



# Shoreline Revival

## Integrating Nature-based Solutions for Sustainable Coastal Design and Enhanced User Experience

Dawlish and Dawlish Warren, UK

University of Delaware Bachelor of Landscape Architecture
Senior Capstone 2023

Project By: Lexi Dart

Capstone Committee Members
Anna Wik, RLA, ASLA
Dr. Chris Spencer, University of the West of England

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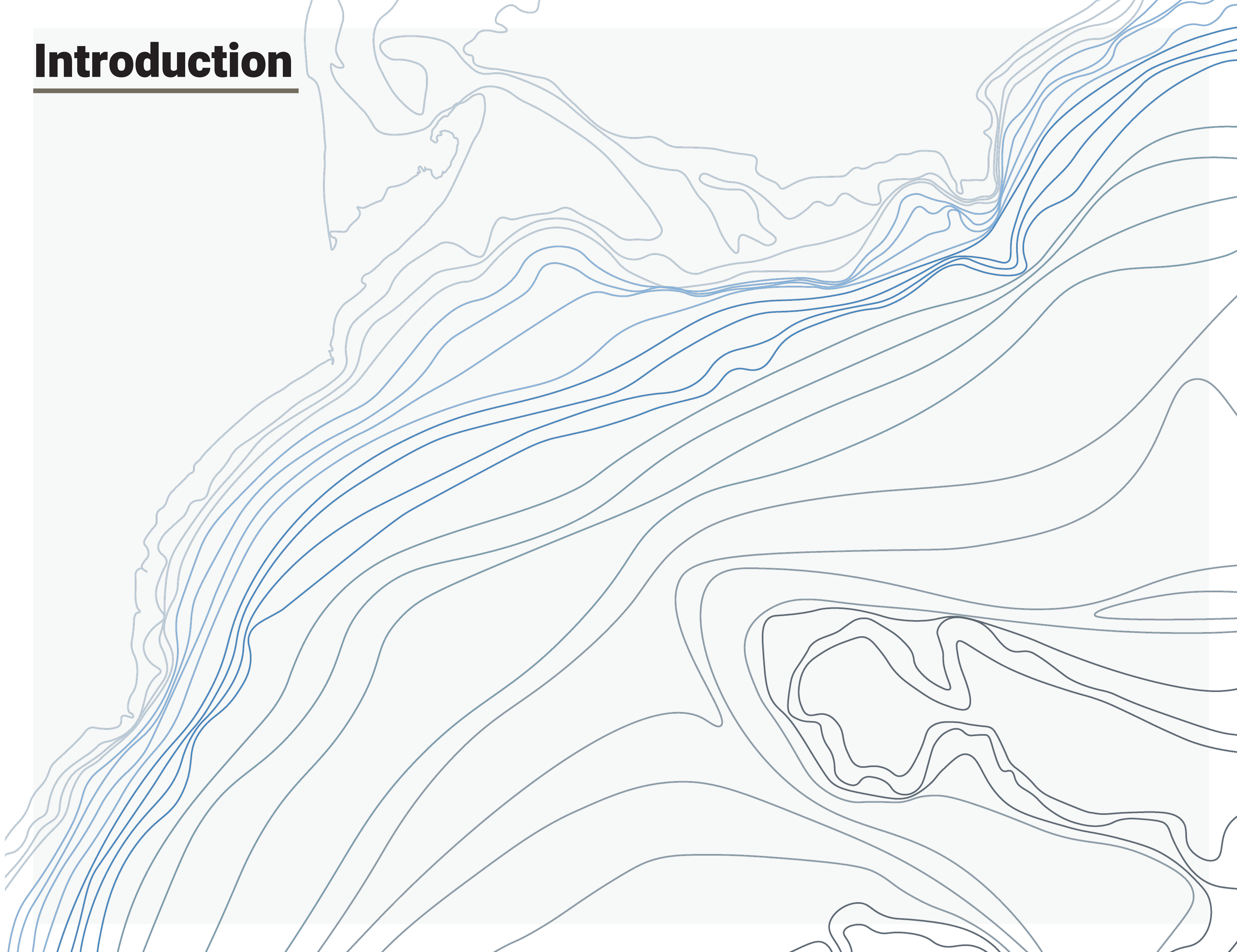
# Introduction



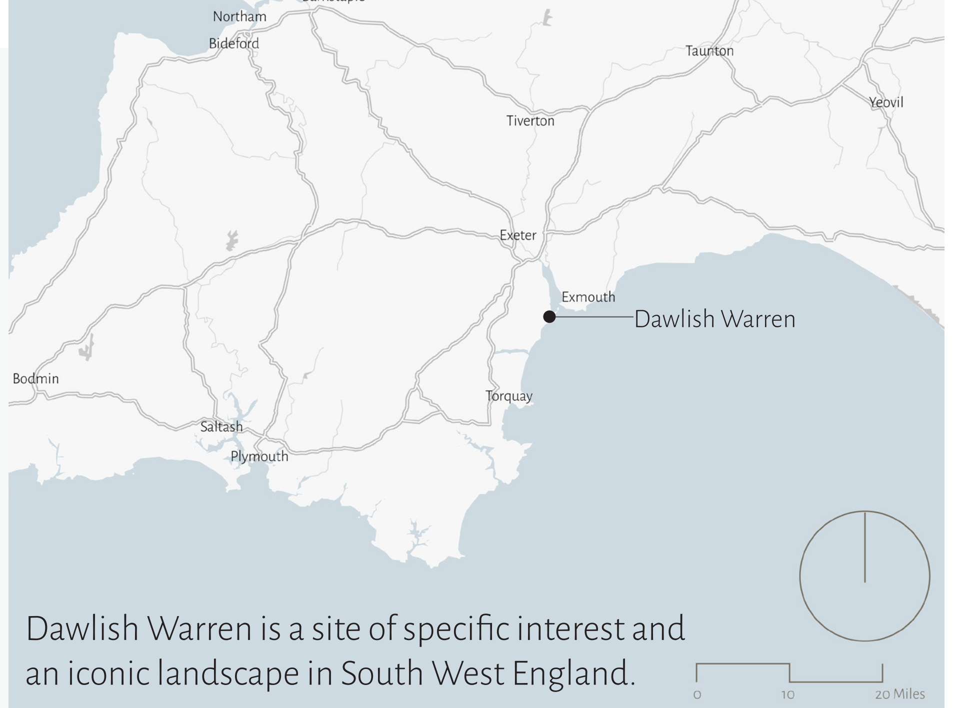
# Site Profile

Dawlish Warren is a seaside resort located on the south coast of Devon in England. Holiday accommodation and facilities for holidaymakers comprise the majority of Dawlish Warren. It is located at the mouth of the Exe Estuary and has a beach, National Nature Reserve, a golf course, and a seafront amusements area.

During the summer months, thousands of visitor flock to the area, with holiday visits to the region being 421,000 between 2017-2019 (Visit England, 2022). The area heavily relies on tourism, with the beach essential in sustaining this destination. A train line runs through the resort, connecting down to Cornwall and up to London and onwards. One main road runs through the town, and several other roads connect the surrounding areas. There are also bus routes linking people throughout the county to the area. Additionally, there are coastal paths spanning the entire coastline of Devon, passing through Dawlish Warren.

The site is relatively low and flat, extremely exposed to extreme weather events. This has caused the landscape to evolve over time looking significantly different from the landscape in the early 1900s. A freshwater lake once split the landscape, but this was filled in between 1950 and 1960.

Shoreline erosion has been a problem at Dawlish Warren for years, with numerous strategies being employed to reduce sand loss from the beach and protect the dune system (see figs. 12,15, and 19, pg. 15-17). Currently, groins line the beach trapping sediment on either side. Many of the groins have been updated recently, with only the groins on the far north end of the beach not being renewed. There are Geotubes holding the dune system up, but many of these are exposed, causing significant slippages of sand (Environment Agency, 2017). Additionally, gabion cages located around groin 12 have been entirely destroyed by wave energy and need to be removed, and an alternative measure needs to be used.




Location of Dawlish within Devon


Map shows the topography of the area



# Seafront

Dawlish Warren seafront has been an active landscape welcoming tourists from all over the UK and beyond since the mid 1800s. During the summer months, the fair opens rides open, attracting families with young children to the site. Pictured in the image to the right is a passive, unprogrammed large green space prone to water collection. There is a slope down into this space which leads to water building up at its center.
Currently, there are some buildings under construction. These will be used for retail and will sit alongside an arcade and restaurant called 'The Boat House' that currently exist.

# Beach

Both Dawlish and Dawlish Warren have beaches, but the addition of seawalls along the cliffs of Dawlish has caused much of the shoreline to be eroded away. The beach at Dawlish Warren also experiences erosion, being exposed to high wave energies. Multiple coastal protection strategies have been installed along Dawlish Warren beach, such as groins, gabion cages, Geotubes, and rock armor (see figs 12,15,and 19). Many of these strategies have failed from regular high wave energy or storm events. The beach is backed by a dune system which has experienced high rates of erosion, creating a shelf with plant roots exposed.

# Nature Reserve

The Nature Reserve is typically left untouched by beach tourists. Birders use the area all year round to see the hundreds of bird species that frequent the site.
The image to the right shows the flooding from the Greenland Lake. This lake once connected out into the River Exe, but in 1940 was filled in. This has lead to flooding occurring during rainy periods which drastically changes this landscape.
Hundreds of plant species have been recorded in this area, with this location being one of the only in the UK to host Sand Crocus.

fig. 1 - green space at Dawlish Warren

fig. 2 - groins on Dawlish Warren beach

fig. 3 - flooding in the nature reserve at Dawlish Warren

Images located on map on page 6

# Opportunities for Improvement

Erosion is one of the main problems along this stretch of coastline, drastically reducing beach frontage each year. High wave energy also leads to issues in this area, disrupting dune systems and tearing down sea walls. Investment in hard-engineering has stopped natural sediment movement and led to the loss of critical habitats (Morrish & Rees, 2013).

Additionally, the seafront zone is in need some exciting new amenities to boost the economic value of the area. This space is uninspiring and dated, with an arcade and fair rides being all the space has to offer.

An active train line runs through Dawlish and Dawlish Warren; this is a major constraint in sea level rise planning but is important in bringing people to the area. The train line divides this area from the rest of Dawlish Warren creating a narrow entrance to the site.

This portion of the coastline has so many rich experiences to offer. With this project, I want to extract these experiences and adapt the landscape, so people are drawn to explore the area.

fig. 4 - aerial image of Dawlish Warren

## Goals

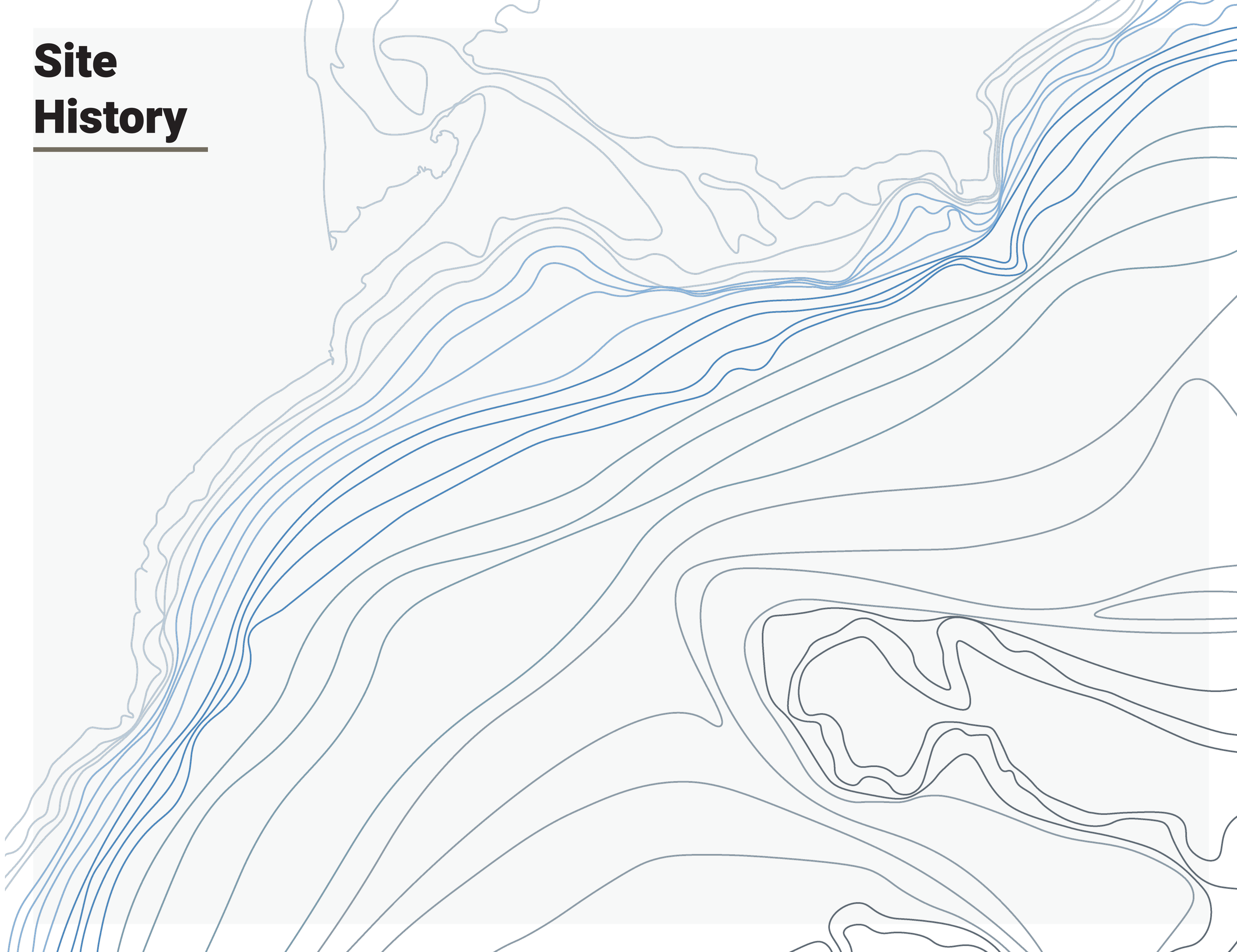
1. Prevent shoreline erosion by reducing the wave energy reaching the shoreline.
2. Maintain shoreline availability for habitats and human activity by encouraging sediment build-up along the shoreline.
3. Create new opportunities for recreation and exploration at Dawlish by establishing unique spaces for users of all ages.
4. Promote biodiversity by creating new habitats and increasing plant species diversity.

## Objectives

1. Promote the history of the site through design decisions and use past forms to inform the design choices.
2. Increase recreational opportunities and promote biodiversity in the area.
3. Use nature-based solutions to alleviate the area's current problems.
4. Examine deficiencies in existing coastal engineering solutions to inform new design and identify areas of significant storm damage.



# Site History



# Early History

Proof of settlement in Dawlish did not come until 1044, with settlers establishing a village in a protected area sheltered on three sides by hills and on the remaining face by the sea. The sea provided limited food, while the wooded area harbored animals that gave meat, and wood for burning. People worked cultivating salt marshes which also created a source of food but, most importantly, created trade with other communities.

fig. 6 - photo of Dawlish from 1915

Dawlish is synonymous with 'Devil Water', local history explains that the name came from the red waters which flow from the hills after heavy rain - this still happens today, and frequently streams of red run through the town after heavy rain. This occurs due to the rock type in the area being Aeolian and fluvial sands with some interbedded bressia beds (Durrance et al., 2022)

In the mid-19th century, the construction of a railway was a massive appeal to holiday-makers, and the "Warren Halt" station was constructed in 1905. An increase in leisure activities saw the establishment of Warren Golf Club on the Inner Warren in 1892.


fig. 5 - Dawlish Warren seafront 1910s

During this period of time, the settlement which grew into Dawlish was not on the coast. Many feared the sea; nobody knew what was 'over the water's edge.' Locals knew that the sea flooded the land with damaging storms emerging from it. Farming was popular in the area with settlements being found in the surrounding areas (Dawlish History).

fig. 7 - Whit Monday in 1919 at The Warren



# Timeline

**1817**
5 acres of sand washed way in one storm

**1824**
"The Great Gale" an extreme hurricane hit Dawlish Warren. A gap was made in the outer bank of Dawlish Warren

**1846**
South Devon railway extended from Exeter through Dawlish and Dawlish Warren

**1869**
A storm ripped through the Warren and displaced sand were dumped on top of the oysters

**1869**
Exe Bight Oyster Fishing and Pier company laid down 30,000 oyster beds in Greenland Lake

**1872**
Gap in the outer banks had grown to a furlong wide (201m)

**1892**
Improved transportation links to the site boosted tourism and recreation in the area leading to "The Warren" golf course being formed

**1898**
The sea repaired the breach

**1899**
The first bungalows were built on the spit

**1902**
A violent storm created waves that rose high above the dunes


**1911**
Winds of eighty miles an hour, drove huge waves onto Dawlish Warren. The sea cut away in many places and bungalows on spit were destroyed

**1913**
Storm damaged caused the loss of bungalows

**1940**
Greenland Lake channel was filled in

**1949 1962**
Peak erosion ~7m per annum loss

**1950**
Prediction made that the spit had a 15 year lifetime

**1962**
Rock armor added to the southwestern part of Dawlish Warren

**1963**
Timber groins (17) and gabion cages installed

**1971**
Major works commence to try stabilize the spit

**1974**
Large section of the Dawlish railway platform was demolished by a storm

**1992**
Improved seawall and hard-engineering rock armor installed at the start of the spit to protect the rail line

**2008**
The railway was affected by storms

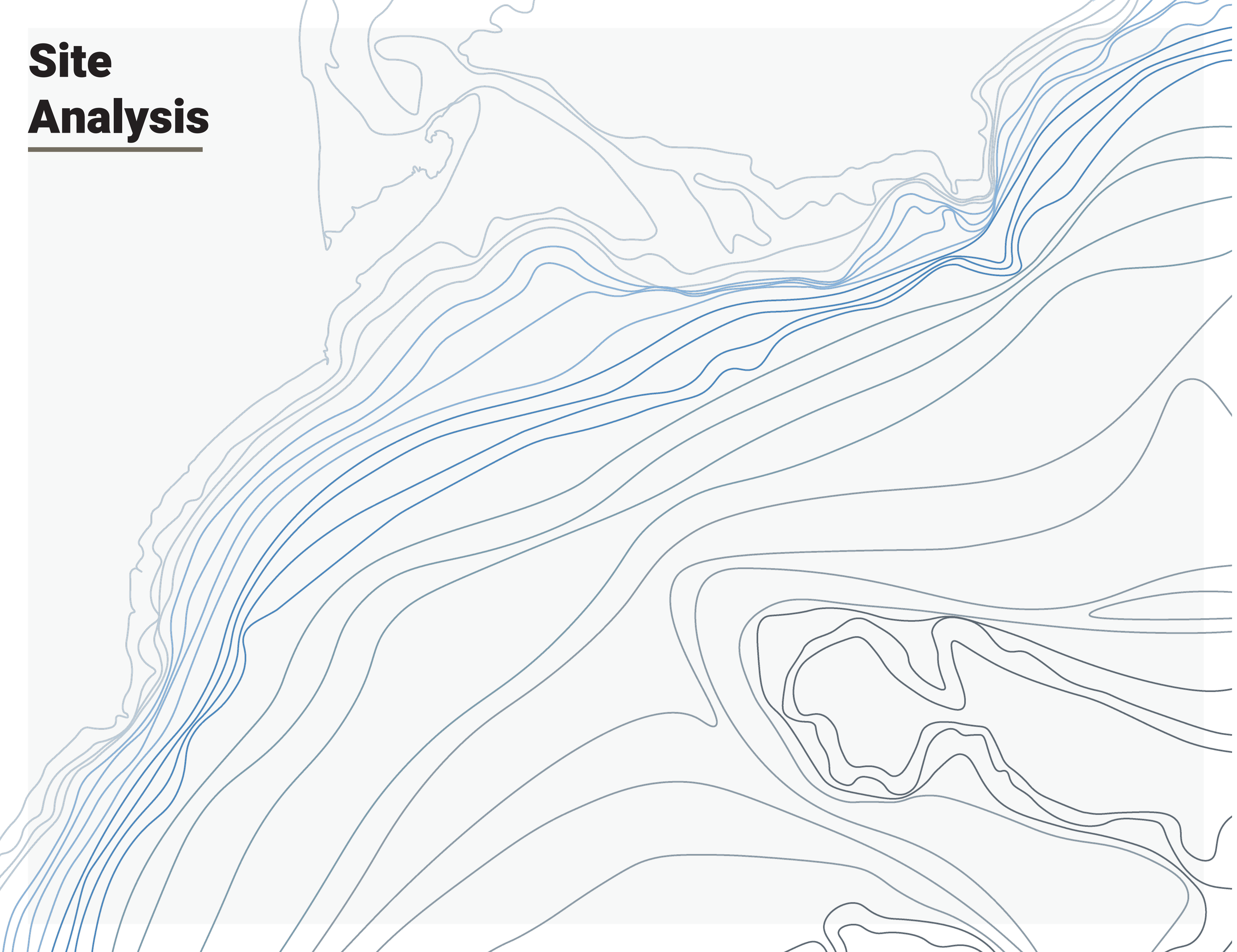
**2010**
Dramatic sand losses, with a single storm removing 10 meters of dune frontage

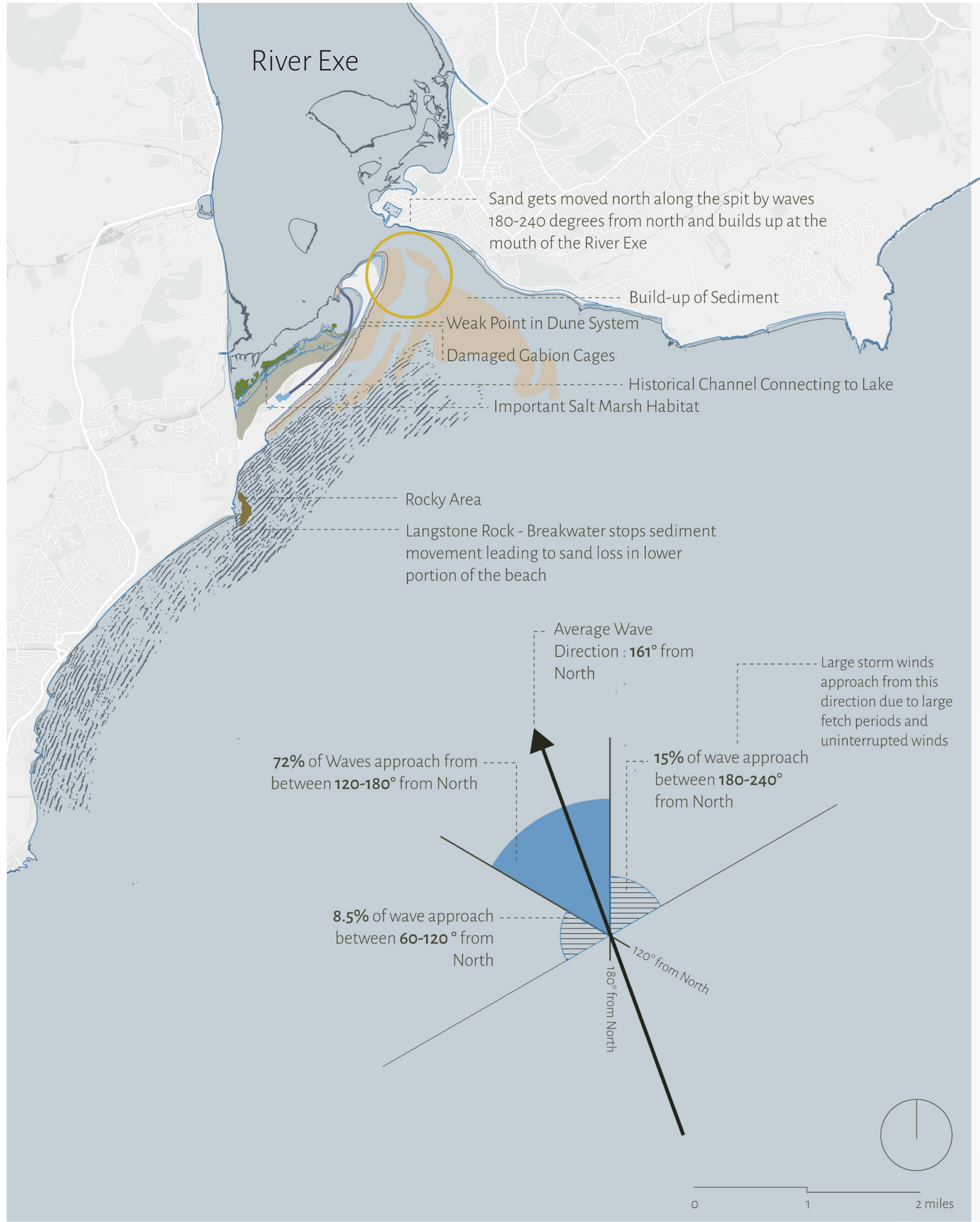
**2014**
80 meters of railway line left dangaling and 20,000 tones of rock swept into the ocean

**2017**
Most of the gabion baskets were removed and most of the groins were replaced. Geotubes 3 meters high were installed after groin 10 to stablize the dunes. Dredging also occured

**2019**
Geotubes are exposed

# Site Analysis






# Site Vulnerabilities

I used sea level rise predictions to understand how this portion of the coast would be impacted. Due to the current hard-engineering solutions on the site, sea level rise will not impact any businesses or homes but will cause issues for the sand spit, nature reserve, and golf course. Damage to properties will only occur if seawalls fail from storm events.

Currently, the railway pay's for all the repairs to this area. This is because this landscape is critical in protecting the train line.

The dominant wave direction comes from 120-180 degrees from the North. Waves from this direction build up over a very long fetch since the nearest land is France.

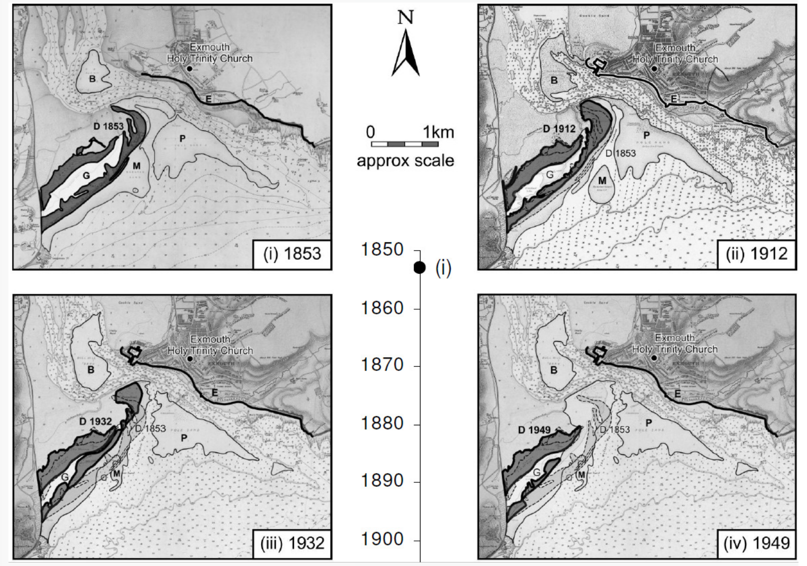
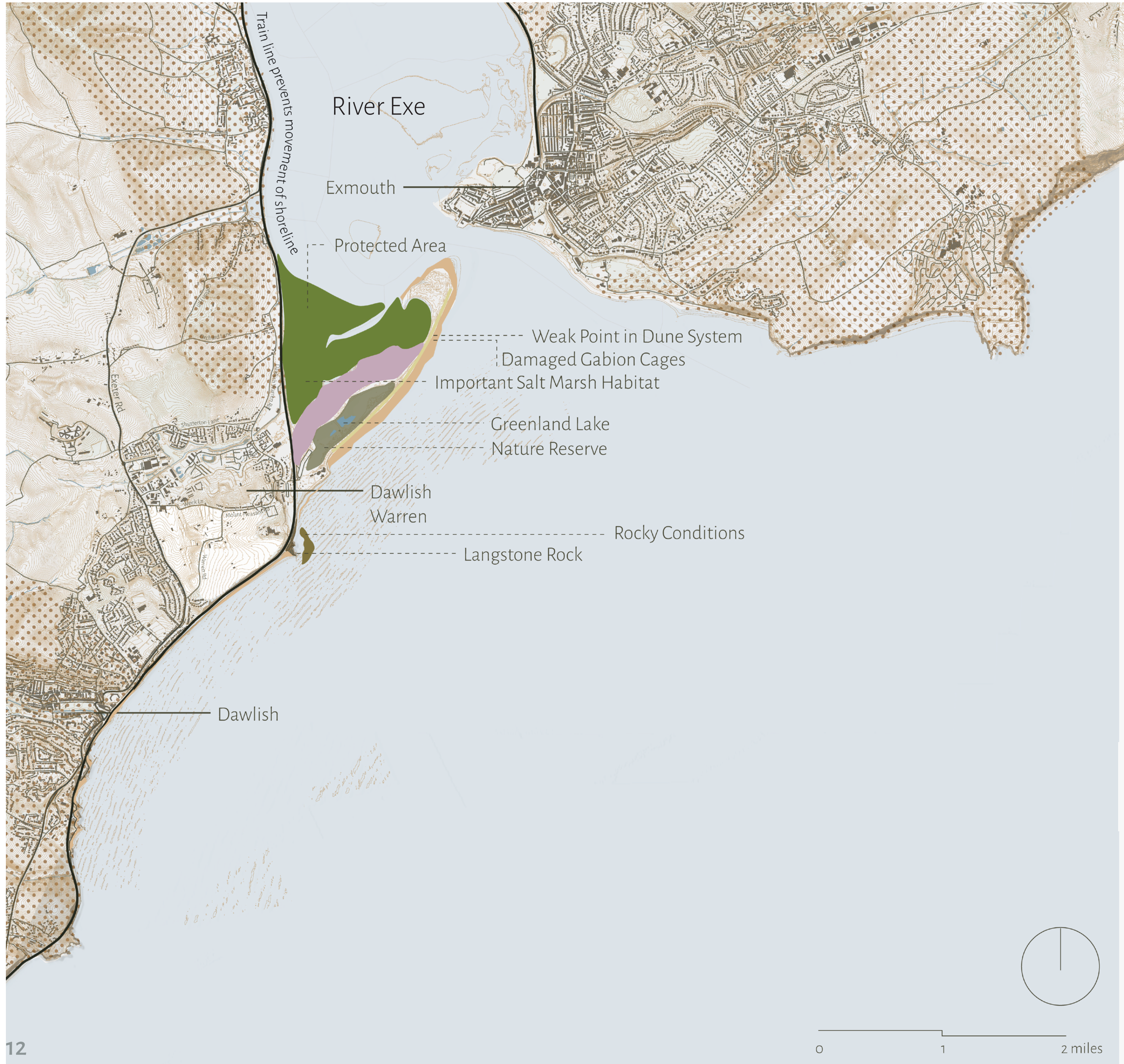



fig. 8 - Dawlish Warren land use and coastline evolution

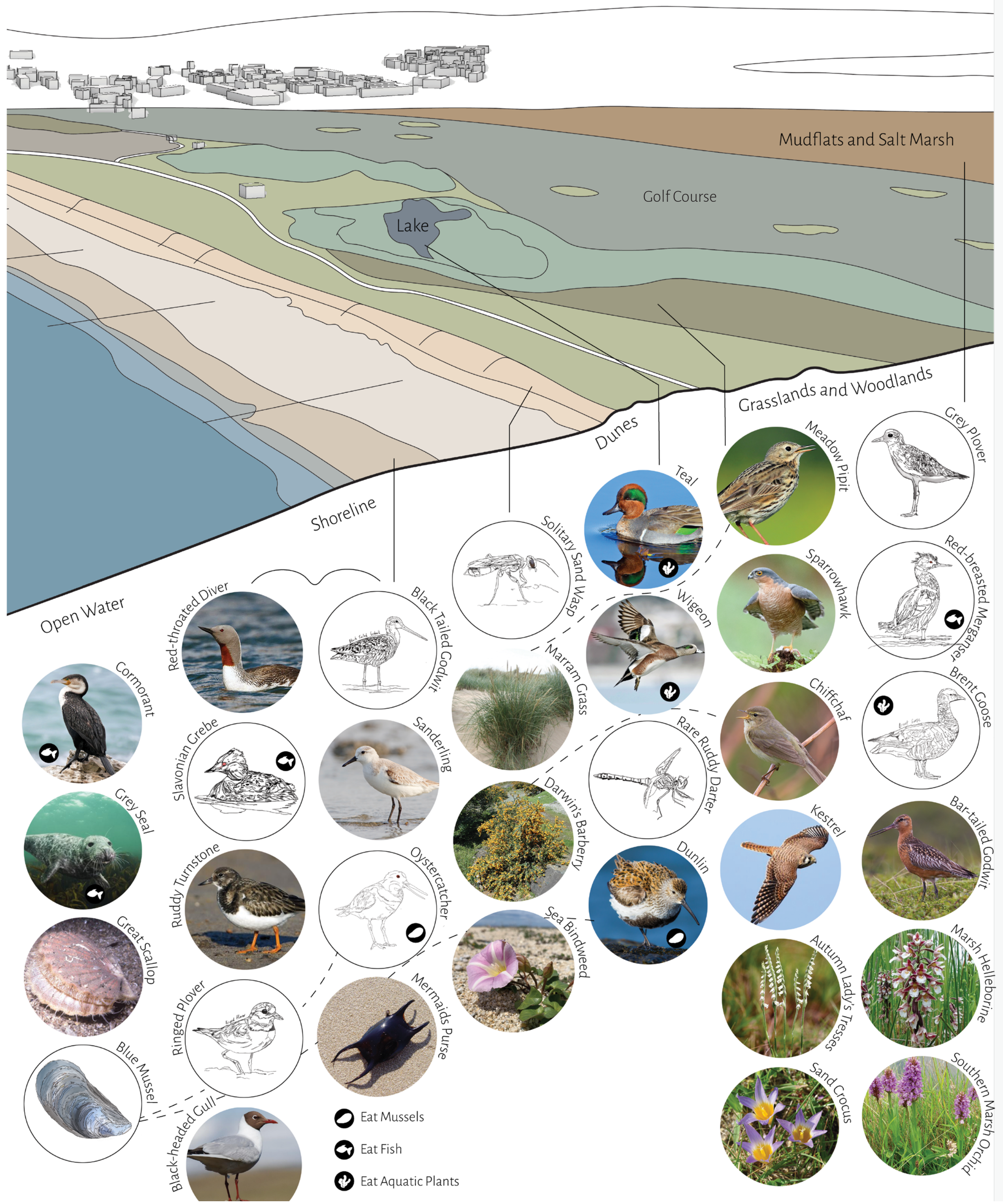



# Site Constraints

The coastline is rugged and very steep in parts. Additionally, the rock along the cliffs is very soft, making them highly erodible (West, 2016).

The railway development made way for homes to be built along the cliffs due to the protection the seawalls should offer. This may lead to issues in the future as the railway is currently looking for alternative routes to connect the southwest of England as it is becoming too expensive to keep repairing million-pound sea walls.





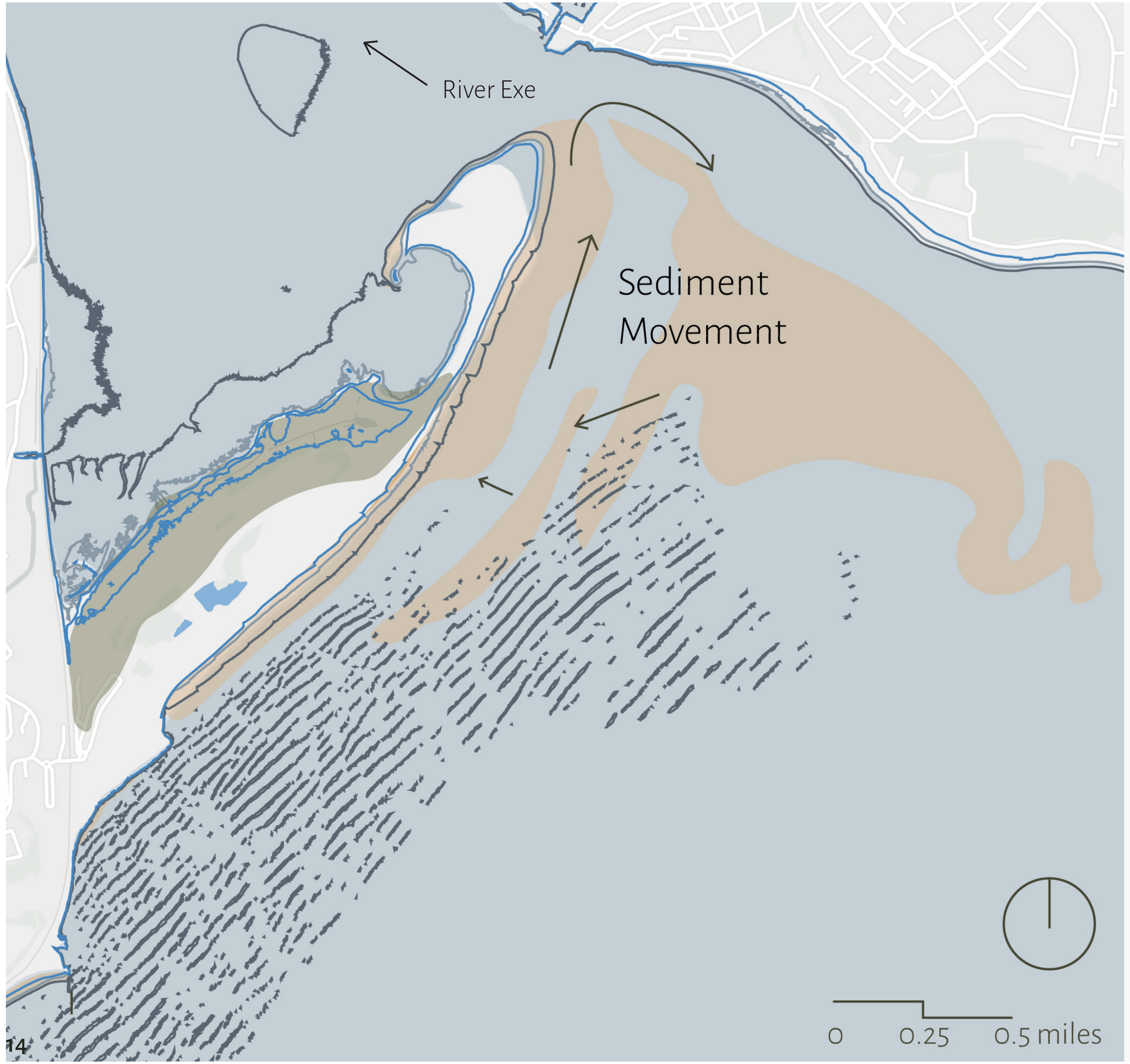

# Plant, Wildlife, and Habitat Analysis

Dawlish Warren is a National Nature Reserve, a Site of Special Scientific Interest (SSSI), a Special Area of Conservation (SAC), and forms part of the Exe Estuary Special Protection Area (SPA) and Ramsar site (Teignbridge District Council, 2022). Each year thousands of birds come to feed, on migration, or to spend the winter at Dawlish Warren. The site hosts grasslands, dunes, and mudflats and centers on a 1½ mile-long sand spit/beach across the mouth of the Exe Estuary.

Each autumn, up to 23,000 wildfowl and wading birds travel to the Exe Estuary from the far north to escape the cold. These birds start arriving in August and stay until late March. Over 600 species of plants have been recorded on the site, and the grasslands and dunes host a collection of rare species in the UK. Many of the birds that visit the site rely on its unique characteristics which are present on site. Mudflats and salt marshes are special landscapes in the UK; these parts of the site are not accessible to the public.

fig. 9 - damaged dune system at Dawlish Warren

fig. 10 - flooding in the nature reserve in January 2023




# Natural Processes

Pole sands is a large sand bank that sits just off the shore of the sand spit at Dawlish Warren. Sand builds up on Pole Sands due to tidal movements and longshore drift. The tides move in and out of the River Exe transporting sediment back and forth. Longshore drift pushes sand along the beach towards the North of the spit and out into the River Exe Channel. This sandbank builds up, and over time, large portions break off and begin to move onshore. This provides natural nourishment for the beach at irregular intervals. I am intrigued to explore how this process could be simulated elsewhere on the site to provide regular shoreline nourishment.

fig. 11 - pole sands viewable from Dawlish Warren Beach




fig. 12

fig. 13

125 meter long breakwater

50 meter long breakwater

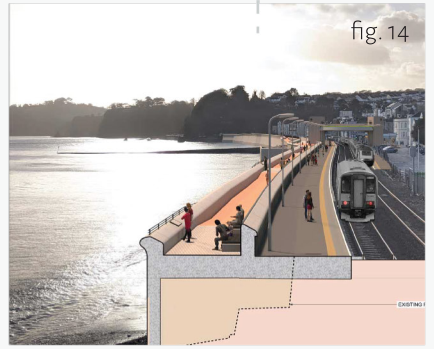


fig. 14

New seawall construction is ongoing - increasing the current height by 4.2 meters to a height of 8 meters

https://www.networkrail.co.uk/running-the-rail-way/our-routes/western/south-west-rail-resilience-programme/dawlish-sea-wall-section-two/#:~:text=New%20sea%20wall%20and%20promenade&text=It%20will%20run%20from%20the,further%20out%20towards%20the%20sea.

# Sea Defenses

There are multiple breakwaters and seawalls protecting this portion of the coastline. The breakwaters experience sediment buildup on the southern side because the predominant wave direction is 120-180 degrees from the North. The lack of beachfront has exposed the railway to high wave energy leading to the failure of portions of the sea wall, causing major disruption to transportation networks.

In 2014 eighty meters of the railway line were left dangling, and 20,000 tons of rock were swept into the ocean. The seawall and line were quickly repaired, although this area is still highly exposed today.

The development of this line connected the southwest of England to London and other further away destinations. This led to increased tourism in the area, eventually resulting in The Warren Golf Course being built in 1892.

fig. 15

Seawall and riprap line this stretch of the beach where little to no beach exists


fig. 16

Ⓐ Main Entrance to Dawlish Warren


fig. 17

70 meter long breakwater at Langstone Rock


fig. 18

8 meter high sea wall

# Sea Defenses

Along this portion of the coast, the cliffs are formed of very soft rock. In 1864 the South Devon Railway was extended from Exeter through Dawlish and Dawlish Warren. This led to the railway company investing in protecting this portion of the coast. Today a sea wall lines the coast, starting at Dawlish and extending into the River Exe. Seawalls prevent natural sediment movement, making many beaches along this stretch unusable, even at low tide.

In the southern portion of Dawlish Warren, rock armor was installed in front of a seawall to protect a portion of the train line. Rock armor is formed of large boulders with gaps between the rocks. This has been a successful solution installed at the site requiring little maintenance. The only issue with this solution is that with high waves, sea creatures can be thrown against the rocks and trapped between them.

Langstone rock pictured to the left is also formed of very soft rock. This formation was once connected to the headland before the railway was built. Sea caves have formed at weak joints of Langstone rock making it unsafe and presenting the risk of falling rocks. A seventy-meter breakwater protects this area and causes the sand to build up, forming a nice beach for visitors to use in the summer. The seawall pictured to the left provides the pedestrian connection from Dawlish to Dawlish Warren.



fig. 19


fig. 20

Battered dunes with exposed roots


fig. 21

Groin 12 that was renewed recently


fig. 22

Damaged gabions


fig. 23

Exposed Geotubes that were installed in 2017

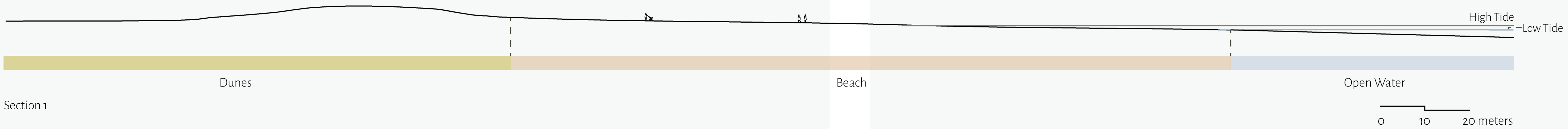
# Sea Defenses

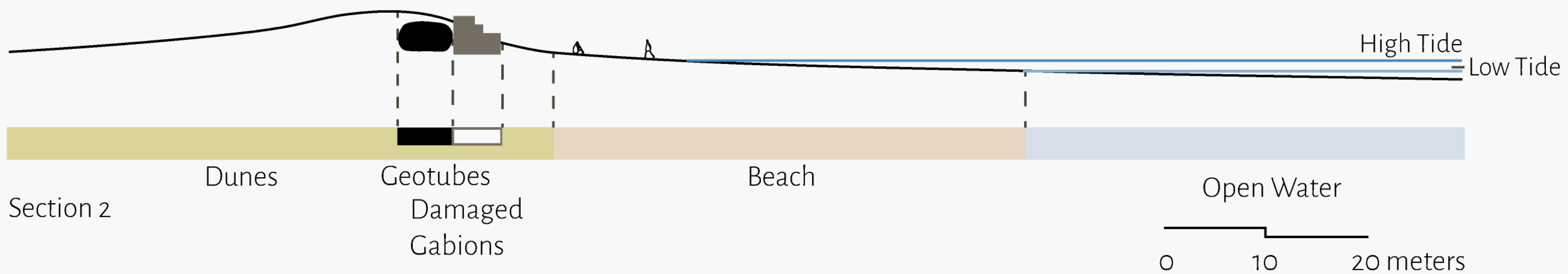
Along the sand spit at Dawlish Warren, eighteen groins line the beach capturing sediment and nourishing the beach. Most of the groins were replaced recently, but after around groin 13, the old groins are still present.

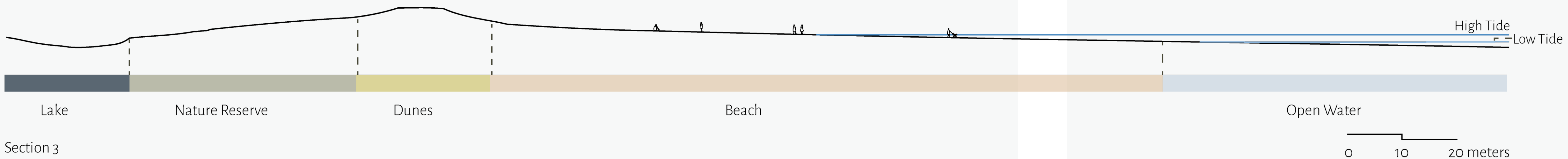
From groin 11 to 15 is the narrowest portion of the dunes. Multiple engineering solutions have been implemented in this zone over the years. Most recently, Geotubes were installed, which involved the movement of huge volumes of sand.

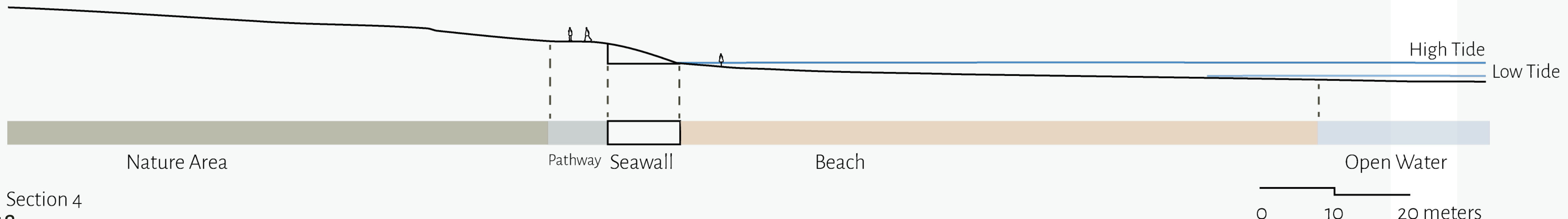
The remains of gabion cages are also present in this area.

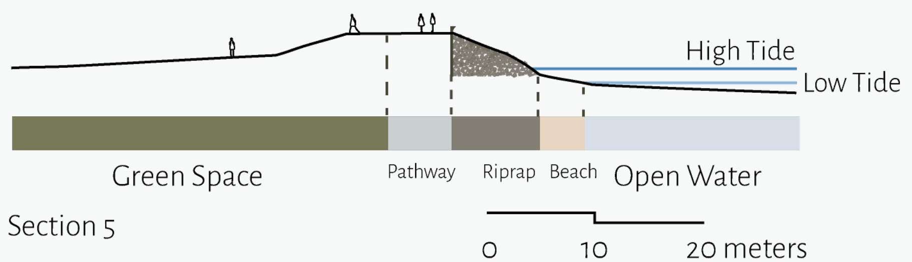
# Site Conditions



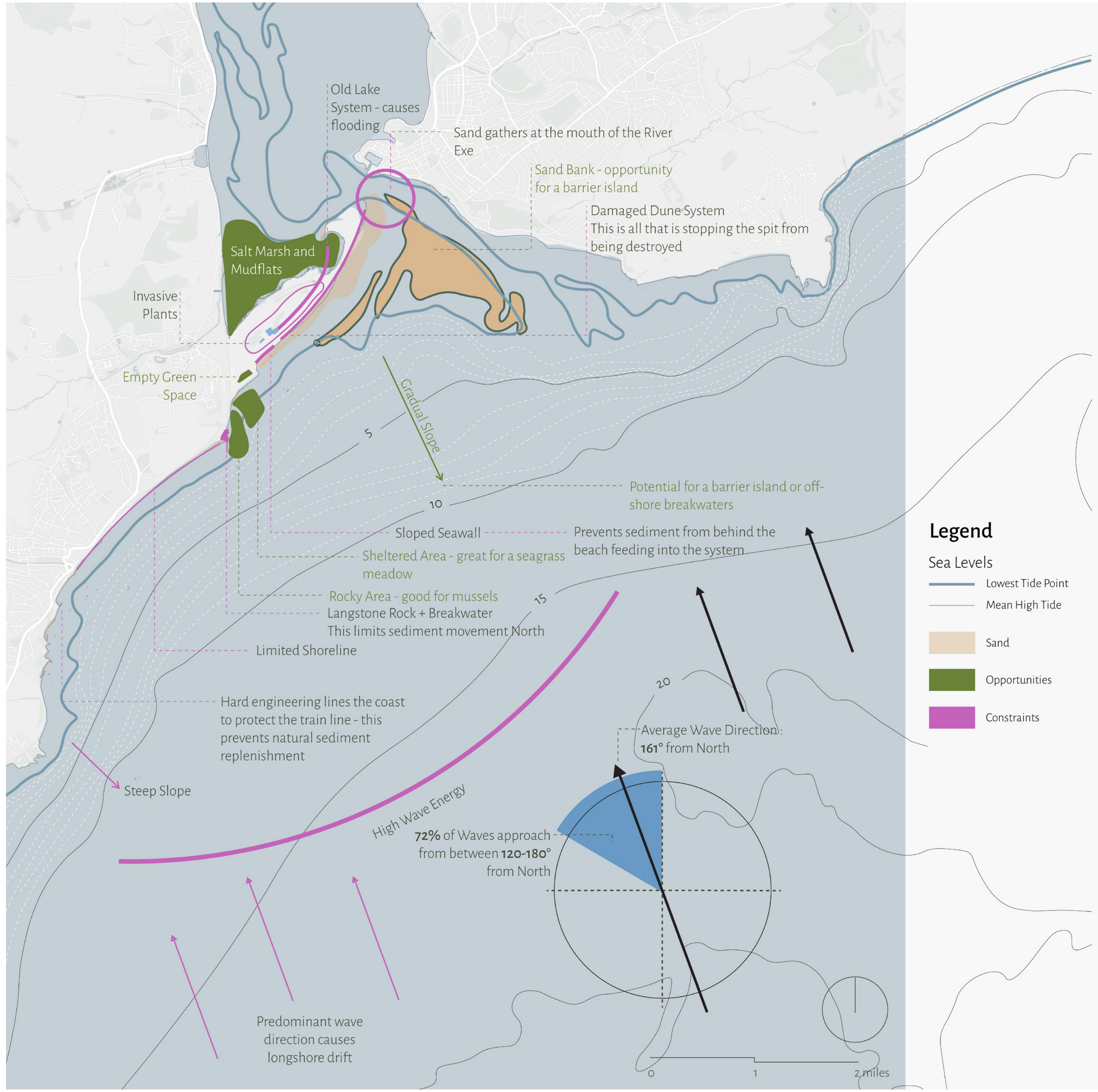




# Shoreline Change


This graphic demonstrates how dramatically this shoreline changes from year to year. I think the forms seen within this graphic are compelling and could be incorporated into the seafront design.






# Opportunities

Just North of Langstone Rock is a rocky area supporting mussel growth. This area is also protected from high wave energy, so it would be well suited to developing a seagrass meadow.

Pole Sands exists just offshore of the sand spit at Dawlish Warren and could support the creation of a barrier island. This would create new habitats for birds and marine animals and protect the northern end of the spit from wave energy.

The bathymetry data shows a gradual slope just east of Langstone rock, which could be a good zone for some type of offshore protection.

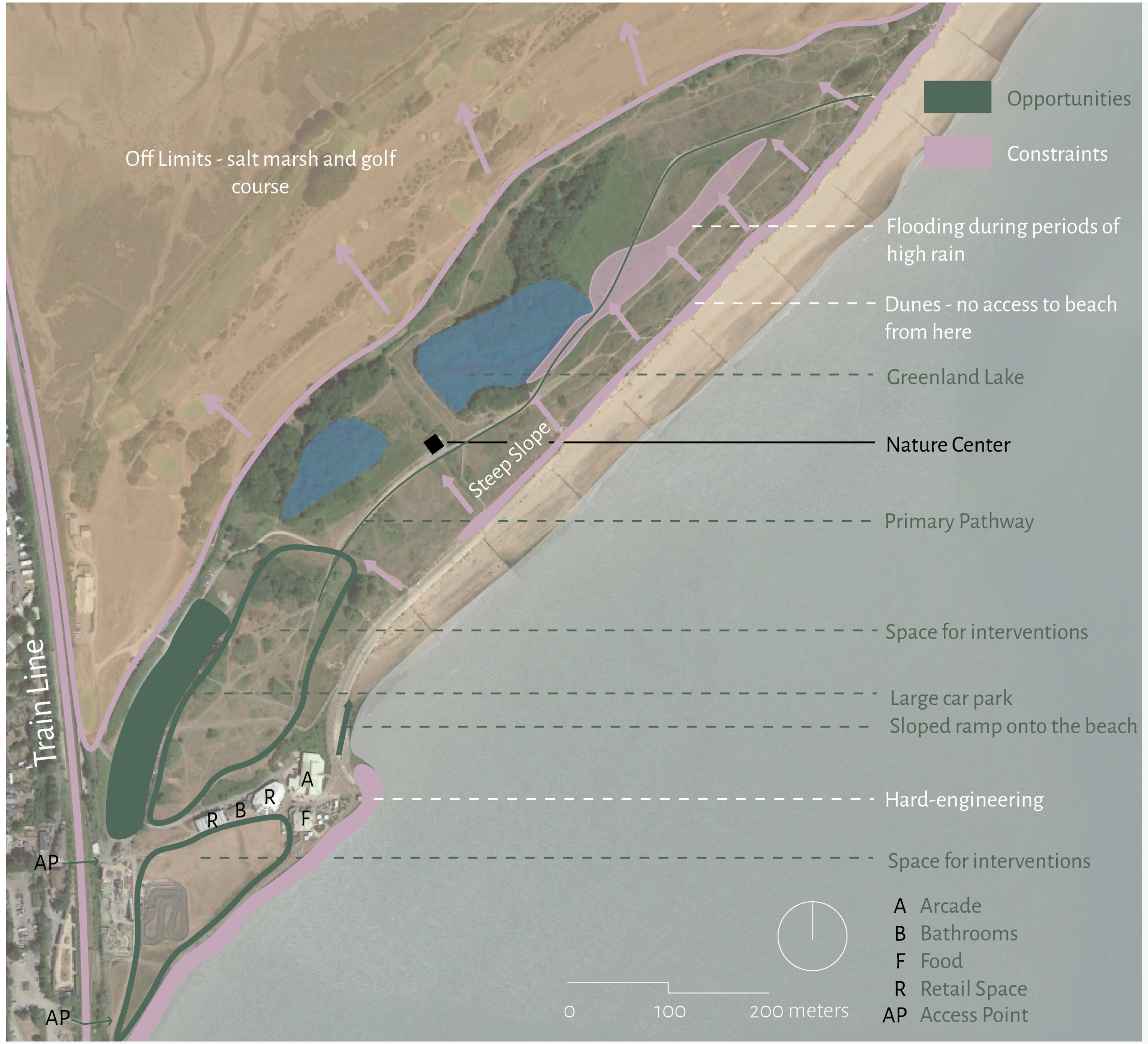
# Constraints

Multiple rock breakwaters along this coastline prevent sediment movement, causing the loss of the beachfront.

The train line is probably the biggest constraint in this area, stopping natural sediment processes from occurring.

The damaged dune system at Dawlish Warren is all that is stopping the spit from being split into two. This area desperately needs a solution that will protect the dunes from failing.

# Dawlish Warren Opportunities and Constraints



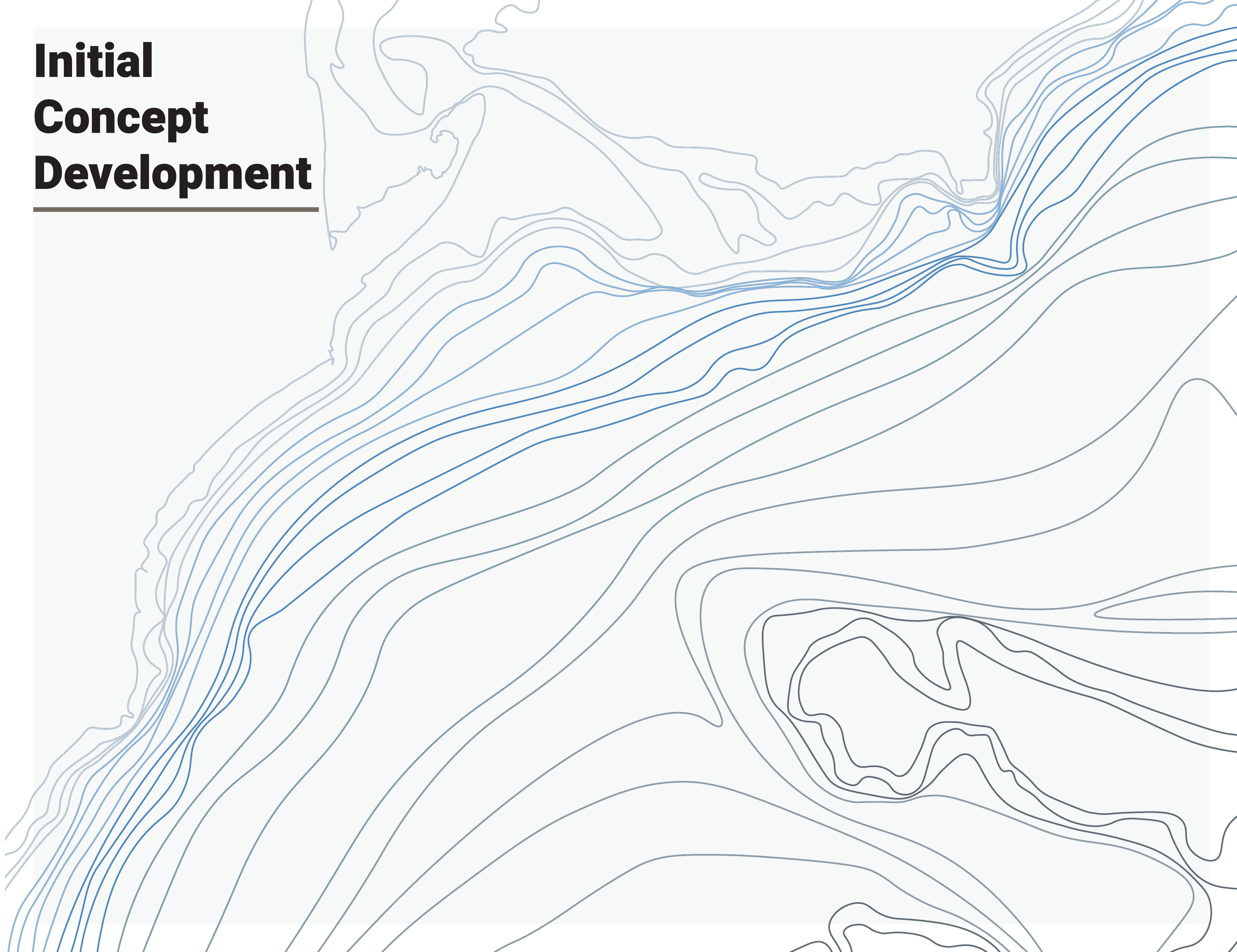


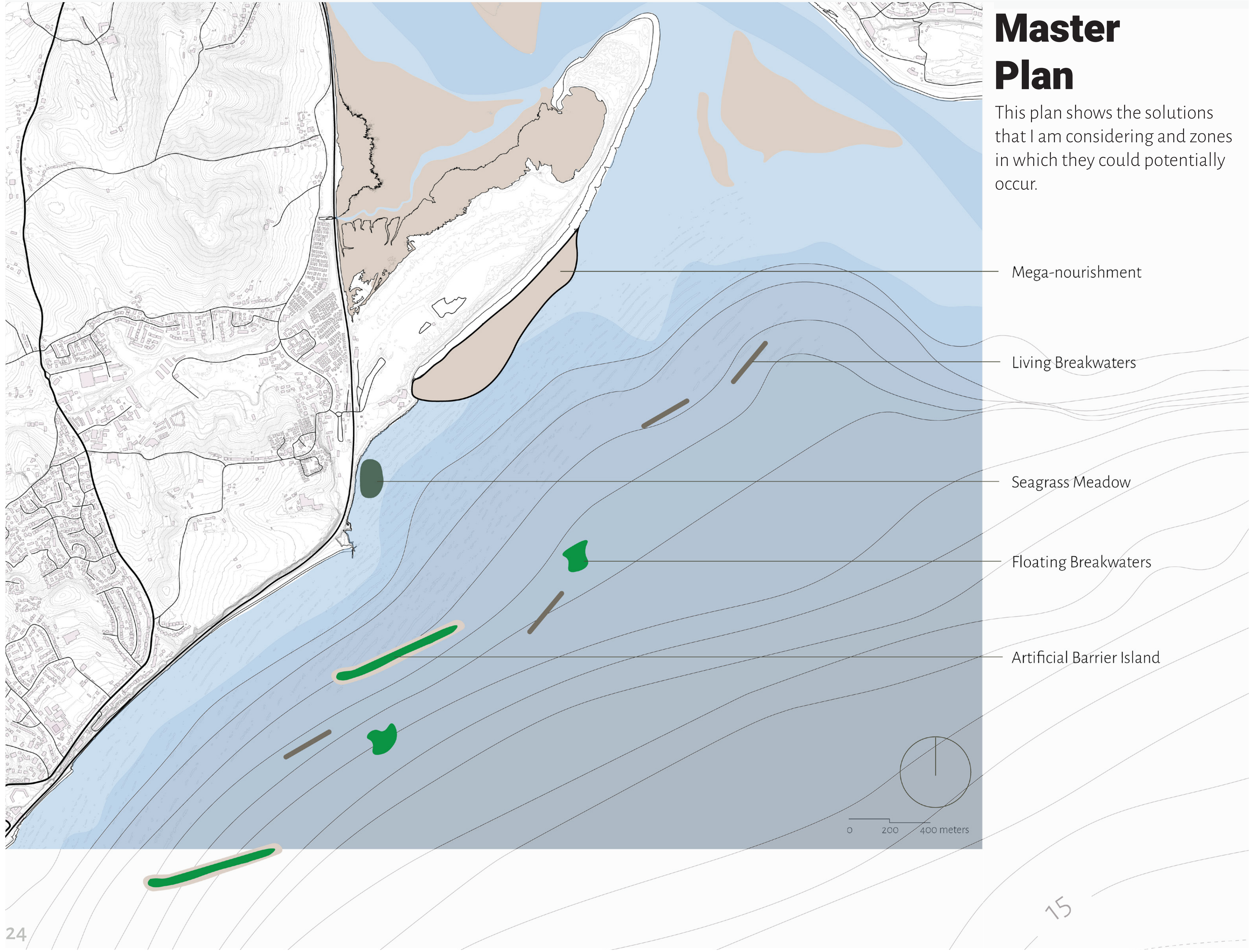
Zones at Dawlish Warren

This area has lots of empty green space which provides opportunities for enhancing the user experience at Dawlish Warren. There are some areas with steep slopes which limit the programming of these spaces.



# Initial Concept Development






# Master Plan

This plan shows the solutions that I am considering and zones in which they could potentially occur.



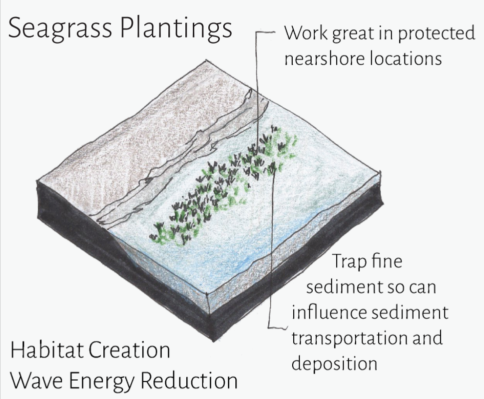
# Potential Nature-based Solutions

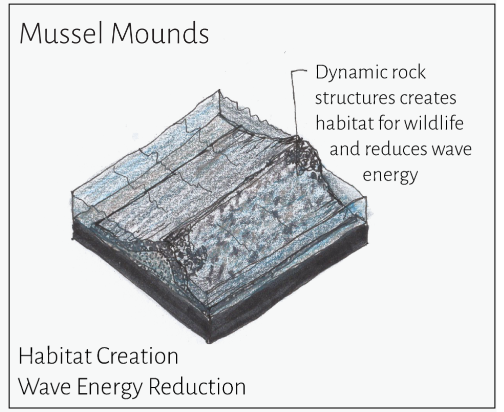
**Mega-nourishment**
More efficient, economical, and environmentally friendly than typical beach nourishment
Long life expectancy allows for constant nourishment over a long period of time

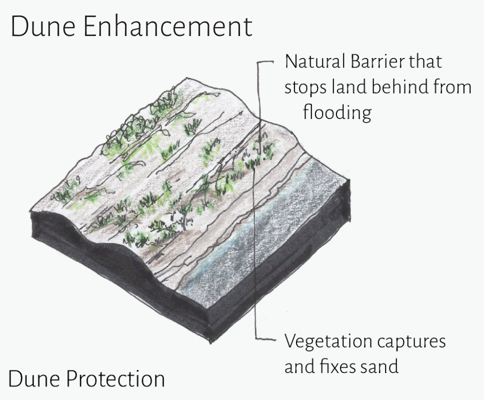
**Seagrass Planting**
It can significantly reduce wave heights and erosion at the shore
Able to attenuate long periods of wave motion
Green nourishment provides an input of sand into the system
Creates a new habitat offshore

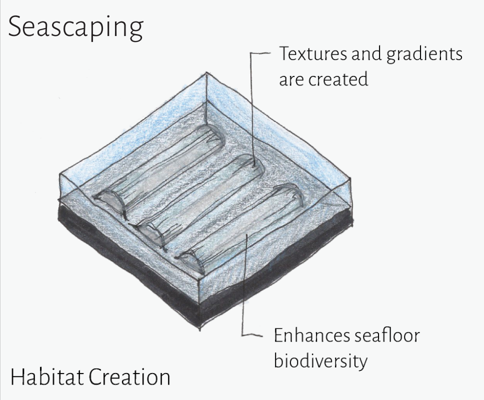
**Artificial Barrier Islands**
It would create a calmer near-shore environment
Makes use of beneficial dredge material
Constructing these is an imaginative blend of ecology and infrastructure
It can reduce wave energy before it reaches land, which in turn would reduce erosion of the shoreline

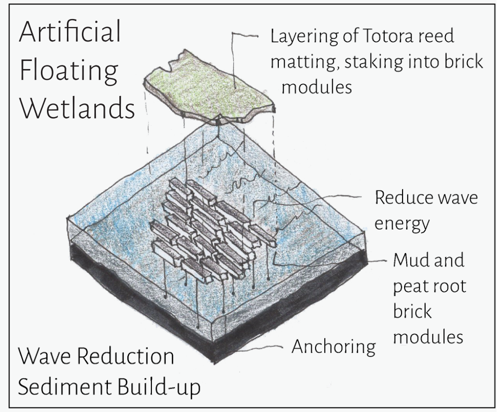
**Wave Energy Converters**
Have the potential to produce local environmental benefits
Installations have the capacity to work as both artificial reefs and fish aggregation devices
Wave farms on the near shore can improve sediment distribution along the beach
Can significantly reduce wave energy

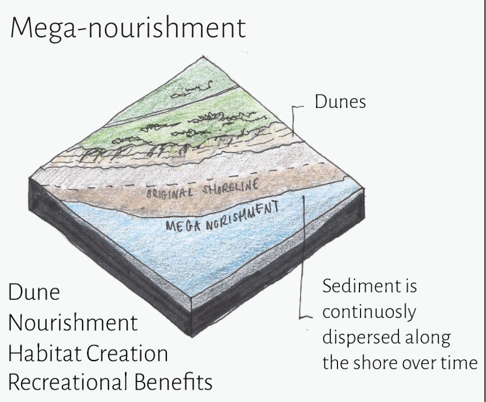



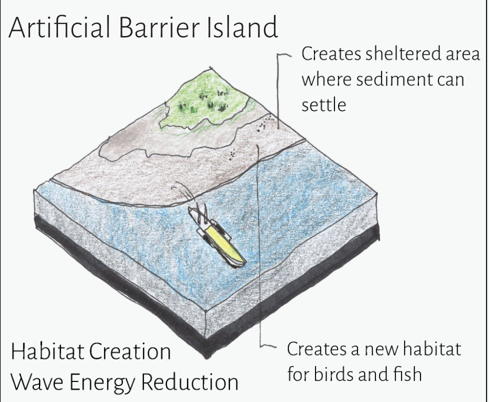



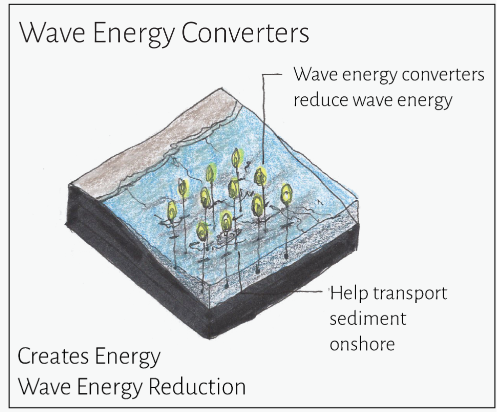



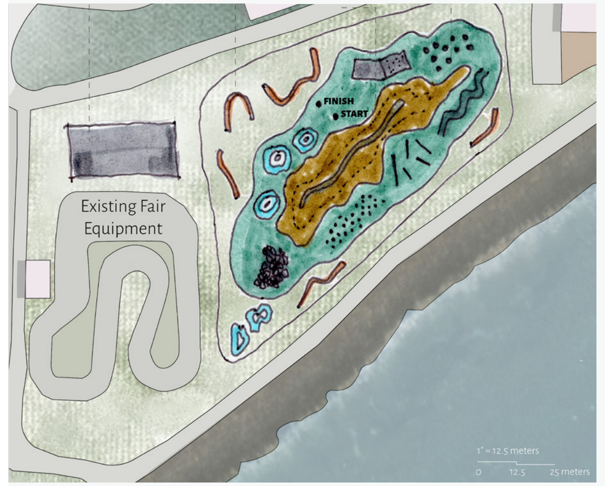




**Artificial Floating Wetlands**
This is a sustainable adaptable solution created by a South American civilization named Uros
This idea has the potential to act as a floating breakwater that can improve water quality and provide bio-diverse habitats
This solution is also completely biodegradable, so the floating wetlands could just be replaced every so many years
(Watson & Davis, 2020)

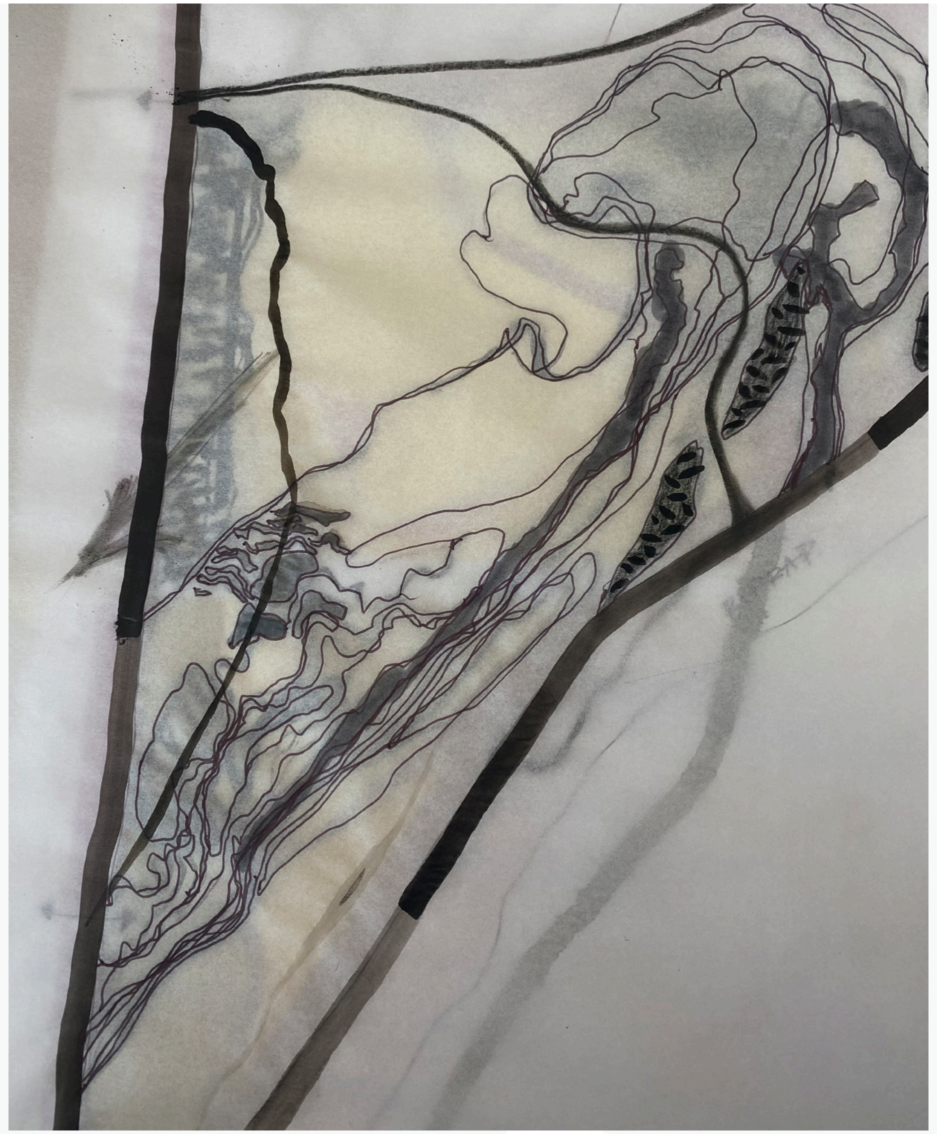
# Seafront Design Evolution

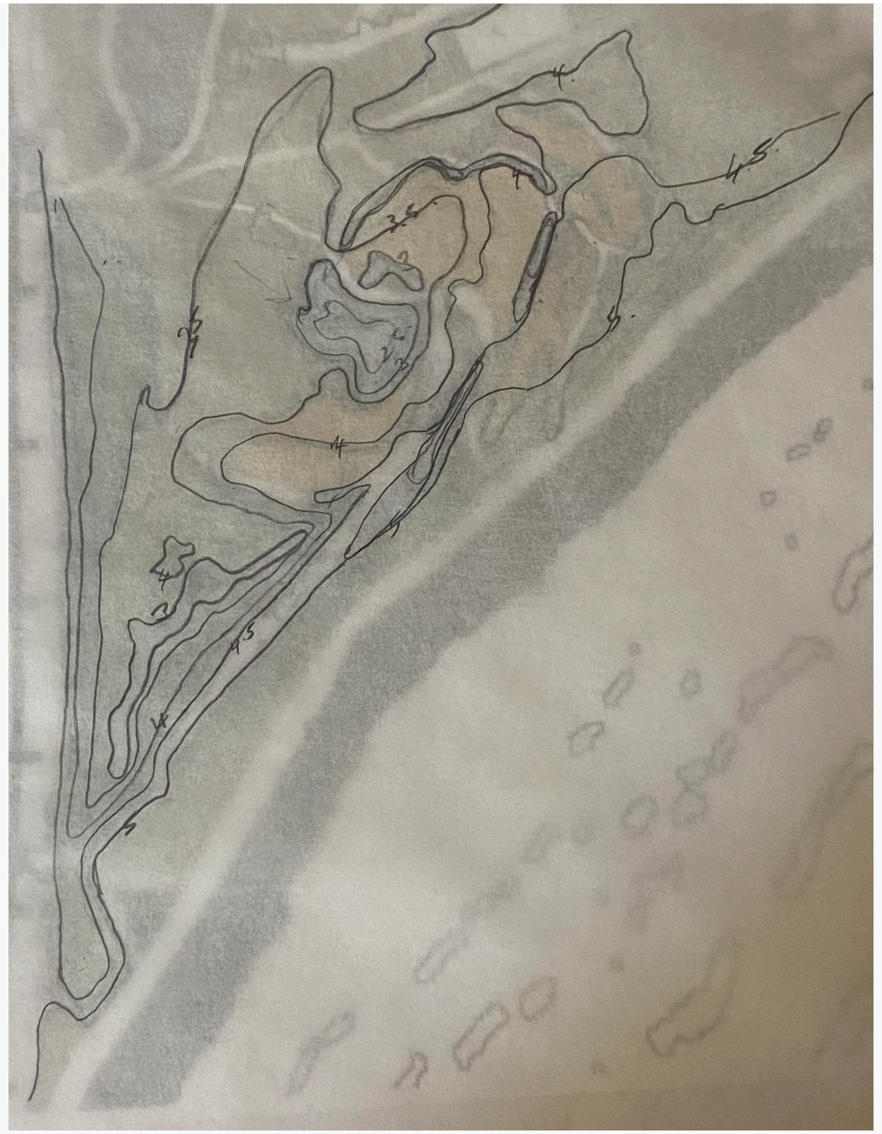

These graphics show the design development process I took to reach the final design for the renewed Dawlish Warren Seafront.

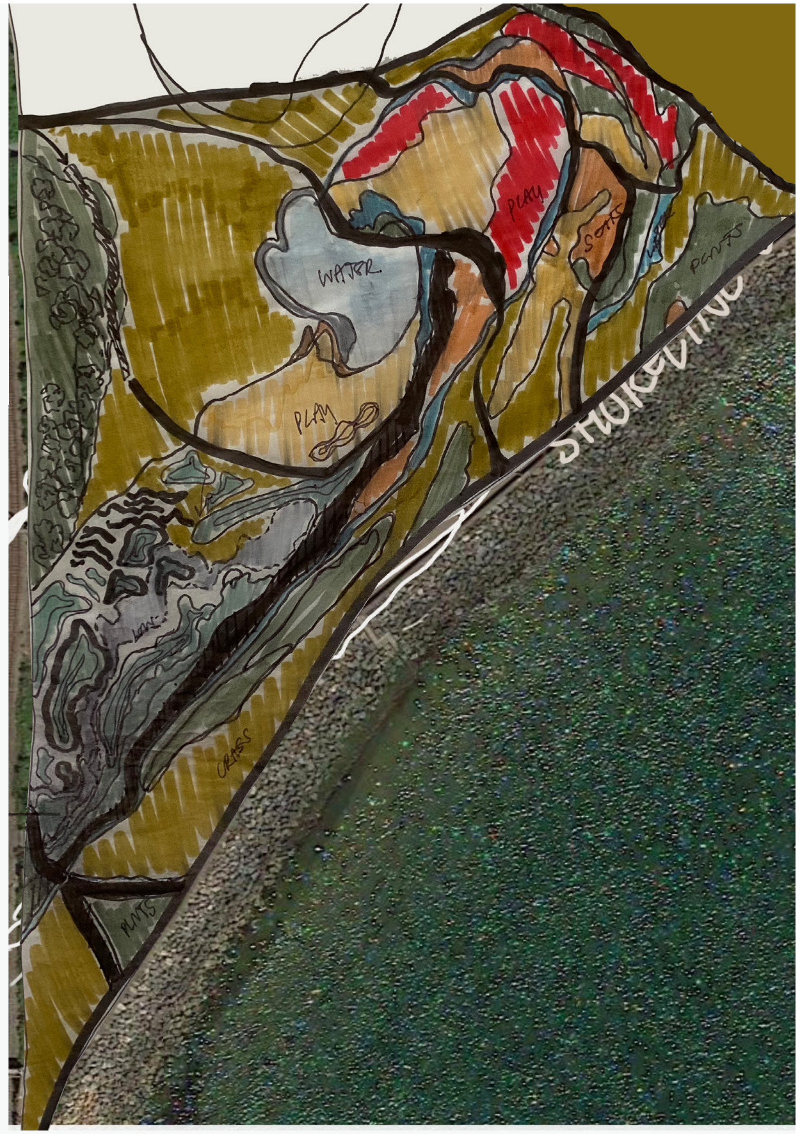














Seafront greens are often secondary spaces to the beach itself. I wanted to explore how this green could become an attraction on its own. I used the forms of shoreline change to inspire the shapes seen within this area. I would like this space to have a modern feel and be a space that both children and adults can enjoy.

By using the shapes created from shoreline change to decide the programming in this area, I think this could spark people's interest in the site's history and show how dynamic this shoreline is and demonstrate the impact that tides and storms have on our coasts. This space will have a multiple play areas, storm water management, walking loops, and native plantings.

# Design Concepts

## Shoreline Revival Master Plan

There are multiple plans for different areas within the map shown on this page and the following. The areas shown on this plan are Zone 2, the Seafront, the Nature Reserve, and the Nature-based Play Area.

# Shoreline Revival Master Plan

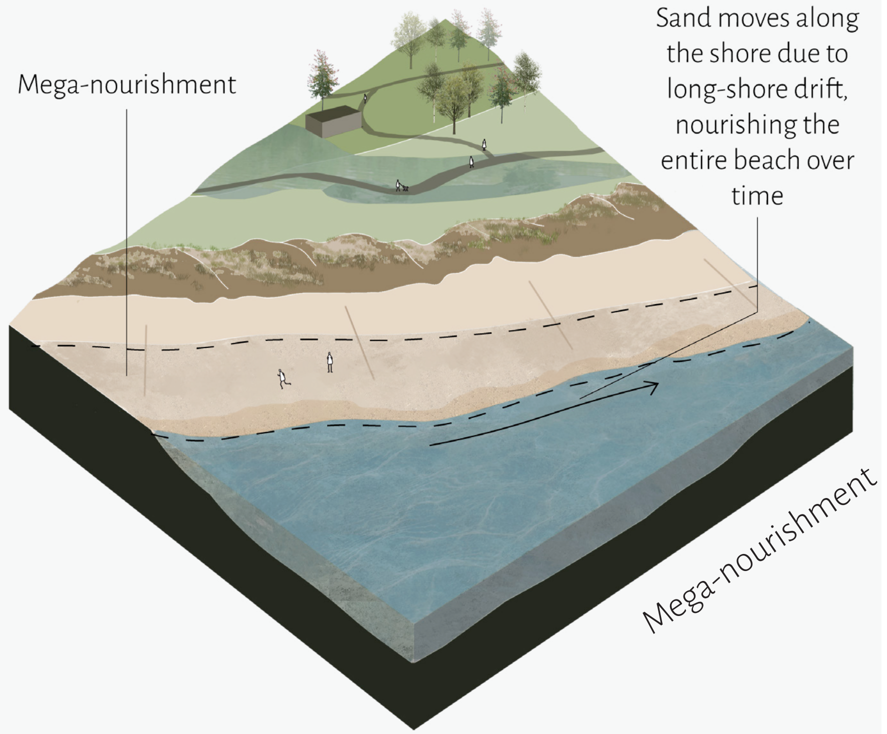
This plan shows Zone 1 and the location of Langstone Rock and Dawlish.

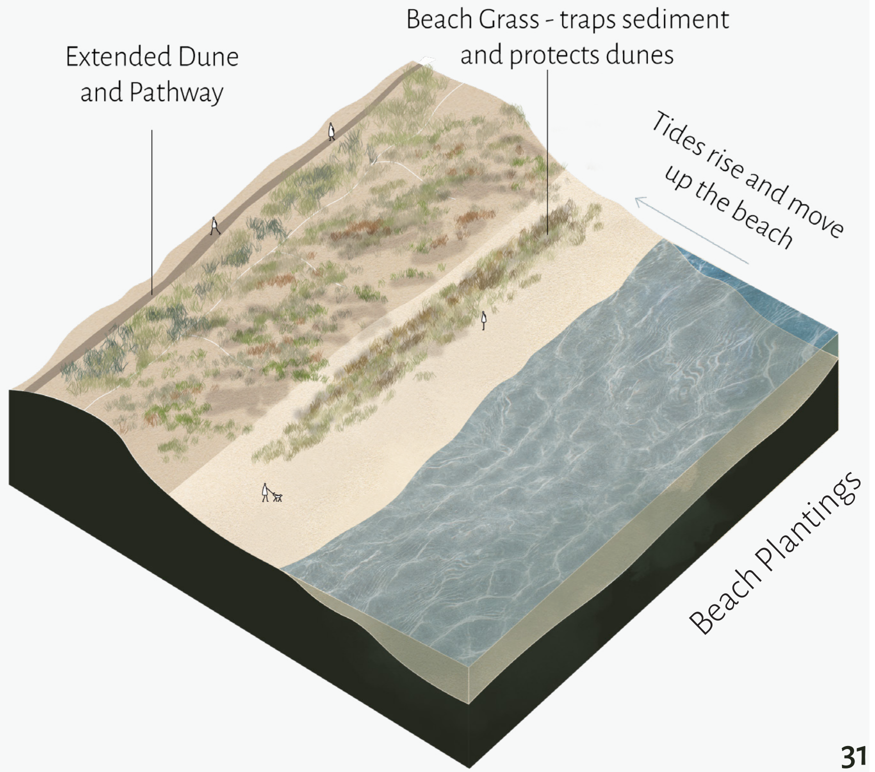



# Shoreline Revival Zone 1

Dawlish Warren Beach sits in front of a dynamic dune system that experiences high levels of erosion due to a lack of protection and high wave energy. This area currently has 18 groins placed along the shoreline that capture sediment from long-shore drift. There are also Geotubes placed within the dunes, which are now exposed and damaged gabion cages.

I am proposing to implement two nature-based solutions. The first is mega-nourishment, which involves intentionally placing large volumes of sand so that sediment moves along the beach over time, nourishing over an extended period. The second is beach plantings - these would be placed at the foot of the dunes, intended to capture sediment and buffer wave energy reaching the dunes. For these methods to be most effective, it is essential that the existing groins be maintained, and the dunes be planted with new native plants.

# Shoreline Revival Zone 1 - Additional Measures

## Groin Maintenance

Currently, 18 groins exist along Dawlish Warren Beach. In 2017-2018 many of the groins were updated or repaired. The groins must be regularly maintained for them to continue functioning efficiently.

For the mega-nourishment and beach plantings to be sustained, the current groins must be maintained. Groins trap sediment and reduce longshore drift; this is crucial for keeping the sand from the mega-nourishment on the beach for as long as possible.

Groins typically have a lifetime of 10-25 years (Climate Adapt, 2023). Groins 15 to 18 were not repaired recently, but many other groins on the beach will only need repairing around 2035.

fig.24 - new groin number 12

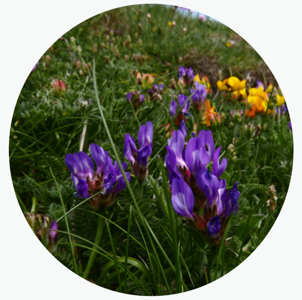
## Dune Planting

One of the goals of this project is to promote biodiversity by creating new habitats and increasing plant species diversity. In 2018 large Geotubes were installed within the dunes scarring the landscape and removing many of the dune plants.

Dune erosion at Dawlish Warren is occurring at an alarming rate, with the dune front taking a battering every high tide. This has created a shelving effect and led to plant roots being exposed.

Plant roots play essential roles in holding the sand in place, so ensuring the dunes are densely planted will help reduce erosion and increase the variety of plants available to the local wildlife on the dunes.

fig.25 - exposed roots on dunes



*Astragalus danicus*
Purple Milk-vetch

Height: Up to 1ft
Types: Attractive, downy and, spreading perennial
Habitat: Coastal habitats including sand dunes and sea cliffs
Flowers: Long purple clusters

*Carex arenaria*
Sand Sedge

Height: Up to 1.5ft
Types: Creeping perennial
Habitat: Grows on sand dunes
Flowers: Comprise pale brown spikes, in a terminal head

*Crambe maritima*
Sea Kale

Height: Up to 1.75ft
Types: Robust perennial forms domed and expansive clumps.
Habitat: Sandy beaches and dunes
Flowers: Small white flowers with four petals, flat topped clusters.

*Euphorbia paralias*
Sea Spurge

Height: Up to 2ft
Types: Upright perennial
Habitat: Grows on sandy beaches and dunes
Flowers: Yellow with petal like bracts and horned lobes in umbel-like heads.

*Leymus arenarius*
Lyme-grass

Height: Up to 5ft
Types:Blue-grey perennial
Habitat: Grows on sand dunes and sandy beaches
Flowers: Borne in tall heads of paired, grey-green spikelets

*Limonoium binervosum*
Rock Sea-lavender

Height: Up to 1ft
Types: Hairless perennial
Habitat: Coastal cliffs and stabilized shingle beaches, sand dunes, and saltmarshes
Flowers: Long and pink-ish lilac flower branches

figures 26-28 top row left to right, figure 29-31 bottom row left to right

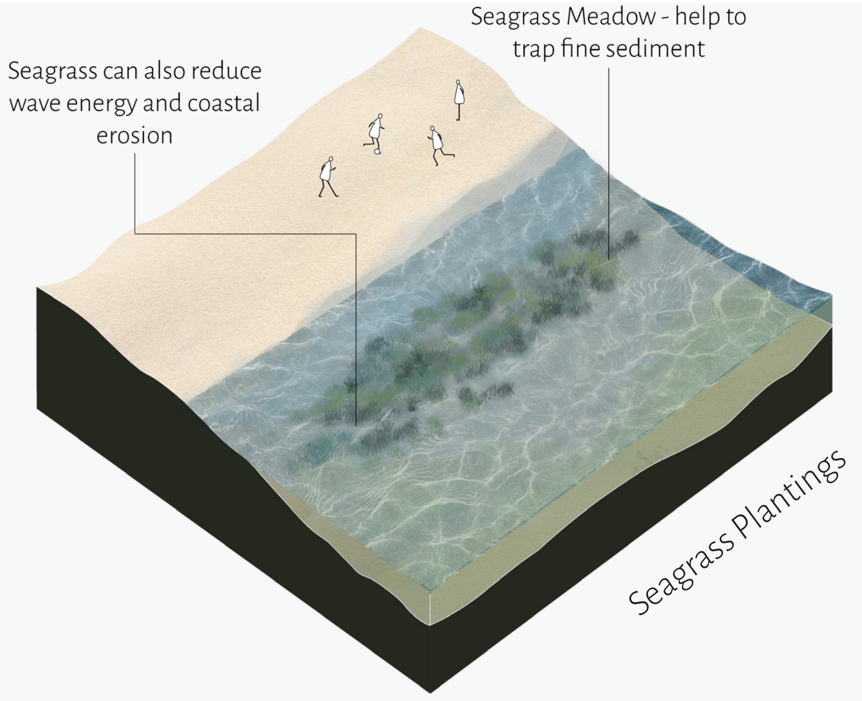


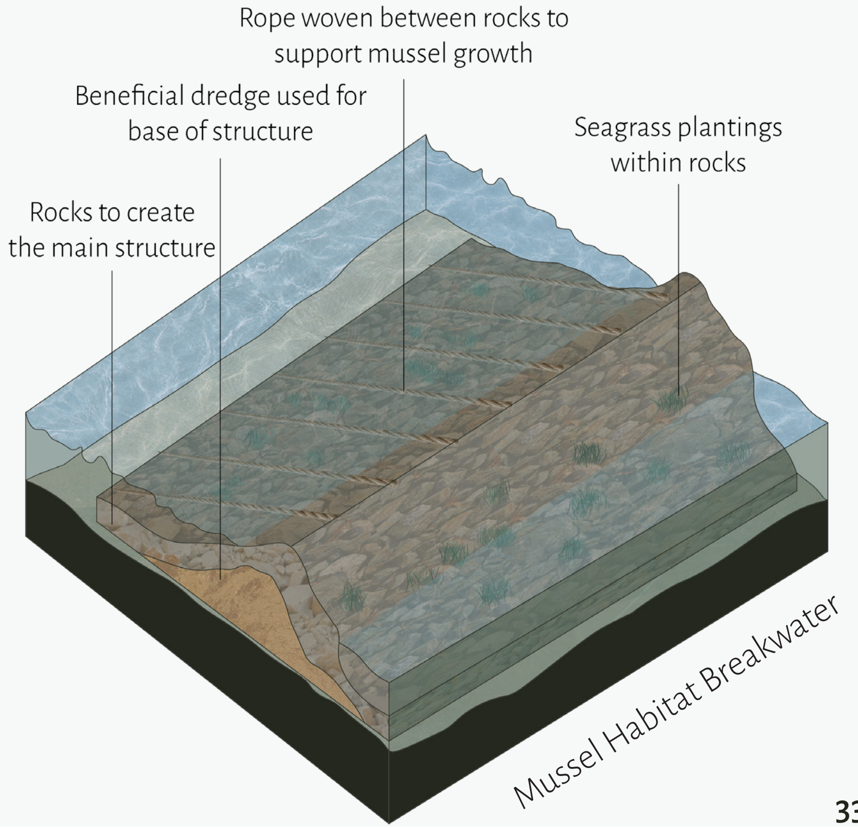
# Shoreline Revival Zone 2

This portion of the coastline experiences high wave energy and has been hammered by storms in the past, causing damage to the train line and infrastructure behind the beach. There is only a small sliver of shoreline within this zone, limiting the recreational uses.

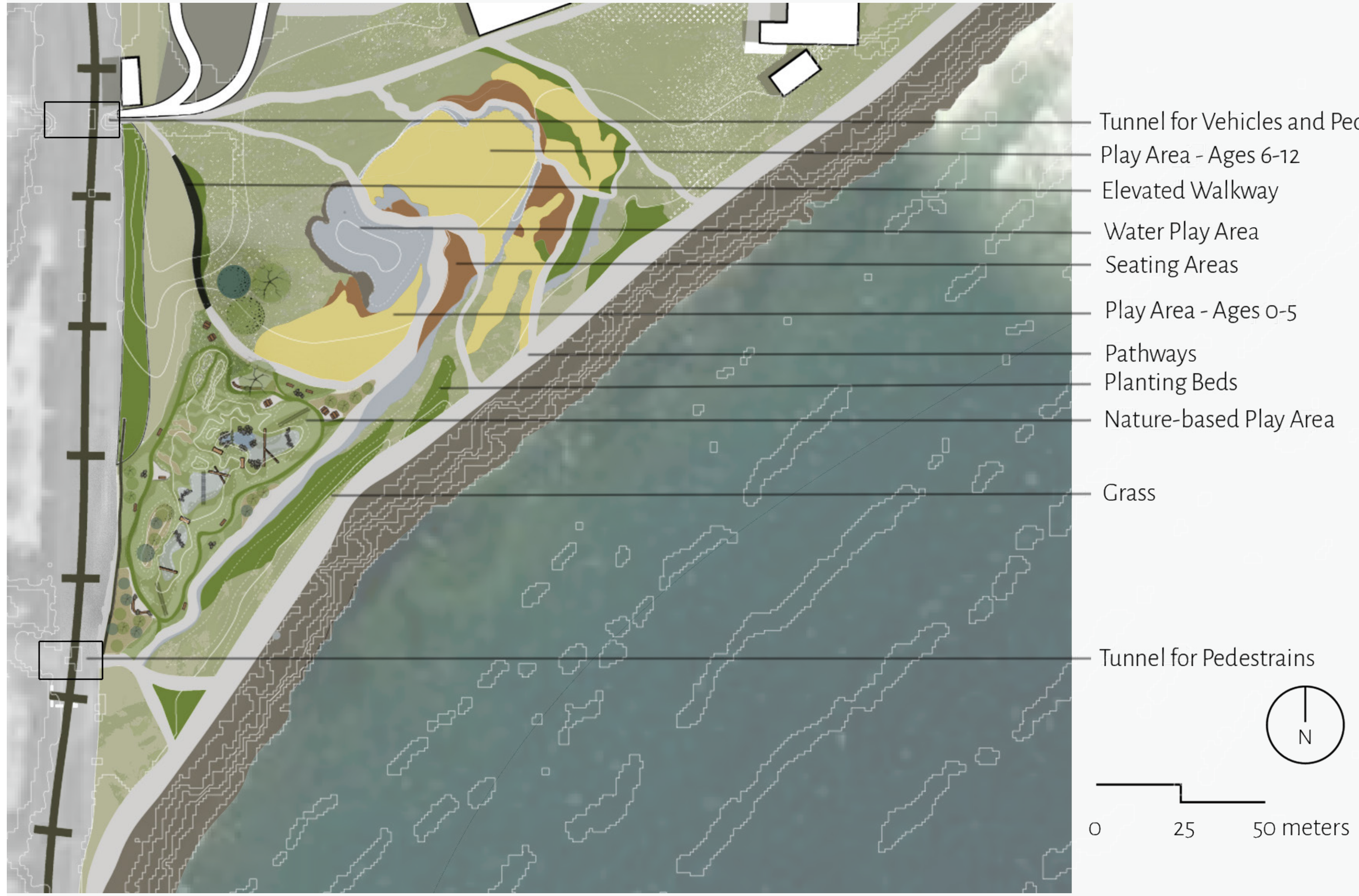
I am proposing installing offshore breakwaters and near-shore sea grass plantings. Offshore breakwaters reduce wave energy and support wildlife. Seagrass plantings are also beneficial for local wildlife and can trap fine sediment that can move onshore and nourish the beach.


Dawlish to Langstone Rock



# The Seafront




The shapes seen within this design were informed by shoreline change on Dawlish Warren Beach. By using these forms, I was able to create a dynamic space that echoes how this site has evolved and shifted due to coastal processes.

This design creates new play spaces for children of all ages to enjoy. The play equipment within these spaces will be inspired by coastal defense solutions, with the intention being for the children to act as the water while engaging with the play elements.

There are also multiple seating areas and walking trails for adults to enjoy the space.



# The Nature-based Play Area


The Nature-based Play Area sits within the Seafront Plan. This space seeks to manage rainwater and foster unique experiences.

This area is prone to flooding during rainy periods, so this design takes this problem and creates an adaptable play space.

A big part of this design comes from the use of topography. I dramatically altered the topography in the northwest corner to create dune-like forms to mimic those along the beach. Trampling on the dune is not encouraged since it causes damages the dunes and plantings, so by creating this experience elsewhere on the site, I hope this discourages users from walking on the actual dunes.

All elements within this space will created from naturally occurring materials.

# The Nature-based Play Area



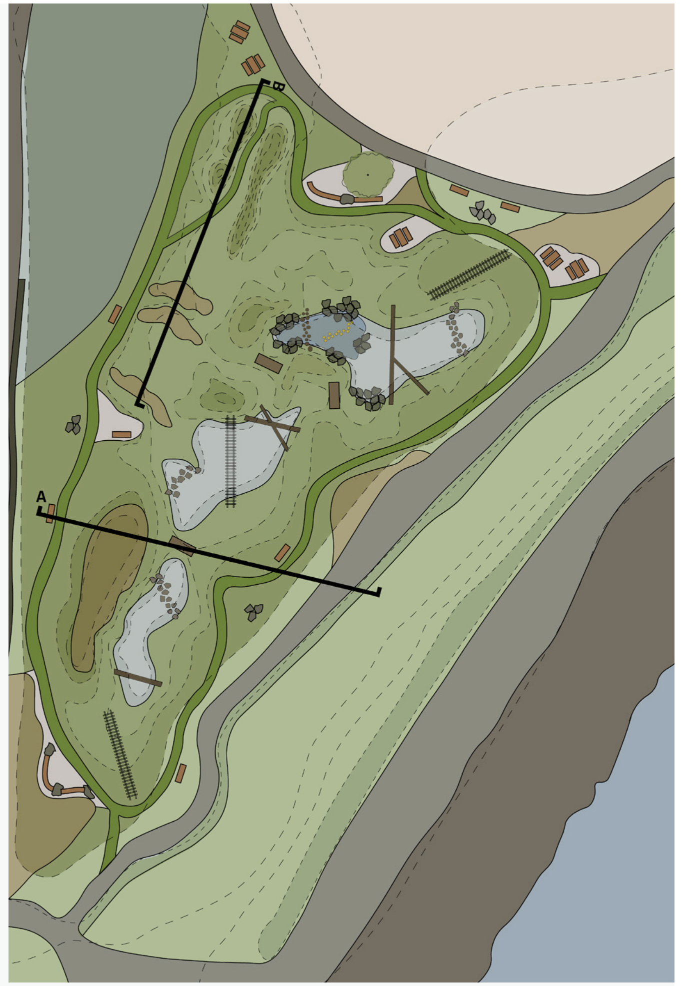

# The Nature-based Play Area

# The Nature-based Play Area

## Sectional Conditions

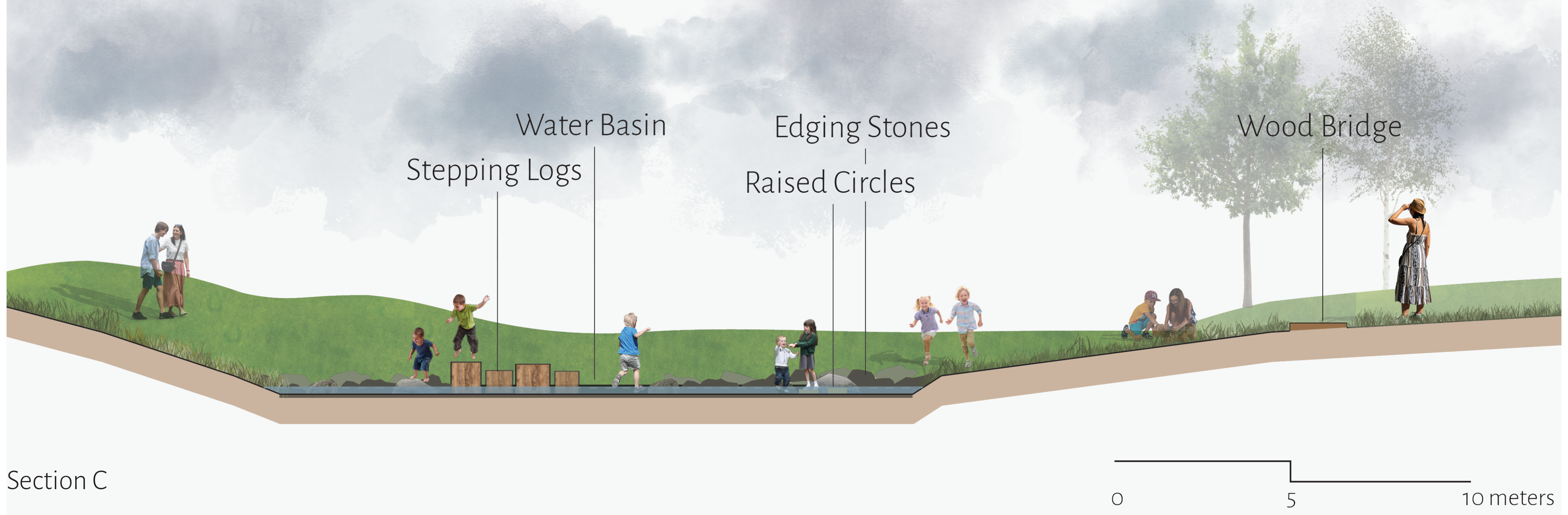

Section A


Section B



# The Nature-based Play Area

## Sectional Conditions




Section C

Rainwater flooding causes issues in this area throughout wetter periods of the year. I used topography to shape the space and create areas for water to pool and create play experiences for those using the site. There will be stepping stones and other play elements within these areas to make the space fun even when the basins are dry.

## Offsetting the Carbon Footprint

Hard-engineering solutions lead to the release of $CO_2$ into the atmosphere, and this site has had multiple hard-engineering solutions implemented over the last 80 years. Increasing the number of trees on site and introducing tall grasses and dense shrub areas will start contributing to reducing the site's carbon footprint. Adding 70 new trees to the site will offset over 1600 pounds of carbon annually. Additionally, since many of my design solutions are nature-based, this will also contribute to reducing the site's carbon footprint.



# The Nature Reserve


The nature reserve is relatively untouched, with many people who visit the site not even exploring the space. This plan aims to peel back some of this landscape to draw people in and encourage them to explore.

During the winter and rainy periods areas surrounding the existing lake systems flood frequently. This causes issues for users. This plan takes the areas that frequently flood and creates a flood basin. This basin will be planted with plants able to tolerate saturated soils.

Multiple pathways provide users with various experiences, with seating points along the way. All the paths are ADA-accessible, even allowing users to traverse the dune pathway.

This design also includes a pathway and ramp over the dunes, allowing people to move from the beach and over the dunes into the nature reserve.

# The Nature Reserve

## Sectional Conditions


Section D

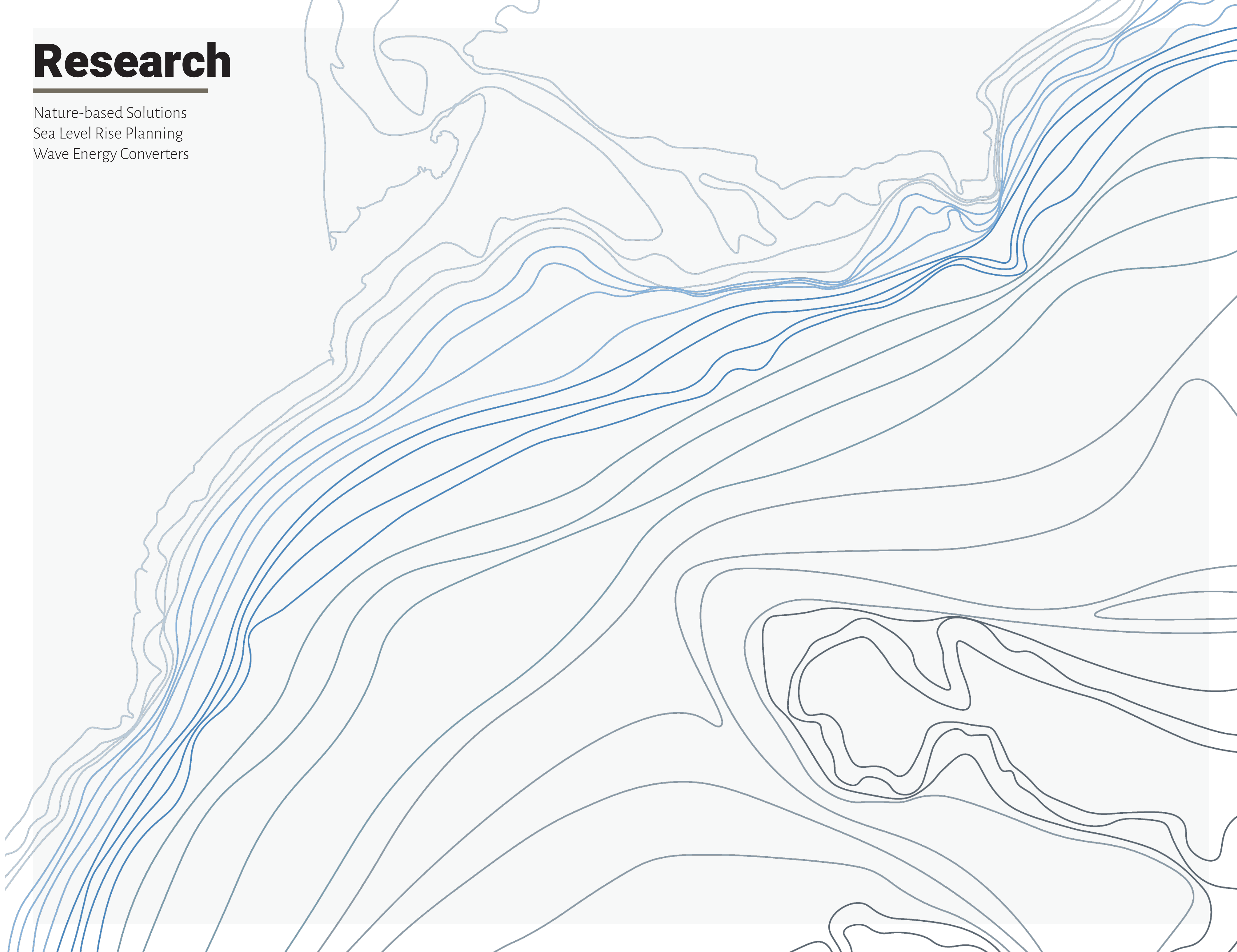

Section E


Section F



# Research

Nature-based Solutions
Sea Level Rise Planning
Wave Energy Converters



# Usability of the climate-resilient nature-based sand motor pilot, the Netherlands

## Summary Paragraph/Abstract

This study assesses the applicability of the Dutch coastal management initiative known as the Climate-Resilient Nature-Based Sand Motor Pilot. A number of techniques were used to evaluate the project's success in enhancing habitat quality and coastal resilience. The project's outcomes showed how it could endure the effects of climate change while improving the physical and ecological attributes of the coast.

## Main Points or Topics

- The project is located along the coast of the Netherlands.
- The project applied mega-nourishment to a specific area along the coast of the Netherlands. This approach is more efficient, economical, and environmentally friendly than traditional beach and shoreface nourishments.
- The study found that only 5% of the sand added disappeared after four years. This meant that the life expectancy would be longer than 20 years which was initially expected.
- The shape changed over the first two years and extended seaward, becoming 2.2 km longer.
- Due to the shape of the Sand Motor Pilot, habitats for birds and fish has increased along the coast as a whole.
- The beach has been temporarily increased in size, which has allowed for more leisure activities


fig. 32 - mega-nourishment

Coastal Management and Resilience | Nature-based Solutions | Climate Change Impacts

Author(s): Christophe Brière, Stephanie K. H. Janssen, Albert P. Oost, Marcel Taal & Pieter Koen Tonnon
Source:
Brière, C., Janssen, S. K., Oost, A. P., Taal, M., & Tonnon, P. K. (2017). Usability of the climate-resilient nature-based sand motor pilot, the Netherlands. Journal of Coastal Conservation, 22(3), 491–502. https://doi.org/10.1007/s11852-017-

## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- This strategy could work well in the area I am focusing on, as a large amount of sand has built up offshore. Potentially nourishment could connect the shoreline to the sandbars offshore and extend the usable beach space whilst protecting the beach's northern end.
- I need to look into past nourishment that has been done in the area to understand how long the sand remained in place.
- If I use this strategy, I need to understand how sediment moves in the area so sand can be placed to move into the best location with wave energy.



# Green Nourishment: An Innovative Nature-Based Solution for Coastal Erosion

## Summary Paragraph/Abstract

This paper explores the concept of green nourishment to address coastal erosion. Green nourishment involves the use of vegetation and other natural materials to protect coastal areas from erosion.
The authors provide an overview of the challenges associated with coastal erosion and the impact it has on coastal communities and ecosystems. They then present green nourishment as a promising nature-based solution for addressing this issue.
The authors conducted a comprehensive review of the scientific literature on green nourishment and analyzed data from field studies to evaluate its effectiveness. They found that green nourishment is a cost-effective and sustainable method for mitigating coastal erosion and restoring coastal habitats.

## Main Points or Topics

- A combination of shoreface nourishment and seagrass planting can significantly reduce wave heights and erosion at the shore
- Positioning the seagrass meadow in the zone where waves break was found to be the most effective location for best reducing wave energy
- Seagrass is able to attenuate long periods of wave motion effectively
- The study found that seagrass meadows could provide protection to the coast against storms by damping the wave and reducing beach erosion
- Planting seeds rather than mature seagrass significantly reduces the cost of installing
- It was also found that green nourishment provides an input of sand into the system

Seagrass Meadows | Shoreline Erosion | Wave Energy Reduction | Green Nourishment | Nature-based Solutions

Author(s): Wen L. Chen, Peter Muller, Robert C. Grabowski, and Nicholas Dodd
Source:
Chen, W. L., Muller, P., Grabowski, R. C., & Dodd, N. (2022). Green nourishment: An innovative nature-based solution for coastal erosion. Frontiers in Marine Science, 8. https://doi.org/10.3389/fmars.2021.814589

## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- I am going to look into seagrass meadows to see how the addition of this to my site could help reduce wave energy and create new habitats. I need to understand where the areas of low wave energy are, as this is where a meadow would do best.
- Additionally, I am going to explore what types of seagrass are native to the UK.
- I need to do research into wave break zones as the optimal positioning of seagrass meadows relies on this information.

# Bridging the gap between coastal engineering and nature conservation?

Author(s): Philipp Jordan & Peter Fröhle

Source:
Jordan, P., & Fröhle, P. (2022). Bridging the gap between Coastal Engineering and Nature Conservation? Journal of Coastal Conservation, 26(2). https://doi.org/10.1007/s11852-021-00848-x

## Summary Paragraph/Abstract

This paper aims to explore the relationship between coastal engineering and nature conservation. The authors argue that the traditional approach of coastal engineering has often been in conflict with the goals of nature conservation and that there is a need to bridge the gap between these two disciplines.
The paper presents an overview of the challenges and conflicts between coastal engineering and nature conservation and discusses potential solutions and strategies for bridging the gap.
The potential benefits of adopting a more nature-based approach to coastal engineering and also discussed, incorporating natural processes and ecosystems into the design and management of coastal infrastructure. It is argued that such an approach could help to reconcile the goals of coastal engineering with those of nature conservation and lead to more sustainable and resilient coastal systems.

## Main Points or Topics

- This paper discusses how dune systems function and change with winds and storms.
- Dune vegetation plays a massive role in the formation and stabilization of coastal dunes
- Dunes provide habitat for a variety of different species that are equipped to live in dynamic nutrient-poor environments
- This paper analyzes the ecosystems benefits of many different Nature-based solutions, clearly showing which provides what benefit
- Salt marshes, mangroves, seagrass meadows, beaches, dunes, coral, and shellfish or oyster reefs bear the potential to bridge the gap between coastal engineering and nature conservation

Coastal Dune Systems | Nature-based Solutions | Hard-engineering

## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- This paper shares valuable information on the benefits of each Nature-based solution. I am going to use this to evaluate current strategies present at the site as well as potential ideas I may include within my proposal
- I understand that there are limitations to Nature-based solutions, but I want to find a way to merge these solutions alongside hard-engineering strategies to achieve the most effective and sustainable solution.
- I need to research past storm events to look for information relating to dune changes in lieu of high-energy events.



# Planning for Sea Level Rise on the South Coast of England: Advising the Decision Makers

Author(s): Malcolm Bray, Janet Hooke, and David Carter

Source:
Bray, M., Janet, H., & Carter, D. (1997). Planning for sea-level rise on the south coast of England: advising the decision makers. Transactions of the Institute of British Geographers, 22, 13-30.

## Summary Paragraph/Abstract

This paper discusses the challenges and strategies for planning for the potential impacts of sea-level rise on the south coast of England. The authors emphasize that decision-makers must take into account the potential impacts of sea-level rise when planning coastal development, as failing to do so could result in significant economic and environmental costs.
It provides an overview of the scientific understanding of sea-level rise and its potential impacts on the south coast of England, as well as an analysis of the legal and policy frameworks for coastal planning. The article concludes with a set of recommendations for decision-makers, the development of long-term planning strategies that take into account the potential impacts of sea-level rise, and the consideration of adaptive management approaches that can respond to changing circumstances and uncertainties.
Overall, this article provides a useful overview of the challenges and strategies for planning for sea-level rise in the context of coastal development in England and highlights the need for careful consideration of potential risks and uncertainties in decision-making processes.

## Main Points or Topics

- The study used multiple factors to most accurately predict sea level rise scenarios for a specific region. They used global warming scenarios, recent sea level (tide gauge record), and local wave climates and storm surges.
- Protected coasts controlled by artificial structures cannot adjust naturally to sea level rise or changing patterns, so they will require frequent nourishment in the future.
- Wetlands are particularly vulnerable to sea level rise from inundation as well as erosion.
- Sedimentation rates are unlikely to be sustained around the UK due to changes made to river systems halting natural sediment movement.
- Natural sandy beaches and dune systems are more sensitive than other coastal conditions and will need more space to retreat as sea levels rise.

Coastal Management | Sea Defense | Public Involvement | Sea Level Rise

## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- I need to look into the sea level rise predictions for the region I am working in. I think I need to find a higher level of accuracy for this data and try to incorporate the other factors discussed in this paper into these predictions.
- My project site and surrounding areas have multiple artificial structures protecting the coast, but I need to evaluate the impact these structures are having on the natural processes.
- I think I need to explore potential methods for increasing sedimentation, as there is no room for the coast to migrate. Currently, sediment builds up at the mouth of the River Exe, so I need to ensure this channel is kept clear for boat traffic.

# Planning for the impacts of sea level rise

## Summary Paragraph/Abstract

This article discusses the potential impacts of sea level rise and the steps that can be taken to mitigate and adapt to these impacts. The author describes the causes and mechanisms of sea level rise as well as the potential impacts of flooding, erosion, and saltwater intrusion.
The article emphasizes the importance of planning for sea level rise, including identifying areas at risk, assessing vulnerability, and developing adaptation strategies. It is suggested that adaptation strategies should be based on a combination of hard and soft measures, including engineering solutions such as seawalls and dikes and nature-based solutions such as wetland restoration and beach nourishment.
The article also discusses the challenges and limitations of sea level rise planning, including the difficulty of predicting future sea level rise and the competing demands for resources and attention from other environmental issues.

## Main Points or Topics

The paper focuses on how to best plan for sea level rise and its implications
Two potential responses are possible; these are mitigation or adaptation.
Land subsidence is contributing to higher sea level rise rates in particular locations
The paper evaluates different effects of natural systems and then examines possible climate and non-climate interactions which may impact the severity of these natural effects. It also discusses the possible adaptation approaches to reduce the likelihood of these effects.
Biodiversity and Settlements/Infrastructure are going to be impacted most by sea level rise
Mitigation is something needing to be tackled at a global scale, linked to climate policies
Adaptation is on a local/national scale linked to coastal management policy.
The main goal of mitigation is to reduce the risk of passing irreversible thresholds
Adaptation can be classified in a variety of ways

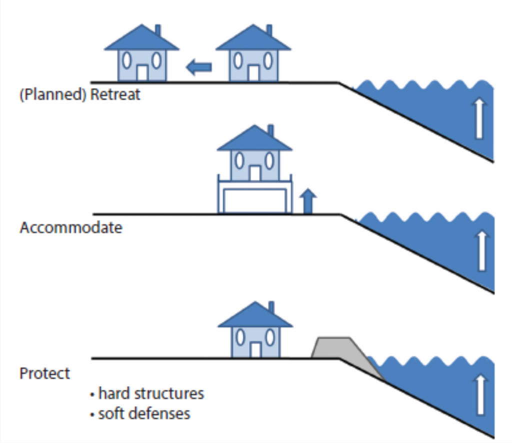
Adaptation | Mitigation | Sea Level Rise

Author(s): Robert J. Nicholls

Source: Nicholls, R. (2011). Planning for the impacts of sea level rise. Oceanography, 24(2), 144–157. https://doi.org/10.5670/oceanog.2011.34

## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- I am going to use methods that will enhance and support biodiversity.
- I need to look into land subsidence to understand if this may impact the region I am working in.
- Adaptation works on a local/regional scale so I am going to explore how I can come up with a strategy that can benefit multiple locations along the coast.






# Adaptation planning for sea level rise: A Study of US Coastal Cities

## Summary Paragraph/Abstract

This article examines the adaptation planning efforts of coastal cities in the United States to address the challenges posed by sea level rise.
The authors found that while many coastal cities have initiated adaptation planning efforts, there is significant variation in the scope and effectiveness of these efforts. The authors identify several factors that contribute to this variation, such as political leadership, resource availability, and public awareness.
The article also highlights the challenges and opportunities associated with adaptation planning, such as the need to balance short-term and long-term priorities, the importance of stakeholder engagement, and the potential for nature-based solutions to complement traditional engineering solutions.

## Main Points or Topics

- It is essential to incorporate the best science in order to get the most accurate sea level rise predictions, so planning best suits future conditions.
- It is important to collaborate with local governments, research institutions, and universities to understand other areas' comprehensive plans so linkages can occur between different plans.
- Hazard mitigation plans are the most suitable places for SLR adaptation planning
- The study found that cost-benefit strategies were missing when deciding the right strategy for an area.

Sea Level Rise Planning | Comprehensive Plans | Climate Change | Hard-engineering

Author(s): Xinyu Fu, Mohammed Gomaa, Yujun Deng & Zhong-Ren Peng

Source:
Fu, X., Gomaa, M., Deng, Y., & Peng, Z.-R. (2016). Adaptation planning for sea level rise: A Study of US Coastal Cities. Journal of Environmental Planning and Management, 60(2), 249–265. https://doi.org/10.1080/09640568.2016.

## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- I will review comprehensive plans for the different councils in the area and look for overlapping strategies
- I think for this project, I will look to create a Hazard Mitigation Plan as these are typically not present in non-metropolitan areas
- I will try to perform a cost-benefit analysis of the solutions I plan on suggesting.

# Environmental Impact Assessment of Wave Energy Converters: A Review

Author(s): Luigia Riefolo, Caterina Lanfredi, Arianna Azzellino, and Diego Vicinanza

Source:
Riefolo, L., Lanfredi, C., Azzellino, A., & Vicinanza, D. (2015). Environmental Impact Assessment of Wave Energy Converters: A Review. In Proceedings of the International Conference on Applied Coastal Research SCACR, 28.

## Summary Paragraph/Abstract

This article provides an overview of the current state of knowledge regarding the impact of wave energy converters (WECs). The concept of WECs and their potential as a renewable energy source is introduced, and the various types of WECs are introduced.
The authors then examine the potential environmental impacts of WECs, specifically discussing noise, electromagnetic fields, and changes to the physical and biological environment. The paper then goes on to evaluate existing methodologies for environmental impacts. It is noted that each method must be assessed to identify strengths and weaknesses to fully understand the impacts these systems can have on marine and coastal landscapes and wildlife.

## Main Points or Topics

It is essential to manage possible conflicts with other sea users – Marine Spatial Planning and Strategic Environmental Assessment are the most sustainable approach to identifying sites where the environmental effects will be minimized.
There are adverse effects to Wave Energy Converters, such as habitat loss/degradation, underwater noise production, and production of electromagnetic fields.
Wave Energy Converters also have the potential to produce local environmental benefits. Installations have the capacity to act as both artificial reefs and fish aggregation devices. Both these systems can enhance biodiversity and fisheries.
A device called "Oyster" is one of the only devices not to have any electromagnetic field issues.
Floating structures are typically located offshore, in water with depths of around 40-100 m. These structures have lower impacts on hydrodynamics and sediment transportation.
Wave farms on the nearshore are typically seen as coastal protection, and studies found that sediment distribution altered along the beach.
Wave power is one of the fastest-growing energy technologies, with floating wave farms located far out in the deep sea drawing more power than those near the coast.

Wave Energy | Coastal Protection | Sediment Transportation | Habitat Degradation

## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- I am going to look more into how wave energy converters can be used for near-shore coastal protection
- I need to obtain bathymetry data for the area I am working so I can use this information to identify water depths
- I am going to explore further the electromagnetic field problem that many WECs produce. I want to understand more about how this impacts marine wildlife so I can make informed decisions regarding the application of this method.





# The Impacts of Wave Energy Conversion on Coastal Morphodynamics in a Changing Climate

Author(s):Cigdem Ozkan

Source:
Ozkan, Cigdem, "The Impacts of Wave Energy Conversion on Coastal Morphodynamics in a Changing Climate" (2020). Electronic Theses and Dissertations, 2020-. 394.
https://stars.library.ucf.edu/etd2020/394

## Summary Paragraph/Abstract

This study highlights the importance of coastal areas and the challenges they face from climate change. The potential benefits of wave energy conversion as a renewable energy source are discussed, and an overview of methodologies used to assess the impacts of wave energy conversion.
The paper also discusses the current state of research on wave energy conversion, as well as presents the advantages and disadvantages of different wave energy conversion technologies. It also provides an overview of key physical processes that govern coastal morphodynamics, including sediment transportation, erosion, and wave transformation. The author notes that there is a need for further research to understand better the potential impacts of wave energy conversion on coastal areas.

## Main Points or Topics

- The article examines multiple case studies where wave energy converters were studied along coastlines to understand how they impact beach morphology.
- It was found that WEC farms do not negatively impact the coastline.
- WEC farms can produce a calmer sea state and reduce the rate of coastal erosion
- These farms can be used as a form of coastal protection
- On English coasts, results found that the WECs could reduce beach erosion by over 4 m and reduce wave energy by around 10 - 30%.
- The layout and geometry of the WEC farms and the distance between the farm and the shore also impact the efficiency of wave reduction.
- A study in Spain found that accretion occurred along some stretches of the coastline. It was also found that the area of the dry beach could be increased, which could create more opportunities for recreational activities.

Wave Energy Converters | Coastal Erosion | Coastal Protection

## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- As I progress with this project, I am going to refer back to the case studies to help guide further research into what type of WEC would suit my site best.
- In the wake of COVID, British holidaymakers are choosing to holiday in the country rather than travel abroad. This has led to many beaches in the south-west of England being crowded during the holiday season. I think focusing on methods that could increase dry beach area could benefit this destination and attract more tourists.
- I need to explore layouts of WECs further if I choose to use this as a method of coastal protection.

# Beach Response to Wave Energy Converter Farms Acting as Coastal Defence

## Summary Paragraph/Abstract

This paper analyzes the perforation of the same wave energy converters in terms of coastal protection to estimate induced shoreline change. The authors introduce the different types of WECs, discussing typical arrangements for the highest wave reduction. Design criteria for each device are also noted within the paper. The paper evaluates different devices in two sites with varying conditions. Numerical modeling is used to produce 2D wave propagation results, showing how conditions at the two sites change with the addition of WECs.

## Main Points or Topics

- Nourishment becomes more efficient if hard engineering strategies are used with it
- Hard engineering solutions should be environmentally friendly, climate-proof, and not visually disrupt landscapes
- Reduction of wave energy may occur in one area but could increase in other areas. It is important to carefully track energy distribution to avoid undesirable effects on beaches.
- Some devices are best suited to longer wave periods, whereas others do best with shorter ones.
- Studies found that devices could reduce wave energy by 20-25% in some locations.
- Understanding the typical wave period of a site helps select a device type that will be more effective.
- Accretion rates varied based on site, device types, and placement.
- If the site has a long length of coastline to protect, then WECs should be placed in deeper waters.
- In areas where high wave reduction is needed, devices that can be placed closer to the beach should be selected.

Wave Energy Converters | Coastal Protection | Coastline Response | Wave Transmission

Author(s):Edgar Mendoza, Rodolfo Silva, Barbara Zanuttigh, Elisa Angelelli, Thomas Lykke Andersen, Luca Martinelli, Jørgen Quvang Harck Nørgaard, and Piero Ruol
Source: Mendoza, E., Silva, R., Zanuttigh, B., Angelelli, E., Lykke Andersen, T., Martinelli, L., Nørgaard, J. Q., & Ruol, P. (2014). Beach response to wave energy converter farms acting as coastal defence. Coastal Engineering, 87, 97–111. https://doi.org/10.1016/j.coastaleng.2013.10.018

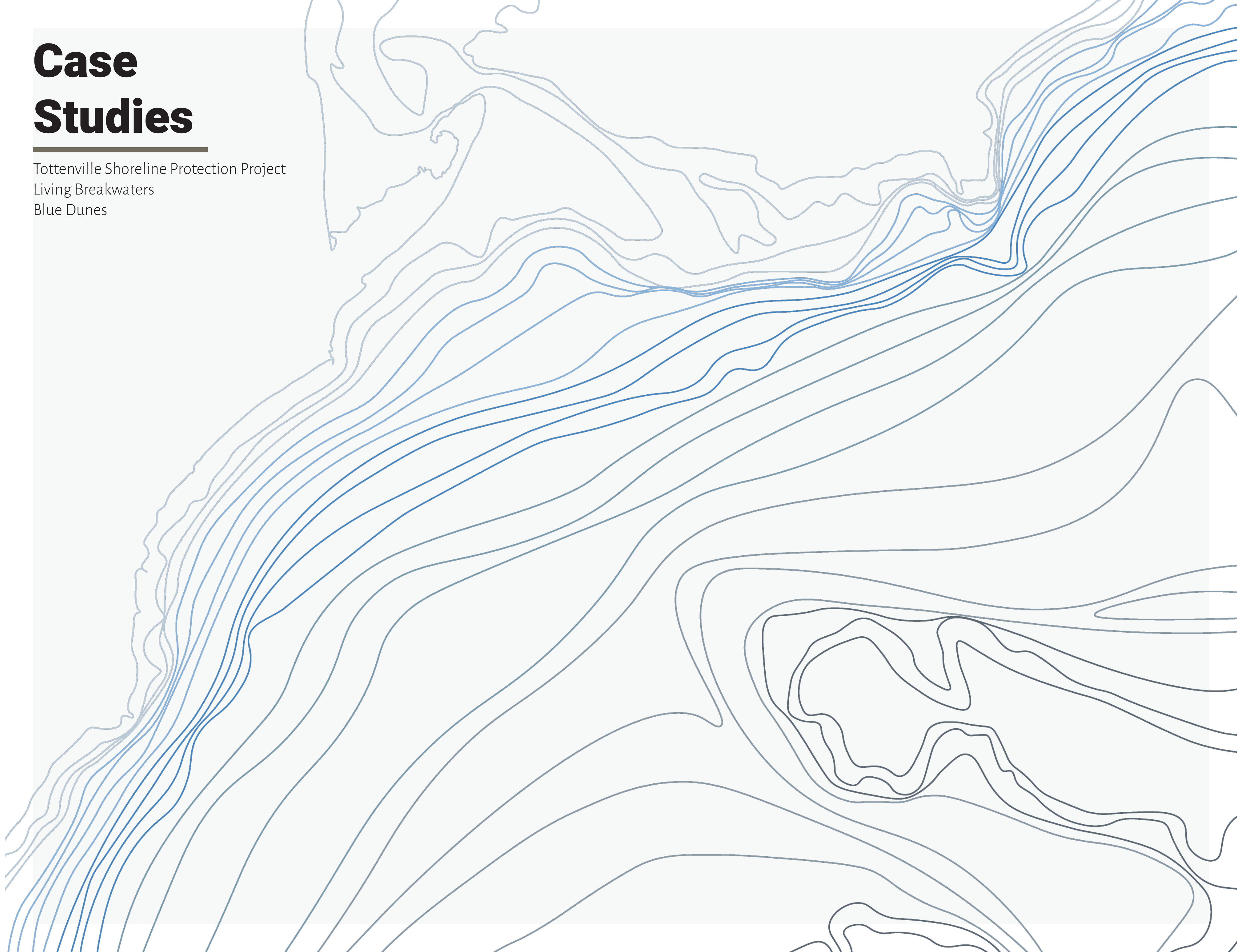
## Design Implications for Adapting to Changing Systems along the South East Coast of Devon

- Once I decide on the scope of my project, this article will be helpful in guiding my decision-making regarding the type of device selected.
- It is essential to understand the implications of engineering solutions on surrounding areas. I am going to analyze the existing defense structures to understand the knock-on effect these may be having on other portions of the coastline.
- I am going to look into wave periods to gather data for my focus area.




# Case Studies

Tottenville Shoreline Protection Project
Living Breakwaters
Blue Dunes



# Tottenville Shoreline Protection Project

Stantec

TOTAL PROJECT ACREAGE **23.8** ACRES

TOTAL BEACH FRONT **5,700** LINEAR FEET

TOTTENVILLE COMMUNITY **3,400** PEOPLE

This project formed part of the New York Rising Community Reconstruction Plans. The south side of Staten Island has sustained decades of coastal erosion, with Superstorm Sandy only worsening its condition. This community was extremely vulnerable to the next coastal storm so this project was implemented.

The Living Breakwaters project by SCAPE and this project were designed to facilitate each other. Teams worked separately on designs but both projects were analyzed under one Environmental Impact Statement due to their geographical proximity and common purpose.

## Location
Southwest side of Staten Island, New York

## Typical Users
Residents, visitors, students, researchers

## Programming
Created an interconnected and seamless trial along the shoreline. Providing access to the beach and park even at normal high tide.

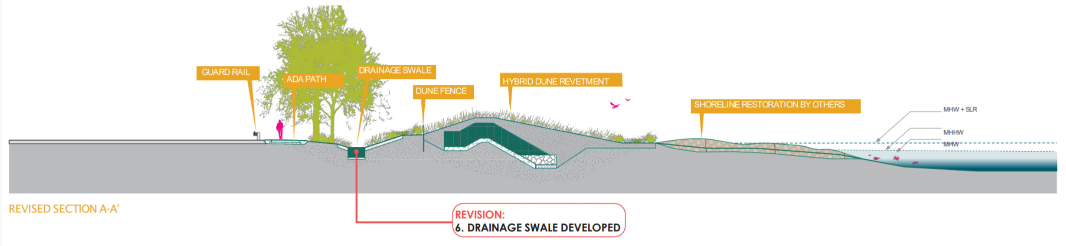
## Formal Design Language
Coastal and Social Resilience

## Goals
Reduce wave action and coastal erosion along the shoreline in Tottenville, while enhancing ecosystems and shoreline access.

- Risk Reduction
- Ecological Enhancement
- Social Resilience

## Innovative Practices
- The designers used layered approach, whereby multiple coastal defense strategies were implemented to form a naturalized barrier capable of reducing the risk of storm damage.
- By layering methods wave action and shoreline erosion could be reduced whilst also enhancing ecosystems.
- This project relied heavily on Nature-based solutions.

## Inspiring ideas
- As the design team progressed with the project they released one solution for the whole shoreline would not work. To this they formulated custom design solutions for each diverse area.

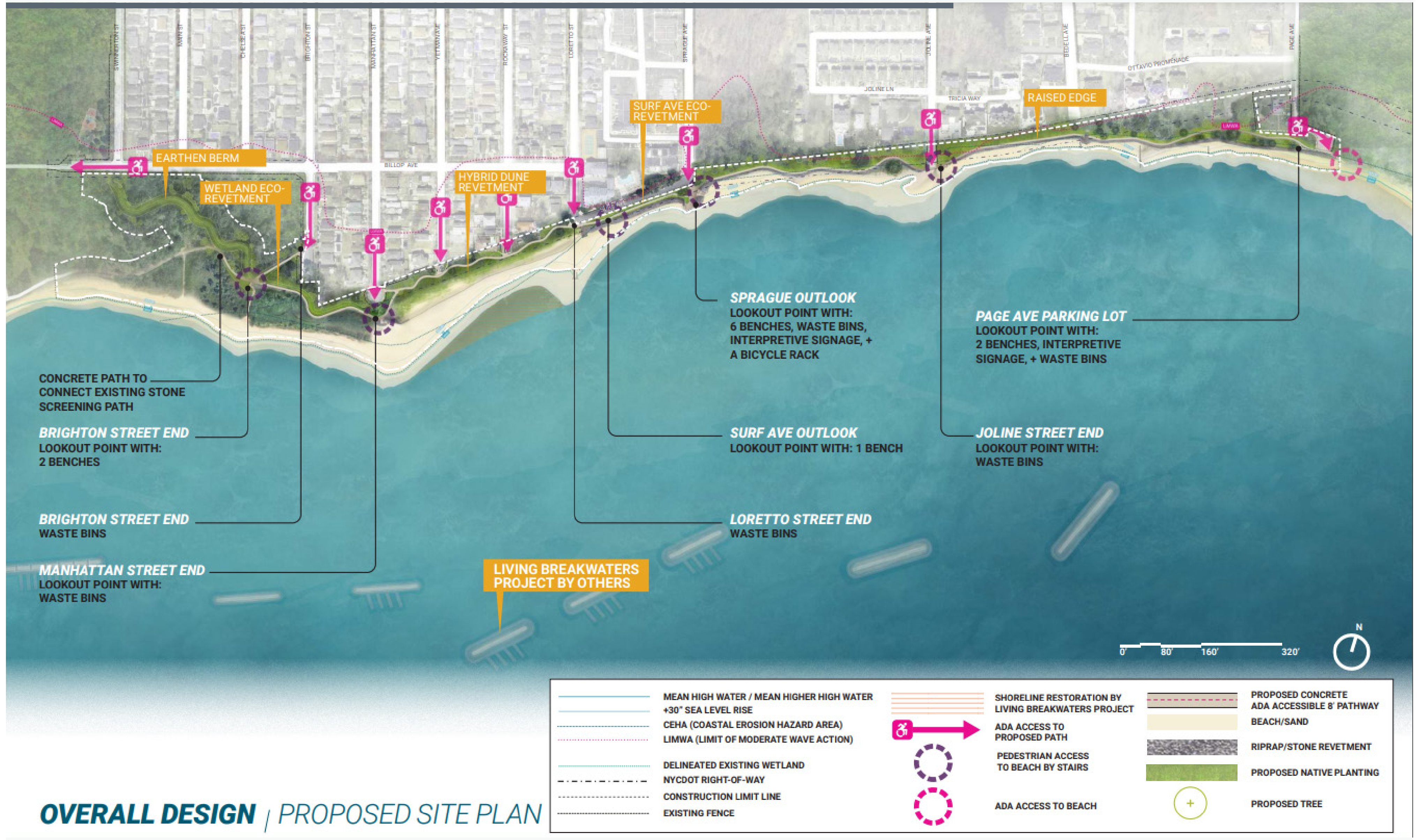



HYBRID DUNE REVETMENT | SITE SECTIONS

fig 33



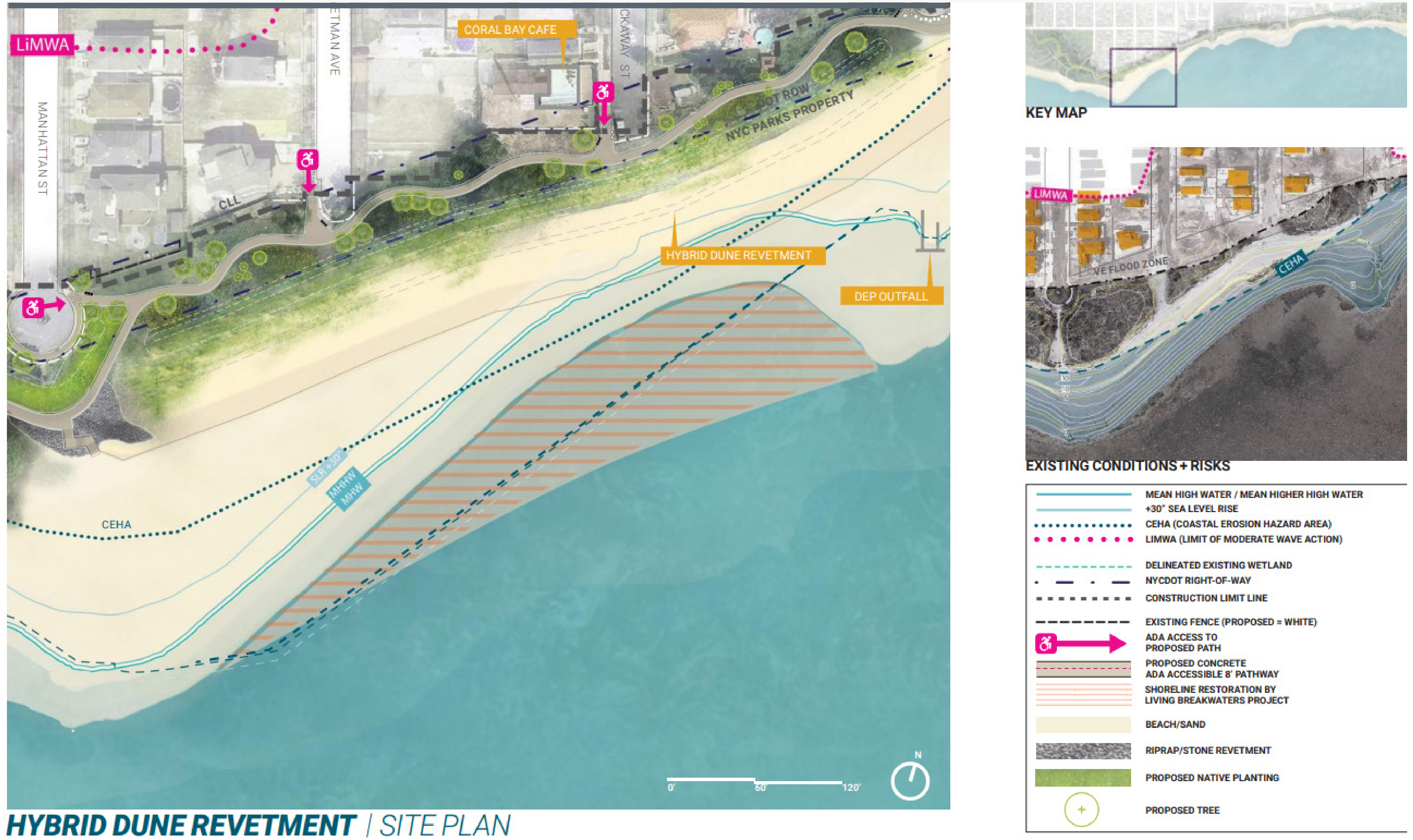
# Tottenville Shoreline Protection Project




***OVERALL DESIGN*** | *PROPOSED SITE PLAN*

fig 34

# Tottenville Shoreline Protection Project




***HYBRID DUNE REVETMENT*** | *SITE PLAN*

fig. 35



# Living Breakwaters

SCAPE

NEAR-SHORE BREAKWATERS **2,400** LINEAR FEET

TOTTENVILLE COMMUNITY **3,400** PEOPLE

This project is highly regarded as a model for climate-adaptive green infrastructure. This site experienced some of the worst waves when Superstorm Sandy hit, damaging or destroying a number of homes and businesses.

Tottenville was historically known as "The Town the Oyster Built." The town was once protected by a wide shelf and a series of oyster reefs that supported oyster farming in the area. Overharvesting, amongst other problems, caused the oyster reefs to collapse.

The shoreline has experienced extensive erosion over the past 35 years, with rates in some parts averaging more than one foot per year.

### Location
Southwest side of Staten Island, New York

### Typical Users
Residents, visitors, students, researchers

### Programming
Residents and visitors can engage with the shoreline and learn about resiliency initiatives and ecological restoration activities. A project in conjunction called the Billion Oyster Project has developed a Living Breakwaters STEM Curriculum designed for students in 6th to 8th-grade public school science classes.

### Formal Design Language
Coastal Resilience

### Goals
- Reduce flood risk
- Enhance physical, ecological, and social resilience along the South Shore of Staten Island

### Innovative Practices
- The breakwaters will be constructed with "reef ridges" and "reef streets" that provide diverse habitat space, with live oyster installation planned once construction is completed.
- The project aims to provide a diverse mosaic of habitat conditions required to increase biodiversity and restore specific ecosystem services.
- The breakwaters were designed to mimic a complex rocky habitat, including extensive pore spaces to make the design environmentally sensitive.

### Inspiring ideas
- The offshore breakwaters reduce energy and create a calm environment for local marine life.
- Breakwaters will continue to attenuate wave energy even if the structures become submerged.

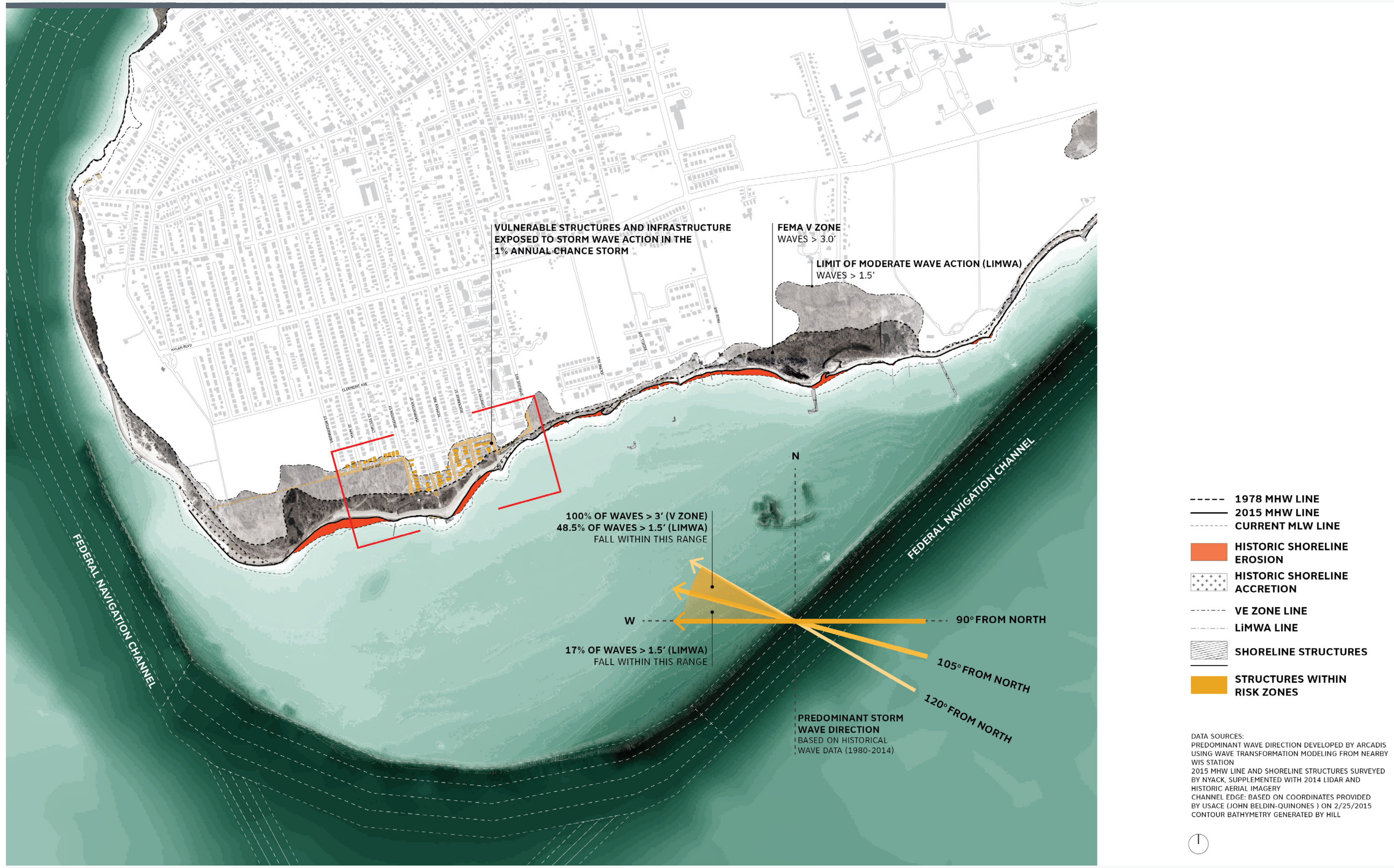



fig. 36

Site Analysis
Wave direction was studied to understand the angle at which most waves were approaching the shore.





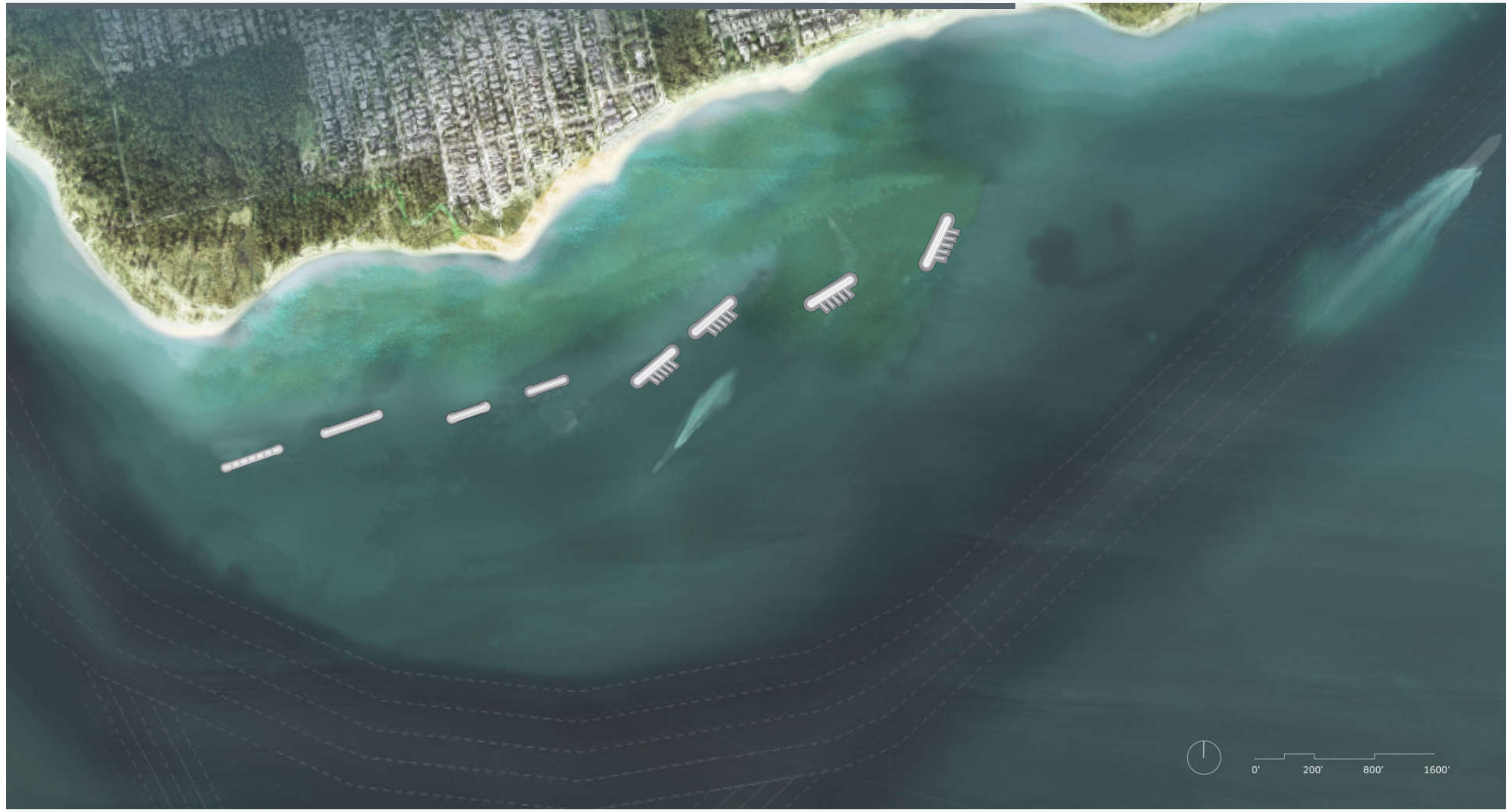
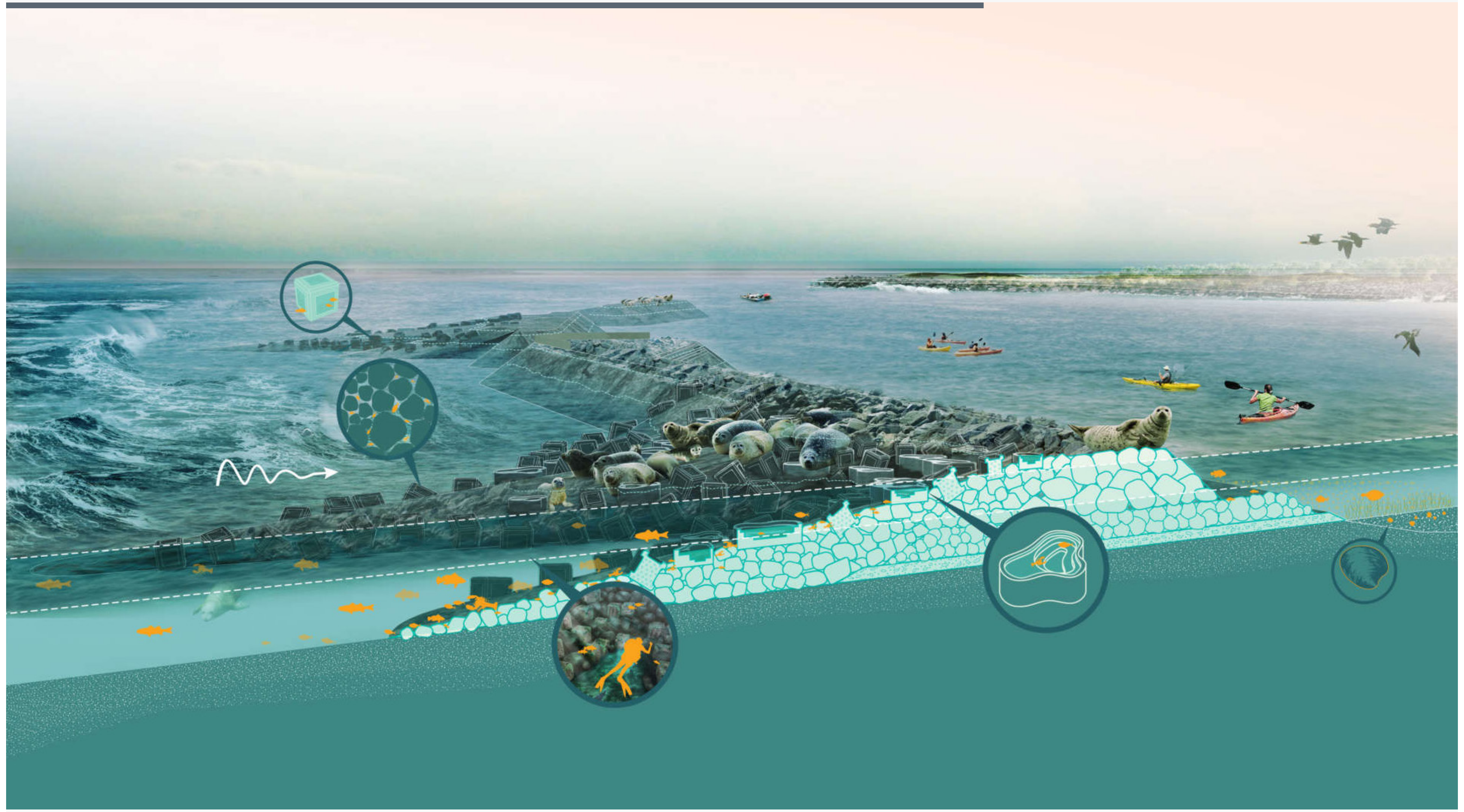



fig. 37

Breakwaters are placed in different directions to effectively reduce wave energy from multiple directions.

# Living Breakwaters



Complex breakwater structure designed to encourage oyster reefs to establish and promote ecology.

fig. 38



# Blue Dunes

WEST 8

This project was submitted for the Rebuild by Design competition that came about after Hurricane Sandy. It aims to address coastal risk from a regional scale. A diverse team of scientists, social scientists, engineers, and designers contributed to the study.
Blue Dunes serves as a model for addressing climate change on a much larger scale and focuses on **taking advantage of the opportunities available**. An essential part of the Rebuild by Design process was to address both local and regional scales. This solution is intended to be scalable and implementable across all areas impacted by Hurricane Sandy.

**Location**
New York

**Programming**
The design would exist nine miles from shore and would not be accessible to pedestrians.

**Formal Design Language**
Coastal Protection and Climate Change Planning

**Goals**

- Mitigate the impact of storm surge and sea level rise
- Restore ecology and create new habitats

**Innovative Practices**

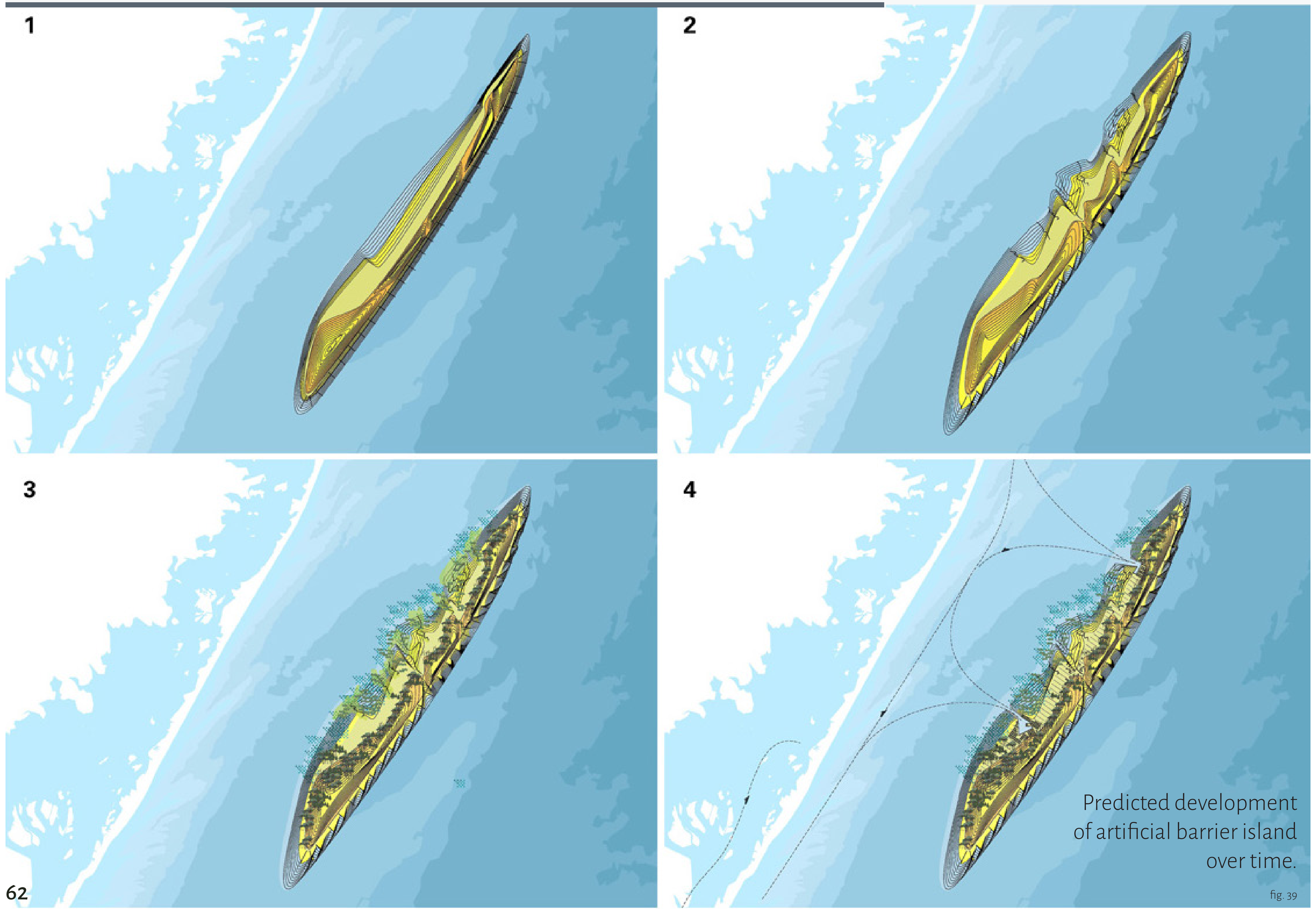
- New barrier islands would create a calmer environment and could see the expansion of critical breeding grounds regionally
- The artificial barrier islands would be susceptible to the natural processes of the ocean. The team hypothesized how the constructed islands might transform over time from erosion, accretion, currents, tides, and winds.
- This project explored the use of beneficial dredge material, looking into various methods of using this resource.

**Inspiring ideas**

- Experimentation is key to responding and preparing for climate change
- Team hypothesized that risk reduction could be achieved through the creation of new landforms seven to nine miles out along the coastal self.
- This project is an imaginative blend of ecology and infrastructure
- This project would create the butterfly effect if one day it was implemented
- Resiliency is the ability to overcome challenges and risk factors - we can assess vulnerabilities to minimize potential impacts to create safe communities.
- The Blue Dunes are designed to thrive in a highly dynamic ecosystem and help restore some of the affected ecologies, providing the opportunity for habitat creation.
- Researchers suggest that offshore turbine arrays could reduce hurricane wind speeds whilst also providing clean energy.

**Coastal Evacuation = Adaptation**
**Coastal Preservation = Resilience**

# Blue Dunes




Predicted development of artificial barrier island over time.

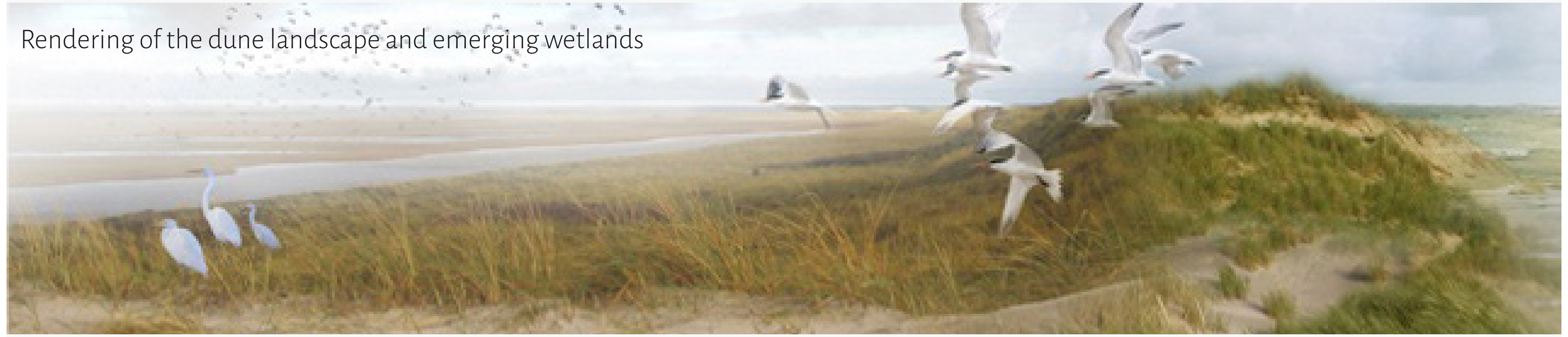
fig. 39



# Blue Dunes

Aerial perspective of the New York Bight with mature artificial barrier islands after all phases of construction are complete.

fig. 40



Rendering of the dune landscape and emerging wetlands

fig. 41

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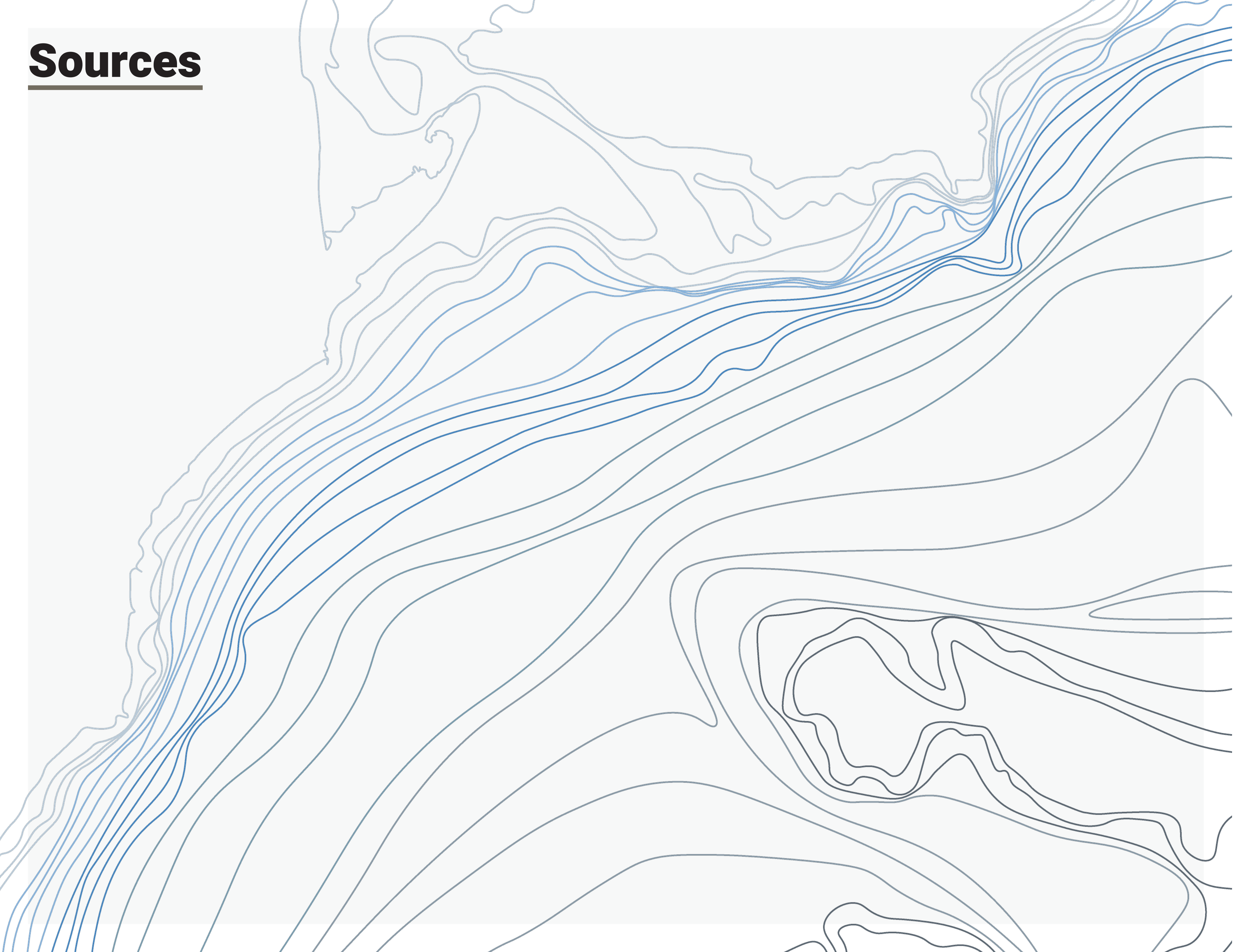

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Cover Page Images: Dart, L. (2023) Dawlish Warren [Photograph].
Figures 1-3: Dart, L. (2023) Dawlish Warren [Photograph].
Figure 4: Google Earth Pro, (2022) Dawlish Warren 50°36'15.67"N, 3°26'01.55"W, elevation 0M. [Online] Available at: http://www.google.com/earth/index.html [Accessed 5 March 2023].
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