Chloe Samaratunga
ID 17980660

Wave Energy Dynamics And Coastal Erosion

A Case Study On Narrow Neck Bay, Auckland

2022

Auckland University of Technology
School of Science

A dissertation submitted to Auckland University of Technology in
partial fulfilment of the requirements for the degree of Advanced Bachelor of Science
(Honours)

Table of Content:

Attestation of Authorship:

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed: Chloe Samaratunga 2022

1. Abstract

Coastal zones mark the boundary between land and sea and are actively evolving due the constant movement of waves. Sea waves are a dynamic feature of coastal zones that play a large role in the erosional processes that occur along the coast (Brocx & Semeniuk, 2009). Coastal views and accessibility to beaches is desired by many and has resulted in the suburban development of the coastal cliff edges at Narrow Neck, Auckland, New Zealand (Jongens, Gibb and Alloway, 2006). The properties along the cliff edge are very vulnerable to coastal hazards and therefore understanding the processes and factors of the coastal zone is important for the mitigation of potential hazards. This study aimed to track the waves impacting along the coast of Narrow Neck to determine wave dynamics such as direction, frequency, concentration and refraction, in order to understand wave energy transfer between sea waves and the coast. The link between sea waves and coastal geomorphology was also investigated to understand the wave dynamics observed and determine the influence wave action has on the coastal erosion occurring at Narrow Neck. The study was carried out by collecting both physical and digital field data. A physical geological survey was undertaken at the field location and digital, full motion video (FMV) footage of the coastal waves was captured using an unmanned aerial vehicle (UAV). The analysis was undertaken primarily using ArcGIS Pro software to process the data and produce the visual results. It was found that coastal waves and coastal erosion are strongly interconnected. The coastal wave dynamics of wave direction, concentration and frequency are influenced significantly by the geological landscape. The geological landscape was found to be heterogeneous along the coastline resulting in corresponding variation in sea wave dynamics. Differential erosion is occurring along the coast due to this variation, resulting in the development of erosional features which shape the coastline.

2. Introduction

Sea waves are driven by many factors enabling them to be highly dynamic in the way they move and behave. Sea waves have the ability to carry and generate large amounts of kinetic energy as they travel along the wave fetch (Ellermann, 2008). Waves exert this energy onto the coast when they make contact with the shore. The waves break and energy is dissipated along the surf zone. The dissipation of wave energy onto the coast contributes largely to the erosional process of wave action (Mei & Liu, 1993). The dynamics of sea waves is hypothesised to be a controlling factor in the occurrence of coastal erosion and geomorphic development of the coast. The aim of this study is to track, through full motion video analysis, sea-waves approaching and impacting upon a ~900m section of coastline at Narrowneck Bay with the objectives of determining wave dynamics (direction, frequency, concentration and refraction) to understand the transmission/transfer of wave energy from sea wave to coastline. This information will be combined with field survey data of the geology and geomorphology of the coastal zone to examine the inter-relationships between the patterns of sea-wave energy transfer and relative coastal erosion. The case study location is Narrow Neck in Auckland, New Zealand. This location has a highly developed coastline that is actively experiencing the gradual loss of land due to coastal erosion (Jongens, Gibb and Alloway, 2006). Coastal erosion poses a danger to many people and properties and therefore it is important to investigate the factors that contribute to coastal erosion. The purpose of this study is to better understand the relationship between sea waves and coastal erosion. Understanding how waves influence coastal erosion is important for the development and implementation of effective mitigation strategies.

3. Literature Review

3.1. Wave Theory

Waves are a motion that occurs on the surface of bodies of water. Water swells to form crests along the surface of the ocean due the circular movement of the water moving below the surface (Ellermann, 2008). The distance between each crest is the wavelength. The crests of the waves break when there are frictional interactions between the wave base and the sea floor. The wave break exerts large amounts of energy and force onto the shore which results in the erosional process of wave action. Wave action is a driving factor to coastal erosion and this is because of the large amounts of energy and force waves hold. Earth's oceans are expansive and are the largest solar energy collector on Earth (O Rourke et al., 2010). The Oceans absorb and hold a lot of energy and waves are one way the oceans transfer out some of this energy. Waves are formed by several different forces; these forces include winds, tides, and underwater disturbances (Mei & Liu, 1993).

Wind is the primary driving force of waves. The distance wind blows over water without obstruction is called the fetch. As wind travels over the fetch, it transfers kinetic energy to the ocean (Ellermann, 2008). Larger fetches often build up greater amounts of energy and travel with high velocity. The transfer of kinetic energy from the wind creates circular currents in the water below. These orbital oscillations occurring in the water is what causes waves to form (Mei & Liu, 1993). The circular motion causes water to swell around the orbitals creating crests and troughs which appear as waves (Figure 1). The wind pushes the waves along the fetch until they reach the coast. When the base of the waves touch land there is friction and the orbitals at the base slow down. The orbitals closer to the surface are still moving at a fast velocity and therefore this difference in speed causes the wave to break and the crest of the wave to collapse (Ellermann, 2008). When the wave crashes the kinetic energy that is being held in the wave is dissipated onto the shore.

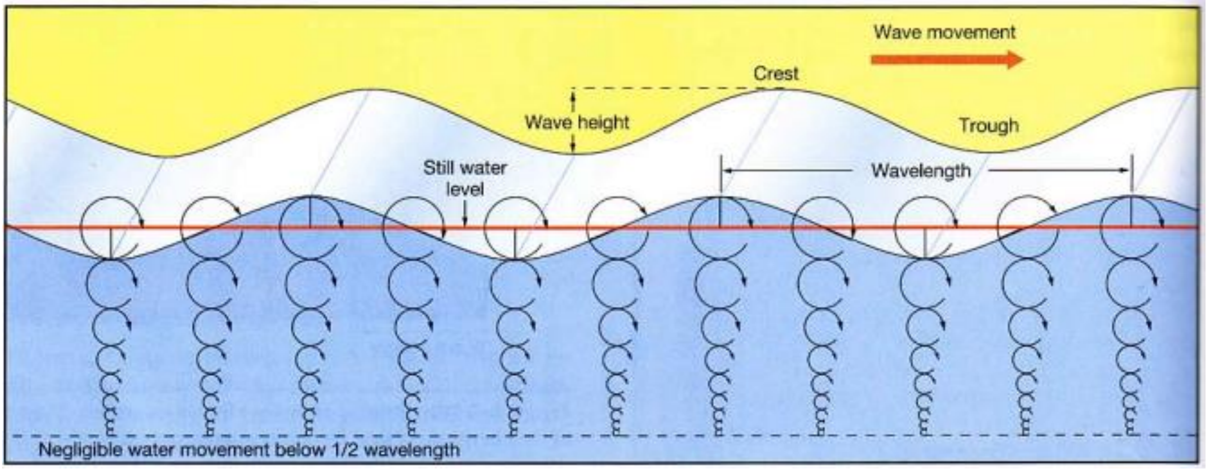


Figure 1: Diagram of the orbitals that drive the movement of waves and key wave parameters - Crest, Trough, wave length, wave height (Trujillo & Thurman, 2005).

Tides are fluctuations in sea level around the world due to gravitational and centrifugal forces (O Rourke et al., 2010). Earth's oceans are pulled towards the moon and sun due to their gravitational force, resulting in high tides where the moon is closest to the earth. The Centrifugal force created by the moon and earth's rotations around a common centre of gravity results in high tides occurring on the opposite side of the earth. Other areas of earth will experience low tides as the water is being pulled away from these areas to create the high tides in the other locations (O Rourke et al., 2010).

The ocean moves via the motion of waves and therefore tides are driven by tidal waves. During high tide, gravitational and centrifugal forces initiate tidal waves that bring in large volumes of water to the coast. During Low tide, the tidal waves are directed at another location (Where the gravitational and centrifugal forces of the sun and moon are strongest). The area of coast between high and low tide is called the tidal range and is the total area where waves crash on the shore and dissipate their energy (Mei & Liu, 1993).

Lastly, waves can also be caused by underwater disturbances. These disturbances include earthquakes, landslides, and underwater volcanic activity. The movement of the sea floor releases energy into the ocean and can trigger waves to form (Pelinovsky, 2006). In extreme cases the waves created would be classified as tsunami waves. Tsunami waves have long wavelengths and low aptitudes which causes them to be extremely large and devastating when they break due to the large amount of energy and force they hold (Pelinovsky, 2006).

Waves are dynamic and move in non linear shapes. Although waves predominantly move in the direction that points to the coast, the waves can be subjected to bending and refracting causing waves to not be limited to movement in straight lines (Munk & Traylor, 1947). The landscape and weather play important roles in determining how waves move towards the coast. Strong wind currents have the ability to alter the direction and angle the waves hit the coast. Large rocks, sandbars, marine platforms and the overall shape of the coastline also impact how waves move (Mei & Liu, 1993). These geological features can cause waves to slow down and break before they reach the coast. This not only weakens the impact the water has on the shore but can also cause waves to refract. Wave refraction occurs when there is a discrepancy in wave velocity (Munk & Traylor, 1947). When the landscape has headlands or large geological features that act as barriers to the coast, the waves directly ahead of the barrier slow down and break on impact with the barrier. The surrounding waves continue moving at a fast speed and as a result of the speed difference, they bend towards the slower waves (Mei & Liu, 1993). Wave refraction is an important process that controls how wave energy is distributed along a coastline and therefore is an important factor for understanding coastal erosion and wave energy (Figure 2).

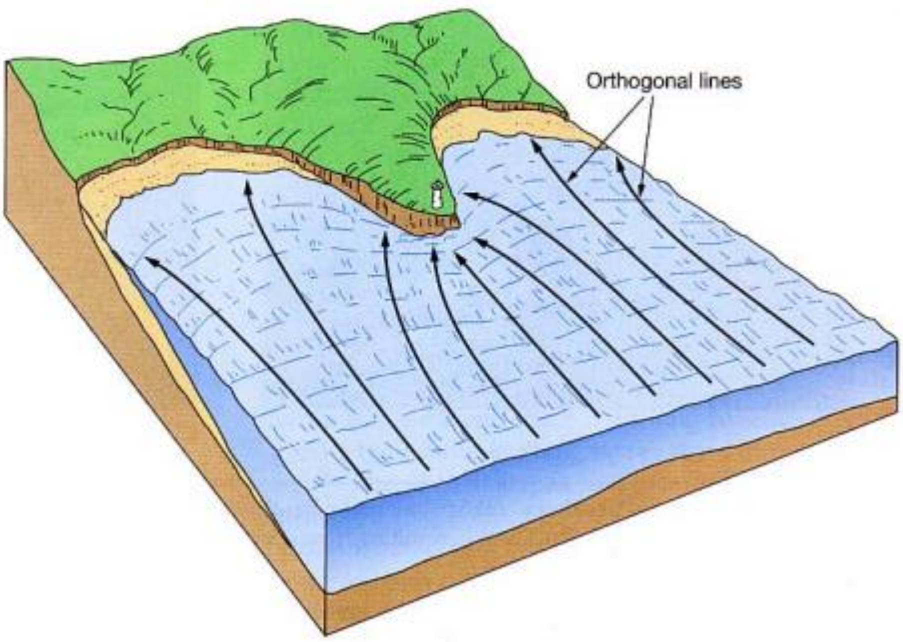


Figure 2: Diagram of wave refraction. Waves bend and target energy heterogeneously along the coast resulting in the formation of geological coastal features such as headlands. (Trujillo & Thurman, 2005)

3.2. Coastlines and Coastline Development

Coastlines are defined as the boundary where the land meets the ocean. These zones are extremely diverse and dynamic due to the variety of erosional and geological processes that occur in these environments.

Oceans cover the lowest parts of the earth's crust due to the force of gravity pulling all mass towards its centre. Water on Earth's surface is drawn downwards resulting in the formation of the world's oceans in the deep basins in the earth's crust (Symonds & Moore, 2000). Due to the large amounts of pressure from the weight of the ocean, the crust is compact and dense and is classified as an oceanic crust. The parts of the earth's crust that remain above the ocean are classified as continental crust (Symonds & Moore, 2000). Coastlines are a transitory boundary between continental and oceanic crust. This boundary between land and ocean is constantly changing and developing. Geological processes are responsible for some of the changes that occur, for example the land could be uplifted or sea levels rise or drop. Erosional processes also contribute to coastline development by producing geological features such as sea arches, cliffs, caves, marine rock platforms, headlands, and gullies. Coastal erosion can also result in cliff recession and the formation of bays and beaches (van Rijn, 2011). The large variation in the features created by coastal erosion is due to erosion not being an independent process. There are subsequent processes that occur as a result of erosion; these processes are transportation and deposition. Firstly, the earth materials that are eroded go through the process of transportation. This involves movement of earth materials away from the site of erosion. Next deposition occurs where earth materials are settled or accumulated. The interconnected processes of erosion, transportation and deposition results in the development of many different coastal zones as earth materials are being removed from some coastlines and deposited at others (Kenny & Hayward, 2013).

Due to all these variables that contribute to coastline development there is large variation in what a coastline looks like. Coastal zones can look like beaches, bays, cliffs, sand dunes or headlands and they can be rocky, sandy or shelly (van Rijn, 2011). The various features seen at the coast are used to differentiate and classify coastal environments into groups. These groups include ‘Drowning coasts’ associated with areas that are experiencing sea level rise and land is becoming submerged, ‘Emerging coasts’ where there has been a reduction in sea level and new land areas are exposed, ‘Erosional coasts’ where coastlines experience limited sediment supply and loss of land, and lastly, ‘Progradational coasts’ where sediment supply is plentiful and earth materials are deposited (Kenny & Hayward, 2013). These categories help determine what are the main processes occurring and how the coastline has and may change over time. A coastline's characteristics exhibits the geological history and unique coastline development of the area and is a testament to the geological and erosional processes that are occurring.

3.3. Coastal Erosion

Coastal erosion is a category of erosion. It is a natural process that occurs at the coast that results in the loss of land (Gibb, 1978). Coastal erosion is not an independent process, it is driven by several different sub-processes which together have the impact to erode away land and sculpt new coastlines. These sub-processes involve a diverse range of biological, chemical, physical, and geological factors (van Rijn, 2011).

Biological weathering is a process that involves the interactions between rock substrates and forms of life. Vegetation growth is a common form of biological weathering that occurs in the coastal zone. The root networks of vegetation often hold on to cracks in the rocks which can apply tension and promote the rock to break into smaller pieces. The weight of large tree canopies can apply immense pressure to coastal cliffs causing them to give way and collapse (Matsukura, 2013). Biological weathering also includes animal and marine life. Birds or other wildlife nesting on cliff ledges can apply pressure to the rocks. Marine life such as oysters and muscles that grow on rocks in the intertidal zone, wear the rocks down and target the cracks and crevices, assisting in the gradual breakdown and erosion of these substrates (Matsukura, 2013).

Chemical weathering is another erosional process that occurs when the substrate undergoes natural chemical reactions due to the environment it is in (Brocx & Semeniuk, 2009). Tidal immersion and spray in the tidal zone contribute to chemical weathering as water can carry minerals and chemicals which can react with exposed rock. These reactions can result in the removal of soluble products which slowly degrade and dissolve the rock (Trenhaile, 2016). Chemical weathering also includes chemical reactions with the air such as iron oxidation. Iron oxidation can result in rocks forming rust which can expand and break up rocks.

Physical weathering is when the rock substrate is directly eroded through physical contact. This type of erosion includes processes such as hydraulic action, attrition and abrasion (Brocx & Semeniuk, 2009). The physical battering of strong winds and rain can cause the rock to weaken and break over time. Hydraulic action is defined as the interaction between tidal action and earth materials (Keaton, 2017). Water is a powerful force that is able to move rocks. The swash and backwash movement of waves throw rocks around in the water and through this action the rocks are ground down and broken into smaller pieces due to the attrition and abrasion they experience (Keaton, 2017). Waves also physically erode away the base of cliffs, undercutting them and therefore impacting the overall stability of coastal cliffs (Brocx & Semeniuk, 2009).

Geological processes also contribute to coastal erosion. The natural faulting and fracturing of rocks create weak points that are especially vulnerable to erosion (Brocx & Semeniuk, 2009). Landslides are the mass movement of earth's materials down a slope. Landslides occur when the cliffs are not structurally stable and the weight of the rocks cannot be supported (Moon,1984). Landslides are a process that rapidly erodes away coastal cliffs due the large volumes of earth material that are removed at once.

3.4. UAVs and Full Motion Video

Unmanned aerial vehicles (UAV) are an aircraft type that is driven autonomously. UAVs operate with a ground based controller that has a communication system with the vehicle. The common use of UAVs is to capture aerial imagery, the UAV can have a built-in camera that can be used to capture high quality imagery from angles and distances that are not possible from land. Full motion video (FMV) is a form of imagery that can be collected via UAVs. Full motion video combines visual and spatial data. For FMV generation, spatial metadata must be collected alongside video data, capturing key flight parameters. The minimum parameters that need to be captured are UNIX Timestamps (also referred to as Precision Time Stamp), Sensor Latitude, Sensor Longitude, Frame Centre Latitude, and Frame Centre Longitude (Esri, 2020). This metadata enables the video frame centres to be pinned to a spatial location. Additional attributes can be collected such as Platform Heading, Platform Pitch, Platform Roll, Sensor Relative Azimuth, Sensor Relative Elevation, Sensor Relative Roll, and Horizontal FOV. These additional metadata attributes can be used to delineate each frame to create camera footprints that mark where the video imagery is located on a map (Madison & Xu, 2010). The spatial aspect of FMV allows the video data to be analysed in a GIS environment which provides many opportunities in how the data can be utilised. The use of UAVs and FMV enable convenient and efficient data collection and analysis. Measurements and quantifications can be taken from the imagery/FMV using GIS systems, reducing the need for multiple trips to the site location for data collection fieldwork (Madison & Xu, 2010).

UAV and FMV technology is being used in many scientific methodologies and has been proven to be a successful method for data collection and analysis. A study on using UAV technology for ecological mammal monitoring in Tanzania concluded that UAV technology provides many benefits in monitoring topographically challenging wildlife areas and is a complementary method to traditional techniques (Mangewa et al., 2019). A 2010 study by Madison and Xu discussed several ways FMV can be utilised to enhance geospatial intelligence, these include providing more accurate coordinates for objects of interest, orthorectified imagery, and visualisation of graphical control measures.

3.5. Case Study Location

Narrow Neck Bay is located on the East Coast of Auckland and is surrounded by the Hauraki Gulf (Figure 3). The Hauraki Gulf runs between the Coromandel and the Auckland region and has over 50 islands within the marine park (Thrasher, 1986). This landscape is a result of coastal drowning. New Zealand is part of the Zealandia continent that has been hypothesised to have undergone crustal thinning and sunk beneath the sea over time (Figure 3). The oceans that surround New Zealand are shallow due the remnants of the Zealandia continent that lay beneath the water. High points of elevation in the Zealandia continent sit above the water and make up the mainland and offshore islands of New Zealand (Campbell, 2013). Many islands in the Hauraki Gulf are a result of the drowning of the Zealandia continent but also many have formed as a result of the region's volcanic activity such as Rangitoto Island, Auckland's largest and most recent volcanic cone (Campbell, 2013).

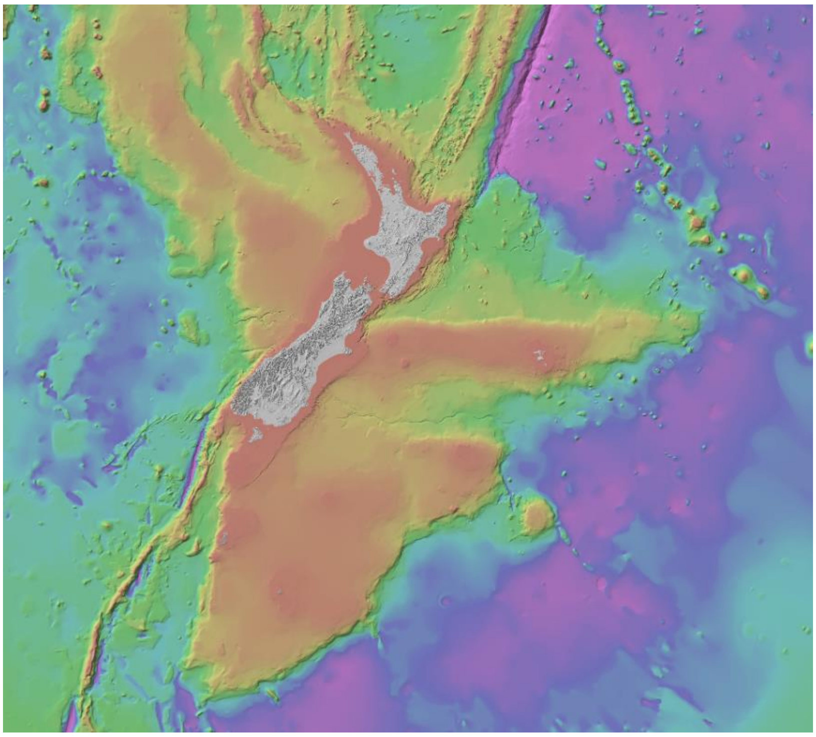


Figure 3: Image of the Bathymetry surrounding New Zealand. Ocean depth is shallow around NZ indicating the hypothesised Zealandia continent that has drowned due to crustal thinning (CANZ, 2008)

The drowned landscape of New Zealand has resulted in the East Coast of Auckland having very protected and shallow coastal waters. There are channels of deep water present amongst the shallow water. These channels were carved into the landscape by rivers prior to the drowning of the land. An example of these channels is the Rangitoto channel that can be seen in figure 4, which travels into the Waitemata Harbour. The many islands of the Hauraki Gulf that surround the coast act as barriers to the mainland as they break the fetch that runs across the South Pacific Ocean and therefore take the impact of the strong ocean waves (Thrasher, 1986). The waves that hit Narrow Neck have a fetch of ~3.5 kilometres with the closest obstruction to the wind being Rangitoto Island. Due to the presence of barrier islands, the waves on the East Coast are low intensity. Weather is a variable that is constantly changing; however, there are strong patterns that have been identified by NIWA. The airflow over Auckland predominantly comes from the southwest. In summer the northeast winds are more present but the south westerlies remain as the predominant wind. The waves on the east coast have less direct force from the wind and therefore are not large with a wave height of ~0.2 metres on average (Pickrill & Mitchell, 1979) . Globally waves tend to travel in great circle paths which results in waves generated south of New Zealand from westerlies ending up travelling northward and up the east coast of the country due to the northeast-southwest alignment of New Zealand (Chappell, 2013) . Tides also contribute largely to the wave climate at Narrow Neck. Narrow Neck has a tidal range of roughly ~40 metres which is an indication of the amount of seawater that is moved due to tidal action.

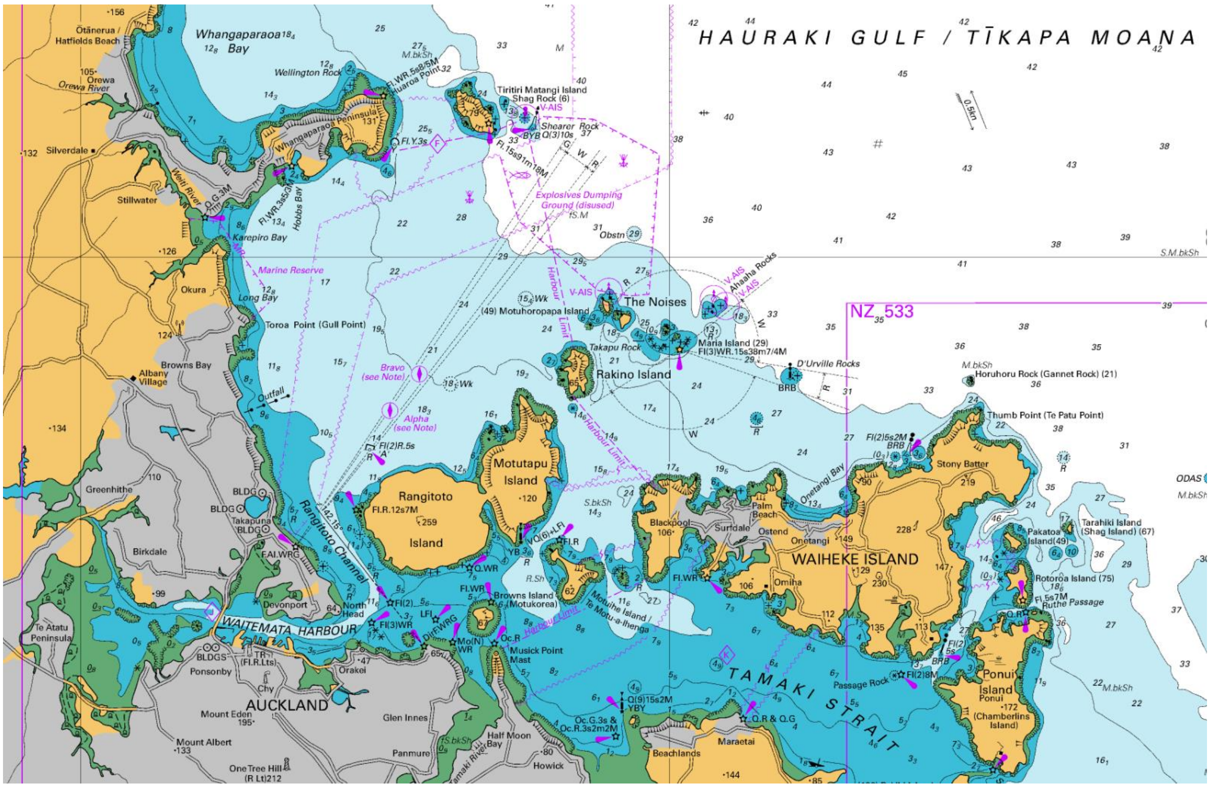


Figure 4: Image of the Hauraki Gulf and the East Coast of Auckland. Waters surrounding the coast are mostly shallow (Dark Blue) with channels of deep water created by old river channels (Light blue channel travelling past Rangitoto Island and into the Waitemata Harbour (LINZ, 2017).

New Zealand is a country that consists of islands and therefore has many coastal areas. Gibb's 1974 geological survey of New Zealand found that almost half of the shoreline is susceptible to coastal erosion. This high susceptibility has resulted in 25% of New Zealand's 10,000km shoreline actively being eroded (Kennedy & Diskson, 2007). Narrow Neck Bay has been identified as one of the areas in New Zealand that is experiencing coastal erosion (Jongens, Gibb and Alloway, 2006). The Auckland regional council found that the East Coast of Auckland is eroding at a rate of 2-4 cm a year from a study that used the marine platform as a geological marker ("Regional Assessment of Areas Susceptible to Coastal Erosion", 2009). There are many factors that contribute to the susceptibility of Auckland's East Coast; however the most significant would be the area's geological properties.

Narrow Neck is underlain by the Miocene Waitemata Sandstone Formation which is the predominant rock unit for the Auckland region (Figure 5). This rock unit consists of a series of marine turbid mudstones, sandstones, siltstones, and conglomerates

(Ballance, 1964). The rock unit was formed in the Waitemata Basin which is located between the Whangarei and Manukau Harbours, and is approximately ~130km by 60km in size (Shane et al., 2010). The basin is described as an inter arc / intra arc basin as volcanic remnants border its west and east margins and horst of Greywacke basement rock bound the north and south ends (Ballance, 1974). The Waitemata Sandstone Formation was created during the lower Miocene time period as a result of deposition from turbidity currents, pelagic fallout, submarine debris flows, siliciclastic and volcaniclastic slumping (Shane et al., 2010). Turbidity currents are underwater flows of water and sediment down a slope. These currents flowed through the Waitemata Basin forming a submarine fan of deposited sediments (Moon, 1984). The sediments were deposited into distinct layers due the difference in weight and density of the sediment material. The heavier and larger sediments would sink to the base of the current and deposit at the bottom of the turbidite, whereas the lighter material would remain suspended for longer and deposit at the top of the turbidite. The rhythmic turbidite sequence that is found in the Waitemata unit is: (1) Large sandstone, rough grains at the base (2) Laminated sands (3) Convoluted sands (4) Ripple-drift-bedded sand (5) Fine, muddy siltstone (6) Very fine sand with ripple-drift-bedding (Ballance, 1964). The turbidity currents would generally have a greater ratio of sandstone material to siltstones resulting in the thickness of sandstone beds ranging from 0.05 m to 1.5 m, whereas the thinner siltstone beds range from 0.01 to 1.0 m in the turbidites (Moon, 1984). In some areas of the basin there are thick layers of volcanic grit and gravel classified as ‘Parnell Grit’ that sit between the turbidite layers. These layers of Parnell Grit are a result of volcaniclastic slumping where slumps of volcanic debris have slid down the slopes of the Waitakere Volcano and were deposited on the basin floor (Kenny & Hayward, 2013). After the Miocene period the area experienced tectonic and volcanic processes which altered the landscape. The basin has experienced uplifting and tilting that has exposed the greywacke basement rock and volcanic eruptions that have created outcrops of igneous rock; however, the Waitemata Sandstone Formation remains the predominant rock type on the East Coast of the North Shore (Bell, 2007). This sedimentary rock is considered a weak rock type as it is made up of uncemented sediment and is highly porous (Moon, 1984). This is evident in the unconfined compressive strength of the rock where it was concluded that siltstone has a strength of \7 MPa and sandstone’s strength is \1 MPa (de la Mare 1992).

Sandstone is slightly stronger than siltstone and therefore differential erosion can be observed in exposed outcrops. Despite the differential erosion, the whole rock unit is weak and susceptible to degradation from erosional processes and therefore Narrow Neck is vulnerable to coastal erosion.

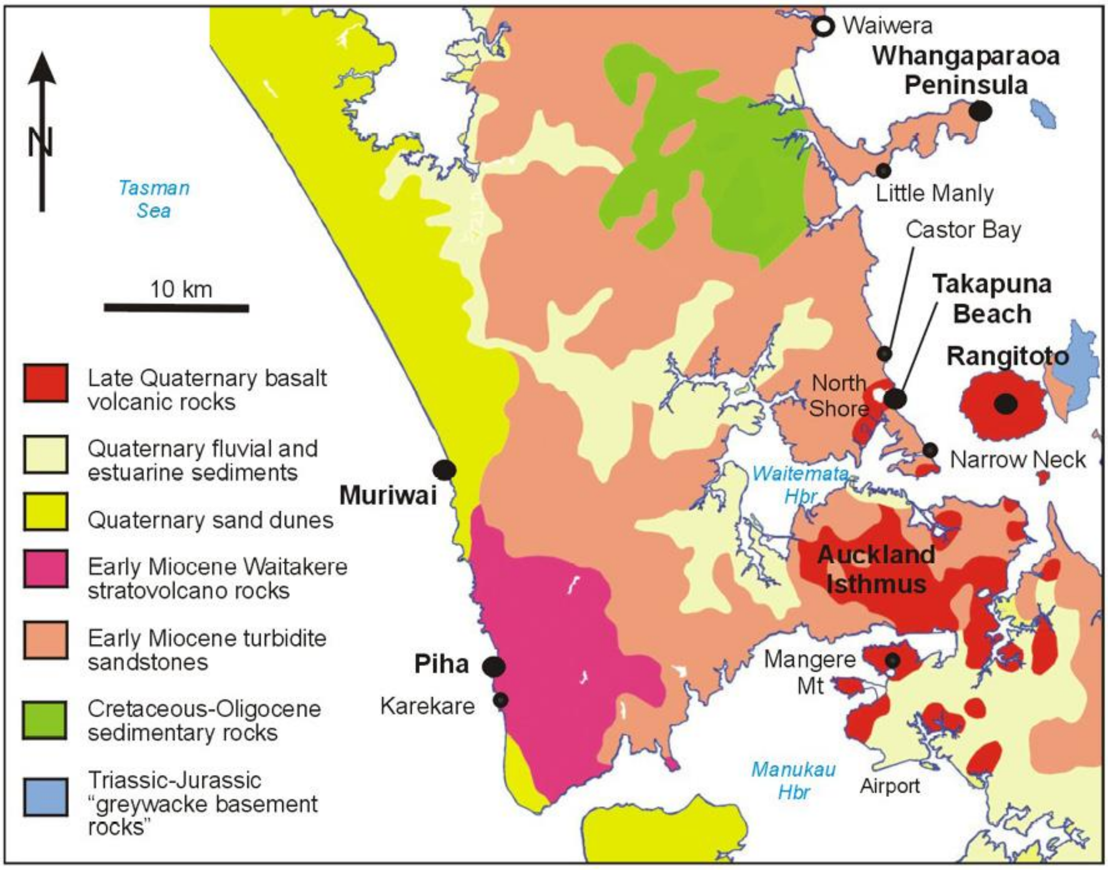


Figure 5: Geological Map of the Auckland region. Narrow Neck is located on the East Coast and is protected by offshore islands in the Hauraki Gulf. The main rock unit in Auckland is the early Miocene turbidite sandstones (Hayward,2017).

4. Methods

4.1. Survey Area

The North Shore of Auckland has one of the most developed cliffed coastlines in New Zealand and is actively experiencing coastal erosion (Jongens, Gibb and Alloway, 2006). These characteristics made this location suitable for a case study as the link between wave energy and coastal erosion could be explored and the highly developed cliffed coastline makes the results of this study extremely valuable as understanding the erosion that is occurring is important for the implementation of mitigation strategies by property owners and the council.

The study involved the use of a UAV to collect the full motion video data in the methods and therefore airspace restrictions had to be considered when deciding on the exact site location. There are many UAV restricted zones along the coast of the North Shore. The North Shore Hospital, Auckland Harbour and Mechanics Bay all have 4km radius aerodromes which overlap with a large proportion of the coast, however there is a ~900m section of coast at Narrow Neck that is free of airspace restrictions (Figure 6). An onsite survey of the area was undertaken to check the suitability of the area in terms of accessibility and presence of geological features. Along the coast of Narrowneck there is a headland that has a width of 20 metres and protrudes 29 metres off the horizontal length axis of the cliffs. This headland was chosen to be the centre point for the transect that was used in the study as it provides an opportunity to see how the waves interact with the various coastal features. The transect studied was 865 metres of coastline, which stretches 700 metres along the horizontal axis of the coast.

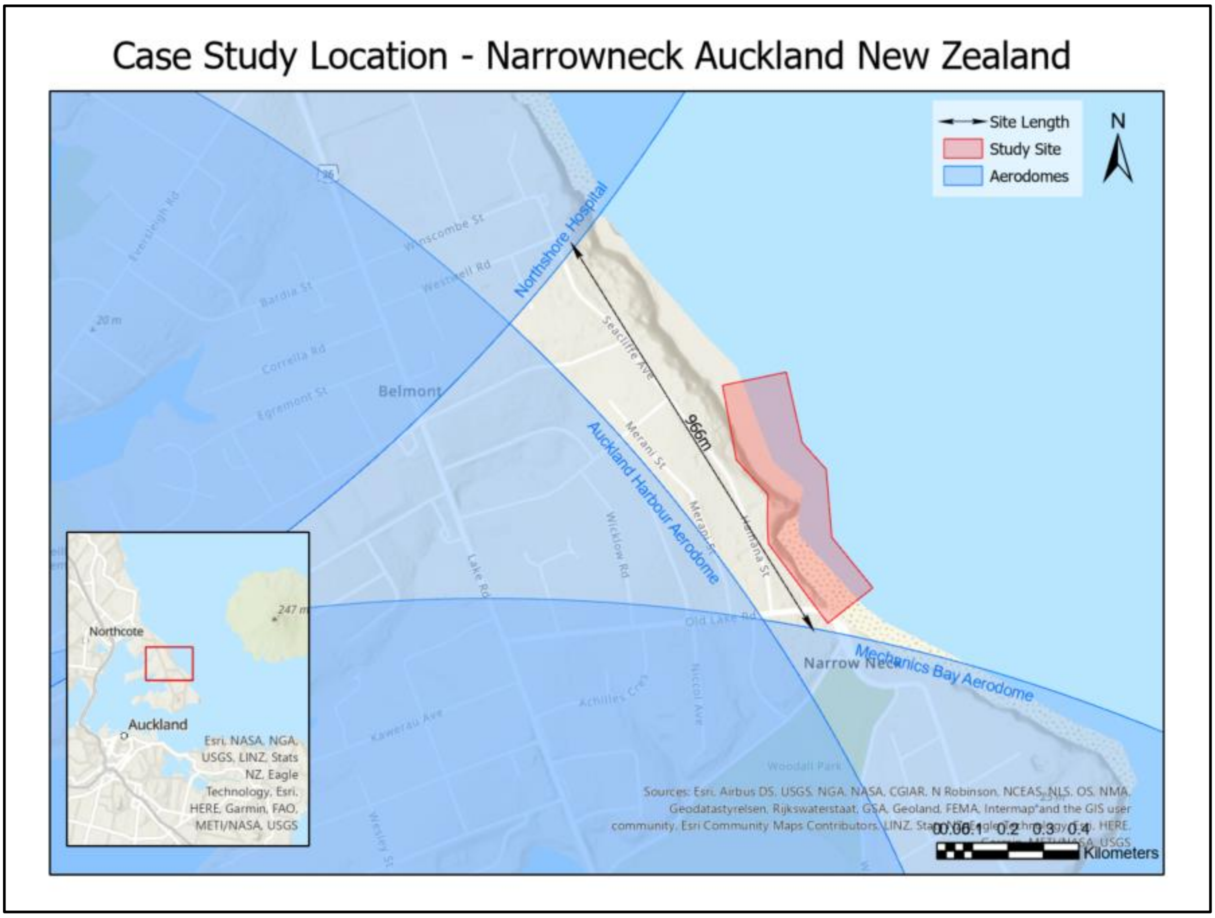


Figure 6: Map of Narrow Neck and the surrounding aerodromes. There is 966 metres of coast that is not under aerial restrictions. Red area is the specific location of the study site. The headland is a significant geological feature that is at the centre of the case study site.

This Wave energy analysis study involved both digital and physical field data. Full motion video was captured via UAV and analysed in a GIS environment to investigate wave energy. A Geological survey was done to understand the interactions the waves have with the landscape and coastal erosion. The Video data and UAV telemetry was captured and processed to FMV by the research supervisor (Graham Hinchliffe) following a proprietary workflow as per Hinchliffe (2021, 2022)

4.2. Wave Analysis Using Geographic Information Systems (GIS)

On-site data collection

Firstly, the area of interest (AOI) for the study was established. The climatic conditions were assessed to ensure it was suitable for aerial flying. The predominant wind was travelling in a North-East direction and moving at a speed of 12 kilometres per hour which equates to a light breeze according to the Beaufort wind scale. The transect was then divided into four sites as the whole site could not fit into one camera frame (Figure 8). Each site was individually captured with the UAV. The unmanned aerial vehicle that was used to collect the video and imagery data was the DJI Mavic 2 Pro (Figure 7). The UAV was operated with manual flights to CAA part101 regulations through the DJI Go 4 app installed on a mobile device. Internal components in the UAV record various telemetry data such as orientation and elevation in addition to the visual video/imagery. This telemetry data is transferred to the phone during the flight. Three flights were taken at each site with different camera angles to provide a variety of frames. Flight 1 had a camera angle of 45 degrees which provided the largest scope of area in its frame, flight 2 was at a 60 degree angle, and flight 3 was at a 90 degree angle which was an orthographic view of the site. Each flight captured video data for 5 minutes in 2.7K resolution. For the data processing the height between the UAV take-off location and sea level is required so this is measured on site with a mobile device.

Figure 7: Image of the DJI Mavic 2 Pro UAV and mobile device that was operated on site to collect the FMV data.

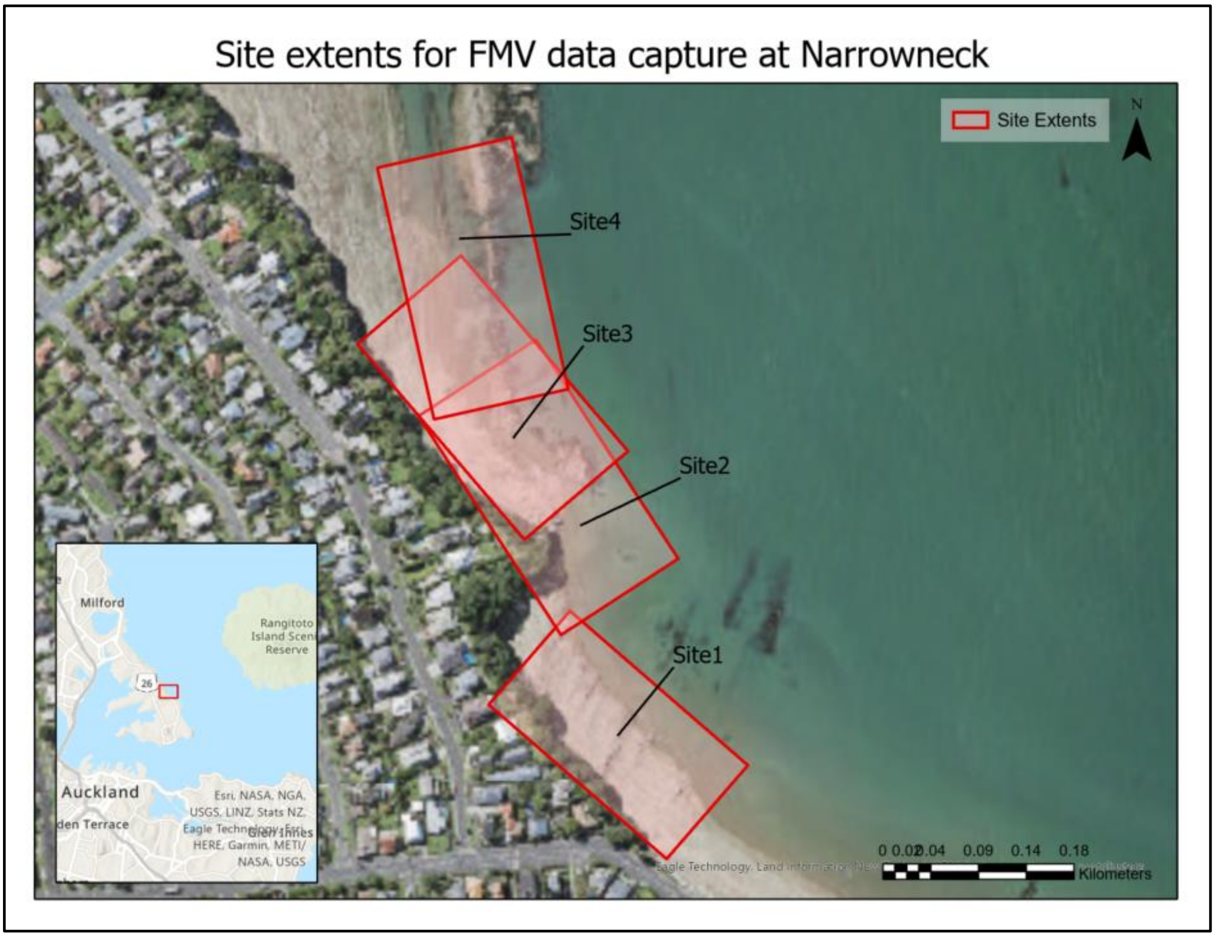


Figure 8: Extents of the 4 sites that were used to capture the Full motion video data using UAV at the study location (Narrow Neck)

Data Processing

The raw video data was then processed and prepared for the analysis using Hinchliffe's (2021, 2022) workflow. The DJI Flight Record .txt log file is copied from the mobile device onto a PC where it is run through a workflow in Python that converts various values from the DJI log into MISB compliant parameters which is then multiplexed in ArcPro to create MISB compliant FMV files. Once the FMV files are created, their height data is corrected to ensure the video is projected as accurately as possible. The UAV records its flying height which is the height the UAV reaches above the take-off location in the telemetry data. The height between the UAV take-off location and sea level that was recorded on-site is used as an offset value and is added to the flying height to get an accurate total height of the UAV. The offset value for site 1 and 4 was 0 metres and the offset value for sites 2 and 3 was 3 metres. The final step of the data editing was to reduce the quality of the FMV files to 1080 high definition to make the file size smaller and easier to process during the analysis. Three videos were taken at each site with varying camera angles. All videos were reviewed and it was decided that the 90 degree angled video would be used in the analysis as the orthographic view would provide the most accuracy when projected onto a two-dimensional space.

GIS Wave Energy Analysis

The corrected FMV data was then imported into ESRI ArcGIS Pro 2.7 software for the data analysis. Using the model builder function in ArcGIS Pro, models were constructed that could iterate the analysis process in sections to allow for efficient data analysis. This GIS analysis firstly created an output of an image time stack of the waves crashing on the coast to see where and how they dissipated on the coast. The first step in model 1 (Figure 9) was to extract frames from the FMV to create a series of images. Using the ‘Extract video frames to images’ geoprocessing tool, frames were extracted from the video every 2 seconds resulting in 150 images per video. The images extracted are multispectral and therefore are made up of 3 bands. The ‘Make raster layer’’ tool was then used to extract band 1 from the images. A raster layer is made of cells, which hold the data values of the image. The raster layers were reclassified into two classes. One class containing the ‘white’ cells of the image and the second class containing the rest of the image. The white cells in the image were separated as the ‘surf zone’ of waves appear white and is the total area where the energy is being dissipated onto the coast. The surf zone in waves appears white due to the way light interacts with the wave when it is in its volatile crashing state. Light scatters when it passes through different materials such as water and air, the surf zone of a wave is made up of an emulsion of tiny air bubbles and water that are created from the wave collapsing in on itself and trapping in air. The air bubbles cause the water molecules to vary in velocity, position and orientation. Light is scattered randomly by the water molecules in the surf zone due to the varying molecule arrangement which causes no light to be absorbed into the water, resulting in the water and air bubbles to appear white. As the surf zone appears white it can be clearly differentiated in the FMV and therefore was used to create an image time stack of the waves crashing and dissipating onto the coast (Figure 10) . The reclassification parameters were experimented with to decide which cell value range would be best to extract the required ‘white’ data. The range of 200-255 was used as these cell values were found to be the most suitable for extracting the white of the waves**.**

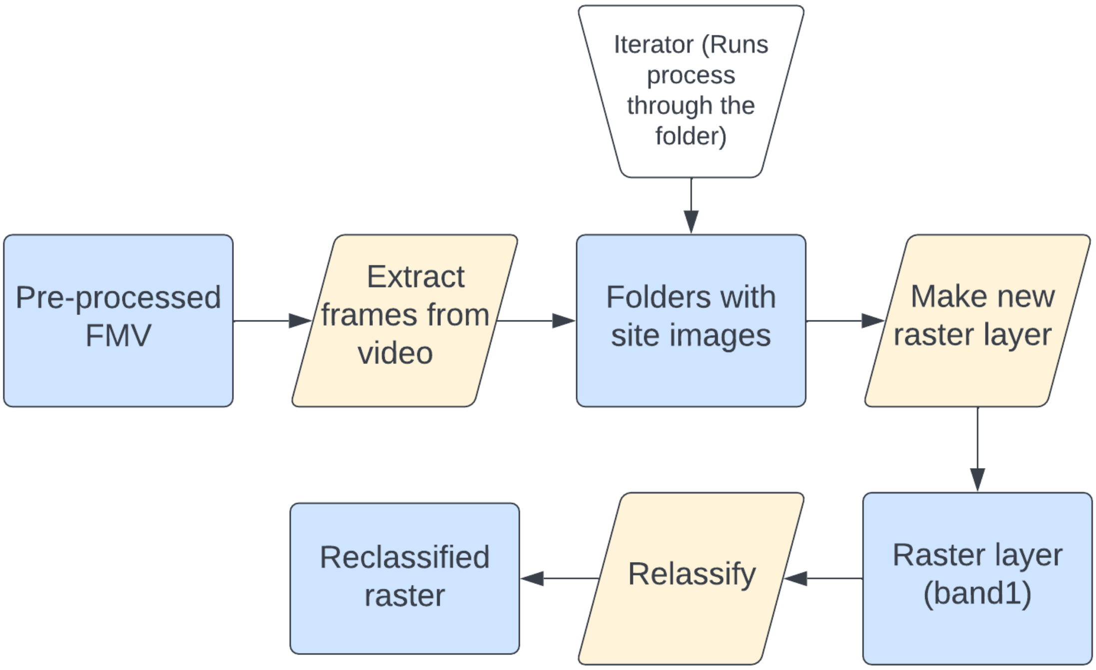


Figure 9: Flowchart of the model used in ArcGIS Pro Model Builder to complete the first section of the GIS analysis. This model extracts images from the FMV and processes the images into raster layers to prepare for the image time stack.

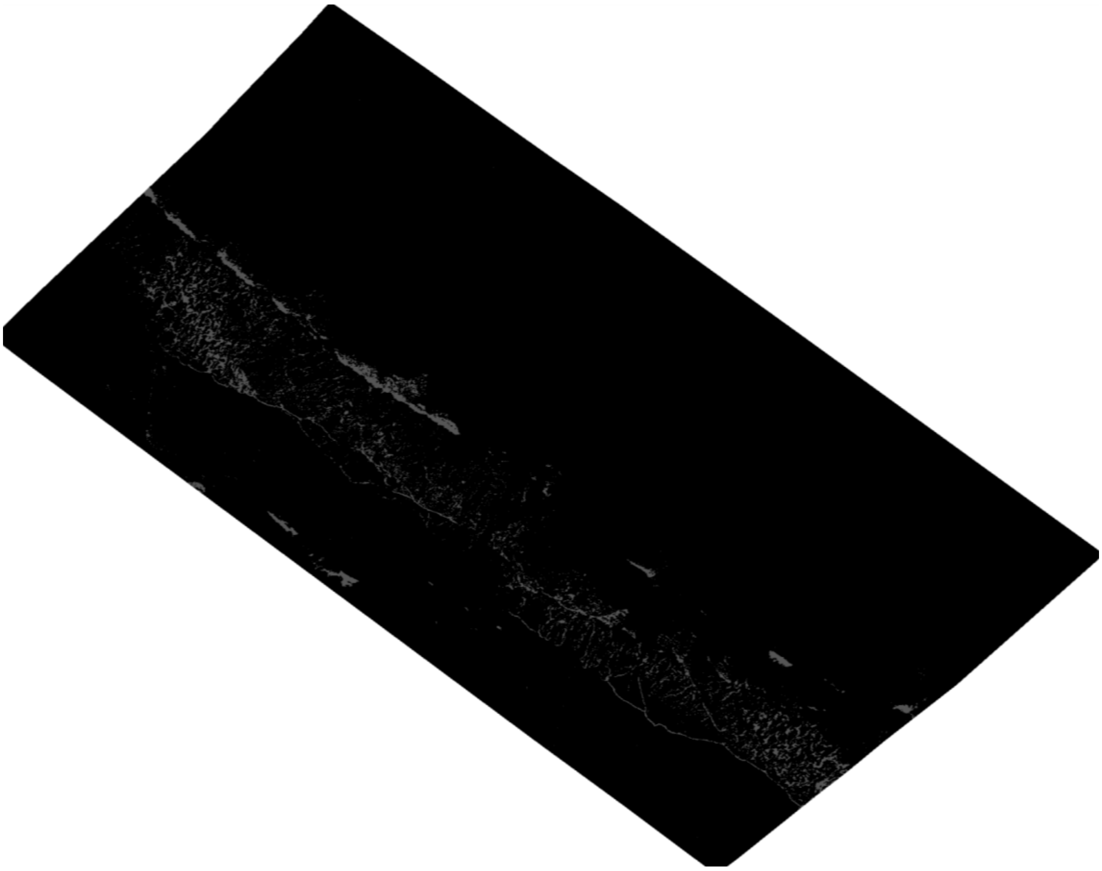


Figure 10: Image of interim stage in the GIS analysis. This is an example of what an output raster looks like after the first part of the analysis. The image has been extracted from the FMV and reclassified so that only areas of wave dissipation have a value (light grey areas).

After the completion of the first model, the current outputs are a folder for each site containing 150 reclassed rasters which highlight the areas of wave dispersion on the coast. These folders are then run through a second model which runs each folder through the 'Cell statistic' geoprocessing tool with the overlay statistic set to sum (Figure 11). This tool overlays all the rasters in the input folder to create a single raster which shows the density of wave dispersion along the coast. The output raster for each site is then reclassified into 20 classes to standardise the scale between the different rasters. A new raster layer was created with the 'Make raster' tool, which has a cell value of zero for the whole raster. This 'zero raster' covers all areas used in this study and was run through a final cell statistic (overlay statistic set to mean) with the individual site rasters to combine the 4 sites together. The output was one raster layer that showed the density of wave action that occurs along the study transect over the measured period of time.

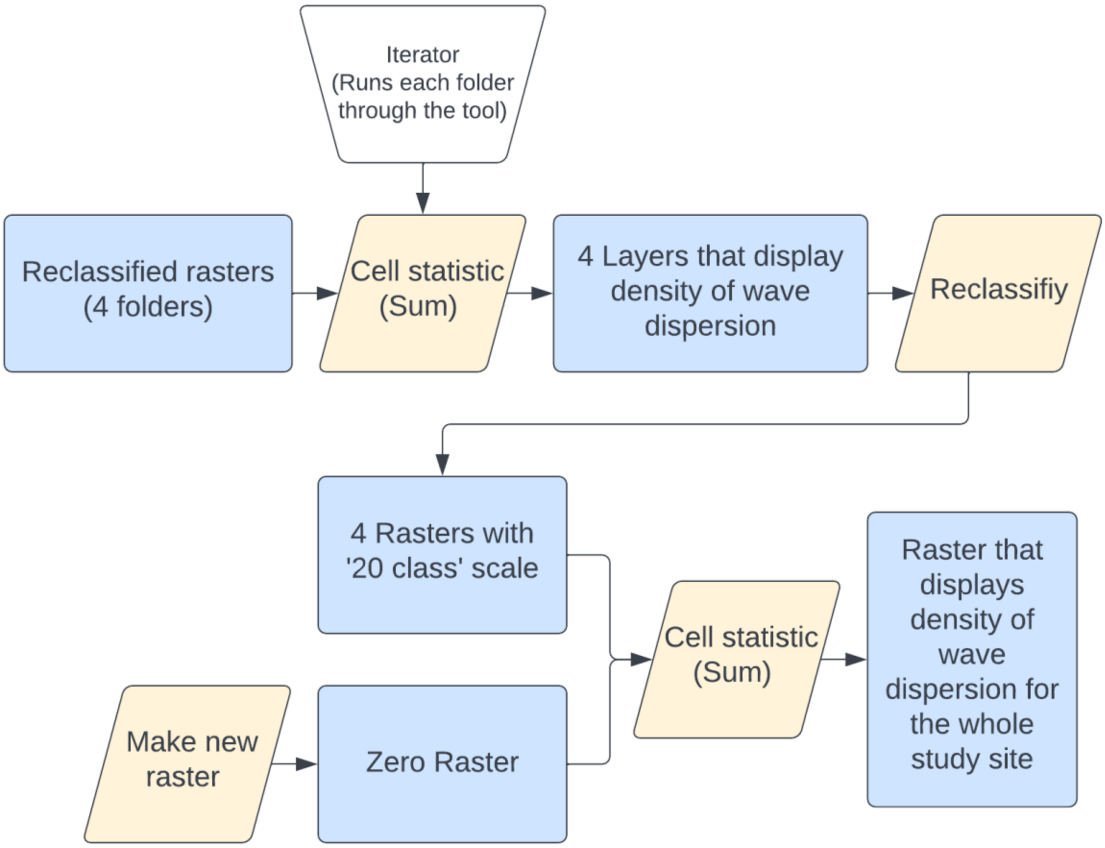


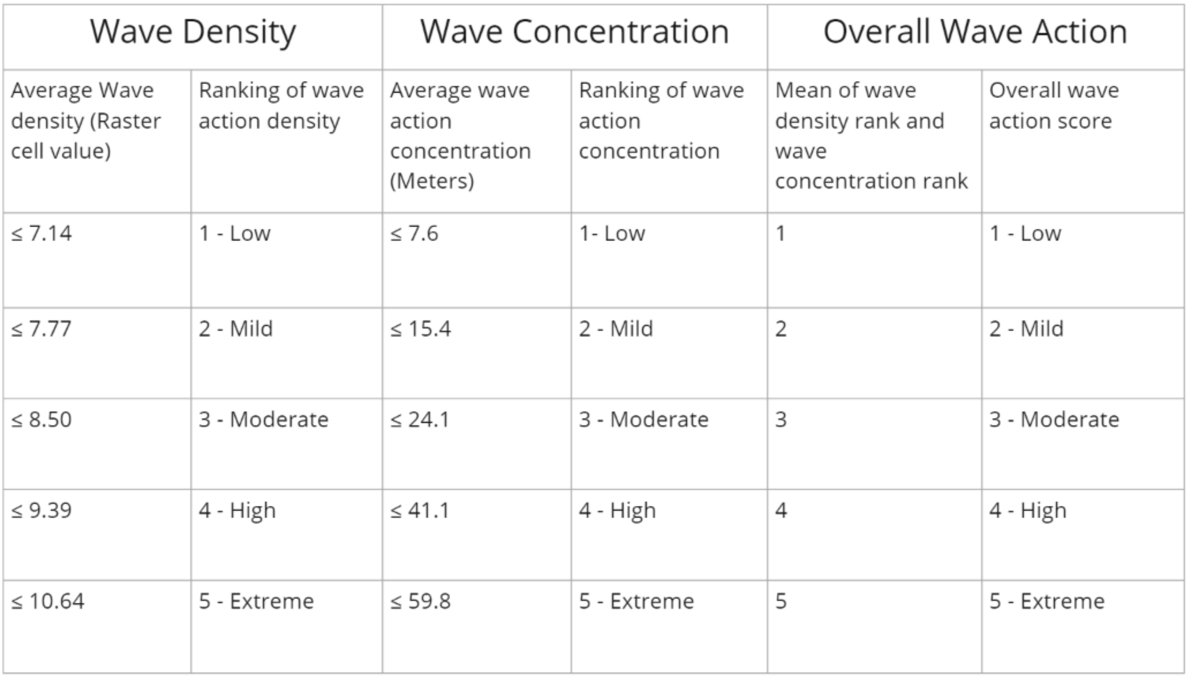
Figure 11: Flowchart of the method used in ArcGIS Pro to complete the second section of the GIS analysis. This section of the analysis creates the image time stack and combines the rasters for the different sites together.

To tidy the data and remove noise, the raster was run through a majority filter to remove any outlying singular cells that have a cell value that do not match its surrounding cells. The layer was then reclassified once more into 6 classes to allow for the data to be clustered by similar cell values. Once the layer was reclassified it was converted into a polygon layer which created polygons around each cluster of cells in the data. The new output still displays the density of wave action that occurs along the study transect; however the area of dissipation that was mapped has been classed into fewer categories making it easier to visually distinguish high, medium and low levels of wave action density.

Now that the layer is in a vector (polygon) form it is easy to manually remove any outliers in the data that were larger than singular cells. When the ‘white cells’ were selected and reclassified from the original raster images, there were a few areas that were not part of the wave surf zone that was selected. These areas include white roofs from neighbouring properties and spots of extreme light reflection. These areas had their polygons either deleted or edited to contain an appropriate value to match the surrounding area. Once the data had been cleaned and symbology was applied, the layer was used to create figure 6, one of the final results of the study.

This result was then translated using an index to quantify the wave energy concentration, wave energy density and the overall level of wave action occurring along the coast (Table 1). The index that was used has been designed and created for this study and therefore the scale of the index is relative to the local environment at Narrow Neck. The input values for the index relate directly to the results produced in the image time stack - wave energy analysis. The index translates the data into a ranking system to determine how wave energy is distributed spatially along the Narrow Neck coast.

Table 1: Index used to determine the level of wave density, wave concentration and overall wave action for the local environment of the case study location, Narrow Neck.



Wave Density		Wave Concentration		Overall Wave Action	
Average Wave density (Raster cell value)	Ranking of wave action density	Average wave action concentration (Meters)	Ranking of wave action concentration	Mean of wave density rank and wave concentration rank	Overall wave action score
≤ 7.14	1 - Low	≤ 7.6	1- Low	1	1 - Low
≤ 7.77	2 - Mild	≤ 15.4	2 - Mild	2	2 - Mild
≤ 8.50	3 - Moderate	≤ 24.1	3 - Moderate	3	3 - Moderate
≤ 9.39	4 - High	≤ 41.1	4 - High	4	4 - High
≤ 10.64	5 - Extreme	≤ 59.8	5 - Extreme	5	5 - Extreme

To apply this index, the visual result produced from the image time stack must undergo a secondary analysis using ArcGIS Pro. Firstly, the study transect is divided into 20 metre sections and is made into attributes for a new polygon feature class. This ‘index’ feature class is then run through a zonal statistic tool with the cell density raster created in the first analysis. The statistic for the tool was set to mean, the index feature class defined the zones and the raster was the input values. The output of this tool is a layer that has an attribute for each 20 metre section with an average cell value assigned. These values represent the average wave density (Occurence of wave action) each section of coast experienced over the study's measured period of time. These values were then classified into 5 classes and then indexed into the 5 ranks of wave density. The second factor of wave action that was indexed was wave energy concentration. The concentration of wave energy can be inferred from the width of the surf zone. The size of the surf zone indicates how large the zone of dissipation is. When the dissipation is spread over a large area, the amount of energy that is being exerted will have a lower concentration and therefore width is used as a measure for wave concentration. Using the measure tool, the width of the surf zone is measured three times for each 20 metre section of coast. The width measurement is taken perpendicular to the study transect line. The average for each of the 20 sections is calculated and then added to the corresponding attribute/section of coast. The average wave width is then classed into 5 groups and indexed into the 5 ranks of wave concentration. The final index takes into consideration the wave action density ranking as well as the wave energy concentration ranking to give sections of the coast a score that determines whether the overall wave action is extreme, high, moderate, mild, or low. This score is calculated from the mean of the 2 rankings which are then indexed into the 5 overall categories.

GIS Wave Tracking Analysis

The FMV data was also used to carry out a wave tracking analysis to determine if there is wave refraction occurring and to what extent. This analysis was carried out in a GIS environment using Esri’s ArcGIS Pro software. The pre-processed FMV data was firstly loaded into ArcGIS Pro and then opened into the built-in digital video recorder (DVR). The DVR acts as a video player for the FMV data. In the DVR there is the ability to add graphics or annotation layers on top of the FMV. This tool was used to undertake the wave tracking analysis. The 90 degree orthographic angled videos were selected for this analysis and were played via the DVR and paused every 15 seconds. Using the annotation tool, a line feature was drawn on top of significant wave crests that were visible in the paused frame (Figure 12). This process was repeated throughout the duration of the FMV. This method resulted in the tracking of the wave crest and showed how the waves moved and changed as they approached the shore over time. The wave crests were identified and tracked for each of the four individual study sites. The spatial metadata of the FMV pins the video to an exact location which is used as a base to derive the spatial location of the features drawn on top of the video frame. The spatial information attached to the annotation line features enables the features to be mapped. Once these features are mapped, wave direction and angle could be inferred.

Figure 12: Image of the interim stage in the GIS wave refraction analysis. This is an example of line features being drawn on top of wave crests to track the wave's movement and patterns.

Firstly, the general wave direction was determined. Areas where the wave crest lines ran parallel to each other were grouped together. There were 4 main clusters that ran along the coast of the study site. The first was located on the northern end of the study site, the next two groups were on either side of the headland and the last group was along the southern end. Line features were then drawn perpendicular to the wave crest lines along the coast. These perpendicular lines resemble the main direction the waves were travelling. The second wave attribute that was determined from this analysis was wave angle. The average angle of the wave crest was calculated for the 4 identified groups of waves as each group shared a similar wave direction. For this angle measurement, North was considered 0 degrees and the angle measurement was taken between the north point and the wave direction lines drawn in the first part of the wave refraction analysis. This measurement was taken using the measure (Angle) tool in ArcGIS pro. The general wave direction and general wave angle for the different areas of the coast was displayed spatially on a map. This map displays the local behaviour of the waves which enables the occurrence of wave refraction to be identified. If the direction and angle of the waves is not homogenous along the coast and there appears to be a pattern of wave bending then wave refraction is occurring.

4.3. Geological Survey and Analysis

On-site Data Collection

The climatic conditions were assessed to ensure it was suitable and safe to carry out an on-site survey. The weather was deemed suitable and the geological data was collected at midday on 29th October 2021 during a low tide of 0.8m. Tidal level is an important factor to be considered as low tide exposes geological features that sit within the tidal range and is the safest time to undertake the survey. The data that was collected on site include both observational and quantitative data.

The area of coast that was examined in the geological survey was the entire study site which is 865 metres of coastline that stretches 700 metres along the horizontal axis of the coast (Figure 6). Firstly an observational survey of the area was undertaken. The study site was walked and significant geological features were identified, photographed, and sketched. The location of these features were recorded as point features on a map using the Esri 'Collector' app to take note of where these features were located exactly as the spatial context of these features are important for understanding their relationship and effect on the waves.

The quantitative data that was collected was measurements of sediment clast size, width of the strata beds in the lithology, and the cliffs profile angles. For the collection of this data it was important to collect data from various locations along the study site to determine whether these attributes vary along the coast to be able to understand how these features impact coastal erosion and wave dynamics.

To account for the potential spatial variation, the study site was divided into 5 smaller study sections. Each section had a 10m transect running perpendicular to the coast, towards the ocean. The measurements were taken along the transect, at each of the 5 sites.

Sediment Clast Size

Sediment clast size was measured at 3 different locations along each of the transects (Figure 13). The first location was at the beginning of the transect, located at the foot of the coastal cliffs. The second was 5 metres down the transect line and the third was a further 5 metres away, located at the end of the transect, towards the ocean. The sediment clast size was measured using a 1 metre by 1 metre square wooden frame and a measuring tape (Figure 14). The frame was placed on the ground at each transect location and the sediment clasts that lay within the frame were measured. Rock clasts are not symmetrical and can have irregular shapes and therefore it was decided that the largest width of each rock clast will be the measurement recorded.

Figure 13: Image of one of the 10 metre transects used to collect the sediment clast size data. Each transect has 3 locations where data was collected.

Figure 14: Image of the 1 metre by 1 metre square wooden frame that was used to select which rocks were measured for the sediment clast size analysis

Lithology

The data collected on the lithology was also collected along the whole study site, however only at location 1 of the transect lines (foot of the coastal cliffs). This data was collected using a mobile device and measuring tape. The mobile device was used to photograph a section of the coastal cliffs. The measuring tape was then used to measure the width of the rock unit's strata. The photograph was then annotated using a digital pen to attach a width measurement to each strata layer captured in the photo. The sediment type of each strata was also identified and annotated onto the image. This was determined by using a 10X21 mm hand lens to examine the grain size of the sediments. The sediment type was either identified as sandstone, siltstone or mudstone.

Cliff Profile

The data collected for the cliff profiles was also at location 1 for the 5 transect lines along the study site. A mobile device was used to photograph the section of the coastal cliff that was being profiled. This image was taken from a side angle to capture the side profile of the cliff in the image frame. Using a digital pen on the mobile device, the general shape of the cliff profile was drawn on top of the image. The angles for each section of the profile drawing were measured using a Brunton Truarc 15 compass and then annotated onto the image.

Analysis of Geological Data

The observational data that was collected was examined and presented with annotations pointing out the important features and relevance the features have to coastal erosion and wave energy. The significant features that were identified were also mapped in ArcGIS Pro using the location data collected on through the Esri Collector app to provide spatial context to the geological features.

The average of the sediment clast size for each location at each transect was calculated from the raw data measurements and was then plotted in a bar graph. This bar graph was appended to a map of the transect locations to provide spatial context to the data and help visualise the patterns observed in the sediment clast size. The lithology data for each transect was examined and there were 2 clear zones in the lithology that were present. The lithology data for transect 2 was used to show the generalised lithology of zone 1 - North and South sections of the coast.

The data for transect 3 was used to show the generalised lithology of zone 2 - Headland.
Stratigraphic columns were produced for each zone using the LithoLogs alpha version 2 online service. The cliff profile data for the transects were examined and 3 clear zones were present: North section, Headland and the South section. The angle data collected for transects 1, 3 and 5 were used to sketch the cliff profiles for the 3 zones identified.

A generalised geological stability map was produced using various geological data. The lithology, cliff profiles, and presence of significant geological features were used to classify the coast into 5 categories to show how the geological properties of the coast vary in strength. Category 1 indicating areas of strong geological properties and 5 indicating areas of weak geological properties. The classification of the coast into the 5 rankings was completed using a qualitative approach. The different geological properties were examined and the coast was ranked based on theory that was tested in previous research that looked into the factors that determine cliff stability (Samaratunga, 2020). The classified coast was displayed on a map using ArcGIS Pro software. The generalised cliff profiles and stratigraphic columns were displayed parallel to the coast on the map.

5. Results

The first set of results from the wave energy analysis are 2 maps displaying the spatial distribution and occurrence of wave action along the coastline. The first output displays the data in raster form and the second output is a more generalised vector version. (Figure 15 & 16). Through these maps it can be seen that wave action occurs along the whole study site with all areas reaching a score of at least 11 in the raster map or 2 in the vector map. The north and south sections of the coast have areas that reach a high rating of wave action (20 - raster map, 5 - vector map). These areas of the coast are subject to wave action and wave energy more frequently than areas that have lower ratings of wave action such as the headland.

Variation between the headland and the north and south sections of the coast can also be seen in how the waves dissipate along the coast. The north and south sections experience a large amount of wave energy dissipation which is shown by their wide surf zones. Whereas the headland has very little dissipation as seen by its small surf zone. A pattern can also be seen in these results, in which wave action appears to occur in the same location and at a higher density where there are large rocks present near the shore.

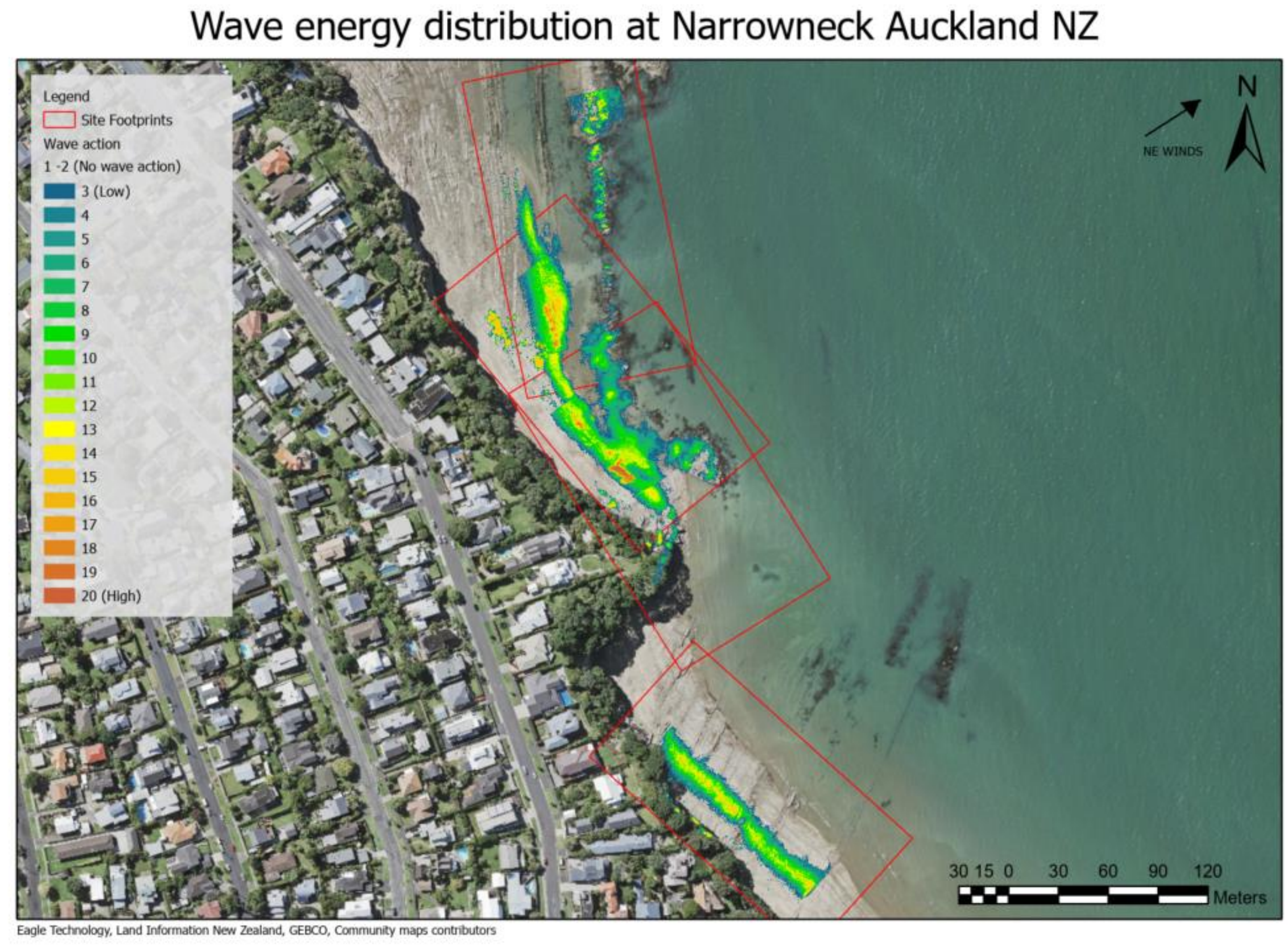
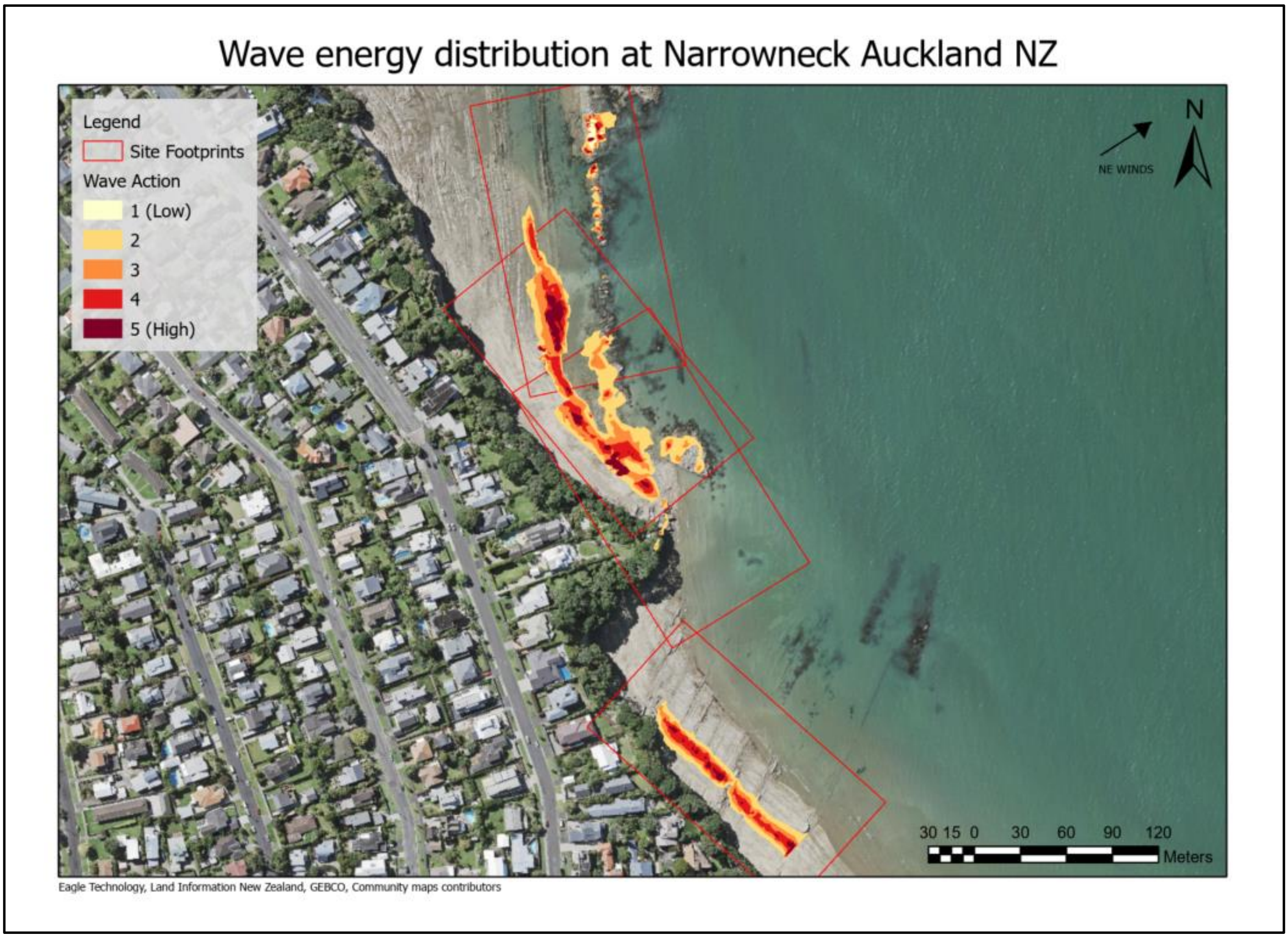


Figure 15: Raster result from the Image time stack - wave energy analysis taken at the study location (Narrow Neck). Map displays the spatial distribution of wave energy dispersion along the coastline as well as the occurrence of the wave action (Low to High scale of wave action).



Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Figure 16: Vector results from the Image time stack - wave energy analysis taken at the study location (Narrow Neck). Map displays the spatial distribution of wave energy dispersion along the coastline as well as the occurrence of the wave action (Low to High scale of wave action).

The second set of results from the wave energy analysis are maps of the indexed rankings of wave density, wave concentration and overall wave action at Narrow Neck (Figure 17). The Wave density map shows how often wave energy is dissipated on the coast. It can be seen that the north and south sections of coast have a high density ranking (3-5) and therefore receive a higher frequency of waves. The Headland on the other hand has a low ranking (1) and therefore is receiving waves less frequently. It was also observed in the results that areas that are not obstructed by near shore rocks experienced more waves.

The wave concentration map displays rankings of the surf/dissipation zone size to determine how concentrated the wave energy that is exerted along the coast is. The dissipation zone at the headland is small in size which is reflected in the high concentration rating of 5. The straight (north and south) sections of coast on the other hand have larger dissipation zones and therefore receive less concentrated wave energy as shown by their lower rankings. The dissipation zone for the north section is divided into 2 areas due to the presence of near shore rocks. This area of the coast has the lowest rankings (1-2) for wave energy concentration.

The overall wave action map shows how the erosional process of wave action varies along the coast. There is large variation in wave action strength seen along the coast. The middle section of the study transect (headland and surrounding areas) appear to receive the lowest ranks of wave action whereas the north and south sections generally have a higher wave action ranking. The headland and middle section of the transect are surrounded by near shore rocks which can act as an obstruction to the sea waves.

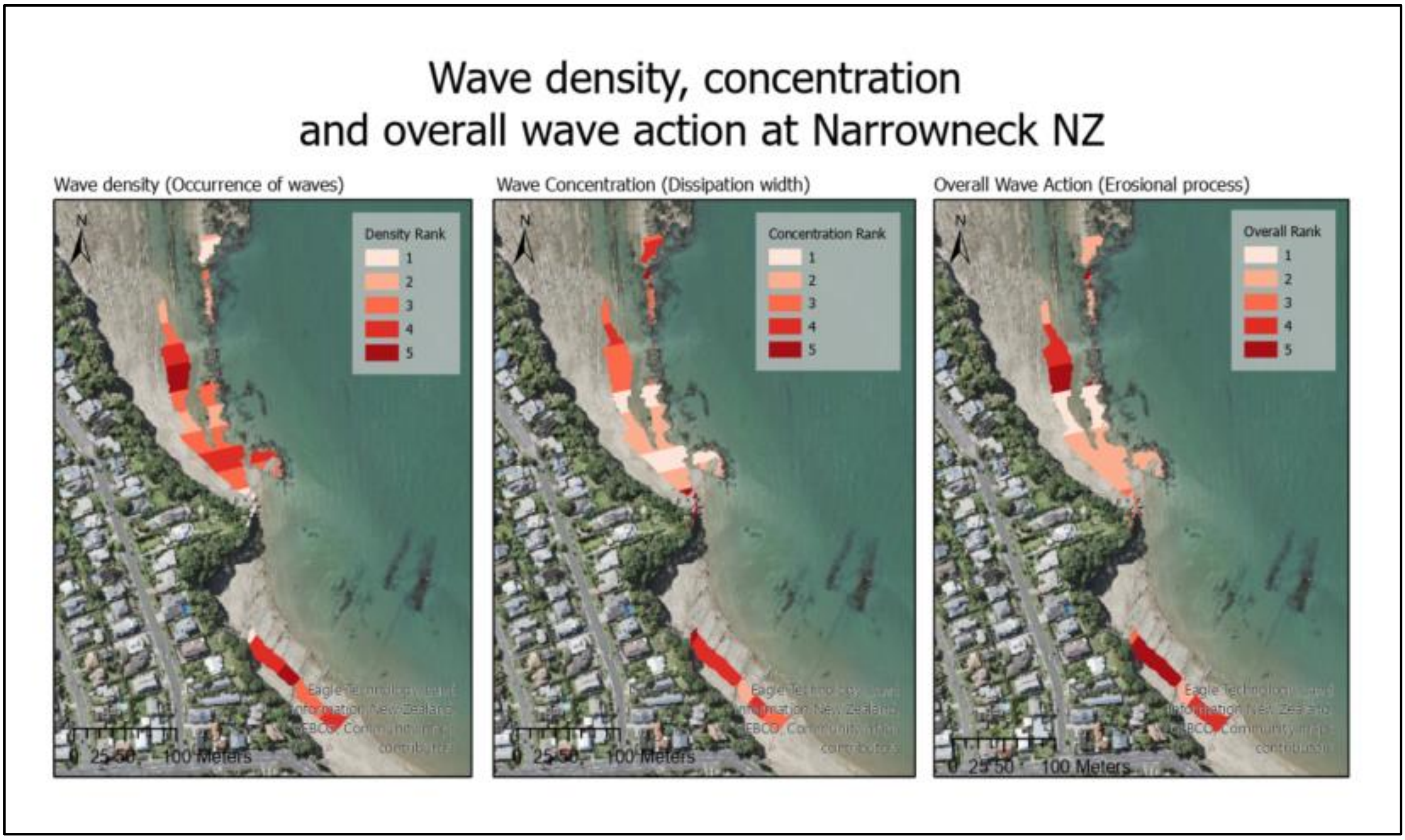


Figure 17: Maps of the Indexed rankings of wave density, wave concentration and overall wave action at the study location (Narrow Neck). Wave density map shows how often wave energy is dissipated on the coast. Wave concentration map displays how spread the surf/dissipation zone is along the coast and the overall wave action map shows how wave action varies in strength along the coast.

The result of the wave refraction analysis was 2 maps as shown in figure 18. The first map displays the digitised wave crests along the coast which demonstrate the behaviour (direction and movement) of the incoming waves. The second map displays the key parameters of wave direction and wave angle along the coast.
In these maps it can be seen that there is variation present in the angle and direction that the waves travel; however, this is a clear pattern that is visible. The waves appear to share similarities in angle and direction with surrounding waves, causing there to be a pattern of ‘clusters’ where the waves share similar attributes. Along the study site there are 4 clusters that can be clearly seen. The waves tracked along the northern section of the study site are a cluster and all appear to be hitting the coast at an angle of 156 degrees. The second group of waves are on the northern end of

the headland, hitting the coast at a 133 degree angle. The next group is on the southern end of the headland with a 175 degree angle and lastly the south section of the study site has a wave angle of 139 degrees. The second map also displays the general wave direction along the coast. The direction arrows represent how the waves have refracted and bent while approaching shore as wave refraction is largely responsible for change of direction in wave movement. The waves in the middle section of the study site bend towards the headland, concentrating more waves onto the sides of the headland. The waves in the north and south sections of the coast appear to move in a linear direction towards the coast.

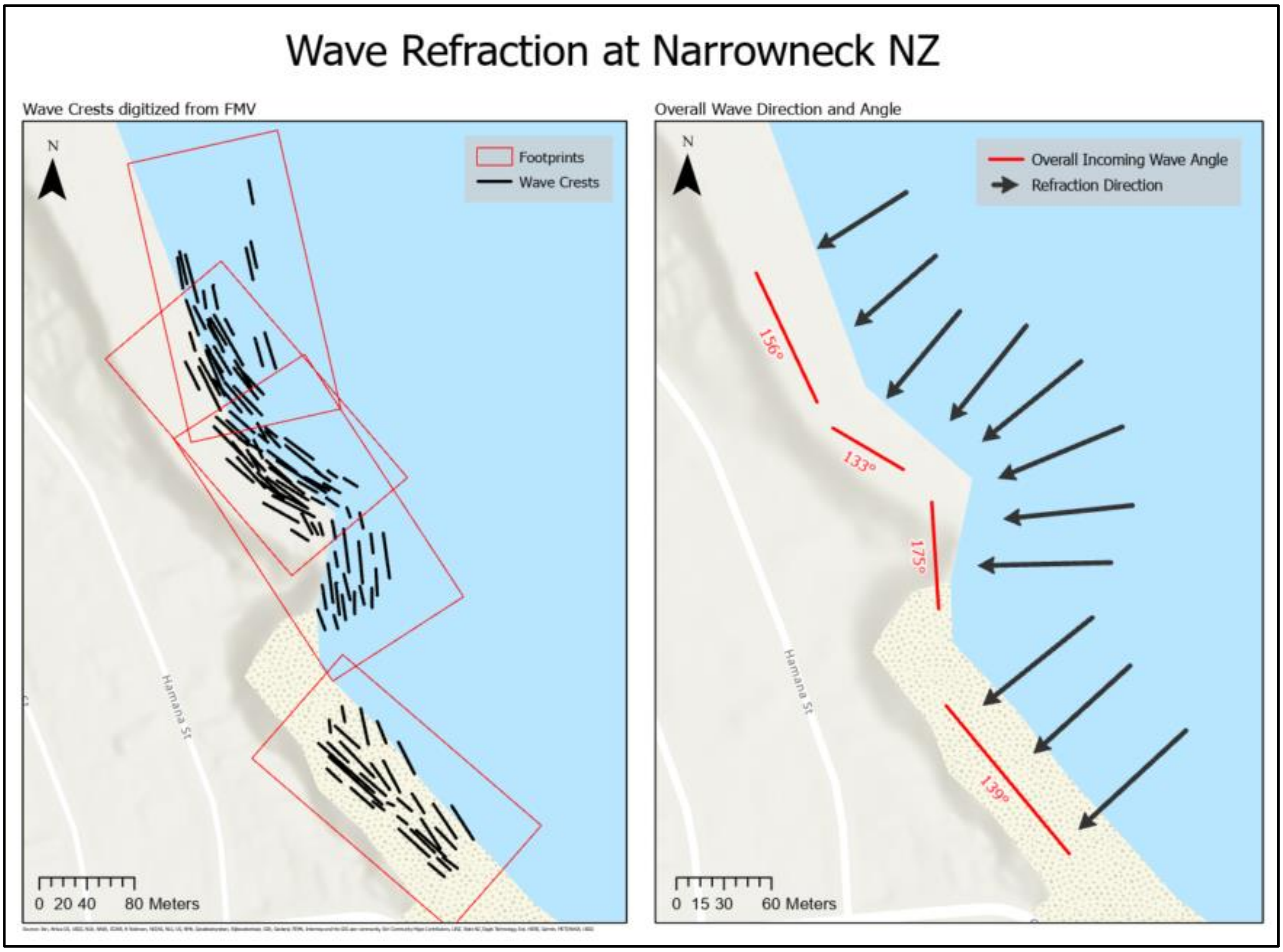


Figure 18: Maps of Wave refraction at Narrow Neck bay. Map 1 displays the wave crests tracked through the FMV data and Map 2 displays the wave direction and angles that were inferred from the wave tracking analysis.

From the geological survey significant geological features were identified and located to understand how the local geological environment impacts wave dynamics (Figure 19). The most significant feature is the headland that is 20 metres long and protruding 29 metres off the horizontal length axis of the cliffs. There are also the early stages of cave formation occurring on the southern side of the headland, a raised marine platform surrounding the base of the headland, undercutting at the base of the cliffs along the northern section, near shore rocks along the coast that protrude out of the water at low tide and lastly the presence of offshore barrier islands in the east of the coast, such as Rangitoto and Motutapu. The satellite imagery used in the map also displays the sandy beach environment in the north and south sections of the study site. The headland has a more rocky environment as it is surrounded by the marine platform and near shore rocks.

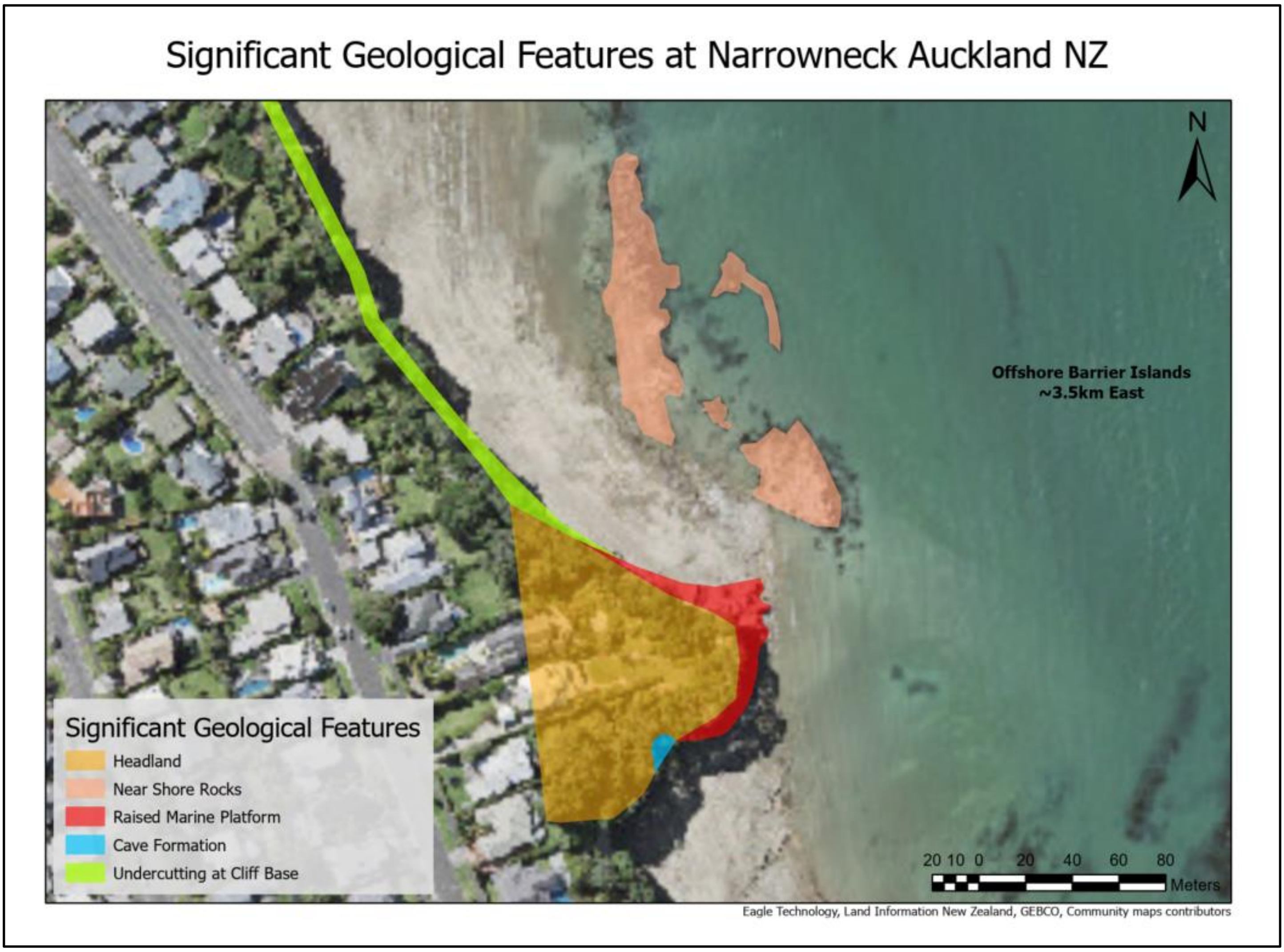


Figure 19: Maps of significant geological features that are present at the study site which have contributed to the dispersion of wave energy.

The beginning stages of cave formation were observed on the southside of the headland (Figure 20). A section of the land eroded away leaving a large indentation in the rock unit. This cave indentation was located within a strata layer that was composed of siltstone. The two strata layers that surrounded the cave indentation were both composed of sandstone.

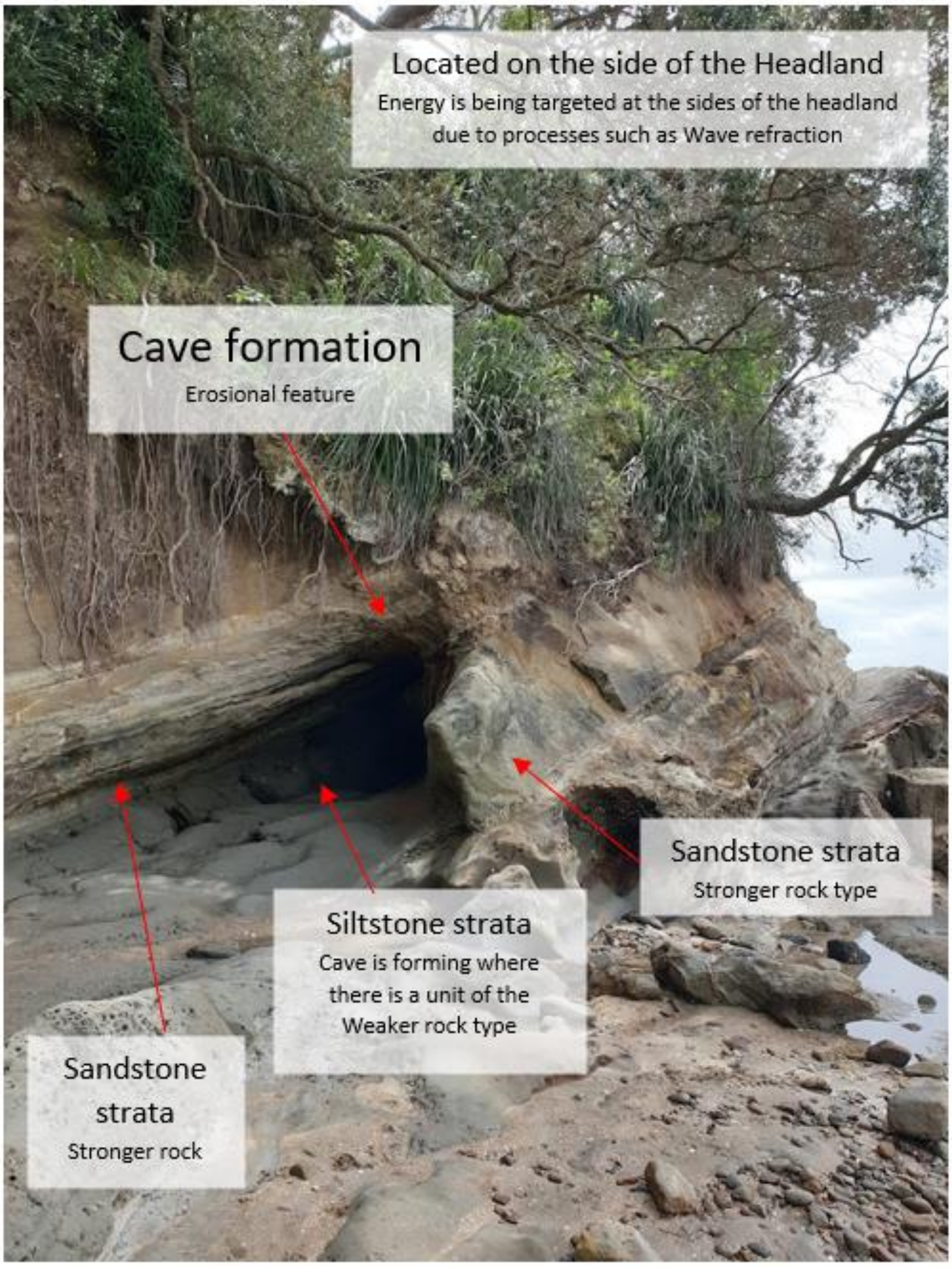


Figure 20: Annotated Image of the cave formation occurring on the south side of the headland at Narrow Neck

The headland is a large section of uplifted Waitemata sandstone that was observed to be tilting upwards on a 30 degree angle (Figure 21). The marine platform is present around the whole headland and is around 1-2m in height. The marine platform acts as a base to the headland cliffs and buffers the headland from direct wave action.

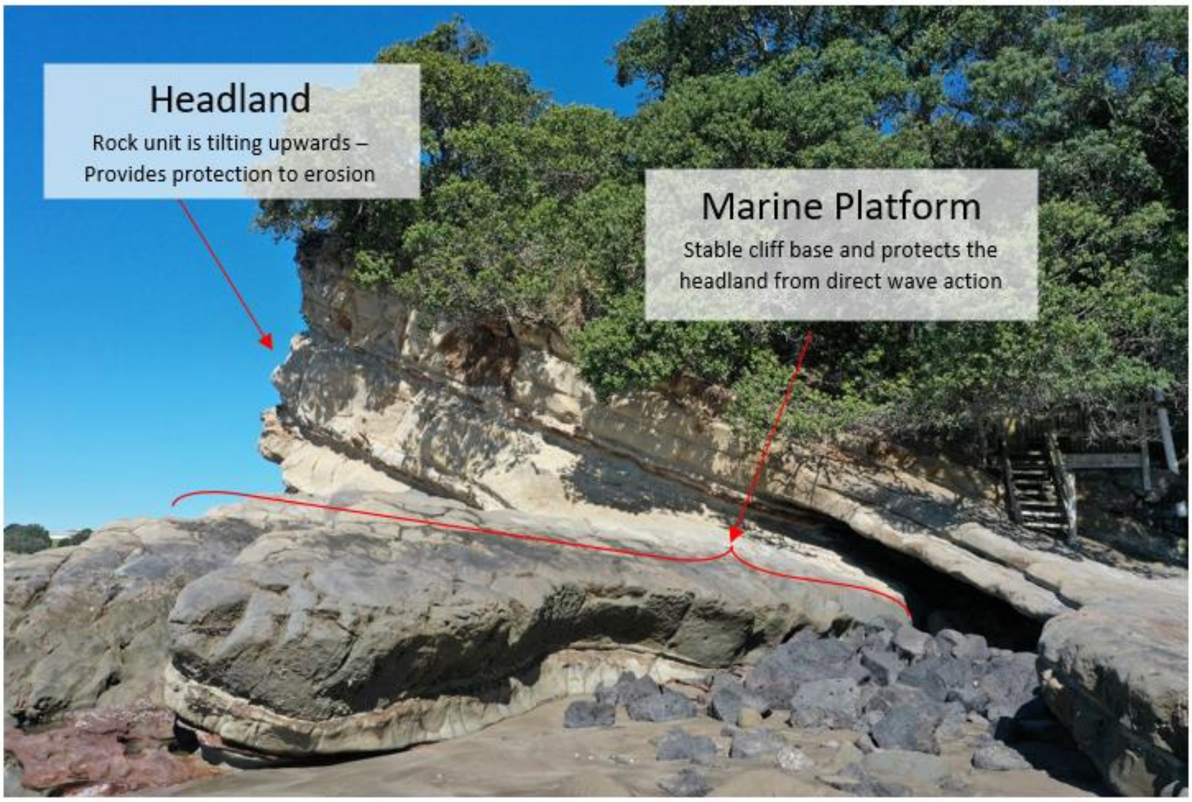


Figure 21: Annotated Image of the Headland and Marine platform at Narrow Neck

Along the northern section of the study site it was observed that the coastal cliffs were experiencing undercutting from the occurrence of wave action (Figure 22). The strata layers at the bottom of the cliffs have been eroded at a faster rate than the layers above resulting in the top of the cliff protruding out greater than the base of the cliffs.

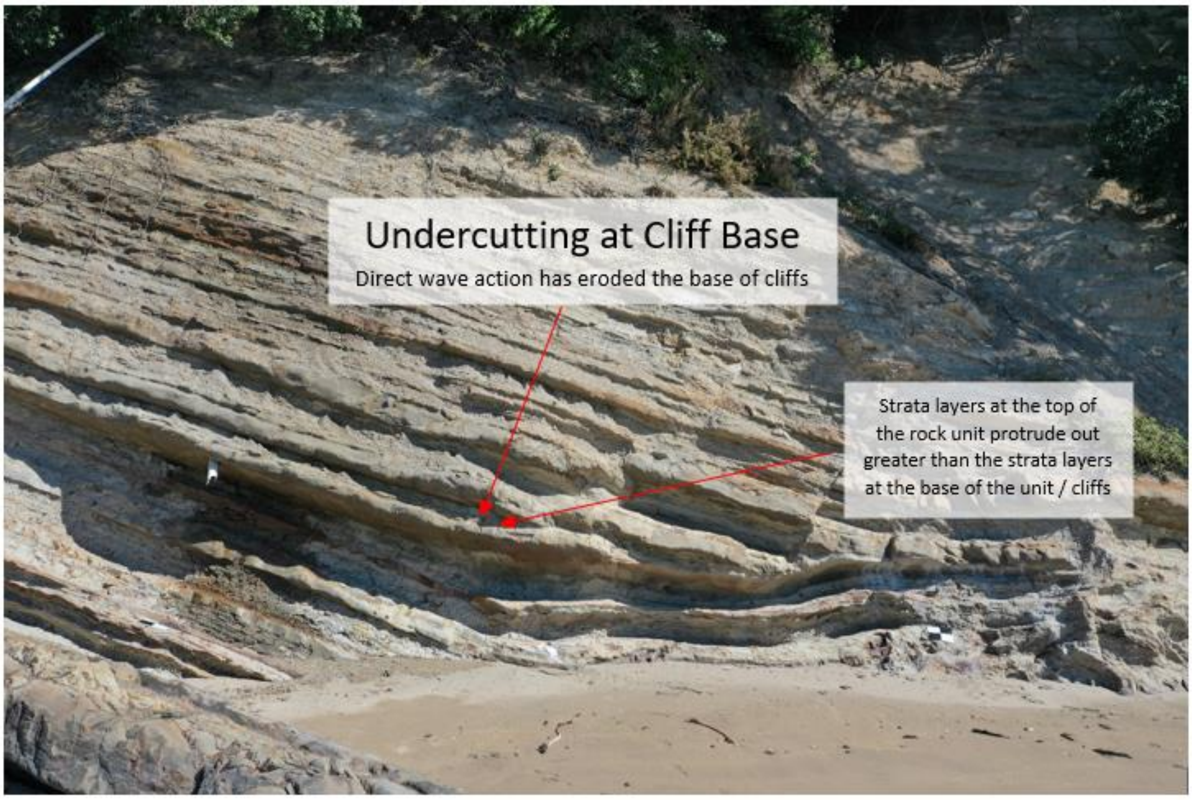


Figure 22: Annotated Image of the Coastal cliff undercutting that is occurring at Narrow Neck

The Sediment Clast size analysis shows how the size of rock fragments vary along the coastline (Figure 23). Through the relationship between sediment size and erosion, the amount of active erosion that is occurring along the coast can be inferred. Large rock clasts indicate that active erosion is occurring as the cliff/substrate is actively being broken down into smaller fragments. Small rocks also represent erosion however at a greater rate as the rocks fragments have been ground down and deposited. In the bar graph it can be seen that most transects appear to have an average clast size of around 10cm however transect 3 had much larger rocks present. Transect 3 is located at the headland and was surrounded by larger boulders whereas the other sites were straight sections of cliff and did not have any rock clasts of significant size. It can also be noted that in general the samples collected at Location 1 (Cliff base) tended to have a larger average size than the other locations.

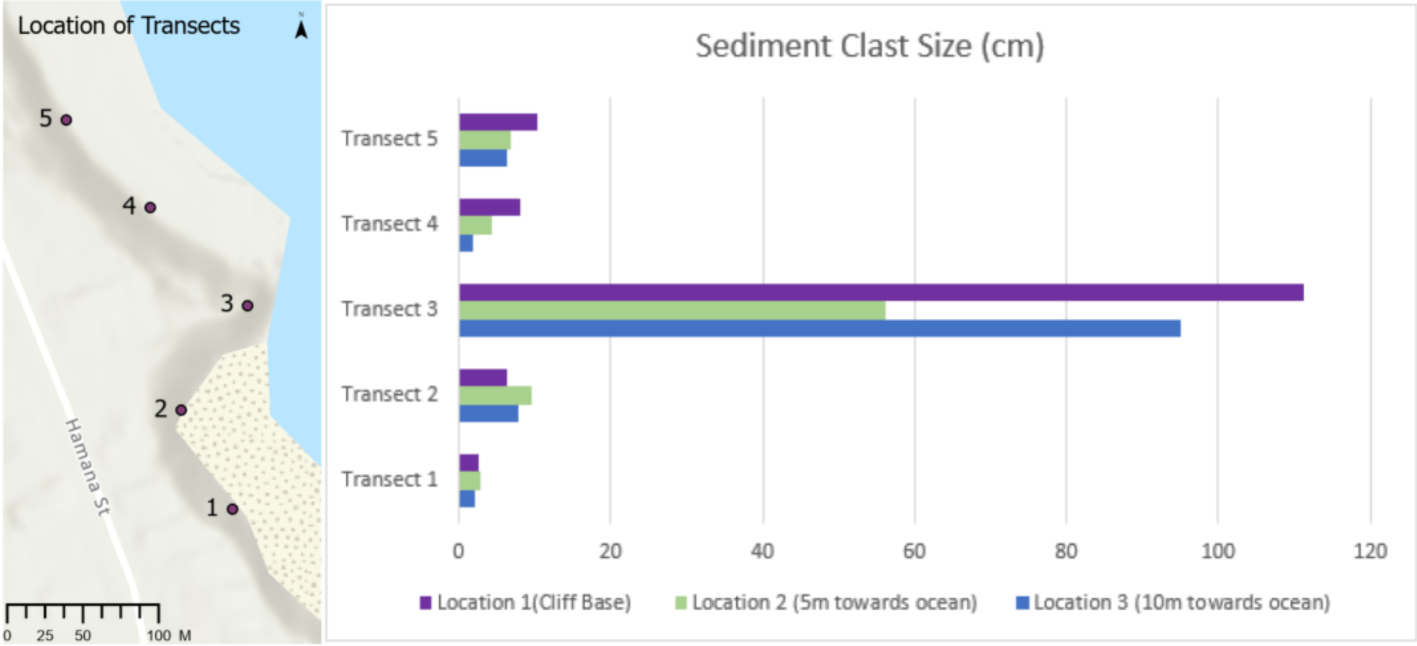


Figure 23: Bar graph of the Sediment Clast size measured along the coast of Narrow Neck.

The generalised geological stability map of the Narrow Neck coast displays how the coast varies in strength/stability and the geological properties associated with the given classifications (Figure 24). It can be seen through this map that the headland is an area that is considered to have high stability. It can also be noted that the headland has a large cliff base, as seen in the cliff profile and its lithology consists mainly of thick sandstone beds. The North and South sections of the coast both have a moderately weak strength. They both share the same general lithology which is sandstone and siltstone bedding. The sandstone beds are slightly larger than the siltstone beds, however the difference is less drastic than observed at the headland. The cliff profiles for these sections share a similar pattern; however the North section is experiencing a greater amount of undercutting with a more steep indent in the cliff profile. The south side of the headland is categorised as the weakest section of the coast with a ranking of 5. This area shares similar geological qualities as the south section, however has been marked as more weak due to the presence of the cave formation features which make the area more vulnerable and reduce its strength.

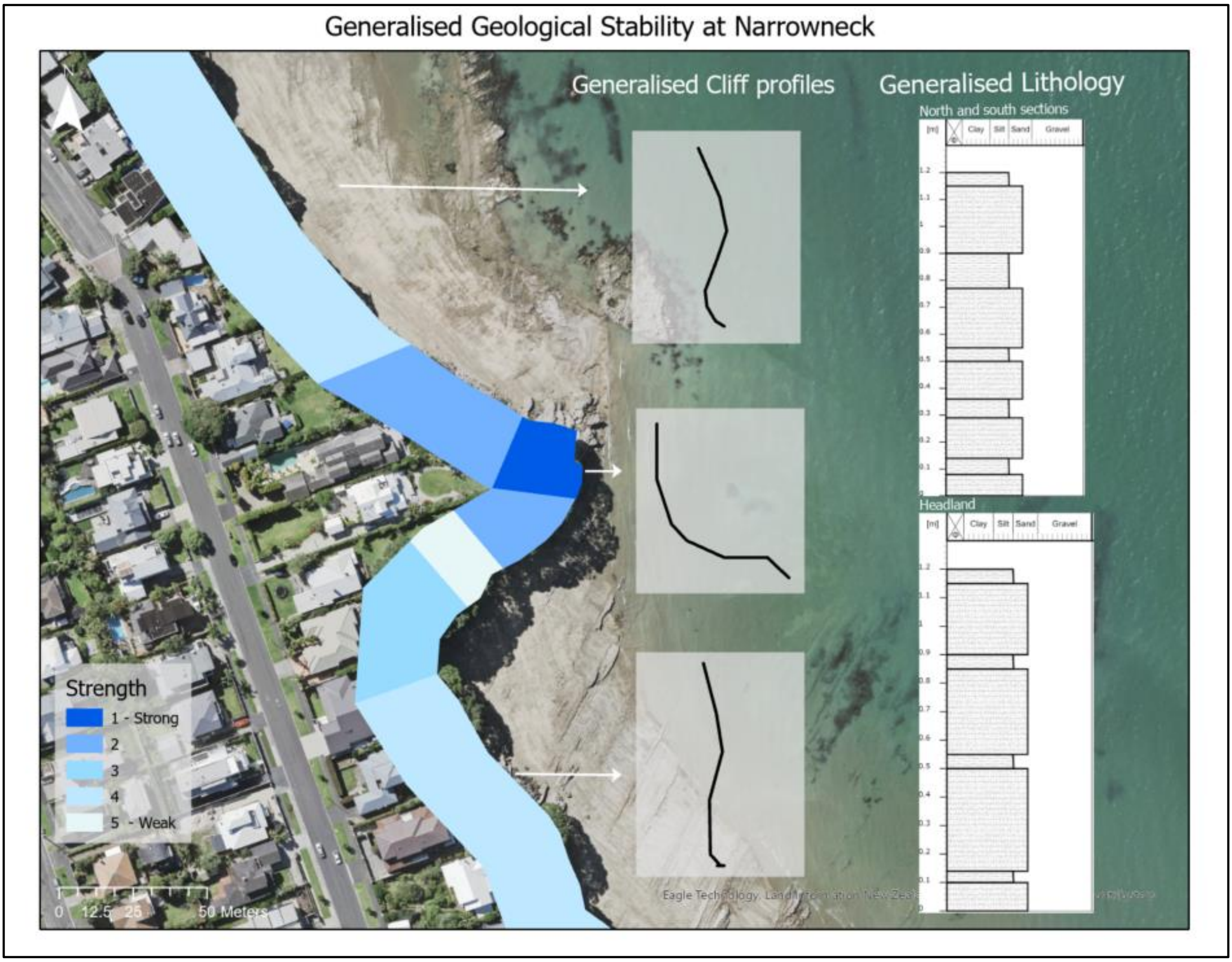


Figure 24: Map displaying a generalised depiction of the geological landscape. The coast line is classified to show areas of weak and strong geological properties. Generalised cliff profiles are displayed parallel to the coast. Stratigraphic columns of the 2 distinct zones of the coast (North and South sections / Headland) are displayed.

6. Discussion

Through the results it has been observed that there is clear variation in how waves interact with the shore along the study site. A noticeable pattern in this variation is the middle section of the study site is repeatedly where the strong differences in the data are located spatially. The middle zone of the study transect includes multiple significant geological features which are major contributing factors to the variation identified. These features include the headland, marine platform, and near shore rocks.

The variation seen between the headland area and the rest of the shore in figure 16 & 17 is that the headland receives a smaller frequency of wave action as well as having a much smaller and concentrated dispersion zone. This observation is due to multiple factors. Firstly, it was found in the geological survey that was undertaken, that the headland cliffs are surrounded by a large marine platform at the base (Figure 21). This marine platform would act as a barrier to the cliffs and prevent waves from travelling further inwards (Hahn, 1994). The obstruction the marine platform poses to further wave movement means the waves are subjected to having a small surf zone. The small surf zone means the incoming wave energy is not dissipated over a large area but instead exerted onto one location, this results in the wave energy at the headland being more concentrated which corresponds to Map 2 (Wave Concentration) in figure 17. The marine platform also prevents the wave dynamic of swash and backwash to occur. Since the platform acts as a constraint to wave movement, the waves are not able to travel up the shore as swash. In standard wave environments, when the swash of the waves begin to travel down the shore as backwash, new incoming waves come in at the same time, resulting in constant wave action (Brookes & Green, 2001). The lack of swash and backwash occurring at the headland contributes to why waves are shown to be less frequent in the results. The absence of swash means that the waves dissipate faster than standard wave environments resulting in there being less constant wave action (Munk & Traylor, 1947). This has been captured in the results as the time period that wave action is visible is less and therefore wave action is not captured in all frames extracted from the FMV unlike the areas that experience swash.

Another factor that may influence the results is wave refraction. The depth of the sea will vary along the coast with water becoming more shallow as it approaches land (Brookes & Green, 2001). The presence of the headland and marine platform will cause the water to be shallower at this section of the coast earlier than at straight (north and south) sections. Due to the early onset of shallow water, the wave orbitals will have friction with the ground causing the waves to slow in speed while the waves travelling north and south of the headland will continue moving at greater speed. This discrepancy in wave velocity will cause wave refraction to occur around the headland (Brookes & Green, 2001). This can be seen in the results from the wave refraction analysis (Figure 18). The wave angle and direction display how waves did not travel directly towards the headland but instead bent slightly inwards. The wave refraction that occurred would be a contributing factor as to why the headland was found to have a low density of wave action occurring as the waves were not predominantly hitting headland head-on but instead from the sides. This also explains why the side of the headland appeared to receive a higher frequency of waves.

Near shore rocks are another geological feature that is important to consider. Near shore rocks are large rocks that sit within the tidal zone that break the surface of the water. These rocks have a large impact on wave dynamics as they act as an obstruction and barrier to the coast. The impact of these rocks are often controlled by sea level and tides. If the rocks are concealed (below water) during high tide, the friction between the water and the rock can cause the waves to refract (Munk & Traylor, 1947). During low tide, the large rocks on the shore may break the surface of the water and be exposed. These protruding rocks will not only contribute to wave refraction but can break the waves creating a larger surf zone (Brookes & Green, 2001). This larger surf zone results in a greater area for dissipation and therefore less concentrated energy occurring at the shore line. This can be seen in the results (Figures 15 & 16) where the surf zone begins where the waves meet with the protruding near shore rocks resulting in a large surf zone. The concentration map (Figure 17) also corresponds to this theory as areas of the coast that are obstructed by near shore rocks are shown to have a weak concentration of wave energy deposition. Wave refraction can also be seen around the rocks, where the waves bend to move in an inwards direction, towards the headland rather than continuing to move straight towards the coast, once past the rocks (Figure 18).

Another significant geological feature that was observed was the cave formation on the south side of the headland. The cave formation indicates an area of strong wave energy and weak lithology. In figure 20 it can be seen that the cave is forming where there is a large siltstone strata bed. Siltstone is a weak rock type and is extremely susceptible to erosion (French & Burningham, 2011). The location of the cave formation unfortunately sits outside the site boundaries for the FMV capture and therefore there is no data on the wave behaviour and dynamics for this location. However the data for the surrounding areas can be used to infer the wave dynamics for the south side of the headland. There are no near shore rocks to act as a barrier and dissipate the waves and therefore the waves would impact the coast with a relatively strong concentration. The pattern of wave refraction seen in figure 18 shows the waves bending inwards towards the headland and therefore this area would receive a high frequency of waves as seen on the north side of the headland (Figure 17). These factors combined, result in high intensity wave action in an area that is extremely vulnerable to erosion (Figure 17). The presence of the cave formation in the geological survey validates these observations in the data as cave formation requires both high intensity erosion and vulnerability in the rock (Kenny & Hayward, 2013).

The geological landscape of the coast is very important for understanding coastal erosion. Figure 24 provides a summary on how the geological properties of the area impact the coast's stability and strength against erosion. Firstly, the headland is considered to be an area of strong stability. This is because the headland is surrounded by a marine platform which acts as a barrier to the incoming waves for the coastal cliffs as well as provides a stable base to the cliffs (Hahn, 1994). The coastal cliffs located at the headland have an upward tilt which provides the headland further protection from erosion as vertical strata are overall more resistant to erosion due to the bedding running opposite to the tidal action and laying against Earth's gravitational force (Ballance, 1964). The bedding at the headland consists of many large sandstone strata which are more resistant to erosion than siltstone and mudstone.

The North and South sections of the coast have a contrasting geological landscape to the headland. These areas of the coast are considered to be more unstable and more vulnerable to erosion. Firstly, these sections of the coast are linear in shape, indicating an even rate of erosion along these areas. These areas do not have wide, stable cliff bases but instead have an indentation at the base of the cliff indicating zones of tidal undercutting. Tidal undercutting is where wave action has resulted in erosion at the cliff base causing the top of the cliff to protrude and overhang further than the base. The tidal undercutting results in the weight of the cliff not being well supported against the force of gravity and therefore the cliff has a high potential for mass land loss/landslides (Moon, 1984). The general lithology for the North and South sections of the cliff have smaller sandstone beds and a greater presence of siltstone beds than the headland. This lithology sequence would be more vulnerable to coastal erosion as there is a greater proportion of the weaker rock type (siltstone)(Ballance, 1964)

There is clear variation observed between the geological properties of the headland and the North and South sections. The variation in the geological properties and wave dynamics that are occurring are ultimately the reasons for how the headland and coastline has formed and developed. Differential erosion has occurred along the coast as a result of the variation present in wave action and geological properties. Differential erosion is when areas of the coast experience different rates of erosion. The differential erosion results in the coast not eroding in a linear formation but instead eroding heterogeneously, resulting in features such as headland and bays (Kenny & Hayward, 2013).

This differential erosion has been made evident in the sediment clast size analysis (Figure 23). In the results of this analysis it can be seen that transect 3 that is located at the headland, had the greatest clast size measured whereas the transects along the North and South sections of the coast had much smaller sized clasts. The larger rock clasts indicate that the headland is experiencing active erosion as the cliff/substrate is actively being broken down, producing the large boulders surrounding the headland (French & Burningham, 2011). The smaller rock clasts also indicate erosion; however the erosion is more intensive as the rocks fragments have been ground down into much smaller clasts (French & Burningham, 2011). The difference in clast size also shows how erosion has contributed to coastal development. The smaller clast sizes seen on the North and South sections of the coast is evidence of depositional beaches. Wave action has preferentially eroded the headland and the sediment clasts have been ground down via erosional processes such as abrasion and attrition and deposited on the coast resulting in beach formation adjacent to the headland (French & Burningham, 2011). In figure 18 it can be seen through the patterns of wave refraction, that the sides of the headland receive more targeted energy. Narrow Neck also has a high overall wave action rating along the North and South sections of the coast and a low rating for the Headland (Figure 17, Map 3). This heterogeneity of wave action along the coast coincides with the observation that headlands are eroding preferentially as the areas adjacent to the headland have more wave energy being exerted onto the coast to drive the process of erosion.

Another trend seen in the sediment clast data was that location 3 tended to have a smaller clast size average than location 1. This pattern is due to location 3 being located further along the tidal range (Figure 13). Location 1 is a deposition zone and therefore the larger rock clasts get deposited there. The larger rocks are heavy and therefore are unable to be carried by the swash and backwash of waves resulting in the larger clasts being stranded at the cliff base (Moon, 1984). Finer sand particles on the other hand weigh less and therefore are carried out further along the tidal zone resulting in smaller clast size found at location 3. This transportation and deposition of sediment along the tidal range is what results in the formation of beaches.

The formation of erosional features is present along the East Coast of Auckland. It can be observed that there is a repeated pattern of bays bordered by headlands, occurring along the coast (Figure 25). It can be inferred from this pattern that the wave action and coastal erosion dynamics observed in this study are occurring throughout Auckland's East Coast and are not limited or unique to the study site.

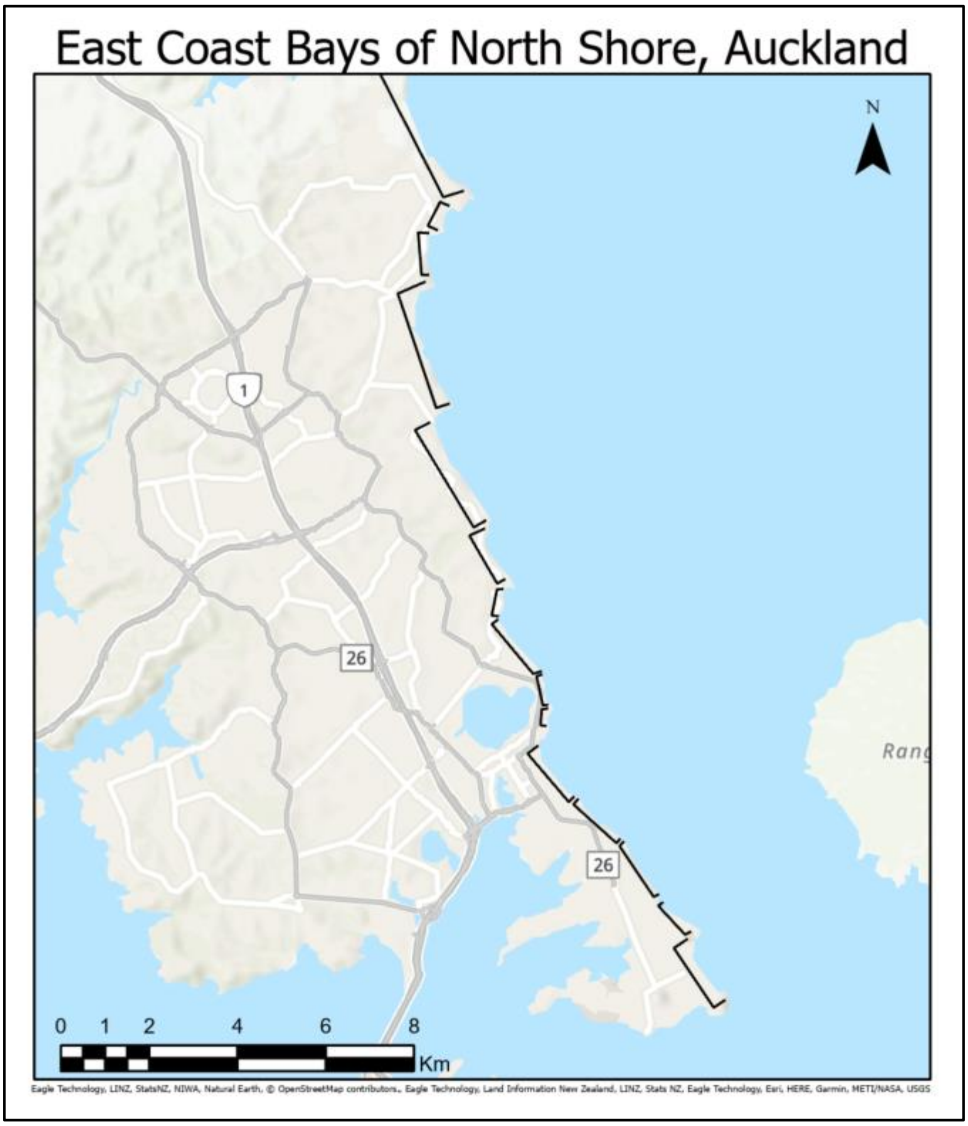


Figure 25: Map displaying the East Coast of North Shore, Auckland. The Coast is not linear but instead has a pattern of bays bordered by headlands that can be seen occurring along the coastline.

Narrow Neck's coastline can be classified as a drowned coastline as well as an erosional coastline. The Hauraki Gulf once sat above the ocean; however, over time the land has sunk and sea levels have risen resulting in the coast we have today (French & Burningham, 2011). Evidence of the downed coast can be seen through the deep water channels and many islands that are present in the Hauraki Gulf. The coast can also be classified as an erosional coast. This classification identifies the processes that are actively occurring. Narrow Neck has features such as headlands, bays, and cave formations that categorise the coast as erosional (Kenny & Hayward, 2013). The erosional processes that are occurring at Narrow Neck are carving out new land formations and shaping the coastline. Wave action is a process that plays a significant role in coastal erosion. The patterns seen in the wave dynamics of frequency, concentration, and overall impact coincide with the patterns of coastal erosion observed. It is clear that wave action is a driving factor to the erosion that is occurring and is therefore a significant control of coastline formation and development at Narrow Neck.

6.1. Limitations

There are a few limitations to this study. Firstly, the extents of the FMV footage collected did not have enough overlap between site 1 and site 2 and therefore there was a section on the south side of the headland that was not fully shown in the video imagery captured. This lack of coverage resulted in a gap in the results where no data was captured. This gap was small and did not have a large impact on the results; however having complete capture of the study site would have improved the quality of the results. Another limitation experienced with the FMV video that the headland was highly vegetated and therefore there were some large tree canopies that obscured the view of the waves breaking from the 90 degree angle footage. This resulted in a very small proportion of the area on the headland not having 100% of wave action captured.

The FMV footage was captured sequentially along the transect line. This meant there was an average of 10 minute time differences between each subsequent site. As the FMV for this study is capturing a dynamic environment that is constantly moving, there is some movement captured between the sites. The FMV was captured during a receding tide (Low tide) and therefore the capture time difference between site 1 and site 4 means there is a slight shift in the site's surf zone visible in the footage. The surf zone of site 4 is located slightly lower along the tidal range than site 1. The shift in the surf zone was not accounted for or removed in the results/data processing as it was a minor shift and each site blended into the shift smoothly.

Lastly, FMV data was captured on a single occasion and therefore variation in wave behaviour with different tides levels and environmental conditions was not considered in this study. Waves are a dynamic force. Their formation and the amount of energy that is held by a wave is dependent on many different factors. There is a lot of environmental variation in terms of weather conditions that can alter the impact of a wave. Tides also have a large impact on wave energy as it can change the volume of water that is held in a wave as well as change the zone of dissipation.

Due to this variation not being considered, the results of the study are specific to the environmental conditions experienced on the day of data collection.

7. Conclusion

In conclusion, waves are a very dynamic force that are controlled by many factors. The geological landscape plays a large role in determining wave concentration, frequency and direction. Wave action and coastal erosion are very interconnected processes where each factor has an influence on each other. The coastline of Narrow Neck has been identified to have heterogeneous geological properties resulting in variation in the coastal erosion it experiences, including the process of wave action. The differential erosion that is experienced results in the formation of erosional features such as headlands, depositional beaches, caves, and marine platforms. These formations make up the overall shape of the coastline and control the future coastline development.

7.1. Recommendations

This study tested out new methodologies which harnessed the FMV to extract multiple avenues of data and produce different analyses and results. The methods used were proven to be effective in identifying and displaying variation in wave energy dynamics along the coastline. To strengthen the results of the study and fully understand the variation that is occurring, the analysis could be repeated in different environment settings. Waves are dynamic and are constantly changing depending on the environmental conditions. The strength and direction of wind plays an important role in determining the angle, speed, length, and direction of waves and therefore repeating this analysis under different conditions will help understand how significantly the geology of the area has influenced the movement and patterns observed in the waves.

Another factor to be considered for further studies is tidal patterns. Tides have a large impact on wave dynamics and it is important to understand how and to what extent waves behaviour changes with tides. A temporal study over a full tidal cycle could be undertaken to decipher whether there are significant changes seen in the pattern of wave wave energy dissipation along the coast during different tide levels.

Coastal zones are incredibly diverse and dynamic. Investigating how waves systems vary in different coastal environments would be extremely valuable for understanding the role of waves in coastal erosion. A similar study could be carried out on the West Coast of Auckland which is considered a ‘progradational coast’ where sediment supply is plentiful (Kenny & Hayward, 2013). The comparison between the progradditional west coast and erosional east coast of Auckland would provide great scope on how waves interact with coastal zones and erosional processes.

FMV is enriched with data and there are so many ways that it can be applied in analyses in addition to the methods explored. Further analyses could be carried out which utilise more of GIS capabilities. FMV data has time data that can be used in conjunction with the spatial data to carry out spatial-temporal studies. Further studies into how spatial patterns change over time would provide great value for understanding the rate and extent of the processes that are occurring. The time aspect of the data also enables more information to be extracted from the FMV. Using the same wave tracking in ArcGIS Pro methodology that was used in this study, waves can be tracked to extract data such as wavelength, wave frequency and speed. Further research into wave physics can also enhance this research as understanding the physics behind wave energy could allow for a formula to be developed to calculate the force of the waves and therefore quantifying wave energy. Speed of waves can be calculated easily from FMV with time and distance measurements. FMV and GIS technology has the potential to collect measurements of wave mass using bathymetry data, therefore providing the base parameters for calculating force using Newton's second law formula (Force = Mass x Acceleration). Quantifying wave energy will determine how much wave energy is exerted onto the coast which can then be directly linked to how much the process of tidal action contributes to coastal erosion.

8. Acknowledgements

Firstly, I would like to thank my primary supervisor Graham Hinchcliffe for his guidance throughout my research, sharing his FMV methodologies and assisting with the UAV fieldwork and data processing. Thank you to my secondary supervisor Professor Michael Petterson, for his support and guidance on the geological aspect of my research and sharing his wisdom on the geology of the area. Lastly, I would like to thank Lycha Galorio for assisting me in the field when collecting the geological survey data and for her support throughout the project.

9. References

Ballance, P. (1964). The Sedimentology Of The Waitemata Group In The Takapuna Section,Auckland. New Zealand Journal Of Geology And Geophysics, 7(3), 466-499. doi: 10.1080/00288306.1964.10422096

Ballance, P. F. (1974) An inter-arc flysch basin in northern New Zealand; Waitemata Group (upper Oligocene to lower Miocene). Journal of Geology 82: 439–471

Bell, J. E. (2007). Towards a Better Understanding of Coastal Cliff Erosion in Waitemata Group Rock; Auckland, New Zealand. (Thesis, Master of Science (MSc)). The University of Waikato, Hamilton, New Zealand. Retrieved from https://hdl.handle.net/10289/2374

Brookes, H. D., & Green, M. O. (2001). Determination of Wave Climate for the Auckland Region, New Zealand. *Journal of Coastal Research*, 23–29.

Brocx, M. and Semeniuk, V. (2009) Coastal geoheritage: encompassing physical, chemical, and biological processes, landforms, and other geological features in the coastal zone. Journal of the Royal Society of Western Australia, 92 . pp. 243-260.

CANZ. (2008). Southwest Pacific Region Bathymetry [Tiff Image]. NIWA. https://niwa.co.nz/static/bathymetry/NZ250mBathymetryRainbow.jpg

Campbell, H. (2013). *The Zealandia Drowning Debate*. Wellington: Bridget Williams Books.

Chappell, P.R. (2013). The climate and weather of Auckland. NIWA Science and Technology Series 60, 40 pp

De La Mare GN (1992) Microstructural controls on the geomechanics of coarse grained soft rocks: Waitemata Group, Auckland, Unpublished M.Sc. thesis, University of Waikato, 126 pp

Ellermann, K., (2008) Generation and dissipation of Ocean Surface Waves. PAMM, 8(1), pp.10677–10678.

Esri, 2020. FAQ: What are the full motion video add-in's motion imagery Standards Board (MISB) metadata requirements? *Esri*. Available at: https://support.esri.com/en/technical-article/000015970 [Accessed April 5, 2022].

Esri Inc. (2020). ArcGIS Pro (Version 2.8). Esri Inc. https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

French, J., & Burningham, H. (2011). Coastal geomorphology. *Progress In Physical Geography: Earth And Environment*, *35*(4), 535-545. doi: 10.1177/0309133311414606

Hahn, G. (1994). Influences of wave stretching on the response of wave-excited offshore platforms. *Ocean Engineering*, *21*(6), 507-517. doi: 10.1016/0029-8018(94)90005-1

Hayward, B.W. 2017. *Out of the Ocean into the Fire. History in the rocks, fossils and landforms of Auckland, Northland and Coromandel.* Geoscience Society of New Zealand Miscellaneous Publication 146, 336 pp.

Hinchliffe, G. (2021). FMV Telemetry conversion (Version 3) [Python]. Unpublished.

Hinchliffe, G. (2022). Low-cost Unmanned Aerial Vehicle Full Motion Video for Marine and Ecological Survey. PhD manuscript in preparation.

Jongens, R., Gibb, J., & Alloway, B. (2006). A new hazard zonation methodology applied to residentially developed sea-cliffs with very low erosion rates, East Coast Bays, Auckland, New Zealand. Natural Hazards, 40(1), 223-244. doi: 10.1007/s11069-006-0019-5

Keaton, J. (2017). Hydraulic Action. Selective Neck Dissection For Oral Cancer, 1-1. doi: 10.1007/978-3-319-12127-7_158-1

Kennedy, D., & Dickson, M. (2007). Cliffed coasts of New Zealand: Perspectives and future directions. Journal Of The Royal Society Of New Zealand, 37(2), 41-57. doi: 10.1080/03014220709510535

Kenny, J., & Hayward, B. (2013). *On the edge - celebrating the diversity of New Zealand's coastal landforms* (7th ed.). Levin: Geoscience Society of New Zealand Guidebook.

LINZ. (2017). NZ 53 Bream Head to Slipper Island including Hauraki Gulf / Tīkapa Moana [Paper Chart]. Land Information New Zealand. https://www.linz.govt.nz/sea/charts/paper-charts/nz53

Madison, R. & Xu, Y., (2010) Tactical Geospatial Intelligence from full motion video. 2010 IEEE 39th Applied Imagery Pattern Recognition Workshop (AIPR).

Mangewa, L.J., Ndakidemi, P.A. & Munishi, L.K., (2019) Integrating UAV technology in an ecological monitoring system for Community Wildlife Management Areas in Tanzania. Sustainability, 11(21), p.6116.

Matsukura, Y. (2013). 7.4 Influence of Physical Weathering on Hillslope Forms. Treatise On Geomorphology, 44-55. doi: 10.1016/b978-0-12-374739-6.00147-0

Mei, C.C. & Liu, P.L., (1993) Surface waves and coastal dynamics. Annual Review of Fluid Mechanics, 25(1), pp.215–240.

Moon VG (1984) Report on coastal cliff geology, City of East Coast Bays. City of East Coast Bays Consultancy Report held by North Shore City Council

Munk, W.H. & Traylor, M.A., (1947) Refraction of ocean waves: A process linking underwater topography to beach erosion. The Journal of Geology, 55(1), pp.1–26.

O Rourke, F., Boyle, F. & Reynolds, A., (2010) Tidal Energy Update 2009. Applied Energy, 87(2), pp.398–409.

Pelinovsky, E., (2006) Hydrodynamics of tsunami waves. Waves in Geophysical Fluids, pp.1–48.

Pickrill, R. A. & Mitchell, J. S., (1979) Ocean wave characteristics around New Zealand, New Zealand Journal of Marine and Freshwater Research, 13:4, 501-520, DOI:10.1080/00288330.1979.9515827

Regional Assessment of Areas Susceptible to Coastal Erosion. (2009). Retrieved 7 November 2020, from http://www.aucklandcity.govt.nz/council/documents/technicalpublications/TR2009009%20Regional%20assessment%20of%20areas%20susceptible%20to%20coastal%20erosion%20appendices_A-J.pdf

Samaratunga, C. (2020). *An Examination of the interconnectedness between geology, lithology, weathering and cliff stability along the coastline of Narrow Neck Bay* (Undergraduate). Auckland University of Technology.

Shane, P., Strachan, L.J. & Smith, I., (2010) Redefining the waitemata basin, New Zealand: A new tectonic, magmatic, and basin evolution model at a subduction terminus in the SW Pacific. Geochemistry, Geophysics, Geosystems, 11(4).

Symonds, P.A. & Moore, G.F., (2000) Characteristics of continental margins. Continental Shelf Limits.

Thrasher, G.P., (1986) Basement structure and sediment thickness beneath the continental shelf of the Hauraki Gulf and offshore Coromandel Region, New Zealand. *New Zealand Journal of Geology and Geophysics*, 29(1), pp.41–50.

Trenhaile, A. (2016). Cliffs and Rock Coasts. Reference Module In Earth Systems And Environmental Sciences. doi: 10.1016/b978-0-12-409548-9.09737-2

Trujillo, A.P. & Thurman, H.V., 2005. *Essentials of Oceanography*, Upper Saddle River, New Jersey: Pearson Prentice Hall.

Van Rijn, L.C., (2011) Coastal erosion and control. Ocean & Coastal Management, 54(12), pp.867–887.