Review of Causes of Northern Bribie Island Erosion

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Executive Summary

This report summarises a review of the causes of beach and dune erosion on northern Bribie Island that resulted in the tidal breakthrough of Bribie Island in January 2022. The review has considered existing datasets to examine a number of postulated causes of erosion on the basis that they are correlated in time with the erosion trends on Bribie Island, show a physical process that could cause erosion to Bribie Island and be of a significant magnitude. Within this report, the following postulated causes of erosion have been investigated:

1. Natural coastal processes, including:
   a. Channel migration within Pumicestone Passage.
   b. Wave erosion
2. Dredging at Spitfire Sand Extraction Zone.
3. Dredging of the Northwest channel.
4. Erosion from vessel traffic, including:
   a. Ship wake and propeller wash.
   b. Estuarine boat wash.
5. Development of Lamerough canal

This review has utilised existing bathymetric surveys, coastal datasets, coastal process models, historical aerial photographs and information obtained from subject matter experts and published literature to investigate each of these postulated causes. The results of this review indicate that natural coastal process influence both shorelines of Bribie Island in the most significant way. On the eastern shoreline, erosion from waves, and in particular large waves from tropical lows or cyclones, is not sufficiently counterbalanced by subsequent accretion, leading to a long-term negative sediment budget and therefore overall erosion of the eastern shoreline. Within Pumicestone Passage, the western shoreline has eroded as a result of the migration of the channel, forced by the growth and migration of sand shoals in the northern part of the passage. These two natural processes have resulted in a consistent trend of erosion from the 1940s to the present time and are identified as the leading cause of erosion on the northern portion of Bribie Island.

Offshore dredging, both at the Spitfire sand extraction zone and in the Northwest Channel, were investigated. There was no evidence to support a hypothesis that dredging at the Spitfire area impacted on erosion of northern Bribie Island, both due to distance and the sand migration patterns in that area. Dredging in the Northwest Channel does not appear to contribute to erosion of Bribie Island. The very flat nearshore bed slopes and exposed rock patches indicate very low to negligible rates of cross-shore sediment transport between the eastern shoreline of Bribie Island and the dredged area within the Northwest Channel.

Ship wake and turbulence from large vessels in the channel east of Bribie Island were investigated, as well as vessel wake within Pumicestone Passage. Waves from ship wake do break on the eastern shoreline of the island, however they contribute to an insignificant proportion of the total wave energy impacting on northern Bribie Island. Turbulence from the ship propellers can create scour of the proximal seabed, but research indicates that this requires shallower water than what is found in the shipping channel and prolonged exposure in the same location to create significant scour. Turbulence of this nature is only problematic when undertaking slow speed manoeuvres within a harbour or port and there is no evidence that it contributes to the erosion of Bribie Island. Within Pumicestone Passage, boat wake from smaller vessels is shown to contribute a minor amount to erosion.

The development of Lamerough canal has created additional tidal volume within Pumicestone Passage. An existing hydrodynamic model was interrogated to investigate the influence of this extra volume on tidal flows in the main channel, with none detected. Furthermore, this channel is upstream of the breakthrough area only on ebb (outgoing) tides, with the erosion trends showing the currents generated by the flood (incoming) tide to be the cause of erosion.

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1 Background

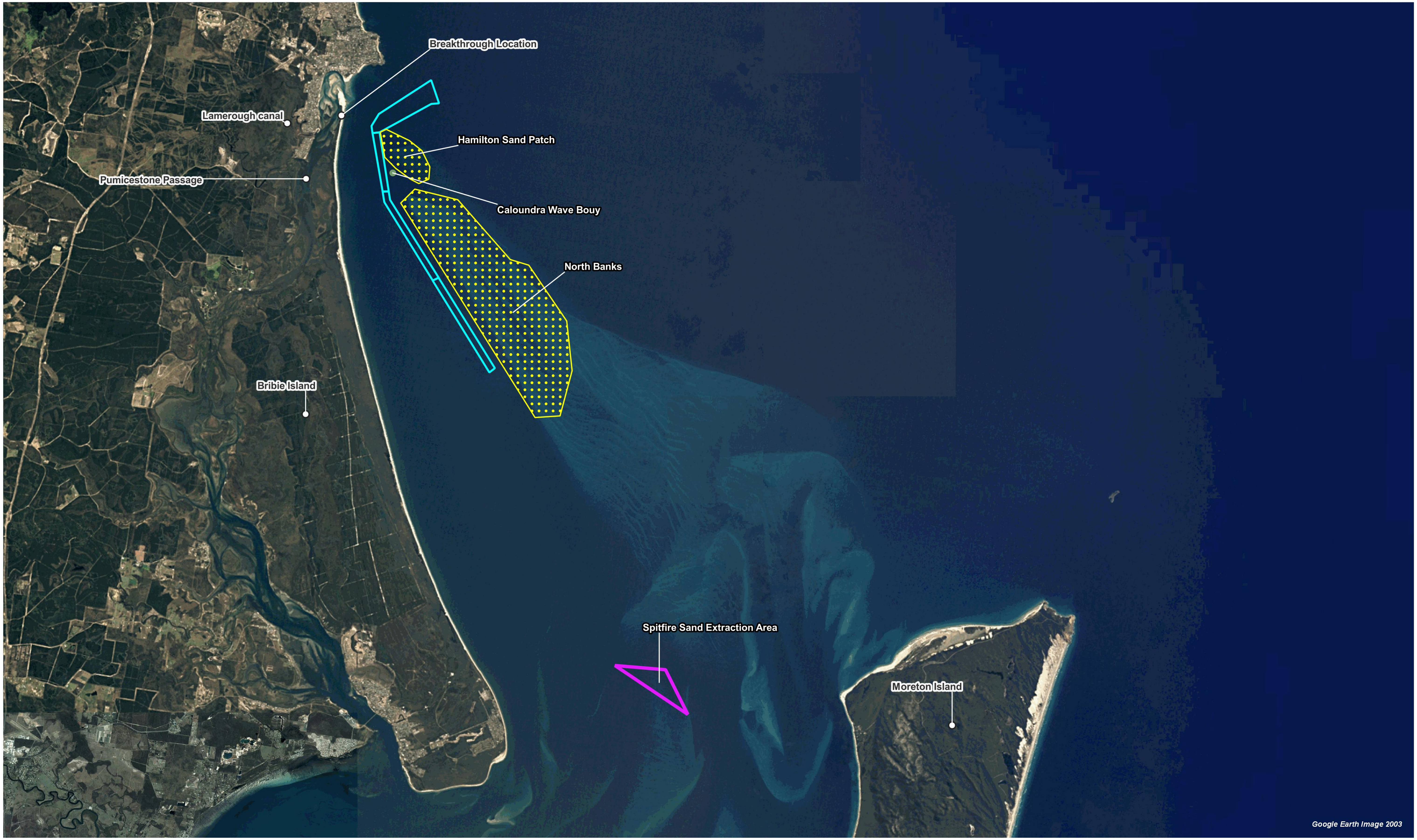
In January 2022, Bribie Island was impacted by waves generated by ex-tropical cyclone Seth that over-washed the island opposite Nelson St at Golden Beach and caused a tidal breakthrough of Bribie Island. Erosion of the northern end of Bribie Island has been a persistent and ongoing issue for many decades, with the gradual narrowing of the Island from both the wave exposed coastal side (east) and the wave protected Pumicestone Passage side (west) (refer Figure 1.1. The breakthrough of Bribie Island has significantly modified the northern region of Pumicestone Passage, resulting in:

- Increased tidal amplitude at Golden Beach.
- Reduced protection from storm tide inundation at Golden Beach.
- Wave penetration through the new opening reaching the shoreline of Golden Beach.
- Issues with navigation for vessels in the northern part of Pumicestone Passage, particularly around access to open water.

Following the breakthrough, there was considerable community angst about the perceived loss of coastal protection to the mainland provided by the Island and a desire to understand the causes of erosion that led to the breakthrough. The Queensland Department of Environment and Science (DES) has been monitoring the erosion on Bribie Island since 1995 and is of the view that erosion along Bribie Island is due to natural causes. However, some in the community were suggesting a possible human cause. DES met with community representatives and identified the following postulated causes of erosion:

1. Storm events, tidal currents and other natural coastal processes
2. Sand extraction at Spitfire Channel near Cowan Cowan on Moreton Island, and within the central bay generally, to extract sand for building and construction purposes
3. Dredging and sand extraction of the navigation channel approximately 1km offshore from northern Bribie Island by the Port of Brisbane
4. The historical development of Lamerough Canal at southern Golden Beach, which is claimed to be exacerbating erosion of the western shoreline of Bribie Island by forcing the flow of ebb (outgoing) tides against Bribie Island
5. Ship wake and thrust turbulence from commercial shipping using the adjacent navigation channel

The purpose of this assessment is to review existing data to establish if there is sufficient evidence that these postulated causes of erosion are physically credible in contributing to erosion of the island, and the relative magnitude of contribution from each of these postulated causes. Datasets examined include bathymetric and topographic survey, aerial imagery from the 1940s to present day, dredge records, scientific literature, coastal process models and feedback from coastal researchers investigating Bribie Island and the surrounding area.



LEGEND

- Spitfire Sand Extraction Area
- Sandpatches
- North West Channel

Title:

Regional Locations Map

Figure: **1-1**

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Legend

- North Pumicestone Shoals
- Cadastral Boundaries

Title:

Northern Bribie Island Map

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2 Assessment Approach

The degree of contribution of each of the listed postulated causes of erosion may vary from non-existent to significant, with the purpose of this review to investigate the potential magnitude of contribution from each cause. The reporting separates postulated causes that are plausible from those that are both causal and significant in contribution of erosion along northern Bribie Island.

BMT have utilised existing data to undertake an evidence-based assessment of the postulated causes of erosion to establish (or not) a causal link between the postulated cause and the erosion of northern Bribie Island, before establishing the likely magnitude of contribution (Figure 2.1). The evaluation of each postulated cause needs to determine, with sufficient evidence, that the cause and effect are correlated, causal and significant, with the following possible outcomes:

- **No contribution:** The postulated cause of erosion has been suitably explored and found that it could not contribute to erosion of Bribie Island.
- **Minor contribution**: The postulated cause of erosion has been suitably explored and found that it would have an insignificant contribution to the erosion of Bribie Island. The postulated cause may directly cause erosion to Bribie Island or modify coastal processes adjacent to Bribie Island in a minor way.
- **Moderate contribution**: The postulated cause of erosion has been suitably explored and found that it could have had a significant contribution to the erosion of Bribie Island but is unlikely to be the leading cause. The postulated cause may directly cause erosion to Bribie Island or modify coastal processes adjacent to Bribie Island in a significant way.
- **Major contribution**: The postulated cause of erosion has been suitably explored and found that it is likely to be the leading cause of erosion of Bribie Island. The postulated cause directly contributes to erosion on Bribie Island in a significant way.
- **Needs more information**: The postulated cause of erosion cannot be suitably confirmed or explored due to a lack of information to confirm either its causal relationship with the erosion or the magnitude of the erosion it may contribute.

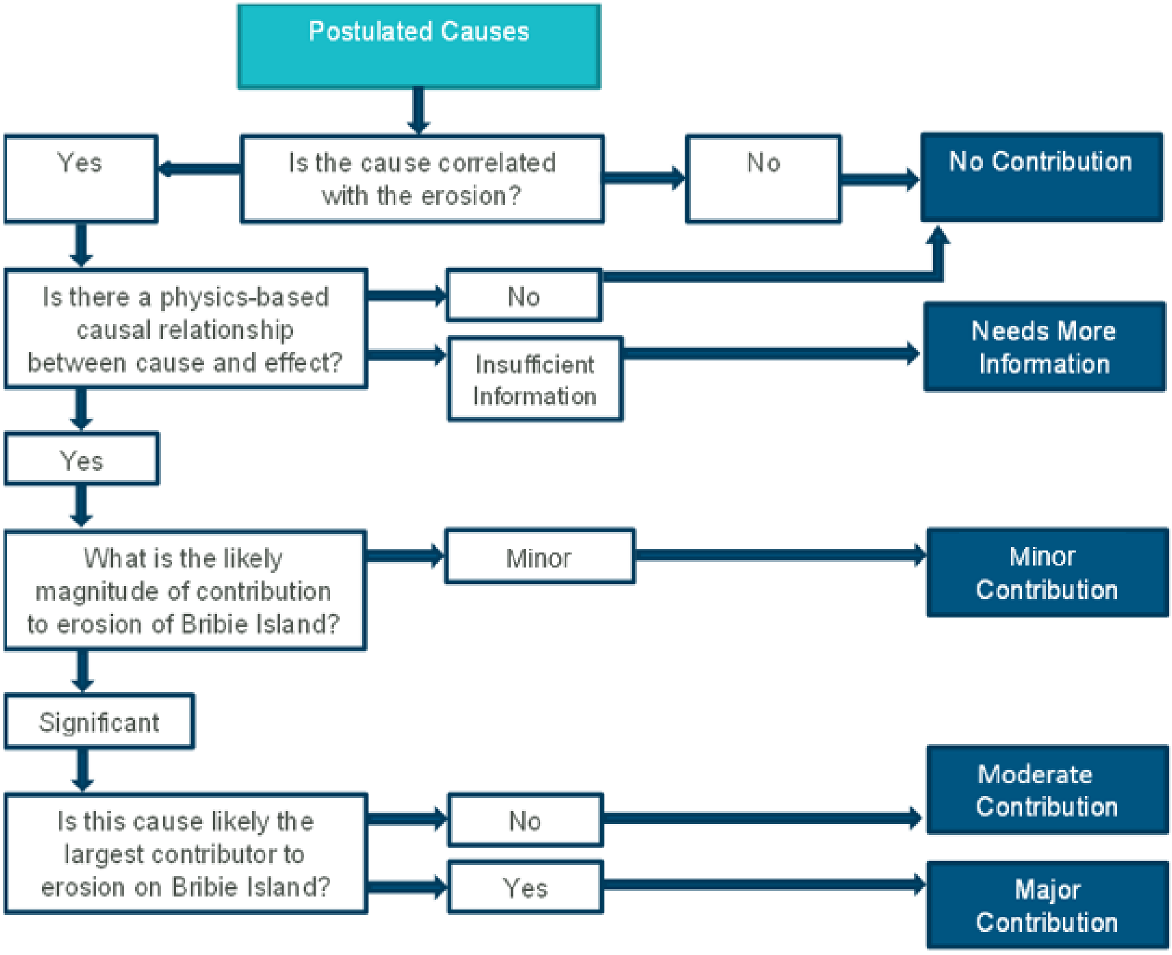


Figure 2.1 Workflow diagram of the investigation of postulated causes of erosion at Bribie Island.

3 Shoreline Evolution and Coastal Processes

3.1 Geological development of northern Bribie Island (-6000 years to present)

The low-lying coastal plains and waterways around Bribie Island have experienced significant change. Over the last 120,000 years large variations in sea level have influenced the evolution of the shoreline. Most of the flat areas west of the present shoreline were formed by sediments deposited during the previous high sea level (about 120,000 years ago). The glacial period that followed caused a major drop in sea level (up to approximately 120m), resulting in eastward migration of the shoreline. From 18,000 years ago the sea level rose again, approximately reaching its present level by 6,500 years ago. In response to the rising sea, the shoreline moved westward, progressively submerging the former coastal plain.

Riedel and Byrne (1979) suggested that the northern end of Pumicestone Passage, as we know it today, formed during the early Holocene period (approximately 10,000 years ago). Before this time the rivers had scoured deeper, narrower channels and were depositing fluvial sediments east of the present Bribie Island shoreline. As sea levels rose, the river channels were drowned, and sediments began depositing within what is now the Pumicestone Passage area. The rising seas reworked the old offshore delta deposits, pushing beach sands onto the eastern side of Bribie Island. Sediment samples indicate the northern end of Bribie Island developed to its present general position approximately 4,000 years ago. Contemporary coastal geology mapping of the study area is presented in Figure 3.1.

Figure 1.1 shows that offshore from Bribie Island is a natural deep channel (Northwest Channel) that is presently maintained as a shipping lane into Moreton Bay, with a series of submerged sand banks further east towards Moreton Island. Positioned at the northern entrance to Moreton Bay, the sand banks are naturally forming bathymetric features that have been evolving since the late Holocene period, however they continue to grow and migrate over geologic time periods of decades to centuries. The sand banks become progressively narrower and lower in crest height as they extend from Moreton Island in the southeast towards northern Bribie Island in the northeast. Consequently, the degree of wave protection to Bribie Island from east and southeasterly swell is progressively reduced, with the northern part of Bribie Island most exposed, allowing sand to migrate north along the northern part of Bribie Island into the northernmost mouth of Pumicestone Passage (near Deepwater Point).

Waves from the northeast are less affected by the sand banks and these drive southerly longshore transport along northern Bribie Island (Jones, 1992). The combination of these two dominant wave conditions results in a littoral drift ‘divide’ along northern Bribie Island, where sediments are shuffled both to the north and south along the beach, eventually being transported either north into the mouth of Pumicestone Passage or south towards Woorim (Figure 3.1). These wave conditions are also discussed further in the following section of this report.

The Hamilton and Northern sand banks are fed by sand that is moving northwest from the tip of Moreton Island, causing the sand banks to grow and migrate slowly to the northwest over a decadal time period (refer Figure 3.6). Sand travelling northwest from Moreton Island is intercepted by these sand banks and therefore isn’t available for Bribie Island (Jones, 1992). With the increasing elevation of the sand banks combined with northwest migration, ebb tide currents have been concentrated into the entrance of the Northwest Channel, increasing the speed of tidal currents flowing north adjacent to Bribie Island in the vicinity of the breakthrough. West of the sand banks, offshore of the breakthrough location, is a series of thinly covered or exposed indurated sand (coffee rock) reefs that indicates long term low sediment supply and limits the onshore migration of sand to Bribie Island (Cossu et. al. 2018). Combined, the evolution of these sand banks has the following consequences:

- Net southerly, nearshore wave and tidal driven sand transport adjacent to the northern end of Bribie Island is due to wave sheltering and refraction afforded by the sand banks.
- Northerly, offshore tidal driven sand transport in the North West Channel is progressively increased, forcing sand to migrate north and into the northern Pumicestone Passage mouth and Hamilton Patches, increasing the volume of sand at the northern end of Bribie Island.
- The sand banks intercept sand travelling northwest from Moreton Island, limiting the availability of sand to migrate onto the Bribie Island shoreline.
- The combination of the above three mechanisms results in long-term erosion of the eastern shoreline of northern Bribie Island due to the inequality in sand volumes entering and leaving the area.
- The westward migration and growth of the sandbanks have forced a subtle migration of the tidal currents west towards the shoreline of Bribie Island.

In summary, accretion of sand to the northern tip of Bribie Island, within Pumicestone Passage, and to the southern parts of Bribie Island indicates that a littoral drift divide along northern Bribie Island has resulted in protracted erosion of the eastern shoreline.

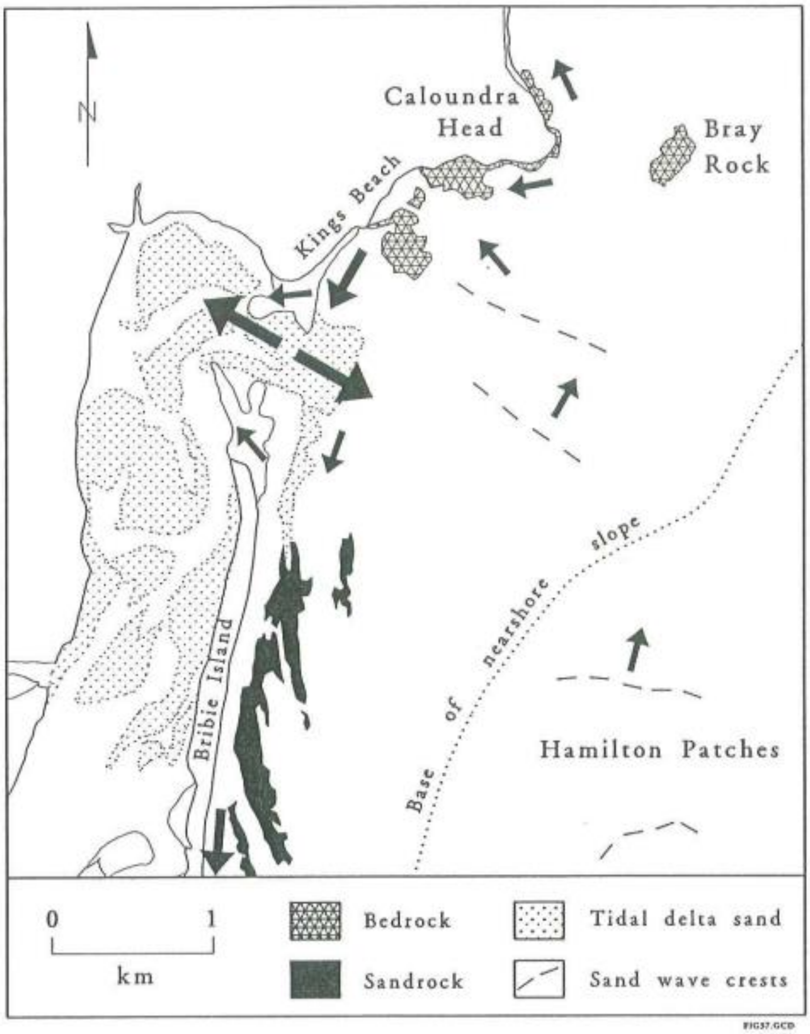


Figure 3.1 Sediment transport conceptual model from Jones (1992).

3.2 Northern Bribie Island Shoreline Evolution (1945 to present)

Northern Bribie Island is a dynamic coastal environment, influenced both by the channels within Pumicestone Passage and wave action on the exposed coastline (Riedel & Byrne, 1979. To update the understanding of the regional coastal processes proposed by Jones (1992), a range of historical aerial photos from the period 1940 to 2021 were evaluated, as well as the DEA Coastlines tool (Geoscience Australia 2021) which has assessed satellite imagery from 1980 to 2021. Historical aerial images are provided in Annex A and are a combination of photogrammetry work undertaken by the former Beach Protection Authority (BPA), supplemented by more recent images from QImagery and Nearmap.

The historical aerial images have been georeferenced to a basemap to allow the images to be comparable across the time-period. Georeferencing involves adding geographic information to a digital image so that GIS software can 'place' the image in its appropriate real-world location. Georeferencing requires the identification of ground control points visible in every image to be matched to present day locations, which can be difficult for older photos where present-day features did not exist. This is particularly problematic for images captured before the development of Golden Beach and Pelican Waters, where very few fixed landmarks are identifiable between this period and the basemap. These georeferencing issues are more problematic for positional errors than they are for scale errors, so the assessment undertaken in this study has not relied on analysis where a high degree (+/- <5m) of positional accuracy is required.

The historical images show the meandering of the channels within Pumicestone Passage (Figure 3.2) have increased the erosive pressure on the western side of Bribie Island because of the substantial growth of the northern shoals of Bribie Island fed by sand eroded from areas immediately south and sand transported into the passage from Kings Beach (Figure 3.3). Jones (1992) had previously identified the northern entrance to Pumicestone Passage as a sediment sink. The period after completion of that study (1992 to present) has seen a significant expansion of the northern shoals, with strong establishment of vegetation also observed. The historical imagery shows the following evolution of northern Bribie Island:

- In 1940 the main entrance channel was within 50m of the small rocky headland on the mainland (Deepwater Point). Shoals within the passage were well dispersed with multiple channels present.
- By 1961 the sand had formed into a spit from the mainland extending 850m southward, but by 1971 this spit had eroded back by 500m. The entrance shown in the 1971 and 1972 images widened following a series of flood and severe wave events associated with tropical cyclone activity. There was a large shoal to the north of the entrance within the passage, and the primary channel running north-south on the western side of Bribie Island was forming. While these changes were occurring to the mainland spit, the vegetated northern tip of Bribie Island was greatly reduced between 1940 and 1972.
- In 1979, the northern shoals in Pumicestone Passage continued expanding north and north west, while the western shoal stabilised, as seen by the growth of vegetation.
- By 1982 the entrance channel had combined into a single, northern channel with the flood tide channel aligned against the mainland until it reached the central shoal, where it was forced to run south-east towards the western side of Bribie Island where it turned south. This abrupt change in direction caused erosive pressure on the western shoreline, with eroded materials deposited further south in the eastern shoal.
- The northern shoal continued to expand by 1992, with the flood tide channel from the previous photo becoming the dominant channel. The channel west of the central shoal decreased in width placing further erosion pressure on the western bank of Bribie Island. The eastern shoal formed by the flood tide continued to grow, indicating continued erosion.

- The images from 1997 to 2021 all show continuation of the same behaviour. The northern shoal of Bribie Island grew, deflected inwards, stabilised and progressively increased in vegetation extent and density. The growth of the northern shoal and the stability of the central shoal forced the channel to run west-east towards the breakthrough location, with the angle of the channel deflection at the western shoreline of Bribie Island becoming more acute over time. Further, the eastern shoal continued to grow, shielding the western shoreline of Bribie Island from ebb-tide currents.

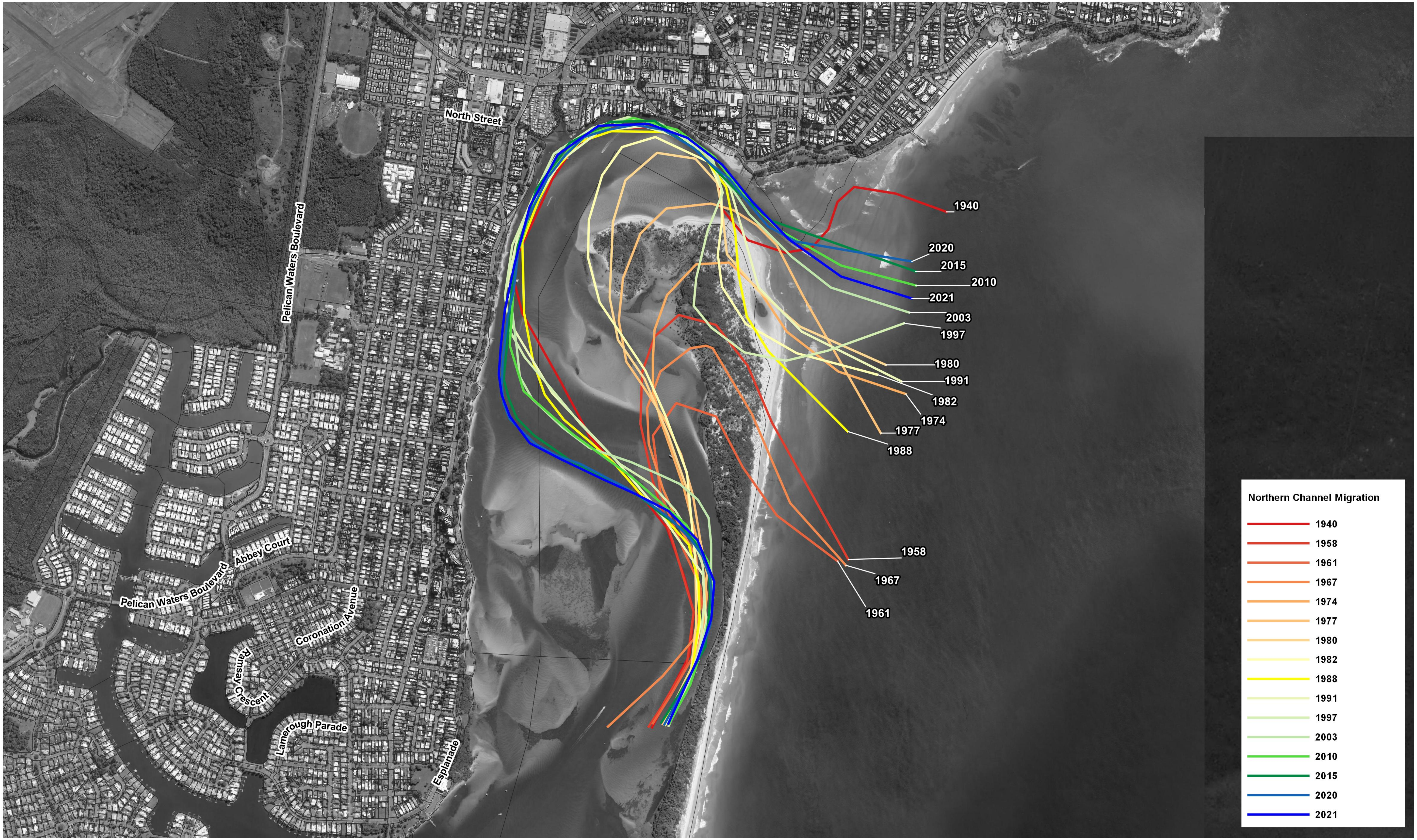
The historical images were also interrogated to measure the distance between the eastern and western extent of the vegetation line. While the high-water mark is typically preferred as the proxy-datum for assessment of changes in shoreline position (Ruggiero, 2013), where corrections cannot be made for tidal fluctuations and wave runup, the shoreline positional error can lead to inaccuracies (Wishaw et. al., 2021). Given the limitations with tidal records as far back as the 1940s and the quality limitation of the imagery, the vegetation line was adopted as a proxy-datum. The vegetation line is suitable for measuring trends in long term erosion but can be less sensitive to situations where erosion is limited to the shoreface, such as can occur in individual erosion events.

Northern Bribie Island is shown to be consistently eroding since before the mid-20th century development of Golden Beach (Figure 3.4). Closely spaced cyclones in the early 1970s of TC Daisy, TC Emily and TC Zoe are clearly seen in the trend line, as the beach was not able to recover between events, while other events, such as TC Oswald (2013) are not prominent in the time series due to the healthy beach condition prior to the event. The erosion trend also accelerated in 2019, when TC Oma caused overwash of the island, resulting in vegetation loss at the breakthrough location and leading to subsequent dune erosion. The trend indicates reasonably consistent narrowing of northern Bribie Island of approximately 1.3m/year, and does not show acceleration by obvious human interventions such as the construction of the Kings Beach groyne in the late 1960s or Lamerough Canal in the late 1980s. Instead, the trendline indicates that consistent change has been occurring since before intensive development of the area occurred.

In addition, the DEA Coastlines tool combines historical satellite data from Geoscience Australia's Digital Earth Australia program with tidal modelling to map the most representative location of the shoreline at mean sea level over time. While only capturing relatively recent imagery, the tool provides an indication of the scale of erosion and accretion trends. This tool was also reviewed for the study area and showed a magnitude of erosion similar to that obtained from the assessment above (Figure 3.5). For northern Bribie Island the calculated rate of change was between 1.1m/ year and 1.6m/year with an error of +/- 0.3m, with erosion identified on both the eastern and western shorelines of Bribie Island.

Overall, this assessment has identified a continuation of the trends identified by Jones (1992), with the following key conclusions of the shoreline evolution on northern Bribie Island:

- A long-term trend of erosion is identified both on the open coast eastern shoreline and on the protected western shoreline.
- A long-term trend of accretion is identified within the entrance to Pumicestone Passage and further south on Bribie Island, at the point where the shoreline alignment changes direction.
- The northern entrance to Pumicestone Passage is a net sand sink with sand accumulating in sand shoals in the entrance.
- The sand shoals have developed over time, with the growth of vegetation on the sand shoals indicating their relative stability.
- The main flood tide channel position and direction has changed considerably over the study period, changing from a north-south alignment to a more tortuous alignment including an abrupt change of direction at the western shoreline of Bribie Island that creates erosion pressure.



LEGEND

Cadastral Boundaries

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Northern Channel Migration

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Cadastral Boundaries

Title:

Northern Shoal Growth

Figure: 3-3

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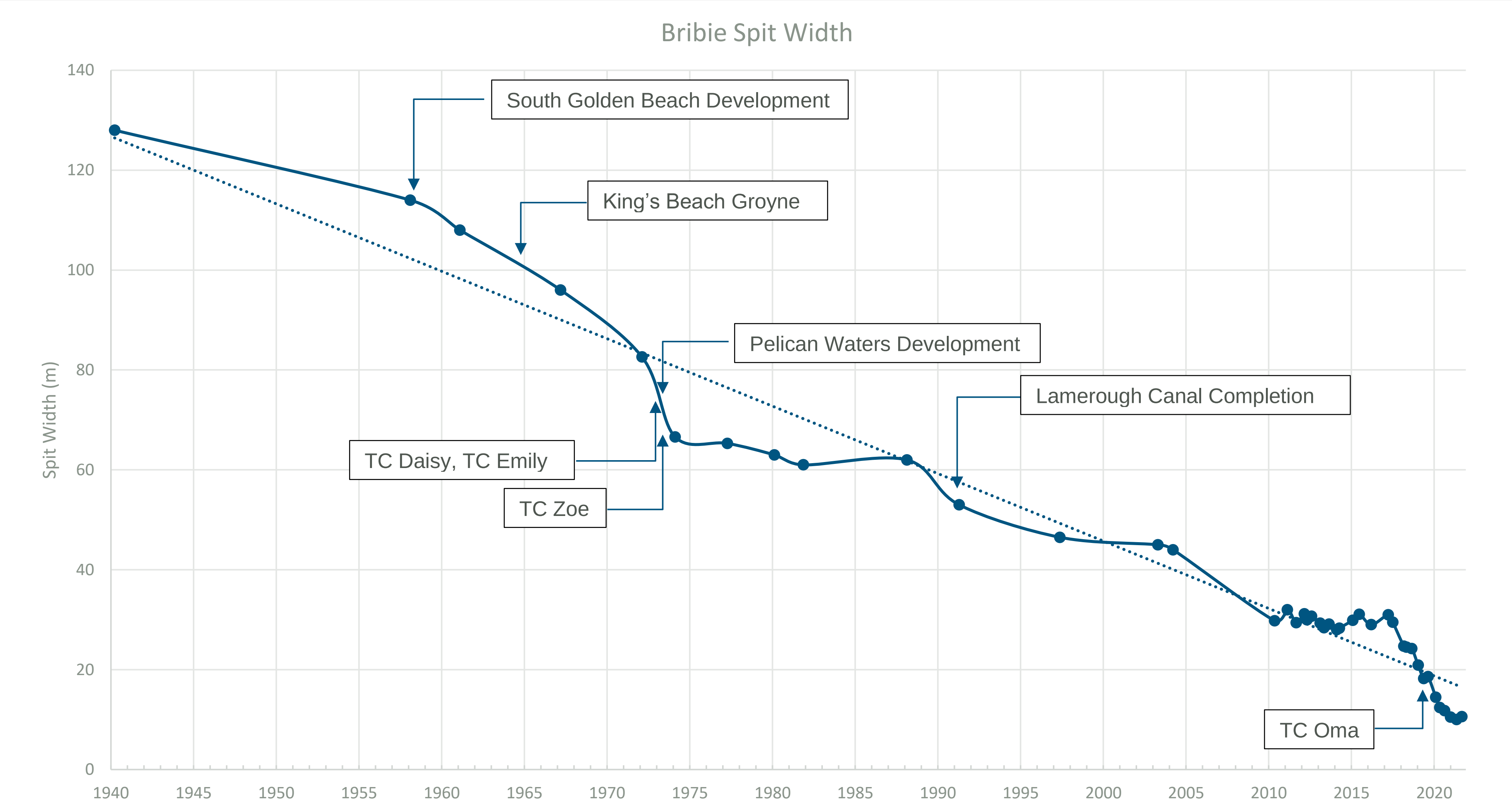
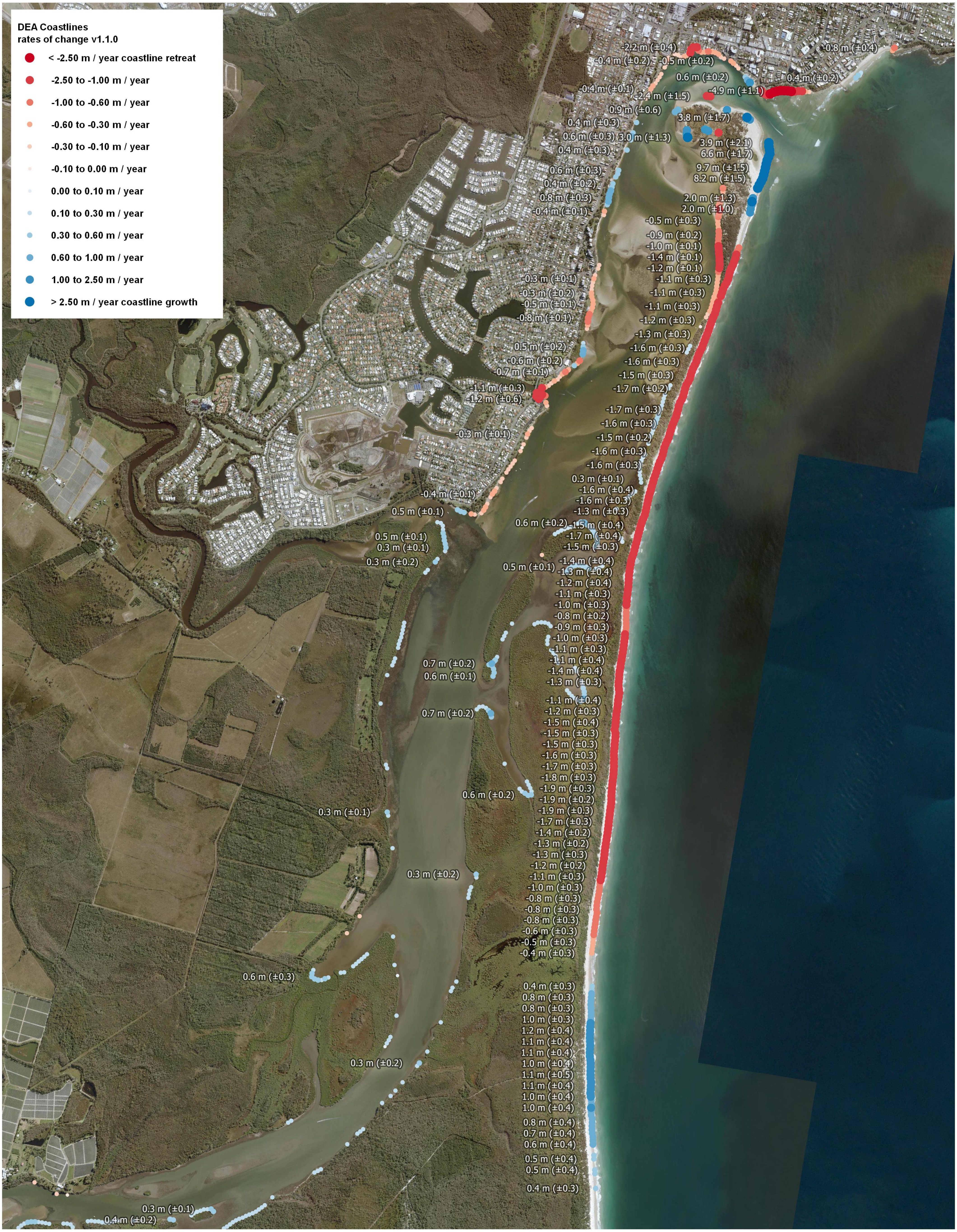


Figure 3.4 Vegetated width of Bribie Island at the location of the tidal breakthrough



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DEA coastlines

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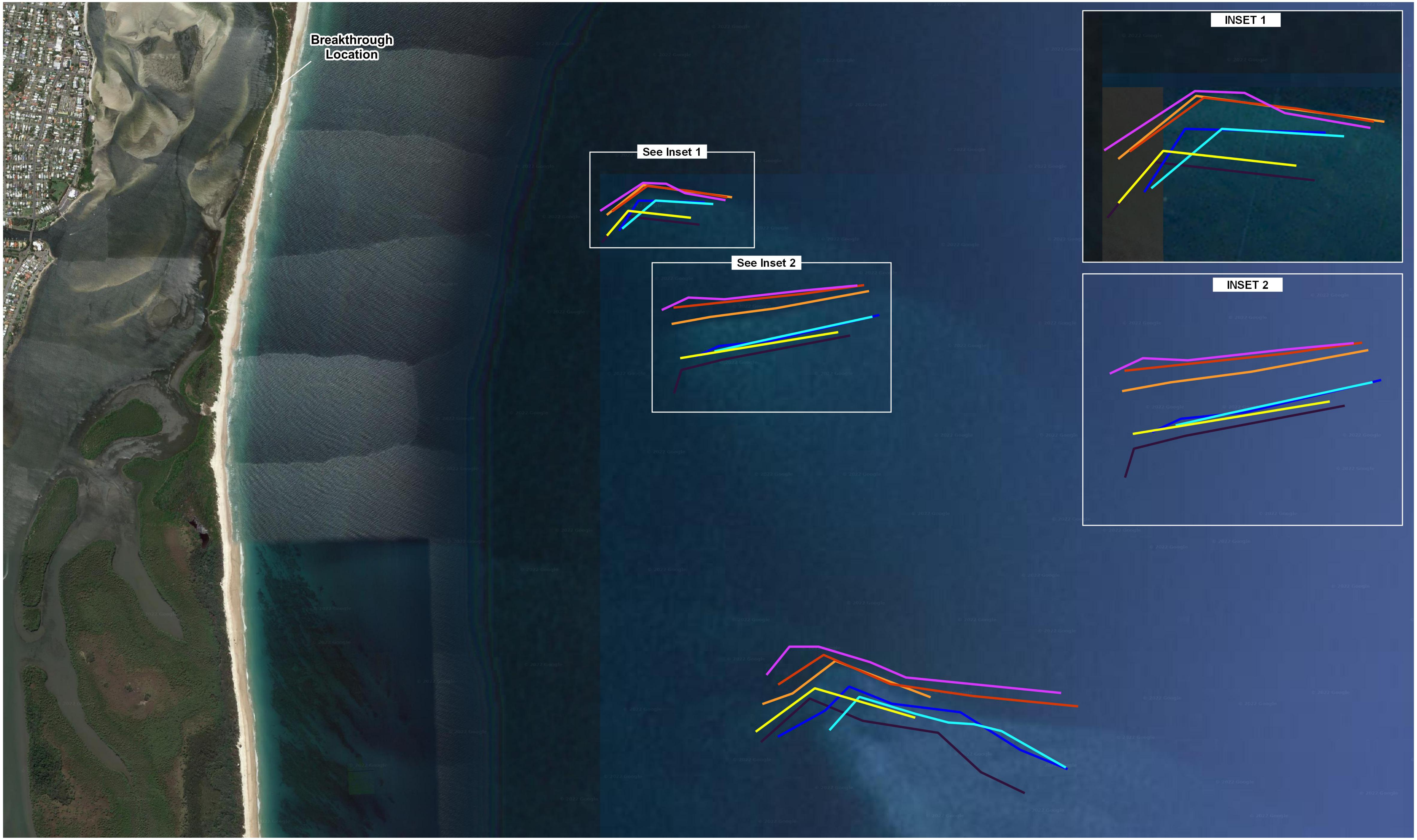

Sand-patch-migration

1974
1977
1982
1988
2003
2013
2020

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Sand Patch Crests

Figure: 3-6

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3.3 Open Coast Wave Environment

Wave conditions on the open (eastern) coast of Bribie Island are recorded by the Caloundra waverider buoy (Queensland Government 2022), approximately 3.3km southeast of the recent breakthrough location (refer Figure 1.1). Operational since 2013, the Caloundra wave buoy is jointly operated by the Department of Environment and Science and the Port of Brisbane Corporation to monitor conditions in the North West Channel. The wave conditions at the Caloundra buoy (Figure 3.7) show a narrow range of wave directions from the east and east-southeast, with a median significant wave height of slightly more than 1m. The location of the wave buoy is partially protected from northeast wave conditions by the Hamilton Patches, and it is possible that the northern section of Bribie Island, which is unprotected from this direction, receives more wave energy from the northeast than the wave buoy indicates.

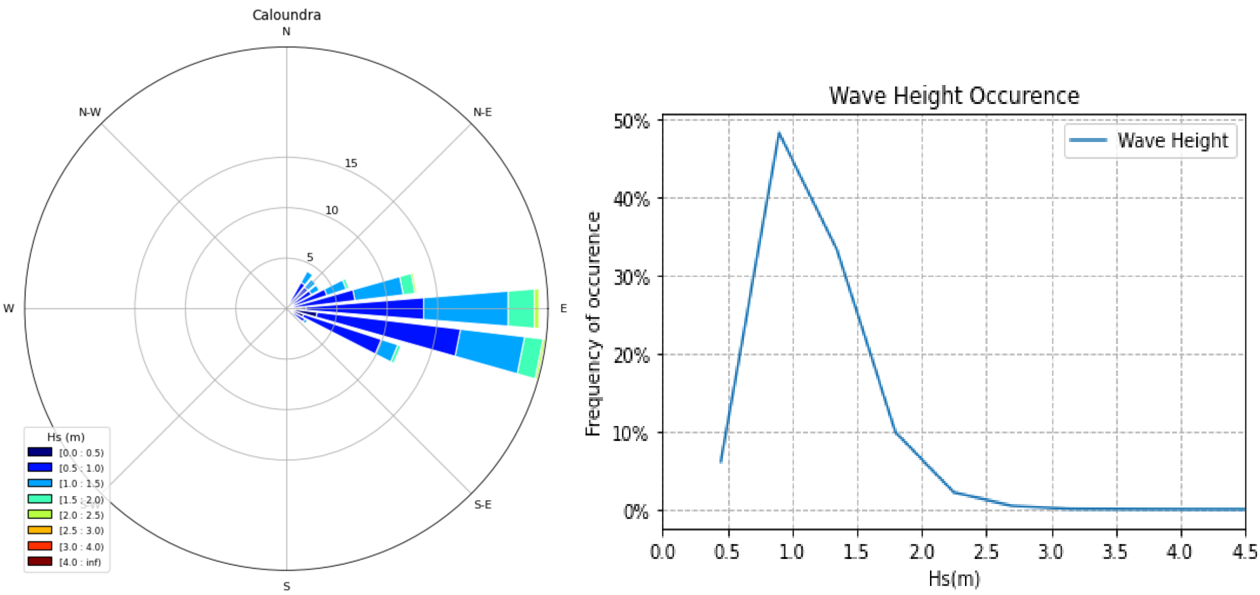


Figure 3.7 Wave conditions at the Caloundra wave buoy for the period 26/04/2013 to 31/03/2022.

Sandy beaches exposed to wave impacts will tend towards an alignment that is perpendicular to the mean wave direction (Goodwin, Stables and Olley, 2006). The northern portion of Bribie Island exhibits a clockwise rotation of beach alignment from south to north of up to 25 degrees, indicating a change in wave exposure along the coast. Northern Bribie Island is well aligned with modal wave conditions from the east-southeast, but poorly aligned with wave conditions from the northeast. As such, it is expected that shoreline-oblique waves experienced during northeast swell conditions will result in longshore transport of sand to the south. Without southeast wave exposure of the southern parts of Bribie Island, this sand is not returned to northern Bribie Island, but accumulates along southern and central Bribie Island where the shoreline is rotated more perpendicular to the northeast swells. Further wave modelling would be useful to establish a sediment budget for these conditions and better understand the protection of Bribie Island from the sand patches.

3.4 Northern Pumicestone Passage Currents

Being sheltered from swell waves and having a limited exposure to wind waves, the western shoreline of Bribie Island is predominantly influenced by tidal currents. As stated by Riedel and Byrne (1979):

> *"The beaches in Pumicestone Passage are very markedly dependent on the positions of the ebb and flood channels. Only when channels are near to the shore do other factors, such as waves and flooding, cause appreciable damage."*

As part of the Pumicestone Flood Study (BMT 2017), BMT undertook a coastal processes assessment of Pumicestone Passage using a hybrid bathymetry representative of an early 2010s scenario. This assessment was primarily focused on delivering results for the flood study, however, our review of the outputs of the 'tide only' model that was created for this project made the following observations:

- Peak flood tide velocities on the western side of Bribie Island at the recent breakthrough location are higher than ebb tide velocities by approximately 30%. Peak tidal velocities at the recent breakthrough location for flood tides are approximately 0.5m/s and ebb tides are 0.35m/s.
- The peak flood tide currents are more concentrated in the channels, while during the peak of the ebb tide currents more flow is distributed across the large sand shoal west of the recent breakthrough location.
- The concentrated flood tide direction turns through approximately 90 degrees at the location of the recent breakthrough, while on the ebb tide this occurs further north of the recent breakthrough location.

Overall, these results indicate that the flood tide currents are of more of a driver for erosion along the western shoreline of Bribie Island, both due to their magnitude and the direction at which they approach the Island at certain locations.

Figure 3.8 Peak flood tide (left) and ebb tide (right) for Pumicestone Passage for normal tide-only conditions.

Tidal velocities at the entrance to Lamerough canal were assessed against those in the main channel to evaluate their contribution to the overall flow. To do this, a timeseries was extracted from a point within the entrance to Lamerough canal and a point within the eastern channel adjacent the western shoreline of Bribie Island and compared (Figure 3.9). The assessment shows that peak flood tide velocities in Lamerough Canal are approximately 0.13m/s, twice as high as ebb tide velocities, and considerably lower than the tidal velocity in the channel, which is up to 0.5m/s. With the main driver of erosion occurring due to flood currents, the entrance of Lamerough canal is therefore 'downstream' of where the channel passes close to the Island and thus is not a contributor to flood tide erosion.

Furthermore, with both the volume and velocity of the water exiting the canal being considerably lower than in the main channel, no influence from the canal on the main channel direction or velocity is detectable within the existing dataset. Further modelling could be undertaken to quantify the contribution, but given the canal is only 'upstream' during ebb tides, which are not the major contributor to the erosion of the western shoreline of the island, this is not expected to provide any further useful insight.

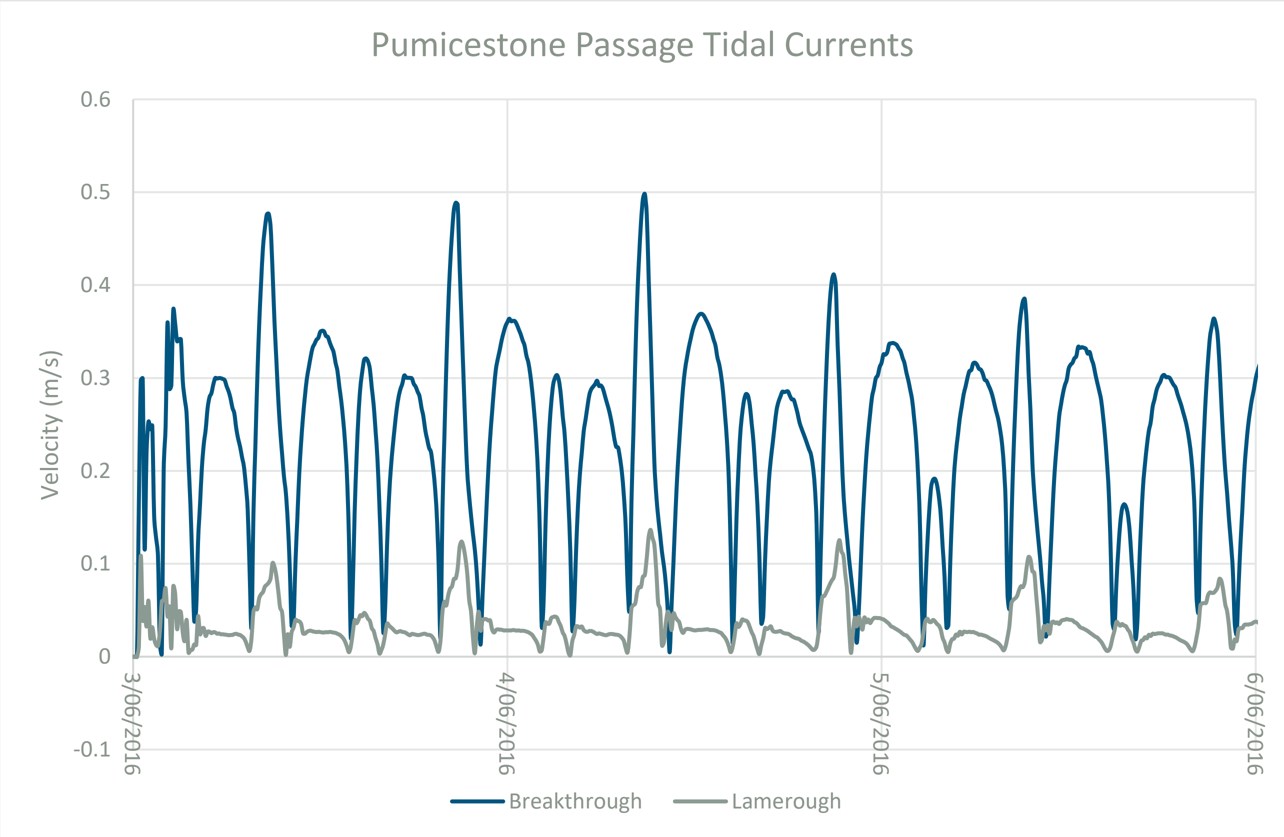


Figure 3.9 Distribution of tidal currents for a location adjacent to the recent breakthrough and at the mouth of Lamerough canal.

4 Offshore Dredging

Dredging activity that occurs offshore of Bribie Island is primarily concentrated into two zones and is undertaken for two separate purposes. Navigational dredging occurs infrequently within the Northwest Channel directly east of Bribie Island to maintain a minimum shipping channel depth of 14m. Extractive dredging also occurs in the Spitfire Sand Extraction zone in Spitfire Channel, 28km south-southeast of the recent breakthrough area (Figure 4.1).

The section of the Northwest Channel that is within 2km of the shoreline of the northern section of Bribie Island has a channel depth that is generally between 15 and 19m below lowest astronomical tide (LAT). As identified in section 3.2, sand migrating northwest from the tip of Moreton Island towards the channel has naturally accumulated to form the Hamilton and Northwest sand patches. A relatively small amount of sand that has been forced over the sand banks by east and southeast swell conditions falls into the eastern part of the channel, and this is periodically removed by the Port of Brisbane to ensure it meets the minimum draft requirement of 14m below LAT. The volume of sand that is removed (Table 4.1) from the Northwest Channel is recorded in sections delineated by the channel markers (Figure 4.1).

Table 4.1 Dredging volumes for the Northwest Channel and Spitfire Sand Extraction area

Dredge Area	Total Dredge Volume (m^3) 2016-2021	Annual Average Dredge Volume (m^3/year)
FWY – NW2	5,000	1,000
NW2 – NW4	83,000	15,155
NW4 – NW6	37,000	6,750
NW6 – NW8	73,000	13,300

Once in the channel, further migration of the sand westwards towards Bribie Island is unlikely to occur due to the depth of water in the channel. Currents from the south migrate sand north in the channel to meet with the Pumicestone Passage delta, where it can migrate onshore to Kings Beach or into the northern Pumicestone Passage entrance under wave and current action (Figure 3.1). Consequently, sand captured within the Northwest Channel does not directly contribute to sand supply for the eastern shoreline of Bribie Island and any extraction of this sand is not a contributing factor to long-term erosion of Bribie Island.

Dredging works within the Northwest Channel occur approximately 1.8km offshore of the nearest section of northern Bribie Island. There is no evidence that sand extracted from this area is creating a sand 'sink' that would require erosion of the eastern shoreline of Bribie Island to 'refill' because:

- the slope of the seabed in the 500m offshore of Bribie Island has stable profile of 1.5 vertical metres for every 100 horizontal metres
- between 500m and 1500m offshore this profile flattens to become 0.9 vertical metres for every 100 horizontal metres
- the seabed profile is flat between 1500m offshore and 1700m offshore as it approaches the Northwest Channel

- the presence of significant exposed patches of indurated sands (coffee rock) between the eastern shoreline of Bribie Island and the nearest dredge area indicates that there is little sand transported in this area

The very flat nearshore bed slopes and exposed rock patches indicate very low to negligible rates of cross-shore sediment transport between the eastern shoreline of Bribie Island and the Northwest Channel, while regional coastal processes indicate that sand transport is to the south in this area. There is therefore no evidence of sustained eastward sediment transport to suggest that sand removed from the channel is supplied by Bribie Island.

The Spitfire Sand Extraction area has been used to supply up to one million m^3 of sand per year since 2006 for usage on land. The Spitfire Sand Extraction area is located approximately 28km to the south-southeast of the recent breakthrough site, at a typical depth of 10 to 15m. A previous review of the Moreton Bay sand extraction activities (BMT 2021) examined progressive bathymetric survey of the Spitfire Sand Extraction zone and noted that:

> *"The most accessible, shallower areas of the permit area clearly showed a pattern of extraction over the past 10 years (hereafter referred to as 'pockmarks'). These pockmarked areas of the seabed … demonstrate the operation of the stationary suction hopper dredges that have been used in the area since 2006."*

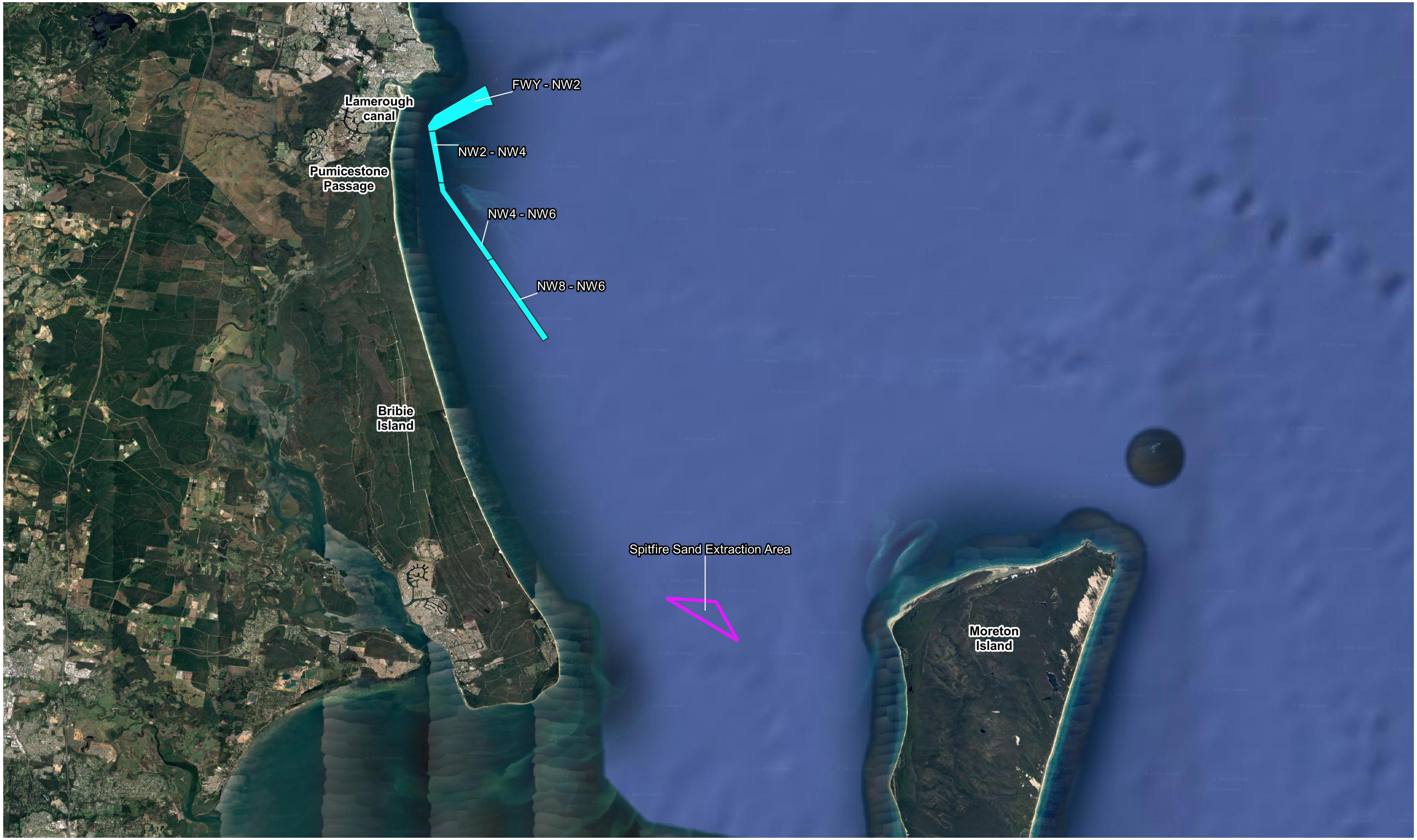
> *"While the MBSES (Moreton Bay sand extraction study) establishes that long term infilling and replenishment of the northern delta from oceanic sources would occur over time, the bathymetry surveys demonstrate little to no local infill or replenishment of sand in the permit area from natural processes. This is expected to be due to the slow annual replenishment rate naturally (with a large proportion of this sand replenishing the northern and eastern part of the delta at Yule Banks and North Banks)"*

The most recent bathymetric survey of the Spitfire Sand Extraction Area has been provided in Figure 4.2 and demonstrates several important features highlighted by the BMT 2021 study:

- Sand extraction "pockmarks" can be seen across the entire extraction area, particularly in the northwest of the area, indicating the refilling of extracted sand is not occurring, or is occurring very slowly.
- Sand migration into the area appears to come from the southeast, as can be seen with the sand forms in the bathymetric profiles.
- Sand migration in the area appears to be limited to the eastern half of the extraction area, with sand waves not visible in the western half of the extraction area.
- There exists a shallower ridge between the Spitfire sand extraction area and Bribie Island (Figure 1.2) that would prevent the formation of gradient that would result in sand from Bribie Island migrating towards the Spitfire sand extraction area to fill in excavation.

Given that sand extraction in the Spitfire sand extraction area has only been occurring since 2006, a contribution to shoreline erosion at Bribie Island before this time could not have occurred. Furthermore, it does not appear that there is infilling of the extraction area on the western frontage (i.e. closest to Bribie Island), nor is there a physical mechanism that would support the theory that extraction is creating a gradient from Bribie Island to the extraction area, given the presence of the shallower ridge between Bribie Island and the extraction area.

While there may be some suggestion that extracted materials from the Spitfire sand extraction area may be removing material that would otherwise migrate to Bribie Island, the BMT study (2021) indicates that there is no evidence to support this. Furthermore, the regional coastal processes indicate that sand transport along the southern part of Bribie Island is in a southerly direction, with accretion at Woorim supporting this. As a result, there does not appear to be a physical natural mechanism for sand to move from the southern part of Bribie Island to the northern part of the Island.



Legend

- Spitfire Sand Extraction Zone
- Shipping Channel

Title:

Sand Extraction Locations

Figure: 4-1

Rev: A

N 0 4 8 km

BMT www.bmt.org

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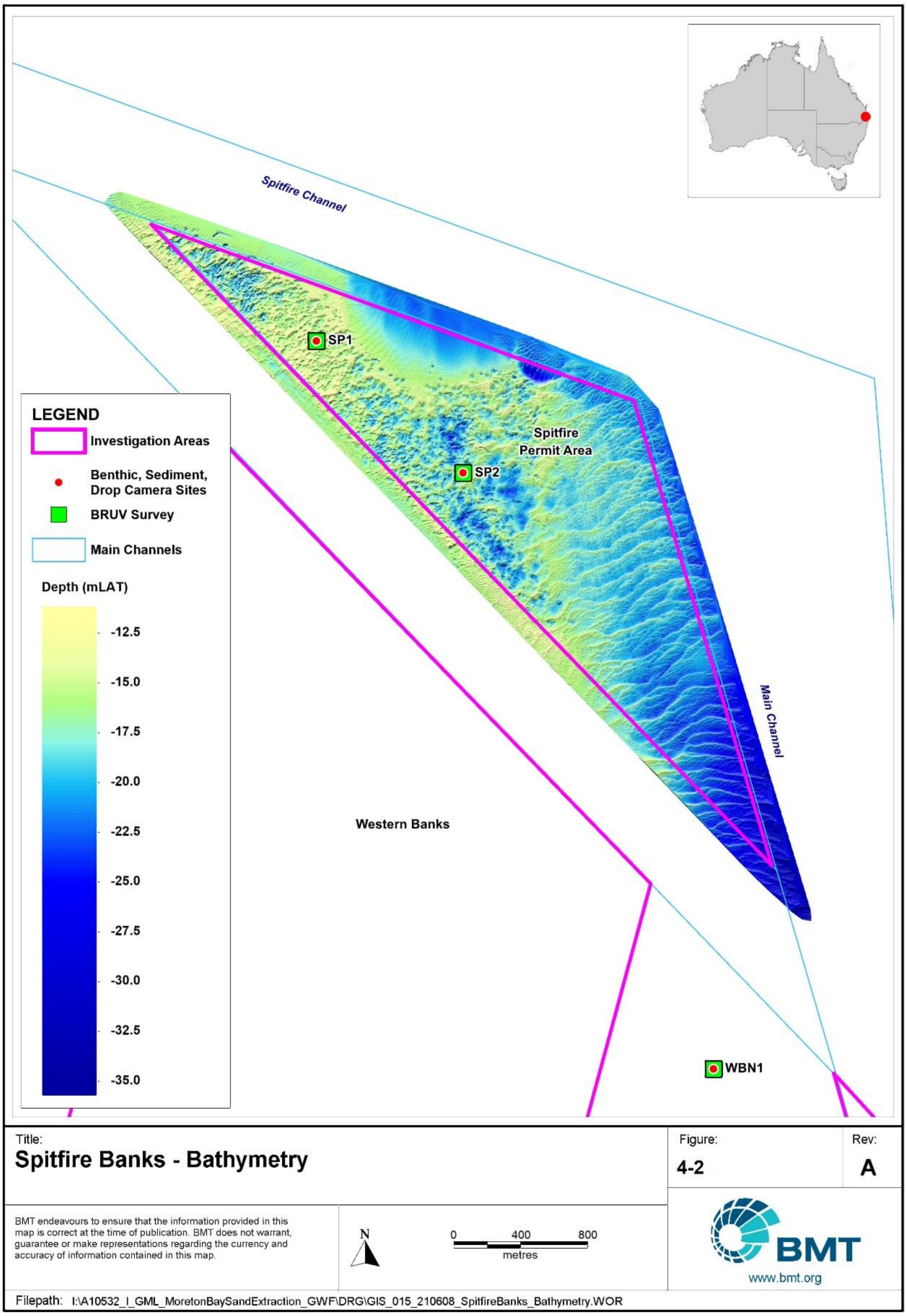


Figure 4.2 Bathymetric survey of the Spitfire sand extraction zone

5 Ship Wake and Turbulence

5.1 Ship Wake

The Port of Brisbane shipping channel (North West Channel) runs parallel with and approximately 1.5km to the east of the eastern shoreline of the northern part of Bribie Island. The shipping channel provides access for vessels from offshore to the Port of Brisbane. Ship tracking data (MarineTraffic, 2022) indicates that between 5 and 10 large (greater than 200m) ships arrive and depart the Port of Brisbane every day, conservatively accounting for up to 20 trips past Bribie Island per day.

A recent study (Metters, D. et. al, 2021) reviewed the generation of waves from container ships offshore of Bribie Island. The study utilised the Caloundra wave buoy to identify ship wake from a passing container ship with a length of 228m, travelling at 12.7 knots. The waves generated from the ship wake are challenging to distinguish from background wave conditions, however, on exceptionally still days with very little wind and wave activity ship wake can be detected. The results indicate that ship wake can reach a wave height of approximately 0.2-0.3m with a wave period of approximately 5 seconds.

Wave records from the Caloundra wave buoy have been extracted for the period 01/01/2021 to 31/03/2022 and the wave energy calculated for each 30 min recording period. An approximation of the wave power has been calculated using the deep-water wave power approximation formula shown in Equation 5.1 and converted to wave energy in Equation 5.2. A synthetic record of ship wake waves for the same period has been created based on a total number of 20 passages per day of large ships, which is at the upper end of the number of vessels per day observed in the records. Figure 5.1 shows the significant wave height and wave energy for each 30-minute window within the extracted date range for both natural waves and ship wake. Figure 5.2 shows the contribution to total wave energy for natural waves and ship wake across this time period. The results show that the contribution of wave energy generated from ship wake detected at the Caloundra wave buoy is insignificant (less than 0.1% of total energy) when compared with background natural wave conditions.

$$P = \frac{\rho g 2}{64\pi} H_s^2 T_p \approx 0.5 H_s^2 T_p \left(\frac{kW}{m}\right)$$

Equation 5.1

$$E = Pt\ (kWh)$$

Equation 5.2

Where, P = wave power per m crest length, ρ = density of water, g = acceleration due to gravity, Hs = significant wave height, Tp = peak wave period, T = time in hours.

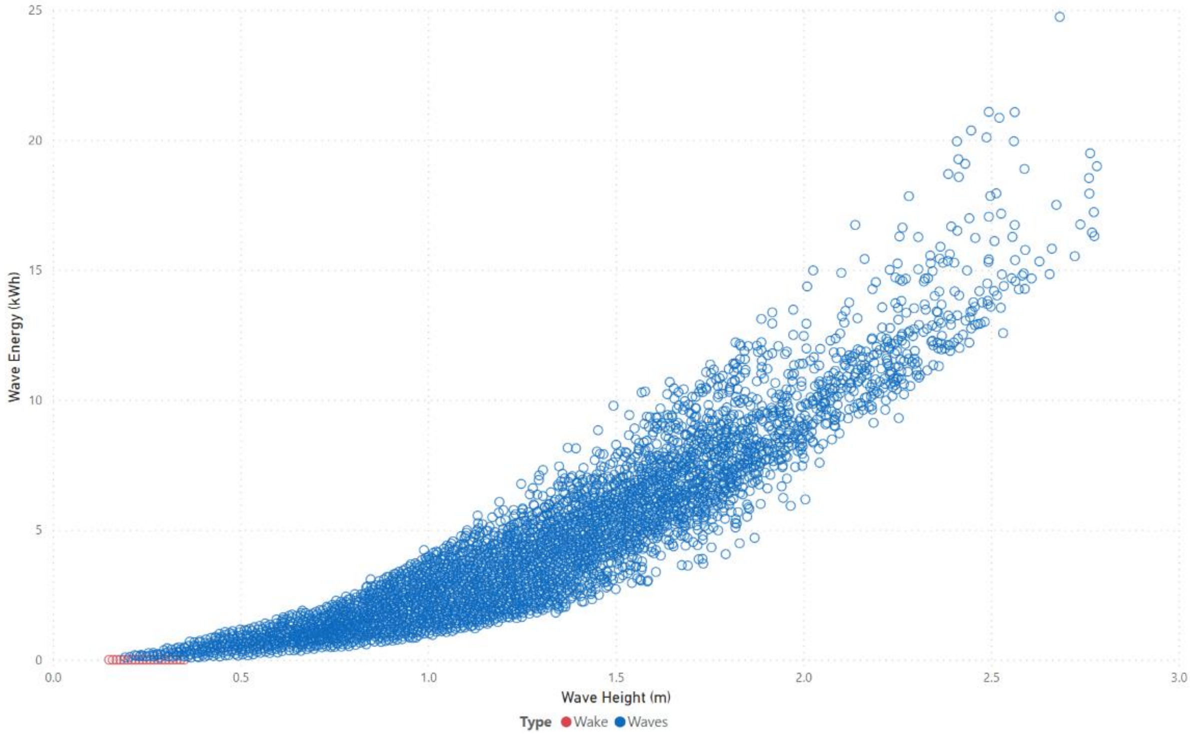


Figure 5.1 Wave height and energy for waves and ship wake, 1/1/2021 to 31/03/2022

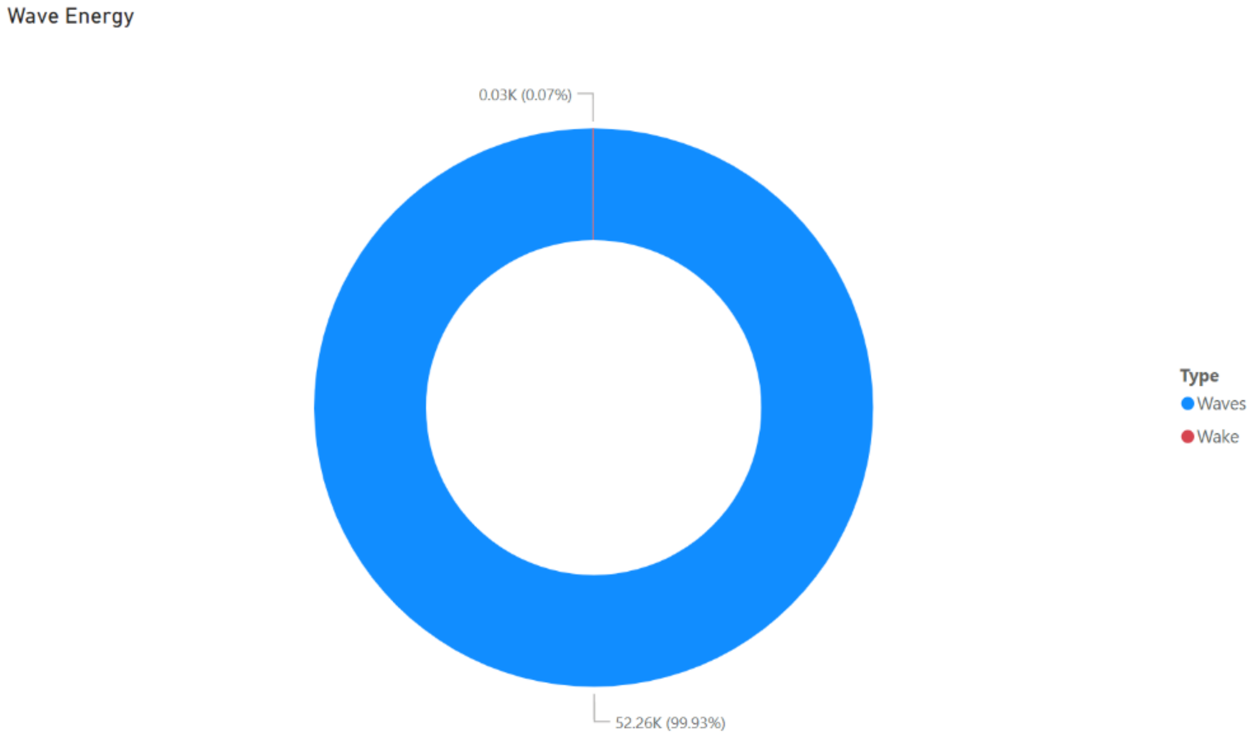


Figure 5.2 Contribution of wave energy from natural waves and ship wake, 1/1/2021 to 31/03/2022

5.2 Ship Propeller Wash Turbulence

A review of literature relating to scour from boat propellers indicates that turbulence from boat propellers is dissipated quickly, with scour from boat propellers detectable only in shallow water within a short range of the propeller (Cui et. al. 2019). Maximum scour occurs when the seabed is within a small multiple distance of the propeller diameter, which for a typical 1.65m diameter propeller would be within a depth less than 5m below the propeller. Bed scour from propellers tends to occur in boat harbours where the propeller is held in a stationary location for a period of time during manoeuvring and not when it is in underway in deep water. In the absence of extremely high boat traffic in stationary positions, it is not considered to be plausible that propeller turbulence is contributing to erosion at Bribie Island.

5.3 Boat Wash on Estuarine Shorelines

The western shoreline of Bribie Island is protected from open ocean waves, with tidal currents and small amplitude waves from wind and boat traffic the main sources of erosive pressure on the shoreline. In the absence of strong wave conditions, estuary banks typically have steeper beach slopes than an open coast equivalent with the same sediment characteristics (Hughes & Cowell,1987). Within Pumicestone Passage, natural wave conditions only occur during strong south or westerly wind conditions, although the small fetch will limit wave size. As a result, the western shoreline of Bribie Island has a naturally steeper and reflective beach face, resulting in limited energy loss from waves incident on the shoreline before impact. Within Pumicestone Passage, wake from boats break on the western shoreline of Bribie Island creating turbulence that can suspend sand that is then migrated with tidal currents, although the magnitude of this has not been studied.

While the contribution of boat wash to erosion has not been specifically studied for Pumicestone Passage, a recent study (Bilkovic et. al., 2019) looked at this issue on the sandy shorelines of Chesapeake Bay in eastern USA. This study assessed the erosion of shorelines from protected (fetch-limited) shorelines where wind-driven wave energy was expected to be low, but boat traffic was moderate to high. In these circumstances, the study found that shoreline recession rates were in the order of 0.3m/year. Baldwin (2008) investigated the boat wake contribution to riverbank erosion in the Murray-Darling River system and noted that the contribution of total energy from boat wake is relatively small compared with the total energy of the river system, while Fonseca and Malhotra (2012) discovered that vessel speeds greater than 7 knots were forecast to generate wakes and sediment movement zones greatly exceeding that arising from natural wind events in a study in North Carolina.

While the reviewed literature appeared to indicate that the degree of erosion was somewhat site dependent, it did indicate waves generated by boat wash can contribute to bank erosion. While the total energy of the boat wash may be small compared with total flows, the ability of the waves to create turbulence and lift sediment into suspension is a substantially different physical process compared to the smooth flow of tidal and riverine currents. In combination, boat wash generated waves and tidal currents can suspend sediments at the shoreline and transport them away from the suspension site, leading to bank erosion, however, the contribution would need to be investigated further.

6 Evaluation of Postulated Causes

Postulated Cause 1a		Natural Coastal Processes (Channel Migration)	
Postulated Erosion Mechanism Evolution of the sand shoals within Pumicestone Passage have forced the migration and reorientation of the channel towards and against the western edge of Bribie Island, leading to bank erosion.			
Commencement of Activity	Pre-1940's	**Correlated with erosion?**	Yes
Physical Process Sand migrating north along northern Bribie Island and south along Kings Beach enters the northernmost mouth of Pumicestone Passage. Once there it either settles into a sand shoal or is washed back out during flood/storm events. The sand shoal in the north of the Passage has stabilised over time and attached to the tip of Bribie Island, with vegetation evident in an area that was once a migratory sand shoal. The central sand shoal has also stabilised over time. The stabilised sand shoals have pushed the primary channel along the western bank at the north of the Passage before it cuts back to the east to re-join its historical alignment travelling south. Consequently, the channel now travels from west to east and is forced through a sharp turn close to the recent breakthrough location, eroding the western bank of the Island on the incoming (flood) tide. Sand is eroded from the island is then deposited into the flood-tide delta further south of the recent breakthrough location.		  **Causal Link?**	Yes
Assessment of Magnitude The realignment of the main channel in northern Pumicestone Passage is expected to have a persistent erosion pattern on the western shoreline of Bribie Island, consistent with the magnitude of erosion experienced.		**Magnitude of Contribution**	Major

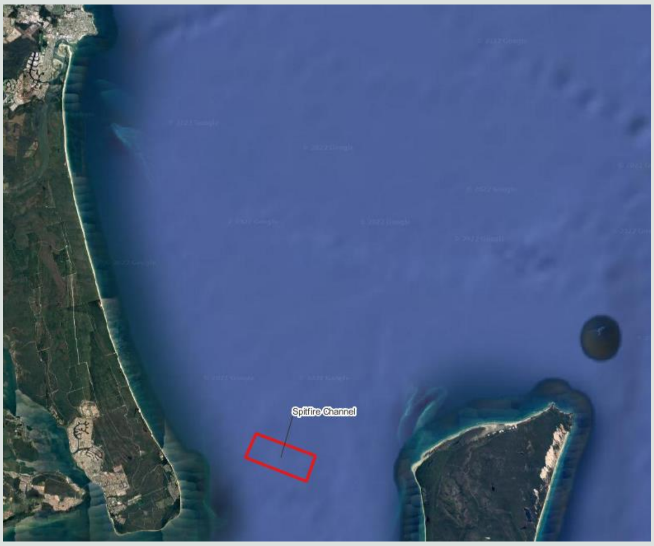
Postulated Cause 1b		Natural Coastal Processes (Wave erosion)	
Postulated Erosion Mechanism Large waves generated primarily by tropical lows and cyclones in the Coral Sea erode the beach that is not completely balanced by accretion between events, resulting in a reduced beach width over time.			
Commencement of Activity	Pre-1940's	**Correlated with erosion?**	Yes
Physical Process Large wave events periodically impact the eastern beaches of Bribie Island, causing erosion of the shoreline. Eroded sand from these events is typically transported south towards Woorim and north towards the entrance of Pumicestone Passage, where it accumulates within the sand bars in the channel. Longshore sand transport at northern Bribie Island is split with the northern 1km travelling net north into Pumicestone Passage and shoreline south of this travelling net south towards Woorim. There is limited evidence of cross shore sand transport, as evidenced by the presence of a series of indurated sand (coffee rock) reefs. Consequently, there is insufficient nearshore supply to replenish the beach, resulting in a disequilibrium of sand transport, where the volume eroded is not fully restored before the next storm occurs, resulting in long term shoreline recession. Periods of increased erosion correlate with periods of increased SEQ tropical cyclone activity, such as in the early 1970s.		 Source: Blueys Photography **Causal Link?**	Yes
Assessment of Magnitude The short-term (storm) erosion along northern Bribie Island can be in the range of tens of metres, with sand transported primarily south away from the site. There is limited sand resupply to the site between events which results in long term sand deficit. This sand deficit forces year-on-year recession in the order of metres to tens of metres consistent with observed records.		**Magnitude of Contribution**	Major

Postulated Cause 2	Dredging of Spitfire Channel

Postulated Erosion Mechanism

Dredging of Spitfire Channel creates a depression in the sea floor, with sand from Bribie Island's beaches "falling" into the depression to return it to its pre-dredge condition.

Extracted materials from the Spitfire sand extraction area may be capturing north-bound material that would otherwise migrate to northern Bribie Island.

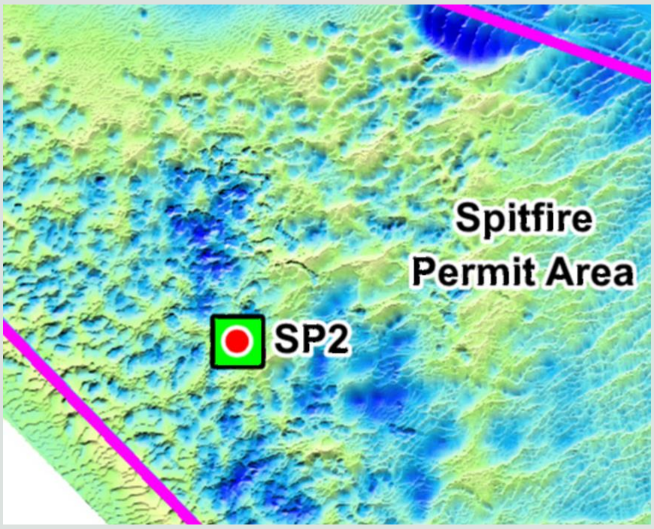


Commencement of Activity	2006	**Correlated with erosion?**	No

Physical Process

A review of bathymetry across the extraction area indicates that dredge holes are not being filled in by natural processes. Instead, the Spitfire Sand Extraction area remains visibly pockmarked by 20 years of sand extraction. Extraction from this area cannot create a sediment transport gradient that results in sand migrating from Bribie Island due to the presence of a shallow ridge between the extraction area and Bribie Island.

While there may be some suggestion that extracted materials from the Spitfire sand extraction area may be capturing material that would otherwise migrate to Bribie Island, the regional coastal process indicates that sand transport along the southern part of Bribie Island is in a southerly direction, with accretion at Woorim supporting this. As a result, any migration of sand onto the southern area of Bribie Island lacks a physical natural mechanism for sand to move from the southern part of Bribie Island to the northern part of the Island



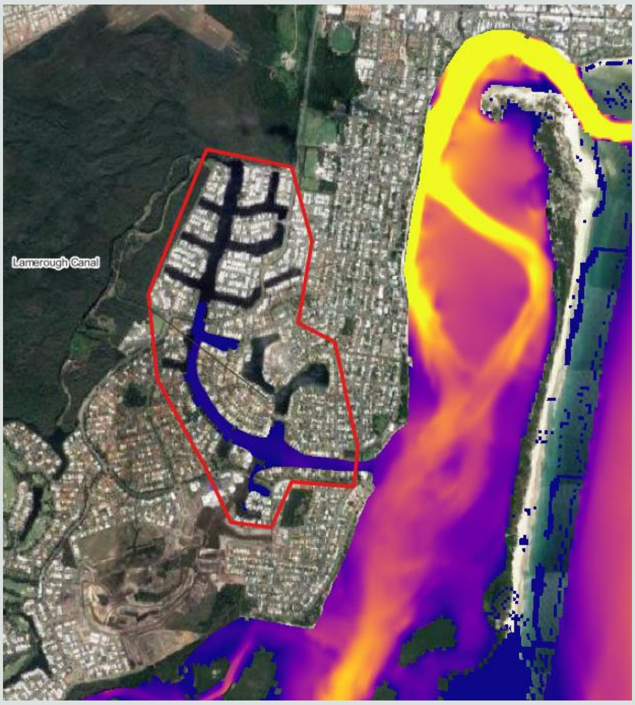
Causal Link? No

Assessment of Magnitude	**Magnitude of Contribution**	None
None		

Postulated Cause 3		Dredging of North West Channel	
Postulated Erosion Mechanism Dredging of the Northwest channel creates a sand sink, with sand from the eastern shoreline of Bribie Island eroding to fill in the dredged portions of the channel.			
Commencement of Activity	2000	**Correlated with erosion?**	No
Physical Process A review of the bathymetric expression between the eastern shoreline of Bribie Island and the nearest dredged region of the Northwest channel indicates that there is limited cross shore sand transport. The nearshore region (within 500m of the coastline) has a stable profile of 1.5 vertical meters for every 100m horizontally. Between 500m and 1500m offshore, this profile flattens to 0.9 vertical meters for every 100m and flattens completely between 1500m and 1700m offshore, where the nearest dredging occurs. Furthermore, there is a continuous outcropping of indurated sand between the eastern shoreline of Bribie Island and the Northwest channel that indicates that there is limited cross shore transport. As a result, there is no evidence that dredging of the Northwest channel is creating erosion pressure on the eastern shoreline of Bribie Island.		**Causal Link?**	No
Assessment of Magnitude None		**Magnitude of Contribution**	None

Postulated Cause 4a		Ship Wake and Propeller Wash	
Postulated Erosion Mechanism Waves and propeller wash from large ships in the shipping channel (North West Channel) create erosion on the eastern shoreline of Bribie Island, resulting in long term recession.		 	
Commencement of Activity	Pre-1940	**Correlated with erosion?**	Yes
Physical Process Large container ships create turbulent thrust from their propellers and a wake wave as they travel through the water. A recent study (Metters, Waldron and Ryan, 2021) reviewed the magnitude of these waves at the Caloundra Site, with ship waves of up to 0.3m detected offshore. These waves are only detectable during very calm days, where there is minimal background wave activity. The average ambient wave height at the Caloundra buoy is 0.92m, while storm events, such as TC Seth that triggered the recent ultimate breakthrough, have peak waves in excess of 5m. As such, wave activity from boat traffic is scarcely noticeable, and are an insignificant part of the total wave energy arriving at these shores. Turbulence from boat propellers is dissipated quickly, with scour from boat propellors detectable only in shallow water within a short range of the propeller (Cui et. al. 2019). As such, it is not plausible that propeller turbulence is contributing to erosion at Bribie Island.		 **Causal Link?**	Yes
Assessment of Magnitude While ship wakes do reach the shoreline of Bribie Island, the magnitude of energy when compared with the background wave conditions is minuscule. Ship propeller turbulence does not influence the Bribie Island shoreline.		**Magnitude of Contribution**	Insignificant

Postulated Cause 4b		Estuarine boat wash	
Postulated Erosion Mechanism Waves created from boat wake within Pumicestone Passage erodes the estuary banks (including the western shoreline of the Island), leading to the eventual breakthrough of the Island.			
Commencement of Activity	1950s	**Correlated with erosion?**	Partial
Physical Process Several studies have looked at boat wash contribution to the erosion of estuary banks. There is some agreement that boat wash creates erosion of the bank, in combination with riverine or tidal flows transporting eroded sediments away from the target site.			
		Causal Link?	Yes
Assessment of Magnitude The literature has contrasting opinions of the contribution of boat wash to estuary bank erosion, that appears to be highly site dependent. Moreover, there does not appear to be an acceleration of erosion trends at Bribie Island as boat traffic increased post development of Golden Beach and Pelican waters. A detailed study of boating traffic in the waterway would be required to confirm the magnitude of this erosion mechanism at this location, however it is not expected to be significant compared to the contribution of other erosion mechanisms.		**Magnitude of Contribution**	Insignificant

Postulated Cause 5	Development of Lamerough Canal
Postulated Erosion Mechanism Increased currents from Lamerough canal produce a 'jet' of water that pushes the main channel to preferentially flow through the eastern channel, adjacent to Bribie Island on the ebb tide.	
Commencement of Activity 1980's	**Correlated with erosion?** Partial
Physical Process A review of a calibrated coastal process model for Pumicestone Passage indicates that ebb tide currents from Lamerough canal are below 0.05m/s, while main channel currents are at 0.4m/s. The model does not indicate that the canal currents provide any noticeable hydraulic control to the main channel. Furthermore, the presence of a flood tide shoal south of the recent breakthrough location indicates that erosion on the Pumicestone Passage shoreline of Bribie Island is driven by flood tides, which is supported by model results. The image (right) shows the velocity of water in Pumicestone Passage during a peak ebb tide. Of note, the channel deflects further north of Lamerough canal due to sand shoals, but both the east and west channel have similar flow velocities. The east channel is deflected away from the recent breakthrough area by the presence of the flood-tide shoal.	 **Causal Link?** No
Assessment of Magnitude There is no evidence to support that flows in Lamerough Canal contribute to the erosion of Bribie Island.	**Magnitude of Contribution** None

7 Conclusion

A review of coastal and marine processes surrounding Bribie Island has been undertaken to better understand the erosion trends occurring on the northern end of the Island in recent years, which culminated in the breakthrough of the island in January 2022. A range of postulated causes for the erosion have been thoroughly investigated using available data, models and research literature. The findings from the investigation are that the major contributions to erosion of northern Bribie Island are from:

- Growth and migration of the sand shoals within northern Pumicestone Passage changing the orientation of the channels from running north-south to east-west, forcing flood tide flows to directly impact on the western shoreline of Bribie Island.
- Erosion of the open coast shoreline by waves, particularly those from tropical low and tropical cyclone conditions.

The complex interaction of waves and tidal currents migrate sand north into the Pumicestone Passage entrance and south along Bribie Island, with very little sand returned, resulting in a continuous sand deficit and shoreline recession of the eastern beach. The investigations also noted that there were other causes that showed a plausible contribution to erosion of Bribie Island, but that the contribution was insignificant in magnitude:

- Waves generated by large vessels on the exposed coast were shown to provide a miniscule percentage of the total wave power along the exposed eastern shoreline of the Island.
- Scour from estuarine boat movements showed an erosion mechanism that could work in tandem with the natural tidal flows on the western shoreline of Bribie Island, however, a review of research articles suggests this contribution is likely to be very low, although site specific investigations could help quantify this.

Finally, the investigation found that the following postulated causes do not contribute to erosion of northern Bribie Island:

- Dredged areas at the Spitfire sand extraction zone do not appear to be refilling after previous operations; when combined with its distance from the northern end of Bribie Island and the presence of shallow ridge between the area and Bribie Island preclude this as a plausible physical process.
- Dredging in the Northwest Channel does not appear to contribute to erosion of Bribie Island. The very flat nearshore bed slopes and exposed rock patches indicate very low to negligible rates of cross-shore sediment transport between the eastern shoreline of Bribie Island and the dredged area within the Northwest Channel.
- The development of Lamerough canal does not significantly influence the flow of currents in Pumicestone Passage. Ebb tide currents exiting the canal are shown to be below 0.05m/s, approximately 10% of the peak flood currents in the main channel. Furthermore, the erosion to the western shoreline of Bribie Island has been shown to be caused by flood tide flows and not ebb tide flows, and as such, there is no causal link between the outflow from Lamerough canal and the erosion.

8 Further Investigations

This review has summarised the existing understanding of coastal processes around northern Bribie Island and the potential contribution to erosion from several postulated causes using existing datasets. Nevertheless, there remains several opportunities where further detailed investigation would yield greater insight into the relevant coastal processes. Given the recent breakthrough of Bribie Island, the most significant work is the development of a detailed understanding of how the new arrangement of Bribie Island has changed the local coastal processes, however a study of boat wake erosion and the contribution to tidal flows from Lamerough canal are also suggested in the erosion hotspot areas. Each of the discussed further investigations have been outlined in Table 8.1 below.

Table 8.1 Summary of proposed further investigations

Investigation	Method	Benefit
Coastal monitoring	Undertake periodic survey of Bribie Island. Update the bathymetric LiDAR east of Bribie Island and continue monitoring waves and currents in and around Bribie Island.	Continued monitoring of the evolution of Bribie Island and the forces driving this change will be useful for future decision making. A high-quality bathymetric LiDAR survey of the area east of Bribie Island would be useful to compare with the previous dataset to understand how the bathymetry has changed over time. All of these datasets will be essential for development of any coastal process models (below) in future.
Coastal process model of northern Bribie Island	Development of a calibrated numerical wave and coastal process model of Bribie Island that can simulate pre- and post-breakthrough conditions.	An updated understanding of the coastal process around Bribie Island and within Pumicestone Passage. This could be used to: • Assess the stability of the new entrance condition. • Predict evolution of the new entrance and the northern entrance of Bribie Island over the long term. • Update storm tide parameters along Golden Beach. • Update tailwater conditions for flood models into Pumicestone Passage. • Assess water quality implications of reduced tidal flow in northern Pumicestone Passage.
Boat wake erosion study	Field study of the magnitude of erosion caused by boat wake on sandy shoreline.	This study would be used to better quantify the magnitude of estuary bank erosion that may result from boat wake. This could be used to better guide management of these vessels in erosion hotspots.

Investigation	Method	Benefit
Coastal monitoring	Undertake periodic survey of Bribie Island. Update the bathymetric LiDAR east of Bribie Island and continue monitoring waves and currents in and around Bribie Island.	Continued monitoring of the evolution of Bribie Island and the forces driving this change will be useful for future decision making. A high-quality bathymetric LiDAR survey of the area east of Bribie Island would be useful to compare with the previous dataset to understand how the bathymetry has changed over time. All of these datasets will be essential for development of any coastal process models (below) in future.
Lamerough canal tidal flow study	Use the existing models to include/exclude the Lamerough canal to quantify difference in tidal flow patterns.	The study would quantify the contribution of the Lamerough canal to the tidal flows in Pumicestone Passage. However, given the flood currents are driving erosion on the western shoreline of Bribie Island, this study is unlikely to provide any useful information relating to erosion of Bribie Island.

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Annex A Historical Aerial Photographs

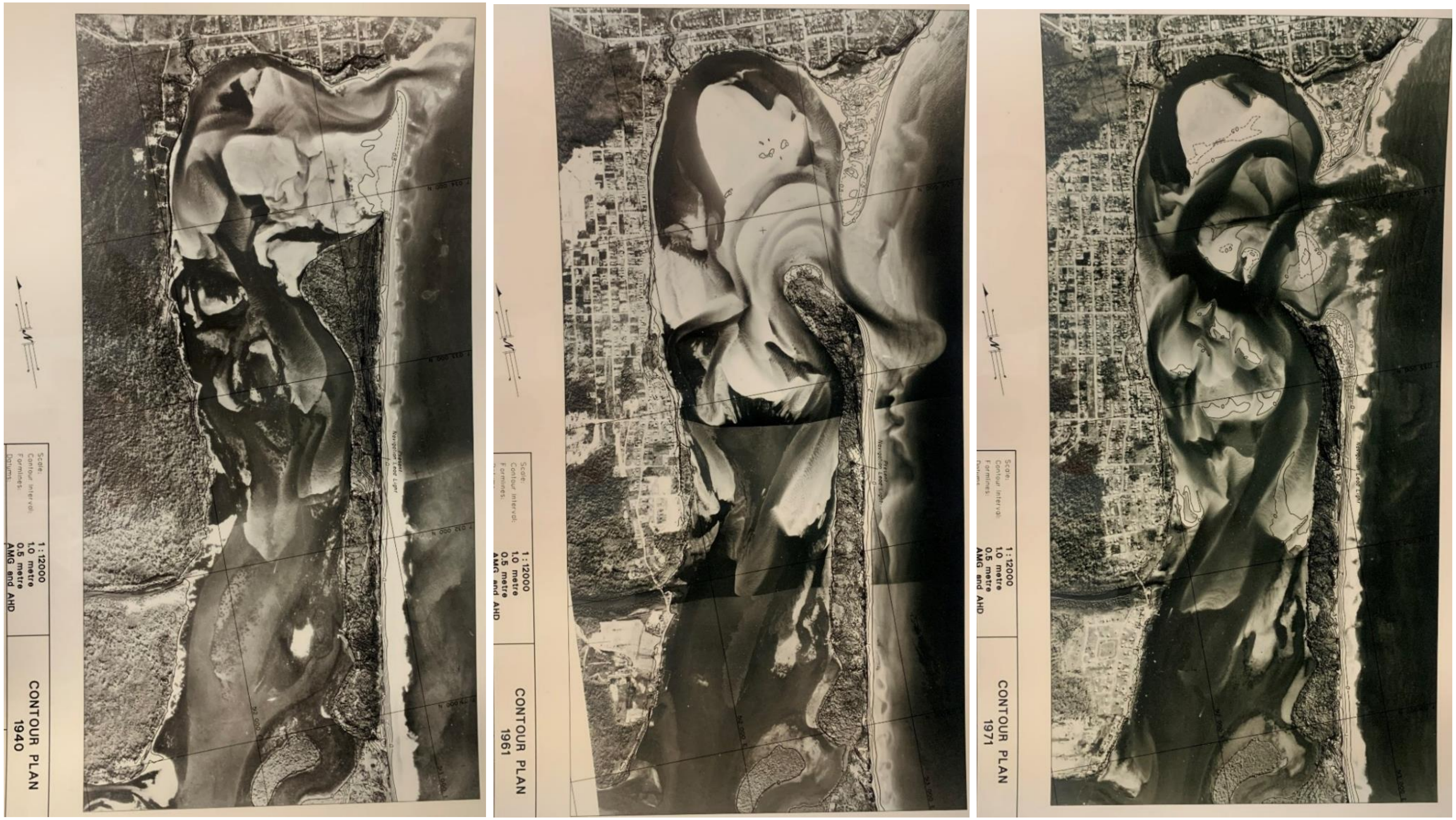


Figure A.1 Aerial images from 1940 (left, Source: BPA), 1961 (centre, Source: BPA) and 1971 (right, Source: BPA)

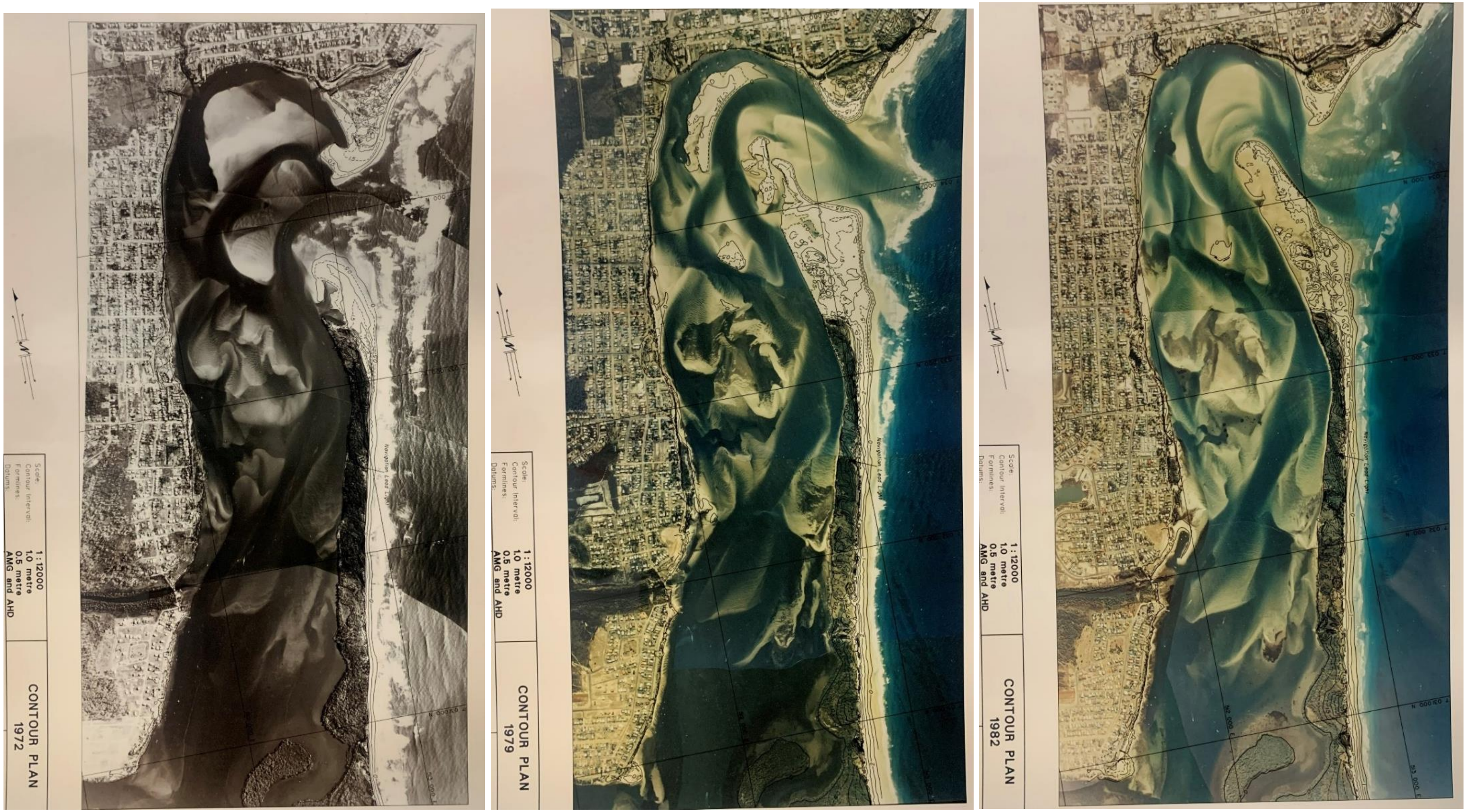


Figure A.2 Aerial images from 1972 (left, Source: BPA), 1979 (centre, Source: BPA) and 1982 (right, Source: BPA)

Figure A.3 Aerial images from 1992 (left, Source: BPA), 1997 (centre, Source: QImagery) and 2003 (right, Source: QImagery)

Figure A.4 Aerial images from 2010 (left, Source: Nearmap), 2015 (centre, Source: Nearmap) and 2021 (right, Source: Nearmap)

Annex B Geology of Pumicestone Passage

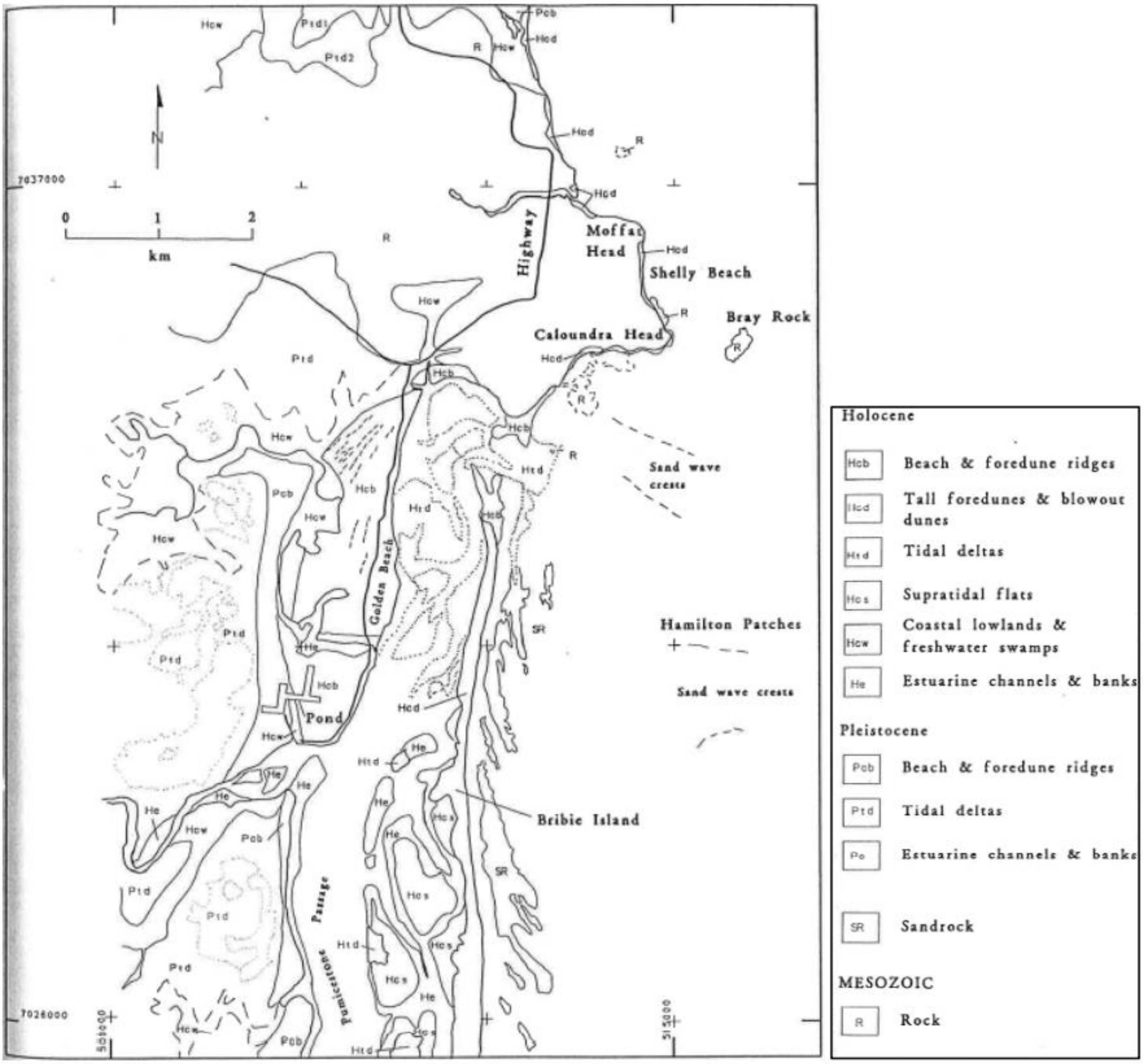
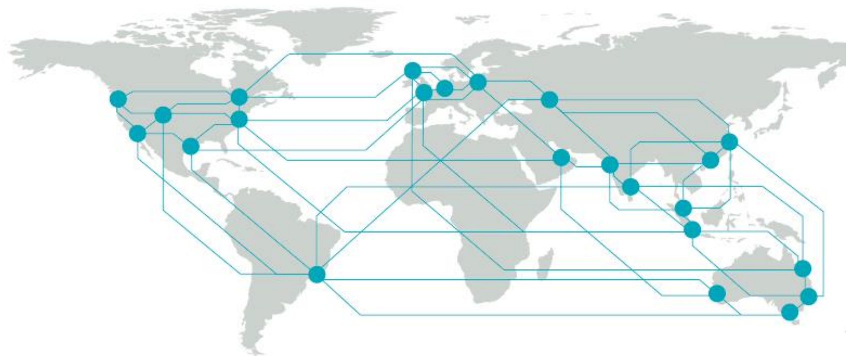


Figure B.1 Geology of Pumicestone Passage (Jones, 1992)



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