Severn Estuary Commission
Socio Economics Workstream

Appendix 8 Flood Risk and Coastal Erosion Topic Paper

Final Report
March 2025

HARDISTY JONES ASSOCIATES
OXFORD ECONOMICS
ARCADIS

Western Gateway – Severn Estuary Commission

Flood and Coastal Erosion

FEBRUARY 2025

Prepared By:
Arcadis Consulting (UK) Ltd

Prepared For:
Stuart Hardisty
Hardisty Jones Associates

Our Ref:
Western Gateway – Severn Estuary Commission

James Watling
Senior Engineer

Steve Cook
Technical Director

Jon Ralph
Director

1 Introduction

1.1. The introduction of a tidal barrage or lagoon in the Severn Estuary has the potential to significantly influence the risk (likelihood and/or consequences) for flooding and/or coastal erosion in both the impounded and non-impounded areas. That influence can be either positive, reducing risk, or negative, increasing risk, in nature.

1.2. The scale of economic impact of flooding and coastal erosion is significant. For example the economic damages in England from the winter 2015/16 floods were estimated to be between £1.3 billion and £1.9 billion[1]. Impacts include damage to residential and commercial properties, vehicles, public and private infrastructure (schools, hospitals, power, water and telecommunications utilities, transportation networks, etc). Repair or replacement of these can exceed 12 months. Economic impact during a flood also includes the costs of evacuation, emergency services, disruption to transport and commercial business. Such impacts can occur significant distances outside the flooded area, for example where a source of power or drinking water is flooded which disrupts supply to customers across the wider region.

1.3. Post-flood economic impacts include the cost of temporary accommodation for displaced residents and businesses, and disposal of damaged goods and building materials. Social impacts predominantly are the risk to life during a flood event and mental health impacts (stress, anxiety, depression, etc) incurred in the months or years after a flood.

1.4. Over the longer-term, repeated flooding of the same location can also lead to the depreciation of local property values and investor confidence otherwise known as “flood blight”. Respective national planning policies in England and Wales steer development proposals away from areas of highest flood risk, restricting potential for future development and investment or requiring increased mitigation measures (with associated costs) to secure planning permissions.

1.5. There are extensive areas at flood risk in the Severn Estuary along both the English and Welsh coasts. These include areas with existing residential and commercial development and areas with development potential that are currently constrained by flood risk. Climate change is predicted to increase the number of properties and infrastructure at risk of flooding over the coming century, which will increase the socio-economic costs of floods. A tidal lagoon or barrage therefore has the potential to provide a reduction in flood risk to one or multiple areas, which could yield socio-economic benefits at a regional or national scale.

1.6. This Annex provides a high level qualitative review of flood and erosion impacts associated with each of the six barrage/lagoon example locations that are being considered for the Western Gateway – Severn Estuary project. The review is based upon high level analysis of the available literature on each of the schemes, flood/coastal defence data, and flood and erosion risk mapping.

[1] Estimating the economic costs of the 2015 to 2016 winter floods, Environment Agency 2018. https://assets.publishing.service.gov.uk/media/5a755ce8ed915d7314959615/Estimating_the_economic_costs_of_the_winter_floods_2015_to_2016.pdf

2 Desk Based Assessment

2.1 Literature Review

2.1.1 A review of the available literature identified that the most researched barrage/lagoon location, in terms of flood and erosion risk, is the Cardiff-Weston Barrage. The Shoots Barrage and Swansea Bay Lagoon locations have some more limited research available. The least researched locations are Stepping Stones Lagoon, Cardiff Lagoon, and West Somerset Lagoon.

2.1.2 The key document outlining flood risk impacts from the lagoon and barrage options is the Severn Estuary Topic Paper (SETP) Flood Risk and Drainage. The SETP provides analysis of five schemes (three barrages, 2 lagoons), including the Cardiff-Weston Barrage, Shoots Barrage and the Welsh Grounds Lagoon.

2.1.3 Although the SETP provides a summary of the flood and erosion impacts, the document has limited technical information regarding how the SETP findings were derived, and so it is not possible to review the data sources and methods used to generate its findings. The SETP was also published in 2010, prior to the most recent developments in flooding and coastal erosion risk analysis, the latest climate change predictions, and implementation of several major coastal flood defence schemes.

2.1.4 The following sources of data have been utilised for this review:

- Severn Estuary Call for Information Relevant Data and Research Relating to the Severn Estuary: Cardiff University Studies Independent Information Report (Roger A. Falconer, Reza Ahmadian, 2024)
- SETP - Severn Tidal Power SEA: Flood Risk and Land Drainage Topic Paper, 2010
- Sea level rise in the Severn Estuary and Bristol Channel and impacts of a Severn Barrage (Reza Ahmadian, 2013)
- Effects of open boundary location on the far-field hydrodynamics of a Severn Barrage (Juntao Zhou, et al. 2013)
- The effects of a Severn Barrage on wave conditions in the Bristol Channel (I. Fairley et al. 2013)
- Modelling the effects of a tidal lagoon on the morphology of Swansea Bay, Wales, UK (J. Horrillo-Caraballolain, I. Fairley, H. Karunarathnala, I Masters, D. E. Reeve 2018)
- Understanding the likely scale of deterioration of Marine Protected Area features due to coastal squeeze: Volume 2- Results and discussion (Natural Resources Wales & ABPmer, 2024)
- National (England) Coastal Erosion Risk Mapping (Environment Agency, 2018)
- Wales Coastal Erosion Risk Mapping (Natural Resources Wales, 2023)
- Technical Advice Note 15 Defended Zones [flood risk] (Natural Resources Wales, 2024)
- NRW Floodzone Rivers and Sea Merged (Natural Resources Wales, 2024)
- Flood Mapping for Planning Rivers and Sea Zone 3 (Environment Agency, 2024)
- Coastal Design Sea Levels (Environment Agency, 2018)
- UK Climate Projections 2018 (UKCP18) User Interface (UK Met Office, 2018)

3 Summary of Flood and Erosion Risks

3.1 Sources of flooding

3.1.1 The relevant sources of flood and coastal erosion risks that may be improved or worsened by the tidal barrier and lagoon options are as follows.

Coastal Flooding where flooding occurs due to a combination of high tides, storm surges and waves overtopping natural land or flood defences. Storm surges are temporary increases in sea levels that result from low pressure weather systems with high winds coinciding with high tides, pushing additional seawater up the estuary which raises sea levels significantly higher than natural high tides to cause flooding.

Fluvial Flooding where flooding occurs from rivers generally from heavy or prolonged rainfall. This can combine with occurrences of high tides and cause a situation known as **tidal locking**, where the tidally raised sea level prevents flood water draining from rivers and causing flooding inland back up the river's course. Tidal locking can also affect manmade watercourse drainage systems that use a pumped or gravity system to discharge water into the estuary, such as the Caldicot and Wentlooge Levels near Cardiff and the Somerset Levels.

Surface Water Flooding where rainfall overwhelms drainage capacity and leads to water spilling out from drains and gullies. This can also be caused by tidal locking at high tides which prevents outfalls which prevent and drains from discharging into the sea.

Groundwater Flooding where the water table rises to the land surface and flooding subsurface (e.g. basements) and surface features.

Coastal Erosion is the permanent loss of coastal land due to a combination of waves, currents and tides.

3.2 Climate Change

3.2.1 Climate Change is a significant factor for the Severn Estuary. Based on UK climate change predictions, climate change is expected to cause sea levels to rise, increase the amount and velocity of peak flows in rivers, and increase the frequency and severity of extreme rainfall events. Climate change will also lead to stormier conditions with greater wind speeds and wave heights. Each of these factors in isolation and combination can cause more frequent and severe flooding to occur. Both increased storminess and sea levels are also predicted to increase rates of coastal erosion i.e. the speed at which a cliff or beach becomes eroded.

3.2.2 UK climate change allowances for these factors are published and periodically updated, most recently in the early 2020's with a regional level of granularity. The allowances provide predictions through a number of epochs into the early 2100's that developers are required by national (English[2] and Welsh[3]) planning policy to take into account.

3.2.3 Each of the lagoons and barrages impact the Severn Estuary in varying scales. As barrages cross the whole estuary and have a large, enclosed shoreline they have a larger impact on overall estuary. Lagoons do not cross the Severn Estuary, have a much smaller enclosed shoreline and therefore have

[2] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

[3] https://www.gov.wales/climate-change-allowances-and-flood-consequence-assessments

a more limited, localised impact. A positive impact in terms of flood risk would represent either a reduced likelihood of flooding or reduced depths of flooding. A negative impact would represent an increase in flood frequency or depths. In terms of erosion a positive impact would be a reduced erosion rate, a negative impact is an increased erosion rate.

3.2.4 The impacts will differ across the impounded and non-impounded areas, with generally positive impacts on the impounded area and negative impacts on the non-impounded area. The **impounded** area refers to the area within the lagoon or upstream of a barrage, whereas the **non-impounded** area is the area connected to open sea and wider estuary.

3.2.5 The positives (benefits) and negatives (disbenefits) have been summarised below in Table 3.1. The basis of the outcomes and benefits has been formulated from the SETP, as well as from additional insight from stakeholder interviews and technical expertise.

Table 3-1. Benefits and disbenefits associated with Barrage/Lagoon options

Positive		**Negative**	
Outcomes	**Benefits**	**Outcomes**	**Disbenefits**
Protection from Impounding Structure	**Applies to the impounded area for both Lagoons and Barrages** • Reduction in storm surges • Reduction of peak tides • Reduced sea level rise effects • Reduced tidal locking over high tide	**Increased low tide water levels**	**Lagoons** • Impedance of natural drainage from rivers and drainage networks, mitigated through outfall redesign, and applies to a smaller impounded area **Barrages** • Impedance of natural drainage from drainage networks, mitigated through outfall redesign though applies over a larger area • Impedance of peak flood discharges from large rivers, mitigated through management of impounded water level
		Increased mid-high tide period	**Lagoons** • No significant impact **Barrages** • Whilst any impact would be resolved in the design a barrage would impound a larger area

Positive		Negative	
Combined reduced tides levels and reduced wave action within the impounded area	**Lagoons** • Reduced coastal erosion • Removes the need for new/existing flood defences upstream • Reduced coastal squeeze and loss of intertidal habitat **Barrages** • Reduced coastal erosion • Removes the need for new/existing flood defences upstream • Reduced coastal squeeze and loss of intertidal habitat	**Increased water levels in the Severn Estuary in the non-impounded area**	**Lagoons** • No significant impact **Barrages** • Minor increase on the seaward side for larger barrages.
Reduced wave action from swell in the impounded area	**Lagoons** • Reduction of wave heights **Barrages** • Reduction of wave heights	**Changes to coastal processes**	**Lagoons** • Some changes in erosion or accretion, managed as part of operation. **Barrages** • Depending on the size of the barrage, some changes in erosion or accretion patterns will occur.
		Increased wave heights and exposure in non-impounded areas	**Lagoons** • No significant impact due to size of lagoons **Barrages** • Increased wave action from reflection off large scale barrage.

4 Cross Cutting Issues

4.1 Designation of a tidal barrage or lagoon as a flood or coastal erosion asset

4.1.1 Following the introduction of the Flood and Water Management Act in 2010 there is specific provision in Schedule 1 of the Act for designating privately maintained or owned structures or features which perform a flood or coastal erosion risk management function as a flood risk management asset.

4.1.2 Under that designation the structures cannot be altered, removed or replaced by the owner without the consent of the responsible authority who designated it, which is either the Environment Agency, Natural Resources Wales, or a Lead Local Flood Authority (local authority).

4.1.3 Designation does not impose any maintenance obligations on the owner of the structure or on the designating authority. Nor does it proscribe who will be responsible for the costs of future maintenance.

4.1.4 Guidance on the designation process was published in 2012[4] but to date designation of assets has been very limited across England and Wales. A review of the designation process and current implementation was published by CIRIA in 2022[5]. For reference, Steve Cook of Arcadis was co-author of the legislation and a steering group member for the CIRIA review.

4.1.5 Notwithstanding the ability to designate a private structure as a flood or coastal risk management asset, a key decision making factor in spatial planning is the level of confidence that the owner of a flood defence structure (designed or *de facto*) has sufficient resources to maintain it to its design standard for the duration of its design life. Coastal defences are typically designed to a 1 in 200 (0.5% annual chance of flooding still happening) Standard of Protection plus an allowance for climate change and wave overtopping.

4.1.6 If a tidal barrage or lagoon has been built to a design that incidentally meets or exceeds the coastal flood Standard of Protection plus allowances, and the regulatory authorities have confidence in its maintenance being resourced (e.g. for power generation purposes), there may be increased likelihood that it could be a factor in enabling landward development.

4.1.7 A tidal barrage or lagoon could also operate as an active flood and coastal defence asset (vs. a passive one such as a sea wall). By closing the Lagoon/Barrage sluices and turbines prior to a high tide, or by pumping sea water out of the lagoon/barrier, a low tide level in the impounded area can be maintained. This will preserve river capacity in the intertidal area and help to accommodate the river flows coming from upstream. There is currently a similar practice in place at Cardiff Bay barrage where Natural Resources Wales alerts the Cardiff Harbour Authority of an expected river flood coming down the Taff or Ely river catchment, enabling the Authority to lower the water level to create capacity and minimise fluvial flooding within the Bay.

4.1.8 This practice could therefore reduce the risk of tidal locking due to a barrage or lagoon and the associated fluvial flooding. However, during these periods no power would be generated and so the scheme's owner may want to receive commercial compensation for providing a flood risk management service to one or several of the statutory flood and coastal risk management authorities. It is highly likely that the statutory flood and coastal risk management authorities would require the barrage/lagoon

[4] Defra / Welsh Government, 2012, Designation of structures and features for flood and coastal erosion risk management purposes: information note

[5] CIRIA C804, 2022, Integration of non-flood defence structures into the flood defence system: a review

owner to adhere to a set of comprehensive, formalised operating procedures for the management of flood and coastal risk.

4.1.9 As assessment of the location, expected frequency and potential mitigation of tidal locking *vis a vis* impounded water levels would help clarify the scale of this issue for future barrage and lagoon proposals.

4.2 Assigning flood or coastal erosion economic benefits to a tidal barrage or lagoon

4.2.1 The methodology for benefit cost analysis on flood and coastal risk management capital schemes is outlined in HM Treasury's Green Book on option appraisal and evaluation. It cites the Multi-Coloured Handbook as a key reference source for methods to use in estimating damage to residential and non-residential properties, vehicle damages and evacuation costs, direct and indirect flood losses to schools, hospitals, utilities, and transportation networks, and agricultural losses. Economic values to be applied are periodically updated, including up to 2024 and further updates are planned.

4.2.2 Large areas of the English and Welsh coast are at risk of coastal flooding, as are areas along main rivers and their confluence with the Severn Estuary. Several major flood / coastal alleviation schemes have been built in recent years or are currently in the process of being constructed. These include:

- the Avonmouth-Severnside scheme of approximately 17km of flood defences. Located from Avonmouth Docks to near Aust to safeguard existing homes, businesses, transport and utility infrastructure and enable development in the Avonmouth-Severnside Enterprise Area (ASEA).
- the Bridgwater scheme, comprising a tidal barrier that can be lowered on the River Parrett to protect Bridgwater and surrounding communities from flooding, new and improved existing downstream riverside flood defences.

4.2.3 Under current appraisal processes, a subsequent tidal barrage or lagoon could not claim the economic benefits for protecting communities and infrastructure that has already benefitted from a prior flood and coastal risk management scheme. However, benefits can be claimed if existing defence assets reach the end of their design life (typically 50-100 years) or need to be improved to address climate change, e.g. raise their height. Examples include the Cardiff-Weston Barrage or Cardiff Lagoon obviating the need to maintain the ageing coastal defences between east Cardiff and Newport. The Environment Agency, Natural Resources Wales and those local authorities with a Coast Protection Authority remit each have data on the age of their flood/coastal defence assets and indicative timetables (e.g. 10-50 years) for future repair or replacement.

4.2.4 Shoreline Management Plans (SMPs) set out a strategic, planned approach to managing flood and coastal erosion risk around the coast of England and Wales through to 2105. They are non-statutory but influential on spatial and infrastructure planning, enabling informed decisions to make communities and infrastructure more resilient to current flood and erosion risk and future climate change.

4.2.5 The SMPs assign each stretch of coastline the most sustainable management policy over three epochs – short term 2005-2025, the medium-term 2026-2055 and long-term 2056-2105. There are four policy options: Hold the Line, Advance the Line, Managed Realignment, No Active Intervention. The SMPs and their policies were updated from the mid 2000s to mid 2010s, and planning is underway on how they should be further updated to account for the latest climate change projections, socio-economic and environmental drivers – all of which are likely to identify increased need for flood and coastal protection measures.

4.2.6 An analysis of the latest SMP policies and current flood / coastal defences' age and condition would identify the locations and scale of opportunity that a tidal barrier or lagoon could enable for flood and coastal erosion economic benefits.

4.2.7 Typically for flood and coastal erosion risk management projects, the avoided economic losses from flooding are considered in the context of existing infrastructure for calculating the amount of central government Grant In Aid funding that will be allocated. That funding can be supplemented from local or regional public and private sources as Partnership Funding, which can take account of the future socio-economic potential for land. Thus a barrage or lagoon could offer such flood and erosion risk improvements as to act as a catalyst, unlocking development opportunities across the Severn that are currently hindered by flood and erosion risk. A possible proxy for the areas that may benefit from 'unlocking development' are those currently defined as Coastal Change Management Areas (CCMA's), which are areas that could be impacted by increased flooding and erosion in the future. These areas have increased planning measures that in some cases require directing local development away from a CCMA to safer areas. The development of a barrage or lagoon that reduces overall flood and erosion risk may remove the requirement for a CCMA and enable more development in these zones. An example of the CCMA's in North Somerset is provided in Figure 4.1, which can be seen to cover the majority of the North Somerset Coastline.

4.2.8 CCMA's are not available for the full extent of the Severn Estuary and so where not available an assessment of 'unlocking development' opportunities could be made from a high multicriteria analysis of flood and risk erosion mapping, town plans and available planning information.

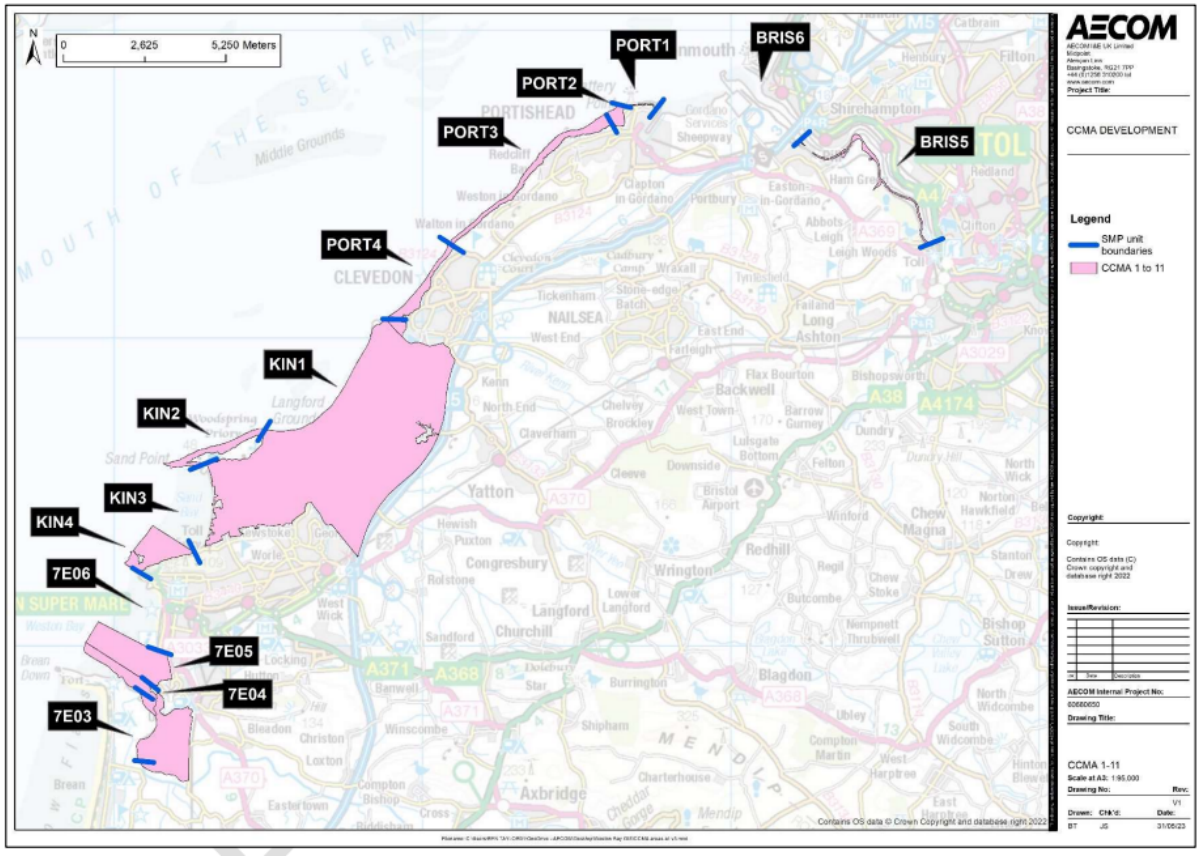


Figure 4.1. The proposed CCMA's in North Somerset (North Somerset Council)

4.2.9 A challenge in claiming of these 'unlocking development' benefits, is that if no barrage or lagoon was constructed then these benefits would potentially be transferred elsewhere, e.g. into other coastal towns on the Estuary, which are at lower flood and erosion risk, and leaving the national/regional picture neutral in terms of benefits. The likelihood of the benefits transferring to other areas will depend largely on the uniqueness of the area effected, the ability of businesses to relocate, and the availability of less flood prone sites. A greater understanding of the risk factors and the local business sentiment along the estuary is required understand these potential socio-economic benefits.

4.2.10 Another benefit that is easier to apply is preventing a reduction in property values due to flooding as this is relative to the individual property. This could be undertaken through a land value uplift calculation comparing the prices of locally non-flooded properties to those which are flooded and unlocking potential benefits. This is likely to significantly increase the benefits compared to flood damages alone.

4.3 Tidal Scheme Configuration — effects upon flood and coastal risk

4.3.1 Flood and coastal protection is effected by the mode of operation and the type and design of the structure. For example, poorly designed elements may create a reflective wave that increases downstream flood risk. The mode of operation changes the natural water levels impounded by the structure, reducing the upper elevation and increasing the lower tidal level.

4.3.2 There are two different types of operating mode:

Mode	Description	Effect on Water Levels
Ebb only	The flood tide fills the basin through sluice gates. Generation begins 1 to 2 hours after the tide ebbs.	The high water mark is close to the natural tide level and there is a period after the tide turns where water levels are static. When generation begins, the rate of reduction in water level is lower than the natural tide and the low water mark rises to the mid point of the tidal prism.
Ebb and Flood	Generation occurs both on the flood and ebb tides.	The high water mark is reduced whilst the low water mark is increased by around the same amount (around 1 to 2m). A period of static water occurs each time the tide turns.
Ebb and Flood - with sluicing	As ebb and flood mode but sluicing is used to reduce water levels in the basin towards the end of the generation cycle.	Similar to the Ebb and Flood mode but the low water mark is closer to the natural tide low water mark.
Ebb and Flood - with pumping	As ebb and flood mode but pumping is used as the tide turns to increase or reduce the water levels in the basin to increase energy production. Sluicing can also be used to reduce water levels in the basin towards the end of the generation cycle.	Similar to ebb and flood but the water levels return to close to (but not equal to) the natural tide level.

4.3.3 In terms of flood risk, the presence of a structure with a crest level designed above the highest predicted tide level and storm surge protects upstream communities and assets from future increased sea levels and storms irrespective of operating mode.

4.3.4 Barrages, if operated to generate only on the ebb, will need to control the upper water level during a storm surge event so that the surge does not enter the impounded area. This is achieved through the sluice gates necessary for ebb only operation. Ebb only operation also causes the impounded low tide level to increase which could block some tide locked drainage outfalls. The affected outfalls would have to be modified to discharge at a higher level and/or for a shorter duration. Impedance of discharges from rivers may only potentially occur during peak flow flood conditions. This could potentially be mitigated through management of impounded water levels before peak flow flood onset is due. These mitigation costs were included within the SETP project estimates.

4.3.5 Lagoons operate using ebb and flood mode and therefore provide substantial protection to the land protected by the impounding structure with reduced likelihood or scale of any disbenefits. Lagoons generally include pumping to reduce the extent of tidal prism loss. As a consequence, for the majority of tide locked drainage outfalls and rivers are likely to continue to discharge without modification. In some locations, such as the Cardiff lagoon, there may be some impedance to tide locked drainage outfalls for some tidal states and these can be mitigated by improving the design of the outfall. These mitigation costs are included in project cost estimates and are significantly less than the positive benefits.

4.3.6 The Severn Estuary is a constantly changing geomorphological entity with continuously changing patterns of erosion and deposition. Any structure placed in the estuary will have an effect on the erosion and deposition patterns.. Erosion and deposition effects from barrages operating in ebb only mode are likely to be greater than for lagoons given the longer period of high water standing time within the impoundment. The cost of mitigation is likely to be significantly less than the flood protection benefits provided by the structure but requires further analysis using up to date values.

5 Cardiff-Weston Barrage – Potential Benefits

5.1 Protection from an Impounding Structure

5.1.1 The construction of a tidal barrage will impede the natural movement of the tide in the estuary and lead to reduced peak high tide levels in the areas impounded by the barrage. The reduced high tide levels will reduce the impact of storm surges, peak high tides, and some of the effects of sea level rise in the upper Severn Estuary, providing widespread flood risk benefits. This includes towns and cities along the Severn such as Weston-super-Mare, Cardiff, Newport and Severnside as well as agricultural land, transport and power infrastructure located along the coast.

5.1.2 The extent of the water level reduction in the impounded area depends on whether power generation is ebb only or flood and ebb generation. Existing research has predominantly focused on ebb only generation, which will yield lower water level reductions than could be offered by flood and ebb generation, as is shown in Figure 5.1.

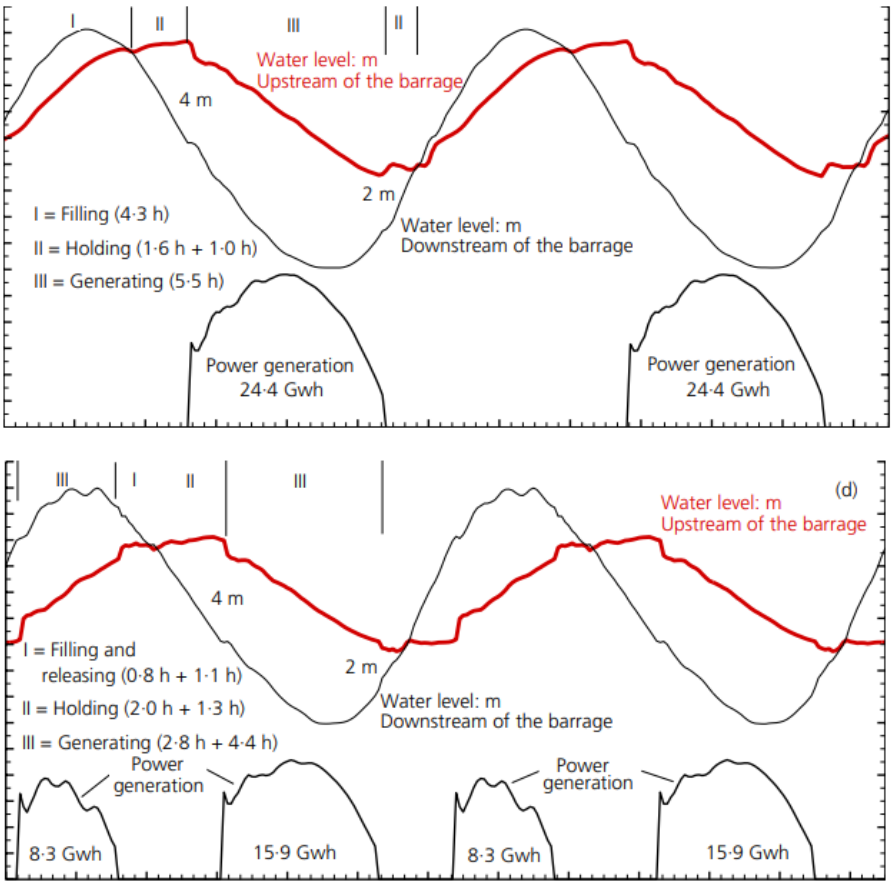


Figure 5.1. The water profiles in the impounded area over a tidal cycle with ebb only generation (top) and flood and ebb generation (bottom). Sourced from Tidal energy from the Severn estuary, UK and originally developed by Professor Roger Falconer, Cardiff University.

5.1.3 The SETP report highlighted that the Cardiff Weston Barrage could create a flood risk benefit for approximately 79,000 residential and 10,000 non-residential properties and 42 essential infrastructure assets.

5.1.4 The economic benefits of the protection of these areas would have a present value of £194m, which would increase to benefits of £330m if lengths of coastal flood defences which may have had to be realigned in subsequent years are included.

5.1.5 The reduction in tide levels over a typical spring tide was modelled by Reza Ahmadian et al using the 1980's Severn Barrage design in Sea level rise in the Severn Estuary and Bristol Channel and impacts of a Severn Barrage (2013). This showed a reduction of water levels in the impounded section as shown in Figure 5.2. In the shorter-term the barrage increases the standard of protection of existing flood defence assets as well as potentially increasing their useful life, benefiting existing homes and businesses protected. It should be noted, as shown in Figure 5.1, the water level at the barrage itself is close to the natural tide for ebb only operation and reduces upstream as shown in Figure 5.2. Ebb only operation is more favourable to the ports close to the barrage as clearance over existing lock cills is much less than if ebb and flood mode operation is used.

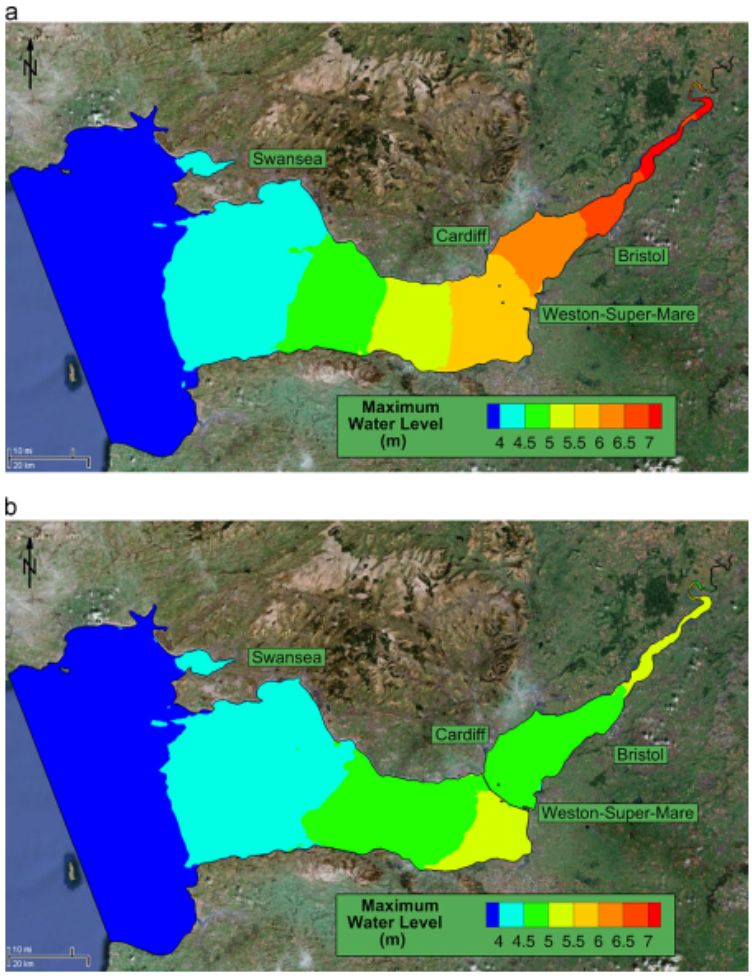
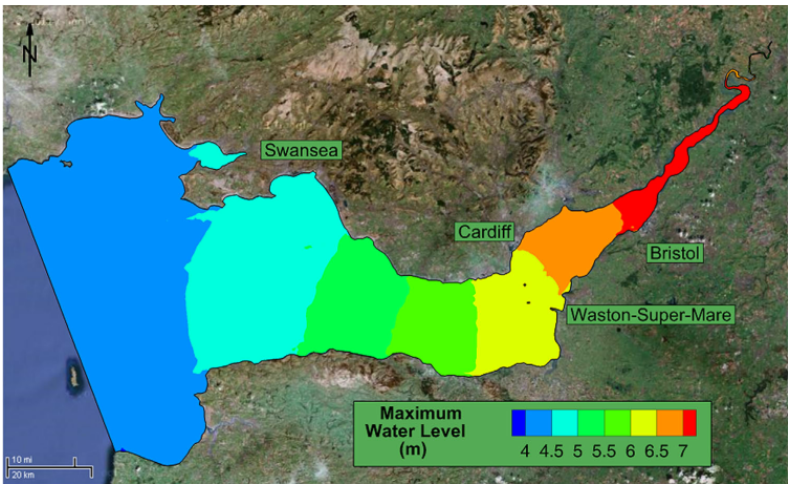


Figure 5.2. Tidal modelling for the Severn Estuary without (a) and with a tidal barrier (b) using 2010 sea levels over a Mean Spring Tide cycle (Reza Ahmadian et al., 2013).

5.1.6 . The 2013 study also addressed the potential peak high tide level reductions under a climate change scenario, including an additional 0.481m of sea level rise, which is shown in Figure 5.3, showing that

the construction of the barrage would mitigate the impacts of sea level rise up to that level. As climate change allowances have since changed with a range of 0.27 to 1.13m being predicted at Cardiff in 2100 in UKCP18, some reanalysis is required. However, this confirms that the presence of a structure with a crest level some metres above the highest tide level protects upstream communities and assets from future sea level rise and increased scale of storm surges irrespective of operating mode.

a



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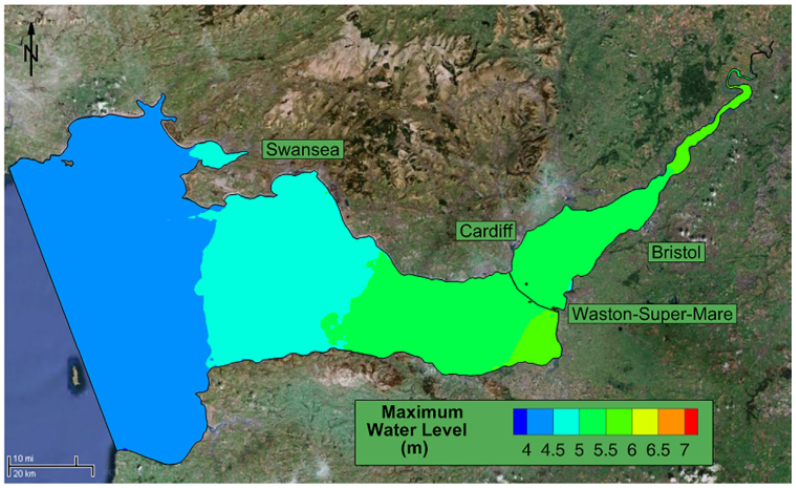

Figure 5.3. Tidal modelling for the Severn Estuary without (a) and with a tidal barrier (b) using 2100 sea levels over a Mean Spring Tide cycle (Reza Ahmadian et al., 2013).

5.1.7 A limitation of existing research is that the impact of a barrage on storm surges has not been assessed. Storm surges are the widest cause of flood risk in the Severn Estuary and will cause peak flood levels that are greater than those shown in Figure 5.2 and 5.3. For example the 1 in 1-year extreme flood levels for the Severn Estuary, as of 2017, are shown in Figure 5.4. These show levels approximately 0.5m greater than the barrage tidal scenarios modelled to date. In principle however, the barrage has the potential to significantly nullify storm surges from propagating upstream, which will require further modelling studies to assess.

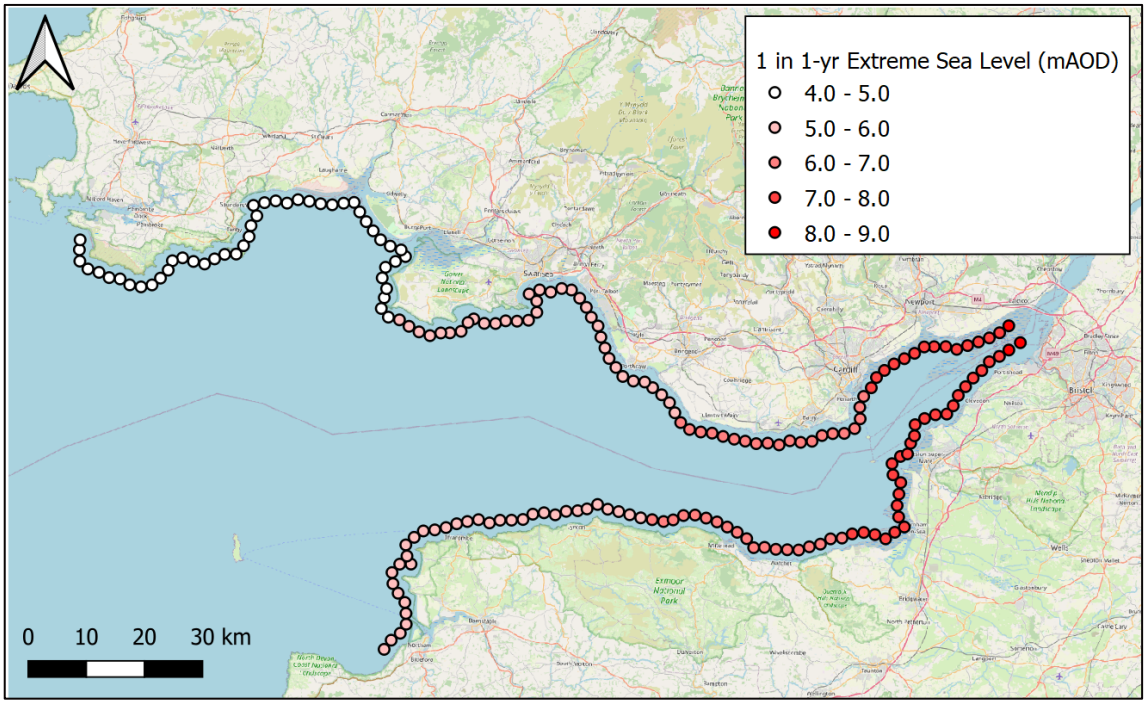

Figure 5.4. Extreme Coastal Levels for a 1 in 1-yr event in the Severn Estuary (Environment Agency, 2018)

5.1.8 Ebb and flood operation may reduce the level and duration of tidal locking in some instances which may benefit areas suffering from combined fluvial and tidal flood events. As well as the River Severn itself this may benefit other rivers which feed into the wider estuary including the Rivers Axe, Old Bridge, Avon, Wye, Usk, Rhymney, and Taff and Ely (via Cardiff Bay).

5.2 Reduction of wave action in the impounded area

5.2.1 The installation of a tidal barrage would eliminate the propagation of ocean swell waves as well as significantly reducing the available fetch (an unobstructed area of sea where wind can generate waves) for locally generated wind waves in the impounded area. Wave action combined with high tides can result in wave overtopping of flood defences or undefended land, causing flooding. A key area that experiences this mode of flooding and may provide economic benefits from protection is Weston-super-Mare. However, the potential for claiming flood or erosion economic benefits will be limited given the development of the 2008 Weston-super-Mare coastal protection scheme which protected the area to a 1 in 200yr standard of protection for a period of 100-years (2108).

5.2.2 The reduction of wave action combined with a reduction in high tide levels will also reduce rates of coastal erosion. Previously this may have been of economic benefit to the coastal frontage to the east of Cardiff, that includes Cardiff's main sewerage works. However, a recent coastal protection scheme that is currently being constructed will soon protect the area and minimising any economic benefit. Similarly, at Weston-super-Mare, which is also at risk of coastal erosion from wave action, there are also limited to no economic benefits due to the existing protection present.

6 Cardiff-Weston Barrage – Potential Disbenefits

6.1 Increased tidal water levels upstream of barrage blocking the outfall of water from rivers and manmade drainage networks.

6.1.1 The impact of this was assessed in the SETP which established that the reduced drainage performance could affect 372 km^2 of land containing 45,436 residential properties, 5,037 non-residential properties and 28 critical infrastructure assets.

6.1.2 To negate these impacts, it was suggested to either provide additional storage or pumping capacity. These would create negative-benefits (costs) of £273m over a 120-year period. Since 2010 climate change allowances for rivers have increased, meaning that river flooding and tidal locking will become a more and more common occurrence, which may mean that the SETP underestimated the costs associated to offset this issue. Additionally, inflation in construction in general has increased significantly since 2010 and so the present-day cost of these mitigation measures will rise further. However, the costs of this mitigation were included in the 2010 project cost estimates so affects the tidal power business case rather than the flood protection economics.

6.1.3 It should be noted that the above analysis was for ebb only generation which is expected to provide worse outcomes in terms of tidal locking compared to flood/ebb generation.

6.2 Increase in tide levels in areas seaward of the barrage

6.2.1 The potential increase in peak tidal water levels in the non-impounded area was assessed by Zhou et al. (2011) using a continental shelf model. This shows a 0.1m to 0.2m increase in levels in the Severn Estuary and a 0.05m to 0.1m increase in the Irish Sea. The impact of the increased sea levels is an increased likelihood and severity of coastal flooding, which may require mitigation.

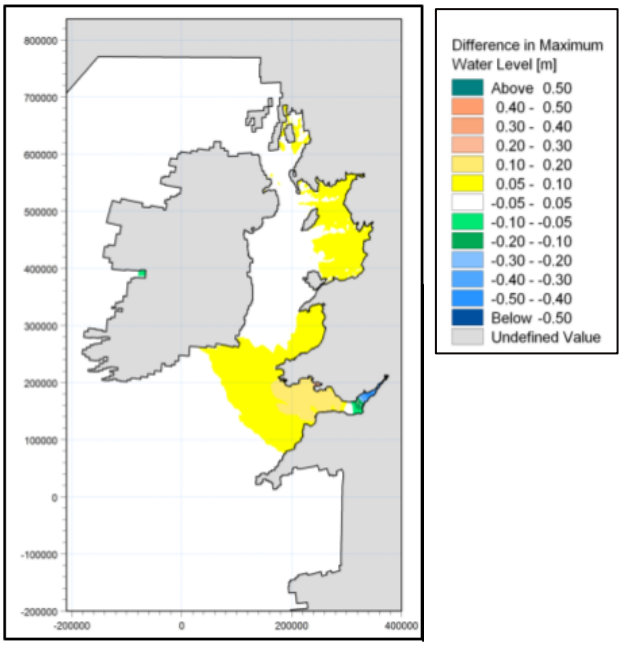

Figure 6.1. Increases in water levels in non-impounded areas with a continental shelf model (Zhou et al. 2011)

6.2.2 The impact of increased non-impounded tide levels was assessed in the SETP by estimating the costs associated for raising defences upstream. They utilised a more conservative 0.3m water level increase, which represents an upper limit without accounting for climate change. They identified 58km of defences that would need to be raised totalling costs of £44M.

6.3 Increased wave action from reflection off lagoons or barrage.

6.3.1 A poorly designed barrage has the potential to block and reflect wave action that would currently propagate up the estuary. This may lead to increased wave action in the non-impounded areas and has been modelled by Fairley et al. (2014), the results of which are shown in Figure 6.2. The modelling shows increased wave action to the south of the barrage in Bridgwater Bay, this is an area seaward of the barrier that is susceptible to both coastal erosion and flooding caused by wave overtopping. Further assessment should be undertaken to assess the negative impacts on Bridgwater Bay from a flood risk and coastal erosion perspective.

6.3.2 As with the increased tidal flooding risk, some of the negative impacts could be offset through local raising of defences. There may also be opportunities to negate these potential impacts through the design of a more dissipative barrage such as a rock revetment or permeable caissons that reduce the degree of wave energy reflected.

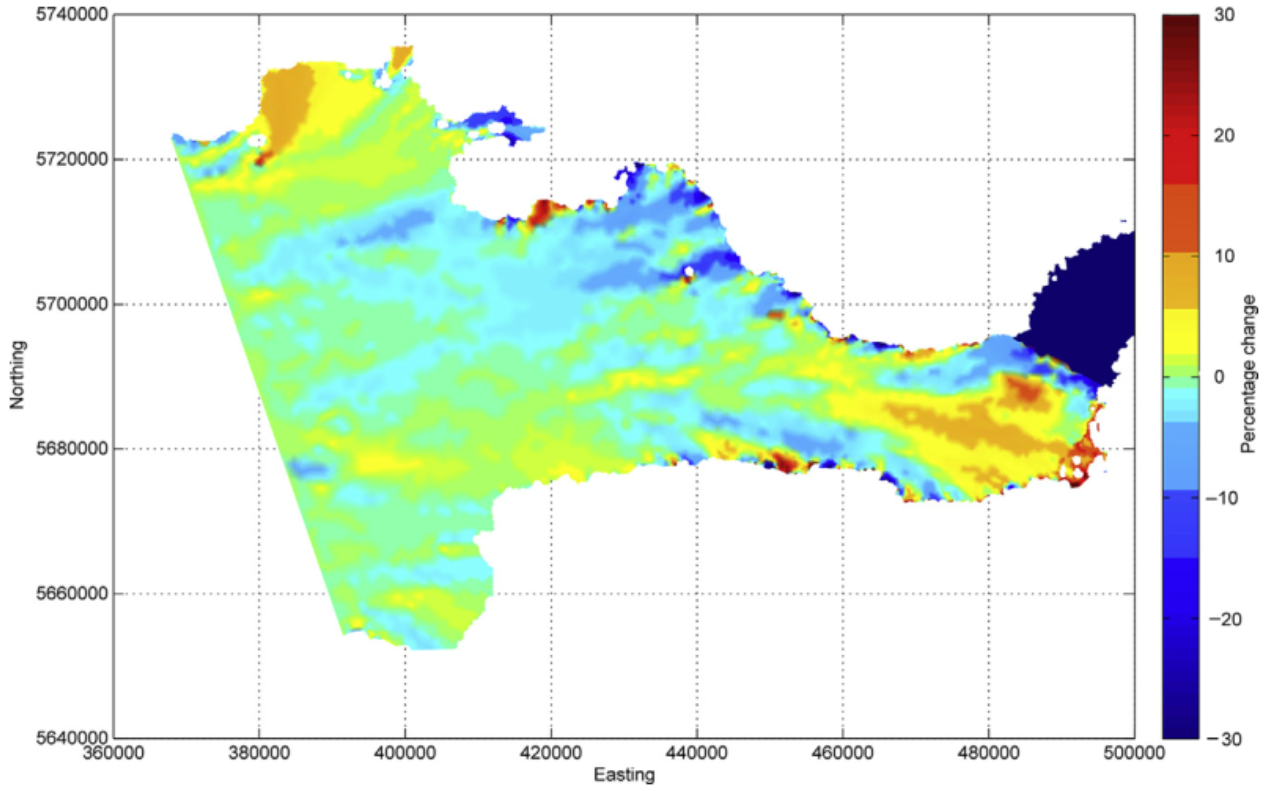

Figure 6.2. Percentage change in wave height in the Severn Estuary with a barrier in place (Fairley et al. 2014).

6.4 Increased erosion or accretion

6.4.1 As highlighted in 6.3.1 the increased reflected wave action in Bridgwater Bay may result in increased erosion risk.

6.4.2 The SETP undertook an assessment of the additional erosion protection that would be required to offset negative impacts from the barrage. This included an estimate of 67km to 201km of additional revetments with a cost of £56M to £355M. The SEPT did not assess the future cost of protection within the barrage and therefore do not produce a delta of the envisaged costs.

6.4.3 The SETP also identified that modelling of long-term siltation within the impounded area does not result in an increase in flood risk.

7 Shoots Barrage – Potential Benefits

7.1 Protection of Impounded Area

7.1.1 There is limited existing research on the flood risk benefits associated with Shoots Barrage, with the only study covering the option is the SETP.

7.1.2 SETP identified that Shoots Barrage offers limited change in peak tide levels in the impounded area and so no flood risk benefits have been calculated for this option. The SETP provides no commentary on the cause of the low impact, it may also be the case that a flood-ebb generation would offer greater flood risk benefits. Additionally, certain barrage operation models, e.g. closing the sluices of the barrage during a potential flood event, as per a tidal defence barrage could yield more benefit to areas upstream and benefit flooded areas (primarily agricultural land) west of Gloucester.

7.2 Wave action in the impounded area

7.2.1 There is likely to be limited benefit to Shoots barrage in terms of wave action as the site is located in a narrower section of the estuary and is largely sheltered from waves. There are also limited flood risk receptors in this area that are impacted by wave action and inundation, with this area of the channel being predominantly impacted by tidal flooding.

8 Shoots Barrage – Potential Disbenefits

8.1 Outfall of water from rivers and manmade drainage networks

8.1.1 The SETP report noted increased flood risk during fluvial flood events as a key issue. The report stated that the option may result in reduced drainage performance that could impact an area of 97 km^2, containing 2,300 residential properties, 92 non-residential properties and 3 critical infrastructure assets.

8.1.2 It should be noted that the above analysis was for ebb only generation - flood/ebb generation is expected to significantly reduce the risk of tidal locking compared to flood/ebb generation. Impedance of natural drainage networks could be mitigated through outfall redesign and pumping, whilst impedance of peak flood discharges from large rivers could be mitigated through management of impounded water levels. Costs for these mitigation measures are already incorporated into the scheme building costs and so have not been included in this assessment of flood dis-benefits.

8.2 Tide levels in areas seaward of barrage

8.2.1 The impact on the non-impounded areas of the Severn is likely to be less than the Cardiff-Weston Barrage given the reduced volume of the estuary where tidal flow is restricted. However, the SETP report has considered 0.3m increase in peak tide levels, as was the case with the Cardiff Weston Barrage.

8.2.2 The report identifies a length of 62km would need to be raised at a cost of £47M to offset the additional risk.

8.3 Wave action from reflection

8.3.1 There is no research available outlining the impact of reflected waves for the Shoots Barrage option. These negative effects are likely to be less onerous than those created by the Cardiff Weston Barrage given its less exposed and shallower location.

8.4 Erosion or accretion

8.4.1 The SETP report highlights the potential for both erosion and accretion to occur due to Shoots Barrage. It provides a figure for potential erosion of 3m over the next century at Woodhill Bat and Severn Beach.

8.4.2 The report also highlights that accretion is a concern upstream of the barrage with up to 7m predicted over the next 120-years.

8.4.3 The costs to offset these negative impacts are estimated in the SETP report at £26M to £149M, to protect a 36km to 109km long extent. No assessment was made to the costs of maintaining the bank within the barrage and therefore no additional cost due to the barrage could be calculated.

9 Swansea Bay Lagoon - Benefits

9.1 Protection of Impounded Area

9.1.1 The Swansea Bay Lagoon will provide limited economic flood risk benefits as a result of reduced peak tidal water levels. The lagoon may offer some protection to Swansea Dock and Swansea Bay University Campus however the flood risk in this area is widespread, with additional flood pathways to the east which will not be prevented by the lagoon.

9.1.2 The area behind the University at Crymlyn Burrows is relatively low lying and further analysis may be helpful to assess the magnitude of benefit that could result from a reduction in tidal locking of the drainage network during high tide events.

9.2 Wave action in the impounded area

9.2.1 The Swansea Bay Lagoon will provide limited protection to Swansea Dock and Swansea Bay University Campus from wave action, reducing flooding and erosion and will prevent erosion occurring under the foundations of coastal structures. Currently the frontage of the University is protected by a revetment however no information is known of its design life or the level of protection it provides. If the revetment does provide a moderate level of protection both now and in the future, then the potential economic benefits of the lagoon are limited.

10 Swansea Bay Lagoon – Disbenefits

10.1 Outfall of water from rivers and manmade drainage networks

10.1.1 The proposed Lagoon has been designed to prevent negative impacts on both the River Tawe and River Neath which are situated at the western and eastern extent of the lagoon. As there are no rivers located within the impounded area there will be no impact on tidal locking or fluvial flooding.

10.2 Tide levels in areas seaward of lagoon

10.2.1 The impact of Swansea Lagoon on tide levels in Swansea Bay was assessed by Horrillo-Caraballo et al. (2018), who determined there would be no changes to water levels in the bay over a spring tide and neap tide scenario.

10.3 Wave action from reflection off lagoons or barrage.

10.3.1 The barrage has the potential to reflect wave action which may lead to local increases in wave climate. No modelling has been undertaken to assess these impacts and so further research is required.

10.4 Erosion or accretion

10.4.1 The effects of the Swansea Lagoon on the morphology in Swansea Bay has been modelled by Horrillo-Caraballo et al. (2018). The modelling showed key changes to flow patterns in the bay however did not provide detail of specific effects on erosion or accretion.

11 Stepping Stones Lagoon - Benefits

11.1 Protection of Impounded Area

11.1.1 There are limited flood risk benefits associated with this option as the impounded area includes no properties at risk of flooding. There may be benefits to the local intertidal habitat which could be threatened by sea level rise, such as a small amount (0.26km^2) of saltmarsh at Watch House Beach.

11.1.2 This section of coastline impounded contains several cliff formations which would benefit from lower erosion rates that would occur with lower peak tide levels and some scheduled monuments which would be protected from sea level rise. This may benefit the Fontygary and Porthkerry Caravan Parks, Rhoose Point and areas of west Barry where around 20m of coastal erosion is projected (NCERM, 2018). If the lagoon was to reduce rates of erosion there would be economic benefits from the protecting these locations, however, would require detailed erosion modelling to determine the change in erosion rate. Currently mapping shows around 80 caravan plots at Fontygary which are at risk of erosion, and a further 11 at Porthkerry.

11.2 Wave action in the impounded area

11.2.1 The lagoon would reduce wave action across the coastal frontage between The Knap and Watch House Beach, the reduction of wave action would also assist in reducing cliff erosion rates and contribute to the benefits outlined in 11.1.2. It should be noted however that these benefits are expected to be minimal.

12 Stepping Stones Lagoon – Disbenefits

12.1 Outfall of water from rivers and manmade drainage networks

12.1.1 There are no significant watercourses or drainage networks located in the impounded area. The coastline in this location is predominantly cliffs which are situated well above the tidal range.

12.2 Tide levels in areas seaward of the lagoon

12.2.1 As per 12.1.1. no impacts are expected.

12.3 Wave action from reflection off lagoons or barrage.

12.3.1 The proposed lagoon may reflect and focus wave energy, the effects of this are most likely to occur to the west of the lagoon where it is most exposed to wave action. The waves would be reflected to an area that consists of Breaksea Point where the former Aberthaw Coal Plant is located. Additional wave action in this area could increase erosion rates over the site Coal Plant site, however there is unlikely to be any tangible economic impact from this.

12.4 Erosion or accretion

12.4.1 There is no data available that covers erosion or accretion risk that occurs as a result of Stepping Stones Lagoon.

13 Cardiff Lagoon – Benefits

13.1 Protection of Impounded Area

13.1.1 The Cardiff Lagoon could offer significant benefits in the impounded area. Current areas of flooding in the impounded area between Cardiff and Newport include Pengam Green, St Mellons, Marshfield, and Duffryn. This also includes areas with key infrastructure such as the South Wales Main Line railway and Lamby Way Solar Farm. As the option may protect several urban areas there may be moderate socio-economic flood risk benefits from this option.

13.1.2 At Rover Way and Lamby Way there is 20m to 40m of erosion predicted (NCERM, 2018). As identified in Section 5.1, there is currently a coastal defence being developed for this stretch of coastline to protect against erosion risk. The reduction of peak tide levels will also likely reduce erosion rates and help to protect these areas.

13.2 Wave action in the impounded area

13.2.1 The construction of a lagoon will reduce the degree of wave action in the impounded area which may assist with the reduced flood risk in behind the lagoon. It may also reduce erosion rates as outlined in 13.1.2.

14 Cardiff Lagoon – Disbenefits

14.1 Outfall of water from rivers and manmade drainage networks

14.1.1 The lagoon may impact tidal locking on Rhymney River, which is the only main watercourse that feeds into the impounded area. No assessment has been made over the potential costs of drainage or storage capacity required to offset this risk.

14.1.2 There is a high likelihood that the lagoon would negatively impact drainage in the area. The area immediately behind the lagoon is heavily reliant on a network of drains, and the increase of the low tide level may impact the functionality of these drains and lead to surface water flooding. Similar to Cardiff Weston and Shoots barrage options this may require pumping or additional storage capacity to offset.

14.2 Tide levels in areas seaward of the lagoon

14.2.1 There is no direct assessment of increased tidal risk in the non-impounded areas of the Severn Estuary as a result of the lagoon. The SETP does however estimate a 0.3m increase in peak tide levels in the Bristol Channel for the nearby Welsh Grounds Lagoon, which is of a similar size and scale to the proposed Cardiff Lagoon. If the impact of Cardiff Lagoon was comparable to Welsh Grounds Lagoon then raising would be required for around 25km of defences, at a cost of £19M.

14.3 Wave action from reflection off lagoons or barrage.

14.3.1 There is no wave study available for Cardiff Lagoon, the lagoon may lead to waves being reflected eastwards towards Cardiff and Penarth. Both are areas that are not at risk of flooding and erosion from increased wave action.

14.4 Erosion or accretion

14.4.1 There is no assessment of erosion or accretion risks associated with this option.

15 West Somerset Lagoon - Benefits

15.1 Protection of Impounded Area

15.1.1 The West Somerset Lagoon could offer moderate flood risk benefits across the area currently at risk of flooding in Minehead, Blue Anchor and Watchet. This includes the Minehead Butlins Resort and Minehead Railway Station.

15.1.2 This section of coastline is at risk from erosion with NCERM outlines providing estimates of up to 40m of erosion. This includes the caravan parks at Blue Anchor, the West Somerset Railway and the B3191. The West Somerset Lagoon would likely reduce erosion rates in all these areas as a result of reduced peak tide levels in the impounded area.

15.2 Wave action in the impounded area

15.2.1 A reduction of wave action may help to reduce the rate of coastal erosion which impacts the areas noted in 15.1.2.

16 West Somerset Lagoon – Disbenefits

16.1 Outfall of water from rivers and manmade drainage networks

16.1.1 There are several watercourses which may be impacted by tidal locking, any increase of flood risk during low tide tidal locking is likely to be offset by reduced tidal locking at high tide.

16.1.2 The increase of impounded water levels may reduce the drainage networks effectiveness leading to surface water flooding. To address this pumping capacity or additional storage may be required to mitigate the additional risk.

16.2 Tide levels in areas seaward of the lagoon

16.2.1 As with some other locations there is an increased risk in the non-impounded areas of the estuary. The extent of these impacts has not been assessed for West Somerset Lagoon.

16.3 Wave action from reflection

16.3.1 Wave action is likely to be reflected from the western wall of the lagoon and directed eastward. There are no areas east of the lagoon that are at significant risk from flooding or coastal erosion from increased wave action.

16.4 Erosion or accretion

16.4.1 No information is available regarding erosion or accretion for West Somerset Lagoon.

17 Location Summary

17.1 Cardiff-Weston Barrage

17.1.1 Cardiff-Weston barrage is the most researched option of the six locations considered, however all previous research focuses on ebb-only operation which will likely provide lower net flood and erosion risk benefits compared with the currently favoured flood-ebb generation. Nevertheless Cardiff-Weston Barrage would provide the greatest potential for flood and erosion risk benefit of the options considered. The option may improve protection in key towns and cities such as Western-super-Mare, Cardiff, Newport and Severnside. The socio-economic benefits were quantified in the SETP report, which yielded £194M to £330M of benefits. It should however be noted that since 2010 some of these areas have gained flood defences, which will reduce the potential benefits as properties that are already protected will not yield flood risk benefits.

17.1.2 The Cardiff-Weston Barrage also produces tidal locking and raises tide levels in the wider Severn and Irish Sea. The cost to mitigate the tidal locking effect was calculated as £273M in the SETP. These mitigation costs were included in the overall project costs to ensure the project had no negative impact. Whilst flood-ebb was not considered in the final stages of the SETP it was recognised during the study that a flood-ebb system would likely lead to the closure of the main ports on the estuary. The cost of increased tide levels in the non-impounded Severn were calculated in the SETP as £44M, this does not account for the more recent modelling which shows impacts in the Irish Sea, which would significantly

increase this figure. The combined disbenefits from tidal locking and increased tide level determined by the SETP total £317M, this would, based on the SETP analysis, wipeout most if not all the positive flood risk benefits for the option. At the time not all the financial benefits were considered as part of the study and therefore further analysis would be required to confirm the cost impact.

17.2 Shoots Barrage

Whilst the SETP report did not identify any flood or erosion risk benefit, the structure does provide protection from future sea level rise. The cost of approximately £210M to mitigate against increased tidal locking and increased tide levels in the Severn were included in the overall project costs to ensure the project had no negative impacts. Additionally, certain barrage operation models, such as closing the sluices of the barrage during a flood event, could yield some limited benefits to areas upstream

17.3 Swansea Bay Lagoon

17.3.1 The Swansea Bay Lagoon provides limited economic benefits from flood and erosion risk mitigation, as it covers only a short section of coastal frontage, encompassing the Swansea Bay University Campus and Swansea Dock. Both of these facilities would still be at risk of flooding from the surrounding low-lying area. Where the option may provide more benefits is the prevention of tidal locking of the local drainage network at Crymlyn Burrows, however, this is likely to be a limited in the context of the overall scheme as again these properties are likely to still be subject to coastal flooding from the east of the lagoon.

17.4 Stepping Stones Lagoon

17.4.1 The stepping stones lagoon covers a shoreline that predominantly consists of cliffs with limited flood risk present. The key potential socio-economic benefits for this option is from a potential reduction in cliff erosion rates, which would benefit several Holiday Parks and other shoreline features, for example. Additionally, the lagoon would also only reduce the rate of erosion and not permanently protect these areas further reducing the potential benefits.

17.5 West Somerset Lagoon

17.5.1 The Western Somerset Lagoon could offer moderate flood and erosion risk benefits protecting Minehead, Blue Anchor, Watchet, Butlins Resort and the West Somerset Railway. No study has been undertaken into the socio-economic benefits that this option could provide however Minehead, which is the most populated area at risk, is currently in part protected by a coastal defence scheme that was undertaken in the 1990s which may reduce potential benefits. As with other locations there may be some tidal locking of river and drainage networks that also needs to be considered, which may offset further negate some of the benefit.

17.6 Cardiff Lagoon

17.6.1 The Cardiff Lagoon may offer moderate economic flood risk benefits to the area as it impounds an area of coastline with key urban areas and infrastructure (the South Wales Mainline), however no assessment has been made to date. The project includes the potential for locking of the drainage network and River Rhymey. The costs to mitigate this tidal locking were included in the overall project costs however further study is be required to fully gauge the scale of this requirement.

18 Summary Table

18.1.1 Table 18-1 provides a summary of the high level indicative assessment for flood and erosion risk benefits and disbenefits associated with each option's scale of influence upon communities and infrastructure. A score of 5 indicates a relatively large benefit in terms flood risk or coastal erosion, 4 indicates a relatively small benefit, 3 is neutral, 2 is a relatively small dis-benefit, and 1 a relatively large disbenefit. Scores for dis-benefits are based on residual scale of impact after likely mitigation measures have been implemented in lagoon/barrage design and operation or wider mitigation. 'Unknown' indicates a lack of sufficient available data to make an assessment.

18.1.2 Overall benefits, assuming all adverse impacts are mitigated and costed in the projects themselves, are positive, primarily because of the increased protection against future storm surge frequency and sea level rise.

Table 18-1. Summary table of benefits and disbenefits for each option.

		Cardiff-Weston Barrage	Shoots Barrage	Swansea Bay Lagoon	Stepping Stones Lagoon	Cardiff Lagoon	West Somerset Lagoon
Benefits	Protection from future sea level rise	5	4	3	4	5	5
	Reduced wave action from swell in the impounded area	4	3	3	4	3	4
Disbenefits	Increased water levels in the Severn Estuary in the non-impounded area	2	2	3	3	3	*Unknown*
	Changes to coastal processes	2	2	*Unknown*	3	*Unknown*	3
	Increased wave heights and exposure in non-impounded areas	2	*Unknown*	3	*Unknown*	*Unknown*	*Unknown*

19 Overall Conclusions

19.1. This Annex evaluated the potential flood, and coastal erosion impacts for the six example tidal lagoon and barrage locations in the Severn Estuary using existing available data and research. Of the six locations considered the most researched in terms of flood and coastal risk is Cardiff Weston Barrage, followed by Shoots Barrage and Swansea Bay Lagoon. Stepping Stones Lagoon, Cardiff Lagoon, and West Somerset Lagoon have limited research available. The 2010 Severn Estuary Topic Paper (SETP) Flood Risk and Drainage is the only source of costed flood and erosion impacts.

19.2. In principle there is nothing to prevent a privately owned or maintained barrage or lagoon operating as a flood defence asset. If the structure was to deliver that flood risk management role in an active manner, i.e. pumping water in or out, it is highly likely that the statutory flood and coastal risk management authorities would require adherence to comprehensive, formalised operating procedures.

19.3. If the barrage or lagoons design met or exceeded flood and coastal design standards of protection it may unlock the potential for enabling landward development in the areas protected.

19.4. Economic benefits resulting from a flood and coastal risk management scheme can normally only be claimed once, so a barrage or lagoon is unlikely to be able to take account of properties already benefitting from an extant flood or coastal defence scheme, of which several have been or are being built in the estuary. However, such benefits could potentially be claimed where a barrage/lagoon would remove the need for an existing defence to be improved or replaced in the future.

19.5. There is potential to a wider range of social, economic and environmental benefits using the modern benefits management approach the UK Government expects major projects to use. This could offer an opportunity to identify more quantifiable and intangible benefits to help strengthen a tidal scheme's business case and demonstrate its wider value for money to society. Such a study is outside the scope of the current research commission within the socio-economics workstream.

19.6. The benefits associated with the lagoon or barrage differ between the impounded area and the non-impounded wider estuary, the positive impacts are all associated with the impounded area. Positive flood and erosion benefits include reduced peak tide levels, reducing flooding through lower high tides, reduced storm surges, as well as mitigating the impacts of sea level rise. These will also reduce rates of coastal erosion and the loss of habitat from coastal squeeze.

19.7. The Cardiff-Weston barrage could potentially raise sea levels along the coast of Somerset, Devon, Wales, eastern Ireland and southwest Scotland; this might trigger the need for new or enhanced existing coastal defences to maintain the present-day risk levels. The financial costs of this were assessed by SETP however this assessment did not assess the full extent of the impact and is now outdated against current construction pricing and climate change information. Further assessment would be required.

19.8. Another key negative impact is the increase of inland flood risk from tidal locking within the impounded area, which prevents rivers and the drainage network from flowing into the sea. The SETP identified that the Cardiff Weston Barrage could negatively impact 372 km^2 of land containing 50,473 properties. This however was based on ebb only generation and the assessment also predate several key studies which may alter this conclusion, further research on this topic is required.

19.9. Overall benefits are varied across all options. A review using an ebb/flood model plus up to date socio-economic flood benefit calculations would be expected to improve the understand of this situation.

19.10. The experience of interviewees from previous barrage or lagoon proposals highlighted the risks of leaving an evidence and messaging vacuum that a scheme's opponents could fill. Across all the six schemes the current evidence base is relatively poor or outdated and comprehensive research is

recommended to create a robust understanding of positive and negative effects for flood and coastal risk management.

20 Recommendations

Stage 1 – Short Term Recommendations

1. Undertake a review of current Shoreline Management Plan policies and coastal flood defences' age and asset condition to identify the timeline of future flood defence investment and the scale of opportunity for a tidal barrage or lagoon to realise flood and coastal erosion economic benefits.
2. Assess land value uplift and place-making/development potential by removing coastal flood risk as a major obstacle, like at Avonmouth-Severn side.
3. Establish specific methods to assess benefits and costs based on the Flood and Coastal Risk Management appraisal approach to ensure a systematic and equitable approach between options.
4. Assess the wider social, economic and environmental benefits to complement those that would be identified solely through the Flood and Coastal Risk Management appraisal methods.
5. Develop a plan for stakeholder engagement with the Environment Agency, Natural Resources Wales, Internal Drainage Boards, Lead Local Flood Authorities, and key infrastructure stakeholders.
6. Undertake a high level review and case study of the likelihood and consequences of tidal locking on rivers and drainage networks through existing available river modelling and data.
7. Collate knowledge on sea-river FRM management and reflected wave effects from Thames Barrier, Cardiff Bay and any other relevant UK or international barrages

Stage 2 – Longer Term Recommendations

8. Develop a single hydraulic model of the estuary that can be used by any scheme proponent, providing a single consistent evidence source and assessment baseline and enabling in combination/cumulative effects of multiple schemes to be assessed accurately and efficiently.
9. Modelling should consider the mode of each barrage/lagoon operation e.g. ebb/flood or ebb only.
10. Modelling should extend to the continental shelf and beyond to improve accuracy of predicted far field effects from large barrages
11. Hydrodynamic modelling should be based on the latest extreme value analysis and climate change analysis and cover:
    - Multiple time horizons to coincide with barrage development and design life.
    - Coastal surges (presently modelling to date only assess changes over the typical tidal range)
    - Coastal erosion/near shore wave action
    - Sediment process modelling to estimate areas of accretion and erosion
    - Wave action (including reflected waves) taking account of predicted climate change including wind direction, strength and storm frequency/severity
    - A review of the likelihood and consequences of tidal locking of the tributaries and drainage networks feeding into the Severn. This should be based upon the coastal modelling results to inform the fluvial modelling downstream boundary. It should also include the impacts of climate change on increased rainfall and river flows. The work should also assess the viability and associated cost of mitigation measures such as pumping and storage.

12. Assess the location, likelihood and consequences of tidal locking, where impounded water levels prevent rivers in flood or pumped drainage systems from discharging.
13. Undertake a detailed appraisal of the flood and coastal risk benefits utilising the complete, up to date modelling, and utilising the appraisal approach developed in Stage 1.