Chris Sharples B.Sc. (Hons), Ph.D.
Consultant Geoscientist
Coastal Geomorphology, Geodiversity and Landform Management

ABN: 68 034 834 434

Monitoring the physical effects of boat wakes on shorelines in the Derwent River Estuary

Report to:

Derwent Estuary Program

By:

Chris Sharples

April 2022

GPO Box 1941, Hobart, Tasmania, 7001, Australia
mobile: 0408 396 663
email: chris@sharples.com.au

Cover photo: Aerial view showing boat wake configuration produced by the Derwent catamaran ferry emerging from Kangaroo Bay (RHS) enroute to Brooke St. Pier at Sullivans Cove (LHS). Photo by Chris Sharples (24th November 2021).

Contents

SUMMARY

This report describes a project to assess the usefulness and practicality of simple photographic techniques for monitoring and detecting any physical impacts of boat wake waves on shorelines in the Derwent River estuary (southern Tasmania). Two methods have been investigated and trialled, namely ground-based photo point monitoring (at Kangaroo Bay and Montrose) and the analysis of a time series of air photos (at Montrose).

At Kangaroo Bay, 13 photo viewpoints on the shoreline were defined at potentially erodible sites, and initial photos were taken shortly before the introduction of a new passenger catamaran ferry service to and from the bay in August 2021. Although the Kangaroo Bay shoreline dominantly comprises resilient hard bedrock and artificial shores, numerous loose intertidal cobble accumulations and backshore soil margins (exposed just above the mean High-Water Mark over the bedrock) are readily erodible and display evidence of previous storm wave erosion impacts. Monitoring photos were taken of defined views from each photo point at approximately two-week intervals for an initial trial period of three months.

Analysis of photos taken over the three-month trial (as described in Section 2.2.3) did not reveal any additional wave impact on exposed soil margins (with and without prior erosion scarping), and these are inferred to only erode in unusually large and infrequent storms when wind-generated storm waves reach well above the normal High-Water Mark. However, at least three wind-wave exposed photo point sites showed clear evidence of a significant movement of intertidal cobbles that was mainly occurred during a period of several weeks around late November when a number of windy weather events are inferred to have driven energetic wind-waves to the upper parts of the shoreline intertidal zone. In addition to this naturally driven change, one site close to the new ferry route exhibited a progressive removal of intertidal cobbles over the whole monitoring period beginning after the commencement of ferry operations. This site is relatively swell- and wind-sheltered, and the change does not clearly correlate (in timing) with the wind-wave activity at the three sites referred to above, thus is inferred likely to be a response to the introduced ferry wake waves. It is recommended that the photo monitoring program at Kangaroo Bay be continued at 3-monthly intervals and immediately following any large storm events, particularly with a view to continuing to monitor and better understand the photo point sites where cobble movements were detected in the initial trial program.

The Montrose shoreline comprises cohesive but erodible deposits of cobbles in a finer silty clay matrix, overlain by patchy loose cobble accumulations. This shore has been directly exposed to boat wakes from two “Mona Roma” catamaran ferries several times a day since the nearby Museum of Old and New Art (MONA) opened in 2011. Shoreline erosion and movement of loose cobble accumulations (beach ridges or berms) on the Montrose shoreline since that date has been anecdotally attributed to the Mona Roma ferry wakes, however no monitoring data is currently available that could confirm or test this assertion. To remedy this data gap, five photo point locations were selected and defined on the Montrose shoreline in October 2021, at locations directly exposed to the ferry wake waves and in view of shoreline erosion scarps and cobble accumulations potentially attributable to boat wakes. A first set of photographic views were taken from each photo point, and it is recommended that these be repeated in future at approximately 3-month intervals or after major storm wave events, with a view to eventually analysing the photographic data for any shoreline changes and any indications of the causes of such changes, as has been demonstrated by this project for the Kangaroo Bay photo point data. The possibility of a long-term collaboration on such a project with the adjacent Montrose High School may be a fruitful opportunity for both parties.

As a complementary source of photo information for the same shoreline, high-resolution ortho-rectified aerial photography covering the Montrose shore was obtained for three dates prior to the opening of MONA (2002, 2006, 2009) and three dates after the opening (2012, 2015, 2019). The cohesive cobbly intertidal substrate at Montrose is identifiable as a dark-toned surface in the aerial photography at all these dates. However, beginning on the 2012 photo and more widespread on the 2015 and 2019 air photos, is the appearance of large areas of light-coloured material which in parts show landwards movement in the intervals between photos. Comparison of the current shoreline with the air photos strongly suggests the light-coloured materials are the loose cobble berms still seen on the shore today, however the reason for their appearance only after 2011 is unclear. Two possibilities are that they were winnowed out of the erodible cobbly shore substrate by increased boat wake action (as inferred from anecdotal reports), or alternatively they may have been artificially placed to protect the shore from increased wave (boat wake)

attack. Recent enquiries with Glenorchy City Council, Montrose Bay High School and Montrose Bay Yacht Club have failed to confirm the latter explanation. It is recommended that historical information be sought more widely to ideally resolve the origin of these materials. In any case it is worth noting that an ongoing program of photo point monitor should record any further deliberate artificial modifications to this shore in future.

This trial has demonstrated that photo point monitoring can be quickly and simply set up without any *on-site* marking or indicators, and easily conducted (using the methods described in section 2.2.2). Using this data, significant results can be obtained from a very simple process of visual comparison of photos (this analysis method is described in Section 2.2.3). This method is thus ideally suited to being quickly deployed in advance of new developments (such as new ferry routes). Monitoring shores for as long as possible in advance of the introduction of new boat routes or other disturbances is important in order to confidently identify any shoreline changes resulting from the new disturbances.

It is recommended that in the case of new ferry routes or other potential disturbances being proposed which may generate changed wave impacts on shorelines in the Derwent estuary, the following steps be taken to set up photo point monitoring:

1. Determine proposed boat route and identify closest shorelines with highest (most direct, closest) exposure to boat wakes.
2. On the potentially exposed shores, identify the shoreline types more and less susceptible to wave erosion using existing geological mapping and field inspections (see discussion in Section 4.2 of this report).
3. Set-up and commence photo point monitoring at susceptible locations ASAP in advance of the commencement of the new identified disturbances.

A critical aspect of photo point monitoring is the need to securely archive all photos obtained, and metadata including photo point locations and photo dates. This issue is often neglected and can result in future loss and unavailability of data that might have been of critical importance in future assessments of changes sites.

1.0 INTRODUCTION

1.1 Preamble

Boat wake waves are a well-established cause of shoreline erosion in estuarine waters, and have previously been an issue of concern in places such as the Gordon River estuary, western Tasmania, (e.g., Bradbury et al. 1995). More recently, shoreline erosion in the Derwent Estuary at Montrose and East Risdon has been anecdotally attributed to wakes from the “Mona Roma” ferries travelling between Hobart and the Museum of Old and New Art (MONA) at Berriedale multiple times each day, however no quantitative evidence is known to have been collected to demonstrate this.

This report does not provide overview or technical details of boat wake hydrodynamics, beyond a few basic details of the observed boat wakes at the study sites, since these details are beyond the scope of this report but accessible from an extensive existing literature. or

1.2 The purpose of this report

The commencement of a new catamaran ferry service between Hobart and Kangaroo Bay (Bellerive) in August 2021 has provided an opportunity to undertake monitoring of susceptible shores for boat wake impacts, commencing prior to commencement of the ferry service. A key aim of the project was to investigate the usefulness of quick and efficient but low-cost methods such as photo point monitoring and the use of air photo times series to track soft shoreline changes over time.

Three key aims of the project described by this report are as follows:

1. Set up and conduct three months photo point monitoring of ferry boat wake effects on the Kangaroo Bay shoreline, starting prior to commencement of a regular ferry service. Document methods adopted, results and any lessons learned. Also set up and conduct initial photo point monitoring for Montrose Bay (soft shoreline types assumed to have already been modified by MONA ferry over some years.).
2. Conduct initial evaluation of shoreline change at the same Montrose site using an historic air photo time series beginning prior to known changes. Compare method as an alternative or supplement to photo point monitoring.
3. Identify Derwent estuary shore types likely to be more or less susceptible to changes (typically erosion) in response to boat wakes. Identify priority shoreline types for monitoring if and when exposed to boat wakes.

The results of these three investigations are documented in sections 2.0, 3.0 and 4.0 of this report. These are intended to provide a basis on which to evaluate the need for shoreline monitoring of any future ferry routes in the Derwent estuary, and to quickly set-up and conduct a suitable photo-monitoring project whenever the need becomes apparent.

Evidence collected from regularly repeated Photopoint and aerial photo monitoring can allow testing of the attribution of shoreline erosion to boat wakes in two basic ways, namely:

1. Assessing whether the spatial distribution of new erosion fits a boat wake model?

   and:

2. Assessing whether the temporal occurrence of erosion fits the timing of the introduction of boat wakes to a shoreline and characteristics such as their frequency.

In particular regard to point 2 above, the commencement of Photopoint monitoring should commence prior to the introduction of a new source of boat wakes so as to be able to compare shoreline conditions before and after the wake introduction.

1.3 *Glossary*

This is (obviously) not a comprehensive glossary, however its purpose is to provide quick definitions of a few key terms used frequently in this report. The definitions provided here are simple explanatory descriptions by Chris Sharples, are not derived from any internationally-recognised dictionary or authority, and may not necessarily cover all varieties of the features defined.

Beach ridges — Shore-parallel low ridges of loose sediment (mostly sand, pebbles, or cobbles) formed by wave action pushing the sediment up a beach.

Berm — Break of slope on a beach comprising a steeper seawards wave run-up slope to the limit of wave run-up, with a flatter beach surface behind and to landwards. May develop into a beach ridge

Intertidal — The intertidal zone of a shoreline is that zone between the High and Low tide levels which is frequently wetted by the sea. Only rare energetic storm waves run further inland than the intertidal zone, and it is these which cause most coastal erosion.

1.4 *Acknowledgements*

This project was initiated and guided by Inger Visby, Akira Weller-Wong and Ursula Taylor of the Derwent Estuary Program (Tasmania), who provided considerable information and encouragement for the project.

2.0 KANGAROO BAY PHOTO POINT MONITORING

This chapter records the set-up of a trial photo point monitoring project at Kangaroo Bay whose primary purpose was monitor for any boat wake impacts on the shoreline resulting from the introduction of a new ferry service from Sullivans Cove (Hobart) to Kangaroo Bay during August 2021. This monitoring was under-taken for a 3-month period during which shoreline impacts potentially related to the boat wakes were detected at one monitoring site, although most of the changes detected at other sites were inferred to be related to wind-wave storms (see section 2.2.3).

Lessons learnt and observations made during this monitoring project have informed broader conclusions and guidelines for shoreline erosion and boat wake monitoring in the Derwent Estuary (as discussed in Sections 2.0, 3.0 and 4.0).

Figure 1: Overview of Kangaroo Bay (roughly centred in this photo) showing the wake of the ferry following departure from the indicated ferry berth. The ferry is just out of the photo to the left, heading west towards Sullivans Cove (Hobart city). Photo by Chris Sharples, 24th November 2021.

2.1 *Shoreline environment and types in Kangaroo Bay*

2.1.1 Wave climate

The swell wave climate of the south-eastern Tasmanian coast is dominated by south-westerly swells originating in the Southern Ocean, although south-easterly swells originating in the Tasman Sea occasionally reach the east and south-east coasts (Short 2006). These swells refract around the coast and into the Derwent estuary, reaching and refracting north-eastwards into Kangaroo Bay as small attenuated waves typically breaking at heights of 20 cm or less, which are roughly comparable in height and energy to ferry boat wakes observed in the bay (compare Figure 2 below with Figure 6 and Figure 7). Under rare storm wave conditions, larger erosive swell waves may penetrate to Kangaroo Bay, as is inferred to have happened during a large swell storm on 9th – 10th July 2011 which caused considerable wave erosion around much of the southern Tasmanian coast (Sharples 2020). Unfortunately, no site-specific records of the effects of this event in Kangaroo Bay are known to the writer, nor are other data on swell wave in Kangaroo Bay known to the writer.

Figure 2: A typical ("average") swell wave breaking at Kangaroo Bluff after attenuating on its long refraction pathway up the Derwent Estuary from the Southern Ocean (the following swell wave is also visible breaking on the rocky platform a hundred metres or so further south). Photo taken near viewpoint KBPP2 and close to high tide. Compare the height (proportional to energy) of this typical breaking swell wave with the typical breaking ferry wake waves illustrated in Figure 6 & Figure 7. Photo by Chris Sharples (17th August 2021).

Locally generated wind waves are also significant on Kangaroo Bay shores and may be quite variable in size and power. The dominant (most frequent) winds in the Derwent estuary are north-westerly and northerly winds topographically steered down the deep broad valley of the Derwent estuary (see Figure 12). Relatively small waves generated by these winds under average weather conditions will impact mainly on the southern and south-western shores of Kangaroo Bay, leaving the northern shore most sheltered from their influence. However, less frequent winds from the southwest may include notably stormy conditions with high energetic wind-waves generated across more than 5 kilometres of fetch across the lower estuary. These impact most directly on the northern and north-eastern shores of Kangaroo Bay. These waves can be particularly erosive at high tide under storm surge conditions associated with low pressure weather systems. This sort of wind-wave storm is inferred most likely responsible for notable soil margin erosion above the normal High-Water Mark on the north-eastern shores of Kangaroo Bay (see Figure 3). Again, however, no measured data on wind waves in Kangaroo Bay is known to the writer.

Although rare, tsunami waves have been known to propagate into the Derwent estuary. An example occurred during early 2022 when a tsunami generated by a volcanic eruption near Tonga in the Pacific Ocean was measured at tide gauges in the lower Derwent estuary region (Karen Palmer, University of Tasmania, *pers. comm.*). However, the tsunami had decayed to a very long wavelength / low amplitude wave by the time it reached Tasmania, where it would probably passed un-noticed by casual observers, and it probably had little or no erosional impact on shores.

The boat wakes in Kangaroo Bay which this project aimed to monitor the effects of are discussed in section 2.2.1 below. These wake waves (see Figure 5, Figure 6 & Figure 7 below) are comparable (in size and energy) to fair-weather swell and locally-generated wind waves observed in Kangaroo Bay (e.g., see Figure 2). It is implicit that storm waves (whether swell or locally wind generated) may be considerably larger but of much less frequent occurrence that the observed boat wakes in Kangaroo Bay. Hence, whilst natural swell and wind-generated storm waves are likely to cause more erosion than boat wakes during brief intense storm events, any erosion caused by boat wakes will most likely be a result of frequently repeated relatively small waves, especially at high tide when these waves can run furthest up the shore profile.

2.1.2 Shoreline substrate types

This section briefly describes the shoreline substrates in Kangaroo Bay, noting which components are susceptible to mobilisation or erosion by waves.

South side of Kangaroo Bay:
Most of this shoreline comprises a natural resilient hard rock (siltstone and dolerite) intertidal platform with thin patchy sand and cobble beaches (veneers), which is mostly backed by a resilient artificial stone wall. This bedrock shore is mostly resilient to wave attack, except for likely redistribution of the small loose sand and cobble veneers in front of artificial wall. The soil margins and backshore areas are protected by the mostly resilient artificial wall backing the intertidal zone.

South of the low-gradient rocky shore platform shore is a hard rock cliff with little or no readily erodible material exposed to wave attack (not photo-monitored).

The eastern and inner end of the south side of Kangaroo Bay comprising artificial shorelines of several types, which are assumed to be resistant to wave erosion by design. These shores are mostly east of the ferry berth.

North side of Kangaroo Bay:
Apart from some resilient artificial boulder shores at its eastern (inner) end, the north shore of Kangaroo Bay comprises mostly moderately sloping hard rocky shore (dolerite) backed by moderately rising bedrock slopes with soil mantles overlying the bedrock just above High-Water Mark. This shore has no artificial shore protection except adjacent a couple of small stone jetties. The bedrock exposures on this shore are expected to be erosion-resistant, however some intermittent loose cobble beaches also exist in the intertidal shore area, ranging from a few metres wide to one about 50m long in front of the Tas Water plant. These are expected to be susceptible to some degree of mobilisation under wave impacts.

The seawards soil mantle margins behind and above the rocky intertidal zone are relatively soft and are potentially at risk of wave erosion. At the 2021 commencement of this monitoring project, some of these in the north-east part of the bay were already showing active (pre-ferry) wave erosion in several exposed locations, but elsewhere soil margins are mostly still vegetated and show no recent signs of erosion.

As demonstrated by Figure 3 below, there were only minor indications of fresh or "active" shoreline erosion (inferred to caused by storm swell or wind-waves) around the Kangaroo Bay shoreline prior to the introduction of the ferry service and photo monitoring described here. Most of this was erosion of soil margins over hard bedrock above the High-Water Mark (and thus implicitly caused by infrequent storm wave events).

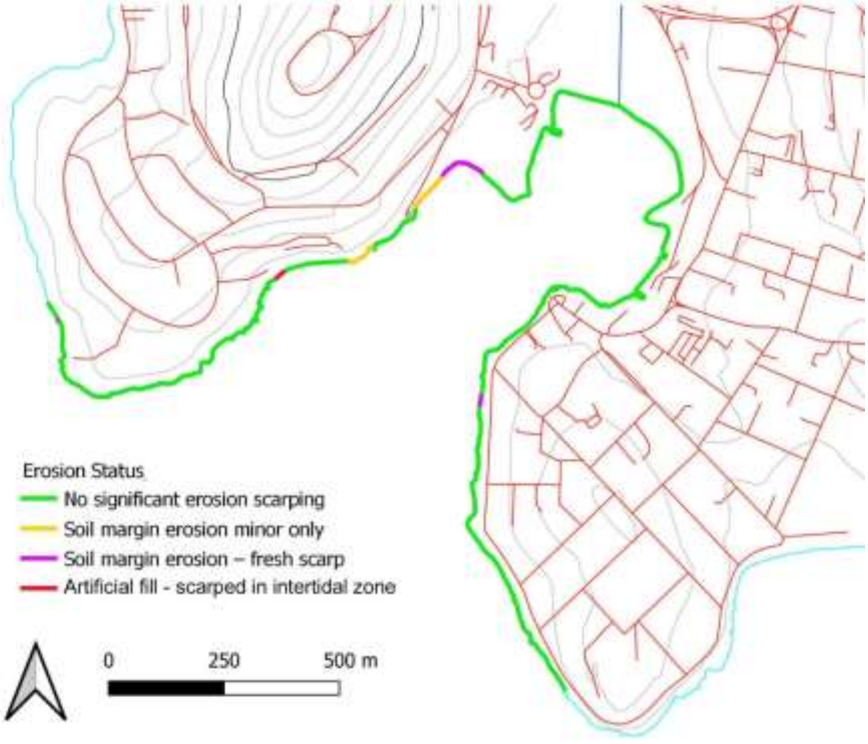

Figure 3: Kangaroo Bay shoreline erosion status prior to regular ferry service. Ground-mapped by C. Sharples, August 2021.

2.2 Kangaroo Bay photo - monitoring program

2.2.1 The boat and its wake

The Derwent Ferries service between Hobart (Brooke Street Pier) and Kangaroo Bay commenced on 9th August 2021 using a catamaran vessel (see Figure 4). During the monitoring period, the ferry made 15 (one-way) crossings to or from Kangaroo Bay each day between 6:20am and 9:00am, and between 4:10pm and 5:50pm.

Aerial and shore-based observations of the boat wake (both arriving into and departing from Kangaroo Bay) showed that the boat wake waves are most effective and noticeable between roughly photo points KBPP2 and KBPP12 at the bay entrance (see Figure 8) but were significantly diminished by the time they reach photo points KBPP1 and KBPP13 outside the bay (see also cover photo and Figure 5), Typical breaking boat wake wave heights were of the order of 0.3m height at the shoreline (see Figure 6). Boat wake waves were most noticeable along the middle and outer bay shorelines (west of the Kangaroo Bay ferry berth), and much less effective along the inner (eastern) shorelines within the bay (see Figure 1). This is mainly due to much slower ferry speeds approaching and departing the berth within Kangaroo Bay. The boat wake wave heights were comparable to the fair-weather refracted and attenuated swell waves that typically reach the entrance of Kangaroo bay (see Figure 2).

Figure 4: The Kangaroo Bay commuter ferry leaving Kangaroo Bay for the Brooke St. Pier, Hobart, on 17th August 2021. The hard, rocky and forested north shore of Kangaroo Bay is seen in the background. Photo by Chris Sharples.

Figure 5: Commuter ferry (catamaran) wake pattern under calm conditions. Ferry is travelling from Kangaroo Bay (RHS) to Brooke St Pier (Sullivans Cove, Hobart, LHS). Photo by Chris Sharples, 24th November 2021.

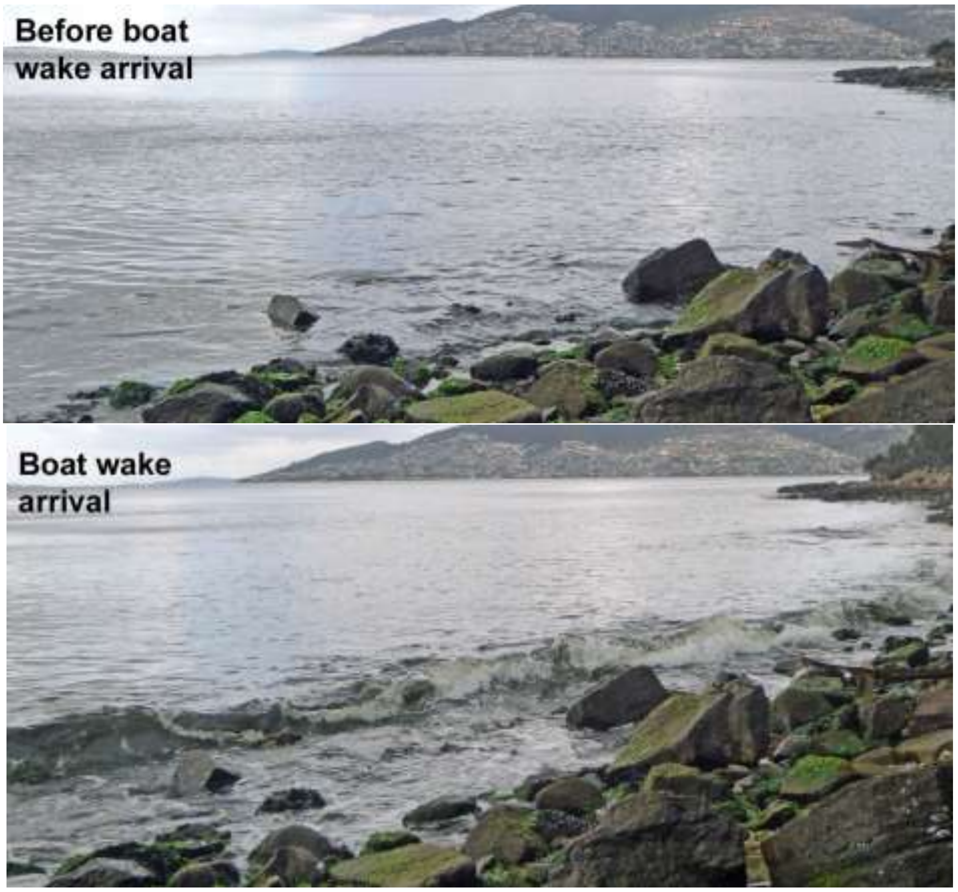

Figure 6: Commuter ferry boat wake viewed from the Kangaroo Bay north shore near photo point KBPP10 (see below and Appendix 1) during calm weather on 7th October 2021. The ferry (not visible) was about 200 metres offshore, travelling eastwards into Kangaroo Bay and beginning to slow down at the end of its river crossing. **Top:** Calm water before boat wake arrival. **Bottom:** Boat wake wave arrives at shore, a few seconds after top photo.

Figure 7: Commuter ferry boat wake viewed from the Kangaroo Bay South shore at photo point KBPP4 (see below and Appendix 1) close to high tide during calm weather on 17th August 2021. The ferry (not visible) was about 170 metres offshore, travelling eastwards into Kangaroo Bay and slowing down at the end of its river crossing. **Top:** Calm water before boat wake arrival. **Bottom:** Boat wake wave arrives at shore, a few seconds after top photo.

2.2.2 The monitoring program

Photo-monitoring started on 8th August 2021 (baseline photos) prior to commencement of regular ferry services on 9th August 2021. Photos were then taken at thirteen monitoring sites around Kangaroo Bay at roughly two-weekly intervals over a three-month period finishing on 12th November 2021.

The following procedures were used to define and use the photo points established at Kangaroo Bay:

Selection of photo points

The full length of the Kangaroo Point shoreline was reconnoitred prior to the ferry service commencement by walking it to a little beyond the major points defining the north and south ends of the bay entrance (close to photo points KBPP2 and KBPP12: see Figure 8). Subsequent field observations of the ferry boat wake indicated that the boat wake waves are most noticeable within the bay shoreline defined by these points (compare aerial photos of boat wake on Figure 1 & Figure 5).

Shoreline geomorphic types were mapped during this reconnaissance, along with any evidence of existing fresh or active shoreline erosion (see Figure 3). The main purpose of this mapping was to identify sections of shoreline likely to be most susceptible to wave-driven erosion or other modifications, and thus suitable targets for monitoring the shoreline impacts of boat wakes.

The reconnaissance demonstrated most shorelines within Kangaroo Bay to be either hard moderately sloping bedrock outcrops (dolerite and siltstone), robust (concrete and boulder) artificial shorelines, or combinations of these. It was deemed unlikely that these shoreline types would show any short- to moderate-term changes in response to the ferry wakes.

However, in some places the hard rocky shorelines were associated with softer components which either showed some evidence of erosion or were judged to have potential to erode rapidly if exposed to sufficient wave energy. The main types in Kangaroo Bay comprise:

- *Cobble and sand veneers:* Cobble beaches or sandy cobble beaches, usually as short patchy intertidal veneers over mostly hard rocky shores. The largest cobble beaches in the bay occur along the rocky (dolerite) north shore, particularly immediately adjacent the TasWater treatment plant (see KBPP9 photos Figure 10).
- *Soil margins:* The seawards margins of terrestrial soil horizons developed over moderately sloping hard bedrock have in the past been truncated by wave action at a height and landwards distance that represents the effective limits of storm wave action on these shores. Most of these are well vegetated and show no signs of recent erosion, however in some locations they do show recent erosion which pre-dates the recent ferry services in Kangaroo Bay (see Figure 22).

Thirteen photo points were selected around Kangaroo Bay (see map Figure 8). Each photo point was located with a clear view of one or more of the softer erosion-susceptible shore components listed above (see Appendix 1, Table 4). Several locations were selected where fresh recent soil margin erosion was present, along with locations where the soil margins were intact and stable but deemed to be potentially susceptible to eroding.

In most cases photo points were selected well to seawards in the lower intertidal shore zone, in order to provide as extensive a view of the (landwards) upper intertidal zone where erosion impacts are generally most extensive and mostly likely to be noticeable. However, this meant that most photo points are underwater at mid- to high tide, or at least wet and potentially quite slippery with algal material. Hence it was preferable for photography to be taken at or close to low tide when the photo points are dry and easily accessible. Where practical, photo points were also selected on stable features (e.g., bedrock, large boulders).

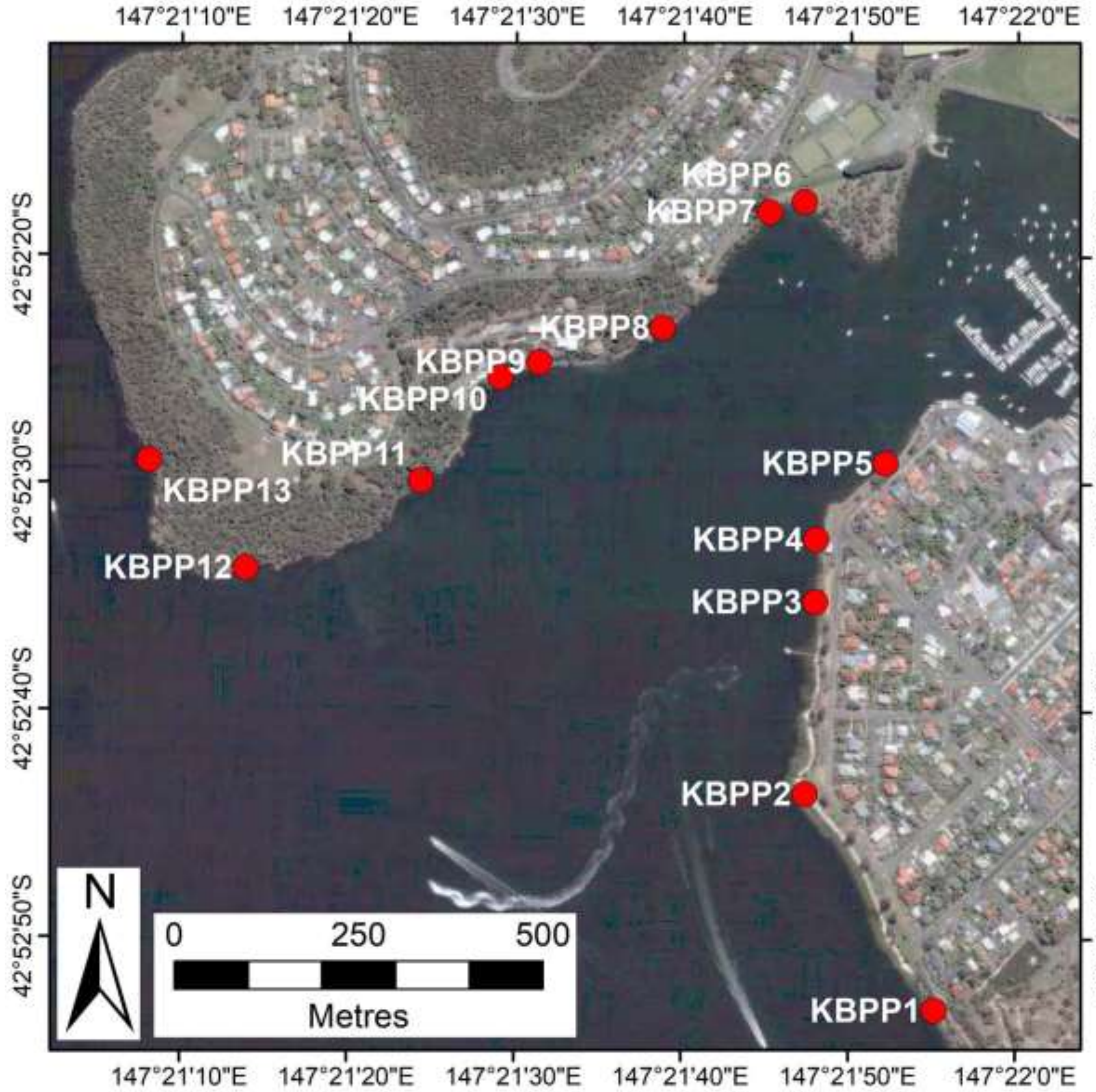

Figure 8: Kangaroo Bay photo point locations. Base map is an undated aerial view taken prior to construction of a concrete breakwater across part of the bay. All photo points are outside the breakwater-sheltered inner part of Kangaroo Bay.

Recording of photo points

Some photo point monitoring methods rely on using marked viewpoints; however, these may be subject to vandalism or regarded as visual pollution. The method adapted at Kangaroo Bay relies on using clearly recorded (but not physically marked) viewpoints.

The photo point or "viewpoint" is a location that a person stands on to take repeated photos of defined view fields. Once each viewpoint was selected (as above), it was given an identifier (e.g., "KBPP4") and its location was recorded in two complementary ways, namely:

1. *Co-ordinates*. The photo point position is recorded in map co-ordinates, which are generally determined in the field using a handheld GPS unit yielding position error margins of ± a few metres. A variety of map co-ordinate systems may be used, however for this project the Map Grid of Australia (MGA Zone 55) metric Universal Transverse Mercator (UTM) co-ordinate system (GDA94 datum) was used. The MGA map co-ordinates for each Kangaroo Bay photo point are provided in Table 4 of Appendix 1,
2. *Reference photos*. A temporary marker (such as a red notebook) is placed on the photo point, which is defined as the precise position one stands on to take the monitoring photos. The photo point is then photographed - ideally from more than one direction - along with recognisable

surrounding fixed features. Ideally at least one of the photos should be taken from the landwards side looking seawards, since this will later make it easier to search for photo points without getting too wet. The photos are archived along with the photo point co-ordinates. Photo point reference photos for Kangaroo Bay are reproduced in Figure 24 of Appendix 1.

Where the best available photo points do not have available easily recognisable features to identify them by on the reference photo, it may be necessary to measure a distance and direction to the photo point from some other nearby fixed reference feature which can be identified in a reference photo.

Photo point monitoring procedure

On each photo monitoring sortie, a GPS loaded with the photo point co-ordinates and a set of the photo point reference photos was carried in the field, along with a camera and notebook. Many modern digital cameras – including Smartphone cameras – produce photos of adequate quality for photo monitoring purposes, and no particular camera is recommended here. However, it is worth using the same camera for a given photo monitoring project in order to make it easier to achieve consistent settings (especially focal length) across all photos taken. Before each monitoring sortie, it is useful to check the camera's clock is set to the correct date and time so as to ensure the metadata recorded in the header file for each photo is correct.

Photo monitoring was undertaken at arbitrarily selected two-week intervals (± a day or two) at times as close as practical to the lowest daily tide (for easier and safer photo point access), and ideally under cloudy conditions without direct bright sunlight (to obtain less contrasty photos with less chance of glare). In practice these conditions were not always achievable, and it was considered more important to obtain some photos (even if imperfect) at reasonably regular intervals than to have large gaps in the record due to repeated unsuitable conditions. For example, if some sun glare was unavoidable, its effect was minimised by trying to shield the camera lens from sun glare.

Each photo monitoring sortie comprised three key stages for each photo point, namely locate viewpoint, take monitoring photos, and archive photographs, as follows:

Locate Viewpoint: Because hand-held GPS measurements typically have error margins of +/- several metres, relocating each photo point was usually a two-stage process: (1) Go to the location specified by the GPS; this should be within a couple of metres of the photo point. Then (2) use the photo point reference photos to compare features on the ground to identify the exact photo point to stand on.

Photography: Key issues for photo monitoring are to achieve as consistent a field of view and lighting conditions as possible for each set of photos (i.e., the photos taken of a given view from a given photo point). Lighting conditions are difficult to standardise, but ideally photos taken under cloudy conditions should provide the least contrasting light conditions. However, field of view is easier to standardise:

From each photo point a set of standard view directions was defined on the first monitoring occasion. For each Kangaroo Bay photo point these were a simple view leftwards (alongshore), directly landwards, and rightwards (alongshore). In each view as much of the mid- to upper-intertidal area as possible was included in the view since this is where erosion is most likely to occur. Photos were taken at the normal focal length for the camera, that is, neither wide angle nor telephoto views were used.

It was found useful to carry printed copies of the first set of monitoring photos on subsequent monitoring sorties in order to assist in framing subsequent photos consistently with the first photos.

For all subsequent monitoring runs the same fields of view were photographed from each photo point in the same order, and at the same (normal) focal length. If this is done consistently, and assuming the photo points are also visited in the same numerical order each time, it should not normally be necessary to take field notes provided that the photos are labelled and archived promptly.

A scale rod was included in some Kangaroo Bay monitoring photos. The usefulness of a scale rod varies depending on the nature and purpose of monitoring and was not considered essential for this project where the detection of changes was not strongly scale dependent.

Archive photographs:
Photos should be labelled (named) with date, location (geographical area), photo point number and view description (e.g., L or R). Correct date and time should also be automatically recorded in photo header file. Refer to Section 5.3 regarding long term archiving.

2.2.3 Monitoring results

Monitoring photos were taken at the thirteen monitored Kangaroo Bay site on seven occasions at approximately two-week intervals, over a three-month period (8th August to 12th November 2021)

The monitoring photo record was analysed by simple visual comparison of photos to identify physical changes to shoreline forms and distribution of soils, bedrock, boulders, cobbles, and sand deposits. Initially, the first and last photos taken at each site were compared to identify any net changes over the whole period. Then, all the photos taken on each view direction at each site were then visually compared in sequence to identify any progressive or short-term changes.

This simple qualitative analysis method has enabled identification of several change patterns at various sites over the monitoring period. More sophisticated and quantitative photogrammetric analyses could now be conducted if required, but it was beyond the scope of this project to explore these.

Table 1 below summarises the observed physical shoreline changes at the Kangaroo Bay monitoring sites over the monitoring period. In addition, as examples of the changes detected, the full sequence of photos taken at three site viewpoints are shown in the following Figure 9 (KBPP5 view leftwards), Figure 10 (view KBPP9 leftwards) and Figure 11 (KBPP11 view onshore). First and last photos illustrating net changes (or lack thereof) at all sites are also reproduced in Appendix 1 of this report (Figure 29 to Figure 41). All monitoring photos taken during this project are provided as separate image files accompanying this report (see Appendix 4).

Table 1: Table of observed changes over the photo-monitored period at each photo point site. View directions are L = leftwards along shore, O = onshore (landwards), R = rightwards along shore.

Photo point	View Direction	Changes from 8th Aug. to 21st Oct 2022	Changes during last period 21st Oct to 12th Nov. 2022	Notes
KBPP1	L, O, R	No changes detected	No changes detected	
KBPP2	L, O	Some notable changes in cobble distribution over the period.	Significant removal of cobble veneers (moved seawards?) and exposure of underlying bedrock.	Notable changes to cobble distribution throughout monitoring period
	R	Minor cobble changes	Minor cobble changes	
KBPP3	L, O, R	Negligible changes detected	Negligible changes detected	
KBPP4	L, O, R	Negligible changes detected	Negligible changes detected	
KBPP5	L	Progressive significant removal of cobbles throughout period	Further significant removal of cobbles exposing underlying bedrock.	*Notable progressive reduction in cobble veneer throughout monitoring period (see Figure 9)*
	O	Minor changes	Minor change	
	R	Negligible changes	Negligible change.	
KBPP6	L, O, R	Minor changes in cobble and sand distribution throughout (no soil margin scarp changes)	Minor changes in cobble and sand distribution (no soil margin scarp changes).	Minor changes throughout monitoring period
KBPP7	L, O, R	Negligible changes	Negligible changes	
KBPP8	L, O, R	Negligible changes	Negligible changes	
KBPP9	L, O	Negligible changes	Significant removal of cobbles from upper beach	*No significant change over most of monitoring period, then major removal of cobbles after 21st October (see Figure 10).*
	R	Negligible changes	Minor removal of cobbles	
KBPP10	L, O, R	Negligible changes (incl. no change in backing erosion scarp)	Negligible changes (incl. no change in backing erosion scarp)	
KBPP11	O	Negligible change until some moderate bedrock exposure by cobble removal in 21st Oct. photo	Major removal of cobbles and exposure of bedrock.	*Only minor changes up to 21st Oct., then major removal of cobbles by 12th Nov. (see Figure 11)*
	L, R	Negligible change	Minor cobble removal.	
KBPP12	L, O, R	Negligible change in cobble distribution	Negligible change in cobble distribution	
KBPP13	L, O, R	Negligible change in cobble distribution	Negligible change in cobble distribution	

The main styles of change indicated in Table 1, and possible explanations for these are described following:

Changes limited to cobble-veneer and beach redistribution. In all cases where shoreline changes have been detected at the photo-monitoring sites, these have entirely consisted of the movement of cobbles on intertidal (wave-washed) cobble beaches or as patchy veneers over stable bedrock. Some associated sands (e.g., at KBPP6) may in some cases have also moved but this proved difficult to detect against movement of the cobbles.

No erosion of existing backshore soil margin erosion scarps occurred during trial period (but this must occur sometimes). No photo sequences show any further erosion of pre-existing soil or fill-margin erosion scarps at the back of the intertidal zone (e.g., at KBPP6, KBPP7, KBPP8, KBPP10). The existence of these scarps demonstrates that the soil margins at these sites are occasionally exposed to waves large enough to reach and erode them, however this evidently did not occur during the trial monitoring period.

No changes were detected at some sites, including some with erodible cobble beaches. No changes over the monitoring period were detected at KBPP1, which comprises mainly hard bedrock and bedrock boulders, with erodible soil exposures occurring only landwards of and above the intertidal zone. Cobble veneers or beaches showed no significant (i.e., easily detectable) changes at KBPP3, KBPP4, KBPP12 and KBPP13 (for reasons which are mostly unclear).

Random movements of cobble veneers occurred at some sites over the whole trial period. Several sites exhibited noticeable non-progressive or 'back-and-forwards' movements of thin cobble veneers over hard bedrock shore platforms at times throughout the monitoring period, most noticeably at KBPP2 and KBPP6. This is inferred to be a frequent occurrence at these sites, perhaps resulting from frequent waves of slightly different characteristics (e.g., alternately dominant swell vs. locally generated wind-waves or possibly boat wakes).

Time-correlated changes to cobble beaches observed at two sites most exposed to south-westerly wind-wave storms. At two cobble beach sites (KBPP9 and KBPP11) only minor cobble movements are detectable up until the 21st October 2021 photos, however the next and last photos (12th November 2021) demonstrate a significant lowering of the cobble beach surface, with increased exposure of boulders and underlying bedrock surfaces (see Figure 10 and Figure 11). These changes are inferred to be the result of energetic wave backwash dragging cobbles down the beach profile towards the sea (since no other transport direction for the "missing" cobbles appears plausible). These sites on the north shore of Kangaroo Bay are highly exposed to long southerly to south-westerly fetches across the Derwent estuary, and several windstorms from that direction occurred in the Hobart region during the 21st Oct – 12th Nov. period[1]. Public wind hazard alerts were issued for several windstorms during this period. Hence, the timing and spatial patterning of cobble beach changes at KBPP9 and 11 suggest that these were most likely the result of these sites being particularly exposed to energetic wind waves locally-generated by a cluster of south-westerly storm wind events during October – November 2021.

Progressive net changes to cobble veneers at one site may be a response to the introduction of ferry boat wakes. The photo-monitoring at KBPP5 has demonstrated a progressive and non-reversing net reduction in the extent of cobble veneers in the intertidal zone at this site over the 3-month monitoring period (see Figure 9). Of the 13 monitoring sites, this is the only one which demonstrates a significant change that is time-correlated with – and hence might be caused by - the introduction of new ferry wakes on 9th August 2021.

---

[1] Daily Bureau of Meteorology records from the Battery Point (Hobart) BoM weather station (available at http://www.bom.gov.au/climate/dwo/202110/html/IDCJDW7021.202110.shtml) recorded the following maximum daily wind gusts during the 21st October to 12th November 2021 period:

Date	Direction	Speed (km/h)
24th Oct.	S	61
25th Oct.	SSW	50
29th Oct.	SSW	69
30th Oct.	SW	54
12th Nov.	S	59

These are extreme wind events that would have produced energetic wind waves impacting on the exposed north shore of Kangaroo Bay. These would have been capable of moving intertidal cobble deposits at most stages of the diurnal tidal cycles.

Figure 9: Comparison of the whole sequence of KBPP5 (leftwards view) monitoring photos throughout the trial monitoring period. The earliest (8^{th} Aug.) photo shows a dominantly cobble foreshore, but following photos show a progressive loss of the cobble beach (veneer) and progressively increasing exposure of underlying dolerite bedrock, particularly towards the lower right-hand side of each photo. Zoom in to examine details of photos.

Figure 10: Comparison of the whole sequence of KBPP9 (leftwards view) monitoring photos throughout the trial monitoring period. Note that no photos were taken at this site during the 3rd week of August (2nd monitoring run) due to lack of permission. Other than varying amounts of seaweed wrack on the cobble beach there is little change to the cobble and boulder beach from the first (pre-ferry) monitoring photo (8th Aug) until the second-last photo (21st Oct). However, between 21st Oct and 12th Nov there is a lowering (erosion) of the cobble beach resulting in greater exposure (but no significant movement) of the larger boulders in the beach. Zoom in to examine details of photos.

Figure 11: Comparison of the whole sequence of KBPP11 (onshore view) monitoring photos throughout the trial monitoring period. This sequence shows negligible to minor changes in cobble cover between 8th Aug. and 21st October 2021, then major removal of cobbles and exposure of bedrock between 21st October and 12th November 2021. Zoom in to examine details of photos.

Unfortunately, the photographic record of the site begins only the day before the introduction of the new ferry. Ideally it would be useful to know whether the cobble veneer was constant (similar to the initial photos) or changing significantly over a period of at least some months prior to the ferry start date. In any case, it is necessary to ask whether ferry wakes might plausibly cause the observed changes, or whether other known processes at the site may plausibly cause them instead. In this respect, it is notable that site KBPP5 is probably the site most sheltered from both wind-waves and swell-waves entering Kangaroo Bay (see Figure 8), and hence has not shown the windstorm-related erosion pattern and timing seen at KBPP9 and 11 (see above). It is possible that the boat wakes introduced on 9th August 2021 have subsequently been the most energetic waves affecting the KBPP5 shore and have consequently resulted in a redistribution of cobble veneers into a new equilibrium with the new wave regime.

A test of the possibility that boat wakes may be a cause of the observed redistribution of cobbles will be (a) whether the observed changes persist while regular boat wakes of the scale observed since 9th Aug. 2021 continue; and (b) whether any temporary or permanent interruption to the boat wakes results in the cobbles reverting to their former distribution as seen on 8th August 2021 (Figure 9).

2.3 *Conclusions*

The photo point monitoring trial at Kangaroo Bay has demonstrated that the method is both quick and simple to conduct yet is capable of quite sensitively detecting shoreline change.

In summary, over the trial monitoring period no wave events occurred in Kangaroo Bay – from any cause including the regularly-generated boat wakes – that were energetic enough to reach to the back of the shoreline tidal zone and erode the backshore soil margins, albeit this degree of erosion must occur occasionally during severe wave events as indicated by the pre-existing backshore soil margin erosion scarps around parts of the bay. However, the photo-monitoring provided evidence of minor movements of cobble veneers and beaches in several parts of the bay, although most of these were probably related to natural wind- or swell-wave events.

One site did however provide possible evidence of shoreline change related to the introduction of a source of regular boat wakes, namely the progressive removal of cobbles from the shore at KBPP5. This site is one of the parts of Kangaroo Bay most sheltered from prevailing westerly to south-westerly wind waves, and also from the south-westerly swells, and is thus in a location where boat wakes may have become the dominant source of wave energy following the introduction of the new ferry. In this case, it is inferred that the sudden introduction of a new source of regular boat wakes might be sufficient to significantly redistribute shoreline cobbles, in a progressively changing pattern which might not occur at locations where typical wind and swell wave energies are strong enough to counterbalance any tendency towards change due to boat wakes.

3.0 MONTROSE SHORELINE CONDITION MONITORING

The Montrose shoreline area (see Figure 13) is a part of the Derwent estuary within Glenorchy City Council local government area, north of Elwick Bay and adjacent Montrose High School. The Montrose shoreline includes soft to somewhat cohesive sediment shorelines (cobbles in a silty clay matrix) that are potentially susceptible to erosion and mobilisation under the impact of wave action, including boat wakes.

The Montrose shoreline is close to the route of two catamaran ferries (Mona Roma 1 & 2) which have transported visitors to and from the nearby Museum of Old and New Art (MONA) several times each day for much of the last decade (MONA officially opened in 2011). These shoreline sediments exhibit some intermittent low vertical erosion scarps (Figure 14) and loose cobble berms or beach ridges (Figure 15) that have evidently migrated landwards within the last decade, partly covering prior vegetation in the intertidal shoreline zone (see also examples on Figure 17). These indicators of recent sediment mobility have anecdotally been attributed to the impact of the Mona Roma boat wakes. However, although this attribution seems plausible, no observational or monitoring evidence is available to support or refute it.

This chapter describes the initial establishment and application of two monitoring techniques (photo point monitoring and aerial photography time series analysis) at a section of the Montrose shoreline that is regularly passed by the Mona Roma ferries and is directly exposed to their wakes several times each day (see Figure 13). The purpose is to enable future monitoring work to collect evidence relating to shoreline change and its potential causes.

The authors field observations indicate that the Mona Roma ferries pass the Montrose shoreline at a distance of several hundred metres offshore on multiple occasions most days. The author has observed boat wake waves generated by these ferries breaking at approximately 0.3 – 0.4 m high on the Montrose shoreline under calm conditions. This is similar to the ferry wake waves observed in Kangaroo Bay (see Section 2.2.1 above).

The purpose of the work described in this chapter was to create a basis for monitoring of the Montrose shore, with a view to beginning the collection of data which may in future yield more definitive data on the question of the degree of impact of the Mona Roma (and any other) boat wakes on the Montrose shoreline. To this end two monitoring techniques have been initiated and are described below, namely photo point monitoring (Section 3.2) and aerial photo monitoring (section 3.3). Preliminary observations and recommendations for ongoing monitoring using these techniques are provided in sections 3.2.2, 3.3.2 and section 5.1.

3.1 Shoreline environment and types at Montrose

3.1.1 Wave climate

Swell waves (originating in the Southern Ocean) are negligible or absent at the Montrose shoreline owing to the degree of refraction and attenuation these undergo on their long pathway up the Derwent estuary to the Montrose shore.

Locally generated wind-waves are the main (or only) natural source of wave energy at the Montrose Shore. The nearest long-term wind record is the Bureau of Meteorology (BoM) Ellerslie Rd (Hobart City) record which demonstrates dominantly north-west to northerly winds blowing down the deep and broad Derwent valley (see Figure 12: *Bureau of Meteorology original data 1893 to 2015*, processed by Chris Sharples). These are the result of the westerly winds (which dominate air flows across Tasmania) being "topographically-trained" as they enter and blow down the Derwent Valley. Although no long-term wind record has been obtained for the Glenorchy/Montrose area, given the similar topographic situation on the floor of the Derwent Valley it is reasonable to infer similar dominantly north-westerly to northerly wind directions – and thus wind-wave directions - at the Montrose shoreline. The monitored Montrose shoreline is exposed to north-westerly to northerly wind waves over fetches ranging from 1.0 to 2.5 kilometres, which is quite sufficient to generate energetic wind-waves under windy conditions.

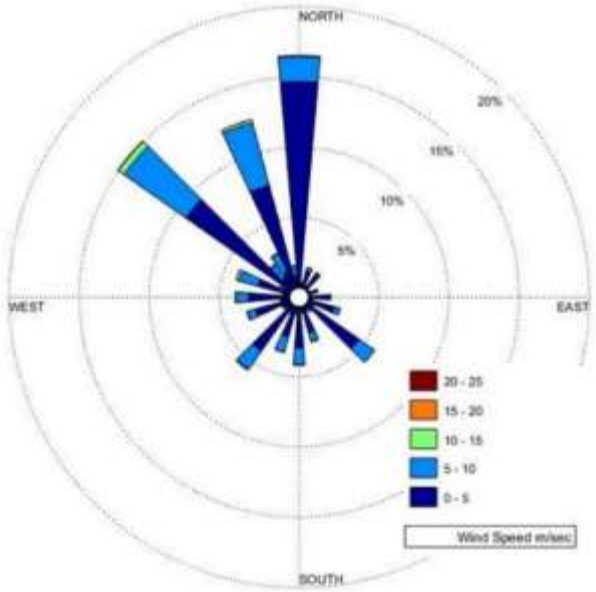

Figure 12: Synoptic wind rose for Hobart City (Ellerslie Road) Bureau of Meteorology weather station. The weather station is situated in the deep but broad valley of the lower Derwent River, hence the dominant northerly to north-westerly winds are inferred to be mainly topographically steered down the Derwent Valley at low levels. Given the similar topographic situation of Montrose in the floor of the lower Derwent Valley, similar dominant wind directions are inferred for the latter. The figure uses all synoptic wind data for 1893 to 2015, plotted by Chris Sharples using data supplied by the Australian Bureau of Meteorology.

The Ellerslie Road wind record shows that winds (and thus wind-waves) may also be generated in a wide range of other directions, but that this only occurs in a small proportion of cases (albeit some of these cases may include unusual easterly windstorms). The same is likely to be true for the Montrose shore.

As already noted above, the monitored Montrose shoreline is directly exposed to boat wake waves generated multiple times each day by the Mona Roma ferries passing a couple of hundred metres away and roughly parallel to the Montrose shore. The writer has observed these waves breaking on the shore at wave heights of 0.3 – 0.4 m high under otherwise calm conditions.

3.1.2 Shoreline types and substrates

The substrate exposed in the un-vegetated intertidal foreshore zone along the section of Montrose shoreline examined during this project (red box on Figure 13) comprises a conglomerate of rounded rock cobbles embedded in a cohesive but soft dark silty-clay matrix (see examples in Figure 14 & Figure 17), overlain in patches by low ridges and berms of loose cobbles (see Figure 15).

The cohesive material corresponds in description to the substrate depicted immediately landwards of the shoreline at the same location by the most recent available 1:25,000 scale Tasmanian Geological Mapping of the region (Forsyth and Clarke (1999), see reproduction on Figure 13). This material (depicted as a geologically-young sediment *Qpad*) is described by Forsyth and Clarke (1999) as "Alluvial terrace deposits dominantly of cobbles and small boulders of dolerite and sub-ordinate Parmeener clasts". This description corresponds well to the exposed cohesive substrate seen in the foreshore at the study site.

However, the published geological mapping additionally depicts the narrow shoreline zone at the Montrose study site as a different unit *Qhmm* (Figure 13), which the map legend describes only as "Man-made deposits". In the absence of an Explanatory Report for this map, the physical nature of *Qhmm* is unclear, although some other areas of "*Qhmm*" on the same map are presumably artificial fill comprising a range of quarried materials from elsewhere. At the Montrose study site, it is possible that "*Qhmm*" refers to the loose patchy cobble deposits partly overlying the cohesive *Qpad* in the intertidal foreshore area. However as noted in section 6.3.2 below, these loose cobble deposits appear to have only become a feature of the shoreline after 2012, whereas the geological mapping depicting *Qhmm* was published well prior to that date, in 1999. Hence the nature and identification of "*Qhmm*" at the study site is currently unclear to this writer.

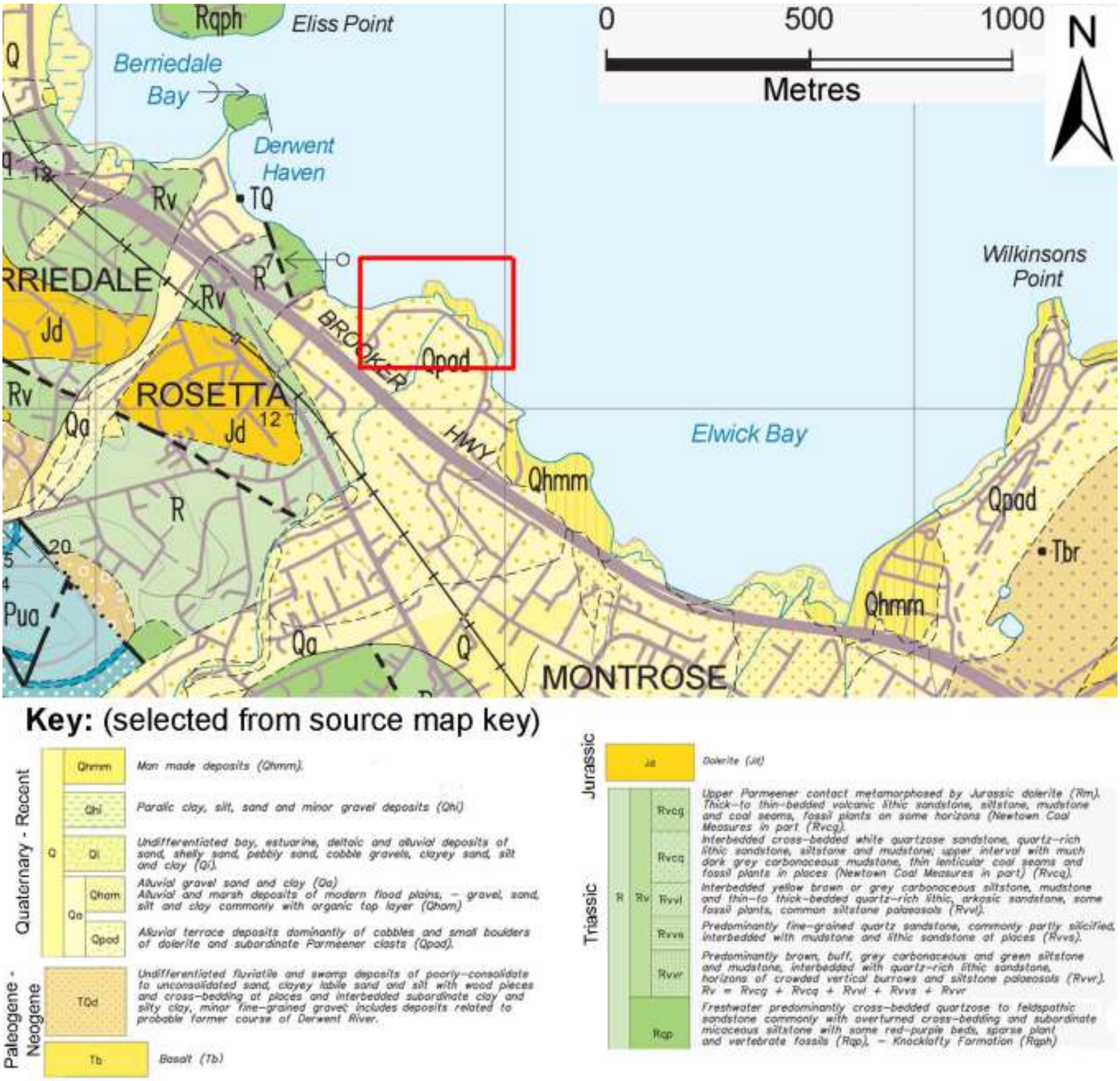

Figure 13: Geological map of the Montrose Shore area. Map section and key extracted from the 1:25,000 scale Hobart Geological Map Sheet (Forsyth & Clarke 1999). This depicts much of the Elwick Bay shoreline as artificial fill (*Qhmm* on the map key). The selected area for photo point and aerial photo monitoring is indicated by a red rectangle.

Regardless of this uncertainty, it is clear that the study area shoreline comprises two distinctive materials, namely a cohesive substrate of cobble conglomerate in a dark silty-clay matrix, which is patchily overlain by low ridges or berms (beach deposits) of loose cobbles simar to those embedded in the cohesive conglomerate. Small erosions scarps visible in the cohesive conglomerate (see Figure 14) demonstrate that this material is susceptible to wave erosion, likely including boat wake erosion.

The loose cobble berms are also susceptible to being mobilised by wave action (which may include boat wake waves), as indicated by current observations of this material evidently having relatively recently moved landwards and engulfed areas of vegetation (see Figure 15), as well as infilling the outlets of several storm water drain outlets along the foreshore (Appendix 2: Figure 43 & Figure 46). The cobble berms or ridges have impounded foreshore drainage in some areas, forming wet upper intertidal depressions colonised by saltmarsh vegetation (Figure 15).

Figure 14: Eroding soft dark cohesive cobbly substrate at Montrose Shoreline. Photo taken close to monitoring photo point MSPP3, showing scarps eroded into the substrate material by wave action at two different levels (upper: vegetation line and lower: waterline at the time this photo was taken). Wave excavation of the obvious rounded cobbles and pebbles from their dark finer-grained cohesive matrix is a likely source of the loose cobble berms (beaches) or ridges also found along this shore (see Figure 15 below).

Figure 15: Loose pebble and cobble beach ridge or berm over cobbles in a dark cohesive silty-clay matrix on the Montrose Shoreline. View looking south from close to monitoring photo point MSPP1, showing a loose light-coloured cobble ridge which can be seen to have moved from left to right, engulfing vegetation as wave action pushed the loose mass landwards. These loose cobble ridges seem to have appeared mostly after 2012, possibly as a result of increased wave action excavating cobbles from the underlying dark cohesive silty-clay matrix as seen in Figure 14 above. Photo by Chris Sharples, 6th September 2021.

3.2 Montrose shoreline photo-point monitoring program

The Montrose shore photo point monitoring project has been set up using the same protocols as for Kangaroo Bay. Details of these protocols are provided in Section 2.2.2 above.

3.2.1 Monitoring program set-up (21st October 2021)

The area readily available and suitable for monitoring was constrained by the presence of artificial (erosion-resistant) seawalls on a large proportion of the shores in Elwick Bay from the Montrose Sailing Club southwards, and by an area of publicly inaccessible private freehold shoreline north of Montrose High school. The area selected for monitoring lies between these areas and is a stretch of publicly accessible foreshore adjacent Montrose High School indicated by a red rectangle on map Figure 13. This shoreline is well-suited for monitoring purposes, being directly exposed to Mona Roma ferries and their wakes (which pass by a few hundred metres offshore on multiple occasions each day), as well as comprising potentially erodible and mobile shorelines of cobbles and pebbles in a cohesive but unlithified silty-clay matrix together with loose mobile patches of cobbles without any cohesive matrix. Existing geological mapping characterises these materials as partly natural alluvial deposits (*Qpad*) and partly as artificial deposits (*Qhmm*). See discussion in Section 3.1.2 and map Figure 13.

The selection and recording of five photo viewpoints within the chosen monitoring area was conducted in the same manner as described for Kangaroo Bay (see Section 2.2.2). The individual monitoring viewpoints were selected on the basis of being reasonably accessible on foot, containing features (such as cobble beaches and ridges) that might be expected to be susceptible to change under repeated boat wake waves, and also containing some fixed features to serve as reference points in future photography. Figure 16 below maps the location of the photo points, and other details of each viewpoint are provided in Appendix 2, along with reproductions of the first monitoring photos taken on 21st October 2021 at each viewpoint (Figure 43 to Figure 47). These are also provided as separate image files accompanying this report. As well as being reproduced in the Appendices, Figure 17 below also reproduces one of the 21st of October 2021 views from each of the five viewpoints which illustrate features identified on an air photo time series and discussed in Section 3.3 below.

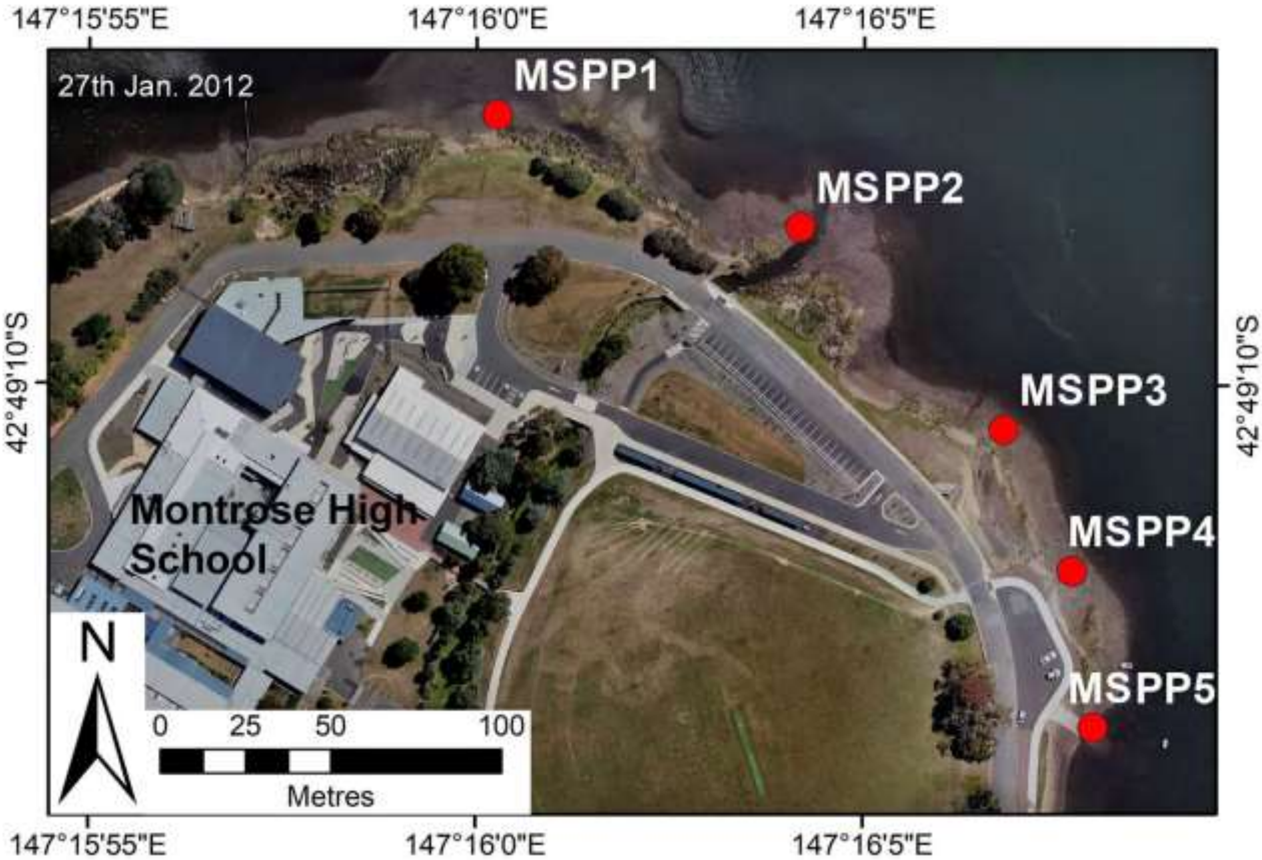

Figure 16: Montrose Photo Point locations. Locations indicated over 2012 aerial photo showing the Montrose shore at low tide.

3.2.2 Initial Photopoint monitoring results (status at 21st Oct. 2021):

Continuing exposure of this shoreline (between MSPP1 & 5) to increased wave action (attributable to boat wakes, sea-level rise, rare weather events or some combination of these) can be expected to result in continuing detectable changes of the following types:

1. Continued landwards migration of loose cobble veneers and beach-ridges, potentially burying currently vegetated areas on the landwards side. Examples of this will be visible and detectable from most of the viewpoints, but in particular MSPP1 (view left), MSPP2 (view left), and MSPP4 (view left).

2. Continued choking of stormwater culverts by cobbles pushed landwards by wave action, at MSPP1 (view onshore), MSPP3 (view right), and MSPP4 (view onshore).

3. Continued erosion of scarps into cohesive cobbly substrate exposed in the upper intertidal area where this is not covered by loose cobble beaches, particularly at MSPP3 (view left and onshore).

4. Soil margin erosion at the landwards limit of the intertidal zone, where this has not been inundated by loose cobble deposits, in particular at MSPP5 (view left and right).

Table 2 below lists the key features of the view field at each of the five photo-points as photographed on 21st October 2021, noting in particular features likely to be eroded, mobilised, or otherwise changed by wave action.

Summary:

The observations listed in Table 2 (below) show that the intertidal zone (high tide line to low tide line) encompassing the five photo points is of a similar geological and geomorphic character throughout. The intertidal zone is underlain by a dark grey-brown substrate comprising well-rounded pebbles and cobbles in a finer cohesive clayey-silty matrix. This is partly overlain by deposits of loose, mobile light-coloured cobbles and pebbles occupying the upper, more landwards parts of the intertidal zone, where they form cobble beach veneers and beach-ridge deposits. These loose mobile cobble deposits may have been winnowed out of the underlying cohesive cobbly sediment by wave action during the last decade (see air photo results in section 3.3.1 below). They show clear indications in several places of having in recent years been moved landwards by wave action over formerly vegetated backshore areas, as well as having choked the outlets of three stormwater culverts (near photo points MSPP1, 3 & 4) with wave-transported cobbles. It is possible that the landwards transport of cobbles evidenced by these observations is wholly or partly driven by boat wakes, in particular from the Mona Roma ferries, however in the absence of monitoring data tracking the progress of any shoreline changes from prior to the introduction of the ferries, it is not possible to unequivocally demonstrate this. See further discussion in section 3.3.1 below.

In a few areas where the underlying cohesive cobbly sediment is not covered by loose cobbles in the upper parts of the shoreline and intertidal zone, wave action in the upper intertidal zone has been able to erode low scarps into the cohesive substrate, for example at MSPP3 (leftwards view: Figure 17). Soil margin erosion scarps at the upper extremity of the intertidal zone are also discontinuously present along the shore in places such as MSPP5 where the underlying substrate has not been inundated beneath landwards – migrating loose cobble beach ridges.

Continuing exposure of this shoreline (between MSPP1 & 5) to increased wave action (attributable to boat wakes, sea-level rise, rare weather events or some combination of these) can be expected to result in continuing detectable changes of the following types:

1. Continued landwards migration of loose cobble veneers and beach-ridges, potentially burying currently vegetated areas on the landwards side. Examples of this will be visible and detectable from most of the viewpoints, but in particular MSPP1 (view left), MSPP2 (view left), and MSPP4 (view left).

2. Continued choking of stormwater culverts by cobbles pushed landwards by wave action, at MSPP1 (view onshore), MSPP3 (view right), and MSPP4 (view onshore).

3. Continued erosion of scarps into cohesive cobbly substrate exposed in the upper intertidal area where this is not covered by loose cobble beaches, particularly at MSPP3 (view left and onshore).

4. Soil margin erosion at the landwards limit of the intertidal zone, where this has not been inundated by loose cobble deposits, in particular at MSPP5 (view left and right).

Table 2: Key features in the view field of Montrose shoreline photo points MSPP1 to MSPP5, as observed on 21st. Oct. 2021. These features are seen on the first set of monitoring photos taken on that date, one of which is reproduced for each site on Figure 17 below, and all of which are reproduced in Appendix 2 (Figure 43 to Figure 47).

Photo Point	Shore landforms and sediments	Notes (incl. potentially mobile features)
MSPP1	Lower intertidal zone exposes dark-coloured intertidal substrate of cobbles in finer cohesive matrix, overlain in upper intertidal area by light-coloured loose (mobile) cobble beaches and beach ridges (likely winnowed out of underlying cohesive cobbly sediment by waves?).	See Figure 17 below and Appendix 2, Figure 43. Any increased wave action likely to (continue to) mobilise loose cobbles and cobble ridges landwards and higher. An example at this photo point is a stormwater culvert choked with cobbles that have already been mobilised landwards (see Figure 43).
MSPP2	Lower intertidal zone exposes dark-coloured intertidal substrate of cobbles in finer cohesive matrix, cut through by drainage channel and overlain in upper intertidal area by extensive light-coloured loose (mobile) cobble beaches and beach ridges (likely winnowed out of underlying cohesive cobbly sediment by waves?).	See Figure 17 below and Appendix 2, Figure 44. Any increased wave action likely to (continue to) mobilise loose cobbles and cobble ridges landwards and higher.
MSPP3	Intertidal zone exposes dark-coloured intertidal substrate of cobbles in finer cohesive matrix. Rightwards of the viewpoint this is extensively overlain in upper intertidal area by a light-coloured loose (mobile) cobble beach (likely winnowed out of underlying cohesive cobbly sediment by waves?). However, to leftwards of the viewpoint the dark cohesive cobbly sediment is widely exposed with only minor loose cobble veneers in the upper intertidal area. Low (c. 20-30 cm high) erosion scarps are wave-cut into the cohesive cobbly sediment at two or more levels (see Figure 17).	See Figure 17 below and Appendix 2,Figure 45. Any increased wave action likely to (continue to) excavate erosion scarps into the cohesive cobbly sediment, and to mobilise loose cobbles and cobble ridges landwards and higher. An example at this photo point is a stormwater culvert choked with cobbles that have already been mobilised landwards (see Figure 45)
MSPP4	A dark-coloured intertidal substrate of cobbles in finer cohesive matrix is exposed only in the lowest part of the intertidal zone. The intertidal zone in this part of the shore is dominated by an extensive beach of loose (mobile) light-coloured cobbles (likely winnowed out of underlying cohesive cobbly sediment by waves?), forming a low beach ridge at the upper and landwards extremity of the wave-washed intertidal zone.	See Figure 17 below and Appendix 2, Figure 46. Any increased wave action likely to (continue to) mobilise loose cobbles and cobble ridges landwards and higher. An example at this photo point is a stormwater culvert choked with cobbles that have already been mobilised landwards (see Figure 46).
MSPP5	A dark-coloured intertidal substrate of cobbles in finer cohesive matrix is exposed in the lower part of the intertidal zone. The upper intertidal zone in this part of the shore is dominated by a beach of loose (mobile) light-coloured cobbles (likely winnowed out of underlying cohesive cobbly sediment by waves?), This is backed at the upper limit of the wave-washed intertidal zone by an eroded soil margin scarp about 20 – 30 cm high,	See Figure 17 below and Appendix 2, Figure 47. Any increased wave action is likely to (continue to) mobilise loose cobble beach materials landwards and higher, and to continue eroding back the soil margin scarps backing the intertidal zone.

Figure 17: One view from each of the five 21st October 2021 Montrose Shore Photo-monitoring viewpoints showing aspects of the features A to D identified on aerial photos and described in section 3.3 below. Top left: Photo point MSPP1 view L to air photo feature A; Top Right: Photo point MSPP2 view L to air photo feature B; Middle left: Photo point MSPP3 view L to air photo feature C; Middle right: Photo point MSPP4 view R to air photo feature C; Bottom: Photo point MSPP5 view R to air photo feature D. See Appendix 3 for reproductions of all Montrose Bay monitoring photos for 21st October 2021.

3.3 Historic air photo time series analysis of Montrose shoreline change

3.3.1 Air photo time series results for the Montrose Shore

A qualitative visual assessment of geomorphic (landform) changes visible on aerial photography of taken at six dates between 2002 and 2019 was undertaken for the same stretch of the Montrose shoreline as was selected for ground-based photo points (section 3.2). This allowed interpretation of features on the air photos to be usefully informed by details visible in the ground-based photos. The primary rationale for the air photo assessment was to test for shoreline changes potentially attributable to Mona Roma ferry wakes, which began after the opening of MONA in 2011. Hence three scanned air photos from the period 2002 – 2006 - 2009 (prior to MONA opening) were used together with three following the opening (2012, 2015 and 2019), in order to test for any changes that might be time-correlated with the introduction of the ferries.

The photos were obtained as digital images from the Department of Primary Industries, Parks, Water and Environment (DPIPWE) by the Derwent Estuary Program, and their details are listed in Appendix 3. The three older air photos were ortho-rectified by Chris Sharples using Landscape Mapper™ software, whilst the three more recent photos were ortho-rectified by DPIPWE. Chris Sharples measured position error margins for all photos relative to the 2012 photo as a reference image and obtained good positional error margins not exceeding ±1.2 metres across all 6 photos. Four sites were selected at the Montrose shoreline for identification of changes detectable on the air photos. These sites (labelled A, B, C, and D) were selected at locations with the view field of some of the monitoring photos also photographed at ground level during October 2021, as described in section 3.2 above. The location of these sites and adjacent photo points are shown on Figure 18 and Figure 19, whilst Figure 17 shows the ground-level photos that include views of each site. Table 3 provides a tabular listing of geomorphic features observed at each site on each air photo date. A summary of the geomorphic features identified, and the changes observed since 2002 follows:

Results:

The intertidal shoreline area (between the high and low tide lines) in the Montrose Bay photo point monitoring area as shown on Figure 13, Figure 18, and Figure 19, is underlain by a cohesive but unlithified sediment comprising hard well-rounded cobbles and pebbles in a finer soft but cohesive dark grey silty-clay sediment. This is visible today at many points along the shore and is also visible as a distinct dark grey substrate making up most or all of the wave-washed intertidal zone on all the air photos (see the ground-level photos in Figure 17 for examples of this dark substrate in the lower shoreline areas of most of the photos). This material seems likely to correspond to the Quaternary alluvial terrace deposits (*Qpad*) which the Hobart 1:25,000 geological map sheet (Forsyth & Clarke 1999) depicts close to this location, however it is unclear whether it is properly this unit or *Qhmm* (man-made deposits), which are also depicted at the same location but are not described by (Forsyth & Clarke 1999).

Wave erosion scarps are currently (2021-2022) evident in exposed areas of this sediment, for example in the view fields of photo points MSPP3-left and MSPP5-right (see Figure 17), however these are both too short in alongshore extent to draw meaningful inferences from their changes, and moreover are difficult to clearly discern on the aerial photography due to poor contrast of dark scarps against the dark substrate[2]. Hence no attempt was made to track changes over time in the few erosion scarps present along this shore.

From 2002 until 2012, four air photos show no significant change to intertidal or shoreline landforms at the four chosen sites (A, B, C & D), with the dark grey cobbly substrate dominating throughout, with the exception that several small patches of smooth-textured light material appear at site C (only) on the 2012 air photo. However, by the 2015 air photo large areas of light-coloured smooth-textured materials were extensively covering the dark grey substrate at all four sites, and this continued to be the case in the 2019 air photo. These light-coloured smooth-textured areas in the air photos are interpreted (by comparison with the 2021 ground photos; see Figure 17) as being loose accumulations of pebbles and cobbles in beach and beach ridge deposits, which have continued to dominate parts of the shoreline up to 2021 and beyond. There is clear field evidence that some of these cobble ridges have been migrating landwards where they

[2] Erosion scarps on a sandy beach or dune face are much easier to discern and map from air photos due to high contrast between sandy scarps ant their vegetated backing dunes areas.

have buried areas of vegetation, and indeed at site 'A' the landwards edge of one cobble ridge can be seen to have migrated approximately 4 metres inland between the 2015 and 2019 air photos.

Owing to a lack of ground-level monitoring data and general observations between 2012 and 2019, the origin of these loose cobble accumulations is not known to this writer, however it is clear that they are a current feature of this shoreline that were not present between 2002 and 2012 but had appeared by 2015 and have persisted to the present. This timing suggests the possibility of a relationship to the introduction of the Mona Roma ferries after 2011. Two possible explanations have been suggested as follows:

1. The cobbles have been quarried elsewhere and artificially placed after 2012 as a protective erosion buffer along the Montrose Bay shore in response to community concerns that the ferry wakes were causing erosion damage to the shore. Alternatively, these materials might correspond to the (somewhat enigmatic) "man-made" *Qhmm* unit depicted at the site on geological mapping (Forsyth & Clarke 1999). However, the air photo assessment described here suggests these loose cobble deposits were not present until after 2012, whereas the geological mapping dates from significantly earlier (1999). Moreover, recent (2021) inquiries to Glenorchy City Council, Montrose Bay High School and Montrose Bay Yacht Club by Inger Visby (Derwent Estuary Program) yielded no records or memories of cobble gravels having been artificially placed on the shore during the past decade.

2. Another alternative explanation is that frequent boat wake waves have actively winnowed cobbles out of the soft dark intertidal substrate and have pushed those cobbles landwards across the shore to accumulate as upper intertidal cobble beaches and berms. Anecdotal evidence from the Montrose Bay Yacht Club suggests a considerable impact on this foreshore area by boat wake from around the time the MONA ferries commenced operation. This includes a large influx of pebbles (cobbles) onto the shore on the southern side of the club jetty, which prior to this time was a sandy beach; washing out of concrete jetty foundation; erosion of river bottom; and undercutting of boat ramp infrastructure (M Grose and R Marshall, 2022, *pers. comm*. to Inger Visby). Ongoing photo monitoring (as discussed in Section 5.1 below) may lend support to this explanation if the production and landwards movement of the loose cobble deposits can be seen to be continuing and to have a likely causal relationship to the ferry wake waves.

Table 3: Tabular summary of shoreline changes observed at four Montrose Shore sites (A to D) across six air photo dates (2002 to 2019) and one photo point monitoring date (2021). See air photos Figure 18 & Figure 19 for site locations. The 2021 photo point monitoring views specified (bottom row) cover the 4 air photo sites specified.

	Shoreline state, changes, and comments			
Air photo site	**A**	**B**	**C**	**D**
Shoreline material	Dark grey substrate of cobbles in finer-grained cohesive matrix, overlain at times by pale-coloured loose cobbles.	Dark grey substrate of cobbles in finer-grained cohesive matrix, overlain at times by pale-coloured loose cobbles.	Dark grey substrate of cobbles in finer-grained cohesive matrix, overlain at times by pale-coloured loose cobbles.	Dark grey substrate of cobbles in finer-grained cohesive matrix, overlain at times by pale-coloured loose cobbles. Soil margin erosion scarp just above High Tide Line
23rd November 2002 Near high tide, intertidal zone mostly under-water & not observable.	Higher parts of darker cohesive cobbly substrate visible in a low eroding (?) ridge. No pale loose cobble accumulations visible.	Upper intertidal parts of dark substrate exposed and partly vegetated at shoreline, vaguely visible through water in lower intertidal area. No pale loose cobble accumulations visible.	Substrate exposed in smooth broad upper inter-tidal zone (looking pale coloured due to sun angle (?) but same features are dark grey in subsequent photos). No pale loose cobble accumulations visible.	Substrate exposed just below vegetated soil margin (looking pale coloured due to sun angle (?) but same features are dark grey in subsequent photos). No pale loose cobble accumulations visible.
8th December 2006 Near high tide, intertidal zone mostly under-water & not observable.	Same as at 23rd Nov. 2002 (above).	Same as at 23rd Nov. 2002 (above).	Same as at 23rd Nov. 2002 (above). Exposed substrate clearly seen to be normal dark grey colour in this image.	Same as at 23rd Nov. 2002 (above). Exposed substrate clearly seen to be normal dark grey colour in this image.
19th March 2009 About mid-tide, lower intertidal dark cohesive cobbly finer-grained substrate visible.	Same as at 23rd Nov. 2002 (above), with more of dark cohesive lower intertidal substrate visible.	Same as at 23rd Nov. 2002 (above), with more of dark cohesive lower intertidal substrate visible.	Same as at 23rd Nov. 2002 (above), with more of dark cohesive lower intertidal substrate visible.	Same as at 23rd Nov. 2002 (above), with more of dark cohesive lower intertidal substrate visible.
27th January 2012 Approx. low-tide, lower intertidal dark cohesive cobbly finer-grained substrate visible.	Same as at 19th March 2009 (above).	Same as at 19th March 2009 (above).	Mostly the same as at 19th March 2009 (above). A few small patches of pale, likely loose cobbles at upper margin of intertidal zone.	Same as at 19th March 2009 (above).
19th Dec. 2015 Near high tide, intertidal zone mostly under-water & not observable due to surface reflections.	Highest (only) parts of darker cohesive cobbly substrate visible in low ridge, with patches of pale coloured smooth-textured loose cobbles visible, covering parts of dark grey substrate previously visible in same places on and adjacent low ridge.	Upper intertidal parts of dark substrate exposed and partly vegetated at shoreline, with a few small patches of pale smooth-textured cobble accumulations visible just above shoreline (may extend further underwater but can't tell due to reflections.	Dark cohesive substrate almost entirely covered in upper intertidal zone by extensive pale-coloured loose cobble beach and backing beach-ridge deposits. (Lower intertidal area invisible through water)	Dark cohesive substrate almost entirely covered in upper intertidal zone by extensive pale-coloured loose cobble beach and backing beach-ridge deposits. (Lower intertidal area invisible through water)
24th Feb. 2019 Near high tide, intertidal zone mostly under-water, but grey substrate faintly observable under water.	Highest (only) parts of darker cohesive cobbly substrate visible in low ridge, WITH more extensive pale coloured smooth-textured loose cobble accumulations visible. Landwards edge of loose cobbles has migrated up to 4 metres landwards since 2015 image.	Upper intertidal parts of dark substrate exposed and partly vegetated at shoreline, WITH a large beach ridge or berm of pale-coloured smooth-textured loose cobbles present over dark substrate in upper intertidal area. Underlying darker cohesive substrate faintly visible in lower intertidal area.	As at 19th Dec. 2015 (above). Underlying darker cohesive substrate faintly visible in lower intertidal area, large pale cobble beach restricted to upper intertidal area.	As at 19th Dec. 2015 (above). Underlying darker cohesive substrate faintly visible in lower intertidal area, large pale cobble beach restricted to upper intertidal area
21st October 2021 (MSPP photo point photos only: see also Table 2 and Figure 17)	MSPP1 view left: Part of dark cohesive cobbly substrate exposed intertidally, and showing low ridge still capped by loose pale cobbles (as in 2019).	MSPP2 view left: Part of dark grey cohesive cobbly substrate visible but capped with large pale-coloured loose cobble berm as in 2019 air photo.	MSPP3 view left, MSPP4 view right: Parts of dark grey cohesive cobbly substrate visible in places but mostly covered with large pale-coloured loose cobble beach as in 2019 air photo.	MSPP5 view right: Parts of dark grey cohesive cobbly substrate visible in lower areas, but mostly covered with large pale-coloured loose cobble beach as in 2019 air photo.

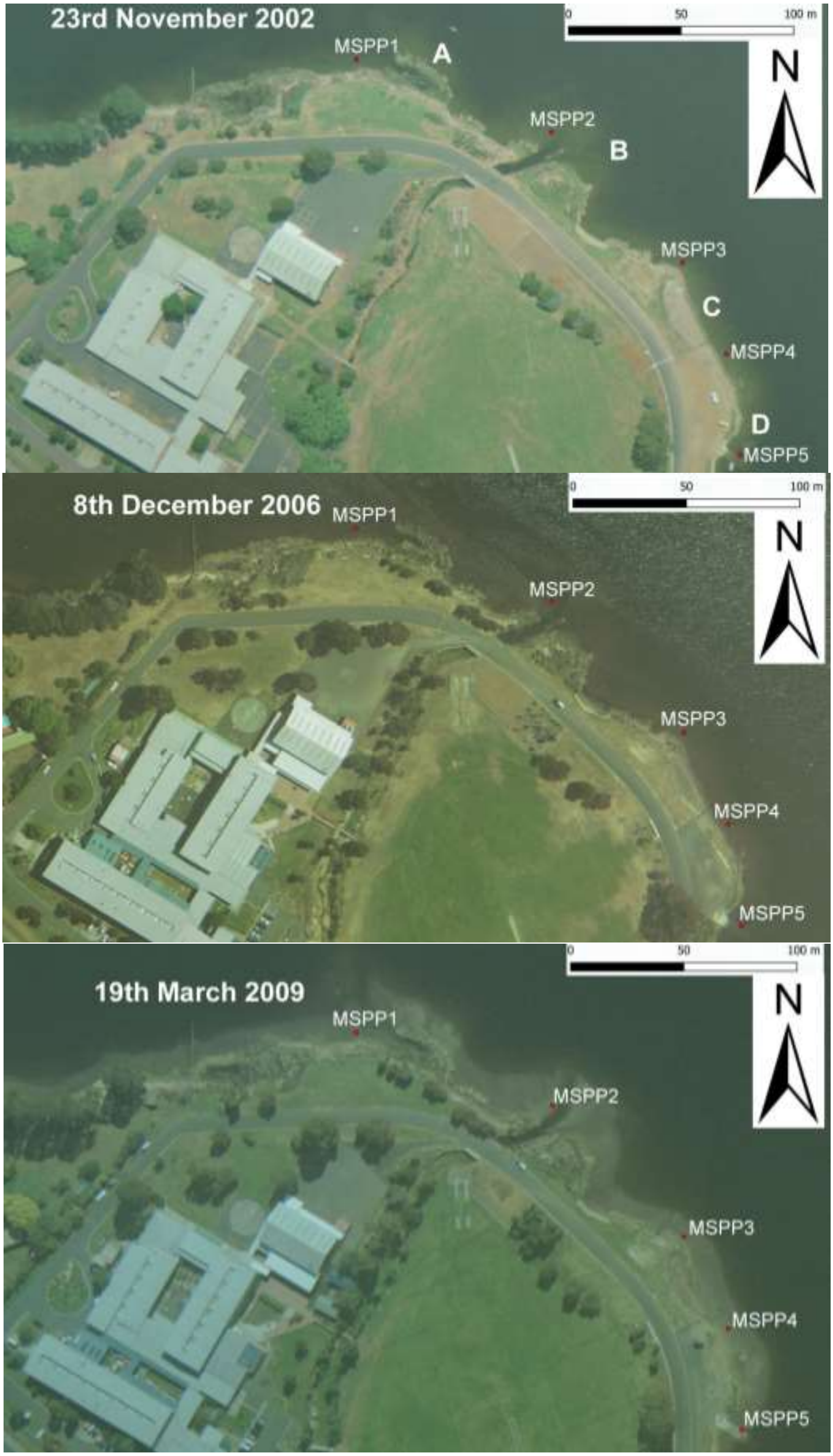

Figure 18: Aerial photos of viewpoints area, Montrose Shore (2002, 2006 and 2009). The location of the five photo monitoring viewpoints whose set-up is described in section 6.2.2 above are indicated on each air photo. Top (2002) photo indicates four locations A – D described in text. Photos © DPIPWE. Zoom in for better detail.

Figure 19: Aerial photos of Montrose Shore study area (2012, 2015, 2019). The location of the five photo monitoring viewpoints whose set-up is described in section 6.2.2 above are indicated on each air photo. Top (2012) photo indicates 4 locations A – D described in text. Photos © DPIPWE. Zoom in for better detail.

4.0 SUSCEPTIBLE SHORELINE TYPES IN THE LOWER – MIDDLE DERWENT ESTUARY

4.1 Introduction

At the time of writing there is considerable interest in providing more ferry-based commuter transport services in the Derwent Estuary. It is not currently possible to predict where these routes might run, but if such ferry services do eventuate there will be good reason to commence Photopoint monitoring of susceptible portions of their routes as early as possible (see also section 5.2 below).

A key criterion in deciding where to locate monitoring photo points will be the identification of shoreline types and substrates potentially most prone to erosion owing to wave attack (including newly introduced boat-wake waves). For reasons noted in section (4.2) below, there are some limitations in using currently available coastal erosion vulnerability mapping of the Derwent estuary for identifying shorelines most susceptible to boat wake erosion. It was beyond the scope of this project to undertake a more detailed level of coastal erosion vulnerability mapping in the Derwent Estuary, however observations made during the work described in this report have yielded a number of insights which will help identify high priority susceptible shores for monitoring in future (see below).

4.2 Susceptibility of shoreline types to wave erosion

It is important to recognise that estuarine (and other) shores susceptible to boat wake (and other) wave erosion are not necessarily simply predicted. The simplest and one of the most important examples is that shorelines mapped as "sloping hard rock shores" have in the past been classified (by the present writer as well as others) as resilient shores with low susceptibility to wave erosion. These shores continue to be mapped as such in, for example, coastal vulnerability mapping prepared by Sharples (2006) and available at www.thelist.tas.gov.au . However, in many cases these shores are mantled by soft erodible soil mantles just above the High-Water Mark, which are frequently reached by storm waves and so commonly show fresh erosion scarps at their seawards margins. Since these eroding soil mantles often support key ecosystems or support infrastructure including roads, paths and pipes, their actual susceptibility to erosion can be a significant issue[3] despite the resilience of their underlying exposed rocky intertidal zones which remain unlikely to be eroded significantly on human time scales.

The following sections identify shoreline types of greater and lesser susceptibility to wave erosion in the Derwent Estuary. Whilst this is not an exhaustive catalogue it is intended to assist in selecting appropriate monitoring locations related to future boat wakes as outlined in section (5.2).

4.2.1 Resilient Shoreline Types

Some shores within the Derwent Estuary are likely to be mostly resilient to erosion by boat wakes. The two most important categories of these are listed below.

Cliffed and sloping hard rock shores

Resilience to wave attack and erosion is most likely where hard rock cliffs plunge into water or where other hard rocky shores (e.g., shore platforms) do not have significant veneers of loose sediment (e.g., cobbles) or overlying soil horizons within reach of storm waves. Examples in the Derwent Estuary include:

- Bellerive Bluff cliffed shore
- Bedlam walls cliffed shore (see Figure 20)

---

[3] The writer has observed non-systematic evidence that similar fresh soil margin erosion scarps are becoming more common on sloping rocky shores in Tasmania (and elsewhere) than they have been in the past. This suggests that the gradual rise in global and local sea-levels over the last century is beginning to result in more frequent erosion of these soil margins by more frequent smaller storms that did not previously reach as high on the shore profile as they now can on today's higher mean sea levels.

Figure 20: Resilient hard cliffed rocky shore with no soil mantle or other readily erodible material within reach of foreseeable wave action. Bedlam Wall (East Risdon area, Derwent Estuary). Shores such as this are unlikely to be significantly eroded by boat wakes in the foreseeable future. Photo by C. Sharples (25th Dec. 2020).

Most artificial concrete or boulder shores

Well-designed and engineered artificial shoreline protection can be resilient to wave attack where they are constructed using robust materials such as large boulders or thick heavy concrete structures. Resilient artificial shores of these sorts comprise much of the eastern (inner) end of Kangaroo Bay. Similarly resilient artificial boulder walls are present behind part of the formerly-eroding sandy beach at Cornelian Bay (Sharples 2003) and at Saunderson's Road (East Risdon: see Figure 23 below).

4.2.2 Susceptible shoreline types

The majority of shores in the Derwent Estuary are either comprised of soft erodible sediments or have significant erodible components associated with otherwise hard resilient shores (e.g., cobble beaches and veneers over a hard bedrock surface). Many of these are potentially susceptible to eroding or mobilising their soft components in response to introduction of boat wake waves. Key types are listed below.

Soil margins over various substrate types

This category has not been widely recognised as an erosion-susceptible shoreline type, since it occurs as a soil mantle over a variety of bedrock and sediment types which are themselves more frequently identified as the shoreline "type". However, the writers' observations on Tasmanian coasts have shown that the soil mantle at its seawards coastal margin is frequently highly susceptible to wave erosion irrespective of the resilience or susceptibility of the underlying coastal substrate exposed in the intertidal shoreline area. Hence, whereas hard rocky shores have in the past been broadly regarded as resilient to coastal erosion, it is now recognised that in many cases their overlying soil mantles are indeed eroding in response to wave attack, and in ways that may threaten coastal assets and infrastructure.

Exposed coastal soil margins are very widespread and occur at the seawards margin of shores of nearly any sort, such as sandy, rocky, and cobbly shores. The erosion of coastal soil margins makes them very susceptible to infrastructure damage since they comprise the zone immediately above and landwards of the intertidal zone, where considerable amounts of coastal infrastructure may exist, such as roads, pathways, pipes and cables.

Two examples of eroding coastal soil margins in the Derwent estuary are described below:

Figure 21: Current soil margin erosion status behind the eastern half of Cornelian Bay Beach. Although a narrow sandy beach is present at this location, the overlying eroding material is not a coastal dune, but rather is a clayey terrestrial soil horizon undergoing storm wave attack at its seawards margin. Photo by Chris Sharples (January 2022)

Figure 22: Recent soil margin erosion on a hard rock (dolerite bedrock) shore in north-eastern Kangaroo Bay. Although this site would typically be classified as an erosion-resistant hard-rock bedrock shore, it is likely that erosion of the overlying soil under conditions of a rising sea-level will be able to proceed a significant distance landwards before the underlying bedrock slope becomes too high and steep to permit further erosion.

Soil margins backing sandy beaches: Cornelian Bay

Cornelian Bay beach is a thin veneer of sand over clayey sediment, and is not backed by an identifiable foredune except at its western extremity. Sharples (2003) described fresh soil margin erosion scarps backing most of the beach and used historic air photos to demonstrate that erosion and shoreline recession behind the south-central part of the beach commenced around 1973. The construction of a sandstone seawall behind the south – central part of the beach shortly after 2003 successfully halted erosion in that area, however soil margin erosion has continued up to the present behind the unprotected northern half of the beach (see Figure 21).

Soil margins overlying hard bedrock shores: Kangaroo Bay

Hard dolerite bedrock shores and a short sandy beach form the intertidal shoreline in part of the north-eastern side of Kangaroo Bay. This area of the bay is directly exposed to south-westerly wind waves generated over several kilometres of fetch across the Derwent Estuary, and exhibits large erosion scarps in the soil horizons directly overlying both shoreline types (see Figure 22 above and also Figure 34 to Figure 36 in Appendix 1). These erosion scarps were present prior to the introduction of the new ferry service to

Kangaroo Bay and are most likely the result of infrequent storm erosion by south-westerly storm wind-waves.

Examination of similar hard-rock shores along the northern side of Kangaroo Bay shows that they tend to retain intact vegetated soil margins where the sloping rocky intertidal zone is steeper (approximately 30° or steeper), with eroded soil margins being more prevalent behind narrower and more gently sloping rocky intertidal zones. This suggests that lower-gradient intertidal zones are likely to more frequently allow storm waves to run-up onto the backing soil margin above High-Water Mark, whereas this is less likely to occur on steeper higher rocky intertidal zones.

Nevertheless, the writers' observations of narrow rocky intertidal areas in the Rose Bay and Geilston Bay areas also indicated little erosion of vegetated soil margins close to the High-Water mark in those areas. In these cases, lesser exposure to long-fetch wind-waves is likely to be a key factor in preventing soil margin erosion.

Semi-lithified or unconsolidated ("soft") *in situ* Quaternary – Neogene sediments (alluvial and colluvial)

As a general rule, shorelines composed of unlithified sediments are likely to be susceptible to wave erosion. These materials may range from muddy alluvial and deltaic deposits (e.g., above Bridgewater) through sands to cohesive but soft sediments of pebble to cobble-grade in a finer clayey silty matrix. The substrate at the Montrose monitoring site is a good example of an erodible cohesive cobble deposit (see Section 3.1.2). Soft sediment deposits of various types are widespread around the Derwent Estuary shores. In many places these are indicated on available 1:25,000 scale geological mapping (e.g., Forsyth & Clarke 1999); however it should not be assumed that all occurrences of shoreline soft sediment deposits ar e depicted on this scale of mapping.

Reworked pebble/cobble shores and beaches

Loose pebble and cobble deposits (with no cohesive silt or clay matrix) are common as superficial veneers on shorelines in the Derwent estuary, and during this project were encountered at both the Kangaroo Bay and Montrose monitoring areas. These materials may range from thin discontinuous veneers on rocky or other shores (as seen on the south side of Kangaroo Bay), to quite large cobble beaches such as those seen on the northern side of Kangaroo Bay (see Appendix One Figure 37 for example).

The results of this monitoring project indicate that these materials are very mobile and may be readily eroded and moved by both natural wind-waves and probably by boat wakes

Sandy Beaches

Sandy beaches are very susceptible to erosion and mobilisation by all types of waves including boat wakes but are of limited extent in the Derwent estuary upriver of the Tasman Bridge. Cornelian Bay beach is perhaps the largest estuarine beach in that region and was undergoing significant erosion (of uncertain cause) up until circa 2003 when a boulder wall was constructed along the western alf of the beach (see Sharples 2003).

Much larger sandy beaches are present in the lower Derwent estuary at Bellerive, Howrah and Nutgrove beaches. These beaches are exposed to significant swell wave and wind-wave action, which is likely to overwhelm and mask the (probably lesser) impact of boat wakes on these beaches. All these beaches have been subject to monitoring by Clarence and Hobart City Councils, utilising aerial photography and at times beach profile surveys (see www.tasmarc.info).

Artificial fill (uncemented)

Artificial fill of various sorts is commonly dumped on shorelines, either in an effort to control prior erosion or to "reclaim" areas for dry-land use. The fills used may vary considerably, but in some cases will be quite susceptible to wave attack and erosion. Two examples in the Derwent Estuary are provided below:

- Coarse rocky (cobble-boulder grade) road fill exposed to wave action at Saunderson's Road (East Risdon) was seen to be eroding in recent years. This was anecdotally assumed to be due to Mona Roma boat wakes, however no monitoring or observations known to have been undertaken.

Figure 23: New seawall constructed circa 2020 at East Risdon, Derwent Estuary. This robust boulder wall protects a shore at Saunderson's Road (East Risdon), which was previously exhibiting significant erosion in the cobble-grade artificial fill visible above and below the new boulder wall. This material was previously directly exposed to the wake waves generated by the Mona Roma ferries which pass through this narrow reach of the Derwent Estuary several times a day. Photo by C. Sharples (21st October 2021).

However, Clarence Council was aware of the erosion and repaired it with an improved artificial stone revetment circa 2019 or 2020 (see Figure 23 above).

- Gravel-grade artificial fill is exposed to wave attack below the TasWater plant on the north shore of Kangaroo Bay and is actively eroding at and above the High-Water Mark level (see Appendix 1, Figure 38). This erosion predates the ferry and is likely to be attributable to storm waves (possibly swell and or local wind waves) especially at high tide. Although monitoring during this project failed to detect any additional erosion, the evident erodibility of this material indicates that it may be susceptible to erosion by boat wakes under some conditions.

Wave erosion has also been reported from under artificial wharves and other shoreline structures at the Nyrstar industrial site at Risdon (Akira Weller-Wong *pers. comm.*). This erosion has reportedly been previously documented by Nyrstar personnel prior to 2014; however, no details could be obtained during this project. The substrate in which the erosion has occurred, and its causes, are therefore unknown. However, given the location it is possible that boat wake erosion of artificial fill used in construction at the site may be involved.

Inadequate Seawalls and Revetments

Under-engineered coastal protection work are common, and frequently result in failure and erosion of the protection works under wave attacks they were not properly designed to cope with. This is often the case with private *ad hoc* protection structures but may also occur with structures built by responsible authorities.

One example occurs close to the Montrose Monitoring site described in Section 3.0, where an artificial seawall south of the monitoring area (near the Montrose Sailing Club) is known to be exhibiting early signs of failure in a few spots.

5.0 RECOMMENDATIONS

5.1 *Ongoing monitoring*

Kangaroo Bay:
It is recommended that the photo monitoring program at Kangaroo Bay be continued at 3-monthly intervals and immediately following any large storm events, particularly with a view to continuing to monitor and better understand the photo point sites where cobble movements were detected in the initial trial program

Montrose Shore:
A first set of photographic views were taken from each photo point, and it is recommended that these be repeated in future at approximately 3-month intervals or after major storm wave events, with a view to eventually analysing the photographic data for any shoreline changes and any indications of the causes of such changes. The possibility of a long-term collaboration on such a project with the adjacent Montrose High School may be a fruitful opportunity for both parties.

It is also recommended that historical information be sought more widely to ideally resolve the origin of the loose cobble deposits at the Montrose shore, which aerial photo analysis suggests have mainly appeared after 2012 (see discussion in section 3.3.1).

5.2 *Future Monitoring*

It is recommended that in the case of new ferry routes or other potential disturbances being proposed which may generate changed wave impacts on shorelines in the Derwent estuary, the following steps be taken to set up photo point monitoring:

1. Determine proposed boat route and identify closest shorelines with highest (most direct, closest) exposure to boat wakes. Whereas hydro-dynamic wake modelling might be the most robust method of predicting where the wakes of proposed new ferry routes might have the greatest impact on shores, this may be a difficult and expensive option in the short term. However, simple map-based visual estimation based on expected ferry routes on the estuary is likely to be sufficient for determining optimum locations for new photo point monitoring sites.
2. On the potentially exposed shores, identify the shoreline types more and less susceptible to wave erosion using existing 1:25,000 scale geological mapping and field inspections (see discussion in Section 4.2 of this report).
3. Set-up and commence photo point monitoring at susceptible locations ASAP in advance of the commencement of the new identified disturbances (see methods described in section 2.2.2).

Note that (as demonstrated by the Kangaroo Bay example to date) it is useful to monitor current weather and wave data for large or extreme wind or wave events during the course of active monitoring projects. Then, if a shoreline erosion event is detected in the photo record, it will be possible to identify any natural events (or absence thereof) which may have caused erosion or shoreline change in between photo dates.

5.3 *Data archiving*

A critical aspect of photo point monitoring is the need to securely archive all photos obtained, and metadata including photo point locations and photo dates. This issue is often neglected and can result in future loss and unavailability of data that might have been of critical importance in future assessments of changes sites.

Arguably a critical requirement for data longevity and access is active ongoing management of the data. One option worth exploring is the possibility of photo monitoring data being incorporated into the existing TASMARC beach monitoring data project (see www.tasmarc.info).

REFERENCES

Bradbury, J, Cullen, P, Dixon, G & Pemberton, M 1995, 'Monitoring and management of streambank erosion and natural revegetation on the lower Gordon River, Tasmanian Wilderness World Heritage Area, Australia', *Environmental Management*, vol. 19, pp. 259-272.

Forsyth, SM & Clarke, MJ 1999, *Sheet 5225 Hobart*, Digital Geological Atlas 1:25000 scale series, Mineral Resources Tasmania.

Sharples, C 2003, *Shoreline Erosion and Coastal Geomorphic Processes at Cornelian Bay, Hobart: An Assessment of Causes and Response Options*, Report to Hobart City council, Hobart.

—— 2006, *Indicative Mapping of Tasmanian Coastal Vulnerability to Climate Change and Sea-Level Rise: Explanatory Report. 2nd Edition*, Department of Primary Industries & Water, Tasmania, Hobart.

—— 2020, 'Identifying attributable physical effects of contemporary climate change-driven sea-level rise on soft coastal landforms', PhD thesis, University of Tasmania, <https://eprints.utas.edu.au/36024/>.

Short, AD 2006, *Beaches of the Tasmanian Coast & Islands: A guide to their nature, characteristics, surf and safety*, Sydney University Press, Sydney.

APPENDICES

Appendix 1: *Kangaroo Bay photo point monitoring records*

This appendix provides:

- The locations (co-ordinates) and descriptive details of the thirteen photo points established and monitored at Kangaroo Bay during August to November 2021. (Table 4), together with downsized reference photographs of the standing viewpoint comprising each photo point at (Figure 24 to Figure 28).

- Downsized and cropped reproductions of the first and last monitoring photos taken at each photo point during this project, showing net changes (if any) at each site over the three-month period of this monitoring trial (Figure 29 to Figure 41).

All the photos referred to above, together with all the original full-size photo point reference photos and the original full-size monitoring photos taken at fortnightly intervals, are supplied in digital format with this report (see Appendix 4).

Table 4: Photo point details for Kangaroo Bay photo-monitoring sites

PhotoPoint	**UTM co-ordinates of PhotoPoint** (MGA Zone 55, GDA94 datum, GPS-derived)	**Site Description**	**PhotoPoint Description**
KBPP1	529833mE 5252287mN	Hard siltstone shore platform backed by hard siltstone cliff. Patches of boulders on platform and erodible colluvial soil accumulations at foot of cliff.	Top of large whitish siltstone boulder (normally dry) amongst other slightly smaller boulders.
KBPP2	529658mE 5252581mN	Hard siltstone intertidal shore platform with thin patchy cobble veneers, backed by artificial stone and concrete wall ~ 1m high, backed in turn by gentle slope of soil over bedrock.	Flat *in situ* whitish siltstone bedrock outcrop, identifiable from surrounding joint patterns.
KBPP3	529672mE 5252842mN	Intertidal sand and cobble veneers with scattered boulders and a few bedrock outcrops protruding; backed by artificial stone and concrete wall ~ 1m high, backed in turn by gentle slope of soil over bedrock.	Large boulder amongst numerous slightly smaller boulders in lower intertidal area.

KBPP4	529674mE 5252926mN	Sandy intertidal pebble/cobble veneer with large dolerite bedrock outcrops and boulders protruding; backed by artificial concrete wall ~1.5m high backed in turn by gentle slope of soil over bedrock.	Middle of concrete jetty at last slab join before seawards end.
KBPP5	529768mE 5253030mN	Intertidal cobble veneer over dolerite bedrock with a few scattered boulders, backed by artificial stone and concrete wall ~ 1.5m high, backed in turn by gentle slope of soil over bedrock.	Top of concrete stormwater pipe in lower intertidal zone (poorly selected – very slippery and usually underwater).
KBPP6	529658mE 5253385mN	Intertidal sandy and cobble beach with dolerite boulders and outcrops at the south (right views) end, backed by eroding soil margin ~1.0m thick with shelly layer (likely midden).	Low flat-topped boulder amongst a cluster of lower-intertidal boulders on mostly sandy shore (photo point mostly wet).
KBPP7	529611mE 5253371mN	Intertidal zone dominantly dolerite boulders and cobbles with several dolerite bedrock outcrops protruding; backed by bouldery soil margin erosion scarp ~1.5m high.	Top of average boulder on a cobble beach with scattered boulders in lower intertidal zone (mostly wet).
KBPP8	529465mE 5253214mN	Intertidal zone is dominated by gently sloping dolerite bedrock outcrops with scattered boulders; backed by scarped (eroding) bouldery soil margin ~0.5m high.	Flattish top of hard-to-pick boulder amongst numerous other boulders in lower intertidal zone (mostly wet).
KBPP9	529298mE 5253168mN	The longest (~50m) dominantly cobble beach in Kangaroo Bay, with minor protruding boulders and possible bedrock outcrops. The intertidal beach is immediately backed by erodible and artificially placed soil, gravel and	Flat (sloping) top of prominent boulder on lower part of cobble beach. Near a few other smaller boulders. Underwater at high tide.

		other construction fill (not currently eroding at KBPP9).	
KBP10	529245mE 5253147mN	Intertidal cobble beach with numerous large siltstone boulders artificially dumped on it from adjacent TasWater works; backed by artificial gravel-soil fill exposed in actively eroding backshore scarp immediately above cobble beach.	Top of smallish boulder amongst numerous similar boulders, can be difficult to pick. In lower intertidal area, generally wet with slippery algae on standing point!
KBPP11	529137mE 5253007mN	Intertidal zone is dolerite cobble beaches (as thin veneers over bedrock) with many dolerite bedrock outcrops protruding; backed by moderately rising soil slope with no recent wave erosion evident at the seawards margin.	Normally dry flat ledge on large protruding dolerite bedrock outcrop in the intertidal zone.
KBPP12	528899mE 5252889mN	Intertidal zone is dominantly dolerite cobble beach, with some dolerite bedrock outcrops protruding; backed by moderately rising soil slope with no recent wave erosion evident at the seawards margin.	Flattish normally dry ledge on large dolerite bedrock outcrop protruding between cobble beaches in the intertidal zone.
KBPP13	528768mE 5253036mN	Intertidal zone dominantly dolerite cobble beach with a few boulders, between bedrock outcrops at either end of beach; backed by moderately rising soil slope with only minor evident wave erosion scarping at north end of cobble beach.	Top of concrete cable housing in lower intertidal area (wet and slippery most of the time).

Figure 24: Reference photographs of photo points KBPP1 – 3 at Kangaroo Bay (two views per photo point). In each case, the arrow points at the red notebook marking the standing viewpoint.

Figure 25: Reference photographs of photo points KBPP4 - 6 at Kangaroo Bay (two views per photo point). In each case, the arrow points at the red notebook marking the standing viewpoint.

Figure 26: Reference photographs of photo points KBPP7 – 9 at Kangaroo Bay (two views per photo point). In each case, the arrow points at the red notebook marking the standing viewpoint.

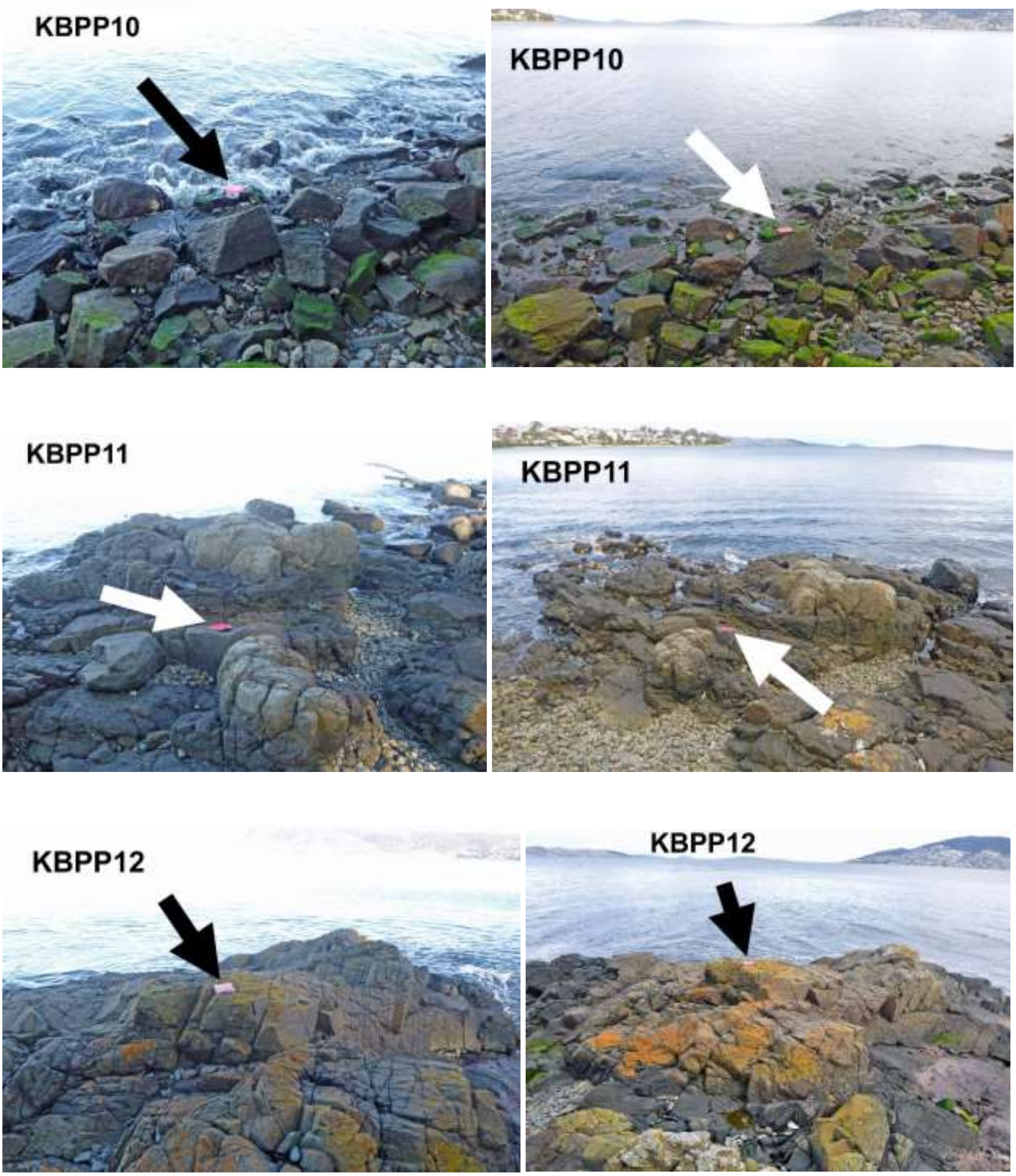

Figure 27: Reference photographs of photo points KBPP10 - 12 at Kangaroo Bay (two views per photo point). The arrow points at the red notebook marking the standing viewpoint.

Figure 28: Reference photographs of photo point KBPP13 at Kangaroo Bay (two views). The arrow points at the red notebook marking the standing viewpoint.

Figure 29: First (8th Aug 2021) and last (12th Nov 2021) photos taken at Kangaroo Bay photo point KBPP1. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. No significant changes detected between first and last photos.

Figure 30: First (8th Aug 2021) and last (12th Nov 2021) photos taken at Kangaroo Bay photo point KBPP2. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. Some changes in cobble distribution are evident between the first and last photos, with scouring of cobbles off the bedrock platform particularly obvious in part of the left-hand view.

Figure 31: First (8th Aug 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP3. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. Changes between first and last photos are negligible, although a great deal of sand and cobbles at this site could be susceptible to wave action.

Figure 32: First (8th Aug. 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP4. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. Note that the last photos (12th Nov) were taken at too high a tidal level to allow proper examination of soft shoreline components present at this site. A lower tidal level than shown here is desirable for monitoring photos.

Figure 33: First (8th Aug. 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP5. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. A notable depletion of the intertidal cobble veneer over the dolerite bedrock is especially noticeable in the final view leftwards as compared to the first view leftwards (top images).

Figure 34: First (8th Aug. 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP6. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. Some removal of cobbles from the lower (foreground) beach face and of shells from the upper beach face is evident in the last photo, together with the presence of larger than normal amounts of seaweed wrack. These changes are indicative of recent energetic wave action, however no significant additional erosion of the soil margin scarp backing the beach face is apparent.

Figure 35: First (8th Aug. 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP7. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. No discernible change evident.

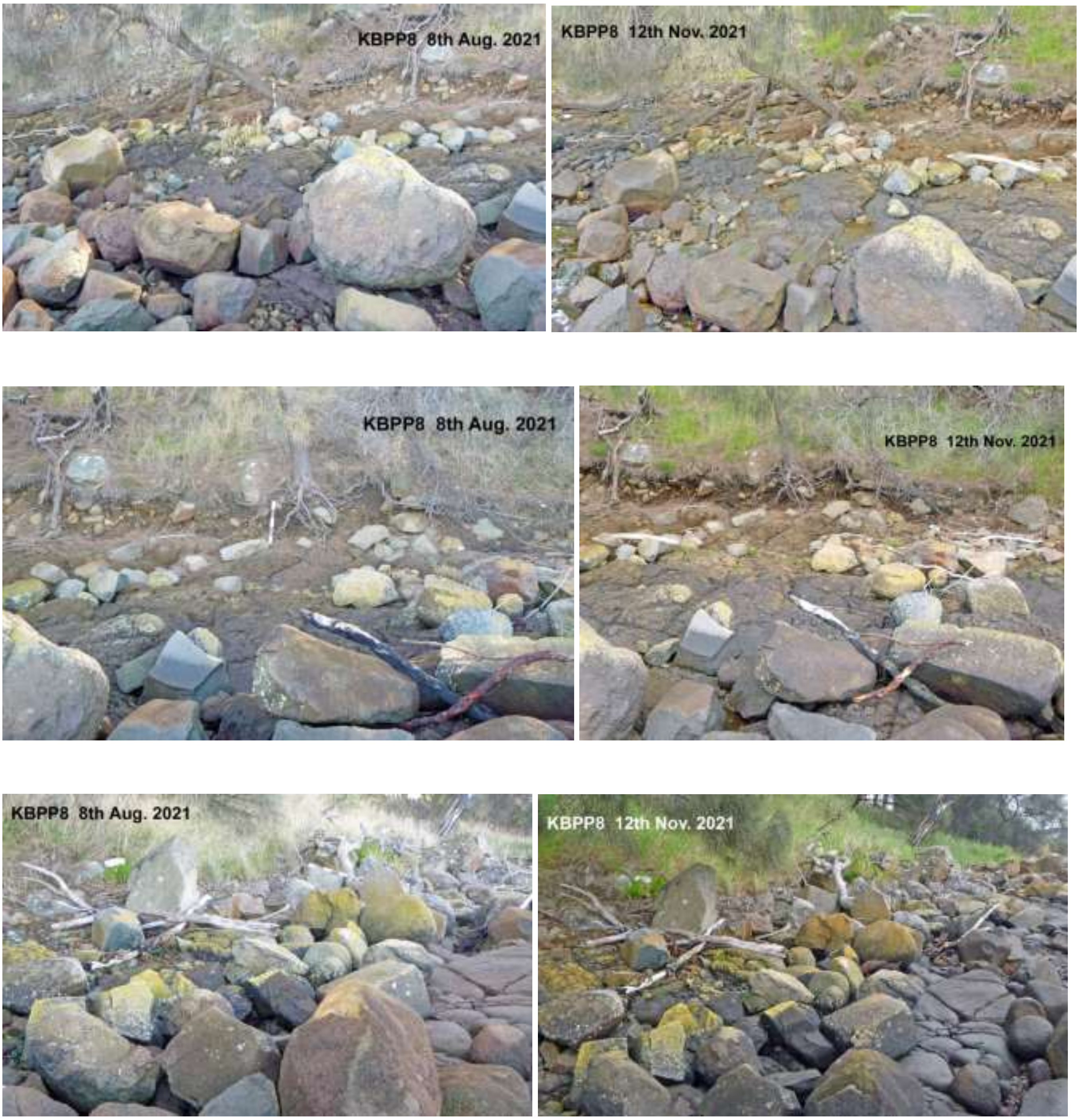

Figure 36: First (8th Aug. 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP8. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. No detectable change.

Figure 37: First (8th August 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP9. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. Minor cobble beach lowering is evident in the lefthand 12th Nov. view, suggesting energetic storm wave backwash has dragged cobbles down the beach profile. However, the onshore and righthand views show little change, with bits of the same wrack (flotsam) evident at the top of the beach in both the August and November onshore views, suggesting storm waves did not reach the back of the beach in that location (only a few metres from the lefthand view).

Figure 38: First (8th Aug. 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP10. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. No changes detected between 8th August and 12th November 2021.

Figure 39: First (8th Aug. 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP11. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. Comparison of the two onshore views demonstrates removal of a significant amount of cobbles (exposing underlying bedrock) which have probably been moved seawards by energetic storm wave backwash.

Figure 40: First (8th August 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP12. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. Negligible change detected despite large area of cobble beach at this site. This suggests that this site was more sheltered from the early November storm waves than otherwise comparable sites such as KBPP11 and KBPP9.

Figure 41: First (8th Aug. 2021) and last (12th Nov. 2021) photos taken at Kangaroo Bay photo point KBPP13. First photos in LH column, last photos in RH column. Views top to bottom are leftwards, onshore, and rightwards. Negligible changes to the cobble beach or soil margin are evident, however the last photos show that several large logs have washed up on this shore; this suggests stronger wave activity prior to the last photo.

Appendix 2: *Montrose Shoreline photo point monitoring*

This appendix provides:

- The locations (co-ordinates) and descriptive details of the five photo points established at the Montrose shore on 21st October 2021 (Table 5), together with downsized reference photographs of the standing viewpoint comprising each photo point at (Figure 42).

- Downsized and cropped reproductions of the first monitoring photos taken at each photo point on 21st October 2021 (Figure 43 to Figure 47).

All the photos referred to above, together with all the original full-size photo point reference photos and the original full-size monitoring photos, are supplied in digital format with this report (see Appendix 4).

Table 5: Photo point details for Montrose Shore photo-monitoring sites

PhotoPoint	**UTM co-ordinates of photo point** (MGA Zone 55, GDA94 datum, GPS-derived)	**Site Description**	**PhotoPoint Description**
MSPP1	521805mE 5259280mN (Lat Long WGS84 = -42.818735 147.266732)	Cobble shore with mobile cobble beaches and beach ridges. Photo point is directly seawards of stormwater drain outlet (blocked with cobbles at time of first monitoring photos)	PhotoPoint is 3.8 metres directly seawards of seawards edge of boulder with coke can in PhotoPoint Reference Photo (see Figure 42).
MSPP2	521893mE 5259247mN (Lat Long WGS84 = -42.81903 147.267819)	Cobble shore with mobile cobble beaches and beach ridges.	Root end of log partly exposed in cobble shore next to stream channel outlet (see Figure 42).
MSPP3	521953mE 5259187mN (Lat Long WGS84 = -42.819563 147.26855)	Exposed semi-lithified cobble deposits (intertidal) with mobile cobble beaches and beach ridges. Near stormwater drain outlet (blocked with cobbles at time of first monitoring photos).	PhotoPoint is 1.3 metres seawards of erosional vegetation line of small “point” (see Figure 42).
MSPP4	521973mE 5259146mN (Lat Long WGS84 = -42.819936 147.268795)	Cobble beach shore with mobile cobble beaches and beach ridges. Photo point is directly seawards of (inferred) stormwater drain outlet (blocked with and buried by cobbles at time of first monitoring photos)	PhotoPoint is 1.7m seawards of seawards edge of boulder with red daypack in PhotoPoint Reference Photo (see Figure 42).
MSPP5	521980mE 5259100mN (Lat Long WGS84 = -42.820349 147.268872)	Cobble beach shore with mobile cobble beaches and beach ridges.	PhotoPoint is in middle of concrete boat ramp, 3.1 metres down (seawards along) central concrete join (groove) from cross-join under red daypack in PhotoPoint Reference Photo (see Figure 42).

Figure 42: Reference photos for Montrose Shore monitoring photo points (viewpoints) MSPP1 to MSPP5 See also details in Table 5. Each photo point / viewpoint is indicated by arrow; see map co-ordinates and further location details in Table 5. Zoom in for better photo details.

Figure 43: Initial monitoring photos from Montrose Shore photo monitoring point MSPP1. Initial monitoring photos dated 21st October 2021 (views leftwards, onshore, and rightwards). This photo point is directly seawards of stormwater drainage outlet or culvert which at the date of these photos was completely blocked by cobble-grade shoreline sediments inferred to have been washed shoreward by wave action (see onshore view). Note that a ring of boulders around the culvert have not prevented the cobbles being washed into the culvert. Zoom in for better photo details.

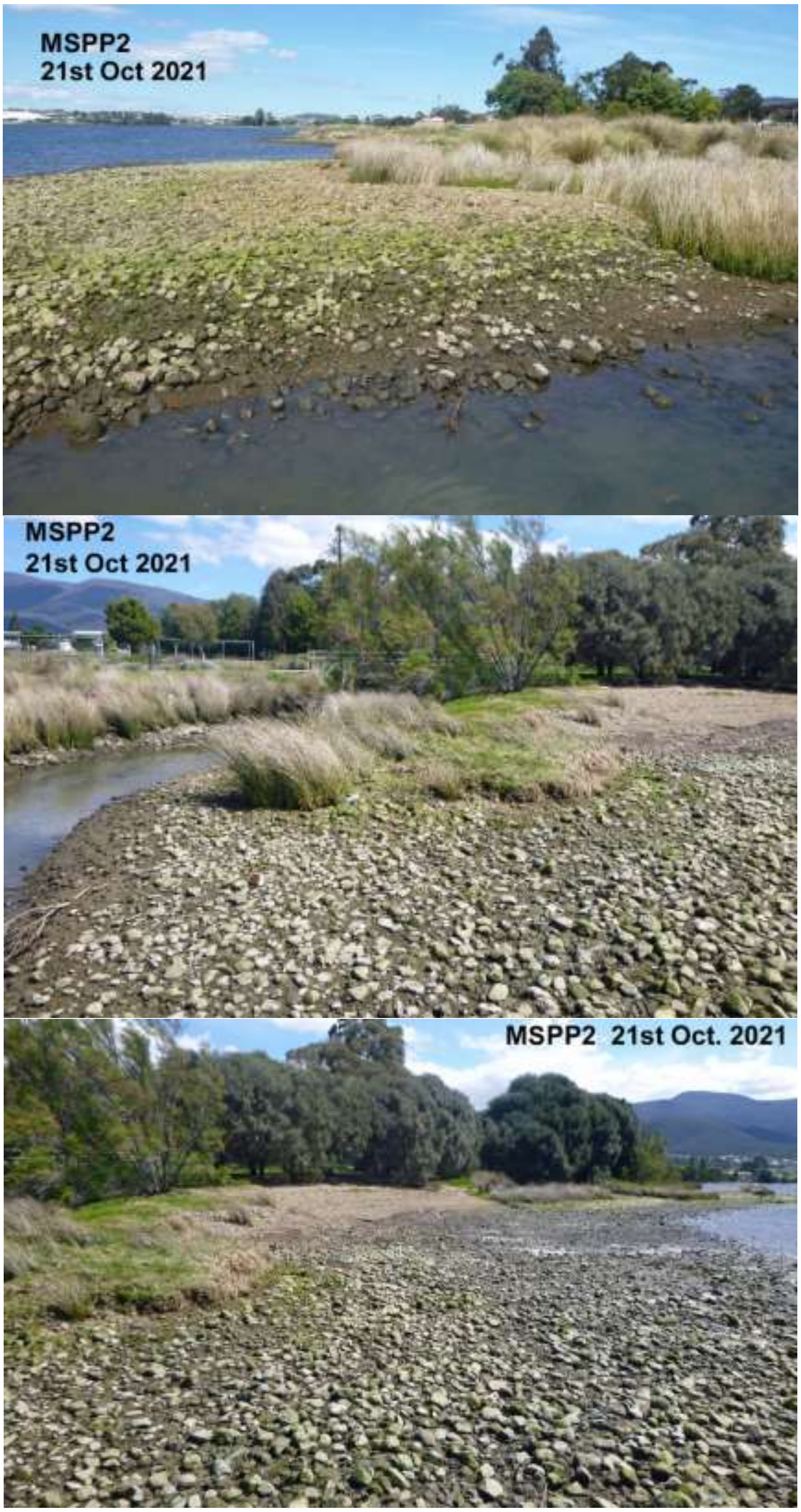

Figure 44: Initial monitoring photos from Montrose Bay photo monitoring point MSPP2. Initial monitoring photos dated 21[st] October 2021 (views leftwards, onshore, and rightwards). Zoom in for better photo details.

Figure 45: Initial monitoring photos from Montrose Bay photo monitoring point MSPP3. Initial monitoring photos dated 21st October 2021 (views leftwards, onshore, and rightwards). This photo point is near a stormwater drainage outlet or culvert (rightwards view, between boulders) which at the date of these photos was completely blocked by cobble-grade shoreline sediments inferred to have been washed shoreward by wave action. Zoom in for better photo details.

Figure 46: Initial monitoring photos from Montrose Bay photo monitoring point MSPP4. Initial monitoring photos dated 21st October 2021 (views leftwards, onshore, and rightwards). This photo point is directly seawards of (inferred) stormwater drainage outlet or culvert which at the date of these photos was completely buried by cobble-grade shoreline sediments inferred to have been washed shoreward by wave action (see onshore view). Note that a ring of boulders around the culvert have not prevented the cobbles being washed into the culvert. Zoom in for better photo details.

Figure 47: Initial monitoring photos from Montrose Shore photo monitoring point MSPP5. Initial monitoring photos dated 21st October 2021 (views leftwards, onshore, and rightwards). Zoom in for better photo details.

Appendix 3: Air photos for Montrose

These aerial photos have been described and analysed for the purposes of this project in section 3.3 of this report. Photos were selected using DPIPWE LIST air photo viewer with scale 12,500 or better, with no sun glare on nearshore waters, and avoiding photos with area of interest on photo edge.

Table 6: Details of aerial photo time series used for assessment of changes at the Montrose shore before and after the commencement of ferry transport to the MONA site circa 2011. See Section (3.3) for further details.

Photo Date	**Original DPIPWE air photos (film-frame) / Ortho-photo name**	**Final image resolution (original scan resolution if downsized) / pixel size of final ortho-photo**	**Original photo scale**	**Mean measured feature position error relative to reference photo (± metres) for ortho-photo** [No. of measured feature position reference points]	**Comments**
23/11/2002	1361-106 (scan: *1361_106.jp2*) / 1361-106_2002ortho.tif/tfw	1000 dpi (2039 dpi) / 0.28m pixel size	1:10,000	1.20 m [8]	Ortho-rectified by C. Sharples (used 2012 ortho for Ground Control Points)
8/12/2006	1410-67 (scan: *1410_067.tif*) / 1410-67_2002ortho.tif/tfw	1000 dpi (2039 dpi) / 0.20m pixel size	1:7,000	0.91m [6]	Ortho-rectified by C. Sharples (used 2012 ortho for Ground Control Points)
19/03/2009	1437-88 (scan: *1437_088.jp2*) / 1437-88_2002ortho.tif/tfw	1000 dpi (2039 dpi) / 0.30m pixel size	1:10,000	0.99 m [9]	Ortho-rectified by C. Sharples (used 2012 ortho for Ground Control Points)
27/01/2012	*Glenorchy_1.ecw / Derwent_Estuary_10cm_2012.tif/tfw*	0.10m pixel size	1:400	0.0 m by convention [n/a] REFERENCE PHOTO	Cropped mosaic ortho-rectified by DPIPWE
19/12/2015	*Glenorchy_19-12-2015.ecw / Derwent_Estuary_10cm_2015.tif/tfw*	0.10m pixel size	1:400	0.52 m [10]	Cropped mosaic ortho-rectified by DPIPWE
24/02/2019	*Glenorchy_10cm_2019.ecw / Derwent_Estuary_10cm_2019.tif/tfw*	0.10m pixel size	1:400	0.48 m [10]	Cropped mosaic ortho-rectified by DPIPWE

Appendix 4: Image files accompanying this report

Images files accompanying this report are listed under their folder names as follows:

> Kangaroo Bay Monitoring Photos 2021 Originals (original photos, all monitoring dates)
>
> Kangaroo Bay Photo Point Reference Photos 2021 (2 photos per photo point at two dates, annotated)
>
> Montrose Monitoring Photos 21st October 2021 Originals (original photos, First set of photos)
>
> Montrose Photo Point Reference Photos 2021 (1 photo per photo point, annotated)
>
> Montrose Orthorectified Air Photos (See details in Section 3.3 and Appendix 3)

Also included are a selection of downsized and annotated versions of some of the photos in these folders.