*Geo-Resilience 2023 Conference, Cardiff, Wales*
*D.G. Toll & M.G. Winter (Eds)*
*British Geotechnical Association, London. 2024*
*https://doi.org/10.53243/Geo-Resilience-2023-6-5*

# Geo-Infrastructure Vulnerability to Coastal Geohazards and Climate Change: Planning, Adaptation and Resilience

Roger MOORE[1], Liz RIVERS[2]

[1]Jacobs, Birmingham, United Kingdom
[1] Professor Emeritus of Applied Geomorphology, University of Sussex, Falmer, United Kingdom
[2]Jacobs, Bristol, United Kingdom
Corresponding author: Roger Moore (roger.moore1@jacobs.com)

**Abstract**

Climate change is one of the most significant issues affecting modern society. The predicted impacts of climate change at the coast are increasingly severe. Future predictions indicate global sea level rise of up to 1 metre by year 2100, with 2.5m possible under more extreme scenarios. The effects on climate are equally concerning, with more frequent extreme weather events, such as heavy rainfall, storms and heat waves. It is widely regarded that climate change is potentially one of the most serious threats to humanity, with far reaching and devastating impacts on coastal communities, infrastructure, natural environments and economies. Coastal erosion and instability are often overshadowed by flooding in terms of profile and awareness as flooding tends to impact more people. However, the impact of coastal erosion and instability on geo-infrastructure can be disruptive with knock-on impacts to the economy and welfare of affected communities. It is clear from recent high-profile failures and accidents that geo-infrastructure owners face a huge challenge to future-proof existing assets and designs resilient to climate change. Equally, operators need to evolve real-time weather response systems to ensure network safety and operational efficiency. The paper presents the background to the climate response coastal planning and adaptation challenges through illustration of case work from geo-infrastructure asset owner and transport network operator perspectives.

Keywords: Climate Change, Sea Level Rise, Cliff Stability and Erosion, Infrastructure, Resilience

## 1. Climate Change Risk to Geo-Infrastructure

Further to publication of the IPCC (2022) 6th Assessment Report, it is widely accepted that the global impacts of climate change are happening and the effects of sea level rise, intensified erosion by the sea and extreme weather and storms, pose serious risks to coastal infrastructure and communities worldwide (Figure 1).

Over the last 150 years, the increasing interaction between natural hazards, infrastructure and the growing coastal population of England and Wales has magnified the levels of risk, leading to the demand for coastal risk management and adaptation systems to be put in place (Defra, 2010). Of an estimated 6,251 km of coastline in England and Wales, 3,327 km (53%) are cliffs (>5m above sea level) subject to erosion with 2,924 km (47%) of lowland subject to flooding. A legacy of coastal defences from the last century continue to provide a good standard of protection while others provide a diminishing standard of protection or have fallen into disrepair.

Coastal local authorities are faced with the increasingly complex task of balancing development needs and managing coastal hazards in the face of climate change. Given the combined effects of future development demands at the coast and the physical impacts of coastal erosion, flooding and cliff instability, these problems are growing in intensity. Despite this, the progress towards more sustainable coasts has been a relatively slow process in many parts of the world. In 1988, the United Kingdom House of Commons Agriculture Committee, in its report on *'Flood and Coastal Defence',* stated, *"We are of the opinion that flood and coastal defence policy cannot be sustained in the long-term if it continues to be founded upon the practice of substantial human intervention in the natural processes of flooding and erosion. Indeed, it is of concern to us that the legacy of flooding and erosional problems arising from this practice, and the likely increase in future climatological and other environmental pressures on the UK's ageing flood and coastal defence infrastructure, might combine to present flood and coastal defence local authorities with insuperable difficulties"* (House of Commons Select Committee, 1992).

This report was responded to positively in the United Kingdom by the Department for Environment, Food and Rural Affairs (Defra 2006; 2007), which worked with the Environment Agency, Coastal Defence Groups and other key organisations to help shape a sustainable shoreline management framework that would allow assets to be protected where economically justifiable, and where suitable technical solutions could be found without detriment to the environment. An active programme of research, together with funding to allow the development of shoreline management plans, also provided a framework that would allow decision-making to take place in a more sustainable way, taking account of the impacts of climate change and other factors.

**Figure 1**: Examples of the impacts of coastal storms and vulnerability of infrastructure; Top left: Dawlish, Devon, 7th February 2014; Top right: Ventnor, Isle of Wight, 3rd November 2022; Lower left: Hemsby, Norfolk, 6th December 2013; Lower right: Totland Bay, Isle of Wight, 26th December 2012. Images courtesy: Network Rail, Alamy Stock Photo, Solent Coastguard.

**2. Coastal Planning & Adaptation**

In many countries a key government objective, through the planning process, is to support transition to a low carbon economy, taking full account of risks arising from climate change. In order to achieve this objective, the planning system should seek to:

- minimise vulnerability and provide resilience to impacts arising from climate change; and
- avoid inappropriate development in areas at risk by directing development away from such areas or, where development is essential, making it safe without increasing the hazard elsewhere.

To achieve these objectives, national governments and local government planning authorities often adopt proactive strategies to mitigate and adapt to climate change. *"Adaptation will be crucial in reducing vulnerability to climate change and it forms the only effective way to cope with the impacts that are inevitable over the next decades. Without early and strong mitigation, the cost of adaptation will rise sharply…governments have a role to play in making adaptation happen, starting now, providing both policy guidelines and economic and institutional support"* (Stern, 2006).

This statement by Stern highlighted the importance of introducing adaptation as a tool to manage coastal change and is particularly relevant when addressing the question of natural hazards at the coast. For new development, local government planning officials need to be satisfied that the developments:

- do not impair and, where possible, enhance the ability of communities and the natural environment to adapt sustainably to the impacts of climate change;
- will be safe throughout their planned lifetime (up to 50 or 100 years) without increasing risk to life and property or requiring new or improved coastal defence measures; and
- consider and identify measures for managing any development at the end of its planned life, including proposals for the removal of those developments before the site is threatened by significant changes.

Coastal adaptation and risk reduction share the same ultimate goal: reducing exposure and vulnerability to hazardous events. There are synergies to be exploited in closely coordinating risk reduction and adaptation policies. Risk reduction and prevention in the short and medium term will primarily address socio-economic developments and climate variability to reduce the impacts of natural hazards, while adaptation aims at developing longer-term planning to address climate change impacts (Figure 2).


**Figure 2**: Components to successful coastal planning and adaptive management (Moore & McInnes 2021).

It is important to note that uncertainty is inherent to coastal policymaking. Policymakers face deep uncertainties from a range of external factors, such as climate change, population growth, new technologies and economic developments. Adaptation policy is no exception. In addition to these 'external' factors influencing adaptation policy, other 'internal' influences on policy: societal preferences, stakeholders' interests, and stakeholders' evaluation of plans might also change over time. The end point is, therefore, not only determined by what is known or anticipated at present, but also by what will be experienced in future, and by policy responses to events (European Environment Agency, 2013).

Traditionally, coastal scientists have used models that assume incremental change in the environment and in the social and economic context. However, the weaknesses of this approach are becoming more evident. Facing a deeply uncertain world, new approaches are needed to allow policy to adapt over time in response to how the future unfolds and changes in the environment and society.

'Adaptation pathways' is the umbrella term given to the application of this flexible approach and delivers a selection of options that can be called upon as some uncertainty about future climatic and socio-economic developments decrease and new uncertainty appears. The adaptation pathways approach is iterative, relying on constant updating by information flows that deliver additional resilience in decisions. It stresses the importance of designing dynamic and flexible plans by creating a strategic vision of the future, committing to short and mid-term actions, and establishing a framework to guide future and longer-term actions (European Environment Agency, 2013; Frampton *et al*., 2019).

In certain situations, coastal hazards and risks may be so problematic that it is necessary to consider the relocation of a whole community or other assets, and to identify and allocate more suitable land within the development plan where a community may be relocated (Siddle *et al.*, 2015). In the case of a coastal location affected by erosion, cliff instability or flooding, 'rolling back' or relocation away from the area of active coastal change may be a practical option. Depending on the level of risk or the timeframe in which implementation is required, the planning authority may be in a position to approve some limited but modest developments, which can exist and operate within time-limited constraints. Planning conditions may be applied to such new developments where it is possible to manage the risk to the proposed development during its lifetime.

Such adaptive approaches aimed at trying to address potentially increasing levels of risk are part of a process that will be essential to address worsening coastal conditions aggravated by climate change. The definition of successful adaptation is likely to depend on the viewpoint of the stakeholders that are affected. A community facing permanent loss of assets or infrastructure may see things very differently to communities who are not immediately affected or at risk.  Similarly, successful adaptation will depend on a wide range of socio-economic conditions. Some locations have high levels of social well-being, whilst other locations face much greater levels of deprivation. These impacts will set the tone for the challenge, and the process of proactively involving communities in preparing and planning for adaptation (Defra 2010; 2012).

To achieve successful adaptation, communities need to be supported and involved in the outcomes that will shape the future of their community. There needs to be an open and honest debate on what coastal change may mean for their community, and agreement on the basic problems to be addressed in terms of infrastructure, buildings and livelihoods. The process of building a vision for the future is a long-term one, particularly when partnerships are genuinely community-based.

While consideration of risk should be taken into account at all levels of governance, it is often at the local community level where a coherent and acceptable response to managing the impacts of changing risks can be achieved most effectively. To be most successful this should bring together all sectors of a community, including homeowners, local businesses and landowners, as well as other parts of the whole community that contribute to the shape and functioning of the location, for example, heritage and natural assets that attract tourism. There is no definitive list of all the stakeholders that could be involved as this will vary from one location to another, however, these are likely to include local authority staff, local politicians and councillors', key businesses, utilities and infrastructure providers alongside local residents.

The response to coastal change at the community level varies considerably across the world in terms of effective management action. Often local residents do not have clear and accurate information about coastal erosion, cliff instability or flood risk to which they are currently exposed nor the scenario impacts for the future. *"There is typically no insurance or compensation for losses from coastal erosion for homeowners to mitigate the risk of losing their properties.  Consequently, homeowners at risk may not take action to relocate or consider strategies beyond trying to protect their existing asset"* (Committee on Climate Change, 2018).

Whilst the case for adaptation at the coast is irrefutably strong, there are several fundamental reasons why the process has been slow to implement. In many locations, this is a result of short-term planning horizons, which fail to make proper consideration of the longer-term consequences of coastal change. In addition, governments often lack the resources to fund adaptation solutions although possible options may have been studied and agreed at the community level. Therefore, actions are required at government level to ensure that funding and investment is available to support adaptation initiatives. In parallel with this at the local level, local authorities and planners, in collaboration with affected coastal communities, need to raise awareness of the issues including, for example, the increasing evidence of accelerating coastal change.

The benefits for local communities working with their local authorities on adaptation are particularly important as their engagement will highlight:

- the value of a shared understanding of the nature and risks of coastal change, the problems to be addressed, and the basis for agreeing joint actions.
- the desirability of building adaptive capacity in coastal communities, which means they will be more resilient, creative and prepared for coastal hazards and accelerated rates of change; and
- the value of making good use of the local community's knowledge and resources to significantly improve coastal planning, particularly through developing governance mechanisms that enable areas to be managed in a holistic way.

### 3. CASE STUDY 1: Canvey Island, Essex

Canvey Island is approximately 17km$^2$ in area and lies off the southeast coast of Essex in the Thames Estuary (Figure 3). Canvey Island has an interesting history and relationship with the sea, as it is almost entirely below high tide level, with beaches to the south and a population of approximately 39,000 (Zhujiworld.com, 2022). The island is protected from daily tidal inundation by substantial seawalls and two tidal barriers. Inland, a pumped and gravity drainage system removes fluvial water to the sea. The motto on Canvey Islands Coat of Arms 'Ex Mare Dei Gratia' means 'From the sea by the Grace of God'.

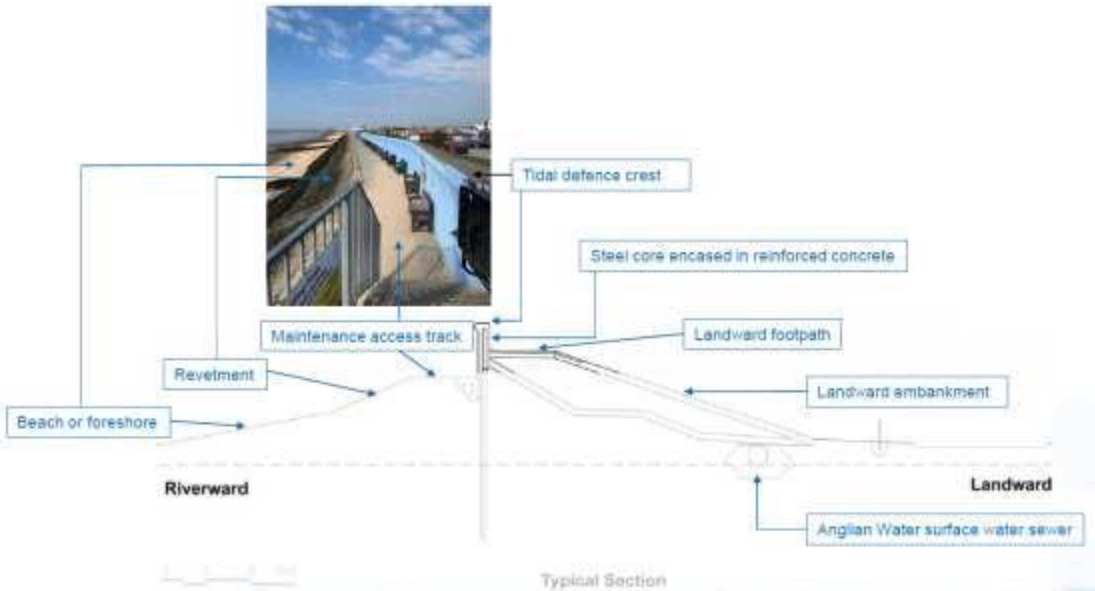
The Saxons introduced sheep farming to the marshes in the 5th century, but due to the frequent inundation from the sea only the shepherds inhabited the island. In the 14th century, attempts were made to protect the land with rudimentary sea defences, but these made little substantial change and by the early seventeenth century part of Canvey Island was becoming lost to the sea. Things changed in 1622 when the landowners transferred a third of their land to a Dutch businessman in exchange for the Dutchman reclaiming the whole of

Canvey Island from the overflowing tides and encroachment of the sea, and to maintain effective sea walls at his own cost and expense. The Dutchman employed around 200-300 Dutch workers to create a wall round the island with local chalk, limestone and the heavy clay from the marshes and face the main length along the Thames frontage with Kentish ragstone to protect it from wave action (Canveyisland.org, 2022).

At the start of the 20th century, Canvey Island became a popular holiday destination and the population of the island gradually increased on the eastern side. The tragic East Coast tidal surge caused the death of 58 people on Canvey Island on 1st February 1953 and evacuation of the whole island (BBC News, 2022) (Figure 3). Following these floods, a new seawall was built in 1955 and the island's civil defence sirens were adopted as a flood warning system, a recommendation of the 1954 Waverley Report (Hansard HC Deb., 3 June 1954). The sirens were replaced in 1996 by the Environment Agency's first flood warning system, which was improved to an online system in 2001 and an enhanced flood warning service comprising text, email and phone alerts being made publicly available in 2006.

Top left: Canvey Island location (Source: Esri, 2023[1])

Top right: Aerial photo after the 1953 flood (Alamy Stock Photo)




Typical cross section of current tidal defence along southern frontage, since 1980s upgrade (Environment Agency, 2023)

**Figure 3**: Canvey Island coastal flooding and defences.

The defences present today are the result of significant upgrades which took place in the early 1980s as part of the estuary wide defence raising required under the 1972 Thames Barrier and Flood Prevention Act. These

[1] The map in Figure 3 was created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com.

defences were designed to provide a 1 in 1000 year standard of protection in the year 2030. The works comprised installation of sheet piles through the pre-existing earth embankments, construction of reinforced concrete seawalls at the crest, raising of the landward berm and installation of a new maintenance track on the riverward side (TEAM, 2016).

However, areas like Canvey Island need continual management to ensure the tidal defences continue to provide a high standard of protection. This is being achieved through the Thames Estuary (TE) 2100 Plan (Environment Agency, 2012). This document, published by the Environment Agency working in partnership with various partners across the estuary, sets out the strategy for an adaptive approach to managing tidal flood risk from sea level rise attributed to climate change. The TE2100 Plan identified five possible strategic flood risk management policies applicable to 23 discrete "policy units" which segment the tidal flood plain from Teddington (west London) to Shoeburyness and Sheerness. The current preferred flood risk management policy for Canvey Island, is 'to take further action to keep up with climate and land use change so that flood risk does not increase' (Environment Agency, 2012).

The TE2100 Plan is monitored against ten key indicators of change and is reviewed every 5 and 10 years to ensure its aspirations are in-keeping with those key indicators – two of which include sea level and peak surge level. Current modelling of Canvey Island's estuarine environment, inclusive of sea level rise predictions, shows it benefits from a standard of protection which exceeds the 1 in 1000 year level of flood risk management and will continue to do so past 2030. The current modelling has also indicated the defence level may need to be higher than the existing seawall defence level in a few localised places by 2070. Detailed overtopping assessments have been undertaken with consideration of extreme water levels and wave overtopping to confirm the tolerability. This will continue to be reviewed as more evidence and data become available for updated modelling to support the 2040 strategic defence review regarding defence crest levels and dates for future raising (TEAM2100, 2019).

The focus today is on a 3km stretch of Canvey Island's southern shoreline. Engineering surveys, investigations and assessments of recent years identified that although the seawalls were in good condition and the defence level was satisfactory in relation to the TE2100 Plan, the revetment was showing clear signs of failure in this area. The ever-increasing revetment defects, predominantly of loose, sunken or missing blocks, are hard to predict and not cost-effective to repair. These increasing defects pose a risk to the structural integrity of the embankment, such as the failure recorded at Chapman Sands in January 2014, and risk destabilisation of the piled concrete seawall defence (Figure 4). Therefore, following an optioneering phase, the decision was made to replace the revetment with Open Stone Asphalt (OSA) to provide a cost-effective solution with the lowest whole life carbon. The OSA will also be installed at a shallower angle than the existing revetment frontage, to maintain the same level of stability in relation to the effects of sea level rise on embankment porewater pressures.

Revetment failure following storm in January 2014 (left) and after repairs (right)

**Figure 4**: Chapman Sands revetment failure (Courtesy: Environment Agency).

The Environment Agency has begun the £75M construction phase of the project (Gov.uk, 2022). The 3km stretch of revetment along the southern amenity shoreline will be renewed, maintaining the very high standard of protection to just over 6000 properties for another 50 years. The works will also include enhancements for the built and natural environment, with improvements to the public access walkways either side of the seawall, new steps to the beach and foreshore and biodiversity enhancements. These will comprise planting of flowering seed mixes and the creation of localised rock pools to boost habitats.

**4. CASE STUDY 2: South Devon Railway, Dawlish, Devon**

The South Devon Railway is one of the UK's most celebrated main line routes owing to the spectacular coastal scenery. Between Dawlish Warren and Teignmouth, the rail track has been constructed at the base of high cliffs formed of characteristic red sandstones and breccias (Figure 5). The line was opened in 1846 after several years' construction, led by Brunel, who scaled back the cliffs using explosives, excavated five tunnels and built the coastal defences. From the early years of operation, there has been a long history of breaches in the coastal defences and occurrence of cliff falls causing adverse impacts on the rail track and services (Figure 1). With sea levels predicted to rise by up to 1 metre, and possibly 2.5m under high emissions scenarios, and the frequency of storms and extreme winter rainfall by 2100, the railway will be increasingly vulnerable to wave overtopping, cliff falls and landslides without intervention.

**Figure 5**: The Southwest Coast Railway, Kennaway Tunnel and cliffs, looking north (Courtesy: author).

**4.1 Network Rail Response**

Following unplanned closure of the railway between Feb-Mar 2014, Network Rail commissioned 'The Exeter to Newton Abbot Resilience Study' (CH2M 2016) to prepare a strategy and intervention plan to ensure the long term resilience (i.e. safe and uninterrupted operation) of the railway in the future. The economic case for adopting this strategy followed Department for Transport's (DfT) WebTAG appraisal guidance. The main costs are spread across several phases of intervention works whilst the benefits are derived from reduction of disruption to the rail network. In the long term, the estimated benefit cost ratio is over 90 (due to significant long term cost savings and benefits accrual) which falls within DfT's Very High value for money categorisation, this is because with worsening climate change, the value of the proposed interventions is likely to increase substantially over time. Additionally, there would be wider benefits to the economy of Cornwall and West Devon from improved resilience of the railway.

A reasonably clear picture emerged from the CH2M assessment with regard to the location, nature and scale of coastal and geotechnical hazards that could impact the railway under adverse climatic conditions in the future. In most cases the nature of the hazard was reasonably well defined to mitigate the problem using standard design methods. Only in a few cases, was the nature of the geotechnical hazard uncertain and complex necessitating further detailed ground investigations and specialist studies, to inform design of cliff stabilisation and drainage measures. Coastal defence improvement schemes have since been completed at Dawlish Station and cliff stabilisation measures are currently under construction between Dawlish and Holcombe. A future scheme between Parsons Tunnel and Teignmouth is also in development.

From a network operations perspective considerable attention and investment is being made by Network Rail to improve real time weather alerts and use of SMS technology to inform train drivers of speed and line restrictions to manage transient risks and services. Similarly, use of in situ smart monitoring of geo-assets considered to pose a risk to the railway can be deployed to provide warning of geotechnical slope failures.

**References**


BBC News, 2022. Weblink
Canvey Island.org, 2022. Weblink. Accessed December 2022.

CH2M, 2016. *The Exeter to Newton Abbot Resilience Study:* Resilience Strategy, Single Option Selection Report.

Network Rail.

Committee on Climate Change, 2018. *Managing the Coast in a Changing Climate*. London. Weblink.
Defra, 2006. *Shoreline Management Plans Guidance*. Crown Copyright.

Defra, 2007. *Environment Agency Strategic Overview for Flood and Coastal Erosion Risk Management*. Crown Copyright.

Defra, 2010. *Adapting to Coastal Change: Developing a Policy Framework*. Crown Copyright.
Defra, 2012. *Coastal Change Pathfinder Review*. Final Report. Crown Copyright.

Environment Agency, 2012. *TE2100 Plan*. Weblink. Accessed January 2023.

Environment Agency, 2023. Getting to Know Canvey Island's current tidal defences (image). Weblink
European Environment Agency, 2013. *Adaptation in Europe*. ISBN 1725-9177.

Frampton, A., Von Lany, P. H. & Russell, A., 2019. *Adaptation Pathways for Shoreline Management Planning*.

ICE Coastal Management Conference, La Rochelle.

Hansard. HC Deb 03 June 1954 vol 528 cc102-5W. Weblink. Accessed January 2023.

House of Commons Select Committee, 1992. *Coastal Zone Protection and Planning*. London. HMSO.

IPCC, 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

Moore, R and McInnes RG 2021 Coastal Erosion and Climate Change: Guidance for Policymakers, Planners and Stakeholders. Jacobs. 86pp. Weblink.

Moore, R. and Davis, G. 2015. *Cliff instability and erosion management in England and Wales*. Journal of coastal Conservation. DOI.

Pontee, N. I. & Parsons, A. P. 2012. *Adaptation as part of sustainable shoreline management in England and Wales*. Proceedings of the Institution of Civil Engineers Maritime Engineering 165 September 2012 Issue MA3 Pages 113–130. Weblink.

Siddle, R., Rowe, S. & Moore, R., 2015. *Adaptation to Property Loss due to Coastal Cliff Instability and Erosion: Case Study into the Knipe Point Cliff Retreat Pathfinder Project*. Baptiste, A., (Ed.) *Coastal Management*: Proceedings of the International Conference, Amsterdam, 8-9 September 2015. ICE Publishing, 2016. ISBN: 978-0-7277-6114-9.

Stern, N., 2006. *The Economics of Climate Change*. Report for the UK Government. 700pps.
TEAM2100, 2016. Engineering Investigation Report

TEAM2100, 2019. Canvey Southern Shoreline Appraisal Report Version P04
Zhujiworld.com, 2022. Weblink. Accessed December 2022