"THE OCEAN IS A SUPREME METAPHOR FOR CHANGE. I EXPECT THE UNEXPECTED BUT AM NEVER FULLY PREPARED"

Tim Winton – A Coastal Memoir

02

Coastal Environments: Features and Processes

KEY INQUIRY QUESTIONS

WHAT NATURAL PROCESSES FORM AND TRANSFORM COASTAL ENVIRONMENTS? KN UN

HOW HAS THE CONCENTRATION OF PEOPLE LIVING ON THE COAST HAD AN IMPACT ON ENVIRONMENTAL PROCESSES? UN AN EV

PART 2
CONTENTS

THE COASTAL ZONE

The coast is more than the line where the land meets the water, beach or headland. It is a dynamic transition zone between the land and the sea and contains a diversity of landforms, ecosystems and water bodies.

Figure 1: Features of coastal environments. Currumbin looking north towards Palm Beach. Source: Tweed Sand Bypassing

It is estimated that coastal zones make up 8 per cent of Earth's surface. Globally, human settlement is concentrated in coastal locations including 80 per cent of the world's population, and many of the world's largest cities such as New York, Mumbai and Shanghai. In Australia 85 per cent of people live within 50 km of the coast and every state capital city is located on the coast.
People are attracted to coasts for economic, social and environmental reasons including climate, water resources, land for settlement and economic activities such as agriculture and commercial fishing. The coast also offers a range of cultural ecosystem services such as recreation, a sense of place and community and spiritual connection.

Humans are impacting on coastal processes with consequences for human activities and communities. Erosion for example threatens properties and infrastructure built too close to the coast in many suburbs of Sydney, Adelaide and Perth. Climate change is causing rising sea levels and an increase in extreme weather events, which are impacting coastal environments and cities at a global scale. Figure 2a and 2b.
The management of coastal environments is a contemporary present-day global issue.

Figure 2a: New York. Source: Brendan Church

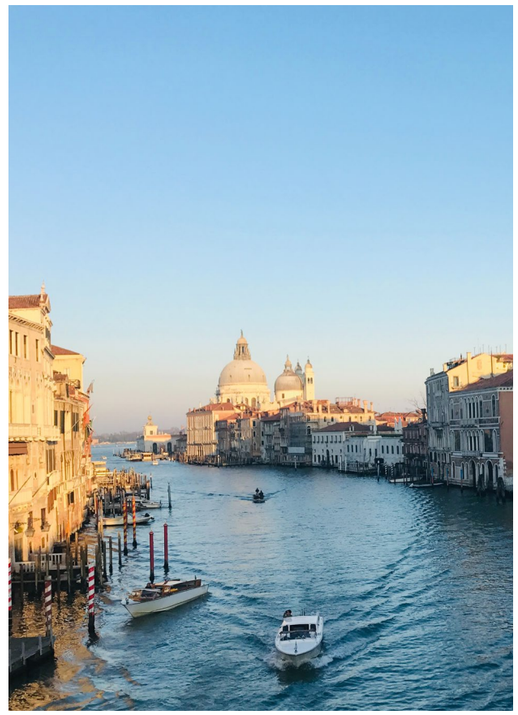


Figure 2b: Venice. Source: Cristiano Pinto.

STUDENT ACTIVITIES

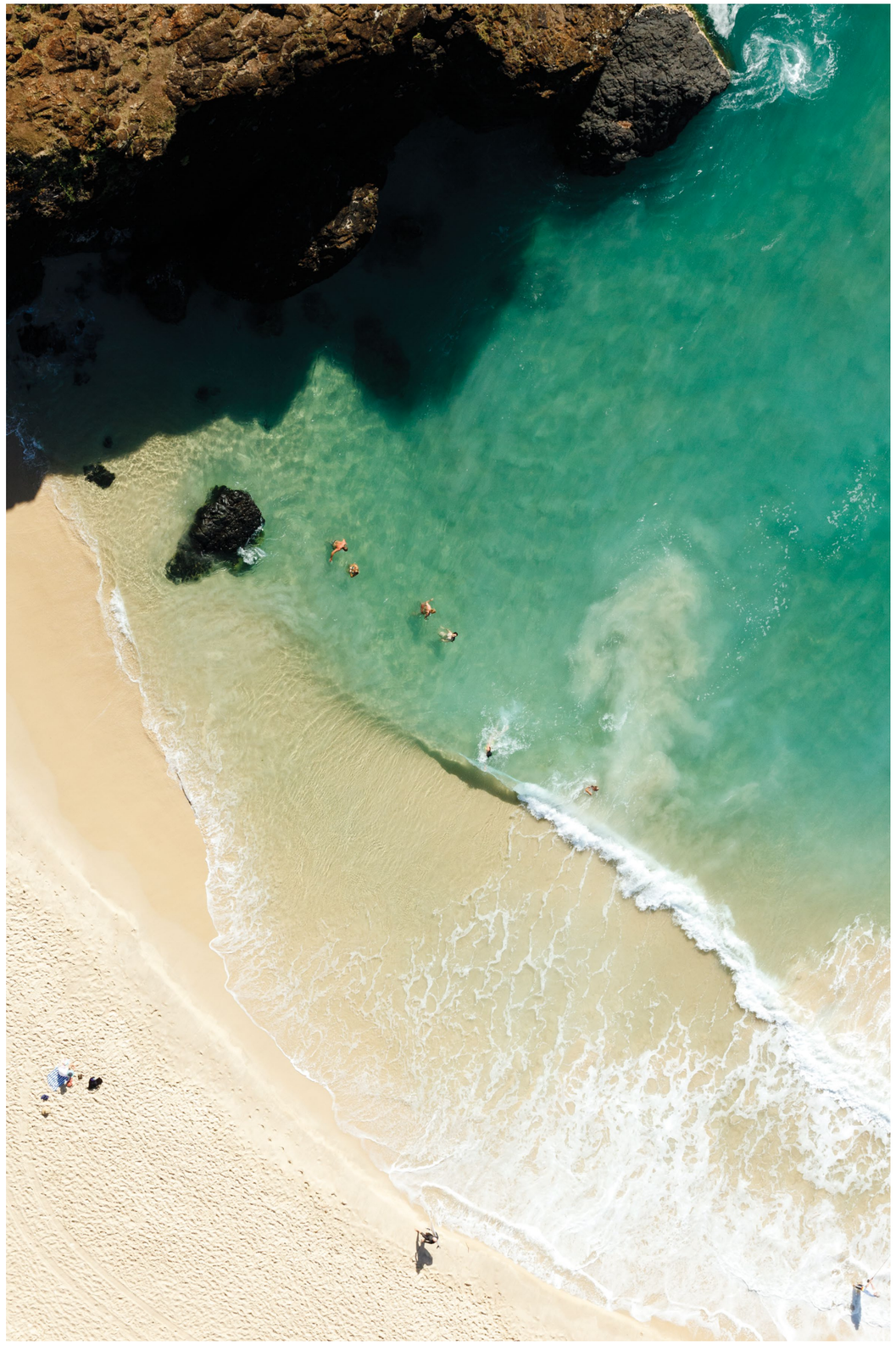
KN KNOW
UN UNDERSTAND
AP APPLY
AN ANALYSE
EV EVALUATE
CR CREATE

1. Why do you think so many people are attracted to living on the coast? UN AN

2. In pairs or small groups tell stories about your favourite beach. Talk about what makes your chosen beach your favourite. Discuss how this beach has changed over time and what the causes of change could be. KN UN AN

3. Use Google Earth to do a visual observation of **one** beach in NSW or Queensland. Choose from Stockton (Newcastle, NSW); Collaroy /Narrabeen (Sydney, NSW); Belongil (Byron Bay, NSW); Palm Beach (Gold Coast, Queensland); Mooloolaba, or Noosa (Sunshine Coast, Queensland). UN AN EV
   i. What do you understand by the concepts 'dynamic' and 'stable'?
   ii. Use the time tool to look for evidence that this beach has been 'dynamic' or 'stable' over time. Suggest an explanation for your answer.
   iii. Do a Google search for **two** recent media reports about the selected beach. Do these support your conclusion about whether the beach is dynamic or stable?
   iv. Identify any causes of change in these reports.

4. Use the Speak like a Geographer Activity Worksheet 1 to create a glossary of geographical terms used throughout this resource. Suggested terms are highlighted in orange. At the end of the unit list the concepts alphabetically and provide a definition of each. KN UN CR



COASTAL FEATURES AND ENVIRONMENTAL PROCESSES

In order to manage coasts, it's important to understand the natural coastal processes and the different temporal and spatial scales on which they operate. Coasts are the product of millions of years of weathering, erosion, deposition, climate and sea level changes and tectonic movements in the Earth's crust. Other natural influences on coasts include geology such as rock type and structure, ocean depth, weather and the tides and climate. These natural influences vary spatially and make every coastline unique.

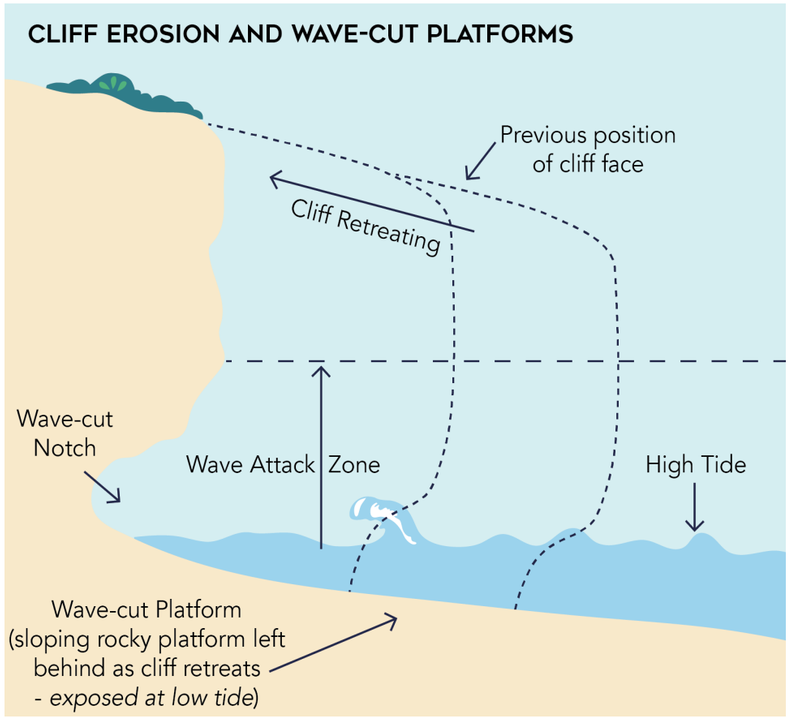


Figure 3: Formation of cliffs and rock platforms

Rocky coasts: features and processes

Headlands form where coastal geology (rock) is resistant to erosion. Environments dominated by *headlands, cliffs, rock platforms, caves, arches, stacks and blowholes* are called rocky coasts. These landform features are the result of erosion due to wave action concentrated onto headlands. Wind, rain, salt spray, plants and animals play a role in the *weathering* and *erosion* of rocky coasts. Eroding headlands are a source of sediment transported to sandy coasts. Headland erosion results in coastlines receding inland leaving behind cliffs and rock platforms. Figure 3.

Differential erosion occurs due to variations in rock type and structure resulting in caves, arches and sea stacks such as the Twelve Apostles in Victoria. Over the long term, rocky coasts recede inland leaving little evidence of where the coastline once existed and a coastline that is straighter. Only eight of the Twelve Apostles remain as evidence of where the Victorian coastline was located in the past. Figure 4.

Figure 4: Oblique aerial image showing the twelve apostles in Victoria, Australia. Source: Shutterstock

STUDENT ACTIVITIES

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AN ANALYSE
EV EVALUATE
CR CREATE

1. Refer to Figure 3. KN UN EV
   i. Work in pairs to investigate and explain the processes of hydraulic action, corrosion and abrasion. Contribute to a class discussion to clarify your responses.
   ii. What role do these processes play in the erosion of rocky coasts?

2. Select **one** landform feature found on a rocky coast. UN AP EV
   i. Explain in your own words how this feature was formed. Use the terms, weathering, erosion and differential erosion.
   ii. Share your response with another student for feedback. Adjust your explanation.
   iii. Find a real-life photograph of the selected landform feature in Australia.
   iv. Annotate the photograph to show what this landform might look like in 500 years.
   v. Justify the change you have made.
   vi. Explain the connection between rocky coasts and beaches.

2. When rocky headlands are continually eroded over time coastlines will straighten. Explain this statement. AN

Sandy coasts: features and processes

Beaches and dunes

Sandy coasts are found in bays and inlets formed by the erosion of less-resistant rock or on long stretches of low-lying coast where headlands are absent. These coasts are formed of sediments such as sand, gravel, coral and shells from rivers, eroded headlands and offshore reefs. Sediment is deposited through the action of wind, waves and currents to form *beaches* and *sand dunes*.

Sediment is deposited on beaches during periods of *constructive waves*, usually during periods of calm weather. This is called cross-shore deposition. Beaches are eroded by *destructive waves* during storms, and sand is removed offshore by backwash and rip currents. Figures 5a and 5b.

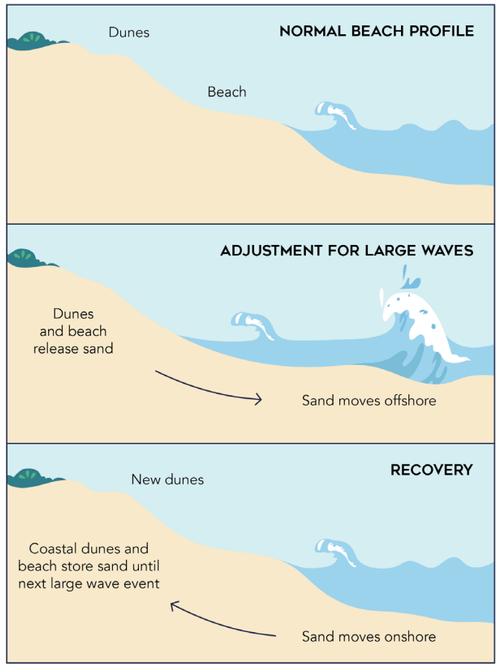

Figure 5a: Natural change caused by wave action on beaches

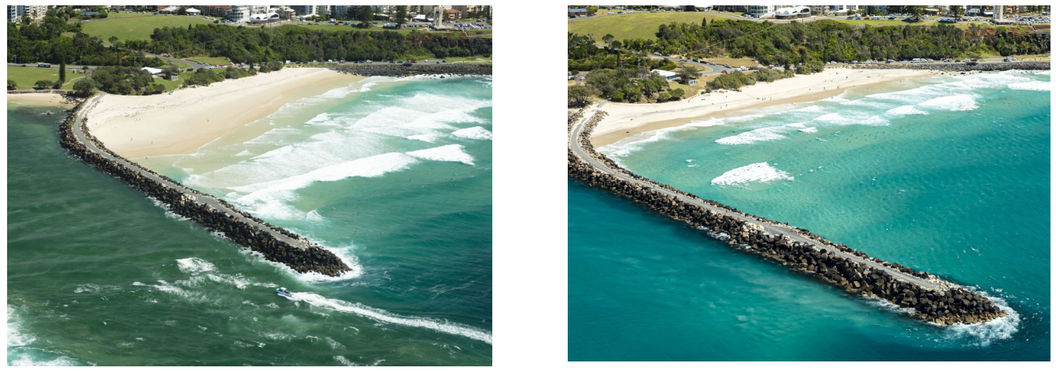

Figure 5b: These two images of Duranbah in northern NSW show the effects of cross-shore sand transport. In the left image (March 2018), due to generally calm conditions, cross-shore transport has created a wide beach. The right image (October 2019) illustrates the effect of cross-shore transport under larger wave conditions – sand has been removed from the beach and the width has been reduced.
Source: Tweed Sand Bypassing

Sand is also transported along, and deposited on, beaches by *longshore drift*. For example, sand flows northwards along the northern NSW coast at a rate of approximately 500,000 cubic metres per year (which is equivalent to 200 Olympic-sized swimming pools full of sand). This is because the dominant wave direction is from the south-east which pushes this sand from south to north.

Figure 6: South-easterly waves move sand from south to north along the NSW north coast through the process of longshore drift.
Source: Tweed Sand Bypassing

For beaches in southern Queensland the northerly movement of sand through *longshore drift* is vital for beach formation and renewal after periods of erosion. Beach drift and longshore currents develop when waves reach beaches at an angle resulting in sand particles zigzagging along beaches or being transported by nearshore currents that form where the swash meets backwash (see Figure 6). Wind-blown sand forms coastal dunes at the back of beaches which over long periods of time can form extensive systems of inland dunes such as those at Stockton in NSW.

Sand spits and sand bars

Sand spits and *sand bars* are formed by the deposition of sand above and below water. Sand spits are usually an extension of beaches and bars form where water moving in different directions meet, e.g. in the surf zone where backwash meets incoming waves or rivers where tides meet waves. When the water stops moving, as in a collision, sand is deposited. Letitia Spit is an excellent example of a sand spit that has been stabilised by vegetation over time, see Figure 7.

Figure 7: Aerial photograph of Letitia Spit south of the Tweed River mouth in northern NSW taken in 1941.
Source: Tweed Sand Bypassing

NATURAL CYCLES

Beaches are extremely dynamic landforms that change daily, seasonally, yearly and over longer time periods. Beaches go through natural cycles of deposition (accretion) and erosion and recover in the short-term from sand losses. In the longer term, if eroded sand cannot be replaced, beaches will recede inland, taking land and development in the process. The Holderness Coast in England has receded four kilometres inland since Roman times, has an erosion rate of one to two metres per year and has lost many settlements to the sea.

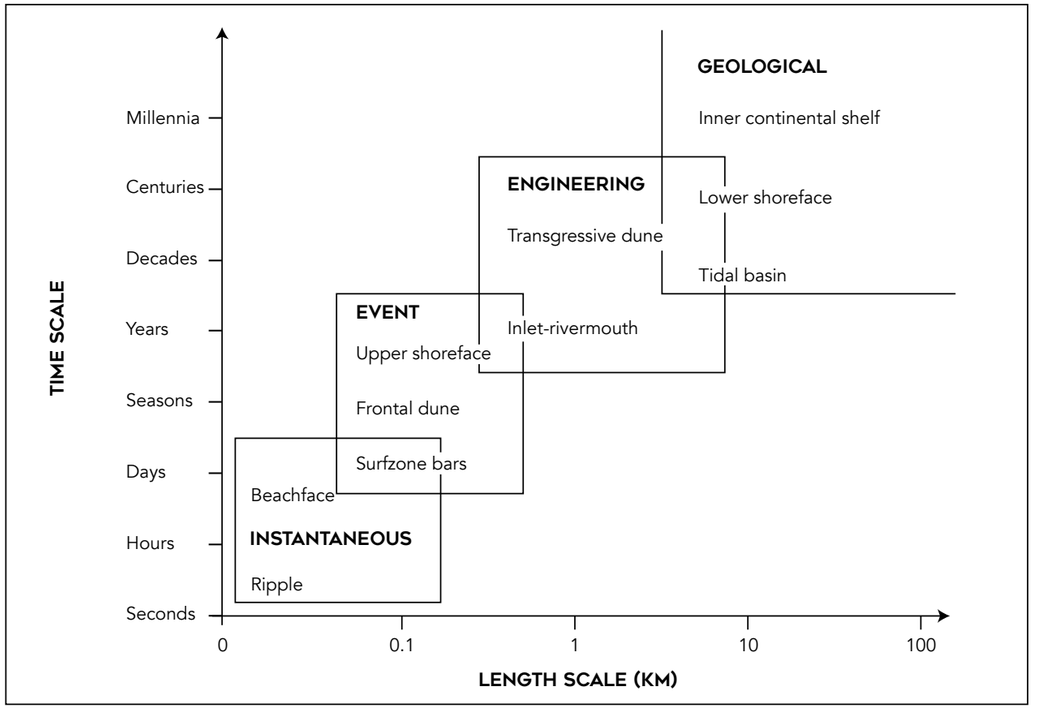

Figure 8. Changes to the coast operate over different time scales.
Source: adopted from Masselink and Hughes, 2003

STUDENT ACTIVITIES

KN KNOW
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AP APPLY
AN ANALYSE
EV EVALUATE
CR CREATE

1. Refer to Figures 5a and 5b. KN UN AP
   i. Use research to find diagrams of constructive and destructive waves.
   ii. Identify the key differences that explain how different types of waves change beaches.
   iii. Where does sand eroded from beaches go?
   iv. Explain 'cross-shore' transport of sediment in your own words.

2. Refer to Figure 6. UN
   i. What is the prevailing (most common) wave direction causing sand to move northwards from NSW to Queensland?
   ii. Predict the outcome of a rock structure built perpendicular to a beach where longshore drift moves northwards. Draw a diagram to show this.

3. Refer to Figure 8. Show your understanding of time scales by completing the following statements using these words: instantaneously; a few hours; many years; several weeks; several months. UN AP
   i. During calm wave conditions, waves move sand from offshore bars and deposit it onshore, gradually widening the beach.
      Timescale: _____
   ii. When a wave breaks sand is moved.
      Timescale: _____
   iii. During an east coast low or cyclone, large destructive waves erode sand from beaches and deposit it far offshore.
      Timescale: _____
   iv. Beaches change seasonally, increasing in width in summer during constructive waves that push sand onshore and decreasing in width in winter when large waves move sand offshore.
      Timescale: _____
   v. Climate change affects beaches over a longer period.
      Timescale: _____

4. Sandy coasts are naturally dynamic. What does this mean? UN AP

ESTUARIES: FEATURES AND PROCESSES

Estuaries are zones of transition where fresh water that's transported by river flows meets salty ocean waves. Estuaries are similar to beaches because they are dynamic environments that are continuously shaped by the deposition and erosion of sand. Sand bars and shoals develop in estuaries where incoming and outflowing waters meet, and sediment is deposited. Sand spits may grow and block the entrance of estuaries to the sea.

The supply of sediment and nutrients in estuaries supports important coastal ecosystems including mangrove forests, saltmarshes and seagrasses. Estuaries constantly change under natural influences and are vulnerable to human activities that alter the supply of sand and movement of water such as upstream dams. Sedimentation in estuaries is a hazard for navigation and may require management interventions like dredging, see Figure 9.

Figure 9: Sand shoals, bars and spits at the Manning River estuary in NSW. Source: Ashley Cleaver

STUDENT ACTIVITIES

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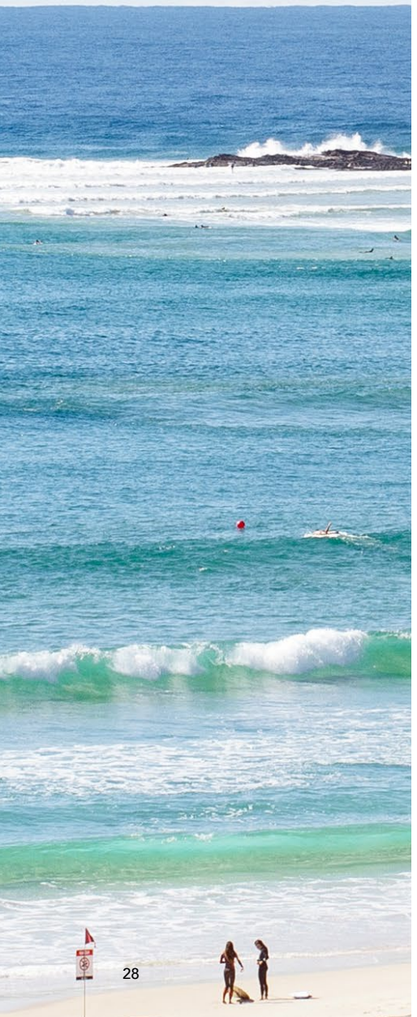
UN UNDERSTAND
AP APPLY
AN ANALYSE
EV EVALUATE
CR CREATE

1. Refer to Figure 9 AP AN CR
   i. Construct a line drawing from the photograph in Figure 9.
   ii. Use arrows to show the inflow and outflows of water in the estuary. How would this vary throughout the day?
   iii. Label areas of deposition.
   iv. What issues would ocean fishermen face navigating this estuary?
   v. Suggest a solution to this problem.

2. Create two diagrams to show deposition occurring in an estuary – incoming waves meet outgoing tides or river flows. The diagrams should represent: UN CR
   - a birdseye view
   - a cross-section view (imagine you are in the water).

3. Predict the impact of damming the river upstream from this estuary. Consider changes to sediment and water flows. AP AN

4. How might climate change impact on the features of estuaries in Australia? Refer to a drier or wetter climate and increased extreme weather events. AP AN



ARTIFICAL REEFS

Coral reefs develop in shallow coastal waters, forming barriers that protect shorelines from storms and waves. Reefs help to prevent erosion by causing waves to break offshore, limiting the energy of the waves before they reach the coastline.

In some parts of the world, artificial reefs are being used to reduce coastal erosion. These reefs can sometimes double as artificial surfing reefs, and also provide habitat for marine ecosystems. Examples include Boscombe artificial reef in England, and Narrowneck and Palm Beach artificial reefs on the Gold Coast, Queensland.

Figure 10a: The construction of Palm Beach Artificial Reef (also known as the Palm Beach Shoreline Project) in 2019 on the Gold Coast. Source: City of Gold Coast

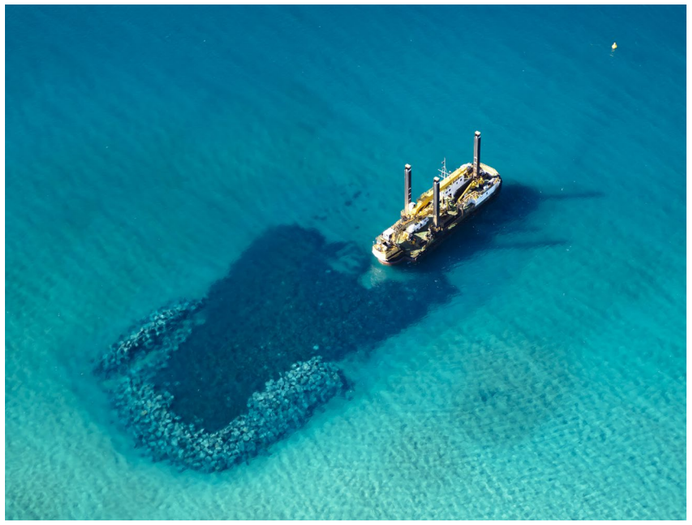
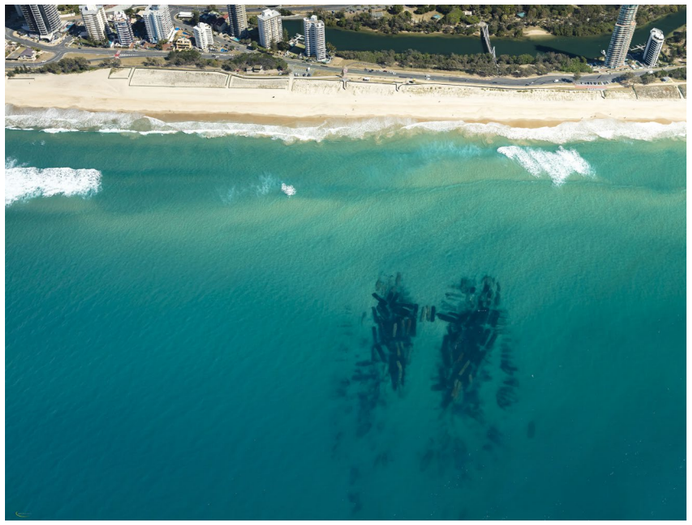


Figure 10b: Palm Beach Artificial Reef (also known as the Palm Beach Shoreline Project) in 2019 on the Gold Coast. Source: City of Gold Coast

Figure 10c: Narrowneck artificial reef on the Gold Coast. Source: City of Gold Coast



WEATHER, WAVES AND TIDES

The weather has an important role to play in coastal processes. Wind direction, fetch and strength determine wave size. Wind blowing over long distances of ocean (fetch) forms larger waves while wind blowing off the shore will flatten waves.

A single high tide, *king tide* or storm event such as an *east coast low* can bring dramatic changes to beaches in a few hours.

During 4–6 June 2016, an east coast low affected 2,000 km of coastline in eastern Australia. The storm caused heavy rain, strong winds and powerful waves that caused Sydney beaches some of the worst erosion they had experienced in 40 years.
Figure 11a, 11b, 11c.

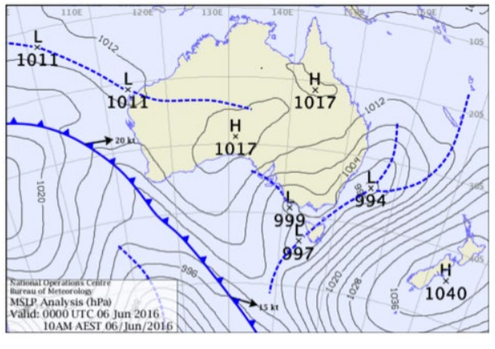


Figure 11a: Synoptic chart of an east coast low (10am AEST 06 June 2016).
Source: Australian Bureau of Meteorology

11b. Oblique photograph taken from a drone showing coastal erosion due to an east coast low at Collaroy Beach, 2016.
Source: UNSW Water Research Laboratory

11c: Coal ship the Pasha Bulker stranded 100m offshore of Nobby's Beach, Newcastle, NSW due to an east coast low in June 2007.
Source: Adobe Stock

Queensland and parts of northern NSW can also be impacted by tropical cyclones. These are severe low pressure systems that form over warm tropical waters. Tropical cyclones are very dangerous as they cause strong winds, heavy rainfall and storm surge.

A storm surge is caused by the drop in atmospheric pressure in the atmosphere. As the air pressure drops, there is less weight in the atmosphere pushing down on the ocean, and it rises. This local and temporary rise in sea level is also made worse by the effects of large waves and the tide. When combined these factors create a storm surge that can cause extensive coastal erosion and flooding.

Figure 13a: Surfer at Kirra Point (Gold Coast, Queensland) during Tropical Cyclone Oma.
Source: City of Gold Coast

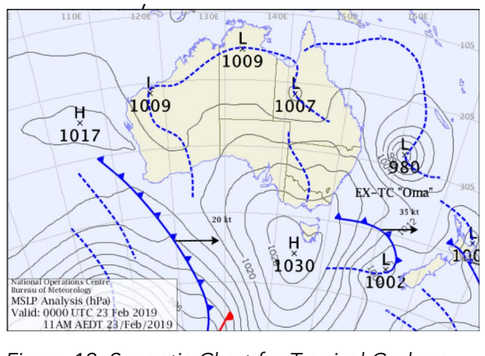


Figure 12: Synoptic Chart for Tropical Cyclone Oma, 23 February 2019.
Source: Australian Bureau of Meteorology

Figure 13b: Waves breaking at Kirra Point (Gold Coast, Queensland) during Tropical Cyclone Oma.
Source: City of Gold Coast

STUDENT ACTIVITIES

KN KNOW
UN UNDERSTAND
AP APPLY
AN ANALYSE
EV EVALUATE
CR CREATE

East coast lows

1. Describe the features of the east coast low shown in Figure 12. UN AP

2. Why do you think that the use of synoptic charts for weather forecasting is important?

3. Visit the *Australian Bureau of Meteorology* blog website to learn about east coast lows.

4. Investigate the impact of the 2016 east coast low on one NSW or Queensland beach. Summarise the features and impacts of the event using a digital mind-mapping tool. AP

Tropical Cyclones

1. Describe the features of the tropical cyclone shown in Figure 12.
How is the east coast low synoptic different to the tropical cyclone one? UN AP

2. Visit the *Australian Bureau of Meteorology* blog website to learn about tropical cyclones.

3. Investigate the impact of Tropical Cyclone Oma on one NSW or Queensland beach. Summarise the features and impacts of the event using a digital mind -mapping tool. AP CR

Stormageddon. Showing Diamond Bay, Vaucluse, during an East coast low on 5 June 2016. Source: Jakob de Zwart Photography

SEDIMENT MODELS

Geographers use models and diagrams to understand natural environments such as coasts. These tools show the inputs and outputs of sediment from a section of coast and are often known as a *sediment budget models.* When the inputs and outputs of sediment are equal, the environment will be balanced and stay much the same. If the inputs exceed outputs, the coast will experience deposition (accretion). If the outputs exceed inputs, erosion will occur and the coast will retreat. These changes may be temporary or permanent, depending on the time scale over which the changes occur.

These diagrammatic tools are useful for coastal management on sections of a coastline where measurements of sand movement can be made or predicted. *Sand budgets* are used when building coastal infrastructure such as dams, walls and groynes that may impact on a section of coastline by changing the inputs and outputs of sediment, see Figure 14.

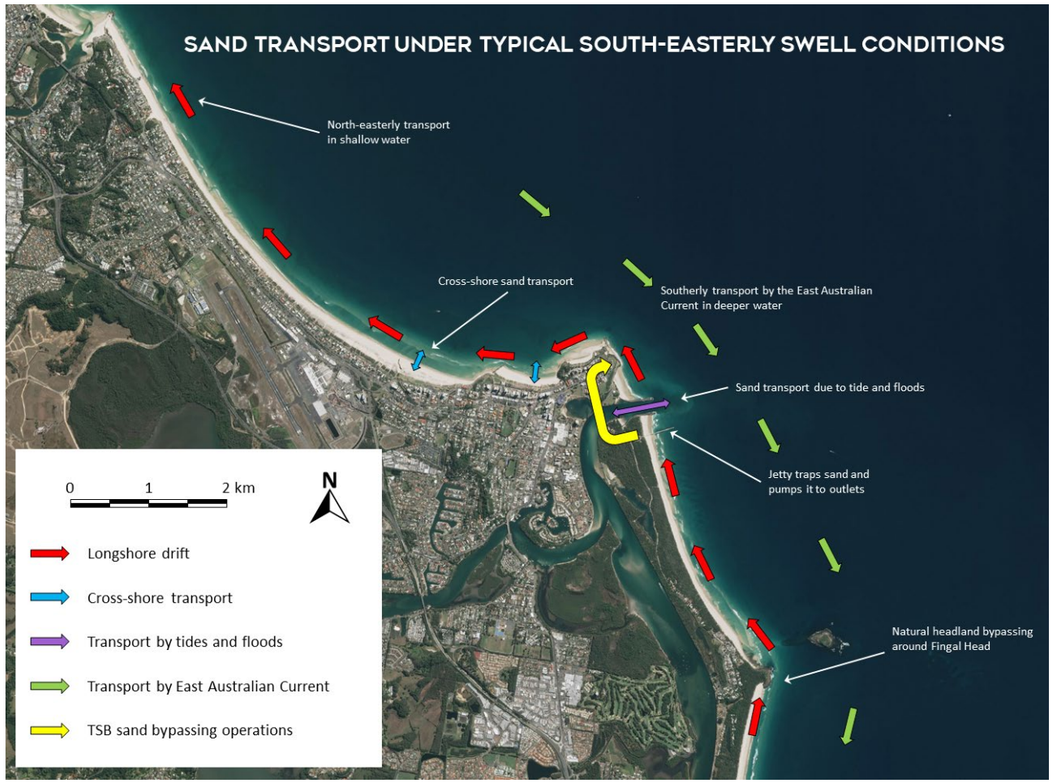


Figure 14: Longshore sand transport pathways for the Tweed Sand Bypassing project beaches under typical south-easterly swell conditions. Source: Tweed Sand Bypassing

STUDENT ACTIVITIES

KN KNOW
UN UNDERSTAND
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Study Figure 14 (Extension Activity)

1. In pairs discuss the meaning of the terms longshore transport and cross-shore transport. AN EV

2. List natural events that could change the transport of sand shown in this model. KN UN AP

3. List human activities that could change the transport of sand shown in this model. KN UN AP

4. Explain how the addition of sediment volumes to this model would improve its effectiveness as a planning tool. AN EV

5. Justify the use of artificial reefs in coastal management. UN EV AP CR

   Show this in a flow diagram that begins with coastal erosion and ends with a stable beach environment.

Coastal erosion → → → etc

CLIMATE CHANGE

The world's climate is changing due to increased levels of greenhouse gases in the atmosphere. This is affecting coastal environments, under increasing pressure from rising sea levels and extreme weather events. Sediment budgets will become increasingly unbalanced resulting in increasing threats to property and community.

The United Nations International Panel on Climate Change (IPCC) has predicted a sea level rise of 90 cm around Australia by 2100 resulting in increased erosion, coastal flooding (inundation), higher estuarine salinity levels and more storm surges.

Changing weather conditions will feature:

- more storms causing erosion and flooding
- higher ocean temperatures and acidity that will increase coastal weathering and stress marine ecosystems
- increasingly variable and unpredictable rainfall that will impact on sediment budgets.

Coasts have adapted to slow, natural changes to climate over millions of years. The pace of anthropogenic (human-caused) climate change, however, is placing greater pressure on coastal managers over shorter time periods.

What **shapes** our coastlines?

The processes that shape our coast are:

Erosion

Land is broken down by waves ...

... and sediment is carried away

Deposition

Waves drop sediment

Transportation

Waves and tides transfer sediment somewhere else

Accretion

Material builds up on a beach

Can be natural, caused by depostion ...

... or artificial, such as beach fill deposited by a digger

Open coast

Waves **deposit** or **erode** sediment

Wind direction drives waves

Current or longshore drift **transports** sediment

Estuaries

Sediment comes from runoff ...

...and is **deposited** as water slows

Accretion of deposited sediment widens the beach

Changes in coastlines happen:

... over hours to days, during storms	... over weeks to months, such as seasonal changes in the ocean	... over years, such as the occurrence of El Niño and La Niña events	... over decades or millennia, such as through changes in sea level and the height of the land (e.g. during an Ice Age).

Human activities can impact the coast on all of these timescales

Climate change may affect coastal processes

Sea level rise

increases erosion, increase inundation

Wave climate changes

increase/decrease wave run-up, increase/decrease erosion and accretion, change transportation

Storm frequency intensity and/or direction changes

changes to wave and storm surge patterns

Rainfall and runoff changes

increase/decrease sediment supply to rivers

Coastal climate change infographic series
www.coastadapt.com.au

Australian Government
Department of the Environment and Energy

CoastAdapt

NCCARF
National Climate Change Adaptation Research Facility

Figure 15a: Infographic summarising coastal processes and causes of change. Source: Coast Adapt

Why is sea-level rise important?

Sea-levels are rising because of climate change

Thermal expansion

Warmer water expands, therefore global warming is causing the water in our oceans to expand

+

Melting ice

Global warming is melting our glaciers and the Greenland and Antarctic land-based ice sheets

=

Higher sea levels

The amount of sea-level rise depends on the amount of climate change

Sea levels are now 19 cm higher

than they were at the beginning of the 20th century

and

will continue to rise over the next centuries

half a metre or more by the end of the century; around 6 m if the Greenland ice sheet melts completely

however

if we limit our emissions,

sea-level rise could be reduced

but not for many decades, even centuries because oceans respond very slowly to change

Sea-level rise creates risks for our coasts

Higher water levels
Floods

+

Higher wave heights
Storm surges

=

Threats

to land, roads, railways, hospitals, schools, houses

A rough rule of thumb

Approximately a 1 cm rise in sea level on a gently sloping beach...

...will bring the water 1 m further landward

1 cm

1 m

Sea level rise is a key consideration for future planning for our coasts. Further information and planning tools are available at www.coastadapt.com.au

Coastal climate change infographic series
www.coastadapt.com.au

Australian Government
Department of the Environment and Energy

CoastAdapt

NCCARF
National Climate Change Adaptation Research Facility

15b. Infographic summarising the impact of climate change on coastal environments

STUDENT ACTIVITIES

KN KNOW
UN UNDERSTAND
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CR CREATE

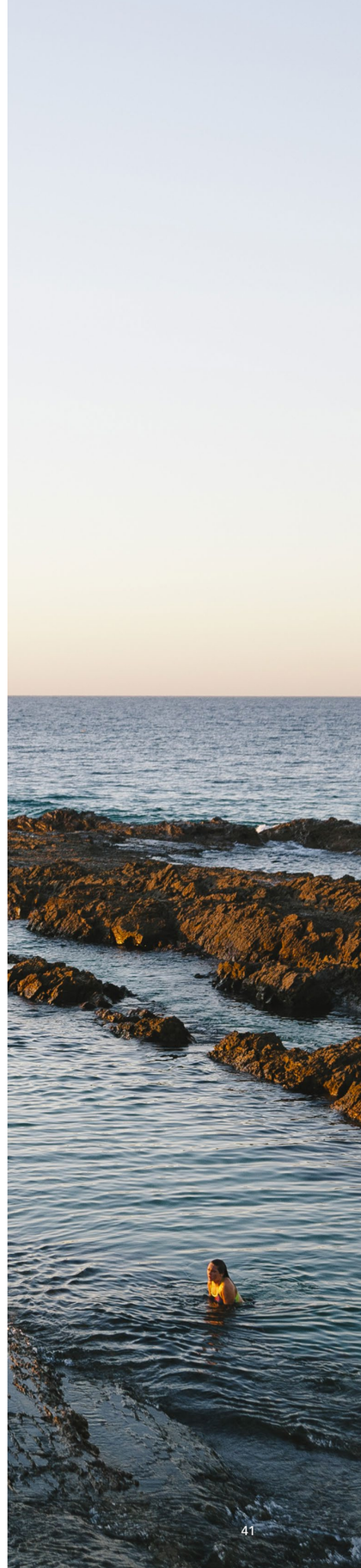
Refer to the Coast Adapt infographics '*What shapes our coastlines*' and '*Why sea level rise is important*' that have been reproduced in Figure 15a and 15b.

1. Use the terms you recorded on Think Like a Geographer Activity Worksheet 1 to create an infographic of your own based on these examples.
   This could include: the impacts of climate change on coasts the impact of storms. Use a digital infographic tool such as Piktochart, Adobe Spark, Canva, Visualize, Easel.ly. CR AP

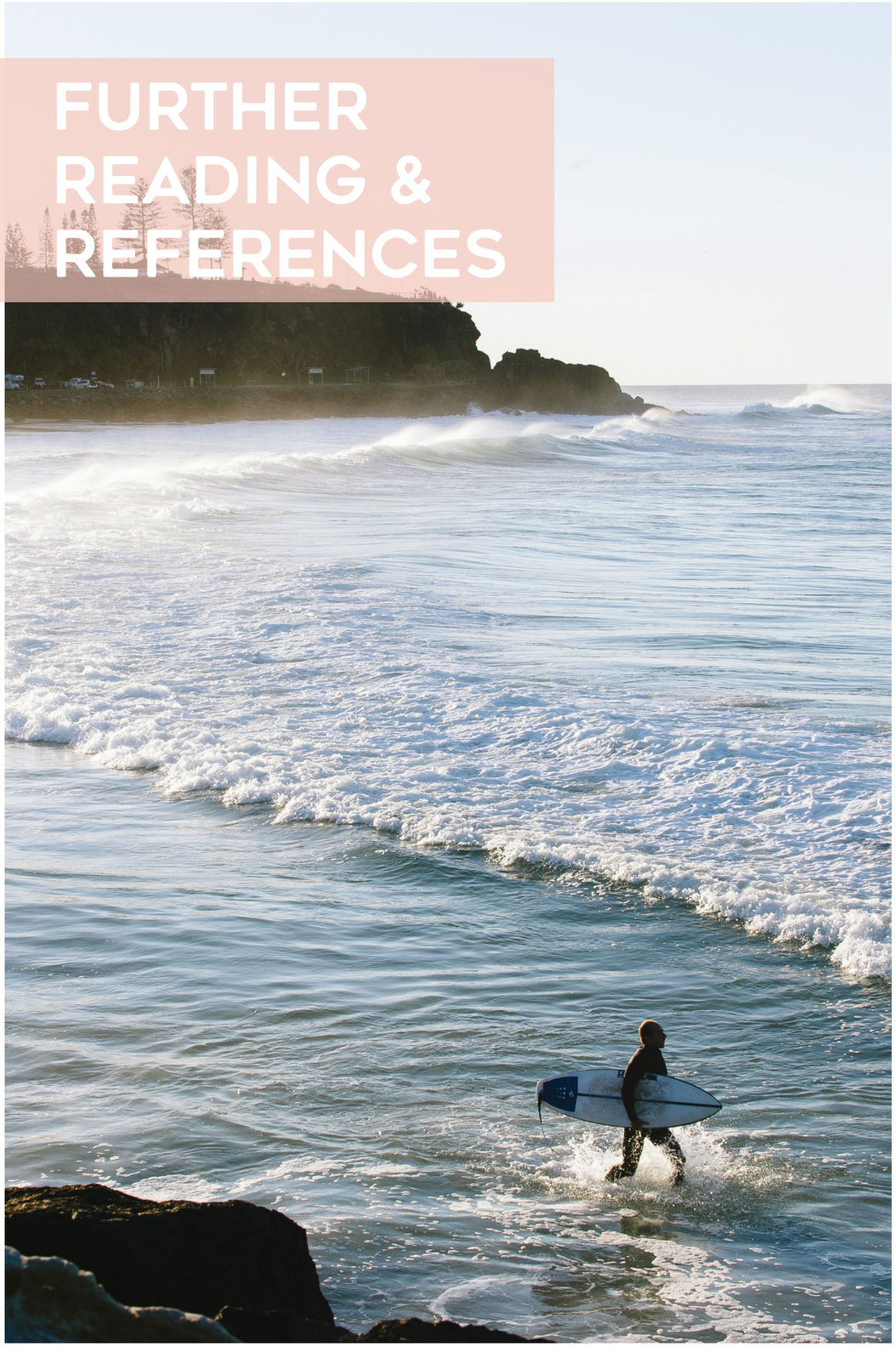
2. Add specific examples from NSW and Queensland coasts to your infographic. AP

KEY LEARNING

- The environmental processes of weathering, erosion, transportation and deposition form and transform coastal environments; however, they function differently on any one section of coast or beach.
- The atmosphere, hydrosphere, lithosphere and biosphere play an interconnected role in how coasts function.
- Coastal features change over multiple time frames from days to decades and millennia.



FURTHER READING & REFERENCES



Further Reading

Tweed Sand Bypassing Project Video

The Conversation: *Climate change may change the way ocean waves impact 50 per cent of the world's coastlines*

The Guardian: *The three-degree world: the cities that will be drowned by global warming*

C40 Cities: *Staying Afloat: the urban response to sea level rise*

Business Insider: *Australia's beach lifestyle could be under threat from climate change, according to a new UN report*

Coastal Zone: *A documentary about beaches and management (part 1)*

UK Environment Agency: *What is coastal erosion?*

Oz Coasts: *What is beach erosion?*

Bureau of Meteorology (BOM): *What is an East Coast Low? (BOM)*

Bureau of Meteorology (BOM): *Tropical Cyclone Knowledge Centre (BOM)*

ABC: *NSW weather: Sydney homes evacuated as king tide combines with east coast low*

Water Research Laboratory (WRL): *Erosion of Collaroy-Narrabeen beach June 2007*

Narrabeen/Collaroy coastal erosion 2016

Coastalwatch: *Collaroy-Narrabeen erosion from June 2016 Storms*

City of Gold Coast: *Palm Beach Shoreline Project*

References

Masselink, G. & Hughes, M. (2003). An Introduction to Coastal Processes and Geomorphology.