
As discussed above the impacts on mangroves on the mud islands will result in a significant increase in the energy reaching the foreshores and inland areas of the islands. This increased energy will make erosion issues significantly more severe. Due to the complex nature of the problem no calculations to quantify the issue exist.

Habitat Impacts
It is likely that with the scale of changes being felt by 2100 many of the natural systems adaptive ability will have been exhausted. Likely impacts expected:

- With a sea levels 0.62 m above baseline it is likely that mangrove forests will be seeing extensive die backs and changes. It is also likely that the visible size of Boigu and Saibai will be appreciably reduced.
- Coral bleaching is expected to become a serious threat to the reef. The loss of reef vigour would contribute to the expected severe erosion problems on the reef top systems.

Groundwater Contamination
With tidal inundation of the mud islands fresh groundwater and the associated terrestrial vegetation will be gone. This will result in a loss of vegetation cover making the soils vulnerable to runoff scour.

On the coral cays and other sand areas in the Torres Strait it is likely that the fresh groundwater tables will still be present. The increasing frequency of inundation by marine events will result in sufficient contamination of the groundwater to destroy or diminish terrestrial vegetation on large parts of Warraber.



NOTES
2100 SSP 1-2.6 (SLR = 0.62m) 100 Year
ARI Flood on Boigu = 4.35m AHD
Level Datum: AHD
Meridian: MGAz54

BOIGU 2100 SSP 1-2.6 (SLR = 0.62m) 100 YEAR ARI FLOOD
1:3000 (A3)

40 0 40 80 120 160 m
1:3000 (A3) 1:1500 (A1)

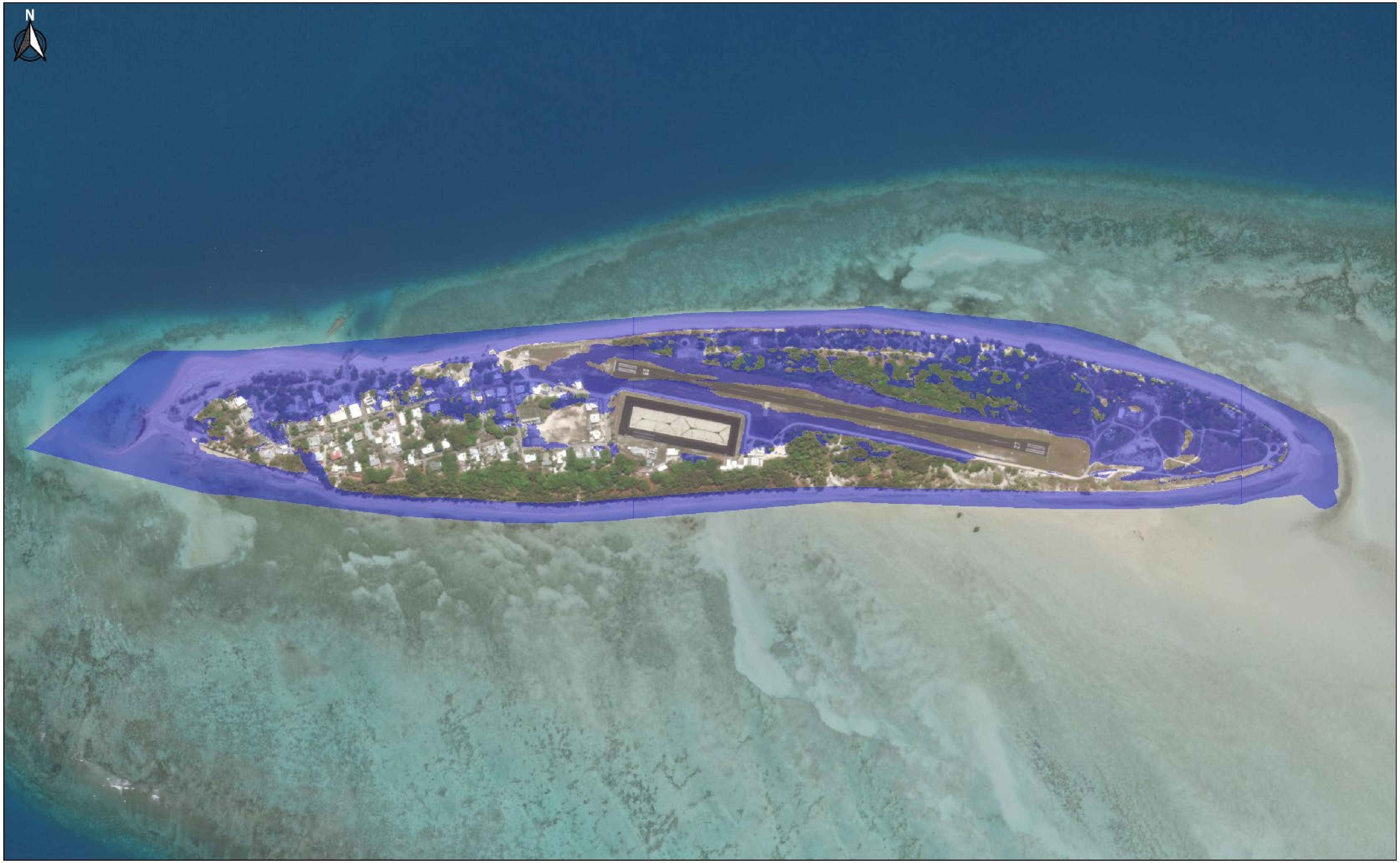
Figure 53 Boigu 2100 SSP 1 – 2.6 100 year ARI flood

NOTES
2100 SSP 1-2.6 (SLR = 0.62m) 100 Year
ARI Flood on Saibai = 3.73m AHD
Level Datum: AHD
Meridian: MGAz54

SAIBAI 2100 SSP 1-2.6 (SLR = 0.62m) 100 YEAR ARI FLOOD
1:5000 (A3)

50 0 50 100 150 200 250 m
1:5000 (A3) 1:2500 (A1)

Figure 54 Saibai 2100 SSP 1 – 2.6 100 year ARI flood



NOTES
2100 SSP 1-2.6 (SLR = 0.62m) 100 Year
ARI Flood on Poruma = 3.67m AHD
Level Datum: AHD
Meridian: MGAz54

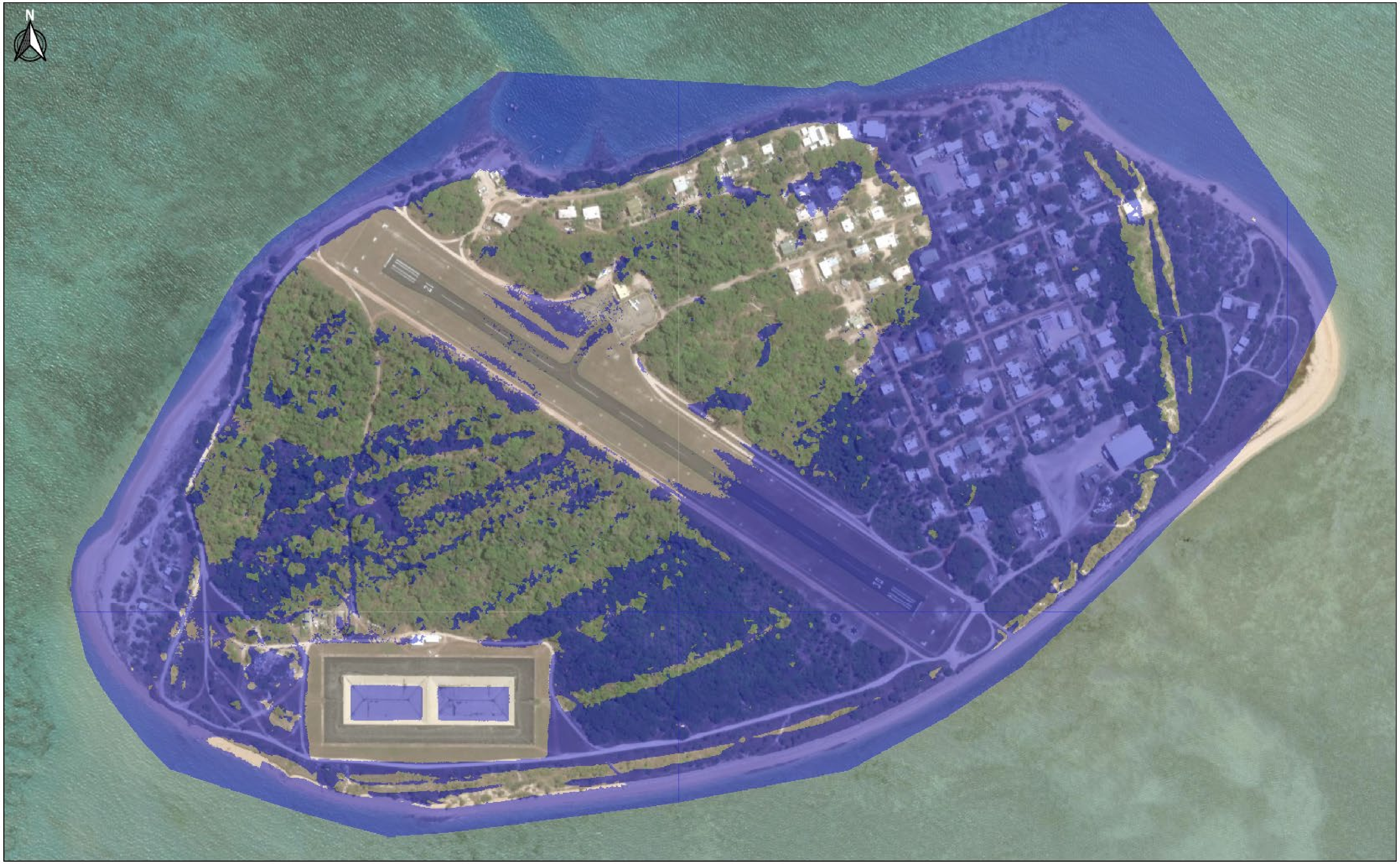
PORUMA 2100 SSP 1-2.6 (SLR = 0.62m) 100 YEAR ARI FLOOD

1:6000 (A3)

100 0 100 200 300 m

1:6000 (A3) 1:3000 (A1)

Figure 55 Poruma 2100 SSP 1 – 2.6 100 year ARI flood



NOTES
2100 SSP 1-2.6 (SLR=0.62m) 100 Year ARI
Flood on Warraber = 3.89m AHD
Level Datum: AHD
Meridian: MGAz54

WARRABER 2100 SSP 1-2.6 (SLR = 0.62m) 100 YEAR ARI FLOOD
1:4000 (A3)

40 0 40 80 120 160 200 m
1:4000 (A3) 1:2000 (A1)

Figure 56 Warraber 2100 SSP 1 – 2.6 100 year ARI flood

5 Further Questions

Letter of Instruction supplementary question:

Supplementary Questions

16. Please describe the actions and infrastructure commonly used to protect against flooding, inundations and the Climate Change Impacts identified in your answer to Question 5(a) (Adaptation Strategies). In your answer, please discuss the costs and effectiveness of different Adaptation Strategies.
17. Please describe the Adaptation Strategies currently undertaken or in place in the Torres Strait Islands (Torres Strait Adaptation Strategies). In your answer, please identify the particular island(s) on which those strategies have been undertaken or put in place.
18. Please explain and discuss the capacity of the Torres Strait Adaptation Strategies to protect Torres Strait Islanders from flooding, inundations, and the Climate Change Impacts:
    a. currently;
    b. as at 2050 under each of the 2050 Projections; and
    c. as at 2100 under each of the 2100 Projections.

    In your answer, please describe:
    i) any limitations; and
    ii) (if applicable) the expected lifespan, of the Torres Strait Adaptation Strategies.
19. Could the Torres Strait Adaptation Strategies have been constituted, planned, designed, or constructed differently to better protect Torres Strait Islanders from flooding, inundations, and the Climate Change Impacts and, in particular, to overcome the matters noted in your response to Question 18(i)-(ii)? If so, please explain how.
20. What, if any, additional or alternative Adaptation Strategies would assist in protecting Torres Strait Islanders from flooding, inundations, and the Climate Change Impacts now and in the future?

Response:

5.1 Common Responses to Combat Climate Change Impacts

This section describes how the issues resulting from climate change are commonly addressed on communities and islands across the globe.

5.1.1 Erosion

The most common and possibly effective reaction to erosion is to retreat. This is basically avoiding the issue by choosing to build in places that are secure indefinitely or for decades.

To combat erosion the commonly applied works are:

- Seawalls that provide a last line of defence and secure land.
    - rock armour
    - stone pitch walls
    - concrete armour
    - vertical or stepped walls of concrete or timber.
- Nourishment with sand won from outside the system (e.g. deeper water) and used to supplement the morphological processes
- Sand traps that hold sand in place

- Groynes
- Offshore wave trip structures

The built solutions that secure the coast are effective in stopping erosion, however, they are expensive and have impacts on coastal processes. Sand that is secured by works is not available to the coastal morphology processes and this can lead to erosion in other areas. It can also lead to the coasts being far less accessible or pleasant (lost amenity).

5.1.2 Flooding

Marine flooding is an issue that has always been a concern on low lying islands. The most common solution is to avoid the issue by location on higher land, where possible. Where occasional flooding is not avoidable then adaptation with elevated floor levels and selective plantings are used to mitigate impacts.

Where flooding issues are more difficult to avoid then commonly applied built solutions are:

- Construction of walls and bunds to exclude the event. Some of the most famous examples are:
  - Dutch dykes that defend a third of the Netherlands
  - Thames Barrier that blocks storm surges impacting southeast England
  - New Orleans bunds that famously failed in Hurricane Katrina
- Raising ground levels is done in many places today with coastal subdivisions.
  - The South China Sea has seen many small cays or atoll islands raised and armoured to secure the land for military and political reasons

5.1.3 Ecological Impacts

For the mangrove die back there is considerable effort invested to encourage mangroves to grow with barriers to waves, avoiding erosion and planting mangroves, however, the effectiveness at combating changing tidal levels is poor. Effectively mangroves are an aggressive type of tree and require the right habitat. The issues that can be controlled are being considered, but this this does not change the fundamental issue of changing tides.

Underlying coral health is an important factor in coral being able to survive climate change impacts. This issue is being addressed with sustained efforts to avoid anthropogenic impacts such as:

- Preserve natural systems by avoiding overfishing, etc.
- Avoid direct mechanical damage.
- Keep water clean by:
  - Minimising turbidity sources in the ocean (dredging and erosion on land)
  - Minimising nutrient rich runoff (manage use of fertiliser and intense animals)
  - Ensuring sewage is treated properly to ensure nutrients are not discharged directly or indirectly.

Coral bleaching's potential impacts on acidification are being researched with broad scale solutions a key focus of the research.

5.1.4 Groundwater Contamination

The issue of groundwater contamination is complex and usually very site specific. The most common method to mitigate the issues is the management of groundwater extraction.

The issue of mitigating seawater inflows due to seawater ingress resulting from sea levels above ground levels has only been addressed by exclusion, with marine inundation excluded by barriers.

5.2 Adaptation used in the Torres Strait

5.2.1 Retreat/Move

Where possible planning has been used to site community infrastructure away from the threats of the ocean and the forecast impacts of climate change. On the ground this is seen in the new subdivisions founded up the hills on the rock islands, or on higher land away from the coast on the cays. This is also seen in abandoning more vulnerable parts of communities.

Retreat is not an option for the mud islands, where there is nowhere to go other than off the island.

5.2.2 Adapt

This primarily refers to living with the problems. In the Torres Strait adaptation is seen primarily in the type of housing that is used. On islands where flooding issues are prevalent the housing is high set, mounted on stilts, with no walls or high value assets at ground level. Similarly the gardens and plantings reflect the periodic inundation with salt water.

Another version of adaptation applied in the region is the management of sand. This is seen in ensuring that sand extracted from the coast is returned to the system down drift. This small action minimises impacts of works on coastal processes and minimises the erosion threats.

5.2.3 Defend

Defend refers to the building of infrastructure to protect the community. This has been applied in the communities since the early days, with effective community built seawalls on Saibai, Boigu and Warraber, and less effective walls on many other communities. Today the following communities have engineered works:

- Saibai
  - Erosion - Seawalls constructed with rock armour
  - Flooding - Earth Bunds and Concrete Wave Walls
- Boigu (rock and concrete armour)
  - Erosion - Seawalls constructed with rock armour and concrete armour
  - Flooding - Earth Bunds and Concrete Wave Walls
- Poruma
  - Erosion - Seawalls constructed with geo-bags
- Warraber
  - Erosion - Seawalls constructed with rock armour and stone pitching
- Iama
  - Erosion - Rock armour seawall
  - Flooding - Concrete walls

5.3 Effectiveness of Adaptation/Defences

This assessment addresses how effective some of the above described approaches have been.

5.3.1 Effectiveness Currently

Seawalls (erosion prevention)
The effectiveness of engineered seawalls at stopping erosion for current conditions has been high. Properly designed and built seawalls work at halting erosion.

Many of the community built structures are less robust and have failed or been replaced.

Flood Barriers
Combating flooding with bunds and wave walls is a more difficult task. The use of barriers to block flooding has issues with:

- Leakage through valves.
- Overtopping during high wave events.
- With high tailwater it is not possible to drain away local rainfall (very intense during wet season) under gravity.
- Extreme events can breach structures.

Under present day conditions the recently built flood barriers on Sabai (crest height 3.4 m AHD) and Boigu (crest height 4.2 m AHD) significantly reduce the marine flooding frequency and intensity. The barriers do leak which means that some water does enter the community during high events.

Even though water levels in Boigu are 0.5 m higher to AHD than those on Saibai the elevation and shape of the Sabai community (low, long and narrow) and a comparatively lower crest has meant that the flood protection on Saibai experience more leakage issues than Boigu.

It is noted that bunds on Saibai and Boigu are built lower than the walls facing the ocean. This was done because observations of historic flooding reveals water levels within the wetlands are appreciably lower than the ocean side due to the impact of the mangrove forests on the storm tides within the wetlands. If there is a reduced mangrove forest cover, compared to the historic norm then this presents a risk of flooding of the community from the wetlands.

[redacted]

5.3.2 Effectiveness in 2050

Seawalls (erosion prevention)
Engineered seawalls are designed for these conditions and will remain effective at stopping erosion. Erosion issues on unprotected foreshores will worsen by this time and this may impact edges of seawalls.

Flood Barriers
With increased sea levels the effectiveness of the flood barriers will be diminished, with leakage issues becoming more severe. Critically by this time the risk of mass overtopping of the barrier during an extreme event has become a possible risk, with event levels greater than 100 year ARI now able to breach the barriers.

As identified above the bunds, facing the wetlands, have a lower crest than the ocean facing walls. In 2050 the mangrove forest may be seeing a diminution in extent and vigour that would reduce the effectiveness of the forests in moderating the wetland storm tide levels. This could further reduce the effectiveness of the flood barrier systems on Boigu and Saibai.

5.3.3 Effectiveness in 2100

Seawalls (erosion prevention)
2100 is beyond the design life for engineered seawalls. Despite this the rock armour seawalls are likely to remain effective. The geo-bag seawalls, adopted for the cays, will be beyond the material design life and it is anticipated that significant bag failure will be occurring. Further by this time the erosion issues will have become very severe for unprotected areas, likely to expose seawall ends to issues.

Flood Barriers
As with the seawalls this horizon is beyond the design life of the structures. By this time the barriers will remain above normal tidal range but would be at a level where they could be swamped by even moderate storm tide events. Also, critically, the mangrove forests are expected to be severely impacted by this stage with loss of cover and likely loss of foreshore dune integrity resulting in significantly less attenuation of high water levels within the wetlands. This would disproportionately worsen flooding levels within the wetland when compared with today. With the bunds facing the wetlands built lower than structures facing the ocean this would make the effectiveness of the bunds even lower than the ocean facing walls.

5.4 How Could Works Have Been More Effective

A key issue is the effectiveness of the flood defences that are vulnerable to leakage and being swamped by the ocean as sea levels rise. These structures could have been built to be more substantial (higher) though this would also act to isolate the community from the sea. Further the leakage and inability to drain during high water levels causes low level flooding. Had the barrier system incorporated pumps, permitting a more complete barrier then many of these issues would be overcome. The incorporation of these measures are significantly more expensive than the adopted solutions.

For the cays erosion issues are exacerbated by the impact of the barge ramp and associated marine infrastructure on coastal processes. [redacted].

5.5 What Can Be Done

The proposed solutions presented here are provided as indications of the sort of engineering works that could preserve communities into the future, though the community amenity and environment may be substantially altered.

[redacted]

[redacted]

[redacted]

[redacted]

5.5.2 Erosion Defences

The construction of engineered seawalls is an effective defence against coastal erosion. The seawalls, though effective at halting erosion, do impact coastal processes and island amenity (seawall vs beach). Further the construction of seawalls does not combat flooding issues, rather they act to worsen overtopping rates in extreme events due to the comparatively steep foreshores created by seawalls compared to mild natural slopes.

5.5.3 Relocate Community to a Secure Location

If the communities cannot be defended a solution is to relocate the community to a secure location. A recent example includes establishment of the community of Bamaga on the western side of Cape York by families from Saibai who relocated after severe flooding in 1946 devasted their community, impacting water supply and groundwater which impacted trees (timber supply).

Relocation could be to other islands or the mainland, though the process would have dramatic impacts on traditional practices that are closely linked to place. On islands with suitable high land the process of relocation to higher land is described as planned retreat.

This solution could be applicable to both mud island and coral cay communities.

6 References

i. Australian Hydrographic Office, 2019, “AusTides 2019”, an electronic version of “Australian National Tide Tables (ANTTs) 2019”.

ii. Bettington, S.H. and Webber, W.T., 2021, “Morphology of Reef Top Islands and Impacts of Climate Change”, Australasian Coasts and Ports 2021 Conference.

iii. Bureau of Meteorology web sites:

http://www.bom.gov.au/iwk/calendars/erub_island_seasonal_calendar.jpg

http://www.bom.gov.au/climate/averages/tables/cw_027054.shtml

iv. Digital Earth Australia web site:

https://maps.dea.ga.gov.au/

v. Duce, S.J, Parnell, K.E., Smithers, S.G., and. McNamara, K.E., 2010, “A Synthesis of Climate Change and Coastal Science to Support Adaptation in the Communities of the Torres Strait”, James Cook University (Reef & Rainforest Research Centre), November 2010.

vi. Gourlay M.R., 1997, “Wave setup on coral reefs: some practical applications\”, Proc. 13th Aust Conf Coastal and Ocean Engin., Centre for Advanced Engineering, Christchurch, Sept, 959-964

vii. Intergovernmental Committee on Surveying and Mapping (ICSM) “ELVIS - Elevation and Depth – Foundation Spatial Data” web site:

https://elevation.fsdf.org.au/

viii. Maritime Safety Queensland, 2010, “Torres Strait Tidal Survey Datum Analysis”, Spatial Information Tidal Unit.

ix. Maritime Safety Queensland, 2022, “2022 Queensland Tide Predictions Blue Book Torres Strait”.

x. NASA, 2023, Sea level change web site:

https://sealevel.nasa.gov/faq/8/is-the-rate-of-sea-level-rise-increasing/

xi. Ribbat, N., 2012, ” Tidal Modelling in Correlation to Prevailing Meteorological Conditions in Torres Strait, Australia”, Masters Thesis, Curtin University of Technology, Department of Imaging and Applied Physics, May 2012.

xii. Systems Engineering Australia (SEA), 2011, “Torres Strait Extreme Water Level Study’, prepared for Torres Strait Regional Authority (TSRA), July 2011.

Royal HaskoningDHV

7 Declaration

I have read the Federal Court's Expert Evidence Practice Note (GPN-EXPT) and the Harmonised Expert Witness Code of Conduct. I agree to be bound by them and I have complied with them in preparing this Report.

All opinions expressed herein are my own and are based wholly or substantially on my specialised knowledge arising from my training and experience.

I have made all the inquiries that I believe are desirable and appropriate and that no matters of significance that I regard as relevant have, to my knowledge, been withheld from the Court.

Regards

Stuart Bettington
Technical Director Coastal

M [redacted] **H** [redacted] | **E** [redacted] | **W** www.royalhaskoningdhv.com
Has Koning Australia Pty Ltd., a company of **Royal HaskoningDHV** | **A** Level 9, 307 Queen Street, Brisbane City, QLD 4000

Glossary

Glossary Term	Glossary Text
AEP	Annual Exceedance Probability (%)
AHD	Australian Height Datum (m)
ARI	Average Recurrence Interval (years)
BoM	Bureau of Meteorology
H_s	Significant Wave Height - average height of 1/3 largest waves in a wave train (m)
HAT	Highest Astronomical Tide (m)
LAT	Lowest Astronomical Tides (m)
MHHW	Mean Higher High Water – diurnal tides (m)
MHWS	Mean High Water Springs – semi-diurnal tides (m)
MLLW	Mean Lower Low Water – diurnal tides (m)
MLWS	Mean Low Water Springs – semi-diurnal tides (m)
MSL	Mean Sea Level (m)
MSQ	Maritime Safety Queensland
SLR	Sea Level Rise (m)
SWL	Still Water Level
TC	Tropical Cyclone
T_P	Peak spectral wave period (s)
WL	Water Level (m)

Appendix A Letter of Engagement

PHI x FINNEY x MCDONALD

1 June 2023

Privileged and Confidential

Mr Stuart Bettington
Royal Haskoning DHV

By email: [redacted]

Dear Mr Bettington,

Pabai & Anor v Commonwealth of Australia (VID622/2021) (Proceeding)

We act for Pabai Pabai and Guy Paul Kabai (**Applicants**) in the above proceeding against the Commonwealth of Australia (**Respondent**) in the Victorian Registry of the Federal Court of Australia.

1. Engagement

1.1. We confirm that you are retained by the Applicants to act as an independent expert in the Proceeding. This letter sets out the terms of that retainer.

1.2. We confirm that your confidentiality obligations in respect of documents and information provided to you for the purpose of this engagement are governed by the terms of this retainer and the terms of the **annexed** Deed of Confidentiality.

2. Background

2.1. The Proceeding is a class action against the Respondent, brought by the Applicants as representatives of all Torres Strait Islanders.

2.2. The Applicants allege that the Respondent owes a duty of care to Torres Strait Islanders to take reasonable steps, having regard to the best available science, to protect them from the harms of climate change.

2.3. We **enclose** copies of the Applicants' Second Further Amended Statement of Claim dated 11 April 2023 and Amended Concise Statement dated 15 May 2023, and the Respondent's Defence to the Second Further Amended Statement of Claim dated 9 May 2023 and Concise Statement in Response dated 14 April 2022, for your information.

3. Role and duties of expert witnesses in proceedings in the Federal Court of Australia

3.1. We **enclose** a copy of the Federal Court of Australia Expert Evidence Practice Note (GPN-EXPT), which includes the Harmonised Witness Code of Conduct (the **Code**) at Annexure A and the Concurrent Expert Evidence Guidelines (the **Guidelines**) at Annexure B (collectively, the **Practice Note**).

3.2. The Practice Note sets out your duties as an independent expert witness and the form that any expert report that you produce must take. Please read the Practice Note carefully and ensure that you comply with its terms at all times.

3.3. The contents of an expert report must also comply with rule 23.13 of the *Federal Court Rules 2011*. We have **enclosed** a copy of this rule for your reference.

PHI X FINNEY X MCDONALD

3.4. There is considerable overlap between the requirements of the Code and the requirements of rule 23.13. Section 5.2 of the Practice Note confirms that an expert, unless otherwise directed by the Court, will be taken to have complied with the requirements of rule 23.13 if the expert has complied with the Code and has complied with the additional following requirements. Section 5.2 stipulates that the expert shall:

(a) acknowledge in the report that:

i. the expert has read and complied with this practice note and agrees to be bound by it; and

ii. the expert's opinions are based wholly or substantially on specialised knowledge arising from the expert's training, study or experience;

(b) identify in the report the questions that the expert was asked to address;

(c) sign the report and attach or exhibit to it copies of:

i. documents that record any instructions given to the expert; and

ii. documents and other materials that the expert has been instructed to consider.

3.5. Section 5.3 of the Practice Note also provides that, where an expert's report refers to photographs, plans, calculations, analyses, measurements, survey reports or other extrinsic matter, these must be provided to the other parties at the same time as the expert's report.

4. Terms and scope of the retainer

4.1. Upon receipt of a signed copy of this letter, we may provide you with a brief regarding this matter.

4.2. By signing this retainer, you agree to provide the following services, to the extent you are qualified as an expert to do so:

(a) consider instructions and materials provided;

(b) provide opinions in respect of those instructions and materials;

(c) advise whether further information is necessary or desirable to provide an opinion, if such information is not contained in the instructions and materials provided;

(d) if requested, prepare a report addressing specified matters, and swear an affidavit attesting to the matters contained in any such report; and

(e) if requested, give oral evidence as an expert witness (either at an interlocutory or final stage).

4.3. We may also ask you to respond to further evidence as it emerges, or expert opinions expressed by others in relation to the Proceeding.

4.4. You should not commence any work in this matter until you are requested to do so. In the event that we agree that the work that you need to do will be done in stages, you should not commence work on any stage until we ask you to do so.

4.5. We will provide you with a brief of materials and a letter of instruction in due course.

4.6. The opinions which you provide must be your own opinions. In the event that you require the assistance of others in carrying out the tasks the subject of this retainer, it will be necessary that you identify those individuals and the assistance they provided to you.

4.7. We will not accept the substitution of another person under this retainer.

4.8. Either party may terminate this retainer immediately by the provision of written notice.

5. Timing of evidence

5.1. Her Honour Chief Justice Mortimer has made orders that the Applicants are to file and serve any expert evidence on the associated impacts of, and adaptation measures for, sea level rise in the Torres Strait by 14 July 2023.

5.2. The hearing of expert evidence in the case is set down for three weeks commencing 30 October 2023.

5.3. You may also be required to attend an expert conclave in the month prior to the hearing.

6. Privilege, confidentiality and use of confidential documents

6.1. It may, as part of the retainer, be necessary to provide you with confidential information and documentation and, accordingly, it is necessary that you execute the Deed of Confidentiality that is **Annexure A** to this letter (**Deed**).

6.2. In summary, the Deed provides that instructing reports, related communications and other documents given to you or prepared by you in accordance with this retainer, will be confidential and are not to be copied or used for any purpose unrelated to the proceeding without our permission.

6.3. Further, any advices and reports given or prepared by you in accordance with this retainer, and related communications and other documents given or prepared by you in accordance with this retainer, will be subject to legal professional privilege.

6.4. In addition, the Deed:

(a) governs your use of all other documents, briefs and information that we and/or our agents provide you with and all documents created by you or at your instruction as part of this retainer; and

(b) requires you (at clause 4), at the conclusion of the proceeding, to immediately destroy all material (such as notes, documents or information) produced by you in connection with this retainer, subject to any direction to the contrary by the Disclosing Party.

7. Conflicts of interest

7.1. As an independent expert, it is important that you are free from any possible conflict of interest in the provision of your opinion.

7.2. The Applicants in the Proceeding are Pabai Pabai and Guy Paul Kabai, represented by law firm Phi Finney McDonald.

7.3. The Respondent in the Proceeding is the Commonwealth of Australia, represented by the Australian Government Solicitor.

7.4. Please disclose if you have a relationship or association with any party to the Proceeding, including any future related proceedings (or any other related proceeding of which you are aware), which may preclude you from providing your opinion in an impartial, objective and independent manner. If these circumstances change, please disclose this to us immediately.

7.5. By signing this retainer, you warrant that you do not, and agree that you will not, act for or have any associations or dealings with any party to the Proceeding that would give rise to a conflict of interest in the provision of services under this retainer.

7.6. If you have any questions or concerns about any possible conflicts at any stage of your work, please contact us immediately to discuss.

8. Fees

8.1. In your letter dated 26 April 2023, you provided the following breakdown of estimated costs for your services:

Services	Cost (exc. GST)
Preparation of technical report	[redacted]
Inundation mapping (first island)	[redacted]
Inundation mapping (each subsequent island)	[redacted]
Additional services beyond preparation of technical report and inundation mapping	[redacted]

8.2. In addition to the technical report, we anticipate requesting that you complete inundation mapping for Boigu, Saibai, Poruma, Warraber, Iama, and Masig. This will be confirmed in your letter of instruction. We have provided you with the survey data required for you to complete this mapping.

8.3. As outlined at paragraphs 4.2(e) and 5.3 of this letter, we may request that you provide additional services beyond the preparation of a technical report and inundation mapping. We understand that you will charge an hourly rate of $310 for the completion of any additional services requested of you under this retainer. Where we provide you with instructions to complete such additional services, we will also ask you to confirm an estimate of related out of pocket expenses. Out of pocket expenses should be billed at cost. Please keep a record of any hours of work performed, and any out of pocket expenses incurred, in the course of completing any additional services.

8.4. On the basis of the costs estimate outlined at paragraph 8.1 of this letter, the fee for your services will total:

(a) [redacted] for the preparation of the technical report and inundation mapping; and

(b) [redacted] per hour for any additional work you are requested to perform by Phi Finney McDonald, including of the kind outlined at paragraph 4.2(e) of this letter.

8.5. Should you become aware that the estimate is likely to alter in a material way (i.e., by more than 10% of the estimate), you must inform us immediately of the likely change and obtain approval for the material increase. If you do not inform us of the likely change, we reserve the right not to pay for the work done in excess of the estimate.

PHI x FINNEY x MCDONALD

8.6. You should submit an account for your fees and out of pocket expenses following the preparation of your report to Brett Spiegel, Principal Lawyer at Phi Finney McDonald, by email to [redacted]. If we request that you perform any additional services, you should submit a separate account for those additional fees at the conclusion of the hearing commencing on 30 October, 2023.

8.7. We confirm that:

(a) we are responsible, under the terms of our fee and retainer agreement with our clients, for payment of your fees and out of pocket expenses incurred pursuant to this retainer;

(b) payment of your fees shall be based on the costs nominated in paragraphs 8.1 to 8.4 above; and

(c) payment is not in any way contingent upon the outcome of the Proceeding.

8.8. Apart from payment of your fees and out of pocket expenses, neither we nor our clients will be liable to you in connection with your services pursuant to this retainer or any matter relating to such services for any indirect, special, punitive, consequential or incidental damages, including loss of profits.

9. Execution of retainer

9.1. Please complete, sign and return this letter (where indicated below) and the Deed of Confidentiality (**Annexure A**) to confirm your agreement to the terms of the retainer.

If you have any questions, please do not hesitate to contact me on [redacted]

Yours faithfully

Brett Spiegel
Principal Lawyer
PHI FINNEY MCDONALD

Encl.

Acknowledgement

I agree with the terms of this retainer letter, and warrant that I will comply with the terms of the Practice Note and rule 23.13 of the FCR

Signed by: Stuart Bettington ____________________ Date: 12 June 2023

Stuart Bettington

PHI x FINNEY x MCDONALD

Annexure A

DEED OF CONFIDENTIALITY

THIS DEED is made on 12 June 2023

PARTIES

PHI FINNEY MCDONALD of Level 3, 325 Flinders Lane, Melbourne VIC 3000
(**Disclosing Party**)

-AND-

STUART BETTINGTON of Level 10, 333 Ann St., Brisbane QLD 4000 (**Expert**)

RECITALS:

A. The Expert is retained under the Retainer to which this Deed is annexed.

B. The Disclosing Party wishes to provide certain Confidential Information to the Expert to enable the Expert to provide the services contemplated by the Retainer.

C. The Disclosing Party wishes to limit the purposes for which that Confidential Information may be used and ensure that such information is protected and remains confidential.

OPERATIVE TERMS:

1. Definitions

1.1. In this Deed and its recitals:

Confidential Information means all information other than the Excluded Information in whatever form, including written, oral or computer encoded or stored, relating to any aspect of the Proceeding, including without limitation:

(a) information relating to the business, affairs or activities of the Disclosing Party or its clients;
(b) information relating to the proposed activities of the Disclosing Party or its clients;
(c) communications between the Expert and the Disclosing Party;
(d) information provided to or obtained by the Expert in accordance with or for the purposes of the Retainer;
(e) reports and related communications and other documents given or prepared by the Expert or directors, servants or agents of the Expert's employer or company, in accordance with the Retainer;
(f) this Deed; and
(g) the Retainer,

irrespective of the source of that information (or document).

Deed means this deed.

PHI x FINNEY x MCDONALD

Disclosing Party means Phi Finney McDonald, identified as the Disclosing Party in the "Parties" section of this Deed, and also includes any persons appointed at any relevant time as an agent of Phi Finney McDonald in connection with the Proceeding.

Excluded Information means all information that:

(a) is in the public domain (otherwise than by reason of a breach of this Deed), in whatever form, including written, oral or computer encoded or stored;
(b) the Expert acquires from a third party who owes no known obligations of confidence in respect thereof; or
(c) was already known to the Expert at the time it received it from the Disclosing Party, as shown by the Expert's prior written records.

Expert means Stuart Bettington, identified as the Expert in the "Parties" section of this Deed, and also includes any persons appointed at any relevant time as an agent of the Expert in connection with the Proceeding.

Proceeding means the proceeding entitled *Pabai & Anor v Commonwealth of Australia*, which is proceeding number VID622/2021 commenced on 26 October 2021 in the Federal Court of Australia against the Commonwealth of Australia, and any related proceeding.

Retainer means the letter to which this Deed is annexed, which is signed or is to be signed by the Expert.

1.2. In this Deed unless the context otherwise requires:

(a) a reference to any party means and includes a reference to that party or its successors or personal representatives (as the case may be) and transferees;
(b) the word "person" also includes corporation, partnership, joint venture, firm and association; and
(c) the singular includes the plural and vice versa.

1.3. In this Deed headings are for convenience of reference only and do not affect interpretation.

2. Use of Confidential Information

2.1. Subject to this clause, the Expert must strictly maintain the confidentiality of the Confidential Information.

2.2. The Expert must not, other than for purposes contemplated by the Retainer, directly or indirectly make any use of Confidential Information.

2.3. The Expert must store and maintain Confidential Information securely and must not use Confidential Information in such a way that risks dissemination of the Confidential Information directly or indirectly to any person, except as contemplated by this Deed.

2.4. Despite clauses 2.1 to 2.3 inclusive of this Deed, and subject to clause 2.5, the Expert is permitted to disclose Confidential Information:

(a) to the extent required by law or to comply with a law, provided that the Expert first notifies the Disclosing Party of any requirement to disclose Confidential Information before it discloses that Confidential Information (to enable the Disclosing Party to seek an appropriate protective order if it wishes to do so);
(b) to any officer, employee, agent, or representative of the Expert's employer or company provided that such disclosure is necessary for the purposes of providing the services contemplated by the Retainer; or
(c) in accordance with the express instructions of the Disclosing Party.

2.5. The Expert may disclose information in accordance with clause 2.4(b) only to a person named as a Party to this Deed or to persons who have agreed in writing to be bound by the provisions of this Deed.

2.6. The Expert:

(a) must take all reasonable steps to ensure that its representatives who receive the Confidential Information observe the Expert's obligations under this Deed;
(b) in the case of third party consultants or advisors who receive Confidential Information, shall ensure that those consultants or advisors are made aware of and agree in writing to adhere to the terms of this Deed as if they were party to it; and
(c) acknowledges that it remains at all times responsible for ensuring that the confidentiality of the Confidential Information is preserved.

2.7. This Deed is in addition to and in no way derogates from, any obligations that are imposed by law on the Expert in respect of the Confidential Information.

2.8. The Expert acknowledges and agrees that:

(a) nothing in this Deed grants or confers any proprietary rights to the Expert in respect of Confidential Information; and
(b) nothing in this Deed obliges the Disclosing Party to disclose any particular information to the Expert; and
(c) the Confidential Information may include information which is protected by legal professional privilege and/or joint or common interest privilege and the provision of such information pursuant to this Deed shall not constitute a waiver of privilege in relation to that information as all information is provided in circumstances where the Disclosing Party is contemplating, participating in or conducting litigation.

3. Breach and Equitable Remedies

3.1. The Expert acknowledges that the Confidential Information may be valuable and is confidential to the Disclosing Party and that the Disclosing Party could be damaged by the release of the Confidential Information or any part of it in any manner that is prohibited by this Deed.

3.2. The Expert acknowledges that if the Expert breaches any of its obligations under this Deed, damages may be an inadequate remedy for the Disclosing Party, and that the Disclosing Party may be entitled to seek an injunction or other equitable relief.

4. Return of Information

4.1. Subject to any direction to the contrary by the Disclosing Party, the Expert must immediately upon conclusion of the Proceeding, destroy any confidential material (such as notes, documents or information) produced by the Expert in connection with the Retainer or the Proceeding, provided that the Expert may, to the extent permitted by law and subject to its obligations under this Deed, retain one copy of its final report and its working papers for the Expert's internal document retention purposes.

5. Jurisdiction

5.1. This Deed is governed by the laws in force in Victoria and the Commonwealth of Australia. The parties will submit to the non-exclusive jurisdiction of the courts and tribunals of Victoria and the Commonwealth of Australia.

6. Severability

PHI x FINNEY x MCDONALD

6.1. If any provision of this Deed is held to be invalid, illegal, or unenforceable, that provision will be deemed to be severed from this Deed to the extent of that invalidity, illegality, or unenforceability.

7. Counterparts

7.1. This Deed may be executed in any number of counterparts all of which taken together shall constitute one and the same instrument and either of the parties may execute this Deed by signing any such counterpart.

8. Waiver

8.1. No variation, modification or waiver of any provision of this Deed nor consent to any departure by any party from it is in any event of any force or effect unless it is confirmed in writing, signed by the parties and such as variation, modification, waiver or consent is effective only to the extent to which it may be made or given.

9. Term

9.1. This Deed continues to operate while the Retainer remains current and terminates automatically when the Retainer terminates.

9.2. The obligations of the Expert under clauses 2, 3 and 4 of this Deed survive the termination of this Deed.

Executed as a **Deed**

SIGNED for and on behalf of **Phi Finney McDonald** by

Brett Spiegel
Principal Lawyer
Phi Finney McDonald

Date: 25 May 2023

SIGNED for an on behalf of the **Expert** by

Stuart Bettington

Date: 12 June 2023

Appendix B Letter of Instruction

21 June 2022

PRIVILEGED AND CONFIDENTIAL

Mr Stuart Bettington
Royal Haskoning DHV

By email: [redacted]

Dear Mr Bettington,

Pabai & Anor v Commonwealth of Australia (VID622/2021) (Proceeding)

---

1. Letter of Instruction

1.1. We refer to our letter of retainer dated 1 June 2023 (**Retainer Letter**) and confirm that you are retained by Uncle Pabai Pabai and Uncle Paul Kabai (**Applicants**) to act as an independent expert in the matter of *Pabai & Anor v Commonwealth of Australia*, VID622/2021 (**Proceeding**).

1.2. We confirm that the confidentiality obligations in respect of documents and information provided to you for the purpose of this engagement are governed by the terms of the Retainer Letter and Deed of Confidentiality dated 12 June 2023.

1.3. We also remind you of the roles and duties of expert witnesses as set out in the Retainer Letter and ask that you refer to them as you prepare your expert report(s) in this proceeding. In particular, please take some time to reacquaint yourself with the following documents, which we provided to you with our original letter:

(a) the Federal Court of Australia Expert Evidence Practice Note (**GPN-EXPT**), including the Harmonised Expert Witness Code of Conduct (the **Code**) at Annexure A of that Practice Note and the Concurrent Expert Evidence Guidelines (the **Guidelines**) at Annexure B (collectively, the **Practice Note**); and

(b) Rule 23.13 of the *Federal Court Rules 2011* (Cth).

1.4. The purpose of this letter is to request that you prepare a written report, providing your independent expert opinion, in response to the questions set out in Annexure B to this letter.

1.5. Should you in your report make any assumptions in the course of providing your answers**,** please state what those additional assumptions are.

1.6. In order to ensure your report is clearly set out, we ask that you please:

a) provide a brief summary at the beginning of the report;

b) use numbered paragraphs, page numbers and headings where appropriate;

c) provide citations to documents where appropriate; and

d) provide citations to any literature or other materials referred to or relied upon by you in support of your opinions, and a bibliography if necessary.

1.7. Please annex to your report:

a) a detailed curriculum vitae, setting out the training, study and experience that establishes your expertise in relation to the issues raised by these instructions; and

b) this Letter of Instruction and the Letter of Engagement.

1.8. At the end of your report, please sign the report and include a declaration to the following effect:

I have read the Federal Court's Expert Evidence Practice Note (GPN-EXPT) and the Harmonised Expert Witness Code of Conduct. I agree to be bound by them and I have complied with them in preparing this Report.

I have made all the inquiries that I believe are desirable and appropriate and that no matters of significance that I regard as relevant have, to my knowledge, been withheld from the Court.

2. Materials

2.1. Set out at Annexure A is an index of the documents provided to you.

2.2. The pleadings have been provided to you so that you are aware of the allegations made and positions taken by each party. Unless an allegation is admitted, the facts are in dispute.

2.3. If you consider that you require any additional information or materials in order to complete your work, please contact us and we will endeavour to provide that additional information and materials.

3. Your Opinion

3.1. We request that you provide a written report addressing the questions set out in Annexure B to this letter.

3.2. In answering the Annexure B questions, please provide detailed reasons for your opinions, including the facts or assumptions that affect your reasoning and conclusions, with specific reference to any material on which you rely in reaching your conclusions.

4. Preparation of Your Report

4.1. We would be grateful if you would set out the answers to the questions at Annexure B in a written report, having regard to the requirements set out in the Federal Court of Australia Expert Evidence Practice Note.

4.2. After you have had the opportunity to consider the questions at Annexure B, we would be grateful if you could advise of any information or material not currently provided to you which you require to respond to any of the Annexure B questions.

4.3. You are requested to complete your report by 14 July 2023.

If you have any questions or if you require any clarification of the facts, assumptions or questions set out in this letter and its annexures, please do not hesitate to contact me [redacted]

Yours faithfully,

Brett Spiegel
Principal Lawyer
Phi Finney McDonald

Encl.

ANNEXURE A

INDEX OF MATERIALS

Tab No.	Date	Description of document(s)
A	**PLEADINGS**	
A1.	15 May 2023	Applicants' Amended Concise Statement
A2.	29 May 2023	Respondent's Amended Concise Statement
A3.	7 October 2022	Amended Originating Application
A4.	11 April 2023	Second Further Amended Statement of Claim
A5.	9 May 2023	Defence to Second Further Amended Statement of Claim
B	**OTHER MATERIAL**	
B1.	26 May 2023	Survey data produced by the Torres Strait Island Regional Council pursuant to the subpoena dated 20 April 2023

ANNEXURE B

<u>Questions</u>

In your report, please answer the following questions and explain the reasons for your answers. Please address whatever matters are necessary or useful for you to answer the questions to your satisfaction.

A. Introduction

1. Please describe your academic qualifications, professional background, and experience in the field of coastal engineering, and any other training, study, or experience that is relevant to this brief (you may wish to do so by reference to a current curriculum vitae).

In answering questions 2-15, please adopt the following assumptions:

*i) As at 2023, global mean sea level has increased by approximately 21cm when compared with global mean sea level at 1900 (the **Baseline**).*

ii) 'Extreme sea level event' means:

> *An event involving different phenomena (such as storm surges, high tides etc.) combining to result in relatively rare and temporary (usually a few days or less) increases (or decreases) in sea level height above (or below) what is normally expected.*

iii) Your answers are to be given by reference to each of the following islands within the Torres Strait:

a. Saibai;

b. Boigu;

c. Poruma; and

d. Warraber.

*(**Mapped Islands**)*

B. Extreme Sea Level Events

2. Please draft maps showing the level of flooding and inundation on each of the Mapped Islands that would be caused by the following:

   a) an extreme sea level event that had a '1 in 100 year' frequency as at the Baseline (**Baseline Event**);

   b) an extreme sea level event that has a '1 in 100 year' frequency as at 2023 (**Current Event**); and

c) an extreme sea level event that causes a temporary increase in sea level sufficient to flood 50% of the township on each of the Mapped Islands (**Township Inundation Event**).

3. In relation to a Township Inundation Event, please discuss:

   a) what would have been the frequency of that event on each of the Mapped Islands as at the Baseline; and

   b) what is the current frequency of that event on each of the Mapped Islands?

C. Climate change impacts in the Torres Strait

4. Please describe the geological features and coastal processes of the different kinds of islands in the Torres Strait (including, but not limited to, each of the Mapped Islands).

5. By reference to the features and processes described in your answer to question 4, please:

   a) explain how the combination of sea level rise and extreme sea level events impacts each of the Mapped Islands (for example, by causing/increasing coastal erosion, salination of soil/water and any other relevant impact) (**climate change impacts**); and

   b) describe what other drivers (if any) may cause/increase the climate change impacts on the Mapped Islands (for example, coral bleaching, loss of mangrove habitat, etc.).

6. Please explain the interactions (including reinforcing feedbacks, if any) between each of:

   a) the climate change impacts identified in your answer to question 5(a) above;

   b) the drivers identified in your answer to question 5(b), above; and

   c) the frequency and severity of extreme sea level events.

7. Please describe the climate change impacts on each of the Mapped Islands today, including increases (if any) in the rates of change that have been observed since the Baseline.

D. Future impacts

<u>*2050 Projections*</u>

*In answering questions 8-11, please use the projected sea levels for the following Shared Socioeconomic Pathways (**SSPs**) as used by the Intergovernmental Panel on Climate Change (**IPCC**):*

i) SSP 1-1.9: assume that sea levels in the Torres Strait in 2050 will be 34cm higher than at the Baseline;

ii) SSP 1-2.6: assume that sea levels in the Torres Strait in 2050 will be 36cm higher than at the Baseline; and

iii) SSP 3-7.0: assume that sea levels in the Torres Strait in 2050 will be 38cm higher than at the Baseline.

*(**2050 Projections**)*

8. Adopting the 2050 Projections, what would be the expected frequency of a Township Inundation Event on the Mapped Islands under each of the SSPs? In answering this question, please identify and explain any differences in expected frequency between the Mapped Islands.

9. In relation to SSP 1-2.6 only, please draft maps showing the flooding and inundation levels on each of the Mapped Islands that would be caused by an extreme sea level event having a frequency of 1 in 100 years as at 2050.

10. Please describe the impact of HAT tides on Saibai at 2050 under each of the SSPs listed above.

11. Please discuss how the 2050 Projections under each SSP will affect:

    a) the climate change impacts identified in your answer to question 5(a), above; and

    b) the rate of change of those climate change impacts.

2100 Projections

In answering questions 12-15, please use the projected sea levels for the following SSPs as used by the IPCC:

i) SSP 1-1.9: assume that sea levels in the Torres Strait in 2100 will be 56cm higher than at the Baseline;

ii) SSP 1-2.6: assume that sea levels in the Torres Strait in 2100 will be 62cm higher than at the Baseline; and

iii) SSP 3-7.0: assume that sea levels in the Torres Strait in 2100 will be 87cm higher than at the Baseline.

*(**2100 Projections**)*

12. Adopting the 2100 Projections, what would be the expected frequency of a Township Inundation Event on the Mapped Islands under each of the SSPs? In answering this question, please identify and explain any differences in expected frequency between the Mapped Islands.

13. In relation to SSP 1-2.6 only, please draft maps showing the flooding and inundation levels on each of the Mapped Islands that would be caused by an extreme sea level event having a frequency of 1 in 100 years as at 2100.

14. Please describe the impact of HAT tides on Saibai at 2100 under each of SSPs.

15. Please discuss how the 2100 Projections under each SSP will affect:

    a) the climate change impacts identified in your answer to question 5(a), above; and

    b) the rate of change of those climate change impacts.

Appendix C Supplementary Letter of Instruction

04 July 2023

PRIVILEGED AND CONFIDENTIAL

Mr Stuart Bettington
Royal Haskoning DHV

By email: [redacted]

Dear Mr Bettington,

Pabai & Anor v Commonwealth of Australia (VID622/2021)

Supplementary Letter of Instruction

1. We refer to our letter of retainer dated 1 June 2023 (**Retainer Letter**) and our letter of instruction dated 21 June 2023 (**June Letter of Instruction**) and confirm that you are retained by Uncle Pabai Pabai and Uncle Paul Kabai (**Applicants**) to act as an independent expert in the matter of *Pabai & Anor v Commonwealth of Australia*, VID622/2021 (**Proceeding**).

2. We confirm that the confidentiality obligations in respect of documents and information provided to you for the purpose of this engagement are governed by the terms of the Retainer Letter and Deed of Confidentiality dated 12 June 2023.

3. We also remind you of the roles and duties of expert witnesses as set out in the Retainer Letter and ask that you refer to them as you prepare your expert report(s) in this proceeding. In particular, please take some time to reacquaint yourself with the following documents, which we provided to you with our Retainer Letter:

   (a) the Federal Court of Australia Expert Evidence Practice Note (**GPN-EXPT**), including the Harmonised Expert Witness Code of Conduct (the **Code**) at Annexure A of that Practice Note and the Concurrent Expert Evidence Guidelines (the **Guidelines**) at Annexure B (collectively, the **Practice Note**); and

   (b) Rule 23.13 of the *Federal Court Rules 2011* (Cth).

4. The purpose of this letter is to provide further questions to be addressed in your written report. These further questions are contained in Annexure A.

5. We request that you prepare a written report providing your independent expert opinion in response to the questions outlined in the June Letter of Instruction <u>**in addition**</u> to those provided in Annexure A of this letter. Please annex this letter to your report in addition to the June Letter of Instruction.

6. In answering questions, please provide detailed reasons for your opinions, including the facts or assumptions that affect your reasoning and conclusions, with specific reference to any material on which you rely in reaching your conclusions.

7. In preparing your written report, please have regard to the requirements set out in the Federal Court of Australia Expert Evidence Practice Note.

8. If you consider that you require any additional information or materials in order to complete your work, please contact us and we will endeavour to provide that additional information and materials.

9. You are requested to complete your report by 14 July 2023.

If you have any questions or if you require any clarification of the facts, assumptions or questions set out in this letter and its annexures, please do not hesitate to contact me [redacted]

Yours faithfully,

Brett Spiegel
Principal Lawyer
Phi Finney McDonald

Encl.

ANNEXURE A

Supplementary Questions

In your report, please answer the following questions and explain the reasons for your answers. Please address whatever matters are necessary or useful for you to answer the questions to your satisfaction.

16. Please describe the actions and infrastructure commonly used to protect against flooding, inundations and the Climate Change Impacts identified in your answer to Question 5(a) (**Adaptation Strategies**). In your answer, please discuss the costs and effectiveness of different Adaptation Strategies.

17. Please describe the Adaptation Strategies currently undertaken or in place in the Torres Strait Islands (**Torres Strait Adaptation Strategies**). In your answer, please identify the particular island(s) on which those strategies have been undertaken or put in place.

18. Please explain and discuss the capacity of the Torres Strait Adaptation Strategies to protect Torres Strait Islanders from flooding, inundations, and the Climate Change Impacts:

    a) currently;

    b) as at 2050 under each of the 2050 Projections; and

    c) as at 2100 under each of the 2100 Projections.

    In your answer, please describe:

    i) any limitations; and

    ii) (if applicable) the expected lifespan,

    of the Torres Strait Adaptation Strategies.

19. Could the Torres Strait Adaptation Strategies have been constituted, planned, designed, or constructed differently to better protect Torres Strait Islanders from flooding, inundations, and the Climate Change Impacts and, in particular, to overcome the matters noted in your response to Question 18(i)-(ii)? If so, please explain how.

20. What, if any, additional or alternative Adaptation Strategies would assist in protecting Torres Strait Islanders from flooding, inundations, and the Climate Change Impacts now and in the future?

Appendix D Resumé for Stuart Bettington

Royal HaskoningDHV
Enhancing Society Together

Curriculum Vitae

Stuart Bettington

Technical Director

E: [redacted]

M: [redacted]

Stuart Bettington is Technical Director at Royal HaskoningDHV in Brisbane, Australia.

Stuart Bettington has over 30 years' experience in coastal and maritime engineering, undertaking all aspects of project delivery from site inspections, approvals design and documentation, construction supervision and project management. Areas of practice include coastal processes, dredging, outfalls, environmental considerations and adaptation, breakwater or revetment design, piling, flood assessment and mitigation, and the collection and analysis of coastal data. In recent years Stuart has developed considerable expertise in tropical and remote coastal and marine works, undertaking projects across Northern Australia, SE Asia and the Pacific.

.

Previously Stuart lead the coastal engineering in AECOM ANZ for 11 years. Before this he worked as a Senior Engineer in KBR for 9 years undertaking a wide range of coastal and maritime projects. Stuart has also help positions as Senior Engineer in the Queensland Government on the Tweed River Entrance Sand Bypassing Project gaining experience in coastal processes, dredging, construction and contract implementations and at the Queensland Government Hydraulics Laboratory managing physical modelling projects. Stuart commenced his career at the UNSW's Water Research Laboratory where he spent 7 years.

Nationality
Australian

Years of experience
33

Years with Royal HaskoningDHV
2

Qualifications
1990 **BEng (Civil) (Hon), University of New South Wales**
1994 **MEngSci (Water), University of New South Wales**

Professional memberships
Professional Member, Institution of Engineers Australia (College of Civil Engineers), since 1995
Certified Professional Engineer, National Professional Engineering Register (NPER-3)
Registered Professional Engineer of Queensland (RPEQ)
PIANC Australia

Language
English

Professional experience
RHDHV 2021 – Present

Cabbage Tree Creek Boat Harbour Upgrade

> 2023 – Present, Queensland, Australia

MSQ are responsible public spaces, trawler berths and foreshore protection for the Cabbage Tree Boat Harbour on Brisbane's northern outskirts. The scope of work involved redesign of the public car spaces (car parks largely), replacement of berths for 18 trawlers and the replacement of several hundred meters of foreshore protection. Stuart led a team undertaking planning, community consultation, and design for all the varied components. The historical nature of the site and mangroves made developing solutions more difficult.

Mooloolaba and Snapper Creek Seawalls

> 2023 – Present, Queensland, Australia

MSQ are responsible for boat harbours in Queensland, including the foreshores. At both Mooloolaba and Snapper Creek, in Tin Can Bay the existing foreshores are in poor condition RHDHV were commissioned to develop design for upgraded revetments, with the aim to maximise the re-use of existing materials. Stuart led the team with innovative design approach to ensure clients aims for budgets could be achieved.

AIMS Harbour Upgrade

> 2022-– Present, Queensland, Australia

The Australian Institute of Marine Science (AIMS) facility at Cape Ferguson, in tropical North Queensland, carries out vital research into Australia's tropical Marine Estate. The facility is serviced by a harbour constructed forty years ago that experienced rapid catastrophic siltation that closed the harbour. RHDHV were engaged to develop a solution and undertake detailed design. Stuart's role included undertaking a morphological study for this complex location with the results used to drive the design of a workable solution.

Sydney Airport Marine Flooding

> 2022 – 2023, NSW, Australia

Working with a team of fluvial engineers in AECOM, RHDHV developed marine inputs for a flood assessment of Sydney Airport. Critically this included consideration of the sea level rise impacts on runway flooding. Stuart lead a small team of modellers to define the met-ocean conditions in Botany Bay, including swell wave penetration and local sea before assessing the overtopping rates and tailwater levels around the airport.

Torres Strait Marine Infrastructure

> 2021 – Present, Torres Strait, Queensland, Australia

Marine infrastructure in the Torres Strait includes jetties, barge ramps and dredged channels. This infrastructure was typically constructed in the 1980's and in 2021 was generally in poor condition. Stuart lead a multidisciplinary team across several projects that included assessment of marine infrastructure and the development of designs for a pontoon solution, jetty solutions, options for barge ramps and dredging.

Nassau Harbour

> 2021 – 2023, Nassau, Cook Islands

Stuart lead the design of a harbour for this small isolated community. The design included a detailed assessment of the design conditions, recognising the highly exposed conditions on the reef platform during cyclonic events. The harbour design allowed for small vessels to have a safe mooring during operational conditions while having a low profile to survive the extreme events. Further the assessment of morphology and minimising impacts of the works on coastal processes was key design outcome.

AUSTAL Cairns Dredging

> 2022 – 2023, Cairns, Queensland, Australia

AUSTAL acquired a slipway site in Cairns that carried a significant contaminated sediment issue. As part of the contractual obligations the contaminated sediments needed to be dredged and disposed of. Stuart lead a team of engineers and planners to assess options, develop a design and prepare proposals. As part of this project dredging into geo-bags was trialled as a method to manage contaminated dredge spoils.

Torres Strait Seawalls

> 2021 – Present, Torres Strait, Queensland, Australia

As the certified design engineer of seawall designs in the Torres Strait Stuart assisted his former employer to deliver the design and construction supervision of seawalls on Boigu, Poruma, Iama, Masig and Warraber.

Coromandel Flooding Hazard

> 2021 – 2022, Coromandel Peninsular, New Zealand

An assessment of the flooding hazard for coastal communities around the Coromandel Peninsula included assessment of storm tides and waves conditions in a climate change impacted future plus the development of remediation options. Stuart drew on extensive experience to review inputs and assist in the development of possible actions.

AECOM 2010 – 2021

Boigu Island Seawall Construction

> 2018 – 2021, Torres Strait, Queensland, Australia

Stuart undertook assessment and planning for the construction of the rock armour and concrete parapet for several hundred meters of seawall on Boigu Island. Key aspects included developing work methods for the selection and management of rock armour and the inspection and certification of the construction work.

Kuching Deep Water Port

> 2018 – 2021, Sarawak, Malaysia:

Stuart undertook assessment of design options for a new deep water port facility at Kuching. This included breakwater design and dredging issues. Issues of particular concern were soft soils, frequency of maintenance dredging, environmental impacts and connectivity. Subsequently he provided oversight of the modelling of marine condition and lead the concept design of the breakwaters for the development.

Ugar All Tide Access

> 2014 & 2020 – 2021, Torres Strait, Australia

Leading a small team of maritime and coastal engineers Mr Bettington prepared a feasibility study into possible options to allow all tide access for this remote island community. Construction of a reef edge facility connected to land via a causeway or deck on pile structure or dredged channel were investigated. The study included community consultation, preliminary engineering, consideration of impacts of options on coastal process and a cost opinion. Subsequently Stuart lead the detailed design of the dredge channel solution.

Sugar Loaf Wharf Upgrade

> 2020 – 2021, Coromandel's, New Zealand

Stuart lead the coastal design aspects of a major upgrade to the commercial/public facility in the Coromandel's known as Sugarlaof Wharf. In his role Stuart undertook assessment of met-ocean conditions, assessment of morphology, design of dredging and the civil aspects such as breakwaters and revetments.

Torres Strait Marine Access Study

> 2019 – 2020, Torres Strait, Queensland, Australia

Stuart lead a multidisciplinary team examining the dredging requirements and spoil disposal options for 5 islands in the Torres Strait. The projects include two islands with small volumes of clean sand, one with a moderate volume of dirty sand and two with large volumes of marine mud. Concept designs, costings and preliminary approvals works were undertaken as part of the scope.

Davis Station Airfield

> 2019 – 2020, Antarctica

As part of multi-disciplinary team Stuart lead coastal assessments for the proposed airfield at Davis Station on the Vestfold at the Australian Antarctica base.

Markham River – Bank Protection

> 2017 – 2020, Lae, Papua New Guinea

AECOM was commissioned to assess flooding and scour risks for a significant industrial land development between the recently constructed Lae Tidal Basin and the highly volatile Markham River. Stuart led a team of engineers in assessing river conditions and developing solutions to assist the client in assessing and guiding a D&C contractor. Subsequently he led a detailed design and documentation of the works.

Hazard Assessment and Adaptation in the Torres Strait

> 2018 – 2020, Torres Strait, Queensland, Australia

Working closely with Council and the communities Stuart lead a team of coastal engineers, planners and designers to assess the threats from coastal erosion and flooding on the Islands of Warraber, Iama, Poruma and Masig. Using the hazard assessment as a guide he then led the development and design of remedial action, including seawalls, levees and planning guidelines. Finally, Stuart assisted the Council in construction with tender evaluation and oversight of works.

Hammond Island Marine Facility– Breakwater Design & Construction

> 2018, Torres Strait, Queensland, Australia

Stuart worked closely with our client to assist in the successful delivery of a rock armour breakwater on Hammond Island. The services provided involved revisiting design, including physical modelling, assessing material options and supervising construction.

Mackay Beach Nourishment

> 2018, Mackay, Queensland Australia

Following coastal erosion resulting from Severe Tropical Cyclone Debbie a beach nourishment program for Lamberts and Midge Point Beaches was developed. Stuart undertook assessment and design of the beach nourishment works for these very different beaches

Merimbula Ocean Outfall

> 2018 – 2020, Bega, NSW, Australia

A new deep-water ocean outfall for treated sewage is planned for Merimbula. Stuart provided a technical role in the numerical modelling and field data exercise for this comprehensive study. Further he led the assessment of morphological impacts of the outfall and pipe on the seabed.

Gove RDA Closure

> 2017 – 2019, Gove, NT, Australia

As part of a multidisciplinary team Stuart undertook coastal assessment and design for the coastal aspects of the closure of this remote facility.

Pago Pago Airport Shoreline Protection

> 2017 – 2019, Pago Pago, American Samoa

Working with colleagues from New Zealand Stuart undertook coastal engineering investigation and design for the proposed upgrade to foreshore defences around Pago Pago International Airport. Ongoing issues with foreshore erosion and revetment stability, were exacerbated by the 2009 Tsunami.

Defence Training Areas Climate Change Adaptation

> 2016 – 2017, Various Sites around Australia

AECOM was commissioned to look at climate change impacts on Defence training areas around Australia. Stuart led a team of coastal engineers in assessing met-ocean conditions and determining the impact of present day and future conditions for coastal erosion and flooding.

Gold Coast Offshore Cruise Terminal Feasibility

> 2016 – 2017, Gold Coast, Australia

City of Gold Coast (CoCG) engaged AECOM, working with Price Waterhouse Cooper to undertake a feasibility assessment of an offshore cruise terminal to allow cruise liners to call at the Gold Coast. Stuart led the coastal aspects of the assessment including breakwater design, assessment of met-ocean conditions and coastal impacts. Prior to the offshore site being selected Stuart played a significant role in the assessment of alternative sites in the Broadwater and other coastal locations.

QGHL Palm Beach Reef Physical Modelling

> 2016, Brsibane, Australia

Due to high work load and staff shortages the recently recommissioned Queensland Government Hydraulics Laboratory (QGHL) physical modelling facility engaged Stuart to assist laboratory staff undertake physical modelling for a number of projects, including the Palm Beach Reef. This assignment was for several months and included physical model planning, execution and reporting.

Wellington Airport Runway Extension

> 2016 – 2020, Wellington, New Zealand

Stuart has assisted the New Zealand team providing expert coastal advice for the ongoing concept development of the proposed Wellington Airport runway extension. Stuart's expertise has been applied to the assessment of a proposed surfing reef and possible revetment protection options.

Funafuti Waterfront Recreational Area Project

> 2015, Funafuti, Tuvalu

Working with the Government of Tuvalu and the dredging contractor Mr. Bettington lead a team that undertook options assessment, environmental planning and detailed design for the creation of 2.4 Ha of land on the foreshore of Funafuti and the nourishment of beaches. A key aspect of AECOM's role was to maximise the benefit that could be achieved with a grant provided by the World Bank to the Government of Tuvalu.

Nukufetau Coastal Intervention Project

> 2015 – 2016, Nukufetau, Tuvalu

Working with UNDP funded agencies and Hall Contracting, Mr. Bettington lead a team that undertook community consultation, environmental assessment and planning, design and construction supervision for several hundred meters of seawalls and wide spread beach nourishment.

Tuvalu Seawall Assessment & Design

> 2015, Tuvalu

Following the devastation caused to the outer islands of Tuvalu by Tropical Cyclone Pam the World Bank undertook to develop foreshore protection works (seawalls). Mr Bettington as the coastal engineer in a multi-disciplinary team assessed conditions and developed seawalls designs within the constraints dictated by the remoteness of the islands and the budget.

Saibai Island Seawall Construction

> 2015 – 2017, Torres Strait, Australia

Mr Bettington undertook assessment and planning for the construction of the rock armour and concrete parapet for several kilometres of seawall on Saibai Island. Key aspects included developing work methods for the selection and management of rock armour and the inspection and certification of the construction work.

Lae Tidal Basin Siltation Study & Seawall Design

> 2015 – 2016, Lae, PNG

Within 6 months of completing dredging a hydrographic survey of the basin revealed that significant siltation had occurred. Leading a team of modellers and designers Stuart undertook an assessment of the siltation issues and identified the key sources of sediment before preparing a design and documentation for breakwater to exclude a significant portion of the siltation. During a site inspections Stuart noted issues with the design and construction of the partially built basin foreshore protection. Although not in the original scope Stuart worked the client to develop a remedial action plan.

Newcastle Port DORC

> 2014, Newcastle, Australia

The sale of Newcastle Port required that the Depreciated Optimised Replacement Cost (DORC) of the assets be assessed. As part of a multi-disciplinary team Mr Bettington undertook the engineering aspects of the DORC study focussing on the breakwaters. This included condition assessment of the existing breakwaters, residual life of the structures, determining original construction methodology and developing a contemporary construction approach.

Torres Strait Coastal Investigations

> 2014, Torres Strait, Australia

Following previous studies in the Torres Strait Mr Bettington undertook assessment of coastal processes and developed engineering solutions to address foreshore erosion issues and mitigate flood risks on the islands of Mabuiag, Warraber, Mer, Dowar and Erub. The proposed solutions were developed within a broader framework of defend, adapt or retreat. Consideration of the economic realities and the likely impacts of climate change were significant aspects in the assessment.

Toorbul Seawall

> 2014, Moreton Bay, Brisbane, Australia

Stuart undertook the concept and detailed design and construction supervision for a section of seawall at Toorbul in Pumicestone Passage in the northern Moreton Bay. The design effort included geotechnical assessment and the development of an innovative stepped concrete seawall design that used a driven toe feature to avoid disturbing Acid Sulphate soils.

Wellington to Hutt Valley Walkway/Cycleway

> 2013 – 2015, Wellington, New Zealand

Stuart undertook the concept design and impact assessments for coastal defence options for the foreshore on this vital transport link.

Tumby Bay Foreshore

> 2013 – 2014, Tumby Bay, South Australia

As Principal Engineer Stuart undertook the review of wave and sediment transport modelling feeding into the concept design of seawalls for the vulnerable foreshores at Tumby Bay. Armed with this information Stuart provided input to and reviewed the proposed seawall design and prepared construction documentation.

Westpark Marina

> 2013, Auckland, New Zealand

Mr Bettington undertook a condition assessment and review of likely future maintenance requirements for the Marina constructed using cut to fill methods some 30 years previously. The review was undertaken as a prelude to lease reviews with a particular focus on the adopted construction methodology of the various parties involved and how this contributed to the issues going forward.

Turtle Island Beach Design

> 2013 – 2014, Bali, Indonesia

Turtle Island Beach Design, Bali Indonesia: As Principal Engineer Mr Bettington managed a study into the design of six beaches, with associated groynes for a major land development. The project included assessment of met-ocean conditions, wave modelling, assessment of coastal morphology, design of costal structures and the preparation of tender documentation.

South Mission Beach Seawall

> 2013 – 2014, Mission Beach, Queensland Australia

Mr Bettington as Principal Engineer undertook the detailed design of several hundred meters of rock armour seawall at South Mission Beach in North Queensland. Mr Bettington undertook selection and analysis of met-ocean data, preliminary and detailed design, preparation of construction documentation and construction supervision.

Saibai Island Foreshore Review

> 2013, Torres Strait, Queensland, Australia

Stuart undertook the detailed design and documentation of rock armour and pattern placed concrete seawall options for the upgrade of coastal defences on Saibai Island. The design incorporated a wave return wall to improve the island community's immunity to present and future extreme water level events and included allowance for vegetation (mangroves) impacts on coastal stability.

Sunshine Coast Airport Expansion EIS

> 2012 – 2013, Sunshine Coast, Queensland, Australia

Mr Bettington provided coastal and maritime input to the concept design of dredging and reclamation associated with the construction of a new runway. Related to this he also assessed marine impacts on flooding and developed innovative solutions to flood mitigation issues.

Port of Townsville B10X EIS

> 2012 – 2013 Townsville, Queensland, Australia

Mr Bettington as Principal Engineer guided the assessment of met-ocean conditions and numerical modelling of wave climates in and around the port and undertook the review of third-party hydrodynamic modelling. Mr Bettington also undertook preliminary design of revetments and breakwaters associated with the proposed port upgrades.

SH16 Causeway

> 2012 – 2015, Auckland, New Zealand

Mr Bettington undertook the review of design inputs and overall coastal design for the upgrade of a road causeway in Auckland. Subsequently Stuart undertook the detailed design effort and documentation, undertook rock selection and construction review for the coastal aspects on the causeway. A key aspect of the design climate change allowances design adaptations.

Brisbane Airport Disaster Risk Assessment

> 2012, Queensland, Australia

Stuart undertook the assessment of marine inundation risks and the contribution of marine water levels to flood inundation risks for a study of the Brisbane disaster vulnerability. Careful consideration was given to both climate change allowances and combined fluvial and marine event scenarios.

Foreshore Stabilisation Rainbow Beach & Tin Can Bay

> 2012- 2013, Queensland, Australia

Staurt led a team of engineers, planners and drafters in the design, costing and environmental approvals for seawalls on two sites experiencing ongoing erosion issues. One site is on a high energy coast, while the other is within the Tin Can Bay estuary. A key concern for the client was managing climate change induced coastal erosion and negotiating the approvals process with relevant authorities.

South Pumicestone Seawall Assessment

> 2012, Moreton Bay, Queensland, Australia

Stuart led a small team of engineers, in an assessment of the seawall condition along 4km of foreshore on the western side of Bribie Island. Services included an assessment of the seawall condition, urgency for action and suggested remedial actions for the various types of foreshore protection used.

Vizhinjam Port

> 2012 – 2015, Kerala, India

Leading a team of engineers Stuart undertook the concept design and preparation of documentation for the breakwater of the planned port. Stuart also undertook the review of numerical modelling on behalf of the client.

Beachmere Seawalls

> 2011 – 2016, Moreton Bay, Queensland, Australia

Stuar led a team of engineers, planners, cost estimators and drafters in obtaining planning and environmental approvals and undertaking concept and detailed design and preparing documentation and construction supervision for three separate seawalls at Beachmere on Moreton Bay. Most recently services included construction supervision and certification for the seawalls and drains.

Abbot Point Multi Cargo Facility

> 2011, Bowen, Queensland, Australia

As part of a multi-disciplinary team Mr Bettington undertook design and physical modelling assessment of revetments and breakwaters protecting the proposed facility. Mr Bettington also managed the numerical modelling program for the project and undertook coastal process assessments.

Saadiyat Island Coastal Zone Assessment

> 2011, Abu Dhabi

Stuart led the assessment of coastal processes to determine safe development set back lines for a planned sub-division on the northern end of Saadiyat Island.

Torres Strait Sea Wall Investigations

> 2011 Torres Strait, Queensland, Australia

Although Poruma, Saibai, Boigu and Iama Islands, have very different geological origins the communities on all islands are located on low coastal land that experience both marine inundation and coastal erosion. With forecast sea level rises there are serious concerns about how these communities can adapt. Mr Bettington assessed coastal processes and developed engineering solutions to address foreshore erosion issues and mitigate inundation risks on these remote Islands in the Torres Strait.

Port of Townsville Expansion EIS

> 2011, Townsville, Queensland, Australia

Stuart undertook assessment of met-ocean conditions, reviewed possible quarries and undertook preliminary design of port revetments and breakwaters, considering the potential impact of climate change on both sea levels and the storm intensity.

Brisbane Airport Parallel Runway

> 2010, Queensland, Australia

As a senior engineer Stuart undertook design of revetments, assessment of impacts on estuaries and the design of significant aspects of the dredge based reclamation process. The low level of backing land made the possibility of significant inundation and overtopping with future sea level rise a key design consideration.

Lihir Interim Power Station

> 2010, Lihir, Papua New Guinea

Stuart undertook the design of revetments, breakwater and access causeway for the development on this remote volcanic island A key consideration in the design is the steep bathymetry and earthquake activity.

Queensland Curtis LNG

> 2010, Gladstone, Queensland, Australia

Stuart developed and managed the program of near field modelling for the proposed desalination plant outfall.

Darwin All Tides Access

> 2010, Darwin, Northern Territory, Australia

Mr Bettington assisted in the planning and review of the numerical modelling and obtained and analysed wave data and assessed long wave penetration into the harbour.

KBR 2001 – 2010

Miri Coastal Process Study-Coastal Process

> 2009 – 2010, Sarawak, Malaysia

As a Senior Engineer Stuart oversaw the study, including numerical modelling to examine coastal processes driven by waves, tidal currents and fluvial inputs. Impacts of sediment extraction, reclamation of wetlands, rubbish and coastal developments were concerns addressed in the study.

Ichthys LNG Plant modelling and breakwater design

> 2008 – 2010, Darwin, Northern Territory, Australia

Stuart supervised numerical modelling of wave penetration and hydrodynamic modelling, together with project administration responsibilities within the Brisbane office. Modelling with the Delft suite of models was used to assess currents, impacts of dredging on mangroves, and likely channel siltation rates. Mr Bettington also undertook the design of the perimeter revetment design, considering the possible protection offered by Darwin's expansive mangrove forests.

Gorgon LNG Plant

> 2006 – 2010, Barrow Island, Western Australia

Stuart undertook the review of met-ocean conditions and the design of the revetments associated with the modular offload facility (MOF). The design included consideration of armour type and the layout of the MOF and construction methodology. Other areas of involvement include supervision of physical modelling (conventional rock, single layer core loc and single layer X-Bloc units) considering; material balance; dredging; and production of documents including the design basis and specifications.

Koniambo Mine and Port Development

> 2007 – 2009, New Caledonia

As a Senior Engineer Stuart was responsible for the numerical modelling of forecast environmental impacts resulting from the development of the proposed mine. Particular effort was required to ensure that all driving forces and the swell induced flow within the barrier reef lagoon system were included. Sensitivity of different coral communities and seagrass meadows were considered when considering the likely impacts of dredging and a desalination plant outfall. From the study construction methodology was developed that minimised impacts on the lagoon system and resultant impacts on local fish stocks that are exploited by local tribal groups.

PNG LNG

> 2007, Port Moresby, Papua New Guinea

Stuart assisted in site selection and preliminary design work for modular offload facility (MOF) and jetty. Including an assessment of met-ocean conditions, data collection program, geological conditions, environmental and social constraints, construction methodology and sequencing, and dredging requirements. Unusual aspects of this study included the consideration of sensitive negotiations with local tribal groups and difficult logistics of the site.

Lower Coomera Dredging Strategy

> 2006, Gold Coast, Queensland, Australia

The study examined dredging volumes and disposal options for the lower reaches of the Coomera River and the Broadwater. Duties included the estimation of dredge volumes, examination of disposal options and the preliminary design of long term rehandling facility. The consideration of the engineering practicalities with social constraints and environmental concerns made this project challenging.

Fraser Straights Marina Dredging and Reclamation

> 2006, Tin Can Bay, Queensland, Australia

Stuart was responsible for the design of the reclamation and dredge spoil disposal area including revetment design and construction sequencing for this small marina dredging and reclamation project. Also supervised numerical modelling used to assess impacts of the development on hydrodynamics and waves, and assess the maintenance dredging requirements.

Moreton Bay Dredge Material Study

> 2005, Moreton Bay, Queensland, Australia

Senior Engineer for a significant spoil disposal study, that including all the dredge sediment sources within Moreton Bay and the lower Brisbane River. An exhaustive list of possible disposal options was developed and reviewed against social, engineering and environmental constraints, while considering cost. A short list of potential solutions was prepared for client consideration.

McArthur River Mine Flood Study and Levee Design

> 2005, Northern Territory, Australia

Stuart's role involved the use of numerical modelling to determine the impact of proposed flood exclusion works as part of a major upgrade to the mine; and design of the flood exclusion embankment and diversion channels, including scour protection at a number of critical locations.

Newport Canal Estate Siltation & Dredge Study

> 2004, Redcliffe, Queensland Australia

A siltation study of the existing canal estate and marinas, including analysis if survey data and numerical modelling of siltation. Stuart's role required the use of modelling to estimate dredging requirements in the expanded future canal estate and cost of long-term dredging and disposal;

Royal HaskoningDHV

design of a dredge spoil receiving basin and preparation of dredging contracts.

Darwin LNG

> 2004, Darwin, Northern Territory, Australia

Stuart's role included analysis of data and development of additional data collection requirements, then determine the design met-ocean inputs. Then designed revetments and groynes at the site; utilising desktop and physical modelling techniques. ([redacted]

Redcliffe Coastal Process Study

> 2003 – 2004, Moreton Bay, Queensland, Australia

Stuart undertook the assessment of coastal process around the Redcliffe Peninsula, located on the western side of Moreton Bay. This study was undertaken using the Delft3D suite of programs and included the examination of waves and currents and their impacts on the morphological processes. Using the results of the modelling, he undertook the design of beach nourishment and maintenance works at a number of beaches on the peninsula

Glyde Point-Industrial Estate Port Facility

> 2003, Northern Territory, Australia

KBR was commissioned to undertake the preliminary design phase of a port facility for a proposed industrial estate. Senior Engineer duties were to establish a numerical model of the complex tidal currents and waves at the site, and define a suitable port layout based on the results of the modelling.

Kanekouch Prawn Farm Effluent Modelling

> 2003, New Caledonia

KBR was commissioned to examine the possible clean water intake location for a prawn farm, with particular concern to avoid re-use of discharge water. Stuart utilised existing model tools to examine the movement and decay of an effluent plume.

Koniambo Mine and Port Development

> 2003, New Caledonia

As a senior engineer for the study Stuart examined the coastal processes within the barrier reef lagoon using the Delft3D model. The model was utilised to examine the impact of the proposed works and the dredging operations. Work included determining the wave climate and designing the foreshore protection on the reclamation works.

Ipswich Rivers Flood Study

> 2001 – 2002, Ipswich, Queensland, Australia

Stuart assessed flood discharges utilising the RAFTS software. The flood discharges were then applied to a 2-D hydrodynamic model to determine flood levels in the Ipswich area.

Queensland Environment Protection Agency, at Tweed River Entrance Sand Bypassing Program, 1999 – 2001

Stuart was a Senior Engineer on the Tweed River Entrance Sand Bypassing Project, assisting the project director in negotiations for, and implementation of, the bypassing system. Duties included review of design documentation, monitoring of the project's progress and impacts, collection of coastal data and the assessment of system performance during the commissioning program; providing professional advice to various groups within the EPA on hydraulic, estuarine and coastal engineering issues. Mr Bettington carried out the role of Project Director Tweed and Principal Engineer Modelling when required, taking on responsibility for both the financial authority and personnel supervision.

Queensland Dep. of Environment, at Queensland Government Hydraulics Laboratory, 1997 – 1999

As Senior Engineer Stuart was responsible for day-to-day management of the laboratory's physical modelling facilities. Duties included preparation of proposals and reports for external clients; project management of physical models, including model design and construction, instrumentation, data collection and analysis; and supervision of staff; maintenance of the UNIX-and PC-based systems; implementation of extensive new software package for model control, data acquisition and data analysis; preparation of a Laboratory Quality System; and acting as Principal Engineer QGHL, including financial authority and personnel responsibilities as required.

Unisearch Ltd. (UNSW) at the Water Research Laboratory, 1990 – 1997

Stuart was employed as a Project Engineer in the Water Research Laboratory, working in the fields of coastal, estuarine, hydrologic and hydraulic engineering. He developed and applied skills in project management; data collection and analysis; numerical and physical modelling; design; and the preparation of technical reports and proposals. During 1996 and 1997 he was the laboratory's Quality Assurance Manager, responsible for the implementation and maintenance of the NATA certified quality systems.

Techncial Papers (Primary Author)

2023 'Morphology and Harbour Siltation at Cape Ferguson', Australasian Coasts and Ports Conference, Sunshine Coast.

2022 'Climate Change Impacts on Reef Top Islands', International Conference on Coastal Engineering, Sydney.
2021 'Morphology of Reef Top Islands and Impacts of Climate Change', Australasian Coasts and Ports Conference, Christchurch.
2019 'A Guide to the use of Geographical, Geological and Ecological Features to Support Coastal Engineering Design ', Australasian Coasts and Ports Conference, Hobart.
2017 'Coastal Engineering Solutions for Remote Island Communities', Australasian Coasts and Ports Conference, Cairns.
2015 'Adaptation to Climate Change in Design - SH16 Causeway Upgrade', Australasian Coasts and Ports Conference, Auckland.
2013 'Adaptation to coastal erosion and marine inundation on Torres Strait Islands', Australasian Coasts and Ports Conference, Sydney.
2011 'Australian Experience with Randomly Orientated Single Layer Concrete Armour for Breakwaters and Revetments ', Australasian Coasts and Ports Conference, Perth.
2007 'Modelling of Dredge Plumes', Australasian Coasts and Ports Conference, Wellington.
2007 'Impact of swell waves on lagoon hydrodynamics', Australasian Coasts and Ports Conference, Melbourne.
2005 'Canal estate siltation modelling. A case study: Newport Waterways, Redcliffe', Australasian Coasts and Ports Conference, Adelaide.
2003 'Modelling of tides in Van Diemen and Beagle gulfs, Northern Territory, Australia', Australasian Coasts and Ports Conference, Auckland.
1997 'Extreme water surface excursions during storm events in NSW', Australasian Coastal and Ocean Engineering Conference, Christchurch.
1997 'Low reflection structures for small harbours (double skirt breakwaters with a perforated front skirt)', Australasian Coastal and Ocean Engineering Conference, Christchurch.
1995 'Model investigation and monitoring of the seawall and bar at Georges Bay', Australasian Coastal and Ocean Conference, Melbourne.
1992 'Racecourse Creek entrance stabilisation and management', Coastal Management Conference, Kiama, NSW.

Other Publications

2010 Technical Memorandum "Sea Level Rise in Coastal Engineering", AECOM.

1994 Master of Engineering Science Project 'Water level extremes during storm events', UNSW.
1997 Unisearch Ltd. Water Research Laboratory, 'Seabees for coastal and embankment protection-Design Manual Version 2.2'.