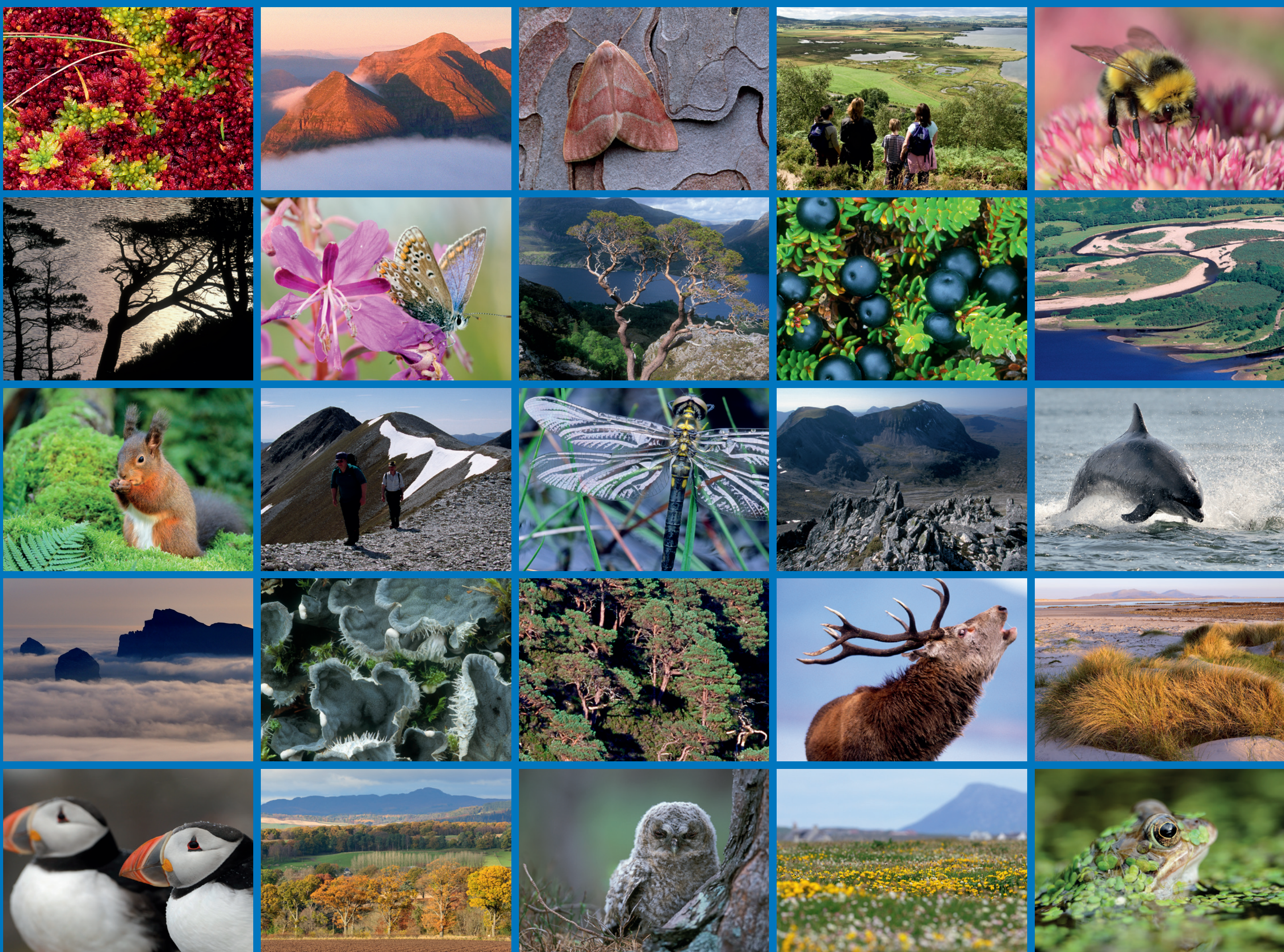
Scottish Natural Heritage
Commissioned Report No. 891

Impacts of sea-level rise and storm surges due to climate change in the Firth of Clyde



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COMMISSIONED REPORT

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Impacts of sea-level rise and storm surges due to climate change in the Firth of Clyde

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COMMISSIONED REPORT
Summary

Impacts of sea-level rise and storm surges due to climate change in the Firth of Clyde

Commissioned Report No. 891
Project No: 14571
Contractor: Arup and University of Glasgow
Year of publication: 2017

Keywords

Firth of Clyde; sea-level rise; managed realignment; climate change; adaptation; coastal flood risk management; storm surge.

Background

The Firth of Clyde Forum brought together various partners to fund and manage this project in order to better understand the threat that sea-level rise and storm surges pose to vulnerable habitats, coastal communities, and infrastructure in the local area. SNH provided funding and commissioned the report, with further funding provided by Clydeplan, Peel Ports Clydeport, Loch Lomond and the Trossachs National Park, and The Firth of Clyde Forum. SEPA also input to the project via the steering group.

SEPA provides mapping of current flood risk and considers projected sea-level rise by 2080 within Flood Risk Management Strategies. As well as predicting the likely mean sea level at 2020, 2050 and 2080, this project aimed to use more detailed local mapping, in particular of projected flood risk in 2080, to identify vulnerable coastal areas. Case study sites were also identified in order to assess the potential for managed coastal realignment to help alleviate local flooding and to provide substantial ecological benefits. The sites were Inner Clyde North and South, Newshot Island and Holy Loch.

This report is intended for use in long-term climate change adaptation strategies including local development planning, flood risk management and regional marine planning.

Main findings

- Using the UKCP09 High Emissions scenario at 95% confidence, sea-level rise by 2080 is projected to be 0.47m in the Firth of Clyde (base year 2008). This takes account of landmass isostatic movements. There are very limited variations in this figure at different locations and therefore a single projection can be used for the whole area.
- Projected future changes in storm surge were very small (millimetres) compared to those of sea-level rise (tens of centimetres) and amount to 1% of the anticipated sea-level rise. This suggests that the contribution of storm surges to sea level will change little with climate change in this area.
- The outcome of a field mapping exercise identified several areas of designated habitats, coastal communities and infrastructure (such as road and rail links) that are currently at

risk of sea-level rise induced flooding as well as adjacent areas that will be at risk in the future.
- The way in which saltmarsh and mudflat habitats will be impacted by sea-level rise is not known in detail, but what is clear is that a lack of sediment delivery from both marine and fluvial sources will impact negatively on the ability of these habitats to keep pace with a rising sea-level and so, with a few very localised exceptions, the present trend of erosion along the saltmarsh edges will continue and likely accelerate, thus increasing the risks to the Inner Clyde Special Protection Area (SPA).
- It is key to point out that this report looks at the impact of higher sea levels during storm surges due to the rise in mean sea level, but it does not consider the effects of sea-level rise on wave overtopping nor the added impact of surface water or fluvial input to the Firth of Clyde, both of which are likely to exacerbate the effects of elevated water levels in the Firth and increase the erosional trend.

Case study sites

- Along the Inner Clyde North study site, the proximity of the railway and built development so close to an eroding saltmarsh edge places serious constraints on the formulation and implementation of any managed realignment scheme. Nevertheless, there may be opportunities along this developed shore for alternative 'greening grey infrastructure' or bioengineering solutions that could be utilised to enhance the habitat potential of the existing or future hard engineering structures. Some key sections of the infrastructure (e.g. Bowling railway station) are currently at risk from the impacts of sea-level rise and increased flooding.
- As far as the Inner Clyde South, Newshot Island, and Holy Loch study sites are concerned, all show realistic opportunities for managed realignment. The parcels of land involved in all three cases are substantial and have few apparent constraints to such future management. All three sites have extensive areas of existing saltmarsh habitat and have the potential for adjacent low-lying land to allow a substantial increase of the current extent, albeit phased over a period of time depending on future rates of sea-level rise.
- Land ownership and the willingness of the landowner(s) to consider managed realignment is beyond the scope of this project, but will be a critical issue to address going forward, at the sites identified in this report, or in future feasibility studies.
- It is acknowledged that the scale of flooding may not be significantly reduced across the wider Firth of Clyde, even if a number of the managed realignment schemes recommended here were to be implemented, as such works would not be of sufficient areal extents to introduce a meaningful reduction in the water levels of the Firth.

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List of abbreviations and acronyms

BAP	Biodiversity Action Plan
CFBC	Coastal Flood Boundary Conditions
DEM/DTM	Digital Elevation (inc. e.g. buildings and trees) Model / Digital Terrain (ground only) Model
EU	European Union
FRM	Flood Risk Management
GIS	Geographical Information System
HLMO	High Level Marine Objectives
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light detection and ranging
MHWS	Mean High Water Spring
MPA	Marine Protected Area
MPS	Marine Policy Statement
NMP	National Marine Plan
PVA	Potentially Vulnerable Areas
SLR	Sea-level rise
SPP	Scottish Planning Policy
SAC	Special Areas of Conservation
SEPA	Scottish Environment Protection Agency
SNH	Scottish Natural Heritage
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
SPA	Special Protection Area
UKCIP	UK Climate Impacts Programme
WEWS	Water Environment and Water Services (Scotland) Act 2003
WFD	Water Framework Directive

Definitions

Coastal flooding – the assessment of areas at risk of flooding used in this study considers only areas of land (defined by LiDAR data) that are below the extreme water level used in each scenario.

Annual exceedance probability (AEP) and Return period (RP) – AEP is the long term average probability of a certain flood event occurring in any given year. Return period is the inverse of the AEP expressed in years. Please note that these are statistical terms and a 1 in 100 year RP event does not necessarily mean the event will only occur once every 100 years.

Confidence interval – the probability that the value calculated is within the range defined by the confidence interval. For instance, if there is a 95% confidence of sea- level rise being X, there is 95% chance that the actual value of sea-level rise will fall within a range up to and including X but with a 5% chance that it will be greater than X.

Climate change mitigation[1] – refers to any strategic intervention and/or anthropogenic action taken to remove the greenhouse gases (GHG) released into the atmosphere, or to reduce their amount, to reduce any risk and hazards of climate change to human life and the environment. The Intergovernmental Panel on Climate Change (IPCC) defines climate change mitigation as 'technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce GHG emissions and enhance sinks'.

Climate change adaptation[2] – Adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimise the damage they can cause, or taking advantage of opportunities that may arise. It has been shown that well planned, early adaptation action saves money and lives later. Examples of adaptation measures include: using scarce water resources more efficiently; adapting building codes to future climate conditions and extreme weather events; building flood defences and raising the levels of dykes; developing drought-tolerant crops; choosing tree species and forestry practices less vulnerable to storms and fires; and setting aside land corridors to help species migrate. Coastal adaptation measures could include altering coastal land use to allow erosion and flooding to occur in a manageable fashion.

[1] http://www.thegef.org/gef/climate_change/mitigation
[2] http://ec.europa.eu/clima/policies/adaptation/index_en.htm

1. EXECUTIVE SUMMARY

The main objective of this study is to provide an evidence base of the projected extent of sea-level rise (SLR) and storm surges in the Firth of Clyde, and associated risks to vulnerable habitats, coastal communities, and infrastructure in order to inform development planning and other strategies such as flood risk management and regional marine planning. This report sets out potential key risks to these built and natural environment receptors that could arise as a result of SLR, coastal flooding and erosion.

The impact of climate change on SLR and storm surge was ascertained using UKCP09 values, which correspond to the 2007 IPCC Annual Report 4 (AR4). The values provided by UKCP09 are the translation of the IPCC global projections to the UK territory. The values of net SLR (including landmass isostatic movement) and increase of surge for 2080 were extracted from the High Emissions scenario, with 95% confidence for the SLR and 50% confidence for the surge component, a dataset publicly available via the UKCP09 website[3].

Since the study commenced, the IPCC has released the Fifth Assessment Report (AR5) in 2014 (IPCC, 2014). For completeness, the study includes an analysis of the AR5 predictions as a way of providing an indication of the additional possible increase of SLR in the study area (see Annex 1B). It is key to point out that SLR projections do not include waves, surface water or fluvial input.

For the mapping purposes of this study the 1 in 1yr and 1 in 200yr water levels for 2080 are selected, as the SLR estimated to occur over the next 30-40 years is lower than 0.25m before rising more rapidly towards 2080. Under this scenario, by 2080, SLR is estimated to be 0.47m in the Firth of Clyde (base year 2008).

The values of future changes in storm surge were very small (millimetres) compared to those of SLR (tens of centimetres) and amount to 1% of the SLR. This suggests that the contribution of storm surges to SLR will change little with climate change in this area.

A digital terrain model using LiDAR data was produced. The results from the GIS were symbolised to indicate areas of flooding in present day (coloured blue on the maps in Annex 7) and additional areas of flood risk in a 2080 High Emissions scenario (coloured red on the maps in Annex 7) for the two flood return periods (1 in 1yr and 1 in 200yr). The mapping exercise was assessed to determine where there were significant areas of SLR induced flood risk to designated habitats, coastal communities and infrastructure such as road and rail links. The use and relevance of this mapping exercise for Responsible Authorities is discussed.

SEPA's published flood risk maps consider extreme sea levels at present (2008) and they have considered projected sea-level rise by 2080 within Flood Risk Management Strategies. This study uses the same scenario for SLR estimates and produces detailed maps, where LiDAR data were available, to identify potential risk to both natural and man-made features in the Clyde Marine Region.

The current Scottish legislation and policy that underlies climate change adaptation, SLR and flood risk management was assessed and a commentary provided. The legislative framework relating to the potential land use impacts of SLR is complex but in combination it does oblige Scottish Ministers, Government Agencies, Responsible Authorities (and any future Marine Planning Partnerships) to adapt to various climate change impacts. However, perhaps the methods and protocols of how this happens have not been explicitly outlined in policy or guidance to date and could be subject to further study or guidance.

[3] http://ukclimateprojections.metoffice.gov.uk/

Case studies were undertaken at three sites on the Inner Clyde (Inner Clyde North, Inner Clyde South and Newshot Island) and at Holy Loch at the edge of Loch Lomond and the Trossachs National Park. More detailed plans were produced for these sites at a 1:10,000 scale. In these locations, a field walkover survey was carried out to assess suitability for Managed Realignment (MR) and to do a rapid appraisal of existing saltmarsh habitat. This rapid appraisal was compared with the most recent (2016) saltmarsh survey of Scotland (see Annex 3).

A key finding is that key pioneer saltmarsh species (SM1 – SM11 categories in the saltmarsh survey for Scotland) were virtually absent from all sites, suggesting that seaward marsh progradation is very limited. This means that the potential for natural colonisation from local sources of existing or any future, newly created MR marshes appears limited. Intensive seeding of existing seaward edges and newly created MR sites may be required to ensure successful establishment of the required pioneer and low saltmarsh communities.

MR opportunities were identified in all case study sites. At Holy Loch and Inner Clyde South it is notable that historical and existing coastal defence mechanisms have already been breached by the sea to varying extents, and saltmarsh species are already encroaching inland onto former defended habitats. Any MR opportunities could be phased over time to manage the impact on adjacent land of breaches and subsequent areal encroachment by salt water. These sites offer localised opportunities of reducing SLR associated flood risk under future climate change scenarios, but they also have the potential to provide clear ecological benefits.

The Inner Clyde North site is largely an old industrial and developed shoreline with constraints for implementing any managed realignment strategy, due in part to the existing eroding nature of the saltmarsh edge, and partly due to the proximity of the adjacent railway, and areas of built development (including waste water treatment works, residential housing, Bowling railway station, and remediated land at the former Exxon site close to the Erskine Bridge in the east of the site). Some of the infrastructure (e.g. Bowling railway station) is currently at risk from SLR and increased flooding and it is important to note that seawater already penetrates under the railway into the landward side. As a result, it is critical that further assessment is undertaken of the risk to the built environment and infrastructure along this section of coast as a result of future SLR. In this context, several lengths of existing shore defence structures are eminently suitable as sites for alternative 'greening grey infrastructure' or bioengineering solutions that could be retrofitted to enhance the existing shore habitat or new-fitted to any hard engineering replacement structures in the future.

The sites at Inner Clyde South, Newshot Island, and Holy Loch all show realistic and achievable opportunities for MR with the parcels of land involved in all three cases being substantial and having few apparent constraints to such future management. All three sites have extensive areas of existing saltmarsh habitat and have the potential for adjacent low-lying land to allow a substantial increase of the current extent, albeit phased over a period of time depending on future rates of SLR.

However, at Newshot Island, some of the land that would be included in a potential second phase of MR might include 'made ground' from previous uses of the site. If that were the case, then the contamination risk could be significant, and it is considered that this would have to be assessed at an early stage of feasibility.

Holy Loch has perhaps the greatest potential for MR over the largest area and with minimal impact on property and land other than agricultural grazings. In this case, three distinct phases have been identified, each with well-defined limits to their landward extents and all confined to improved pastureland currently used for sheep and cattle grazing.

In combination with the case study work already undertaken, there could be wider capacity within the Firth of Clyde for MR to contribute to alleviating local flooding, in addition to allowing space for natural coastal processes to maintain the extent of coastal habitats. However, it is acknowledged that a substantial number of MR schemes would be required to make any substantial inroads into a reduction in the volume of the tidal prism of the Firth of Clyde. Further modelling analysis would have to be undertaken to determine if implementing the MR at Newshot could serve to reduce the impact of SLR and storm surge upstream towards Glasgow.

The way in which saltmarsh and mudflat habitats will be impacted by SLR and storm surge is not known in detail, but what is clear is that a lack of sediment delivery from both marine and fluvial sources will impact negatively on the ability of these habitats to keep pace with a rising sea level and so, with a few very localised exceptions, the present trend of erosion along the saltmarsh edges will continue and likely accelerate, thus increasing the risks to the Inner Clyde Special Protection Area (SPA).

Going forward, a key consideration involves land ownership and the willingness of the landowner(s) to consider MR on their land. This aspect is beyond the scope of this project, but will be a critical strategic issue to address at the sites identified in this report, or in future feasibility studies.

2. INTRODUCTION

The main objective of this study is to provide an evidence base of the predicted extent and associated risks of SLR and storm surges in the Firth of Clyde for its natural habitats and human communities in order to inform development planning and other strategies.

The report outlines the existing information relevant to the Clyde, and includes maps of vulnerable habitats, coastal communities and infrastructure. The aim of the work was that it should inform future long-term strategies (development plans and individual development proposals) with regard to flooding and erosion which affect the built and natural environments.

SEPA has produced a Flood Risk Management (FRM) Strategy for each of the 14 Local Plan Districts in Scotland. The FRM Strategies provide a national picture of flood risk and flooding impacts in Scotland. They also provide objectives and actions for FRM based on long-term sustainable approaches. In 2016, local authorities will publish the Local FRM Plans. The FRM work undertaken to date has largely been done at the regional scale and has identified where more detailed studies are required to better understand the flood risk. The outputs of this study, by contrast, focus on specific areas, mapping constraints to give clearer guidance on opportunities for sustainable development, ecological networks and habitat management and potential MR to provide flood and coastal erosion adaptation.

Arup and the University of Glasgow outlined in their tender submission a range of tasks and outputs that would deliver the above objective for the Firth of Clyde Forum and partner organisations in a straightforward manner. The stages of work are as follows:

- Assimilating and reviewing the relevant legislation and planning context on SLR and storm surges from across the region, specifically where this relates to FRM and climate change. This section of the report also outlines the legislation and guidance within Scotland that relates to climate change adaptation measures such as MR.
- Assessing the SLR and storm surge characteristics within the Firth of Clyde based on the most recent data on climate change. This work reviews the mathematical modelling techniques, and outlines the numerical calculations of SLR and storm surge due to climate change within the Firth of Clyde.
- In parallel with the first two stages, developing an understanding of data availability and knowledge gaps, and outlining how they support the overall deliverables, and where there are constraints to the study outputs.
- Undertaking a GIS mapping exercise based on the numerical calculations of SLR and storm surge to highlight vulnerable human communities and natural habitats. Due to the absence of suitable and comprehensive LiDAR baseline mapping data for all areas within the Firth of Clyde, the mapping of vulnerable human communities and natural habitats is not possible for the entire coastline within the study area. However, the methodology and process used for the mapping exercise can be rolled out for the whole coast in the future. This section also compares the mapping outputs from this study to the SEPA FRM Strategy work.
- Identifying case study locations, in agreement with the steering group, where a more detailed analysis should be undertaken to consider SLR risks in these areas, the erosion and habitat degradation risk, and the potential suitability for MR as a climate change adaptation measure.

Please note that the maps contained in this study are indicative and do not replace or supersede those published by SEPA. No liability will be accepted on the use of the maps other than for the purposes of this study.

3. LEGISLATIVE FRAMEWORK

3.1 Summary of main legislative context

The legislation relating to the objectives of the present study are numerous and varied. The legislative framework is therefore complex and in combination, these legislative Acts combine to oblige Scottish Ministers, Government Agencies, Responsible Authorities (and any future Marine Planning Partnerships) to adapt to various climate change impacts. Aspects of the legislation that are of particular relevance to this project are SLR and flood risk, and there may be opportunities where managing climate change for one Act can also meet the requirements of other legislation at the same time. This legislation, along with examples of how they can work together is summarised below.

The Flood Risk Management (Scotland) Act 2009 (FRM Act) is the legislative instrument driving FRM in Scotland. It places a duty on Scottish public bodies to exercise their flood risk related functions with a view to reducing overall flood risk. SEPA, as the main government agency in charge of FRM nationally, leads this collaborative approach and published the National Flood Risk Assessment (NFRA) in 2011 which included the location of Potentially Vulnerable Areas (PVAs)[4]. FRM Strategies are also a requirement of the Act and have now been completed[5].

Scottish Planning Policy (SPP)[6] underlines climate change as one of the main elements in Scottish planning, with a strong emphasis on adaptation measures being considered, e.g. MR in coastal areas, which is explained and discussed further in Annex 8. It also holds the principle of no development in areas under flood risk, i.e. avoidance of development in functional floodplains. In turn, flood risk areas (as part of functional floodplains) are identified by the work that SEPA and Responsible Authorities are undertaking under the FRM Act.

The Climate Change (Scotland) Act 2009 – and associated frameworks and action plans – imposes a duty on Scottish public bodies to deliver the Scottish Government adaptation programme, with a particular emphasis on adaptation and increased resilience. Equally, the Marine (Scotland) Act 2010 establishes the duty for Scottish Ministers to set objectives related to adaptation to climate change.

Therefore, four key themes emerge from current legislation:

- Climate change as a driver and its impact on flood risk.
- Definition of areas at risk of flooding and limiting development on areas at risk of flooding.
- A firm requirement to create planning tools to adapt to climate change and manage flood risk.
- Implementation of measures (including changes to physical environment) to increase resilience of communities.

Figure 1 presents these themes and the legislative context in a graphical form.

[4] http://map.sepa.org.uk/floodmap/map.htm, retrieved March 2016
[5] http://apps.sepa.org.uk/FRMStrategies/, retrieved March 2016
[6] http://www.gov.scot/Topics/Built-Environment/planning/Policy, retrieved March 2016

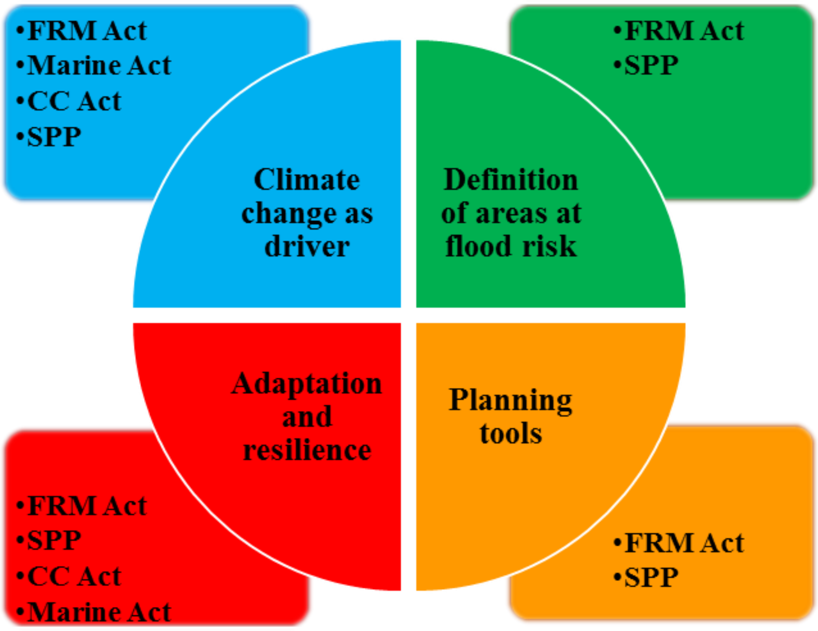

Figure 1. Schematic of the main themes (segments) relating to the present study and their legislative sources (in boxes).

3.2 Flood risk management

The review of the legislative context with regard to FRM and the water environment focused on:

- Flood Risk Management (Scotland) Act 2009 (Scottish Parliament, 2009) along with subsequent actions and requirements by SEPA and Responsible Authorities (local authorities, Transport Scotland, Forestry Commission, etc.) in Scotland;
- Scottish Planning Policy (2014) and FRM contained therein; and
- EU Water Framework Directive (WFD, 2000) and its translation into Scottish legal system: Water Environment and Water Services (Scotland) Act 2003 (WEWS), which is outlined in Section 3.2.3 of this report.

3.2.1 Flood Risk Management (Scotland) Act 2009

The FRM Act is the most important piece of Scottish legislation regulating FRM. It defines SEPA as the main national body for FRM reporting to Scottish Ministers. SEPA has produced Flood Risk Management Strategies (available at http://apps.sepa.org.uk/FRMStrategies/), and liaises with Responsible Authorities to develop FRM plans (available at https://www.sepa.org.uk/environment/water/flooding/local-frm-plans/ and on Local Authority websites). The Act also requires Responsible Authorities to:

- Provide SEPA with information on rivers and coastline to help them produce national flood warnings.
- Work with other Responsible Authorities to produce local FRM plans that extend across catchment-based boundaries.
- Consider Natural Flood Management techniques when looking to manage flood risk.

Local Authorities are also required to:

- Assess relevant bodies of water to determine whether their condition increases the risk of flooding.

– Undertake clearance and repair works of watercourses to reduce flood risk.

The FRM Act requires SEPA to assess whether alteration (including enhancement) or restoration of natural features and characteristics of any river basin or coastal area in a FRM district could contribute to the management of flood risk for the district. The FRM Act defines natural features and characteristics as: i) characteristics that can assist in the retention of flood water, whether on a permanent or temporary basis, (such as flood plains, woodlands and wetlands) or in slowing the flow of such water (such as woodlands and other vegetation), ii) characteristics that contribute to the transportation and deposition of sediment, and the shape of rivers and coastal areas. The present study aims to assess local potential for MR as a means of natural flood risk management and therefore, supports aspects of the FRM Act.

Following the publication of the FRM Act, and as part of the NFRA in 2011, SEPA published Local Plan Districts and PVAs for the whole of Scotland. There are three Local Plan Districts within the Firth of Clyde geographical area: 1. Highland and Argyll, 11. Clyde and Loch Lomond and 12. Ayrshire (Figure 2). Figure 3 shows the PVAs identified by SEPA within the study area, which are, in general terms, along the east coast of the Firth of Clyde and the inner River Clyde estuary.

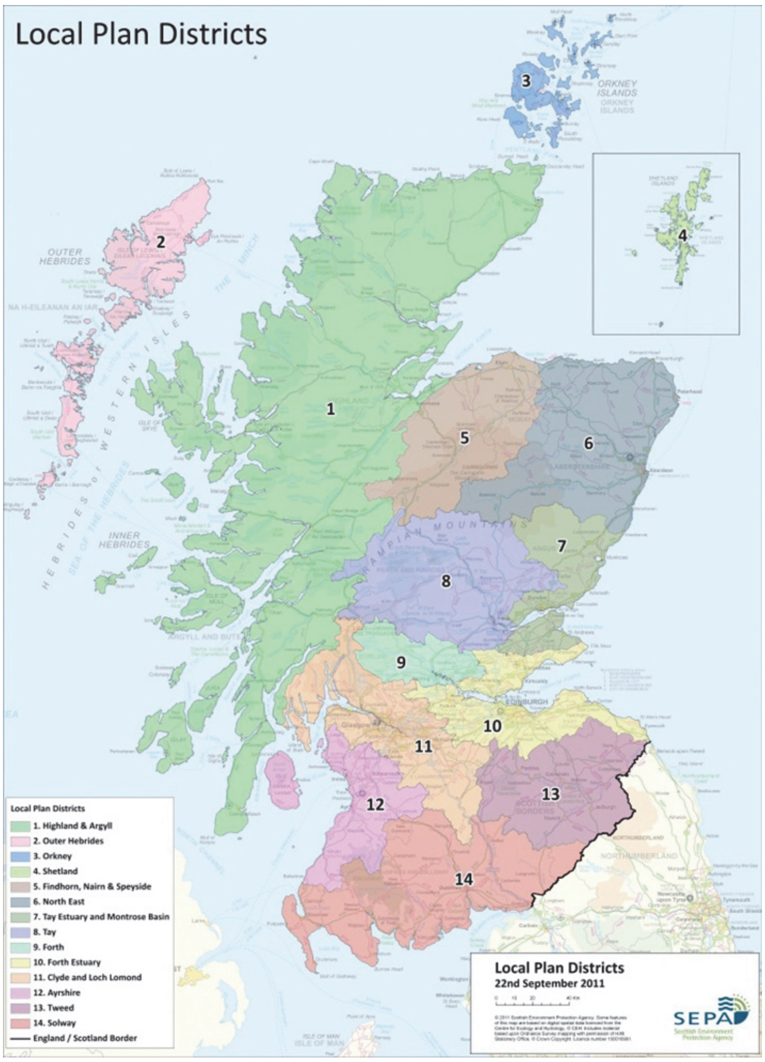

Figure 2. SEPA local plan districts.

http://www.sepa.org.uk/environment/water/flooding/local-frm-plans/

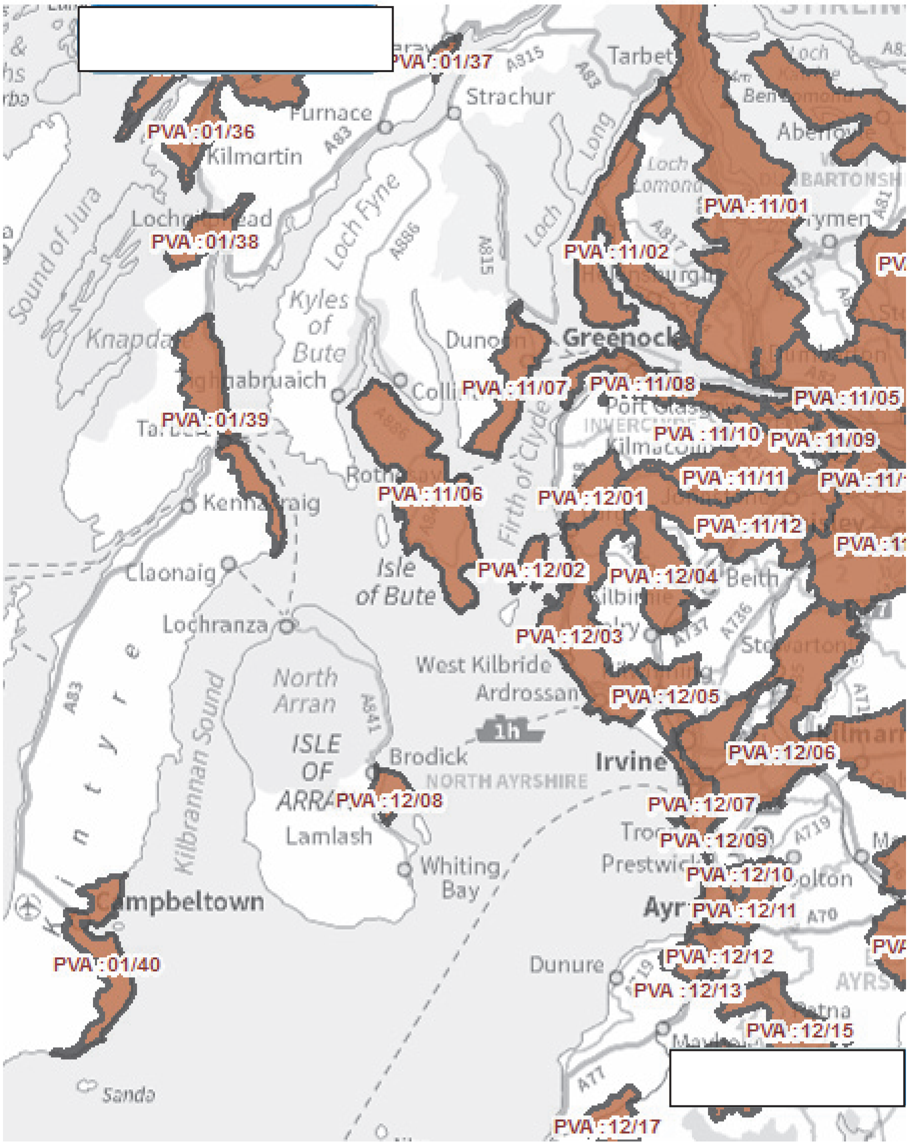

Figure 3. SEPA Potentially Vulnerable Areas (PVAs) (indicated in brown) in the Firth of Clyde.

http://map.sepa.org.uk/floodmap/map.htm

3.2.2 Scottish Planning Policy

SPP includes Scottish Government planning policy on new developments, coastal erosion and flooding. One of its aims is to help all parties to consider flooding issues fully, especially in the light of climate change predictions, and so prevent additional land and development being put at risk from flooding. Thus, SPP takes into consideration the potential impact that climate change could have on coastal erosion and flooding and with this in mind, aims to guide future development in a sustainable fashion.

SPP paragraph 88 states that:

> *"Plans should recognise that rising sea levels and more extreme weather events resulting from climate change will potentially have a significant impact on coastal and island areas and that a precautionary approach to flood risk should be taken. They should confirm that new development requiring new defences against coastal erosion or coastal flooding will not be supported*

except where there is a clear justification for a departure from the general policy to avoid development in areas at risk. Where appropriate, development plans should identify areas at risk and areas where a managed realignment of the coast would be beneficial."

In paragraph 262, SPP states:

"Local development plans should protect land with the potential to contribute to managing flood risk, for instance through natural flood management, managed coastal realignment, washland or green infrastructure creation, or as part of a scheme to manage flood risk".

SPP therefore makes clear the importance of protecting and where possible, enhancing, functional flood plain areas; having a principle of avoidance of development in such areas.

SPP (paragraph 263) states that development plans must identify areas of developed coast that are a major focus of economic or recreational activity, and identify areas likely to be suitable for development; areas subject to significant constraints (including those at risk from coastal erosion and flooding); and areas unsuitable for development. Therefore, there is a need to assess areas at risk of flooding in order to inform development plans.

3.2.3 EU Water Framework Directive

The EU Water Framework Directive (WFD) was adopted in October 2000 and commits European Union (EU) member states to achieve good qualitative and quantitative status of all water bodies by 2015, including up to one nautical mile offshore (European Commission, 2013). Within Scotland, the overall aim is to have 96% of Scottish waters in good condition by 2027 (Natural Scotland, 2009). One of the stated purposes of the WFD is to:

"Establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which…(e) contributes to mitigating the effects of floods and droughts"

(WFD, 2000, p. 8). Thus, it commits the Scottish Government to assess and manage coastal flooding. The WFD requires all member states to identify and assign individual river basins to specific districts, with coastal waters being assigned to:

"the nearest or most appropriate river basin district or districts"

(WFD, 2000, p. 11). Each member state must ensure management plans are created for each river basin (WFD, 2000).

However, SEPA is currently engaged in a consultation to change the way it delivers RBMPs. SEPA is proposing to focus on five main issues: water quality, improving physical condition, removing barriers to fish movement, flows and levels, and invasive and non-native species. In the meantime, further details about the water bodies in this study area can be found here: http://gis.sepa.org.uk/rbmp/ for 2008 status or http://www.environment.scotland.gov.uk/get-interactive/data/water-body-classification/ for more recent water body ecological status and WFD data sheets.

The WEWS Act 2003 is the translation of the WFD into the Scottish legal system and sets out the management of Scottish waters. Of particular relevance to this project is that the Scottish transposition of EC WFD requires Scotland to manage transitional and coastal water bodies out to three nautical miles. WEWS is also relevant for the implementation of any interventions considered in this report; changes to the physical conditions of the water environment will require authorisation from SEPA through the Controlled Activities Regulations (CAR) and wherever relevant from Marine Scotland.

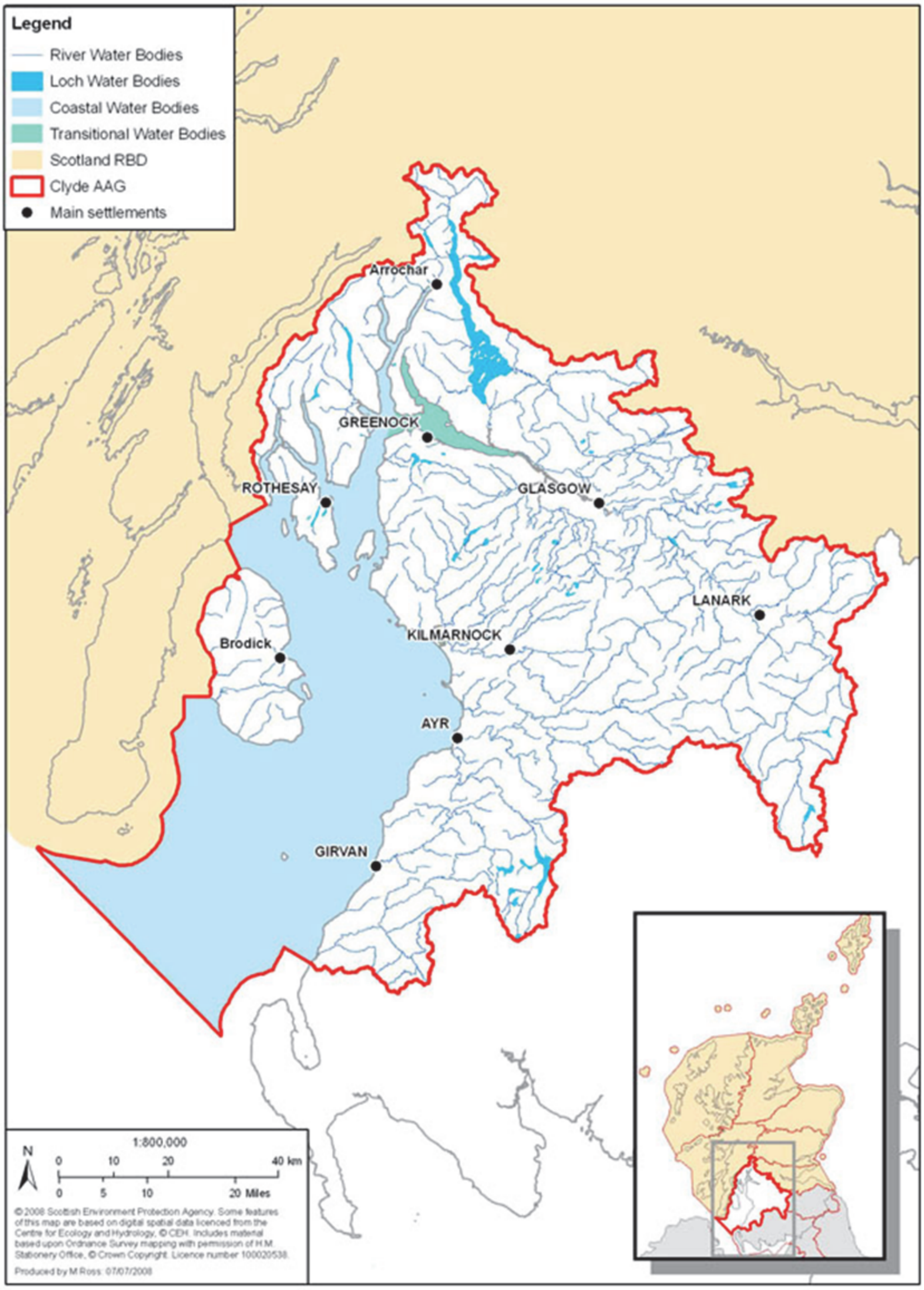

Figure 4. Map of the Clyde Area Management Plan.

www.environment.scotland.gov.uk

3.3 Climate change

3.3.1 Climate Change (Scotland) Act 2009

The Climate Change (Scotland) Act 2009 places the duty on public bodies to deliver the Scottish Government adaptation programme and the duty on Scottish Ministers to submit a strategy for land use, including objectives in relation to adaptation to climate change, to the Scottish Parliament. Thus, land use management and flood risk are primary principles of the Climate Change (Scotland) Act.

3.3.2 Climate Ready Scotland: Scottish Climate Change Adaptation Programme

This programme provides further tools to implement the Climate Change (Scotland) Act 2009, Section 53. The overarching aim of the programme is to:

> *"increase the resilience of Scotland's people, environment, and economy to the impacts of a changing climate," (Scottish Government, 2014, p. 5).*

It addresses the impacts identified for Scotland in the UK Climate Change Risk Assessment (CCRA) published under Section 56 of the UK Climate Change Act 2008. It sets out Scottish Ministers objectives in relation to adaptation to climate change, their proposals and policies for meeting those objectives, and the period within which those proposals and policies will be introduced. Under the Natural Environment theme[7], two main overarching objectives are applicable to this study:

- N1 Understand the effects of climate change and their impacts on the natural environment.
- N2 Support a healthy and diverse natural environment with capacity to adapt.

In particular, the following objectives provide clear policy background and justification for the current study:

- N1-8 Understand the risks associated with coastal flooding through development and implementation of local flood risk plans;
- N1-10 Developing datasets to support flood risk management e.g. Light Detection and Ranging (LiDAR) and Scottish Detailed River Network (SDRN). A requirement of the Flood Risk Management (Scotland) Act is to develop a programme to integrate necessary data. This will include the continuous review of climate change trends[8]; and
- N2-20 Assess and manage coasts, promoting adaptive coastal management that works with natural processes.

3.4 Environment

The review of the current and forthcoming legislative context with regards to FRM and the water environment focused on:

- Marine (Scotland) Act 2010 and Planning Scotland's Seas Draft Planning Circular 2013;
- Habitats Regulations;
- UK Marine Policy Statement, specifically Chapter 2, Section 2.6.7 and 2.6.8 Coastal Change;
- UK Biodiversity Action Plan (BAP) for Maritime Species and Habitats (an important policy related to this project);
- Land Management; and

[7] http://www.gov.scot/Publications/2013/06/2469/4
[8] http://www.gov.scot/Resource/Doc/295166/0091322.pdf, p4

– National Parks (Scotland) Act 2000.

3.4.1 The Marine (Scotland) Act 2010

The Marine (Scotland) Act 2010 (Scottish Parliament, 2010) covers marine planning and conservation issues within Scotland's territorial sea waters as well as the 'seashore' which extends from the edge of Mean High Water Spring (MHWS) level out to 12 nautical miles seawards.

Climate change adaptation and mitigation is explicitly referred to in Parts 2, 4 and 5 of the Marine (Scotland) Act 2010. Part 2 refers to 'Climate Change Adaptation and Mitigation' as a general duty.

Thus, it is clear that the Marine (Scotland) Act reinforces the requirement for adaptation to climate change of the 2009 Climate Change (Scotland) Act. This link is further strengthened under Part 3 Marine Spatial Planning, where action 4(a, ii) in clause 5 (National marine plan and regional marine plans) states:

> "Mitigation of and adaptation to climate change
> In exercising any function that affects the Scottish marine area under this Act, the Climate Change (Scotland) Act 2009 (asp 12), or any other enactment—
>
> (a) the Scottish Ministers, and
> (b) public authorities,
>
> must act in the way best calculated **to mitigate, and adapt to, climate change** so far as is consistent with the purpose of the function concerned."
> Part 2 (clause 4), p. 2.

What does not appear to be explicit in the Marine (Scotland) Act with regards to climate change is how 'adaptable' certain definitions and clauses in the Act are to the predicted effects of a changing climate. This includes changes in the marine surface area and 'seashore' land that are likely to occur as sea level rises, and/or as we use MR to adapt to SLR. The risks of a changing climate to achieving 'Habitat conservation goals/requirements' is another area of the Act which does not appear to be clearly articulated (beyond 'adaptation to climate change'). However, it may be possible to compensate for habitat losses caused by future climate change – via MR, for example – and that such an action would help achieve the requirements outlined in Parts 2 and 4 of the Act.

The Marine (Scotland) Act 2010 also makes clear reference to the conservation of habitats (both inside and outside of Marine Protected Areas (MPAs)), particularly where those habitats are important for species protected under the Habitats Regulations (see below). MPAs exist within the study area for Upper Loch Fyne and Loch Goil, South Arran and Clyde Sea Sill.

3.4.2 Habitats Regulations

There are a suite of international and national nature conservation designations which are relevant for the study area. These include international Ramsar designations, SPAs for birds, and Special Areas of Conservation (SACs) for habitats (collectively known as Natura sites and designated under the UK Habitat Regulations which transposed the EU Habitats

Directive (1992)), and Sites of Special Scientific Interest (SSSIs). The role of these conservation designations is to conserve and protect habitats and species of national and international importance by creating a network of spatially defined sites. SSSIs are a much broader designation as they can be for features of geological and geomorphological interest, some of which are expected to erode and evolve through time.

Importantly, these regulations were enacted prior to widespread consideration of climate change in environmental legislation. This means that it is not entirely clear how particular sites (e.g. Natura sites) will be managed with regard to climate change. The lack of clarity in this area at present means that careful scrutiny of the full suite of related environmental and flood risk legislation is required during decision making processes, along with careful discussions to make 'climate change informed' decisions about habitat management.

Of particular relevance to this project, the Habitats Regulations (via SACs and SPAs) have a goal of achieving 'favourable condition' and clearly state that there must be no net loss of important habitats, including saltmarshes, and that deterioration of these sites and disturbance of designated species must be avoided. It may be possible for MRs to be created and used to compensate for any loss of intertidal habitat associated with climate change, but as yet, there is no known precedent for this in Scotland. It is also worth noting that MRs are typically less functional ecosystems than natural saltmarsh systems, as outlined further in Annex 8, which may affect their ability to serve as compensatory habitats for Habitats Regulations requirements (although they may serve effectively for flood risk alleviation purposes, for example).

The Scottish Government acknowledges that issues such as climate change can influence the condition of individual sites, potentially threatening their original designation feature. Site Condition Monitoring (SCM) is carried out by Scottish Natural Heritage (SNH) in order to monitor the condition of Natura 2000 sites in Scotland. SCM is carried out between every 6–24 years depending on the nature of site features. SNH is required to report features as either in "favourable" or "unfavourable" condition. These results are used by both SNH and partner Government Agencies to evaluate the effectiveness of the current legislative instruments and decide on remedial actions which can be taken when sites do not meet favourable condition. Thus, this is a potential mechanism by which the predicted future climate change risks on these sites can be managed.

Within the study area, there are two Ramsar sites (Inner Clyde and Ailsa Craig including marine extension) which are also protected as SPAs for particular bird species and their habitats. The Inner Clyde SPA is particularly relevant to the case study sites, and is discussed in more detail in Sections 6 and 7 of this report.

3.4.3 UK Marine Policy Statement

High Level Marine Objectives (HLMOs) were jointly agreed by UK and devolved administrations. They underpin the Marine Policy Statement (HR Government, 2011) which was provided for in the Marine and Coastal Access Act 2009. All of the devolved administrations' marine plans need to comply with the HLMOs and MPS. Specific points of interest from the MPS that relate to this project are briefly summarised below:

- Biodiversity is protected, restored and losses halted where marine and coastal habitats are supporting healthy, resilient and adaptable ecosystems.
- Marine spatial planning must adopt an ecosystem approach:

> *"which takes account of climate change and recognises the protection and management needs of marine cultural heritage according to its significance," p. 12.*

– Planning applications must:

> *"take account of potential impacts of climate change mitigation and adaptation in individual applications to ensure that any appropriate adaptation and mitigation measures have been identified," p. 14.*

– Climate Change is explicit in Chapter 2 of the MPS where it states that:

> *"Marine planning will provide an important tool for meeting the long term challenges posed by climate change," p. 23.*

The 'Climate Change Adaptation and Mitigation' and 'Coastal Change' sections of the MPS are available in Annex 2.

These points relate closely to the Scottish Government's 'high level principles' collectively referred to as HLMOs and they form the basis of Scotland's National Marine Plan (NMP) (see Section 3.4.4 below).

This is a key piece of legislation supporting climate change adaptation and mitigation at the coast. As land-based planning and marine planning overlap in the intertidal zone – the area where MRs will occur – linking across Marine Spatial Planning and land-based planning and legislation is especially important. The MPS has been designed to facilitate this where, *"the geographic overlap between the Marine Plan and existing plans will help organisations to work effectively together and ensure that appropriate harmonisation of plans is achieved,"* p. 9 (see also Schedule 1 of the Marine (Scotland) Act).

3.4.4 Scotland's National Marine Plan

The NMP for Scotland, which was published by the Scottish Government in March 2015, is a statutory instrument required by the Marine (Scotland) Act (0 – 12 nm Scotland) and the Marine and Coastal Access Act (12 – 200 nm, UK devolved) and thus makes explicit reference to climate change and SLR. Indeed, the HLMOs outlined above are firmly rooted within a wider climate change agenda for both inshore and offshore waters. Specific general policies relating to climate change and coastal process and flooding are included; these are supplemented with sector-specific objectives.

The primary aim of the NMP is to:

> *"integrate both the ecosystem approach and the guiding principles of sustainable development to deliver a robust approach to managing human impact on Scotland's seas" (Scottish Government, 2015, p.11).*

A key point of relevance to this report is policy GEN 5 where developers and users of the marine environment should seek to address climate change through (mitigation and) adaptation. The policy states that:

> *"marine planners and decision makers should be satisfied that developers and users have sufficient regard to the impacts of a changing climate and, where appropriate, provide effective adaptation to its predicted effects." (Scottish Government, 2015, p.18).*

It also goes on to state that:

"Appropriate proactive opportunities for enhancing natural carbon sinks and allowing natural coastal change where possible should also be considered." (Scottish Government, 2015, p.18).

For inshore waters:

"safeguarding ecosystem services such as natural coastal protection and natural carbon sinks (e.g. seagrass beds, kelp and saltmarsh) should be considered." (Scottish Government, 2015, p.18).

In terms of Regional Policy, regional marine plans should:

"explain how they have taken into account future climate change in terms of climate change adaptation." (Scottish Government, 2015, p.19).

Also of relevance is policy GEN 8 on coastal process and flooding which requires that:

"wherever possible, flood risk management and coastal protection solutions should work with natural processes and features, encouraging managed realignment of coastal habitats such as sand dunes, salt marshes and mudflats." (Scottish Government, 2015, p.23).

In terms of Regional Policy:

"regional marine plans should be aligned with terrestrial development plans and reflect coastal areas likely to be suitable for development, taking into account the most recent flood risk and flood hazard maps." (Scottish Government, 2015, p.23).

This requires marine and land-based development plans to be aligned.

The NMP thus provides a significant statutory instrument to implement solutions to flood management and coastal defence such as those proposed in this report. This would provide any future Marine Planning Partnership, Responsible Authorities and SNH with a statutory lever that could be used to adapt to future SLR risks by working with natural geomorphological processes and actively re-aligning the coast to help adapt to the risks of SLR on habitat loss and flooding of high-value land uses.

The NMP contains several sectoral chapters (e.g. fisheries, oil and gas) which address specific issues. Whilst the sectoral chapters make limited reference to general policies, analysis of fishing, aquaculture and oil sections highlight some potential areas where GEN 5 and 8 may have an important bearing on these sectors, e.g. the fishing chapter makes reference to the fact that some benthic habitats support commercially important fish species by providing nursery, feeding or recruitment areas (p. 43). It may be possible for MRs to provide important nursery fish habitats as well as their primary flood risk reduction function – thereby achieving more than one objective. Intertidal habitats support critical life stages of migrating fish by providing refugia, rich foraging, and a suitable environment for Atlantic salmon (*Salmo salar*) parr to undergo smoltification. However, little work has been done to economically quantify the value of the intertidal habitats[9].

[9] http://www.salmon-trout.org/c/briefing-paper-intertidal, retrieved March 2015

3.4.5 UK BAP for Maritime Species and Habitats

The overall objectives of this plan (relating specifically to saltmarsh) was to offset the current losses due to ‘coastal squeeze’ (sea level rising against fixed coastal defences) and erosion; to maintain the existing extent of saltmarsh habitat of approximately 45,500 ha in the UK (of which 5,840 ha are in Scotland (Haynes, 2016)); and to restore the area of saltmarsh to 1992 levels (the year of adoption of the Habitats Directive which included saltmarsh as a habitat type of community interest) (UK Biodiversity Group, 1999). It was stated that there was a need to identify realistic and achievable targets for creation. The results of individual estuary evaluations during the first five years of this 15 year plan would allow targets to be reviewed and refined. Such studies would also identify potential locations for saltmarsh creation. There was a presumption against any further net loss of saltmarsh to land claim or other anthropogenic factors.

The aim was that there should be no further net loss (currently estimated at 100 ha/year). This will involve the creation of 100 ha/year during the period of this plan. It is not clear from the Joint Nature Conservation Committee (JNCC) website whether the targets outlined in the 1999 document have been assessed or measured. However, a Common Standards Monitoring for Designated Sites report (Williams, 2006) stated that for 146 saltmarsh assessments undertaken, 0.7% had been destroyed or part destroyed, 36.3% were in unfavourable status, 4.8% were recovering, and 58.2% were in favourable status.

A recent survey of saltmarsh in Scotland included sites in the Firth of Clyde (Haynes, 2016). Of the 7 survey sites in the area, 6 failed the UK targets for site condition monitoring. The main reasons for failure of sites in Scotland as a whole, particularly for designated sites, related to the presence of built structures (e.g. embankments) and the lack of natural landward transition habitats. Other issues included grazing and pollution impacts. Pioneer saltmarsh was found at the Pow Burn, Garnock Estuary and also on the Inner Clyde which is considered further within section 6 (Case Studies) of this report.

3.4.6 Land Management

As the success of implementing MR projects is usually dependent on the cooperation and buy-in of private land owners, it is important to understand land management drivers in Scotland.

There are many land management strategies and policies that are relevant to this project, mainly as they recognise the need for a more integrated approach to land management and the environment, especially in relation to improvements in biodiversity and management of flood risk. They are key drivers for land managers to engage with partner organisations to deliver projects such as MR and other natural flood management and biodiversity projects. Two focal points are the Scottish Land Use Strategy and the Common Agricultural Policy (CAP).

Scotland’s first Land Use Strategy was laid in Parliament in 2011 and its development is a key commitment of Section 57 of the Climate Change (Scotland) Act 2009. The Land Use Strategy takes a strategic approach to the challenges facing land use in Scotland, recognising the benefits and implications of decisions and focusing on common goals for different land users, achieving a more integrated approach to land use.

The Strategy sets out three objectives relating to the economy, environment and communities, and provides a set of Principles for Sustainable Land Use to guide policy and decision making by Government and across the public sector. And it builds on the Government’s current activities through further Proposals to help meet the Objectives.

CAP is the agricultural policy of the European Union (EU). CAP implements a system of agricultural support and funding to target support at environmental, economic and community development across rural Scotland. The CAP payments are delivered through two channels, referred to as Pillar 1 and Pillar 2. Pillar 1 relates to direct support payments, such as the Single Farm Payment, whilst Pillar 2 supports the Scottish Rural Development Programme (SRDP).

The Pillar 1 payment system places a ‘greening’ requirement on the applicant to undertake environmental improvement and/or enhancements to their land management practices. This rewards farmers for adopting and maintaining, as part of their everyday activities, a more sustainable use of agricultural land and for caring for natural resources.

The SRDP 2014-2020 delivers Pillar 2 CAP. It funds economic, environmental and social measures for the benefit of rural Scotland. The key purpose of the SRDP 2014-2020 is to help achieve sustainable economic growth in Scotland’s rural areas and the priorities include specific mechanisms to fund projects and actions that will protect and enhance the natural environment and address the impacts of climate change, including natural flood management projects, especially in areas of lower agricultural value.

3.4.7 The National Parks (Scotland) Act

There is 63km of coastline in the Firth of Clyde which is located within the Loch Lomond and Trossachs National Park, including part of the Holy Loch case study area.

Within this area the National Parks (Scotland) Act 2000 sets out four statutory aims:

- To conserve and enhance the natural and cultural heritage of the area.
- To promote sustainable use of the natural resources of the area.
- To promote understanding and enjoyment (including enjoyment in the form of recreation) of the special qualities of the area by the public.
- To promote sustainable economic and social development of the area’s communities.

4. METHODOLOGY AND TECHNICAL CONTEXT

4.1 Data available for this study

4.1.1 Environmental and flood risk management

This study is largely desk-based with the extent of the outputs driven by the available information. The available data have been identified and brought together to support the project. Data gaps were also identified so as to direct any future work or assist future studies. Key amongst these was that LiDAR data coverage of the study area, or access to it, was incomplete and this limited the geographical extent of the study.

Table 1. Current status of the environmental and flood risk management data available for the study

Source of data	Data	Commentary
Scottish Environment Protection Agency (SEPA)	Flood defence asset maps / assessment.	SEPA has indicated that it does not have a collated dataset for all the flood assets within the study area.
	Firth of Clyde design sea levels.	Design sea water levels from CFBC study[10] with extension to inner lochs carried out by SEPA: FoC_Confidence_Intervals.shp.
Scottish Natural Heritage (SNH)	Coastal habitats data, sand dunes and protected areas.	All protected areas datasets downloaded from SNH website, including SPAs, SACs, and SSSIs etc. NVC data. Saltmarsh and sand-dune datasets.
Peel Ports Clyde	Sedimentation datasets including dredging data; development plans e.g. planned infrastructure improvements.	
Local authorities and Government Agencies	LiDAR datasets.	There is no LiDAR coverage between Ayr and Girvan, for most of Argyll & Bute and for Arran (at time of study), which will impact on the level of detail for the analysis of these areas. There are areas of 'No Data' in the case study areas, and further DTM mapping data was obtained. Whilst LiDAR data are held by Local Authorities for the inner Clyde, the licence conditions are such that they are unable to share that data with this project.
	Phase 1 habitat survey maps.	Not received, but Arup believe that the designated site and sand-dune and saltmarsh habitat locations will provide enough information for the study into vulnerable habitats.

[10] Mcmillan *et al*, 2011

Source of data	Data	Commentary
	BAP teams.	Not received, but Arup believe that the designated site and sand-dune and saltmarsh habitat locations will provide enough information for the study into vulnerable habitats.
	Local Development Plans (LDPs) and Strategic Development Plans (SDPs) – GIS layers.	LDP GIS layers were provided for West Dunbartonshire, Renfrewshire, Inverclyde, North and South Ayrshire.
GIS datasets received from Firth of Clyde Forum	Including: coastal flooding areas, British Geological Society, dredge sites, bathing waters, salt marsh areas, recreational waters, SAC, SPA, Ramsar sites, shellfish growing, special dump sites, Scottish Sustainable Marine Environment Initiative site.	All datasets will be added to the project GIS and interrogated for potential impacts arising as a result of climate change.
SNIFFER	Fetch, surge, and Upper Clyde Bathymetry.	

4.1.2 Topography and bathymetry

Given the large geographical extent of the study area, the most appropriate topographical data representing ground elevation is LiDAR or NEXTMap data. These data sets are collected by airborne equipment covering large extents that would be unachievable with traditional ground topographical survey. LiDAR data are generally provided at a finer grid than NEXTMap (typically 2-5m square size, compared with >5m) providing more accurate elevation values (quoted accuracy ~0.2m, compared with 1m).

The present study heavily relies on the availability of remote sensing data to create a high-resolution digital elevation model (DEM) of the study area, so that the areas affected by SLR can be identified.

Since the present study does not include undertaking hydraulic modelling, there is no need to use bathymetric data.

4.1.3 Sea-level rise and storm surge

UKCP09 predictions data used for this report were downloaded from the UK Climate Impacts Programme (UKCIP) website (http://www.ukcip.org.uk/) established in 1997 by the UK government.

The UKCIP website holds climate change predictions for the whole of the UK for a range of climatic and physical variables, such as rainfall, temperature, sea level and storm surge. These data can be consulted and downloaded free of charge.

Since 1997, the Intergovernmental Panel on Climate Change (IPCC) has released a revised report (Fifth Assessment Report, AR5) in 2013.

SNH and Firth of Clyde Forum requested the inclusion of outputs of the latest climate change report within the present study in some form. Discussions between SNH and the University of Glasgow decided that the IPCC AR5 global predictions would be covered in a general sense (see Section 4.5) since there are no specific data available from IPCC AR5 for the Firth of Clyde that supersede the calculations undertaken using UKCP09 data (see also Annex 1B).

Climate predictions are provided as square tiles covering the UK territory and surrounding sea. Data on relative SLR (including isostatic rebound) and storm surge changes were retrieved from the website. Please refer to Annex 1 for more information on the data and numerical calculations underpinning it.

4.2 Data gaps

4.2.1 Terrain data

The availability of LiDAR data for the construction of a DEM of the study area was fundamental for the completion of this project, as the predicted sea water levels were projected against the DEM to assess areas at risk and those identified as with potential for MR. Volumetric calculations are also based on DEM.

The anticipated LiDAR coverage is shown in Figure 5 below. However, upon GIS interrogation of the dataset it was found that there are areas of 'No Data' in the case study areas as previously discussed and illustrated in Figure 6. This has limited the detailed and accurate analysis of SLR for the western areas within the Firth of Clyde and for the three case study areas in the Inner Clyde. Licensing issues and the decentralised procurement and acquisition of LiDAR within the study area has hindered prompt and full access to digital elevation data for this study.

4.2.2 Environmental data

Some of the ecological data requested has not been obtained e.g. Phase 1 habitat survey mapping and locations of Biodiversity Action Plan (BAP) priority habitats. However, SNH datasets have been obtained for designated areas (SPA, SAC, SSSI), for National Vegetation Classification (NVC) surveys, and for sand dune and salt marsh habitats. These are not regarded as the critical datasets for the study and the Phase 1 habitats and BAP data are not regarded as a serious data gap at the current time.

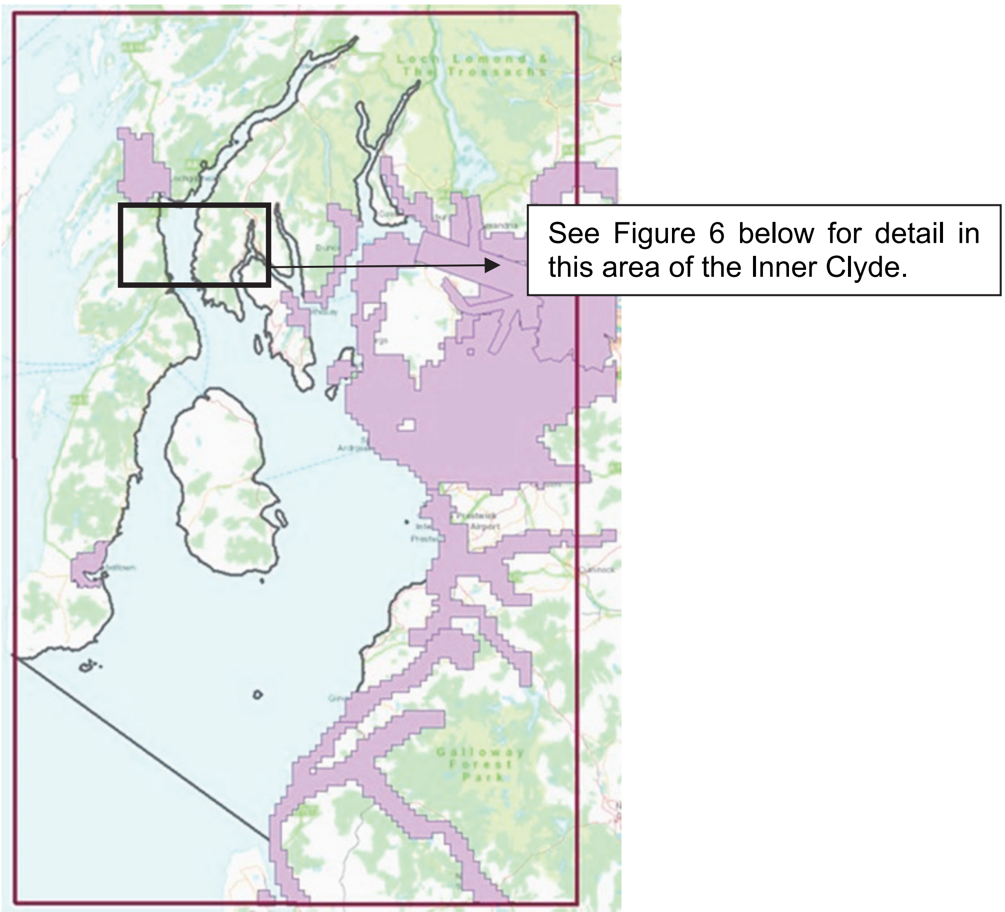

Figure 5. Anticipated coverage of LiDAR data held by SEPA (purple areas). Please note the absence of data along most of the west and north-west coastline within the study area.

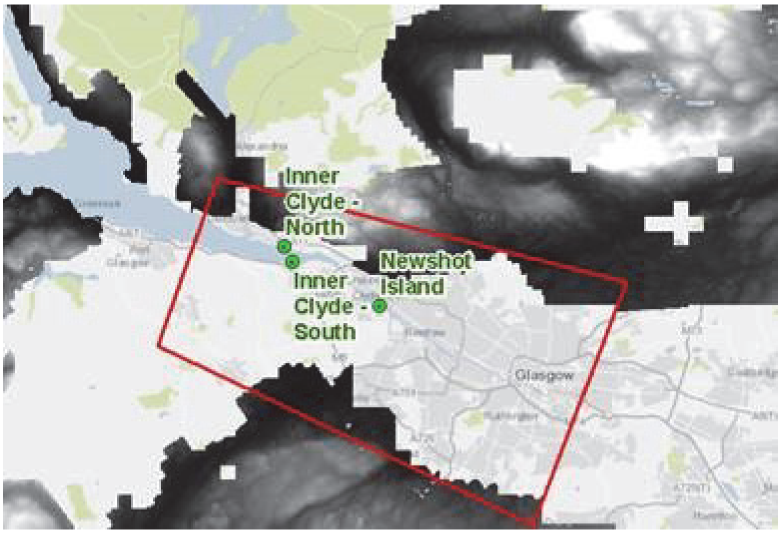

Figure 6. Actual coverage of LiDAR data available to this project for the Inner Clyde area, with the red polygon showing areas of 'No Data' in the case study areas.

4.3 Changes of the Clyde estuary channel bed

It is largely the case that hydraulic modelling for FRM does not include future changes of the river bed, in particular changes of the bed elevation. The River Clyde has a long history of dredging for commercial navigation purposes. Historically dredging occurred in a channel from Greenock all the way to the centre of Glasgow for industrial access, but as heavy industry declined in the city centre, the dredged areas have migrated westwards. Dredging of the Clyde now occurs up to the BAE Systems site in Govan with very limited ad hoc dredging further east (e.g. for the River Festival or Commonwealth Games).

Figure 7 provides approximate predictions of bathymetric changes in the Clyde from the tidal weir at Glasgow Green downstream to Greenock, showing a downstream propagation in higher bed levels. The effects of sedimentation on flood levels were analysed as part of the RCFMS study and the reader is referred to the corresponding report for further details[11], though it is not known whether these predictions were proved to be accurate. It is likely that future sedimentation of the Clyde channel will have implications for the future stability or otherwise of the fringing mudflat and saltmarsh habitat. For example, in places where these habitats are presently erosional, any future additional sediment source derived from increases in bed elevation may have the effect of reversing a long term erosional trend and reinvigorate not only the feed of fine sediment but also vegetation growth.

[11] Halcrow and Fairhurst 2005.

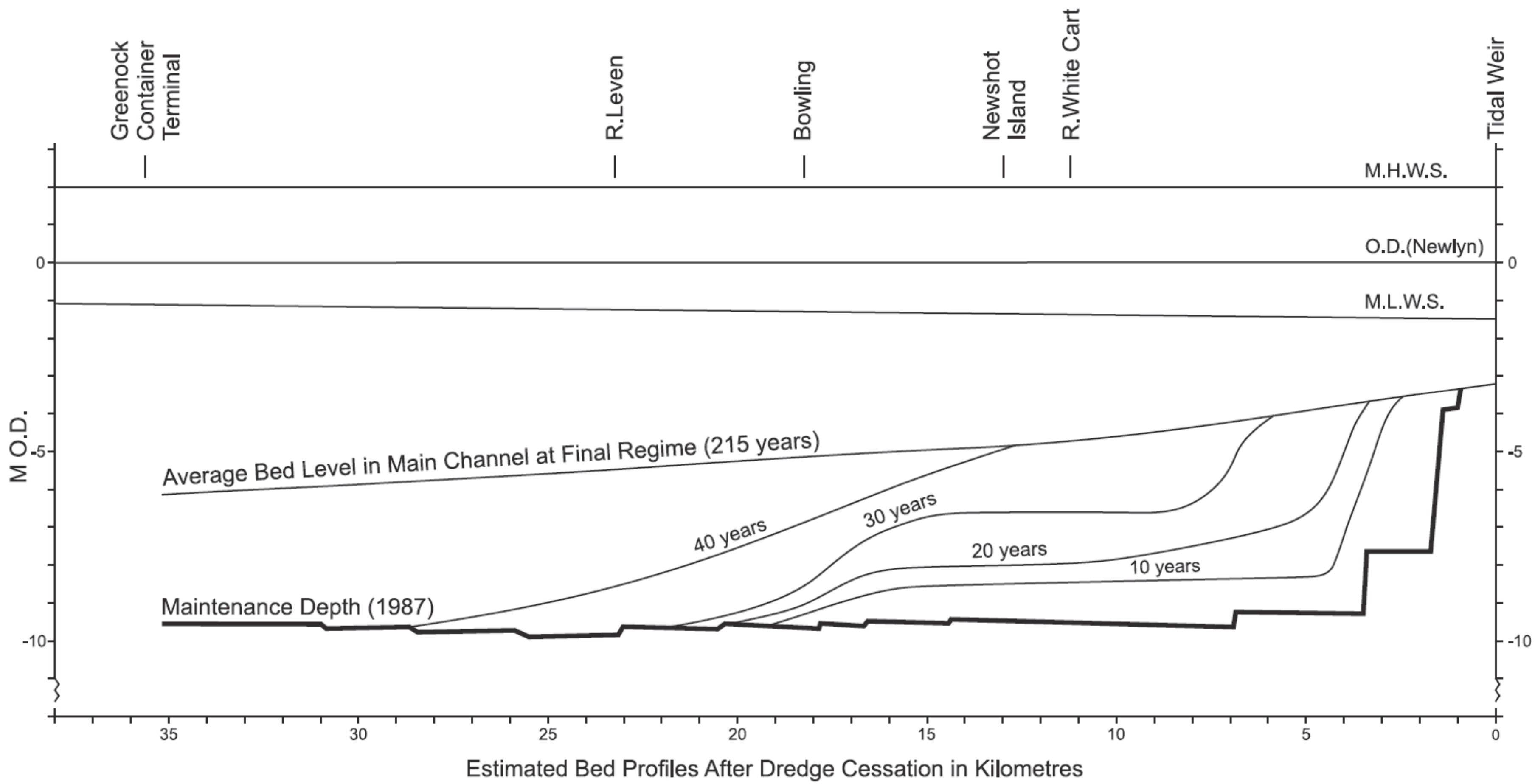

Figure 7. Prediction of changes to River Clyde bed level following cessation of dredging (based on an original sketch provided by Peel Ports Clydeport, date unknown).

4.4 Numerical calculations of sea-level rise and storm surge due to climate change

4.4.1 Introduction

The UKCP09 sea-level projections[12] are based upon information derived from the IPCC[13] Fourth Assessment Report (IPCC AR4, 2007). The IPCC AR4 gives an estimated range (5th to 95th percentile) for global sea level to increase by 18–59 cm between 1980–1999 (the baseline) and 2090–2099. The report estimates that approximately 60% of this rise will be due to thermal expansion with the remaining 40% being due to melting glaciers, ice caps and the Greenland and Antarctic ice sheets. However, the lack of sound current scientific understanding surrounding ice sheet behaviour and impact on global and local sea levels places limits on sea level projections. Due to this, the report provides an additional High++ Scenario. The bottom of H++ is taken from the maximum global mean SLR value from IPCC AR4. The top of the H++ range is derived from indirect observations of SLR in the last interglacial period but is thought to be an unlikely scenario.

For regional SLR projections, the global projection data needs to be combined with changes in the geographical pattern of sea level relative to the global mean. The IPCC AR4 analysed regional patterns of projected sea-level change for simulations from 16 atmosphere-ocean models (multi-model ensemble or MME) forced by the Medium Emissions scenario. Eleven model runs were produced by MME. Most of these were similar to global trends but there are exceptions with one model showing a UK increase of almost double the global mean whilst another shows about half of the global mean.

The estimates from the MME were then combined with land ice melt estimates to give total (absolute) projected sea-level change for the UK for three scenarios in the 21st century (before considering land movement). The vertical land velocities used in UKCP09 are taken from Bradley *et al.* (2008) and are treated as constant for the 21st century projections. Absolute sea-level changes and vertical land movements were then combined to provide estimates of relative SLR; assuming that the vertical land movement rates will remain relatively constant over the 21st century.

Research is currently under way at the University of Glasgow to assess whether the rate of change of vertical land movement is slowing across Scotland. The rates of vertical land movement certainly vary across Scotland and overall uplift rates are expected to decrease over time. Thus, for the Clyde, this study's calculations are likely to be conservative estimates of the combined effect of SLR and a slowing rate of land uplift. At present there is no location on the Scottish coast that experiences land uplift of the magnitude that outpaces SLR and although several areas are experiencing land subsidence which compounds the effect of SLR, these lie outwith the Clyde area (Rennie and Hansom, 2011).

4.4.2 Methodology

The estimates of relative SLR and storm surge component represent incremental changes over a particular baseline dataset of extreme tide levels. In this study the most accurate and recent values of extreme still sea water levels for Scotland were provided by the Coastal Flood Boundary Conditions (CFBC) (see section 4.5.3), setting out the baseline water levels along the coastline. Therefore, the estimates of SLR were added to the extreme still water levels in CFBC. Annex 1 outlines the methodology that has been used to calculate relative SLR, and the degree of uncertainty in the method, and how other factors may affect the estimates i.e. modelling uncertainty, vertical land movement, and coastal erosion.

[12] Lowe *et al*, 2009
[13] Intergovernmental Panel on Climate Change

Two design return periods were considered in the calculations: 1 in 1 year (100% AEP[14]) and 1 in 200 year (0.5% AEP) to represent the range of frequent and rare events in the study area.

The agreed confidence intervals[15] adopted were 95% for SLR and 50% for storm surge; the horizons (target years) considered were 2020, 2050 and 2080. Initially the Medium Emissions scenario was considered.

At a later stage in this study, the Firth of Clyde Forum requested the adoption of the High Emissions scenario for 2080 as the design basis. The estimation of the impact of climate change on SLR and storm surge for these later conditions are the only ones reported here, as they were considered to be the most relevant or likely to occur (data suggests that we are on a High Emissions trajectory) and to be in line with SEPA which uses the High Emissions scenario in its modelling work.

Please note that UKCP09 data provides increases of sea level from the year 1990 whereas the baseline year for CFBC data is 2008. Therefore, in order to combine the two data sets, the climate change assumed to have occurred from 1990 to 2008 must be “discounted” from the final estimates.

Figure 8 shows a work flow of the process for estimating maximum still water levels for this study.

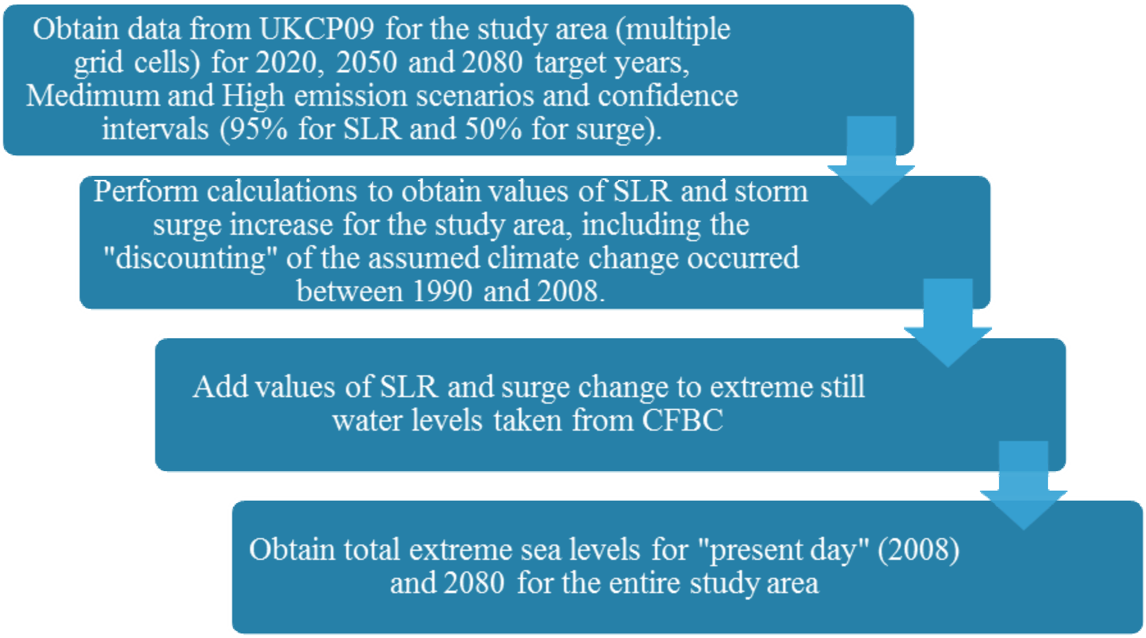

Figure 8. Work flow for the assessment of maximum still water levels due to climate change.

4.4.3 Baseline sea levels

The predictions of increases of sea level and surge calculated here provide figures of the additional extreme still water level likely to be caused by climate change. These values must

[14] Annual Exceedance Probability: probability that an event of equal of greater magnitude occurs in any given year.

[15] The percentage stated in the confidence interval is defined here as the probability that the value calculated is within the range defined by the confidence interval. For instance, if there is a 95% confidence of sea- level rise being X, there is 95% chance that the actual value of sea-level rise will fall within a range up to and including X but with a 5% chance that it will be greater than X.

be applied to baseline sea levels (1980–1999) during extreme events in order to produce total water levels. Please note that the values correspond to still sea levels only and no wave action is considered.

These baseline water levels were taken from the information contained in CFBC; a government led research programme supported by the Environment Agency, Scottish Government, DEFRA and SEPA[16]. It produced maximum still water levels along the UK coast every 2km for a range of extreme tidal/storm events. The original data set did not include the inner lochs in the study area. Projections were extended into the inner sea lochs and estuaries as part of SEPA's coastal hazard mapping project using a combination of results from local studies, observed tide level data and, where no other data were available, by borrowing the sea-level gradient within the estuary or sea loch from similar estuaries or sea lochs for which data were available[17]. Within the study area SEPA's coastal hazard mapping project used levels from the River Clyde Flood Risk Management Strategy[18] between Greenock and the tidal weir in Glasgow, elsewhere borrowed relationships were used (see Figure 9). The extended data were provided to the project team by SEPA consisting of a GIS layer of points along the coast perimeter.

[16] https://www.gov.uk/government/publications/coastal-flood-boundary-conditions-for-uk-mainland-and-islands-design-sea-levels
[17] Royal Haskoning DHV and JBA 2013
[18] Halcrow and Fairhurst 2005

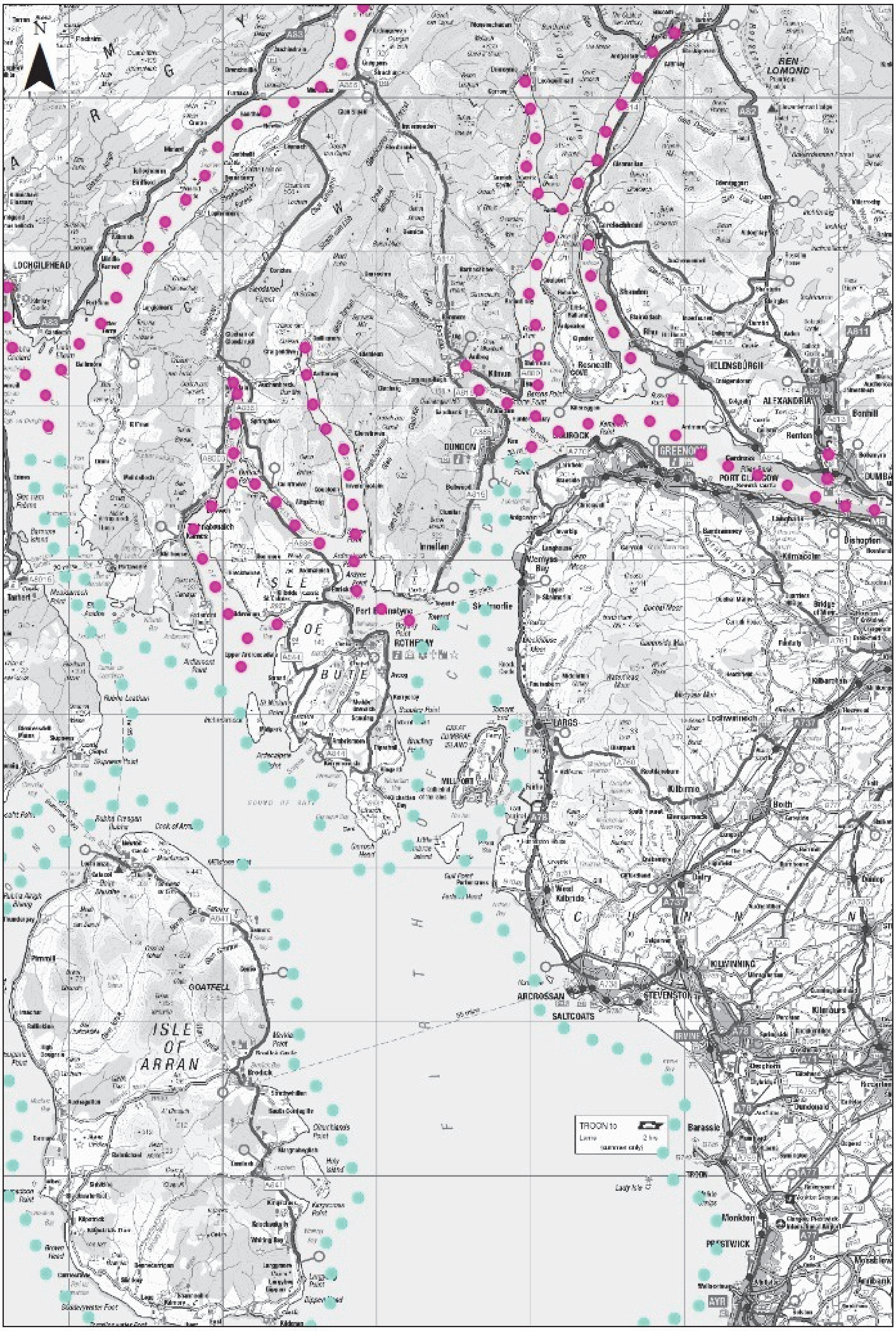

Figure 9. Map showing CFBC data points in blue, with SEPA extension included in pink.

4.4.4 Estimates using High Emissions scenario

The initial estimation of SLR and changes in storm surge due to climate change predictions across the Firth of Clyde was based on calculated values at a selection of grid squares[19] spanning the study area (Annex 1) for the Medium Emissions scenario. The final SLR predictions were based on the High Emissions scenario, taken from UKCP09 data and an academic publication supported by SNIFFER (Ball *et al*., 2008).

The SNIFFER report studied coastal flood risk in Scotland. It shows a map of the Scottish coastline colour-coded with the estimated SLR between 2000 and 2080 (see Figure 10). For the Firth of Clyde three ranges apply, decreasing in value from SW to NE. The scenario A1B (Medium Emissions, which is the same as initially applied in this study) is given as the main one, with A1FI (High Emissions) also provided for comparison. The values range from 1.6 – 24cm in the SW to -2.4 – 20cm in the NE for A1B. For the A1FI scenario the values are 6.6 – 35cm to 2.6 – 31cm respectively; which shows an increase in the SW of 5-11cm from the Medium to the High Emissions scenario. These predictions are based on the IPCC AR4, which is the same one used by UKCP09 and thus, our source data.

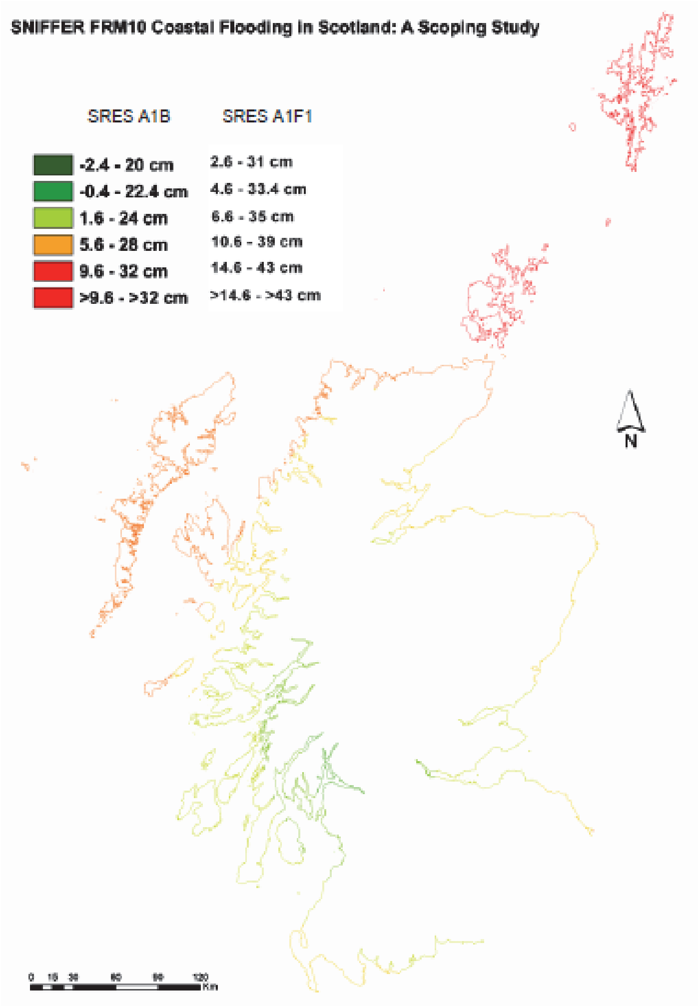

Figure 10. Maps from Sniffer report FRM10 showing estimated sea-level change (cm) around the Scottish coast between 2000 and 2080 for A1B and A1FI scenarios.

[19] UKCIP data are produced over a grid covering the UK

The results of this present study showed that SLR values are similar across the Firth of Clyde within each target year (horizon) and so, their values were grouped into a single figure per horizon for the whole extent of the study area (see Annex 1).

In the case of storm surge changes due to climate change, the values showed higher variability, with increases as well as decreases depending on the grid square (generally decreases in the north and increases in the south). However, the values of future changes in storm surge were very small (millimetres) compared to those of SLR (tens of centimetres) and amount to 1% of the SLR, suggesting that the contribution of storm surges to SLR will change little with climate change. There is also a 10% or greater chance of these values arising by chance. Thus, surge results were amalgamated with SLR to form a single value for the Firth of Clyde (Annex 1). No data were available to allow calculations of storm surge 'funnelling' in the more constricted areas of the Clyde (Figure 2, Annex 1).

The calculations undertaken show a net SLR for the study area for 2080 under the High Emission scenario of 0.465m (base year 2008). The net SLR obtained by adopting the High Emissions scenario is approx. 0.1m higher than that for the Medium Emissions scenario for 2080.This value of difference between High and Medium Emissions is very similar to that in Ball *et al*. (2008); a reasonable outcome since both studies used the same sources.

4.4.5 Adopted absolute still sea levels

Design maximum still water levels will be determined by adding the values in Table 2 to the water levels defined by CFBC along the coast line of the Firth of Clyde, including the extension to the inner lochs done by SEPA (Figure 9). This operation was carried out in GIS, to produce a continuous surface of maximum water levels for each horizon and return period.

Table 2. Summary of final estimates of increase of still sea level due to climate change predictions using High Emissions scenario (Note: the mapping outputs in Annex 7 show the 1 in 1 and 1 in 200 year scenarios for 2080).

Target year	**2020**		**2050**		**2080**	
Event RP (yr)	1	200	1	200	1	200
Adopted total SLR (m)	**0.06**		**0.24**		**0.47**	

For mapping purposes, the 1 in 1yr and 1 in 200yr water levels for 2080 are selected, as this timescale is considered to be when SLR will be starting to rise more rapidly.

The mapping of projected SLR for this project is described further within Section 5 below.

4.4.6 Comments on IPCC AR5

When the present project started in September 2013, the most recent climate data for the area were provided by the UKCP09. Since then, the Intergovernmental Panel on Climate Change (IPCC) has released a revised report (Fifth Assessment Report, AR5) in 2014.[20]

SNH and Firth of Clyde Forum requested the inclusion of outputs of the latest climate change report within the present study in some form. However, there are no specific data for the Firth of Clyde that can replace the calculations already undertaken using UKCP09 data. For completeness, we include below a summary analysis of the AR5 predictions in order to

[20] https://www.ipcc.ch/report/ar5/

provide an indication of the additional possible increase of SLR in the study area. A more complete assessment can be found in Annex 1B.

This analysis is based on the following sources:

- Global mean SLR. IPCC WGII AR5 final draft report. Table 5-2; and
- Briefing on SLR produced for the Scottish Government by SNH in February 2014.

The Scottish Government Briefing states:

> *"IPCC AR5 uses a new set of emissions scenarios which are mostly not directly comparable with AR4. However, sea level rise has also been modelled using A1B[21], which was used in IPCC AR4 and UKCP09. A comparison of global average sea level rise is given (IPCC AR5 WG1 – Table 13.6) and there has been revision upwards with a new central estimate higher than the old upper estimate.*
>
> *AR4 models (SRES A1B) 1990-2100 = 0.37 [0.22 to 0.50]*
> *AR5 models (SRES A1B) 1996-2100 = 0.58 [0.40 to 0.78]"*

Therefore, it appears that the revised predictions for global SLR (AR5) are approximately 60% higher than the previous assessment (AR4). It is unknown whether a similar percentage will apply to the relative SLR estimates currently available for the Firth of Clyde via UKCP09, as the IPCC AR5 outcomes have not yet been translated into small scale geographical areas. However, it is likely that these would occur at local level in UK waters and so it is worth noting this increment of the SLR projection.

[21] Scenario A1B appears to be the so called *Medium Emissions scenario* (http://www.ipcc.ch/ipccreports/tar/wg1/029.htm), which is the one used in the Forth of Clyde study.

5. MAPPING

5.1 Introduction

The maps produced as part of this study are aimed at illustrating the additional areas at risk of coastal flooding if the estimated SLR and storm surge increase occur. Therefore, the emphasis is on the differences between “present-day” flood extents and “future” estimates of maximum still water levels.

The mapping exercise was carried out in GIS. The area of land below the estimated extreme still water level at each location was highlighted with colour. The land elevation was based on LiDAR data provided by the Scottish Government. The extreme still water levels were obtained from the Coast Flood Boundary Conditions data set, provided by SEPA to the project team.

It is noted that there are areas on some of the output maps that show localised areas of potential flooding inland from the coast e.g. Annex 7, overview map 020, Stevenston. These are discrete areas of low-lying land, which the model highlights as within the zone of potential flooding, but local topography (lack of connectivity) between the coast and these would prevent them from flooding from the sea. This occurred infrequently in the mapping and did not impinge on the validity of the mapping exercise.

5.2 GIS Sea Level Rise Flood Mapping Process

The GIS process utilised is shown in Figure 11 and was managed through the creation of a tool to batch process the series of SLR flood return periods, plus those for present day and the High Emissions scenario.

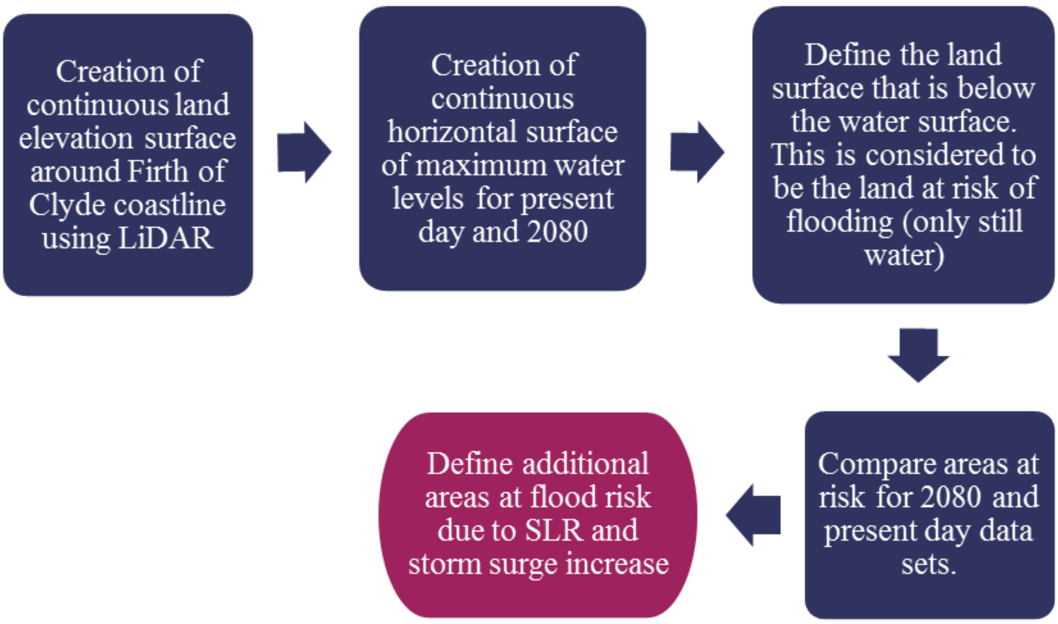

Figure 11. Process flow chart for the mapping exercise.

The first stage was to determine an appropriate model area along the coast to be used as a boundary to mask the DTM elevation model. The DTM indicates the ground elevation of the model area and was used to identify where the modelled SLR results would elevate above ground level and so indicate the areas at risk of flooding. The DTM resolution for a majority of the model area was 1m using LiDAR data sourced from the Scottish Government. The case study areas of Newshot Island and Inner Clyde North and South used DTM data with a resolution of 5m, sourced from Ordnance Survey Terrain 5, since no 1m DTM data coverage was available to the project team.

The second stage was to produce a surface containing the modelled values of SLR which covered the entire model area for each flood return period (1 in 1 year and 1 in 200 year events), for the present day scenario and the High Emissions scenario in 2080. Using the CFBC points containing the modelled values of SLR, Thiessen zonal polygon areas were generated which were then used to create a continuous horizontal surface containing the modelled CFBC SLR values.

The next stage in this process was to compare the SLR surface and the DTM ground elevations to calculate where the SLR values were above ground level, indicating flooding. This comparison subtracted the SLR surfaces from the DTM ground level surface for each flood return period and scenario. The positive values from this comparison show the areas in the model area that are flooding and the negative values indicate the areas where the ground level is above the modelled SLR levels, therefore not flooding. All positive values were extracted and used to generate flood extent area features for each flood return period.

The results from the comparison produced the flood extents for each scenario and flood return period. In order to show the areas of additional risk, the flood extents of the present day scenario were compared against the extents of flooding in the 2080 High Emissions scenario. The High Emission SLR flood extents were adapted to indicate only the areas of additional flood risk in the 2080 High Emissions scenario for each flood return period and each scenario.

The accuracy of the mapping outputs is dependent on both the accuracy of the predicted water levels and from the resolution of the DSM data. All mapped outputs underwent a quality assurance check by the GIS specialist.

5.3 Mapping Overview and Case Study Areas

The results from the GIS Sea-Level Rise Mapping tool were symbolised to indicate areas of flooding in present day (Blue) and areas of additional flood risk in a 2080 High Emissions scenario (Red) for both flood return periods.

The mapped SLR results were overlaid on top of an Ordnance Survey Open Data Basemap and, where data were available, local development plans sourced from the relevant Local Authorities and environmental constraint data sourced from SNH. Overview plans were produced at a 1:25,000 scale running along the Firth of Clyde Coastline within the model area. More detailed plans were produced for the case study areas of Holy Loch, Newshot Island, and Inner Clyde North and South at a 1:15,000 scale. Further plans were produced of the Inverclyde area at a 1:10,000 scale.

5.4 SEPA FRM mapping

It is important to outline the key differences between the SEPA FRM mapping exercises that have been undertaken, and those outlined above for this study.

SEPA has investigated and mapped a range of coastal flood levels, and the maps shown on the flooding website (http://map.sepa.org.uk/floodmap/map.htm) show Present Day[22] High Risk (1:10yr), Medium Risk (1:200yr) and Low Risk (1:1,000yr) scenarios. SEPA estimated the flood levels for these events based on the Coastal Flood Boundary methodology, which takes expected extreme still sea levels at known ports and interpolates these around the

[22] Present Day here is used to refer to the baseline year for the Coastal Flood Boundary Conditions data set, which is 2008.

coast (estimates are generated every 2km along the UK coast). These levels were then projected landward and the land below specific flood levels is highlighted in the maps.

In conclusion, Arup (within this project) and SEPA (more generally) have used a very similar mapping method to identify areas expected to experience coastal flooding. SEPA's published maps consider extreme sea levels at present (2008), whereas this study incorporates the estimated SLR by 2080 under the High Emissions scenario (UKCP09 data) on top of the levels used by SEPA.

6. CASE STUDIES

6.1 Introduction

A core component of the original tender bid requirement was that a case study area or areas should be selected in consultation with the steering group in order to assess the impact of SLR and storm surge on the Clyde. These case studies can be used to demonstrate the potential for, and key elements of, a MR strategy for the Clyde. This section draws on both desk-based modelling as well as field observations at the case study locations. It is structured around the core aims of the case study as follows:

- An assessment of the current erosion and habitat degradation risk as well as additional risks associated with future SLR e.g. evaluation of the risk of reaching an ecological tipping point that might trigger rapid increases in erosion and/or habitat degradation (section 6.3); and
- Evaluation of the MR potential for each of the case study areas, identifying those areas which are most highly suited for MR; those areas where a phased MR could be adopted to gradually realign the coast with SLR; those areas where erosion and/or habitat degradation risks are increased and those areas which are least suited to MR where alternative 'environmentally engineered' approaches could be adopted to improve habitat provision with more limited erosion and flood alleviation benefits (section 6.4).
- A summary of current conditions, potential future risks and MR strengths and weaknesses for each case study in this section. Section 7.3 outlines habitat mitigation and feasibility risks for each site.

A paper to introduce what is meant by MR, why it is being considered as a long term coastal management tool, and the associated benefits and non-benefits, can be found in Annex 8. In brief, MR is a 'soft' engineering technique where river, estuary and or coastal waters are deliberately allowed to extend beyond current flood defences. In the UK, the first deliberate MR site was an area of 0.8 hectares at Northey Island in the Blackwater Estuary, Essex, which was flooded in 1991. This was done by breaching an existing embankment and was chosen as a demonstration project for habitat creation and this procedure has been followed in Scotland at Nigg in the Cromarty Firth, where a small site has been used by RSPB as a demonstration site.

The potential benefits of MR in any given area are as follows:

- Improved ecological condition of habitats, with significant areas of habitat valuable for wading birds and fish;
- Habitat offsetting, compensating for the loss of coastal habitats by creating new areas of valuable habitat;
- Positive impacts for recreation and tourism;
- Carbon sequestration service; and
- Improved flood defence, with the habitats providing buffer zones that reduce the size and maintenance requirements of sea wall defences.

There are also potential non-benefits to consider:

- Loss of land that had previously been protected by flood defences;
- The likelihood of land-owner disputes over compensation;
- Resistance of local communities to "sacrificing" land to the sea;
- Recreated habitat quality may take some time to reach equivalence with natural inter-tidal habitat; and
- Requirement to create new defences further inland of the MR site.

Nevertheless, overall there is scientific agreement that the potential benefits provided by MR greatly outweigh the potential non-benefits.

6.2 Case Study Selection

Following close discussions with the FoCF team and further funding from the project partners, two key areas were examined in detail (Figure 12):

- Both north and south banks of the inner Clyde estuary between Dumbarton and Erskine, although this was subsequently extended on the south side to include Newshot Island; and
- Holy Loch, including the main loch seaward of the A815 and A880 and the river delta upstream of the road inside the National Park.

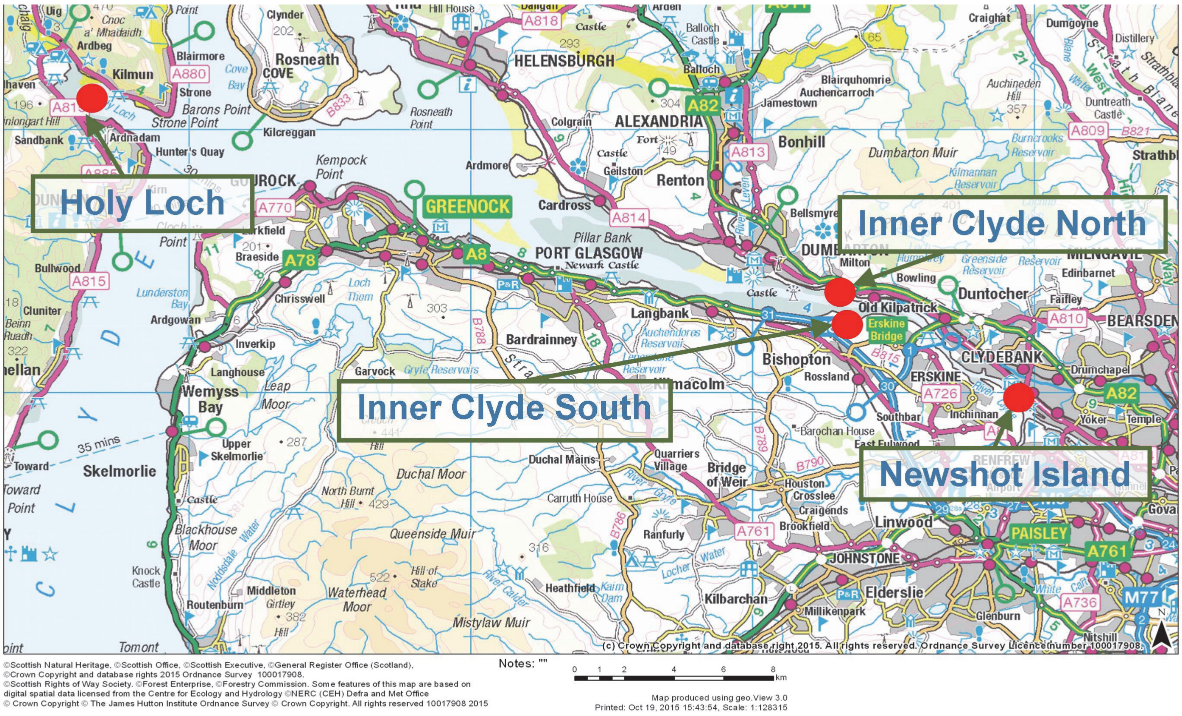

Figure 12. Case Study locations.

The case studies are representative of two of the three dominant coastal settings in the Firth of Clyde that may be subject to climate-driven change in the future. The coastal setting not covered by the case studies is a low-lying, open-coast beach and dune setting such as the areas around Prestwick, Ayr and Troon, since almost all of these urban areas are backed by substantial seawalls with little immediate prospect of MR potential. The case study areas are discussed below individually within each sub-section.

6.2.1 Inner Clyde Estuary

The inner Clyde estuary area is complex, with a combination of industrial, post-industrial and urban infrastructure, agricultural and recreational land uses, as well as existing saltmarsh and mudflat habitat. The corridor of interest stretches on the north side of the Clyde from Castle Green, Dumbarton to Bowling Harbour (hereafter, Inner Clyde North, centred on grid reference NS 41757 74017) (Figure 13) and on the south side of the Clyde from Langbank to the Erskine Bridge (hereafter, Inner Clyde South, centred on grid reference NS 43344 72797) (Figure 14). It also includes an area on the south bank of the Clyde, upstream and to the east of the Erskine Bridge, known as Newshot Island (hereafter, Newshot Island, centred on grid reference NS 48951 69923) (Figure 15).

Figure 13. Figure to show the location of the Inner Clyde North case study area.

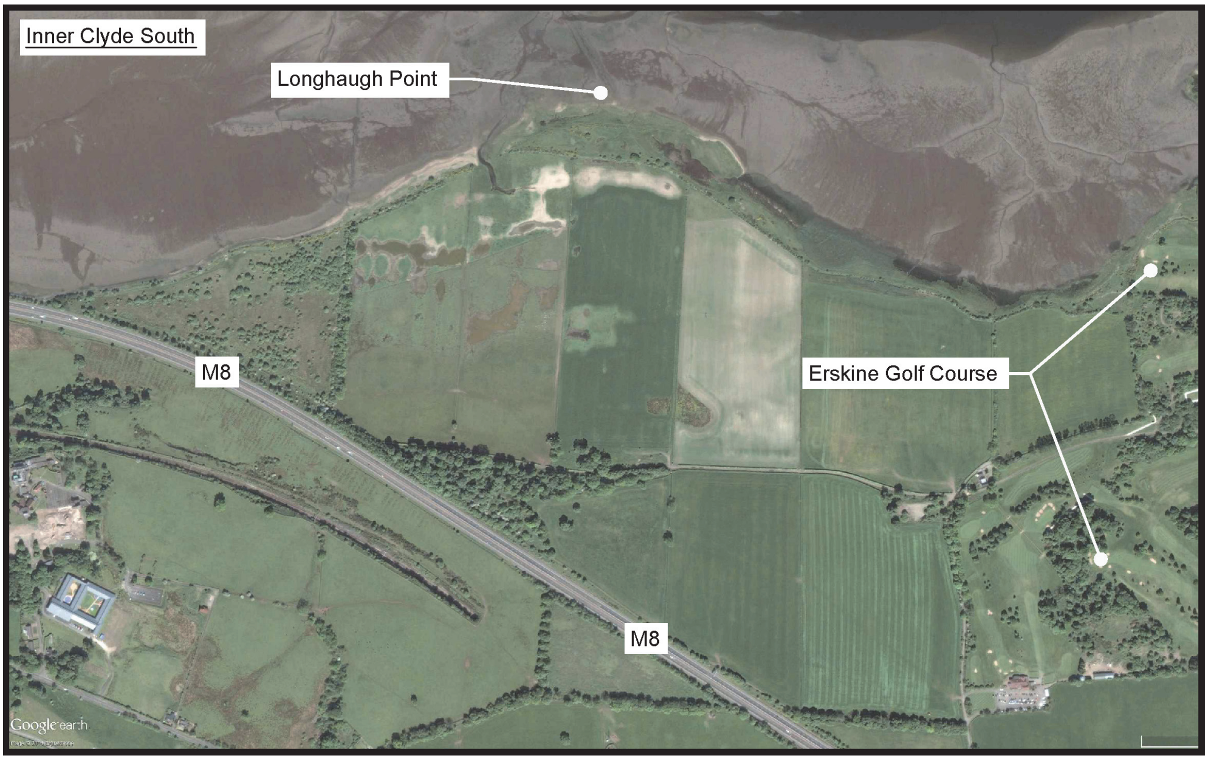

Figure 14. Figure to show the location of the Inner Clyde South case study area.

Figure 15. Figure to show the location of the Newshot Island case study area.

Both sides of the Clyde support industrial, residential and transport infrastructure, particularly on Inner Clyde North where a heavily industrialised area is potentially vulnerable to sea level change, as well as the A82 trunk route and a railway line in addition to important nature conservation assets. This part of the Clyde is a Special Protection Area for redshank (*Tringa totanus*), a Ramsar site, and a Site of Special Scientific Interest (SSSI) notified for birds and for saltmarsh habitat. It includes the Inner Clyde RSPB nature reserve and forms part of two WFD waterbodies, the 'Clyde Estuary – Inner', a heavily modified waterbody and the 'Clyde Estuary – Outer', a transitional water body.

The coastal habitats in the area are primarily mudflats, with some salt marshes, eel grass and mussel beds. These types of habitats are currently at particular risk to erosion (e.g. Foster *et al*., 2013). Any increased erosion associated with storms and SLR will be problematic, particularly where the potential for the habitats to adjust naturally and migrate within an estuary after storm events is limited by structures to the landward, especially at Inner Clyde North.

Along this stretch of inner Clyde estuary there are areas at risk of coastal flooding (e.g. Jones and Ahmed, 2000) – notably the area between the M8 and Erskine Golf Course on the south side of the Clyde, the coastline near Milton and the post-industrial land between Milton and Bowling Harbour (SEPA, 2013).

6.2.2 Holy Loch

The Holy Loch case study site (centred on grid reference NS 15606 81987) lies at the head of the sea loch and covers an area of low-lying agricultural grazing pasture, fronted by a fringing saltmarsh and extensive mudflat (Figure 16). Two gravel-bed rivers enter the intertidal zone at the northern extremity of the saltmarsh, delivering coarse sediment to the area. Past fluvial and glaciofluvial action has resulted in the formation of a series of raised flat-topped gravel terraces into which the present rivers have incised and whose edges mark successive increases in ground elevation. Set well back and above the inter-tidal area, the elevated terraced area is traversed by the A815 road leading north out of the town of Dunoon and along which residential development exists. Coastal flooding of the agricultural land occurs along much of the seaward edge via several failed flap drains and tidal creeks, and minor erosion also occurs along the edges of the two river courses and along the edges of an extensive brackish lagoon close to the river mouth in the north east of the site. The lagoon has been formed by the inundation of former gravel workings of the sands and gravels of the lower glacifluvial terrace. Coastal flooding does not extend upstream of the A815 at the current time.

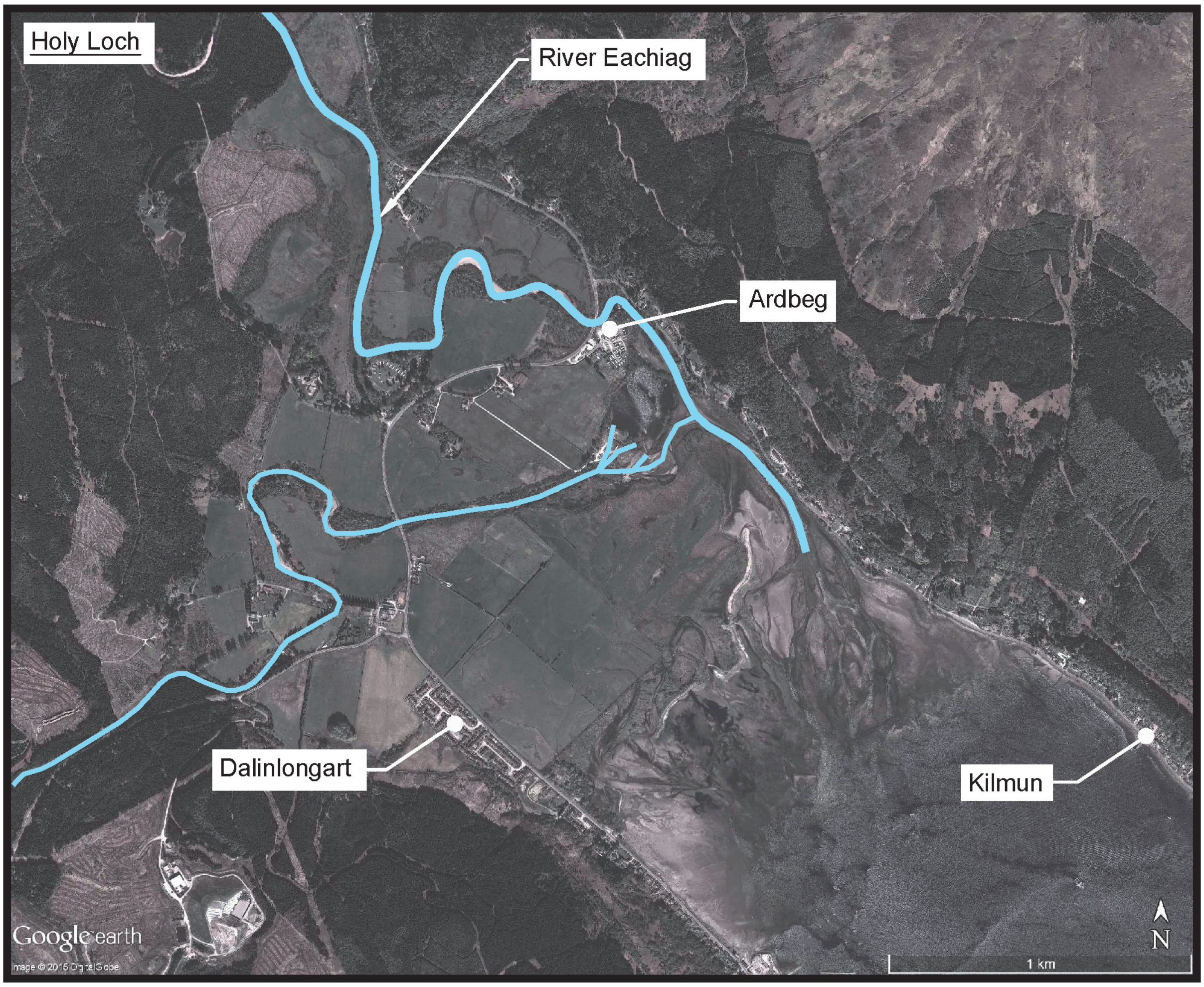

Figure 16. Figure to show the location of the Holy Loch case study area.

6.3 Baseline context, ecological condition, and erosion and habitat degradation risk

Predictions of SLR in the Firth of Clyde (outlined in Table 2 above) show that the still sea level is predicted to increase by 0.06m by 2020, 0.24m by 2050 and 0.47m by 2080. Although the rise in the short term is modest, the subsequent rise to 2050 and 2080 becomes more substantial. However, even a minor increase in the current sea level is likely to result in an increased incidence of the existing rates of coastal flooding, erosion and associated habitat degradation and loss. As well as evidence of coastal flooding, saltwater intrusion, erosion, accretion and/or habitat degradation under current conditions observed during site walkover surveys, the case study areas were also evaluated in light of the desk-based modelling results.

The primary aim of the walkover surveys was to identify areas where present day erosion and deposition is occurring and to assess the potential for MR, since detailed analysis of erosion, accretion and habitat degradation is not required at this stage and is therefore beyond the scope of this study. The risks were assessed for the existing saltmarsh habitat (where present in the case study areas selected) as well as observations of flooding and/or saltwater intrusion of the land adjacent to existing saltmarsh.

6.3.1 Inner Clyde North

6.3.1.1 Physical context

The intertidal foreshore of the north side of the river Clyde between Dumbarton Castle and Erskine Bridge is some 6.8km in length and has been highly modified by human activity for a prolonged period (at least 150 years along most of the intertidal frontage according to an analysis of historic maps) (Figures 17a and 17b over).

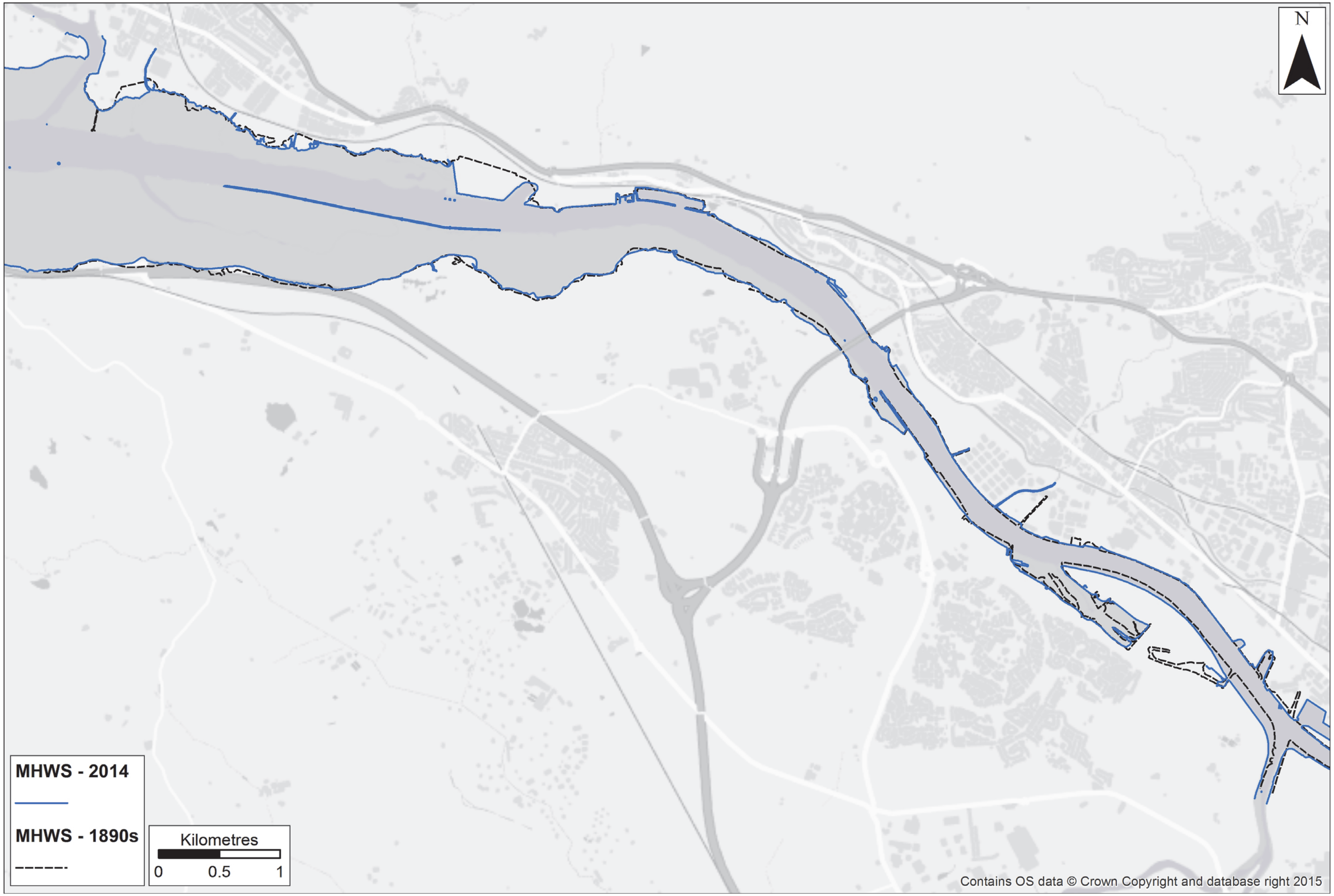

Figure 17a. Georectified Mean High Water Spring (MHWS positions in the Inner Clyde between 1890s (black) and 2014 (blue).

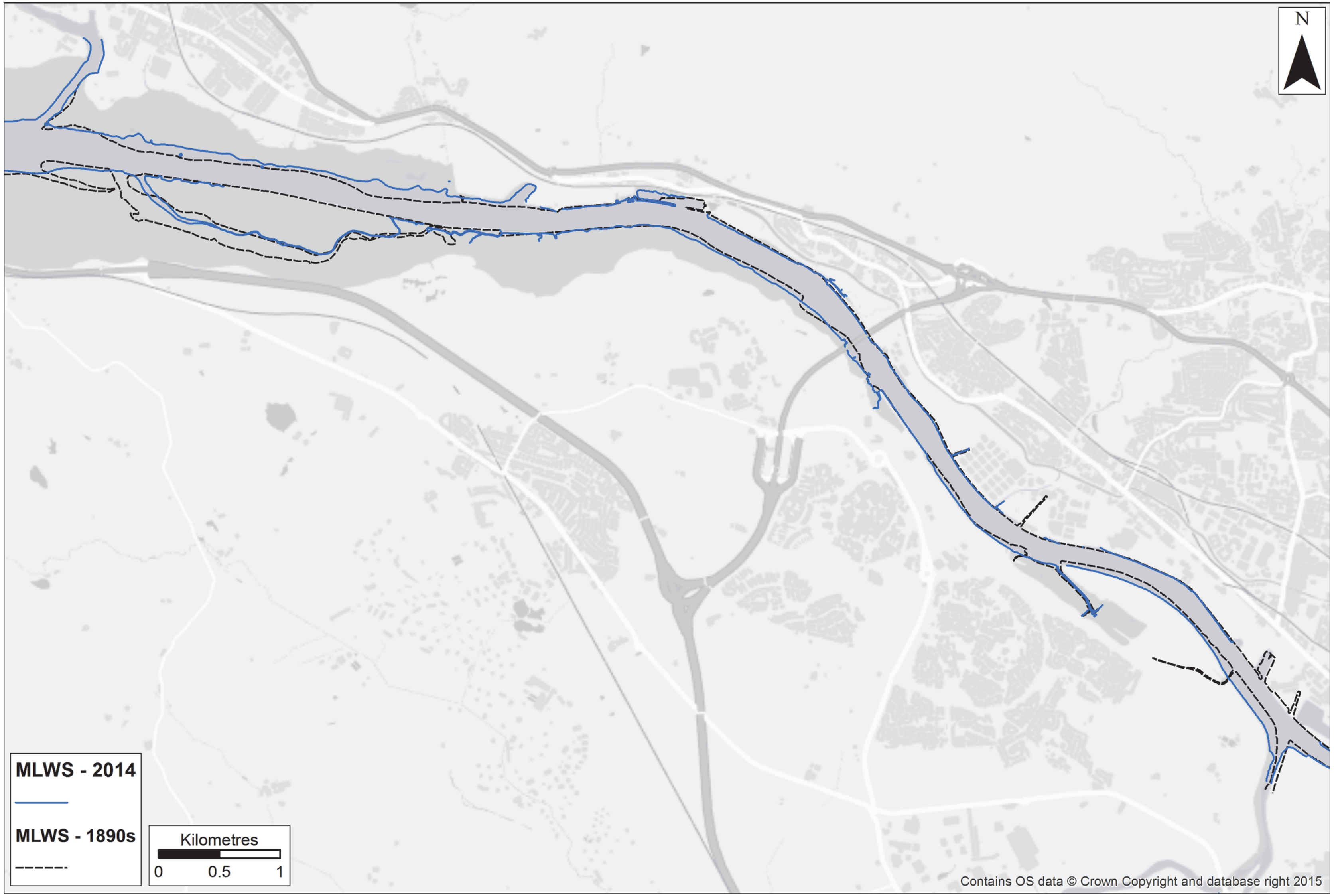

Figure 17b. Georectified Mean Low Water Spring (MLWS) positions in the Inner Clyde between 1890s (black) and 2014 (blue).

Long-term historical industrial activity along this side of the River Clyde, including extensive modification and armouring of the coastline, has resulted in a lack of extensive saltmarsh and mudflat habitat. The terrestrial land behind the foreshore has been highly modified and there is considerable evidence of made ground for large stretches of this area including between Dumbarton Castle and Bowling Harbour and at ‘The Saltings’ nature reserve, immediately below and to the west of the Erskine bridge. This latter site was created from the fill spoil produced when building the Erskine Bridge and the name ‘The Saltings’ is a misnomer, as only the narrow estuarine fringe of this local nature reserve is actually saltmarsh habitat. Just west of Bowling Harbour is an abandoned Exxon oil and gas storage site that is currently undergoing extensive remediation of contaminated land (and at the time of survey was protected along its shore by extensive sheet armour) (Figure 13).

The western limit of the Exxon site (which itself is land claimed since 1900) is marked by a seawall, to the west of which, although limited in area, is the only continuous area of combined saltmarsh and mudflat habitat on this shore. Backing this area of saltmarsh to the landward and west of the Exxon site is the line of an abandoned railway (now a footpath) whose raised bed now represents a barrier to tidal inundation. However, in places land drainage exits with no flap drains allow a limited amount of tidal inundation beyond the path at exceptional tide levels. More importantly, running along most of the Inner Clyde North site between Dumbarton and Bowling Harbour is the main west coast railway line connecting Glasgow with Helensburgh and beyond. This railway, containing walls and raised track bed provides an informal flood defence line under current sea level conditions, although it has been constructed as a coastal defence (Photograph 1). Much of the low lying area behind this railway line is still actively used for light industry and some areas in the vicinity of Dumbarton Castle are in the process of being elevated and converted to housing. In places where land drainage exits (without flap drains) occur, then a limited amount of tidal inundation landward and beyond the track bed occurs at exceptional tide levels.

Photograph 1. Erskine North: Bowling at high tide, with railway line immediately adjacent to the shoreline.

Evidence of erosion

There is clear evidence of active wave erosion and saltmarsh edge degradation (including industrial and domestic waste tipping, flotsam accumulation and incorporation of flotsam into the saltmarsh) of the existing saltmarsh fringe along the Dumbarton Castle to Erskine Bridge (‘The Saltings’ Local Nature Reserve) end of this case study area. Where the erosion has threatened areas of made ground, paths or road access, shore protection structures have been inserted in the past (Photograph 2). Comparisons of MHWS in 1890 with modern mapping shows substantial land claim at Dumbarton Castle and at the Exxon site but elsewhere only very limited amounts of erosion is the norm. On the other hand landward movement of MLWS (up to 100m) along the stretch from Dumbarton to the eastern end of the Exxon site has occurred between 1890 and 2014. Up river of this point there is limited movement of MLWS since the main channel of the Clyde abuts this shore. Thus there has been a net erosion trend of the mudflat over at least the past 100 or so years particularly between Dumbarton and Bowling (Figures 17a, 17b). Analysis of historic maps confirms a similar reduction in saltmarsh extent since the 1850s on this side of the Clyde, associated with edge erosion (Photographs 3 and 4).

Photograph 2. Erskine North: Shoreline immediately to the east of Dumbarton Castle, with hard engineered pathway and eroding saltmarsh present

Photograph 3. Erskine North: Eroding coastline between Dumbarton Castle and Bowling, with former industrial sites and current residential developments in close proximity to the shoreline.

Photograph 4. Erskine North: Limited areas of salt marsh are present along most of this stretch, and evidence from historical maps shows that the shoreline is current eroding.

In addition to the erosion outlined above, evidence of tidal inundation occurs along the accessible stretches of the main railway line (such as at the railway underpass to the east of Orissa Drive), and on the abandoned railway line (close to the Exxon Site). Culverted drainage channels through the railway lines serves to allow occasional saline penetration. In both locations, saltmarsh plant species can be found behind the railway line showing that saline conditions, and hence floodwater or saline intrusion is already occurring. As such, if erosion of the saltmarsh edge continues, it is increasingly likely that the railway line (if maintained in its current position) may potentially have to serve as an erosion and flood defence.

Since the current railway line (and the abandoned stretch) are both supported mainly by a simple gravel embankment with no existing coastal engineering strengthening of its seaward facing toe and slope, it will require upgrading if it is to perform an erosion and flood defence function. The present embankment is composed of loose scalpings through which sea water could penetrate and will be easily undermined and eroded by wave activity. These would have to be replaced by larger calibres of material such as granite boulders, or structures such as gabion baskets, if the embankment is impacted in the future by even modest wave activity. Any such works could potentially seek to have flap drains to prevent the incursion of sea water during flood events.

This will be especially important in the near future as new housing is being developed on former industrial land (at Orissa Drive, Dumbarton). The existing risk of flooding and the potential threat from rising sea levels is evident in the design of the new housing estates. The land on which they are being built consists of 2-3 m of elevated made ground to minimise the existing risk of flood events.

The section of the current railway line at Bowling Harbour is supported on its seaward side by a brick retaining wall that is itself within 0.5m of being overtopped at MHWS (Photograph 1). The retaining wall does not appear to be constructed as a coastal defence structure, probably because it was built at a time when the breakwater and defences at Bowling Harbour were intact and provided adequate protection. This is no longer the case because these defences are now derelict and so there is an existing risk of wave and overtopping damage to the retaining wall that supports the rail bed, a risk that will increase with future SLR.

Ecological condition

Much of the saltmarsh along the north side of the Clyde is degraded with industrial waste dumping and flotsam and at first glance appears to be in poor ecological condition (Photograph 4), especially compared to the marshes observed on the opposite bank (Inner Clyde South). In addition, at the north-west and south east ends of the case study site in particular, signs of active erosion can be seen in the low erosional steps (0.3m in height) in the salt marsh edge (Photographs 3 and 4). Figure 18 shows no pioneer species such as *Spartina* spp. or *Salicornia* spp. observed on the lower intertidal, but small patches of lower saltmarsh *Puccinellia maritima* (SM13a) occur on elevated areas of the mudflat in the east, close to the Exxon site. The upper mudflat/saltmarsh is characterised by narrow but continuous stands of *Scirpus maritimus* swamp (S21) backed by *Puccinellia* or *Festuca rubra* (SM16d) dominated saltmarsh before the strandline vegetation *Elytrigia repens* (SM28) is encountered. Towards Dumbarton the marsh/mudflat edge is fringed with *Scirpus* or *Elytrigia and patches of Phragmites australis* swamp (S4), although some *Festuca* occurs at Dumbarton. Plant succession and zonation is restricted and there exists a very abrupt transition from the upper intertidal marsh grasses into mature freshwater species and trees to the rear, probably reflecting a long term erosional trend of the marsh edge and the constraints on landward migration as a result of embankments protecting industrial use and railway lines (Photograph 3 and Figure 17a). Between the former Exxon site and Bowling Station saltmarsh is very restricted and patchy. At 'The Saltings' immediately west of the Erskine Bridge, there exists only a thin fringe since the main saltmarsh areas of the 1900s has been filled in by construction rubble. Overall, the saltmarsh resource of Inner Clyde

North is very fragmented, discontinuous, degraded and peters out to the east to be replaced by coast protection structures. In spite of this, there may be potential for environmentally engineered ecological enhancement of the seawalls and bulkheads of this stretch that may serve to restore habitat connectivity along this side of the River Clyde and, depending on the extent and design of such structures, also provide some flood risk alleviation value. Examples of bioengineering solutions are shown in Annex 9

Overall, pioneer marsh zone species are notably absent from the Inner Clyde North saltmarshes and the total amount of low marsh species is only 0.18ha or 0.9% of the total saltmarsh area (19.2ha). Without intervention via a seeding/seedling programme, this may present an issue for successful saltmarsh regeneration in the short term.

Figure 18. Saltmarsh zones and NVC classification at Inner Clyde North. Source: Haynes (2016). Species detail in text and in Appendix 3.

Potential for flooding, erosion and habitat degradation with sea-level rise

Given that much of the existing saltmarsh edge has undergone recent erosion, and that this is an extension of a long-term trend of erosion and flooding (otherwise there would be no need for retaining embankments along this stretch of the Clyde), there seems to be every expectation that future SLR will result in a continuation of the existing trend. Acceleration of losses to the saltmarsh area will likely occur during south-westerly storms when waves from this direction impinge on the eroding saltmarsh edge. On many open coast sites, the sediment released by edge erosion often results in sediment gain to the saltmarsh surface and so minor marsh surface elevation occurs. However in the Inner Clyde North, the long-term trend of landward migration of MLWS suggests that this has not resulted in gain on the upper saltmarsh and so it is unlikely to do so in the future, especially since the potential for landward migration remains restricted by artificial embankments protecting infrastructure.

With future SLR, erosion and flood risk are set to increase so that existing areas of saltmarsh will be lost and any limited areas of higher ground behind will be subject to more frequent inundation. Saline intrusion already occurs at the land drainage exits under the current railway underpass east of Orissa Drive and at the abandoned railway (now a path) west of the Exxon site. The extent of this flooding will depend on the amount of SLR over the time period of interest; the local topography to the rear of the coastal fringe; and on the future structural integrity of the railway which currently protects this ground - the extent to which it could be breached during flood events now and in the future. If the railway is relied upon as a coastal erosion embankment in the future, then it would need to be upgraded to be a full coastal flood erosion risk alleviation structure. Current developments appear to be considering these future risks where, for example, the new housing development at Orissa Drive has been consented contingent on the land being raised by 2-3m above the pre-existing level (as evidenced by the substantive earthworks and land raising observed being undertaken in late 2013).

Less clear is the future status of the intertidal mudflats along this stretch. MLWS has undergone substantial landward movement over the last 100 years or so and this will continue as sea-level continues to rise. Importantly, the extent of mudflat appears to have decreased over this time period as the landward movement of MLWS has been much greater than the landward movement of MHWS. On the other hand the planned phased reduction in dredging effort in the Clyde upstream of Greenock may result in a rise in the average bed level of the main channel (Section 4.4) that may also trigger sedimentation on the mudflat surface and possibly lead to lateral mudflat expansion in both Inner Clyde North and South. The extent to which this change in sedimentation leads to accretion and improved resilience and extent of mudflats and saltmarshes is largely contingent on our capacity to create accommodation space as MHWS shifts landwards and thus realign our coast as sea-level rises.

Table 3. A summary of the current condition of saltmarsh habitat, evidence of tidal inundation and the potential strengths and weaknesses of Inner Clyde North for MR as a tool to adapt to a changing climate.

Coastal erosion	Erosion occurs along the saltmarsh edge and to the north at Bowling Station, active erosion of a degraded seawall is evident.
Coastal accretion	None is evident
Strengths for Future MR and erosion mitigation	
Engineered environmental enhancements	Future habitat connectivity could potentially be improved by adding structurally engineered saltmarshes as part of future coastal defences that are likely to be required.

Coastal erosion	New defences or rollback will likely be required as sea-level and storminess increase.
Saltmarsh erosion	Active erosion of the seaward saltmarsh edge between Dumbarton Castle and the sewage treatment works was particularly evident.
Weaknesses for Future MR	
Adaptation Space	Is very limited
Suitability of Land for MR	Heavily industrialised, modified ground reduces the economic and ecological feasibility of MR.
Unknowns	• Effects of altered dredging on sediment supply is unclear • Willingness to change coastal planning to allow rollback • Lack of pioneer species may require seeding/seedling programme untested in this area.

6.3.2 Inner Clyde South

Physical context

Inner Clyde South extends from Langbank in the west (grid reference NS 41959 72842) to Erskine Bridge in the east (grid reference NS 46049 72359) and is characterised by low-lying grazing pasture (improved grassland) adjoining the Erskine golf course, both of which grade north toward the foreshore (Figure 14). In the west the M8 parallels the foreshore and runs along the crest of the embankment which is protected along this stretch by boulder rip rap. Elsewhere, most of the upper foreshore is backed by an earth flood bank that, based on analysis of old maps, appears to have been constructed before the 1890s. North of this embankment the saltmarsh extends for a short distance to MHWS before mudflat is encountered down to MLWS. Analysis of historical maps (Figure 17b) shows very little evidence of landward movement of MLWS over 100 years or so as a result of the main channel having been partly canalised in the past for navigational purposes. The only area with some landward movement of MLWS occurs at the Golf Course extending east to Erskine Bridge.

At two locations along this foreshore, small intertidal sand and gravel spits have developed. Fronting part of the Golf Course one of these spits extends for 0.7km and has a westerly extending distal end, suggesting ebb tide control. A saltmarsh has developed in its sheltered lee. There is a shorter and more gravelly spit 0.4km long, sited riverward (east) of the earth embankment. It fronts grazing pasture east of where the M8 meets the foreshore, and to the west of Longhaugh Point. The recurves of this spit extend eastward suggesting its genesis is related to wave activity from the west resulting in foreshore erosion that supplies sediment for spit and saltmarsh building downdrift and to the east.

Evidence of Erosion and Accretion

Evidence of saltmarsh erosion on the south shore is much less evident than on the northern banks of the River Clyde. Erosion and accretion trends are discussed from west to east. At the western end of this study area, substantial stretches of the saltmarsh at the Langbank and M8 end showed only few signs of erosion (Figure 17a). In the middle of the stretch studied, historical mapping analysis shows that the sand spit at Longhaugh Point has developed since 1900 with accretion then occurring to the east, however, this gives way to patches of erosion toward the Golf Course. At one location in the bay to the east of Longhaugh Point, erosion of the earth embankment defence has been extended along a saltmarsh creek to connect with drainage in the fields behind, the enhanced discharge leading to incision of the creek to a depth of 2m below the ground surface and over a distance of 75m into the field to the landward (Photograph 5). Saltmarsh vegetation was also evident landward of the now breached earth embankment. A recent MSc study (Bowyer, 2014) measured salinity inside the existing grazing marsh landward of the breached embankment and has confirmed that the water in and near this creek is brackish, providing strong evidence of saltwater intrusion triggered by erosion and breaching of the earth embankment as well as overtopping into the fields behind.

Photograph 5. Erskine South: Inlet to the stream from low-lying grazing pasture, showing signs of erosion, with saltmarsh habitats encroaching inland.

Photograph 6. Erskine South: Phragmites (S4) swamp reedbed and fringing Puccinellia maritima *(SM16a), located on the landward site of the historical earth embankment, indicates saline connectivity with tidal water in the Clyde estuary north of the embankment.*

Further southeast, an adjacent field landward of the earth embankment (Figure 14, Photograph 6) also shows clear signs of saltwater intrusion as saltmarsh plant communities are found in a location where erosion and breaching of the embankment is not evident. This suggests hydrological connectivity exists between the outer saltmarsh and fields landward of the earth embankment under current sea-level. This contrasts with the saltmarshes immediately below and fronting the three large fields immediately to the west of the Erskine Golf Gourse (Photograph 8) which show ongoing accretion.

Photograph 7. Erskine South: Erskine Golf Course, with gabion baskets in a poor state of repair. The low-lying areas of the course are already subject to coastal flooding.

Photograph 8. Erskine South: Large expanses of good quality saltmarsh habitat between Erskine Golf Course and the M8, the central part of which show accretion northwards but the western (west of Longhaugh Point) and eastern (east of Erskine golf course) ends show minor erosion of the saltmarsh edge.

Ecological Condition

Based on our assessment during a walkover survey, the current saltmarsh habitat on the Inner Clyde South is in relatively good ecological condition in comparison to that surveyed on the Inner Clyde North. Figure 19 shows large areas of *Festuca rubra-Glaux maritima* (SM16c) at the upper mudflat/saltmarsh junction in the east along the Golf Course spit frontage. Behind the *Festuca-Glaux* are stands of *Elytrigia repens* saltmarsh before Phragmites (S4 saline and S21) swamp is encountered. These stands of S4 and S21 extend along the upper mudflat and saltmarsh boundary for most of the distance along the shore to the western spit. The S4 community also occurs landward of the embankment due to salt water seepage through the bank. The western spit is dominated by narrow coast parallel *Puccinellia maritima* dominant subcommunities (SM13a). A small patch of SD8 sand dune occurs on the east of the spit above a small sandy beach. Figure 17a shows a long term increase in saltmarsh extent in the central area between Erskine Golf Course and Longhaugh Point as described above. Other than this limited amount of seaward expansion of saltmarsh in the past 5 years, the extremities to the west and east show erosion of the salt marsh edge.

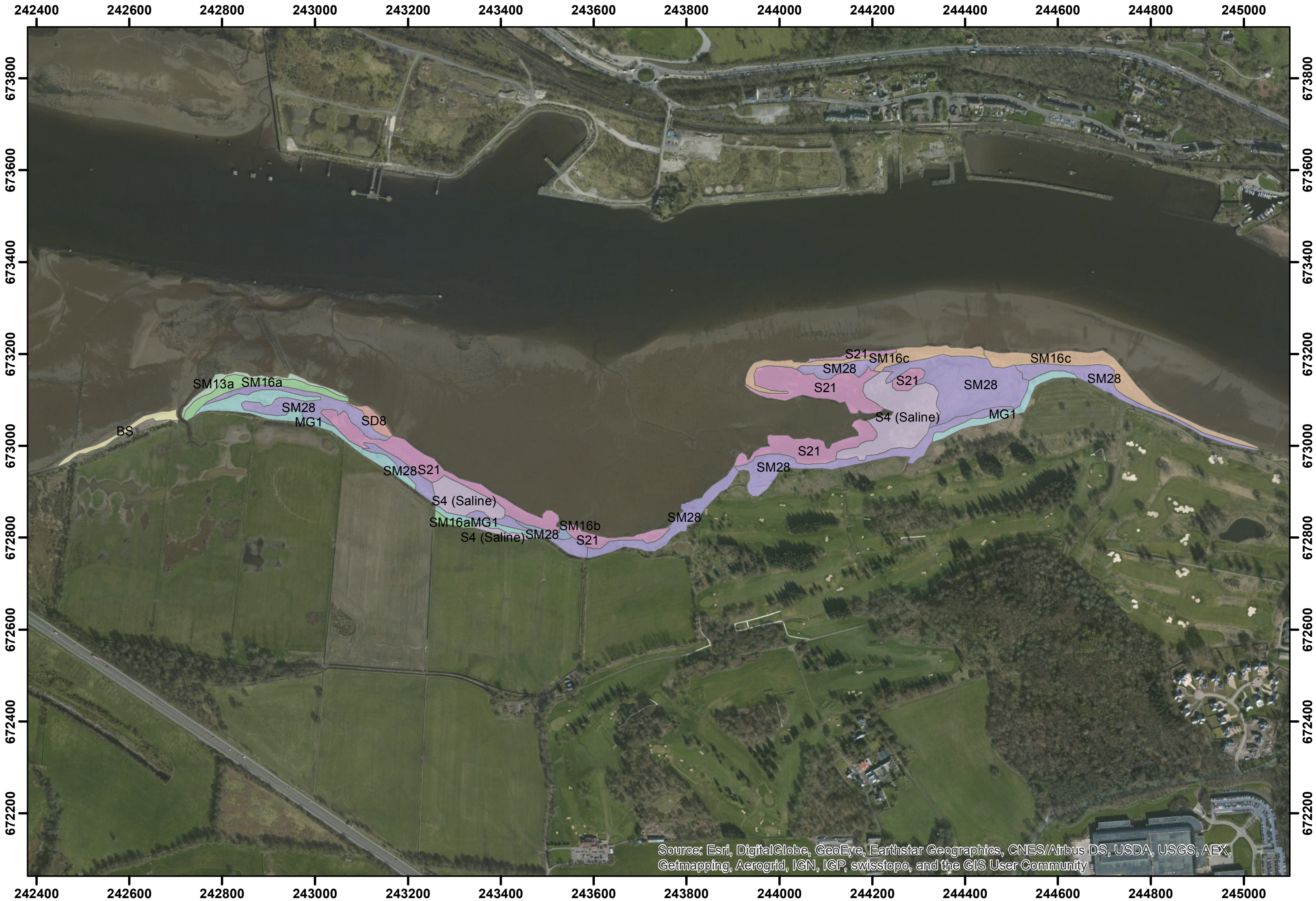

Figure 19. Saltmarsh zones and NVC classification at Inner Clyde South (source: Haynes (2016)). Species detail in text and Appendix 3.

As outlined above, in a number of discrete areas saltwater has penetrated underneath or through the earth embankment as indicated by saltmarsh development on the landward side of the embankment (Photograph 6), with localised areas dominated by stands of common reed (*Phragmites australis*).

Overall, pioneer marsh zone species are notably absent from the Inner Clyde South saltmarshes and the total amount of low marsh species is only 0.32ha or 1.4% of the total saltmarsh area (22.68ha). Without intervention via a seeding/seedling programme, this may present an issue for successful saltmarsh regeneration in the short term.

Potential for flooding, erosion and habitat degradation with sea-level rise

Northwest and central parts of the existing coastal edge have been erosional over recent years (Figures 17a, 17b). There is an expectation that future SLR will result in an exacerbation of the existing trend, leading to an accelerated rate of erosion. This accelerated erosion may be lessened by the proposed changes in dredging regime, but also will be negatively impacted by coastal squeeze. Under storm conditions, the losses will likely occur from the west and north when waves from these directions impinge on the saltmarsh edge which will then be at greater risk of erosion. Sediment released by edge erosion often results in sediment gain to the saltmarsh surface and so it is possible that in some areas, the elevation of the marsh surface may rise in the future and trigger a reinvigoration of saltmarsh vegetation growth. However, the resilience of these marshes to both storms and their enhanced impact as sea-levels rise is contingent on both enough released sediment supply and enough temporal stability between storm events to ensure that pioneer species can become established and allow sediment to be effectively trapped and to sustain marsh elevation or landward migration. One issue is that these marshes are dominated by dense stands of sea club rush (*Scirpus maritimus)* which occupy much of the upper mudflat and saltmarsh edge areas that might otherwise be expected to support the more common pioneer species such as *Spartina* spp. or *Salicornia* spp.

In two places sand and gravel spits have developed. A short and stubby easterly moving spit is attached to Longhaugh Point (Figure 14) and is driven by sediment movement to the east under westerly waves. SLR will likely enhance this eastward movement and reinforce accretion to the east of Longhaugh Point so that the salt marsh is progressively replaced by a sand and gravel spit. The other spit lies due north of the golf course (Figure 14), its westerly progress primarily related to ebb tidal currents reinforced by river flow rather than wave processes. As such, the progress of this spit may be enhanced due to future predicted changes in rainfall and thus peak discharge. The effect of the planned phased reduction in dredging upstream of Greenock, resulting in a rise in the average bed level of the main channel (see Section 4.4) may also enhance sediment supply that will favour westward growth. The extension of this spit to the west will impinge on the mudflat in this area but will enhance saltmarsh expansion in the already enclosed embayment.

With future SLR, flood risk is set to increase along the lower lying parts of this shore as evidenced from our desk-based mapping and flood inundation assessment (such as the lower areas of the Golf Course and the existing tidal creek into the low lying fields behind). It is also expected that the frequency and volume of saltwater flows will increase into those areas where saline intrusion already occurs. The exact amount of this flooding will be dependent on the amount of SLR over the time period of interest matched against the accommodation space (i.e. natural topography and current defences) at the landward edge of the coastal fringe. The landward saltmarsh extent is constrained by embankments and boulder revetment (at the northwestern / M8 end) and gabion baskets at the Golf Course area/southeast end of the Inner Clyde South study area (Photograph 7). Unless land management decisions change substantially to create accommodation space, a real reduction of habitat area is likely. In order to facilitate landward migration of saltmarsh habitat, MR interventions would be required to increase the saltmarsh area, reduce the impact of rising sea-levels and improve the resilience of existing marshes to changing conditions.

Again, less clear is the future status of the intertidal mudflats along this stretch. If management practice change allows greater landward migration of the intertidal zone, then any landward movement of the saltmarsh edge through managed or unmanaged (i.e. naturally breached) realignment will move the upper extent of the mudflat in a landward direction. This could lead to an increase in mudflat extent assuming the lower limit remains as static as it has been for over 100 years (its position defined by the main channel of the Clyde) and that sea-level rise and changing storminess does not disrupt sediment dynamics leading to mudflat loss. Changes in human activities within the river may also mediate these impacts. For example, the planned phased reduction in dredging effort in the Clyde upstream of Greenock will result a rise in the average bed level of the main channel that may trigger sedimentation on the mudflat surface and possibly lead to lateral mudflat expansion.

Table 4. A summary of the current condition of saltmarsh habitat, evidence of tidal inundation and the potential strengths and weaknesses of Inner Clyde South for MR as a tool to adapt to a changing climate.

Coastal erosion	Erosion is variable in this site, with erosion evident at both ends of the study area with notable breaching of the embankment at the northwestern end of the site and secondary defences at Erskine Golf Course at the southern end of the site.
Coastal accretion	Accretion is evident in the middle section of this site (near the spit)
Strengths for Future MR and erosion mitigation	
Engineered environmental enhancements	There is enough scope for more conventional MR designs to be used at this site, such that engineered solutions are less likely to be required. As sea-level rises and/or storminess increases this solution may be deemed necessary if rollback is not undertaken.
Coastal erosion	Rollback will likely be required as sea-level and storminess increase, the topography would allow a natural break of slope to act as a natural defence if farmland and the Golf Course areas were realigned as sea-level rise increases.
Saltmarsh erosion	Erosion is already evident at both ends of the study area, this is likely to increase in the future.
Weaknesses for Future MR	
Adaptation Space	There is considerable adaptation space into fields and the golf course, if land use decisions are taken to enable adaptation.
Suitability of Land for MR	Evidence of brackish water and saltmarsh species behind the current embankment suggest there is good suitability for MR and the local topography favours this with minimal intervention required.
Unknowns	• Effects of altered dredging on sediment supply is unclear • Willingness to change coastal planning to allow rollback • Lack of pioneer species may require seeding/seedling programme untested in this area.

6.3.3 Newshot Island

Physical Context

Newshot Island lies 2.5km upstream of the Erskine Bridge on the south side of the river (Figure 15). It is actually a peninsula extending 1.7km west from the exit of the River White Cart and just less than 0.5km wide at its widest. The island appears to be mainly composed of emerged mudflat sediments possibly interbedded with decayed vegetation evident in the stratigraphy of the eroding 1m high banks along the entire length of its riverside edge (Photograph 9). Newshot was originally a muddy or sandy island that sat in mid channel. However, as bigger ships needed to come up river to Glasgow, the channel on the south or Erskine side of the river was armoured with stone dykes in order to narrow the channel, force faster flow and deepen the channel by scouring. The ‘old channel’ on this south side gradually silted up, allowing the island to elevate in height and extend east to connect with the south bank further up river. Historical First Series 6 inch maps surveyed in 1859 show the course of a proposed new channel along the present route of the Clyde with a smoothed edge to Newshot Island, suggesting that its northern edge may have been artificially excavated. The old channel, that has become the inlet, is shown as a series of shallow creeks with extensive areas of saltmarsh extending the full length of Newshot. The western part of the old channel is depicted on the Second Series 6 inch maps surveyed in 1896 as raised land infilled behind a linear wall and burying the earlier saltmarsh. Remains of an early building and plough marks indicate Newshot was in use as pastureland liable to flooding before 1859. Other than the made ground to the rear and east of the Island, the low-lying ground of Newshot still floods on high tides with the inlets at both ends flooding every tide. As a result Newshot Island provides an internationally significant habitat for over-wintering wildfowl, particularly waders such as redshank from Northern Europe.

Photograph 9. Newshot Island: Earth cliff along the River Clyde, with a large expanse of low-lying areas of grazing pasture that is only occasionally inundated by brackish water and with few saltmarsh species.

To the rear of the western part of the island lies what remains of the old channel: a 0.84km long tidal inlet that is up to 0.2km wide, regularly flooded, and flanked on both sides by saltmarsh dominated by *Phragmites* reed beds (Photographs 10 and 11).

Photograph 10. Newshot Island: Tidal inlet at the downstream end of Newshot Island, with large expanse of existing saltmarsh habitat.

Photograph 11. Newshot Island: Phragmites-dominated expanse of saltmarsh in the Newshot Island inlet.

The tidal inlet is constrained to the south and also to the east by land which rises abruptly to flat terraces at about 4-5 m OD. The uppermost parts of this terrace on the southern side has been developed for housing that extends eastward atop the terrace where it gives way to agricultural fields. To the north of these fields and riverward, a sub-horizontal terrace is bounded in the west by a long rectilinear 2-3m high terrace edge that is artificial and has been in place since at least 1900. Much of this upper terrace surface may thus be made ground before the slope declines in imperceptible steps toward the river and MHWS. The upper marsh surface along the northern shore of Newshot Island gives way to 1m high vertical bluffs that sit above a narrow and bare mudflat surface that, at its widest, extends some 30m to MLWS. The eastern limit of Newshot Island is marked by a small tributary stream that drains from fields behind, with the landward section being obscured by an embankment fronting abandoned industrial workings. To the east, the land is in agricultural use and also houses a sewage works and outfall pipe. To protect this asset, the riverside bank to the east is armoured with a masonry wall along its entire length to the confluence of the Clyde with the River White Cart. The wall shows signs of breaching in two places, the largest of which lies about 100m east of Newshot Island proper, and this has led to erosion eating into the field behind the wall (Photograph 12).

Photograph 12. Newshot Island: Towards the upstream (eastern) end of the study area the arable land and inland sewage treatment works are protected by masonry block hard engineering coastal protection.

Evidence of Erosion

Bank erosion is evident along the western part of Newshot Island where the river bank and saltmarsh edge is severely undercut with about 50m having been lost to the positions of both MHWS and MLWS since 1900 (Figure 17a, 17b). Bank protection is currently lacking in this area but may have previously been in place. However, further east there appears to be only limited loss of saltmarsh edge since 1900 (and little or no erosion). No bank protection is currently in place along most of the island. Only at the extreme eastern end is bank protection in place where a small stream enters. Beyond this to the east, the river bank is continuously protected as far as the White Cart confluence, although breaches in the protecting wall have resulted in minor erosion extending into the field behind. Overall, the position of the river bank at Newshot is almost certainly controlled mainly by river flow conditions and the close proximity of the main channel. It is also possible that any erosion to the western section since 1900 may relate to boat-wash, but this is now much reduced due to a decline in river traffic. Within the inlet behind Newshot Island the modern MHWS lies landward of its 1900 equivalent on both sides of the inlet (Figure 17a), but with limited movement of the MLWS (Figure 17b) and so there has been an expansion of mudflat area as well as of the *Phragmites* reed bed area.

Ecological Condition

Figure 20 demonstrates the lack of saltmarsh habitat along much of the river (northern) side of Newshot Island and its elevation appears to have resulted in mainly freshwater pastureland with some evidence of past plough marks. Two exceptions exist at the eastern end and within the tidal inlet at the downstream end of Newshot Island. The eastern end is dominated by grassland MG12 and 13 but there are also small areas of SM12a (Rayed *Aster tripolinium)* along the upper intertidal slope, and SM28 (*Elytrigia repens*) saltmarsh in the small inlet at the eastern end of Newshot. Within the main tidal inlet at the western end of Newshot large expanses of S4 (saline) *Phragmites* swamp occur (Photographs 10 and 11) but also with small stands of SM16d (*Festuca rubra)* saltmarsh and SM28 (*Elytrigia repens*) along the driftline as well as a fringing occurrence of MG13 around the perimeter of this area. The habitat appears to be in good condition and long-established, but shows a more limited species diversity across the entire area, especially compared to the composition of marshes in Inner Clyde South, which has areas of sea club rush and sea rush, with sea couch grass and scattered *Phragmites* higher up the shoreline. Newshot does, however, form a larger area than the fragmented and degraded saltmarsh habitats on the Inner Clyde North area.

Of significance to any future expansion of the saltmarsh area of Newshot Island is the areal extent of pioneer species with only 0.6ha of rayed *Aster tripolium* comprising 6.6% of the total area of existing saltmarsh vegetation (9ha). Without intervention via a seeding/seedling programme, this may present an issue for successful saltmarsh regeneration in the short term.

Figure 20. Saltmarsh zones and NVC classification at Newshot Island (source: Haynes, T.A. (2016)). Species detail in text and Appendix 3.

Potential for flooding, erosion and habitat degradation with sea-level rise

The existing coastal edge of the western part of Newshot Island has been erosional over the last 100 years or so, and so there is an expectation that future SLR will result in an acceleration of this trend. The losses will likely occur during high river flows coinciding with MHWS and resulting in more frequent overtopping along the river side and within the tidal inlet. As with the previous case studies, it is possible that sediment released by edge erosion may feed elevation of the marsh and reinvigorate saltmarsh vegetation growth but, since this may occur at intermediate tidal levels, much of the released sediment will be exported along the main channel to feed accretion elsewhere (including into the Newshot Island inlet itself). In addition, it is not fully known whether the effect of the planned phased reduction in dredging effort in the Clyde upstream between Greenock and Clydebank may result in enhanced overtopping of the bank and erosion of the bank edge but this is a likely outcome.

With future SLR, flooding frequency is set to increase along the lower lying river bank parts of Newshot Island and within the existing tidal inlet. Unless land management priorities change, rising ground to the rear of both the island and the adjacent tidal inlet will act as a stop-back to limit the adaptive capacity of marshes to respond to coastal squeeze and, whilst defences are maintained, will limit the extent of flooding of landward assets. MR could serve to offset habitat loss, serve as a natural flood management solution and thus sustain important saltmarsh ecosystem services in an area of the Clyde where few exist today.

The extent of intertidal mudflats along this stretch is limited since the gradient is steep along the main channel of the Clyde. Retreat of the saltmarsh edge of Newshot Island will move the upper extent of the mudflat in a landward direction, and may lead to a small increase in mudflat extent.

Table 5. A summary of the current condition of saltmarsh habitat, evidence of tidal inundation and the potential strengths and weaknesses of Newshot Island for MR as a tool to adapt to a changing climate.

Coastal erosion	The seaward edge of the island appears to be actively eroding, but the edge of the marsh does not appear to be subject to much lateral movement over time.
Flooding of land beside existing saltmarsh	Much of Newshot Island is subject to flooding at MHWS with the area of tidal channel to the rear of the island in the west subject to regular flooding at all high tides.
Coastal accretion	There is no evidence of accretion.
Landward Saltwater Evidence	Saltwater intrusion is widespread to the rear and eastern edges (in the old tidal creeks) of the island where *Phragmites* beds are extensive.
Strengths for Future MR and erosion mitigation	
Engineered environmental enhancements	If rollback is the preferred policy option, more conventional MR solutions can be used here. If hold the line is preferred, these approaches may improve ecosystem service provision.
Coastal erosion	Rollback will likely be required as sea-level and storminess increase, the topography would allow for inundation.
Saltmarsh erosion	
Weaknesses for Future MR	
Adaptation Space	There is considerable adaptation space into the island and for the

	historic river channel to be reshaped into a saltmarsh.
Suitability of Land for MR	Subject to the environmental condition of the made ground being favourable, the topography is well-suited to MR.
Unknowns	• Effects of altered dredging on sediment supply is unclear. • Willingness to change coastal planning to allow rollback. • Lack of pioneer species may require seeding/seedling programme untested in this area.

6.3.4 Holy Loch

Physical Context

Holy Loch is 1.5km wide and extends some 4km to the north-west from rocky shores at its junction with the Firth of Clyde at Hunters Quay (Dunoon) on the south shore and Strone Point on the north shore (Figure 16). Much of the north and south shore of the loch is urbanised and protected by seawalls that typically serve as the embankment for coastal roads landward of which residential and commercial land occurs.

Almost everywhere along the sides and head of the Holy Loch there is clear evidence of deposition in the sheltered waters leading to seaward migration of the MHWS, particularly at the head of the loch (Figure 21a). Some areas along the south and north shore have been subject to land claim, denoted by rectilinear sections of the modern MHWS line. The two small spits sited midway along the north and south shores have also accreted. In contrast the position of MLWS shows a landward movement and narrowing of the intertidal gravel beaches along the south shore and with minor movements on the north (Figure 21b). At the head of the loch both MHWS and MLWS have moved seaward by up to 150m between the 1890s and 2014. There has also been a shift in the position of the river exit westwards leading to the infilling of some former river bed areas. The net result has seen a movement seaward and an increase in the intertidal area over 120 years or so.

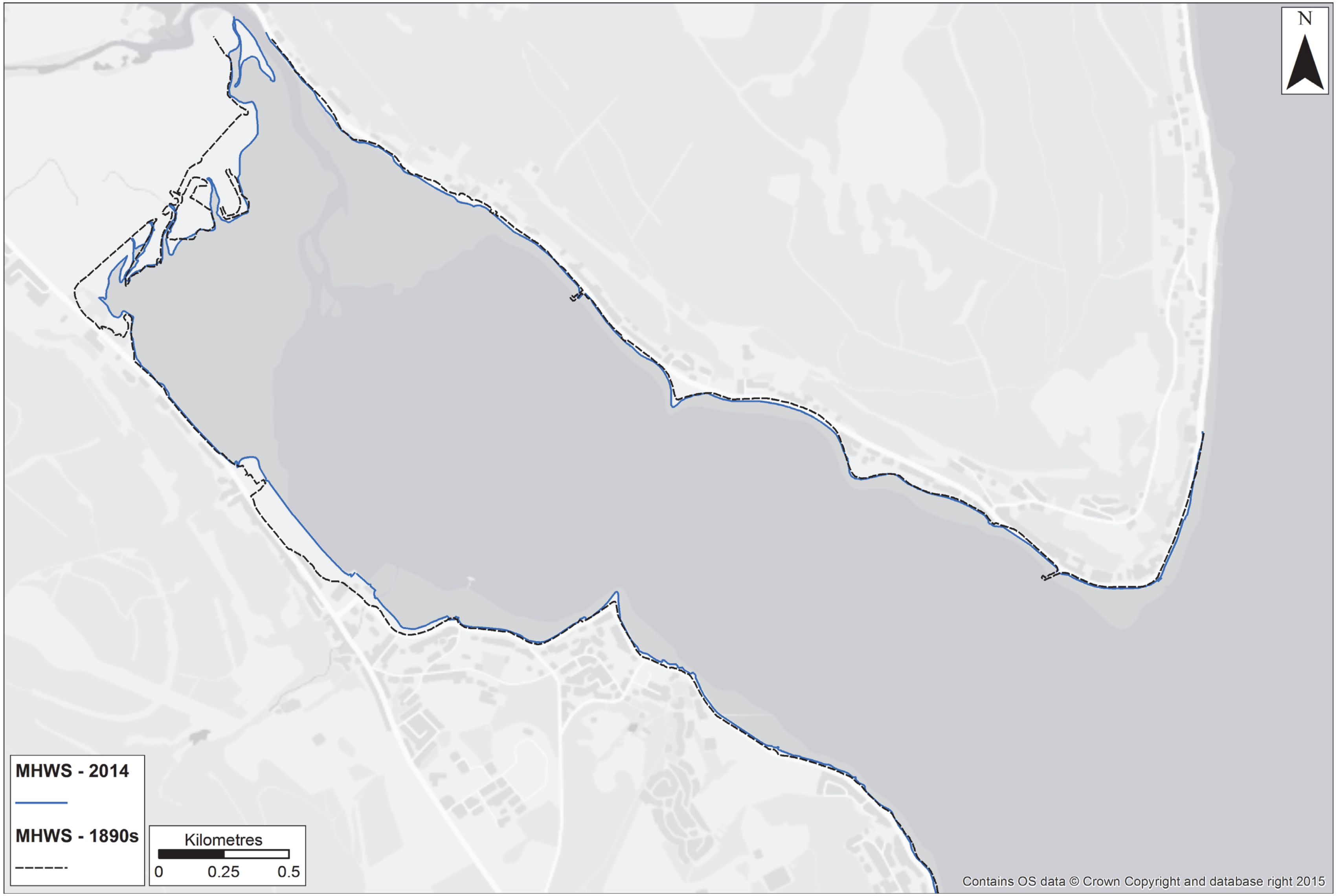

Figure 21a. Georectified Mean High Water Spring (MHWS) positions in the Holy Loch between 1890s (black) and 2014 (blue).

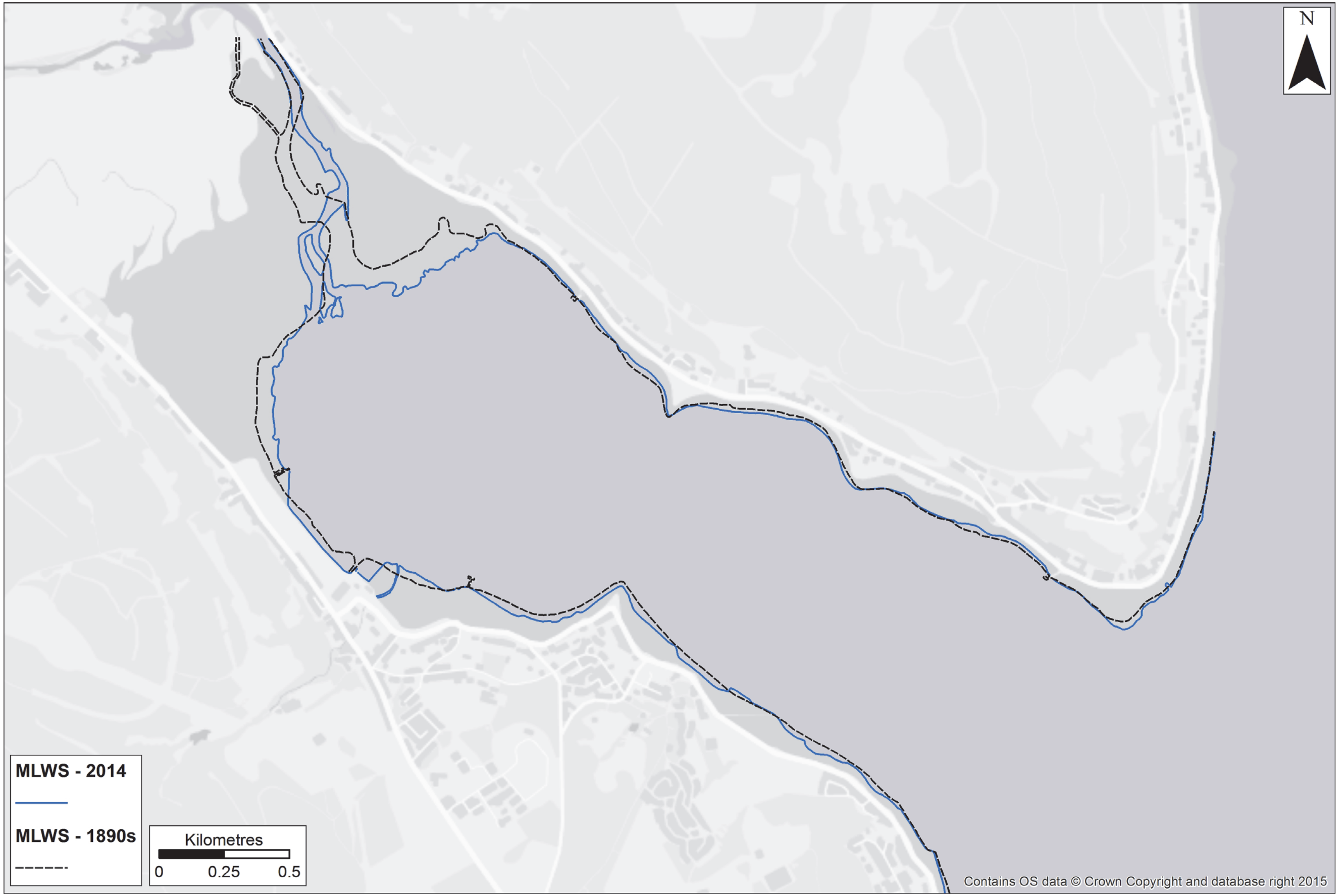

Figure 21b. Georectified Mean Low Water Spring (MLWS) positions in the Holy Loch between 1890s (black) and 2014 (blue).

The northern and southern shores have one or two small areas of beach development but these have limited MR potential by contrast to the extensive and low-lying areas at the head of the loch and along the banks of two rivers that exit here, the River Eachaig from the north, and its lesser tributary the Little Eachaig from the west. At the head of the loch, a 200m wide ribbon of saltmarsh punctuated by saltmarsh creeks (Photograph 13) is fronted by about 1km of mudflat with occasional gravel patches.

Photograph 13. Holy Loch: Inlets within the saltmarsh habitat at the head of the loch, some of which breach a low earth embankment, with evidence of saltmarsh habitat encroaching beyond and into grazing pasture.

The saltmarsh is bounded along its landward (northwest) edge by a low earthen embankment constructed historically for land claim of the saltmarsh areas behind and to allow their conversion to pastureland. However, a saltmarsh creek network still exists and allows tidal inundation into the pastureland via gaps in the bank where flap drains in the headwall to allow outflow of surface water have now fallen into disrepair (Photograph 14). To the north-east of this claimed land a series of ca.2m high glacifluvial terraces rise above the low ground (Photograph 15). At the confluence of the two rivers on the northern edge of the loch, the glacifluvial gravels within the terraces have been quarried in the past but are now inundated by tidal flow through a breach in the seaward-most terrace edge to produce a brackish lagoon (Photograph 16).

Photograph 14. Holy Loch: Earth embankment breached and failed headwall no longer functioning as coastal defence, with large expanses of low-lying grazing pasture behind.

Photograph 15. Holy Loch: The terrace edge in the foreground marked by the tree line rises above low-lying pasture whose slowly rising surface is traversed by old saltmarsh creeks, giving potential for managed realignment.

Photograph 16. Holy Loch: Looking southeast over the former gravel extraction site that now forms a brackish lagoon that fills at high tide via a breach in the terrace (seen in the top right of the image) on its seaward (southern)side. Salt tolerant species are present around the fringes of the site. The River Eachaig is in close proximity to the left of the trees in this view (east) with the River Little Eachaig eroding the south flank of the breached terrace in the top right.

Evidence of Erosion

Given its fairly sheltered location and east-facing aspect, the head of the Holy Loch has very limited evidence of frontal erosion by waves and this has allowed a substantial area of mudflat to develop in the sheltered waters. What erosion exists is almost entirely associated with bank erosion along the creek networks and more importantly along the two rivers that flow through the raised terraces in the north to enter the loch on its northern shore where the positions of the river banks are controlled by river flow conditions rather than interaction with waves and tides (Figure 21a, 21b).

Ecological Condition

The habitats along the northern and southern shorelines of Holy Loch are generally limited to a rocky shoreline, with hard-engineered sea defence walls at the upper reaches of the beach. It is at the head of Holy Loch that there are significant areas of good condition saltmarsh habitat across the entire extent of the bay, from the A815 road to the south across to the A880 road on the north. This forms a strip of intact saltmarsh, between 100-200m wide, in front of the low-lying grazing pasture further inland (Photograph 13). There are a number of now failed concrete headwalls with flap drains that previously prevented incursion of seawater inland into the grazing pasture. The result is that saltmarsh habitats are starting to reform along the alignment of the pre-existing tidal creeks extending inland.

There are low-lying areas alongside the Rivers Eachaig and Little Eachaig, and a former gravel pit, that have saltmarsh habitats inland of the current coastal edge, showing the influence of saline water under current sea-levels. Both rivers show little influence of hard engineering works, flowing in naturally sinuous channels and bordered by native riparian woodland. Figure 22 shows the saltmarsh species in the head of the Holy Loch to be dominated by various types of *Festuca rubra* saltmarsh (SM16a-e) with some smaller areas of fringing *Puccinellia maritima* saltmarsh (SM13 a and b). *Puccinellia* has also extended inland into the pastureland along a former marsh creek via one of the failed flap drains, its extent limited by the tidal limit at the present time. The presence of sand and gravel close to the river exits has resulted in the development of linear, thin fringing sand beaches capped by low embryonic sand dune vegetation (SD3, not indicated on the Figure 22).

Figure 22. Saltmarsh zones and NVC classification at Holy Loch (source: Haynes (2016)).Species detail in text and Appendix 3.

Most of the saltmarsh vegetation of the Holy Loch is a variation on different combinations of *Festuca rubra* upper marsh species. This is of significance to any future expansion of the saltmarsh area of Holy Loch since there are no pioneer marsh zone species present and only 1.16ha of lower marsh zone *Puccinellia maritima*, comprising 7% of the total marsh area (16.5ha). Without intervention via a seeding/seedling programme, this small 'seed-source' may present an issue for successful saltmarsh regeneration in the short term.

Table 6. A summary of the current condition of saltmarsh habitat, evidence of tidal inundation and the potential strengths and weaknesses of this area for MR as a tool to adapt to a changing climate.

Coastal erosion	Erosion is occurring on banks whilst there was no evidence of marsh edge erosion. Minor erosion has occurred along the banks of the saltmarsh creeks, the two rivers and existing embankments, allowing tidal access to the lagoon.
Coastal Flooding	Evidence of failed flood defences and flooding exist where flap drains have not been maintained.
Coastal accretion	There was no evidence of accretion.
Landward Saltwater Evidence	Saltwater intrusion occurs in a few places including along the creek networks, and along the low-lying parts of the river courses where old stop banks have failed or been eroded.
Strengths for Future MR and erosion mitigation	
Engineered environmental enhancements	There is enough scope for more conventional MR designs to be used at this site, such that engineered solutions are less likely apart from in front of existing defences.
Coastal erosion	Bank erosion risk is likely to increase as sea-level rise increases.
Saltmarsh erosion	Lateral saltmarsh erosion along banks/creeks is likely to continue.
Weaknesses for Future MR	
Adaptation Space	There is considerable adaptation space into low-lying areas, but not into the natural rocky shore in the south and north of the site.
Suitability of Land for MR	There are existing saltmarsh habitats in the middle section of the study site behind tidal flap valves, demonstrating the potential for saltmarsh species to develop, showing potential future opportunities for MR.
Unknowns	• Willingness to change coastal planning to allow rollback • Lack of pioneer species may require seeding/seedling programme untested in this area.

Potential for flooding, erosion and habitat degradation with sea-level rise

The existing mudflat, saltmarsh and coastal edge area of the Holy Loch is largely depositional, a condition that is unlikely to alter with SLR in such a sheltered location (unless sediment supply reduces or SLR is rapid). With an easterly aspect it is unlikely to be affected by any increase in the predicted westerly storm activity. Erosion may be increased, however, if easterly airflows enhance wind waves travelling west, although the likelihood of this will be quite low given the limited fetch and depth of this part of the loch. Of more significance is the effect of elevated sea-levels on the incidence of flooding and it is likely that the lower areas of agricultural land to the rear of the saltmarsh and behind the low earthen banks will suffer much more frequent and enhanced flooding and to greater heights than at present. MR as a flood management decision for this area would result in an increase in the extent of saltmarsh habitat as the agricultural land became progressively inundated by tidal water allowing saltmarshes to recolonise landward and mudflats to extend in area. Rising ground in the form of glacifluvial terraces to the rear of the saltmarsh and agricultural ground will act as a natural bank to limit the extent of future flooding with SLR, although there will be enhanced penetration of water levels along the two river courses that bisect the terraced area, perhaps leading to enhanced erosion of the river banks.

6.4 Future Managed Realignment Opportunities

Given the strong likelihood of future inundation of land due to SLR in the Firth of Clyde, MR approaches and related soft engineering techniques are feasible options that, if adopted, could form part of an adaptation strategy to offset some of the potential impacts of SLR. The potential for MR was evaluated here by site walkover surveys only, as detailed soil, water chemistry, vegetation and detailed field-based topographic data collection was beyond the scope of this study. These aspects would require to be developed in any further stages of assessment. The site walkover surveys thus evaluated the MR potential using expert judgement of the ecological, sedimentological and geomorphological requirements for saltmarsh regeneration and the niche requirements of any ecologically enhanced engineering works.

This report summarises the initial technical feasibility of MR as an option in SLR adaption. This is not to say that MR is the only option that could be considered in the future by the Responsible Authorities and clearly other options are available e.g. the provision of hard engineered flood and erosion defences. To date there has been no landowner consultation to discuss the feasibility of the options presented, and no work undertaken to consider the implications or costs for land use and landowners.

An assessment has also been made of the general environmental and planning risks associated with progressing any of these sites for MR projects. This summary is presented in Annex 4. These require to be addressed as part of any future planning application or Environmental Impact Assessment required for the delivery method at the time of implementation.

The walkover considered the potential for phased MR at some of the sites and whether there could be sequential MR interventions as SLR occurs. However, there are no fixed timescales for the suggested phases, and these again would be subject to more detailed future assessment. The walkover survey also served to provide a rapid appraisal of current saltmarsh condition to make a more informed assessment of the risk to current saltmarshes under a changing climate and suitability for MR to help maintain marsh extent as SLR occurs. These walkover observations were used, in combination with the recent Saltmarsh Survey of Scotland, to identify where current landward migration of saltmarsh plants is already apparent and the occurrence of pioneering species crucial to colonisation to sustain existing or support future MR sites. These pioneering species (SM1 – SM11 categories on Scotland's 2016 National Saltmarsh survey) were notably lacking from nearly all of the Clyde case study sites (Haynes, 2016). For example, the Holy Loch case study has the greatest proportion of pioneer and low marsh species present, but at 1.17ha this still represents a very small proportion (7%) of the 16.5ha total saltmarsh at Holy Loch. The lack of pioneering species and lack of a suitable and local seed source means that it will prove increasingly difficult for existing marshes to respond to rising sea-levels or for successful natural colonisation of potential MR sites. To address this, more intensive management of marshes and MR projects will likely be required, such as seeding to improve colonisation success and reduce the risk of erosion before seedlings are successfully established. We highlight this issue here (collectively for all four case studies), as the MR opportunities outlined below need to be framed in this ecological context.

As noted above the Inner Clyde case study area has been divided into three sections: Inner Clyde North, Inner Clyde South, both downstream of the Erskine Bridge, and Newshot Island upstream of the Erskine Bridge on the south side of the Clyde. The Holy Loch options are treated separately below.

6.4.1 Inner Clyde North

A combination of factors (e.g. prolonged and active erosion of existing marshes; industrial land use which has led to severe compaction, contamination and/or covering of soil by made ground; and/or limited potential to modify or re-route essential railway and canal infrastructure) means that there appear to be very limited 'inexpensive and ecologically viable' opportunities for 'conventional' MR approaches along this stretch of the coast. Heavily compacted soil and/or made ground prevents rooting of vegetation and thus is a limiting factor in colonisation success. Similarly, heavily contaminated ground risks being churned up and released during any engineering works to construct MR sites and the toxins themselves may also limit colonisation success. In spite of this, there are opportunities for phased MR, with the caveat that the current absence of pioneering saltmarsh species may further limit the success of any MR schemes unless a seeding or seedling establishment programme is undertaken (Figure 23).

Phase 1

Although outwith the technical definition of MR, in the first phase, there may be potential for alternative hard-engineered flood defence designs to be used where essential infrastructure such as the railway line at Bowling Harbour need to be maintained. These 'structurally engineered design' approaches have been adopted in the River Thames where they have been successfully used to improve the provision of saltmarsh habitat along highly industrialised stretches (Environment Agency, 2008). Further information and examples of potential bioengineered solutions or ecological enhancements are shown in Annex 9.

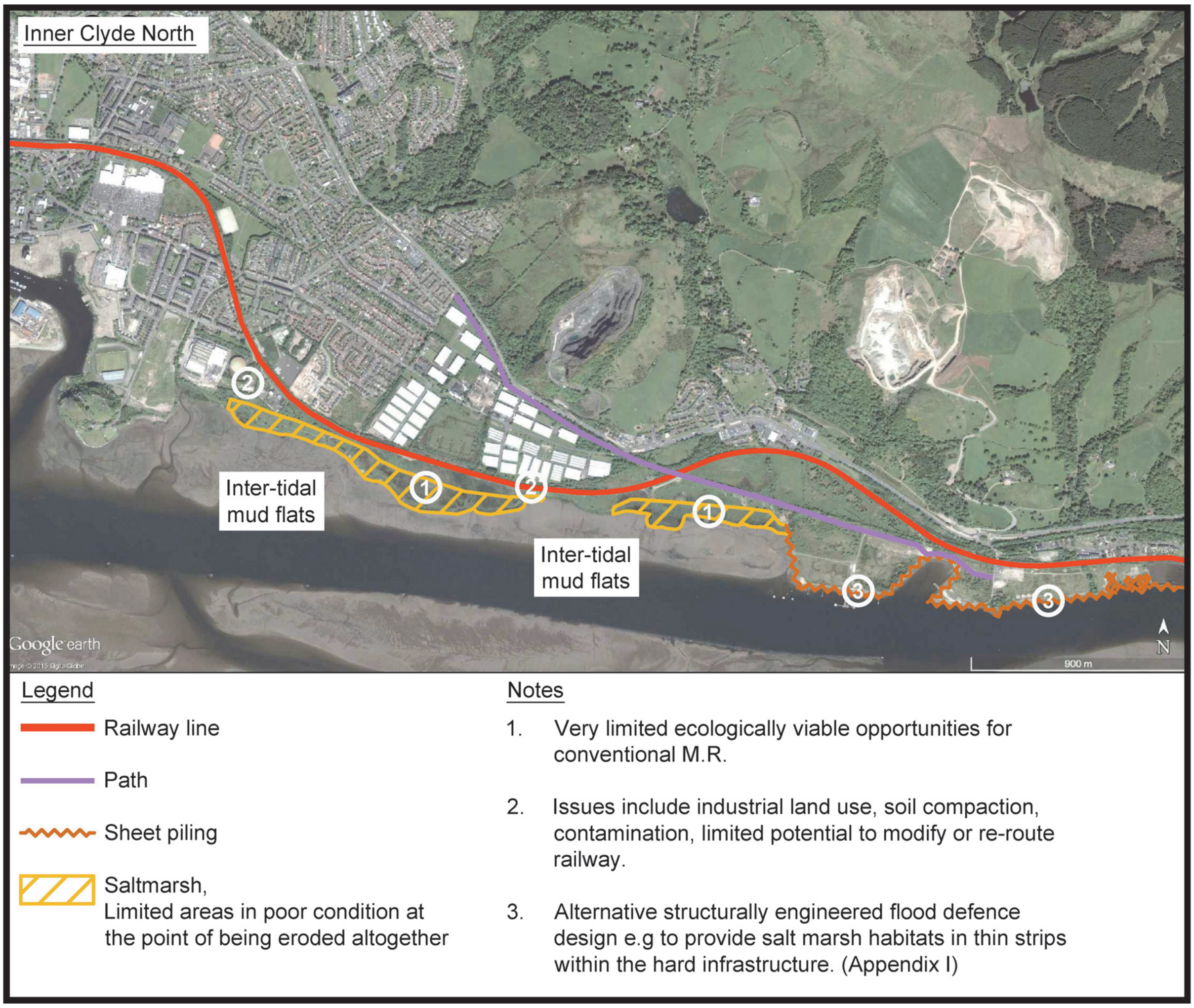

Figure 23. Issues and constraints for MR within the Inner Clyde North case study area.

These structurally engineered saltmarshes can improve both habitat and amenity value. They can also provide some attenuation of flood waters and temporary flood storage since the environmentally engineered surfaces enhance surface roughness to water flows and colonising vegetation and organisms further enhance this. These features can also trap sediments that may otherwise have had deleterious effects on property during flood events. There is good potential for these approaches to be adopted along stretches of the north side of the Clyde (Figure 23). Implementing them would help improve ecological connectivity between currently disconnected areas of saltmarsh at the north-western and south-eastern ends of this case study area. For example, the outer harbour walls and operational railway embankment at Bowling both show clear signs of advanced deterioration which suggests that structural remedial works will be required in the not too distant future to maintain the integrity of the brick railway retaining wall and its masonry supporting wall below. Similarly, such environmentally engineered approaches could be applied or retro-fitted to adjacent heavily engineered shores such as along the former Exxon Mobil site and near the canal lock harbour at Bowling. Moreover, the results from the desk-based modelling show that this area is at risk under future SLR scenarios, firmly indicating that repairs will be required to maintain the railway line. It is recommended that the potential for applying these environmentally engineered designs is actively evaluated as part of strategic and local development frameworks (both marine and terrestrial) or during the setting of biodiversity targets, as well as at the scale of individual coastal protection schemes.

Phase 2

In a second phase, more conventional MR approaches may be possible in low lying areas, avoiding essential assets such as the sewage treatment works. For example, there is a very small area of land through which the Milton Burn flows and across which the track of the disused railway (now a footpath) runs, which is low-lying and not currently in use. There is potential that this is a rare pocket of old mudflat/saltmarsh, where the soil has not been degraded or impacted by compaction and contamination, which may make MR more viable in this location. This would require the footpath and disused railway to be breached or culverted to allow flooding. However, any MR in these low-lying areas would require substantial upgrading of the railway line that lies to the landward (if maintained in its current position in the future) so that it performs as a flood defence structure (as well as its current function as a railway embankment) and is ideally re-designed with the environmental connectivity benefits described in Phase 1 in mind.

Summary

Overall, the potential ecological, economic and flood risk benefits of these structurally engineered design approaches are important since there is limited potential for more conventional MR on the northern side of the river and the existing marshes have poor geomorphological and ecological connectivity at present. This is primarily because the built up, made ground and compacted, degraded soils of this side of the Clyde will greatly reduce the success of traditional MR approaches and be significantly expensive to implement. The use of environmentally engineered approaches (as shown in Annex 9) may serve as a useful alternative along this stretch of coast which, if designed effectively, have the potential to improve the multifunctional benefits (i.e. social, ecological, economic and infrastructure) derived from any future 'hard engineering' flood and erosion defence works. Due to the absence of pioneering species in this area, more intensive seeding activities may be required to ensure MR establishment, if progressed.

6.4.2 Inner Clyde South

The majority of the low-lying land landward of the existing saltmarsh within the Inner Clyde South area appears free from past industrial activity where the pressures have been recreation (golf course), farming (since at least the 1850s) and infrastructure (e.g. M8 towards Langbank). This case study has the potential for a three-phased MR approach as follows. This area is mapped in Figure 24 (and Drawing 026, Annex 7).

Phase 1
MR1 would result in the inundation of the three large low-lying fields (at grid reference NS 43077 72935, from above modelling results) and their reversion to saltmarsh with no need for any secondary embankment works. Although the existing breach in the earth embankment means that a 'do nothing' scenario would allow sea-level rise to continue to encroach on the area, MR could be accelerated by increasing the breaches along this extent, particularly to the east.

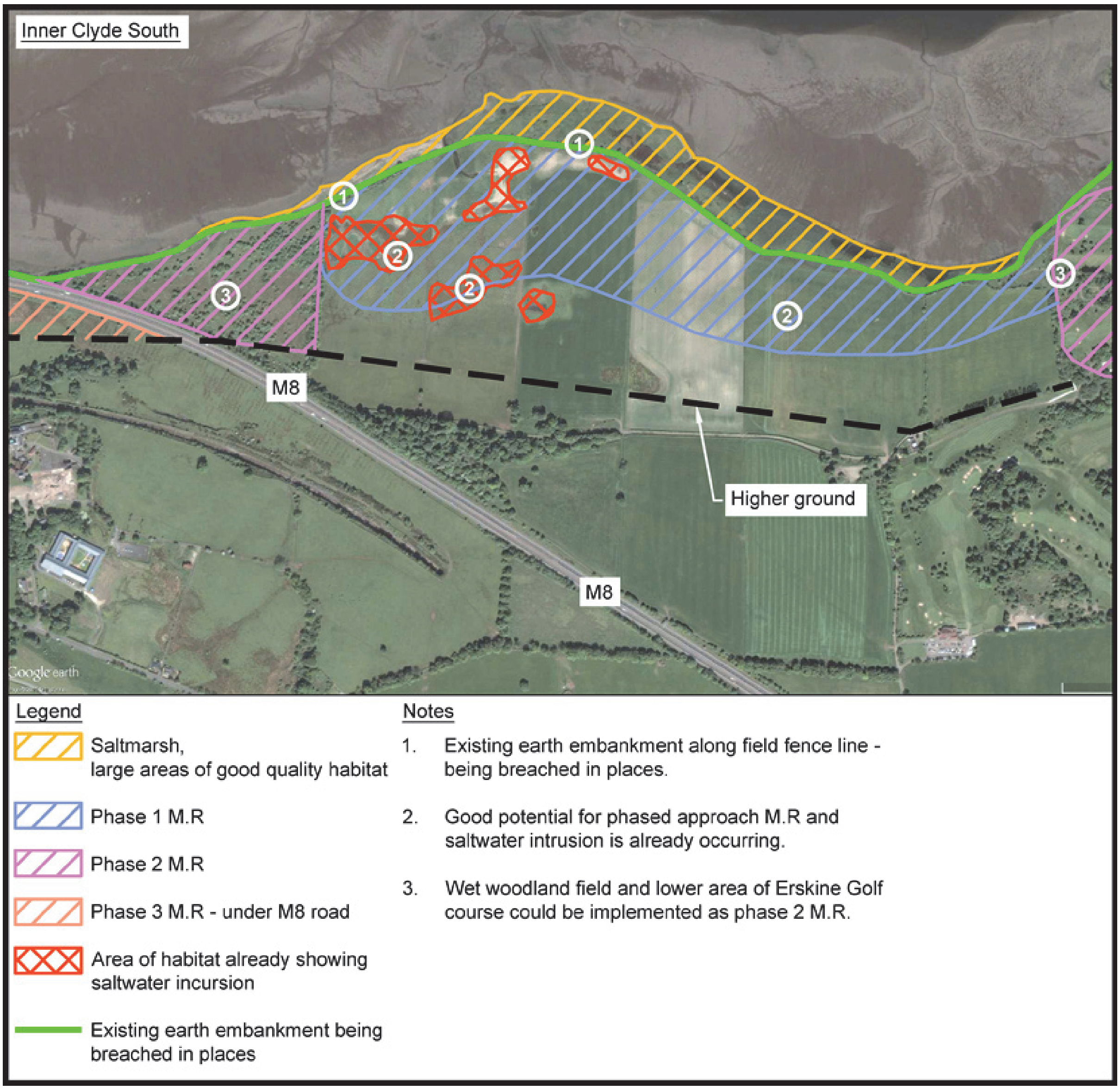

Figure 24. Figure to show the issues and constraints with the Inner Clyde South case study area.

The three fields surveyed during the walkover (i.e. those that include the red hatched areas in Figure 24) are currently in agricultural use (improved grassland) and extend about 0.5km inland to rising ground behind over a distance of in excess of 1km along the river. Since the embankment fronting the field furthest to the west is already breached (Photograph 5) with adjacent fields showing saltmarsh species behind the existing defences, it is likely that MR at this location would be favoured by recolonisation of saltmarsh species from these areas into the newly inundated areas. Overall, the potential for a successful MR here is high since the land has been partly reclaimed by saltmarsh already, a creek network still remains and its current and historic use as agricultural land has meant that it has undergone less soil compaction and human-modifications such as development, contamination or heavy industry-style compaction.

Phase 2

Two viable extensions of the above MR1 would include adjacent wet woodland (the small triangular field (0.3km at its widest and 0.5km long) which abuts the M8) and in the extreme east the lower parts of Erskine Golf Course (Photograph 7). This second phase of MR (MR2) would involve converting the small triangular field located between the recommended MR1 and the M8. To assess the suitability for MR2, a detailed ecological, soils and geomorphological assessment of the site would be required. This area is characterised by wet (terrestrial) woodland habitat and low-lying topography and suitable for MR. However, this would involve removal of existing boulder protection along the coastal edge and relocating this protection along the M8 margin to prevent its undercutting by marine flooding. This may reduce the viability of MR (in cost:benefit terms rather than ecological terms) given the relatively small size of this field.

To the east, the lower parts of the Golf Course are well suited to MR with some gently sloping ground behind and only small embankments along the riverside behind the existing saltmarsh areas. In some locations the embankment has been strengthened with gabion baskets that show signs of undermining and failure due to inundation and wave damage. Indeed there may be little change in the existing land use with MR since the lower parts of the course are observed to become unplayable at present due to flooding during wet weather, and groundwater forcing at very high tidal levels.

Phase 3

To the west of the small triangular field the M8 meets the Clyde shore as an elevated roadway protected by boulder rip rap along its toe. The fields to the south (i.e. landward) of the M8 are low lying and show evidence of having formerly been low-lying flooded areas, possibly saltmarsh since there are relict patterns of pre-M8 drainage channels suggestive of creeks. It is possible that MR3 could involve enhancing the culvert under the M8 that coincides with the main existing drainage route to allow marine inundation of the landward side of the M8. The landward extent of this MR phase would be limited by the steeply rising bedrock, located landward of the railway line to Greenock (Figure 24).

6.4.3 Newshot Island

To the east of the Erskine Bridge some 2.5km of the southern river bank is protected by structural defences and walls that provide little opportunity for MR. Beyond this lies Newshot Island a 1.7km long emerged mudflat that is now vegetated and extends to the confluence of the river White Cart in the east. Sediments exposed in the eroded banks along the Clyde indicate tidal muds with interbedded vegetation, suggesting that the mudflat may have been sequentially colonised by salt-tolerant vegetation in the past. The island comprises an unprotected and eroding riverbank behind which the ground slowly rises to a flat terraces above (Figure 25). Since the eastern part of the island has small areas of *Aster* and *Puccinellia* and the western tidal inlet supports a more substantial saltmarsh with dense stands of S4 saline swamp with *Phragmites,* along with *Festuca* saltmarsh then there is the potential here to ‘do nothing’ and allow sea-level rise into the area with no need for retaining embankments to be constructed to the landward. Whilst this does not strictly fall within the definition of MR, it is referred to as MR1 here for convenience. As discussed earlier, the small areal extent of pioneering and low marsh species may limit the success of MR intervention, which may then have to rely on local, native seeding to establish pioneering marsh communities.

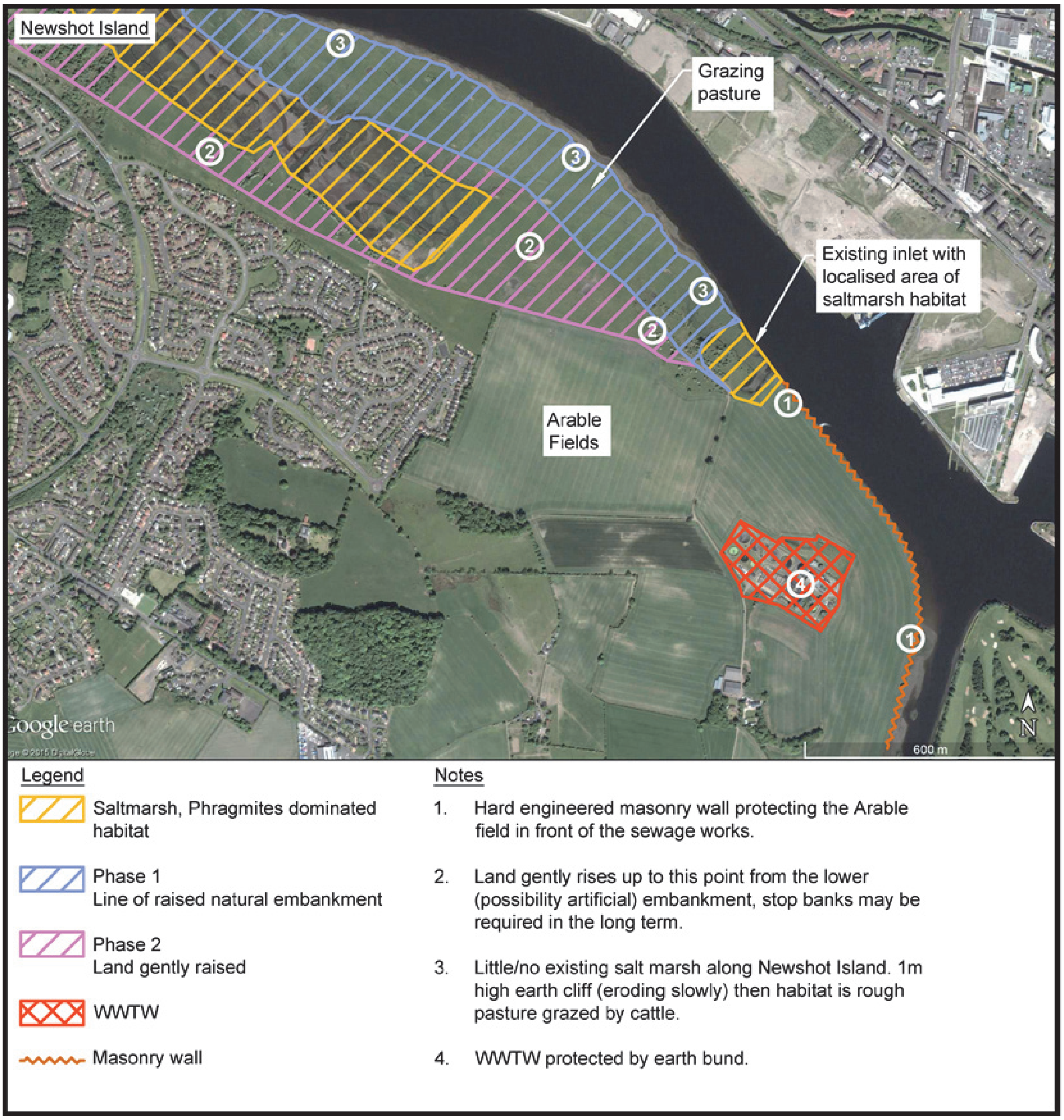

Figure 25. Figure to show the issues and constraints with the Newshot Island case study area.

The eastern limit of the *Phragmites* marsh is marked by a rectilinear bank that forms the edge of a wide and gently sloping terrace. From an examination of historical maps, the embankment runs along the line of an old causeway to what is represented on the map as a tidal saltmarsh on the Clyde bank of Newshot Island proper, and so it is likely to be artificial. If this is the case then a phase 2 MR that includes this terrace may require investigation for any contamination of the land behind. In any case such a phase 2 MR here would require stop banks since the land behind is in use for housing and agriculture (Figure 25). There is also a derelict causeway within the inlet that appears to partly regulate tidal exchange, although the potential benefits of such a structure would have to be subject to detailed further study i.e. the capacity for saltmarsh to develop around the structure.

6.4.4 Holy Loch

Since much of the sides of Holy Loch are urbanised and protected by seawalls upon which sit roadways and residential areas, the key area of potential for any MR lies at the head of the loch at its northwestern end (Figure 26). At this point there is an extensive area of intertidal mudflat, the mouth of two substantial rivers, an area of saltmarsh that fronts a substantial area of former saltmarsh that has been claimed for agricultural grazing and across which meander the remnants of former tidal saltmarsh creeks.

Phase 1

About 1km of mudflat fronts up to 0.2km of saltmarsh (Photograph 13). The saltmarsh is bounded along its length by a low earthen embankment constructed historically to allow land claim of the saltmarsh areas that once lay behind the embankment into what is now pastureland (sheep grazing at the time of the walkover).

A distinct saltmarsh creek network still remains within this area of claimed land that now drains through three failed flap valves (Photograph 14). This has allowed tidal inundation to occur through the gaps where the drains once operated, and saltmarsh habitats are currently encroaching inland. To the north east of this claimed land a series of 2-3m high terraces rise above the low ground (Photograph 15), probably glacifluvial in origin, before the mouth of the Eachaig is reached. Given the degree of existing tidal inundation, the existence of a viable creek network and the use of the land exclusively for grazing and with no housing or development, the entire area would make a highly suitable and viable MR1 site (Figure 26). There would be no need for stop banks since the ground rises by about 2m opposite the end of the cottages at Tom nan Ragh on the south side and the glacifluvial terraces provide a natural barrier in the northeast with the banks of the Rivers Little Eachaig and Eachaig both marking the northernmost extents of the MR1. Limited engineering would be required to encourage realignment as the low earthen embankments at the landward edge of the current saltmarsh could ideally be removed to allow maximum flooding. An alternative but less effective route would be to drive further breaches into the embankments to encourage realignment. Minor and infrequent tidal inundation occurs at present along the courses of the two rivers and into the lagoon at their confluence.

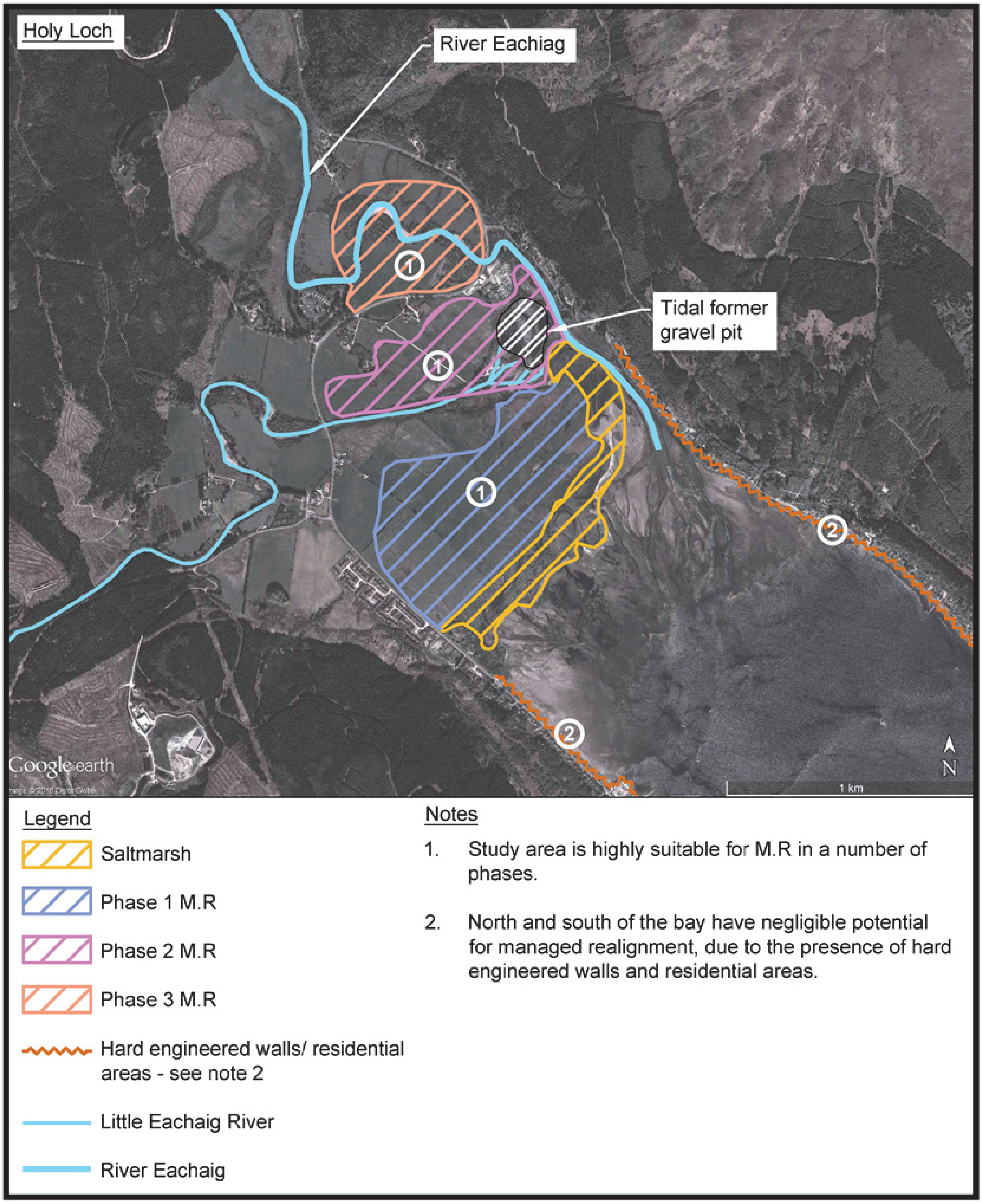

Figure 26. Figure to show the issues and constraints with the Holy Loch case study area.

Phase 2

There is scope for a second MR phase to occur landward of MR1 as a direct result of the transit of the main road from Dunoon crossing a series of glacifluvial terraces only a few metres above the height of MR1. At the northeast end, at the confluence of the two rivers, the flooded sand and gravel quarry and its large shallow lagoon (Photograph 16, Annex 3) is bounded on all sides by an unexcavated but narrow (6m wide) sand and gravel bank. The lagoon is now tidal since its exit has breached at its southern end, rendering this area and the gravel made ground that now houses a boat storage area, suitable for inclusion within MR2. In a sense this area is already a self-made area of MR but enlarging the present exit or creating another on the northern flank at the Eachaig would encourage saltmarsh formation within and along the flanks of the lagoon. Since the main roadway is raised and the areas landward of the roadway are at a similar height to those areas seaward, the roadway could be transformed into the stop bank for MR2. Since the land is more elevated and slowly rises toward the roadway then this option would be some way into the future but may affect six or seven properties and farms including the hotel, caravan park and café at the bridge over the Eachaig at grid reference NS 15463 83103. It is not possible to determine when this may occur but should be investigated further if MR proposals are ever considered. These properties could be protected by the insertion of an embankment, but this would require detailed analysis of the relative SLR and high resolution topographic and geographical data (e.g. LiDAR) which is beyond the scope of this project.

Phase 3

Given that some of the land to the north of the roadway in the National Park is at or lower than the land to the south of the roadway and thus within MR2 a future option could be that the road is culverted to allow MR3 to inundate the grazing pasture fields and riparian woodland to landward (Figure 26). This has the potential to dramatically increase the areas of saltmarsh habitat. SLR will have begun to inundate along the courses of the Little Eachaig and Eachaig rivers, but MR would cause the surrounding land to also potentially become inundated. This will occur regardless of whether MR2 is implemented but its incorporation into a potential MR3 phase would allow advance planning of any stop banks or other mitigation measures in order to protect receptors. The substantial extent of any future MR3 is evidenced by the expansive area of flat and low-lying ground that extends from Tom nan Ragh to Ballochyle via Cladaig House to Benmore and Uig in Strath Eachaig. All of this flatland is composed of glaciofluvial sand and gravels deposited by the Palaeo-Eachaig and Palaeo-Little Eachaig and is backed on all sides by steeply rising bedrock slopes.

If phased MR was to be implemented at Holy Loch, then later stages (potentially over 50 years from now) would have to include a detailed consideration of how potential inundation levels could impact on adjacent receptors such as the A815 and the campsite and how to avoid increasing the flood risk of any properties in the area.

7. DISCUSSION AND SUMMARY

7.1 SLR calculations and Coastal Flood Boundary Conditions

The calculations of the impact of climate change on SLR and surge undertaken, based on the data provided by UKCP09, result in a total increase of sea level of approximately **0.47m by 2080 for the High Emissions scenario** (base year 2008), applicable to the extent of the study area. This increase will be added to the predictions of maximum still water levels available in the CFBC study.

In areas not covered by the CFBC study, sea levels were taken from SEPA's coastal hazard mapping study which took levels directly from the River Clyde Flood Risk Management Strategy. SEPA's coastal hazard mapping study makes a number of recommendations regarding future updates to design sea levels for the Firth of Clyde, these include; updating the study following any update to the CFBC study; utilising all available tide gauge data for the Firth of Clyde and undertaking an assessment of the confidence in the design sea levels in any future update to the River Clyde Flood Risk Management Strategy to provide more information on the uncertainty.

7.2 Potential implication of SLR and storm surges

A review of the mapped outputs (specifically the 1 in 200 year tidal flood extent – High Emissions 2080 scenario) has been undertaken with regard to which areas within the Firth of Clyde could have the potential to be impacted by flood events under this scenario. This has been undertaken by visual analysis of the mapped outputs (Annex 7) from the GIS and LiDAR modelling, to determine those areas most at risk from SLR and storm surges in the 1 in 200 year tidal flood event.

This initial visual review has identified over one hundred locations where there would appear to be risks of changes to the likely flood levels, and where these will be associated with developed areas, designated sites, and infrastructure such as roads and railways. The assessment has been based on where the predicted SLR and associated flood risk appears to be significant with regard to the current coastline. The full list is detailed in Annex 5, but the sites where potential impacts are predicted to be greatest (based on the GIS maps) are outlined in Table 7 below. It is important to note that that these are 'potential' flooding impacts, as this is predicting SLR in 2080, and the actual impacts at the time will have a significant number of other factors or influences beyond the scope of this study e.g. topography and land use. However, the 'flood' mapping doesn't take account of factors such as local surface-water and fluvial input, and erosion associated with wave activity (e.g. likely to be especially important on the Ayrshire seafronts), and therefore underestimates flood risk.

Table 7. Summary of location and predicted or potential extent of SLR impacts

Drawing No	Receptor	Location	Predicted or Potential Extent of Impact[23]
12B	Indicative housing site	Greenock, NS 28589 75945	Sea could potentially inundate this housing site at the quay.
12B	Industrial estate	Greenock, NS 28185 76267	Sea could inundate large sections of industrial estate up to A8.
12B	Residential	Gourock, NS 24970 77296	Sea could inundate residential properties around Steel Street, and properties lining Cove Road.
1B	Town centre	Campbeltown, NR 71940 20758	Sea could inundate large area, extending beyond the B842 and A83 and inundate retail area and parkland. Shore area around quay inundated.
3B	Caravan park and A83	Lochgilphead, NR 85861 88150	Sea extends beyond A83 impacting the majority of the caravan park and residential properties closest to the Burn.
7B	A815 and Residential	Dunoon, NS 16821 76240	Sea extends beyond A815 inundating lots of residential properties seaward of Clyde Street and those inland along Glenmorag Avenue and Glenmorag Crescent.
9B	Faslane bay	Faslane, NS 23786 91126	Sea could inundate residential properties seaward of Old School Road.
11B	SPA & Railway line	Helensburgh, NS 32579 79105, NS 32816 78381, NS 32044 80169	Sea extends inland beyond the train line at these three points. Inner Clyde SPA, Ramsar (aggregations of non-breeding birds) SSSI (Saltmarsh) impacted, sea almost cuts off headland. This will be influenced by the size and nature of any culverts present at the time.
13B	Harbour and SINC	Inverkip, NS 20736 72428	Sea extends beyond harbour to flood grass land and puts some pressure on a SINC.
16B	A78 and residential area	Largs, NS 20244 59883	Sea extends beyond A78, potentially inundating residential property here and just up the coast NS 20015 60337 along Noddsdale Water. Railway line is likely to be negatively impacted, by flooding and erosion.

[23] The flood maps produced as part of this report are indicative and of a strategic nature, in assessing the potential sea-level rise in 2080. Whilst all reasonable effort has been made to ensure that the flood maps are accurate for their intended purpose, no warranty is given by FoCF, SNH or Arup in this regard, since within any modelling technique there is inherent uncertainty. It is inappropriate for these flood maps to be used to assess flood risk to an individual property. Whilst all reasonable effort has been made to ensure that the flood maps are up to date, complete and accurate, no guarantee is given in this regard and ultimate responsibility lies with the user to validate any information given. SNH and FoCF will not be responsible if the information contained in the flood maps is misinterpreted or misused.

Drawing No	Receptor	Location	Predicted or Potential Extent of Impact[23]
20B	B780 and railway line et al	Stevenston, NS 25661 41265	Sea may extend inland of railway line, potentially flooding area between railway and B780, including football pitch and static caravan park.
21B	Railway line and SSSI	Irvine, NS 31279 39799	Sea extends inland along River Irvine and River Garnock. This may produce in-combination marine and fluvial flooding during high discharge conditions. It inundates the majority of Bogside Flats SSSI (Saltmarsh and Mudflats) extending inland of the railway at two points, also putting pressure on the A78 and A737. Residential properties next to River Irvine potentially inundated between low Green Road and A737. Residential properties along Harbour Street also impacted.
23B	Town centre	Troon, NS 32127 31094	Large area in the centre of Troon potentially susceptible to inundation, including residential and retail.
24B	Railway line	Prestwick, NS 35022 26834	Inundation extends inland beyond railway line, flooding area of Pow burn, putting pressure on Prestwick International Airport Railway Station and potentially inundating the airport car park. This will be influenced by the size and nature of any culverts present at the time.
25B	Retail and residential properties	Ayr, NS 33536 22594	Low lying areas, especially roads of industrial estate inundated, on other side of river, sections of Harbour Street and South Harbour Street also inundated, potentially impacting area of residential properties.
25B	Residential	Ayr, NS 32736 20102	Significant areas of residential area between shore and A719 could be partially inundated, sea inundates all of the esplanade.
25B	Residential	Ayr, NS 32633 19317	Significant areas of residential area between shore and A719 could be partially inundated, sea inundates all of the esplanade.
5626B	Retail, residential, infrastructure	Girvan, NX 18640 98156	Water extending to inundate low areas within the town centre adjacent to the Water of Girvan, including majority of bay/ port area.
4B & 5B	Town centre	Rothesay, NS 08656 64769	Sea encroaches inland past A884 potentially inundating residential and retail properties.

Drawing No	Receptor	Location	Predicted or Potential Extent of Impact[23]
16B & 17B	A78 and railway	Kelburn, NS 20976 55988, NS 21088 57278	Sea extends beyond A78, inundating area between it and the railway. Port/ quay areas also have significant inundation.

The above table showing the sites where future inundation may have the greatest impact will have implications for how local authorities may plan and zone for future development in the locations listed and how they manage coastal defence projects to safeguard assets from any predicted SLR and associated impacts. Using the available LiDAR data, areas within Greenock, Gourock, Campbeltown, Lochgilphead, Dunoon, Faslane, Inverkip, Largs, Stevenson, Irvine, Troon, Prestwick, Ayr, Girvan, Rothesay and Kelburn could be impacted. This is therefore a widespread issue affecting the low-lying land around the Firth of Clyde. If LiDAR data becomes available for other areas, Peninver, Carradale, Tarbert, Lochgair, Inveraray, Kames, Innellan, Lochgoilhead, Arrochar, Kilcreggan, and Rosneath amongst others, may be impacted by SLR issues. Clearly SLR and its potential impact represents a widespread issue that will affect much of the low-lying land around the Firth of Clyde.

In addition, the infrastructure that is predicted to be potentially impacted includes a number of A-roads, railway lines on the west coast, and the railway station at Prestwick International Airport. This therefore has significant future implications for responsible authorities such as Network Rail and Transport Scotland. The presence of the waste water treatment works within the Newshot Island case study area, also has implications for Scottish Water.

There are potential impacts predicted for the Inner Clyde SPA (and Ramsar site and SSSI) at Helensburgh. Other designated sites highlighted in Annex 5 include Western Gailes SSSI, Girvan to Ballantrae Shingle Beach SSSI, Southannan Sands SSSI, and Troon Golf Links and Foreshore SSSI. No detailed analysis has been undertaken on the potential impacts that could arise as a result of predicted SLR on these sites, but this could be a focus for future work by SNH and the Firth of Clyde Forum, particularly if they do not have the ecological characteristics that make them suitable for MR or if they do not have space to the landward side and thus could suffer from coastal squeeze.

The work undertaken was aimed at highlighting the potential additional areas at risk of coastal flooding if the adopted SLR occurs. The accompanying flood extents do not replace those issued by SEPA as part of the FRM mapping exercise available through SEPA's website. However, these SEPA flood maps do not include climate change impact and therefore refer to "present-day" flood risk. The maps presented in this report provide complementary information to SEPA's flood maps.

7.3 Potential habitat loss risks and opportunities for habitat loss mitigation

This section of the report assesses key feasibility risks and opportunities for minimising habitat losses in a changing climate. This builds on the assessment of the current situation and the pros and cons for each case study presented earlier in the report. Here, the potential future risks and opportunities to maintaining and improving saltmarsh habitat availability are outlined. Section 7.3.2 briefly identifies other areas outside the selected case studies where MR may prove a feasible option to mitigate against habitat losses for conservation and flood risk alleviation goals. This builds on the assessment of the current situation and the pros and cons for each case study presented earlier in the report. Here, the potential future risks and opportunities to maintaining and improving saltmarsh habitat availability are outlined. Section 7.3.2 briefly identifies other areas outside of the selected case studies where MR may prove a feasible option to mitigate against habitat losses for conservation and flood risk alleviation goals

7.3.1 Existing case study sites

The following Table 8 summarises the key feasibility risks associated with the four current case study sites, and their potential for habitat loss mitigation.

Table 8. Potential for habitat loss mitigation and key feasibility risks associated with four case study sites

Inner Clyde North	
<u>Potential Action and Impacts in the absence of MR</u>	
Saltmarsh Creation Potential	Limited in this site due to the historic and/or current industrial use and newly elevated residential use of much of the corridor landward of the railway and in the west to the seaward side of the railway. The presence of railway infrastructure itself creates a marked barrier that may be difficult to move or culvert to create marsh behind it. Structurally engineered enhancements are possible in particular locations and upgrading of the railway embankment would be necessary to cope with increased coastal inundation.
Inner Clyde SPA impacts	Loss of habitat in this area would greatly impact a significant proportion of redshank (highest mean number of RK recorded in SPA are in Erskine North). Also high levels of lapwing and oystercatcher.
Inner Clyde South	
<u>Potential Action and Impacts in the absence of MR</u>	
Saltmarsh Creation Potential	Three agricultural fields are highly suited for the first phase of MR. A fourth field could be converted fairly readily as a 2nd phase and the M8 could be culverted and the lower parts of the Golf Course close to the Erskine bridge included in an extended 3rd phase MR.
Inner Clyde SPA impacts	Loss of habitat in this area could impact high densities of redshank, oystercatcher, curlew, lapwing and black headed gull. MR would have to consider whether the newly created habitats could support these species.
Newshot Island	
<u>Potential Action and Impacts in the absence of MR</u>	
Saltmarsh Creation Potential	The existing agricultural/naturally vegetated land below 2 m O.D. is highly suited to MR, especially as existing defences are minimal or not maintained. The area landward of this has potential for a 2nd phase of MR, although this appears to be made ground and would have to be tested for contamination, soil compaction and composition as a first step to evaluate MR suitability. The agricultural area east of the small creek at the landward end of the proposed MR1 site is highly defended and it itself acts as a secondary defence for the sewage treatment works so would only be viable for MR if the existing defences were failing and any MR would require improving the defences fronting the sewage treatment works.
Inner Clyde SPA impacts	Loss of habitat in this area would impact high numbers of lapwing as well as moderate number of redshank, dunlin, snipe, curlew and oystercatcher. MR would have to consider if the likely habitats would impact these species.

Holy Loch	
<u>Potential Action and Impacts in the absence of MR</u>	
Saltmarsh Creation Potential	This site has good potential for a phased MR. Three possible phases of MR creation are identified; these could be phased in depending on success of the initial phase and the pace of the predicted SLR. MR1 is the most easily achieved since saltmarsh and creek networks exist, the land is entirely in pasture and with no developments in existence or close proximity. MR extending to the road way incorporates slightly higher ground has not been saltmarsh in the recent past, carries more houses and farm building and is thus a more distant prospect. MR3 involves culverting the roadway to allow inundation of the low-lying land to the north along both river courses. A distant prospect but includes a substantial area of low-lying grazing land. Such extensive work would require detailed consideration of changes to land use, and built constraints.
Designated site impacts	None are currently considered likely.

As noted in Section 6.4, an assessment has also been made of the general environmental and planning risks associated with progressing any of these sites for MR projects. This summary is presented in Annex 4.

7.3.2 Further potential managed realignment sites

A review of the mapped outputs (1 in 200 year tidal flood extent – High Emissions 2080) has been undertaken with regard to whether there are other areas within the Firth of Clyde (with available LiDAR data) that have the potential to be used as future MR case studies or implemented MR projects. These are detailed in full in Annex 6, but the locations are summarised below.

Table 9. Potential managed realignment sites

Drawing No	Area	Location
26B	Caravan park, golf course, B road	Girvan, NX 18427 98319
25B	Up to A719, wet grassland	Ayr, NS 33059 19743
24B	Beyond the railway line, along Dow's Burn	Prestwick, NS 35022 26834
21B	Railway line and SSSI	Irvine, NS 31279 39799
17B	B896	Millport, NS 15190 54350
13B	Harbour	Inverkip, NS 20736 72428
29B	SSSI	Ballantrae, NX 08408 82653

For the above, there has been no detailed analysis of any particular criteria, other than these areas are relatively large expanses of low-lying land that could be subject to significantly increased inundation with 1 in 200 year flood events. They are largely undeveloped areas, though some of the habitats may be sensitive to any potential impacts e.g. the SSSI. It is proposed that these sites may be worthy of investigation, and other suitable sites may exist for areas for which there is currently no LiDAR data.

In combination with the case study work already undertaken, there could be capacity within the wider Firth of Clyde for MR to contribute to alleviating local flooding, in addition to allowing space for natural coastal processes to maintain the extent of coastal habitats. However, it is acknowledged that the scale of flooding would not be significantly reduced across the Firth of Clyde, even if a number of MR schemes were to be implemented, as such works would not be anticipated to make a significant reduction in the tidal prism for the Firth. Further analysis would have to be undertaken to determine if implementing the MR at Newshot could reduce storm surges upstream towards Glasgow.

The areas not covered by the detailed LiDAR data (wider Argyll and Bute areas) should also be further assessed for areas of land that could contribute to MR, and associated biodiversity and flood attenuation benefits.

8. MAKING IT HAPPEN

8.1 Summary of future work

The following table demonstrates and summarises the key focus points of future work and 'next steps'. It should be noted that SEPA have produced a Natural Flood Management Handbook available at https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf.

Table 10. Key focus points of future work

Theme	Issue	Action	Responsibility
Legislation	Cross-sectoral legislation and strategies for the Firth of Clyde	Map out and determine how one of the case study sites could be taken through detailed feasibility and implemented by a Responsible Authority, and how the planning regime would address environmental constraints	SG, Clyde MPP
Data gaps	LiDAR data not available for much of Argyll & Bute and Arran	Continue to acquire LiDAR for remaining areas of the Firth of Clyde, which will allow identification of further key SLR risks and case study areas.	SG, SEPA
Data sharing	Due to licensing issues, LiDAR data from the Inner Clyde was not available for this project with the result that the resolution of mapping output for the Inner Clyde area of this project, including 3 case study areas, is not optimal.	Ensure future contracts for LiDAR data allow for sharing across public bodies and for use within not-for-profit projects such as this one.	SG, SEPA, SNH
Site suitability	Land ownership	Landownership is of paramount importance in successfully implementing adaptive management and managed realignment. Any detailed analysis of site suitability will require landowner consent e.g. ground investigations and topographical survey access	LA,SNH, Clyde MPP
Site suitability	Further detailed analysis of case study sites is required. These will vary on a case by case basis	Further analysis at one or more sites to investigate a) suitability of soil for saltmarsh creation in terms of compaction, contamination, chemistry etc. b) detailed topographical study to assess MR impacts (including on	LA, SNH, Clyde MPP

		adjacent land) and possible extent of MR sites c) potential impacts on designated sites e.g. Inner Clyde SPA, d) cost benefit analysis including habitat creation, and ecosystem services. Assessment of costs for the acquisition of land under compulsory purchase or for compensating landowners for eventual change in land use.	
Further sites	Other potential MR sites have been identified by the flood risk mapping exercise (where LiDAR available)	Consider which sites may be appropriate for future initial analysis similar to the case studies in this report. The sites outlined in Table 4 would be an initial starting point, as LiDAR data exists for these seven sites. However, other sites in Argyll & Bute will be apparent once LiDAR data sourced and the same exercise repeated	SEPA, SNH, Clyde MPP
Further sites	Flood risk mapping not done in most of Argyll & Bute and Arran due to lack of LiDAR data.	Repeat flood risk mapping in Argyll & Bute and Arran to identify potential further MR sites when data available. This will also identify land at increased risk of SLR induced inundation, and other designated sites that could be susceptible to erosion.	SEPA, SNH, Clyde MPP
Best practice	Need to look to other initiatives globally for best practice in ‘natural’ adaptation to climate change and habitat restoration and connectivity opportunities when redeveloping the coastline in urban estuaries.	Consider development of a toolbox of best practice for use by LAs and developers. Undertake review of work that has occurred at Nigg Bay, as part of the Inner Forth Futurescapes RSPB scheme, and elsewhere in the UK. Consider ‘greening grey’ infrastructure strategies that are emerging.	SNH, Clyde MPP
Hydro-dynamic modelling	Further improvement is required to the hydrodynamic model of the Firth of Clyde	Improve hydrodynamic model including fluvial inputs and wave impacts.	SEPA
Climate change scenario	No UK/Scottish guideline exists on appropriate climate change scenario to use for projects such as this	Produce recommendations on which IPCC and UKCP scenario to use when planning for longer-term climate change adaptation.	SG, SEPA

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ANNEX 1: ESTIMATION OF IMPACT OF CLIMATE CHANGE ON SEA LEVEL AND STORM SURGE

ANNEX 1A: Estimation of sea-level rise and storm surge due to climate change

Introduction
An essential component of the study on the impact of sea-level rise and surge on the Firth of Clyde is the estimation of the relative sea-level rise (RSLR) and surge component due to climate change.

This note summarises the procedure, calculations and results undertaken for such estimation.

Data sources and methodology
The estimation of impact of climate change on still sea water levels is based on the values available through the User Interface of the UKCP09 website. All numerical data was downloaded from this website on 22/10/13.
http://ukclimateprojections-ui.defra.gov.uk/ui/admin/login.php

The data sets are divided by variable and location. The variables downloaded (as agreed with SNH) are:

- Relative sea-level rise (RSLR) (m) for the Medium Emissions scenario and,
- Long term trend of the surge component for a range of storm return periods (2-50yr) for the Medium Emissions scenario.

The data is supplied at specific rectangles (grid boxes) which the whole of UK is divided in (Figure 1 and Figure 2). Given the large number of boxes covering the study area, a selection of 10 boxes for RSLR and 8 boxes for surge were selected for downloading and analysis of data (please note that the boxes for RSLR and surge have different sizes.

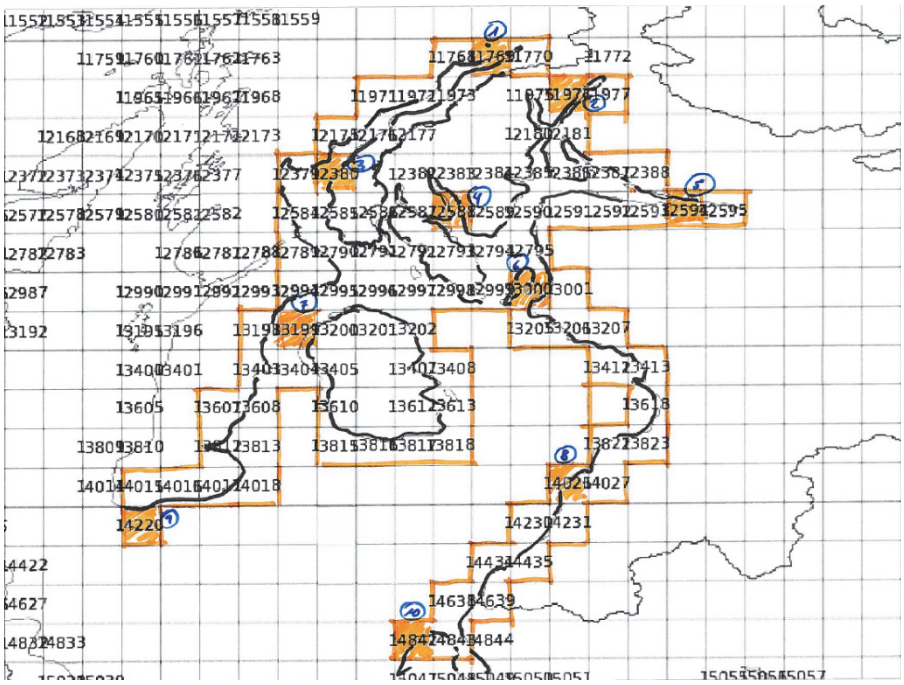

Figure 1. Extract of UKCP09 grid around study area for RSLR (Relative Mean Sea Level Rise_grid_box_ids_over_river_basins.jpg). Rectangles coloured in orange are those selected for this study.

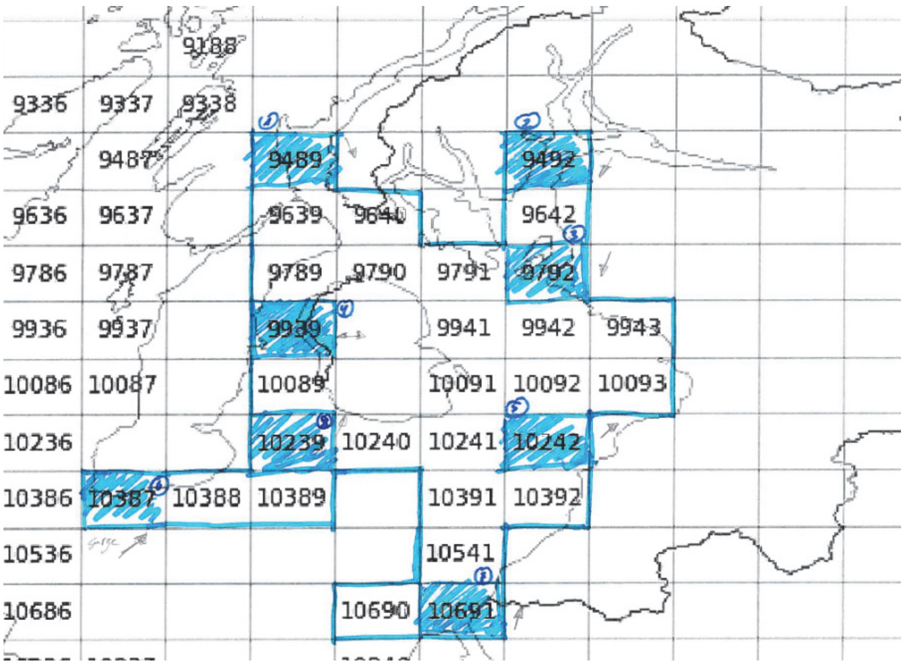

Figure 2. Extract of UKCP09 grid around study area for surge (Storm surge_grid_box_ids_over_river_basins.jpg). Rectangles coloured in blue are those selected for this study.

Relative sea-level rise

The data from UKCP09 for RSLR for Medium Emissions scenario (e.g. SLev_RSLR_Med_14842.csv, grid box 11482) was queried for the target years 2020, 2050 and 2080. Since the baseline year for the data is 1990 and the baseline year for the extreme still water levels provided by CFB (2011)[24] is 2008, an intermediate calculation was required, by which the RSLR assumed to occur between 1990 and 2008 was discounted from the RSLR from 1990 to each target year. This was done for each grid box selected (Figure 1; 11769, 11976, 12380, 12588, 12594, 13000, 13199, 14026, 14220 and 14842). The values used correspond to the 95 percentile, as agreed with SNH.

Surge component
Surge data is provided in the form of long-term linear trend in skew surge (1951-2099) for a range of storm return periods (2-50yr) (mm/yr). Since the events considered in this study are 1yr (100% AEP) and 200yr (0.5% AEP), the values downloaded were used to generate a fitting curve and extrapolate the values of mm/yr for these two events. The data used correspond to the 50 percentile as agreed with SNH.

The estimated surge component was obtained by multiplying the values of mm/yr for the corresponding events times the number of years between 2008 and each target year. Please note that the surge component is given by UKCP09 as a long term trend and therefore, the baseline year can be directly set without discounting the period 1990-2008. The calculation was applied to each of the 8 selected grid boxes (Figure 2; 9489, 9492, 9792, 9939, 10242, 10387, 10691 and 10239).

Results
RSLR
The values of RSLR estimates for the 10 selected grid boxes are shown in Table 3.

Since the values for each target year are very similar for all the grid boxes, a single value for the entire study area can be adopted. In this case, the geometric mean (essentially the same as average and median).

Surge
Table 4 and Figure 3 show the estimates and extrapolations of the surge component for each of the 8 grid boxes analysed. They show an incremental gradient from north to south. The values of increase of sea-level due to surge component range from -4.4mm to +11.1mm for the 200yr event for 2080.

The average of the values across the grid boxes selected and return periods analysed ranges from +0.4mm to +3.7mm, which represent approx. 1% of the RSLR for each target year. Even if the maximum values for surge component were adopted, the percentages of RSLR they represent are about 4%, still very small.

Since the values of RSLR can be amalgamated into a single value for the entire study area, it makes sense adopting a similar approach for the surge, and eliminate the complexity introduced by geographically varying surge components, especially when their influence over total SLR is minimal (≤ 4%).

Thus, single values, coming from the average, will be adopted.

[24] Coastal Flood Boundary Conditions for UK mainland and islands. SC060064/TR2. Environment Agency (2011).

Table 3. Summary of RSLR values

Data from UKCP09	values of RSLR (m)										
		Target year	2020			2050			2080		
UKCP09 baseline year:	1990	years from 1990 to target year	30			60			90		
CFB baseline year:	2008	years from 1990 to 2008	18			18			18		
Grid box	**Uncertainty level (%)**		**1990 to 2020**	**1990 to 2008**	**2008 to 2020**	**1990 to 2050**	**1990 to 2008**	**2008 to 2050**	**1990 to 2080**	**1990 to 2008**	**2008 to 2080**
11769	95		0.097	0.054	**0.043**	0.234	0.054	**0.18**	0.411	0.054	**0.357**
11976	95		0.097	0.054	**0.043**	0.234	0.054	**0.18**	0.411	0.054	**0.357**
12380	95		0.098	0.054	**0.044**	0.236	0.054	**0.182**	0.413	0.054	**0.359**
12588	95		0.098	0.054	**0.044**	0.236	0.054	**0.182**	0.413	0.054	**0.359**
12594	95		0.098	0.054	**0.044**	0.237	0.054	**0.183**	0.414	0.054	**0.36**
13000	95		0.099	0.054	**0.045**	0.237	0.054	**0.183**	0.415	0.054	**0.361**
13199	95		0.099	0.055	**0.044**	0.238	0.055	**0.183**	0.417	0.055	**0.362**
14026	95		0.102	0.056	**0.046**	0.243	0.056	**0.187**	0.423	0.056	**0.367**
14220	95		0.103	0.057	**0.046**	0.245	0.057	**0.188**	0.426	0.057	**0.369**
14842	95		0.104	0.058	**0.046**	0.248	0.058	**0.19**	0.431	0.058	**0.373**
				average	0.045			0.184			0.362
				stdev	0.001			0.003			0.005
				stdev/average (%)	3%			2%			1%
				median	0.044			0.183			0.361
				geometric mean	0.044			0.184			0.362

Table 4. Values of surge components and extrapolations to 1yr (100% AEP) and 200yr (0.5% AEP) events.

Data from UKCP09						Fitting curves			Extrapolations			Increase of surge component for target year (mm)					
	values of mm/yr	RP (yr)							extrapolat	extrapola	Target year	**2020**		**2050**		**2080**	
		2	**10**	**20**	**50**				200	1	years from 2008 to target year	12		42		72	
Grid box	**Uncertainty level (%)**	**Long-term**	**Long-term**	**Long-term**	**Long-term**	A	B	R^2	**Long-term**	**Long-term**	event RP (yr)	**200**	**1**	**200**	**1**	**200**	**1**
9489	50	0.018	-0.013	-0.024	-0.038	-0.017	0.029	0.9961	-0.061	0.029		-0.7	0.3	-2.6	1.2	-4.4	2.1
9492	50	0.035	0.013	0.004	-0.008	-0.013	0.0441	0.9998	-0.025	0.044		-0.3	0.5	-1.0	1.9	-1.8	3.2
9792	50	0.034	0.011	0.003	-0.008	-0.013	0.0424	0.9971	-0.026	0.042		-0.3	0.5	-1.1	1.8	-1.9	3.1
9939	50	0.032	0.019	0.015	0.008	-0.007	0.0368	0.9972	0.000	0.037		0.0	0.4	0.0	1.5	0.0	2.6
10239	50	0.047	0.045	0.044	0.043	-0.001	0.0479	0.9985	0.043	0.048		0.5	0.6	1.8	2.0	3.1	3.4
10242	50	0.053	0.051	0.05	0.049	-0.001	0.0539	0.9985	0.049	0.054		0.6	0.6	2.0	2.3	3.5	3.9
10387	50	0.092	0.117	0.125	0.134	0.0132	0.0843	0.9872	0.154	0.084		1.9	1.0	6.5	3.5	11.1	6.1
10691	50	0.076	0.094	0.1	0.107	0.0097	0.0702	0.9908	0.122	0.070		1.5	0.8	5.1	2.9	8.8	5.1
											average	0.4	0.6	1.3	2.1	2.3	3.7
											stdev	0.8	0.2	3.0	0.7	5.1	1.2
											stdev/average (%)	222%	33%	222%	33%	222%	33%
											max	2	1	6	4	11	6
												1%		1%		1%	

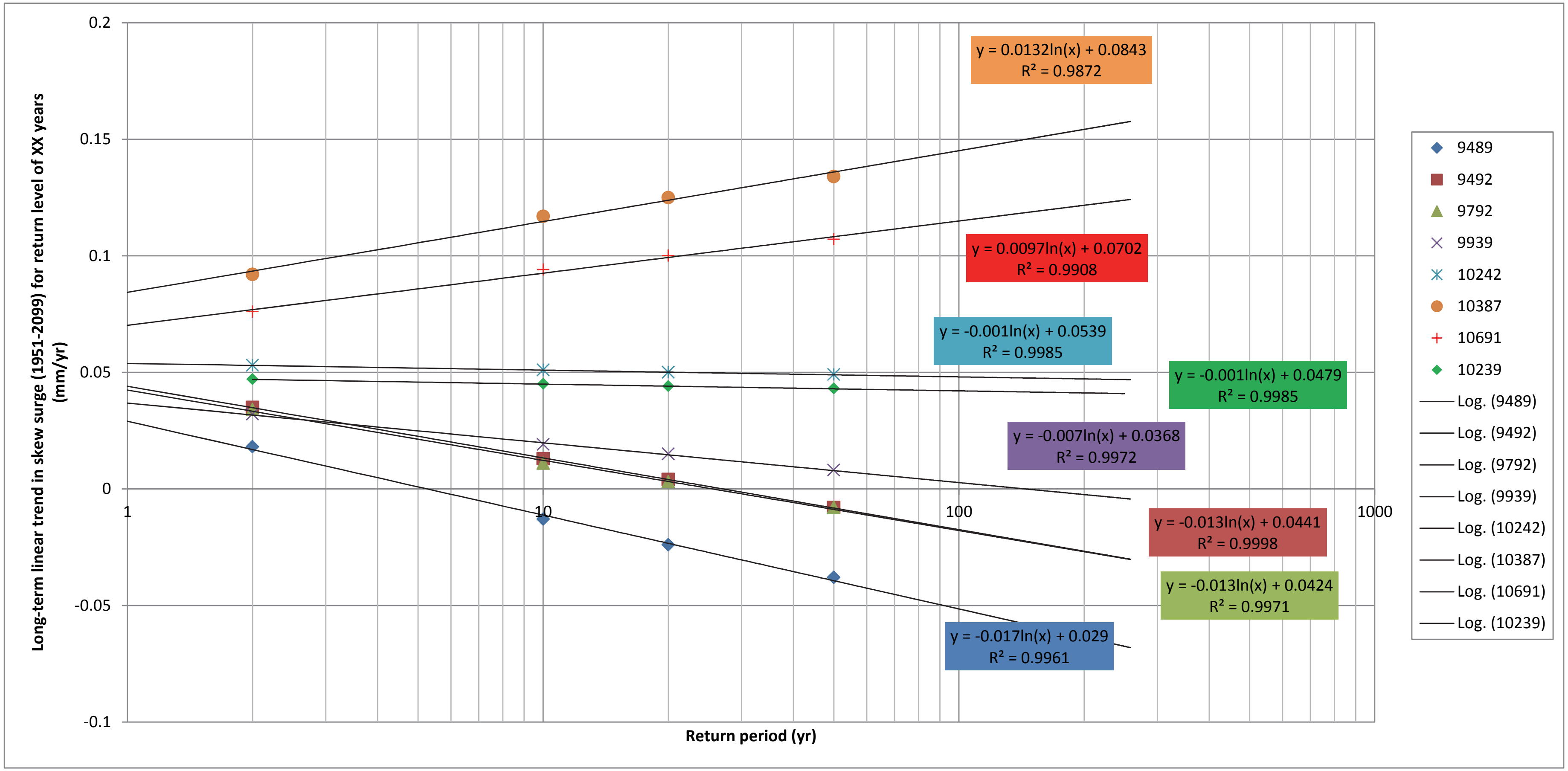

Figure 3. Fitting curves and extrapolations of surge for each grid box.

Summary and conclusions
The calculations leading to estimates of total sea-level rise (SLR) using UKCP09 data were presented. They represent the anticipated relative sea-level rise and increase of surge component for: 2020, 2050 and 2080. No wave action is considered.

Since the results of RSLR for the selected grid boxes area very similar and the relative contribution of surge is very small, single values of RSLR and surge for the entire study area are adopted. Table 5 shows the summary of results and values of total SLR adopted.

Table 5. Summary of impact of climate change on sea-level for the medium scenario (relative sea-level rise and surge component).

Target year	**2020**		**2050**		**2080**	
Event RP (yr)	1	200	1	200	1	200
RSLR (m)	0.044	0.044	0.184	0.184	0.362	0.362
Surge (m)	0.001	0.000	0.002	0.001	0.001	0.002
Total SLR (m)	0.045	0.045	0.186	0.185	0.364	0.365
Adopted total SLR (m)	**0.05**		**0.19**		**0.37**	

As the values of RSLR are not dependent on the event return period and the surge component is very small, the final values of SRL are nearly identical for both 1yr (100% AEP) and 200yr (0.5% AEP).

Please note that the values shown in this note contain three decimal places (millimetres) for mathematical reasons and to differentiate them among target years and grid boxes. However, this degree of definition is arbitrary and should not be taken as certain, especially, when they will be projected over spatial data with larger uncertainties over their elevations. The values of still water levels given by CFB are quoted to the nearest cm; as similar approach is taken here.

Given the similarity of total SLR for the event return periods analysed and the resulting figures after rounding them up to the nearest 1cm, the adopted sea-level rises can be amalgamated into single values for each target year. These will be applied uniformly to the entire study area. This will reduce the complexity of mapping areas at risk. This is considered an acceptable simplification taking into consideration the degree of uncertainty associated to climate predictions and LiDAR digital elevation models.

The climate change estimates of total sea-level rise for the target years 2020, 2050 and 2080 and return periods will be added to the CFB values of still water (every 2km) to obtain maximum still water levels at the target years. Please note that the extreme water levels provided by CFB include both tide and surge components and the total increases in Table 5 will be directly added to them.

ANNEX 1B: Consideration of IPCC Fifth Assessment Report, AR5

Introduction

Arup and the University of Glasgow are undertaking a study on the potential impact of sea-level rise due to climate change on the flood risk in the Clyde estuary (Firth of Clyde).

A cornerstone of the study is the assessment of the relative sea-level rise (RSLR) in the study area using the most recent climate projections.

When the present project started in September 2013, the most recent climate data for the area were provided by the UKCP09, specifically, the data available in their website (http://ukclimateprojections.metoffice.gov.uk/). Since then, the Intergovernmental Panel on Climate Change (IPCC) has released a revised report (Fifth Assessment Report, AR5) in 2014.

SNH and The Firth of Clyde Forum (the clients) requested the inclusion of outputs of the latest climate change report within the present study in some form. Discussions between SNH and the University of Glasgow suggested that a mention of the IPCC AR5 global predictions would be sufficient, as there are no specific data for the Forth of Clyde that can replace the calculations undertaken already using UKCP09 data.

This file note summarises the new data and proposes a form of including the new predictions within the Forth of Clyde study.

Data sources and figures

This note is based on the following sources:

1. Global mean sea-level rise. IPCC WGII AR5 final draft report. Table 5-2. Supplied by Dr. Jim Hansom (University of Glasgow) (see Appendix A.1)
2. Briefing on sea-level rise produced for the Scottish Government. Supplied by Dr. Jim Hansom (University of Glasgow) (see Appendix A.2). This briefing contained links to other sources; some of which were also consulted (e.g. Scottish Climate Change Information: UKCP09 Compendium. UKCP09 Relative Sea-Level Rise data for selected Scottish locations[25]).

The Scottish Government Briefing states:

> *"IPCC AR5 uses a new set of emissions scenarios which are mostly not directly comparable with AR4. However, sea-level rise has also been modelled using A1B, which was used in IPCC AR4 and UKCP09. A comparison of global average sea-level rise is given (IPCC AR5 WG1 – Table 13.6) and there has been revision upwards with a new central estimate higher than the old upper estimate.*
>
> *AR4 models (SRES A1B) 1990-2100 = 0.37 [0.22 to 0.50]*
> *AR5 models (SRES A1B) 1996-2100 = 0.58 [0.40 to 0.78]"*

Note: Scenario A1B appears to be the so called *Medium Emissions scenario* (http://www.ipcc.ch/ipccreports/tar/wg1/029.htm), which is the one used in the Forth of Clyde study.

[25] Please note that a potential typo has been noticed in this document. The captions for the tables for RSL for High and Medium Emissions appear to be swapped.

Therefore, it appears that the revised predictions for global sea-level rise (AR5) are approx. 60% higher than the previous assessment (AR4). It is unknown whether a similar percentage will apply to the estimated relative sea-level rise estimates currently available for the Forth of Clyde via UKCP09, as the IPCC AR5 outcomes have not been translated yet into small scale geographical areas. However, it is worth noting this increment of the sea-level rise projection.

It is also worth noting that Table 5-2 in the IPCC AR5 draft report (data source 1) shows that the global mean sea-level rise for 2100 for the scenarios called Medium and High are very similar – central values are 0.52m and 0.54m respectively- (see Appendix A), so the different emissions scenarios do not provide significantly different projections.

Note that the relative (net) sea-level rise estimated by Arup (based on UKCP09 data) for the Firth of Clyde for 2080 is 0.36m.

Proposed actions and amendments to study

Based on the above figures and data sources and, in line with the agreement between SNH and the University of Glasgow, we propose the following amendments to the Forth of Clyde study:

1. Numerical changes/revisions: None. The calculations undertaken for the relative sea-level rise will still apply given the absence of revised specific data.
2. Text revision:
    a. Acknowledgement of the publication of the IPCC AR5 report (2014) and their higher predictions of global sea-level rise by 2100 (see proposed text below).
    b. Addition to the calculation table of an approximate percentage increase of sea-level rise that may be experience in the Firth of Clyde as an indication of the sensitivity of the values and potential changes.

Suggested text additions to final report:

a) Within body of report
   Since the start of the present study the IPCC has published its Fifth Assessment Report (AR5, see references below), whose predictions for global sea-level rise are notably higher than the previous estimates provided by the Forth Assessment Report AR4. The latter were the source for the UKCP09 geographically distributed data, which were used for the estimation of relative sea-level rise presented in this study.

   The IPCC AR5 includes a comparison of the predictions of global mean sea-level rise (m) with the IPCC AR4 for the emissions scenario SRES A1B. These are reproduced by the Scottish Government Briefing on climate change and sea-level rise:

   AR4 models (SRES A1B) 1990-2100 = 0.37 [0.22 to 0.50]
   AR5 models (SRES A1B) 1996-2100 = 0.58 [0.40 to 0.78]

   Therefore, it appears that the revised predictions for global sea-level rise (AR5) are approx. 60% higher than the previous assessment (AR4). It is unknown whether a similar percentage will apply to the relative sea-level rise estimates currently available - via UKCP09- for the Firth of Clyde, as the IPCC AR5 outcomes have not been translated yet into small scale geographical areas. However, it is worth noting this increment of the sea-level rise.

b) Note on RSLR estimate table:
   ** Estimates from UKCP09 (based on IPCC AR4). Please note that the recently published IPCC AR5 shows a potential increase of global sea-level rise for the A1B*

(Medium Emissions) scenario in the region of 60% for the central projection. Specific data stemming from the IPCC AR5 for the Firth of Clyde is not yet available so this figure cannot be confirmed. However, it is possible that a similar percentage increase may be experienced in the study area.

Conclusion

The above text additions to the final study report are suggested in order to incorporate the latest sea-level rise projections by the IPCC AR5 in a manner that is acceptable by the project clients (SNH and The Firth of Clyde Forum).

Appendix A to Annex 1B: Supporting information and data sources
Appendix A.1: IPCC AR5 Table 5-2

FINAL DRAFT **IPCC WGII AR5 Chapter 5**

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Table 5-2: Projections of global mean sea level rise in meters relative to 1986–2005 are based on ocean thermal expansion calculated from climate models, the contributions from glaciers, Greenland and Antarctica from surface mass balance calculations using climate model temperature projections, the range of the contribution from Greenland and Antarctica due to dynamical processes, and the terrestrial contribution to sea levels, estimated from available studies. For sea levels up to and including 2100, the central values and the 5-95% range are given whereas for projections from 2200 onwards, the range represents the model spread due to the small number of model projections available. Source: WGI AR5 SPM and Sections 12.4.1, 13.5.1, and 13.5.4.

	RCP	**2100 CO_2 Concentration (ppm)**	**Temperature increase (C)**	**Mean Sea Level Rise (m)**					
			2081-2100	2046–2065	2100	2200	2300	2500
Low	2.6	421	1.0 [0.3 to1.7]	0.24 [0.17 to 0.31]	0.43 [0.28 to .60]	0.35–0.72	0.41–0.85	0.50–1.02
Medium	4.5	538	1.8 [1.1 to 2.6]	0.26 [0.19 to 0.33]	0.52 [0.35 to .70]	0.26–1.09	0.27–1.51	0.18–2.32
High	6.0	670	2.2 [1.4 to 3.1]	0.25 [0.18 to 0.32]	0.54 [0.37 to .72]			
	8.5	936	3.7 [2.6 to 4.8]	0.29 [0.22 to 0.37]	0.73 [0.53 to .97]	0.67–1.92	0.92–3.59	1.51–6.63

Table 5-3: Main impacts of relative sea level rise. Source: Adapted from Nicholls et al., 2010.

Biophysical impacts of relative sea level rise	**Other climate-related drivers**	**Other human drivers**
Dryland loss due to erosion	Sediment supply, wave and storm climate	Activities altering sediment supply (e.g., sand mining)
Dryland loss due to submergence	Wave and storm climate, morphological change, sediment supply	Sediment supply, flood management, morphological change, land claim
Wetland loss and change	Sediment supply, CO_2 fertilization	Sediment supply, migration space, direct

Appendix A.2: Scottish Government Briefing on sea-level rise

CLIMATE CHANGE AND SEA-LEVEL RISE
BRIEFING

The following briefing has been prepared with contributions from Adaptation Scotland, SEPA, SNH, Historic Scotland, and Transport Scotland.

The Science
The UK Climate Projections (UKCP09) provide projections of relative sea-level rise for locations around the Scottish coast based on a range of international models (IPCC AR4 models were used as basis for UKCP09).

Adaptation Scotland has compiled a compendium for selected Scottish locations: http://adaptationscotland.org.uk/why-adapt/climate-trends-and-projections/future-climate-projections-scotland

An extract for a Medium Emissions Scenario (A1B)[26] in Edinburgh and Lerwick:

Relative Sea Level Rise (compared to 1990) Medium Emissions Scenario (A1B)	**2020**	**2050**	**2080**	**2100**
Edinburgh	**5.7 cm** (0.9 to 10.6 cm)	**13.9 cm** (2.6 to 12.3 cm)	**24.4 cm** (5.1 to 43.6 cm)	**32.7 cm** (7.3 to 58.1 cm)
Lerwick	**10.8 cm** (5.9 to 15.7 cm)	**24.0 cm** (12.7 to 18.2 cm)	**39.6 cm** (20.3 to 58.8 cm)	**51.3 cm** (25.9 to 76.7 cm)

Although all projections show a trend of increasing sea-level, there is quite a wide range in the amount expected (e.g. Edinburgh ranges from 7.3 to 58.1 cm by 2100), which reflects modelling uncertainty over how global sea-level will respond to climate change in the coming decades.

The rate of relative sea-level rise varies around the Scottish coast, largely due to differing rates of vertical land movement (rebound due to ice sheet). This is evident in the projections for Lerwick above – which are higher than those in rest of Scotland.

An H++ scenario was created due to known limitations of the IPCC AR4 models – which might mean that sea-level rise exceeds those in the main projections. H++ is a low probability, high impact range for sea-level rise around the UK. Although considered very unlikely at the upper limit during the 21st century, it could be useful for contingency planning. H++ scenario range for mean sea-level rise around the UK is 93 cm to approximately 1.9 m.

IPCC AR5:
The recent release of IPCC AR5 report '*Climate Change 2013: The Physical Science Basis*' has notably changed global sea-level rise projections – these are now higher than AR4 models which were used as basis for UKCP09.

[26] Modelling of future climate change requires estimation of future levels of emissions of greenhouse gases and other substances. Future emissions are the product of complex dynamic systems, determined by factors such as population change, socio-economic development, and technological advances. In UKCP09, projections are developed under three different emissions scenarios based on their relative greenhouse gas emissions levels - High (A1FI), Medium (A1B) and Low (B1).

IPCC AR5 uses a new set of emissions scenarios which are mostly not directly comparable with AR4. However, sea-level rise has also been modelled using A1B, which was used in IPCC AR4 and UKCP09. A comparison of global average sea-level rise is given (IPCC AR5 WG1 – Table 13.6) and there has been revision upwards with a new central estimate higher than the old upper estimate.

AR4 models (SRES A1B) 19*90*-2100 = 0.37 [0.22 to 0.50]
AR5 models (SRES A1B) 19*96*-2100 = 0.58 [0.40 to 0.78]

There is an argument that IPCC AR5 process-based models underestimate future sea-level rise[27].

The impact
Sea-level rise affects all parts of Scotland's coast and, crucially, it is clear that sea-level rise now outpaces land uplift on most of the Scottish coast. Long term rates of sea-level rise vary between 0.5 and 2 mm/yr, however, recent short term rates are higher (up to 6 mm/yr). It is unclear whether this is a short term fluctuation or the start of a longer term trend. Sea-level rise was identified as the principle cause of increased flooding within the Aberdeen, Millport & Stornoway tidal gauges; a pattern which is repeated globally.

The impact of coastal flooding is likely to worsen with higher rates of sea-level rise in the future, particularly in low-lying areas. Examples include the Uists, parts of the Orkney Isles and parts of some inner firths (Forth, Moray & Solway. Not Firth of Tay). However, vulnerability to flooding and erosion is complex and is affected by sea defences and other human actions.

Coastal flooding should be considered alongside coastal erosion. Sea-level rise, coastal sediment supply and storm characteristics all influence coastal erosion. Sea-level rise is expected to quicken in the coming decades and an already restricted coastal sediment supply is further reduced by hard defences. Sea walls have been shown (in the long term) to steepen intertidal areas, lower beaches and thereby increase exposure of flood risk. Increased storm frequency is expected to occur and over the coming decades rising sea-levels will make the same storms more damaging, as they over-ride a higher Mean Sea-Level.

Coastal erosion and flooding are most significant on soft, low-lying coasts. 70% of Scotland's coast is classified as hard coast (rock), 29% as soft coast (gravels, sand and silts) and less than 1% as artificial (harbours and sea walls). The last published assessment, identified 75% of our coast as stable, 8% as accretional whilst 12% as erosional (no data on 5%).

SEPA, SNH and The University of Glasgow have developed a Coastal Erosion Susceptibility Model (which informs SEPA Flood Risk Management Strategies), to identify areas which are potentially susceptible to erosion. The model developed does not include a forward look or how susceptibility may alter with climate change including sea-level rise. It also does not show areas that will erode as factors like existing coastal defence condition are not included. However, it is a good start to indicate areas that may be vulnerable to erosion. The preliminary results indicate that nationally 18% (or 3,200 km of the 18,400 km) are susceptible to erosion. Susceptible areas can be found within most constituencies with 12 of 53 constituencies containing over 20% of their coastal frontage within the top two categories of susceptibility. 50% of constituencies have 10% or more coasts susceptible to erosion.

[27] See summary by Stefan Rahmstorf for further information:
http://www.realclimate.org/index.php/archives/2013/10/sea-level-in-the-5th-ipcc-report/

Risks from coastal erosion are significant in some parts of Scotland and likely to affect communities, infrastructure and land-based industries, as well as valued natural and cultural heritage.

Under the provisions of the Coast Protection Act 1949, local authorities have discretionary powers to carry out such coast protection work as may appear to them to be necessary or expedient for the protection of any land in their area against erosion and encroachment by the sea.

As coastal erosion is a natural process, it is important to intervene only where erosion directly threatens homes or businesses. This is because flood and coastal erosion risk management projects often have substantial impacts on the coastal environment, leading to hydrographic changes which can change sedimentation pattern and may lead to erosion / sedimentation processes in adjacent areas. Defences may also lead to accelerated erosion of the coast.

The response

SEPA is in the process of producing the first Flood Risk Management Strategies (FRM Strategies) for the whole of Scotland; to complete by December 2015. These will identify the most sustainable measures to manage flood risk from all sources. The first step in this process was the NFRA, completed in December 2011. This used available and readily derivable information to consider flood risk from all sources, including coastal flooding, taking into account the probability of a flood occurring, climate change, and the vulnerability to human health, economic activity, cultural heritage and the environment. Vulnerability is a factor of susceptibility and resilience.

The NFRA identified 243 areas of potentially significant flood risk, known as Potentially Vulnerable Areas (PVA); 125 had some coastal flood risk identified and 61 were identified as having areas of significant coastal flood risk. Coastal flooding accounts for approximately 17% of all predicted impacts in Scotland and is more important, relative to other sources of flood risk, in Orkney, Shetland and the Western Isles. However, there are also a number of areas around Scotland including the Firths identified as vulnerable to coastal flooding (link to PVA map: http://map.sepa.org.uk/floodmap/map.htm.

SEPA is also in the process of undertaking new modelling to improve the available information, which includes climate change scenarios. SEPA has used the UKCP09 High Emissions scenario, 95 percentile for 2080 to assess the impacts of sea-level rise in coastal flood hazard mapping. The updated flood hazard and flood risk maps will be prepared by 22 December 2013 and will be published on 15 January 2014.

Potential sea-level rise due to climate change is important when considering vulnerability to coastal flood risk and measures which are most sustainable. However, other factors are also important such as the susceptibility to erosion. As such SEPA commissioned the above study via the Centre of Expertise for Waters (CREW) to assess the current potential susceptibility of the coast to erosion.

SNH is identifying coastal natural heritage designated features that are vulnerable to sea-level rise and coastal erosion (expected end of March 2014). This will help us to learn from the natural changes to coastal habitats and how these could support Natural Flood Management options. This is of key importance to Scotland, with its substantial lengths of natural (undefended) coastline. Internationally, Natural Flood Management strategies are increasingly attractive as a less costly option within flood management planning because coastal habitats can grow with sea-level rise and adjust as climate change starts to impact. This shows the benefits of working with nature when adapting to climate change.

Ports
In its 2011 Report *How well is Scotland preparing for climate change?* the Adaptation Sub-Committee (ASC) of the UK Committee on Climate Change noted that “there are 110 ports in Scotland, nine of which are defined as major. Several dozen ports currently provide vital ‘lifeline’ ferry services in the Highlands and Islands, while ports and related infrastructure will be of increasing importance as the supply chain for offshore renewable energy develops. Increases in the frequency and magnitude of storms, flooding and higher rates of coastal erosion could have significant economic impacts on port cities. A recent study estimated that currently Glasgow has $2.6 billion (£1.6 billion) worth of assets exposed to sea-level rise, storm surges and wind damage, which could increase to $6.9 billion (£4.3 billion) by the 2070s[28]”.

Major ports are encouraged to take account of sea-level rise when considering their future developments and investment plans and there is flexibility in existing quay walls.

Heritage Sites
Sea-level rise and coastal erosion presents a risk to heritage sites, in particular coastal archaeology. Coastal Zone Assessment Surveys of around 40% of Scotland’s coast have recorded over 12,000 archaeological sites and remains, and protection of these sites is a considerable challenge. Awareness is particularly high amongst local authorities and community groups in vulnerable areas such as the Western Isles and Orkney. There are reports of increasing losses in recent years and it is likely this will continue or accelerate.

Historic Scotland currently supports the SCHARP project (Scottish Coastal Heritage At Risk) managed by the SCAPE Trust and St Andrews University which encourages volunteer ‘citizen archaeologists’ in Scotland to monitor, record and submit information about local coastal heritage. The draft Scottish Climate Change Adaptation Programme states that Historic Scotland will develop a methodology for assessing climate change risk to heritage sites in order to evaluate which sites are most at threat from coastal erosion and other climate change impacts. This work will be carried out in collaboration with SCAPE and other partners.

Scottish Government
Directorate for Energy and Climate Change
Climate Change Legislation Team
November 2013

[28] Nicholls, R. J. *et al*. 2008. Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates. OECD Environment Working Papers, No.1.

ANNEX 2: UK MARINE POLICY STATEMENT – EXTRACT

Extract from the UK Marine Policy Statement

Chapter 2, Section 2.6.7 Climate Change Adaptation and Mitigation and Section 2.6.8 Coastal Change.

> *2.6.7 Climate change adaptation and mitigation*
>
> *2.6.7.1 Climate change is likely to mean that the UK will experience hotter, drier summers and warmer, wetter winters. There is a likelihood of increased drought, heatwaves, changes in seasonal precipitation and the intensity of weather events such as rainfall leading to flooding.*
>
> *2.6.7.2 For the UK's marine environment, the impacts of climate change include relative sea-level rise, increased seawater temperatures, ocean acidification and changes in ocean circulation.*
>
> *2.6.7.3 Understanding the impacts and effects of climate change is key to maintaining a healthy environment. This will influence how we use and value our coasts and seas both now and in the future. Adaptation, including in the marine environment, is necessary to deal with the potential impacts of these changes which are already in train. Sea-level rises, increased flooding and coastal erosion will lead to increased vulnerability for development*[58] *and significant change along parts of the UK coast.*
>
> *2.6.7.4 Adapting to the impacts of climate change will also be a priority for terrestrial planning on the coast. Marine planning will need to be compatible with these impacts. This will include ensuring inappropriate types of development are not permitted in those areas most vulnerable to coastal change, or to flooding from coastal waters, while also improving resilience of existing developments to long term climate change.*
>
> *2.6.7.5 Marine planning will provide an important tool for meeting the long term challenges posed by climate change. To aid planning decisions in taking account of the impacts of climate change, UK Administrations produced a set of UK climate change projections and will be undertaking a UK Climate Change Risk Assessment by 2012 (to be updated every 5 years). The UK has also established the Marine Climate Change Impacts Partnership (MCCIP) which can provide advice to marine plan authorities.*
>
> *2.6.7.6 Marine planning also has an important role to play in facilitating climate change mitigation, through actions such as offshore renewables and carbon capture and storage; this is described further in section 3.3.*
>
> *Issues for consideration*
>
> *2.6.7.7 In marine planning and decision making consideration will need to be given to how the marine environment can adapt to the impacts of climate change. When developing Marine Plans, marine plan authorities should make an assessment of likely and potential impacts from climate change and their implications for the location or timing of development and activities over the plan period and beyond.*

2.6.7.8 Marine plan authorities should take account of the findings of the latest UK Climate Change Risk Assessment, relevant national adaptation programmes and the latest set of UK Climate Projections, as well as any other relevant research. Marine plan authorities should also consider the opportunities to increase the resilience of the marine environment to adapt to the impacts of climate change including by:

- *Building in sufficient flexibility to take account of climate change impacts, for example by introducing appropriate criteria for selection or de-selection of protected marine areas, seeking the advice of statutory advisors, changing or moving current uses/spatial allocations, or safeguarding areas for future uses;*
- *Encouraging development/projects to take account of the impacts of climate change over their estimated lifetime, in particular taking account of risks such as increased land and sea temperatures and sea-level rise and possible increase in risk from extreme events such as flooding and coastal erosion;*
- *Being in a position to take advantage of the opportunities that climate change may bring to certain marine areas, for example, increase in leisure activities and the aquaculture of acceptable and commercially desirable species;*
- *Considering the opportunities for synergies with, and recognising the benefits of, climate change mitigation actions in the marine environment which may include, but are not limited to, offshore renewable energy, carbon capture and storage and certain types of shipping.*

2.6.7.9 The assessment should be made in consultation with the relevant statutory agencies. If any adaptation measures give rise to consequential or additional impacts, such as on coastal change, as a result of protecting a development against flood risk or coastal change for example, the marine plan authority should consider their impacts in relation to the Marine Plan as a whole.

2.6.8 Coastal change and flooding

2.6.8.1 Coastal change[59] and coastal flooding are likely to be exacerbated by climate change, with implications for activities and development on the coast. These risks are a major consideration in ensuring that proposed new developments are resilient to climate change over their lifetime.

2.6.8.2 Activities on the coast which may be relevant to marine planning include, for example, dredging, dredged material deposition, cooling water culvert construction, marine landing facility construction, land reclamation and flood and coastal erosion risk management. Any of these could, if not managed properly, result in direct effects on the coastline, seabed marine ecology, heritage assets and biodiversity.

2.6.8.3 Indirect changes to the coastline and seabed might also arise as a result in response to some of these direct changes. This could lead to localised or more widespread coastal erosion or accretion and changes to offshore features such as submerged banks and ridges. Interruption or changes to the supply of sediment due to infrastructure has the potential to affect physical habitats along the coast or in estuaries.

Issues for consideration

2.6.8.4 When developing Marine Plans marine plan authorities should liaise with terrestrial planning authorities, drawing on Shoreline Management Plans[60] and equivalent plans where available, any relevant Flood Directive Flood Risk Management Plan or supplementary plan[61] once developed and any other relevant evidence and coastal policies[62] or strategies. Marine plan authorities should be satisfied that activities and developments will themselves be resilient to risks of coastal change and flooding and will not have an unacceptable impact on coastal change. A precautionary and risk-based approach, in accordance with the sustainable development policies of the UK Administrations, should be taken in terms of understanding emerging evidence on coastal processes.

2.6.8.5 Marine plan authorities should consider existing terrestrial planning and management policies for coastal development under which inappropriate development should be avoided in areas of highest vulnerability to coastal change and flooding. Development will need to be safe over its planned lifetime and not cause or exacerbate flood and coastal erosion risk elsewhere. When developing Marine Plans, marine plan authorities should take into account any areas identified as Coastal Change Management Areas by terrestrial planning authorities and consult with them to ensure no significant adverse impacts will arise in those areas.

2.6.8.6 Account should be taken of the impacts of climate change (consistent with the approach to adaptation outlined in section 2.6.7) throughout the operational life of a development including any de-commissioning period. Marine plan authorities should not consider development which may affect areas at high risk and probability of coastal change unless the impacts upon it can be managed. Marine plan authorities should seek to minimise and mitigate any geomorphological changes that an activity or development will have on coastal processes, including sediment movement.

[58] Flood Risk Management Plans (under the Floods Directive) highlight such vulnerability and will lead to actions to mitigate it.
[59] Coastal change in this context means physical changes to the shoreline for example; erosion, coastal landslip, permanent inundation and coastal accretion.
[60] In England and Wales, Shoreline Management Plans provide a large-scale assessment of the physical risks associated with coastal processes and present a long term policy framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner.
[61] Regulation 26 of the Flood Risk Regulations 2009, regulation 16 of the Water Environment (Floods Directive) Regulations (Northern Ireland) 2009 and section 27 of the Flood Risk Management (Scotland) Act 2009).
[62] For example, the Northern Ireland Executive's high level policy statement "Living with Rivers and the Sea".

ANNEX 3: EXTRACTS FROM SCOTTISH SALTMARSH SURVEY NATIONAL REPORT

Citation and Reference

Haynes, T.A. 2016. Scottish saltmarsh survey national report. *Scottish Natural Heritage Commissioned Report No. 786*.

Saltmarsh zones and corresponding NVC classifications including types not present in Scotland (SNH, 2010)

NVC community	Community name
	Pioneer marsh zone
SM3	*Eleocharis parvula* saltmarsh
SM4	*Spartina maritima*
SM5	*Spartina alterniflora*
SM6	*Spartina anglica* saltmarsh
SM7	*Sarcocornia perennis*
SM8	Annual *Salicornia* saltmarsh
SM9	*Suaeda maritima* saltmarsh
SM11	*Aster tripolium* var. *discoides* saltmarsh
SM12	Rayed *Aster tripolium* on saltmarsh
	Lower marsh zone
SM10	Transitional low marsh vegetation with *Puccinellia maritima*, annual *Salicornia* species and *Suaeda maritima*.
SM13a	*Puccinellia maritima* saltmarsh, *Puccinellia maritima* dominant sub- community
	Middle marsh zone
SM14	*Atriplex portulacoides* saltmarsh
SM13b	*Puccinellia maritima* saltmarsh, *Glaux maritima* sub-community
SM13c	*Puccinellia maritima* saltmarsh, Limonium vulgare-Armeria maritime sub-community
SM13d	*Puccinellia maritima* saltmarsh, Plantago maritima-Armeria maritima sub-community
SM13e	*Puccinellia maritima* saltmarsh, turf fucoid sub-community
SM13f	*Puccinellia maritima – Spartina maritima* sub-community
SM15	*Juncus maritimus – Triglochin maritima* saltmarsh
	Upper marsh zone
SM16a	*Festuca rubra* saltmarsh *Puccinellia maritima* sub-community
SM16b	*Festuca rubra* saltmarsh *Juncus gerardii* sub-community
SM16c	*Festuca rubra* saltmarsh *Festuca rubra-Glaux maritima* sub-community
SM16d	*Festuca rubra* saltmarsh tall *Festuca rubra* sub-community
SM16e	*Festuca rubra* saltmarsh *Leontodon autumnalis* sub-community
SM16f	*Festuca rubra* saltmarsh *Carex flacca* sub-community
SM17	*Artemisia maritima* saltmarsh
SM18	*Juncus maritimus* saltmarsh
SM19	*Blysmus rufus* saltmarsh
SM20	*Eleocharis uniglumis* saltmarsh
SM21	*Suaeda vera - Limonium binervosum* saltmarsh
SM22	*Atriplex portulacoides - Frankenia laevis* saltmarsh
SM23	*Spergularia marina – Puccinellia distans* saltmarsh
SM26	*Inula crithmoides* stands
SM27	Ephemeral saltmarsh vegetation with *Sagina maritima*
	Driftline zone
SM24	*Elytrigia atherica* saltmarsh
SM25	*Suaeda vera* drift-line
SM28	*Elytrigia repens* saltmarsh

Dumbarton, Inner Clyde, Renfrewshire				
REF No.	Dominant Species	Sub-Species	Type	Area (Ha)
49	S4 (Saline)	S4 (Saline)	Swamp	0.550372
50	S21	S21	Swamp	0.288845
51	S4	S4	Swamp	0.038897
52	S21	S21	Swamp	0.672124
53	S21	S21 (8) + SM16a (1) + SM28 (1)	Swamp	3.918588
54	S21	S21	Swamp	0.178483
55	SM28	SM28	Saltmarsh	0.985971
56	S21	S21	Swamp	0.11501
57	BS	BS (5) + SM16a (3) + S21 (2)	Bare Sand	0.086538
58	S4 (Saline)	S4 (Saline)	Swamp	0.967514
59	SM16a	SM16a	Saltmarsh	0.076078
60	SM28	SM28 (5) + S28 (5)	Saltmarsh	0.62831
61	S4 (Saline)	S4 (Saline)	Swamp	0.308166
62	S28	S28	Swamp	0.063651
63	S21	S21	Swamp	0.418832
64	SM28	SM28	Saltmarsh	0.446533
65	SM28	SM28	Saltmarsh	0.0926
66	S4 (Saline)	S4 (Saline)	Swamp	0.087753
67	SM28	SM28	Saltmarsh	0.100627
68	SM28	SM28	Saltmarsh	0.092728
69	SM16a	SM16a (5) + S21 (5)	Saltmarsh	0.08291
70	S21	S21	Swamp	0.330543
71	SM16a	SM16a (6) + S21 (4)	Saltmarsh	0.322245
72	SM28	SM28	Saltmarsh	0.532049
73	S4 (Saline)	S4 (Saline)	Swamp	2.239248
74	SM28	SM28	Saltmarsh	0.312974
75	SM16a	SM16a	Saltmarsh	0.040109
76	S21	S21	Swamp	0.084269
77	S4 (Saline)	S4 (Saline)	Swamp	1.329309
78	S21	S21	Swamp	0.031307
79	SM13a	SM13a	Saltmarsh	0.020923
80	SM13a	SM13a (5) + S21 (5)	Saltmarsh	0.148275
81	S21	S21 (8) + SM16a (2)	Swamp	0.097716
82	SM16d	SM16d	Saltmarsh	0.161966
83	SM16b	SM16b	Saltmarsh	0.436746
84	S4	S4	Swamp	0.152593
85	SM28	SM28	Saltmarsh	1.241718
86	S21	S21	Swamp	0.80547
87	S21	S21 (7) + SM16a (3)	Swamp	0.938207

Erskine Golf-Inner Clyde, Renfrewshire				
REF No.	Dominant Species	Sub-Species	Type	Area (Ha)
25	SM28	SM28	Saltmarsh	0.438093
26	S21	S21	Swamp	0.423304
27	S21	S21	Swamp	1.085454
28	SM28	SM28	Saltmarsh	1.376389
29	SM16b	SM16b	Saltmarsh	0.128576
30	S21	S21	Swamp	1.549155
31	SM16a	SM16a	Saltmarsh	0.672825
32	SM13a	SM13a (5) + BS (5)	Saltmarsh	0.323664
33	MG1	MG1	Grassland	0.254807
34	SM16a	SM16a (5) + SM28 (5)	Saltmarsh	0.121418
35	S4 (Saline)	S4 (Saline)	Swamp	0.138908
36	S4 (Saline)	S4 (Saline)	Swamp	2.03044
37	SM16c	SM16c (6) + SM16b (4)	Saltmarsh	0.995409
38	SM16c	SM16c (8) + SM13a (1) + S21 (1)	Saltmarsh	1.359606
39	SM28	SM28	Saltmarsh	0.880605
40	MG1	MG1 (8) + M27 (1) + S28 (1)	Grassland	0.532974
41	S21	S21	Swamp	1.570003
42	SM28	SM28	Saltmarsh	0.406959
43	S21	S21	Swamp	0.21825
44	S21	S21	Swamp	0.164049
88	SM28	SM28 (5) + SM16d (4) + S21 (1)	Saltmarsh	2.481645
89	SM28	SM28	Saltmarsh	1.192588
90	MG1	MG1	Grassland	1.118263
91	S4 (Saline)	S4 (Saline)	Swamp	0.800437
92	SM28	SM28	Saltmarsh	0.364875
93	BS	BS (6) + SM13a (2) + SM16c (2)	Bare Sand	0.31188
94	SM28	SM28 (5) + SM16c (3) + SM13a (2)	Saltmarsh	0.894929
95	SD8	SD8 (8) + SD2 (2)	Sand Dune	0.19966

Erskine, Inner Clyde, Renfrewshire

REF No.	Dominant Species	Sub-Species	Type	Area (Ha)
7	MG13	MG13 (8) + S4 (2)	Grassland	0.700158
8	SM28	SM28 (5) + S21 (5)	Saltmarsh	0.1766
9	MG12	MG12	Grassland	0.824781
10	MG11	MG11	Grassland	0.155051
11	MG13	MG13	Grassland	0.111965
12	SM12a	SM12a (5) + BSH (3) + SM13a (2)	Saltmarsh	0.597347
13	S4 (Saline)	S4 (Saline)	Swamp	1.146718
14	MG13	MG13	Grassland	1.562321
15	S21	S21	Swamp	0.192237
16	S4 (Saline)	S4 (Saline)	Swamp	0.673538
17	SM28	SM28	Saltmarsh	0.313479
18	S21	S21	Swamp	0.33803
106	S21	S21	Swamp	0.080789
107	MG13	MG13	Grassland	0.160941
108	S21	S21	Swamp	0.559523
109	S4 (Saline)	S4 (Saline)	Swamp	1.052524
110	S21	S21	Swamp	0.110667
111	BR	BR (5) + SM13a (4) + S21 (1)	Bare Rock	0.269239
112	S21	S21	Swamp	0.157883
118	S21	S21	Swamp	0.428937
119	SM16d	SM16d	Saltmarsh	0.119355

HOLY LOCH, Argyll South.				
REF No.	Dominant Species	Sub-Species	Type	Area (Ha)
1	SM16b	SM16b (8) + SM16f (2)	Saltmarsh	1.398313
2	M23	M23	Mire	0.22979
3	SM16b	SM16b	Saltmarsh	0.656406
4	SD3	SD3 (5) + BSH (3) + SM16b (2)	Sand Dune	0.556642
5	SM16d	SM16d	Saltmarsh	2.354092
6	SM16b	SM16b	Saltmarsh	0.732651
7	SM16b	SM16b	Saltmarsh	0.261323
8	OW	OW	Water	0.107399
9	SM16b	SM16b	Saltmarsh	0.036945
10	SM28	SM28	Saltmarsh	0.085759
11	SM16e	SM16e	Saltmarsh	0.14912
12	SM16f	SM16f (9) + SM20 (1)	Saltmarsh	0.224862
13	M23	M23	Mire	0.416707
14	W23	W23	Woodland	0.428744
15	W23	W23	Woodland	0.153631
16	SM16e	SM16e (5) + SM16f (5)	Saltmarsh	1.328107
17	SM13b	SM13b	Saltmarsh	0.098951
18	SM16e	SM16e (5) + SM16f (5)	Saltmarsh	1.411844
19	M23	M23	Mire	0.208034
20	S21 (Saline)	S21 (Saline)	Swamp	0.033678
21	SM13b	SM13b (6) + SM16b (4)	Saltmarsh	0.296593
22	SM13a	SM13a	Saltmarsh	0.104648
23	SM28	SM28	Saltmarsh	0.254977
24	S21 (Saline)	S21 (Saline)	Swamp	0.27585
25	W7	W7 (5) + SM16e (5)	Woodland	0.167348
26	SM13a	SM13a	Saltmarsh	0.298109
27	SM16b	SM16b (5) + SM16d (5)	Saltmarsh	2.93501
28	W7	W7	Woodland	0.498396
29	SM16e	SM16e (3) + SM16f (3) + M23 (2) + W23 (2)	Saltmarsh	0.963021
30	SM13a	SM13a (5) + SM16e (5)	Saltmarsh	0.375768
31	SM16e	SM16e	Saltmarsh	0.56375

ANNEX 4: CASE STUDIES - ENVIRONMENTAL / PLANNING ISSUES

Inner Clyde North

Baseline

The Inner Clyde North site is adjacent to the Inner Clyde protected area which is designated as a Special Protection Area (SPA), Ramsar site and Site of Special Scientific Interest (SSSI). These designations are brought about by the various species of birds which aggregate here. Specifically, the Redshank (*Tringa totnus*) population is the reason for the SPA and Ramsar European level designations, whilst the SSSI relates to the Cormorant (*Phalacrocorax carbo*), Oystercatcher (*Haematopus ostralegus*), Red-breasted merganser (*Mergus serrator*), Goldeneye (*Bucephala clangula*), Eider (*Somateria mollissima*) and Red-throated diver (*Gavia stellata*) populations along with the Redshank. The SSSI is also designated for its saltmarsh habitat. Designation extends along the shoreline, incorporating the entire intertidal zone from just above Bowling, up, and extends seawards past the mouth of the River Leven.

The area has several sites of cultural and heritage significance, notably Dumbarton Castle, a category A listed building and scheduled monument on the headland at the mouth of the River Leven. Other buildings of note include the ship model experimental tank, which is category A-listed and the United Reform Church Building, several terraced houses, Milton Primary School, Dunglass Castle, Little Mill Distillery, and an obelisk to Henry Bill which are all category B-listed. Knoxland Square is a conservation area.

The West-Dunbartonshire Council Local Development Plan (LDP)[1] identifies ‘changing places’ that it expects to develop over the next 5-10 years. Two of these ‘changing places’ are within the Erskine North area, (i) Dumbarton Town Centre and Waterfront (figure 1), and (ii) Esso Bowling (figure 2).

The area marked A on Figure 1, currently rough ground, has been identified as a residential development opportunity[2].

[1] http://www.west-dunbarton.gov.uk/council/strategies-plans-and-policies/local-development-planning/local-plan/

[2] https://www.west-dunbarton.gov.uk/media/4140597/dumbarton_town_centre_and_waterfront_revised_strategy.pdf

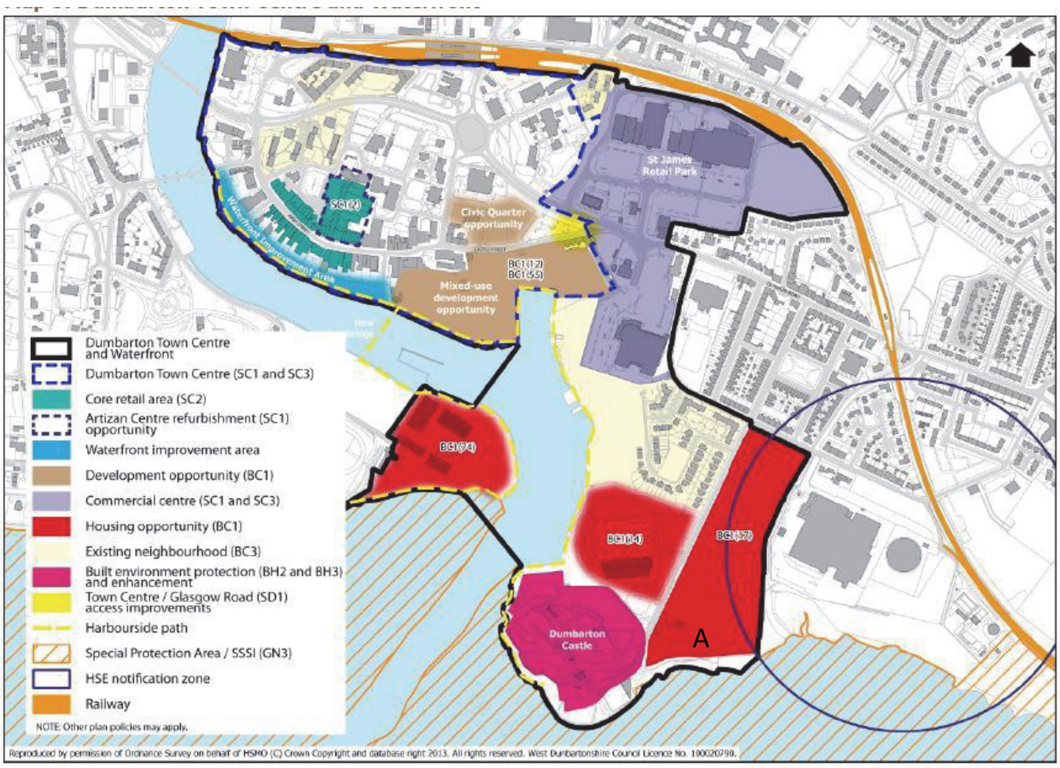

Figure 1. Dumbarton Town Centre and Waterfront Development Area

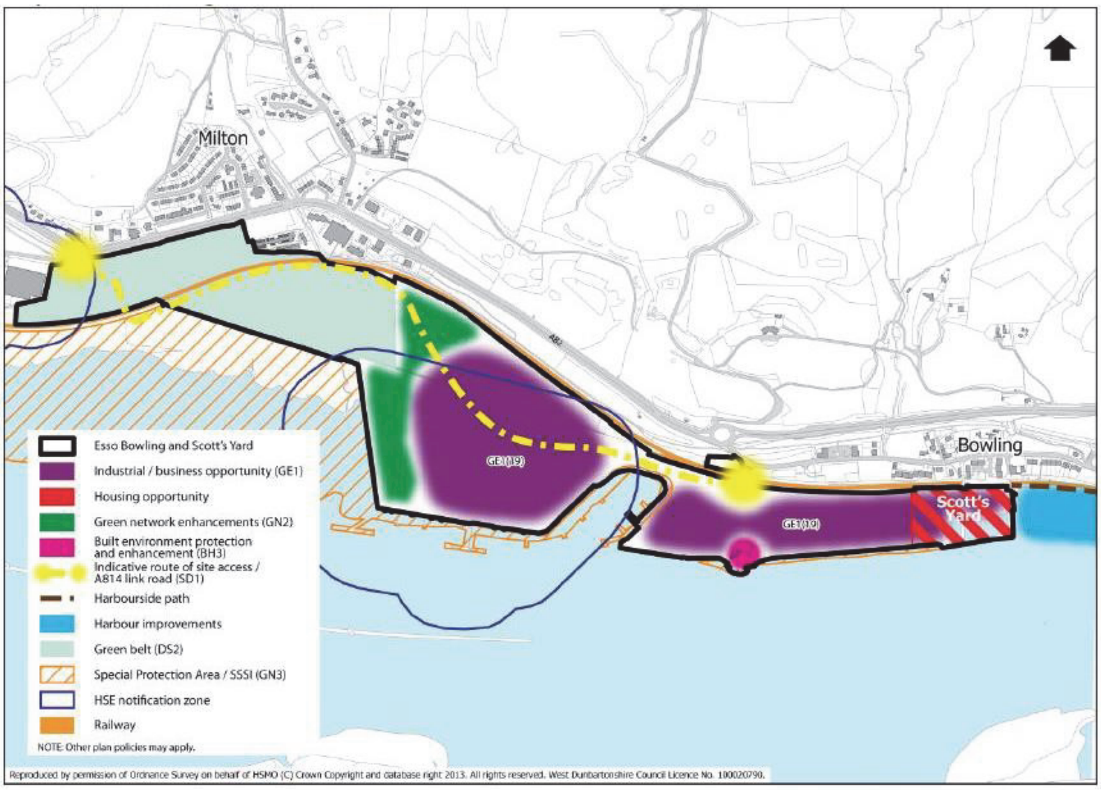

Figure 2. Esso Bowling Development Area

Esso Bowling and Scots Yard site strategy, includes some areas identified as 'green belt' just to the south of Milton which the council envisages potentially being used in coastal realignment[3], see Figure 2.

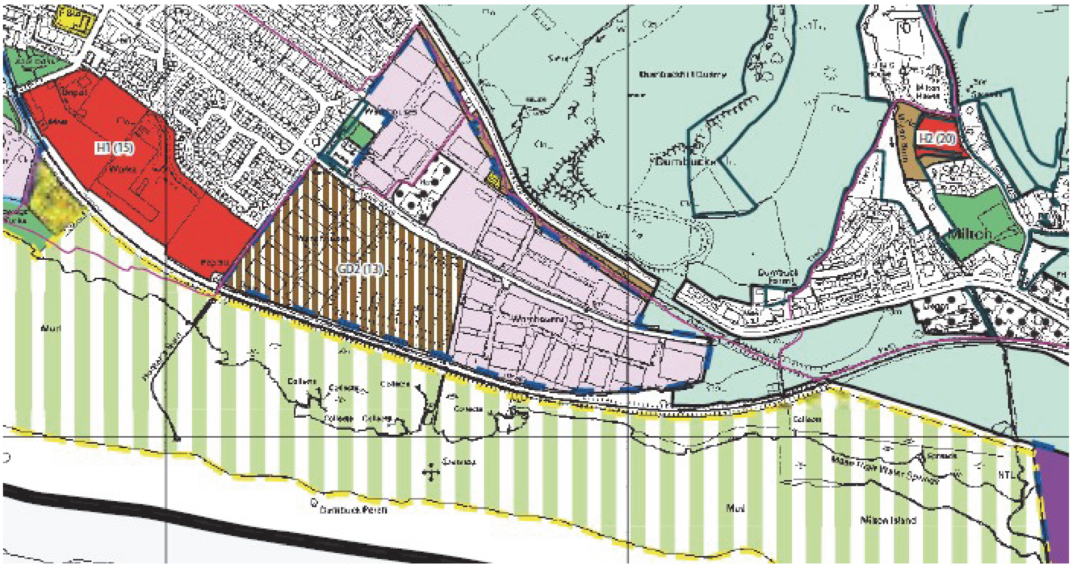

Figure 3. Inner section of the Dumbarton Development Plan showing: proposed housing (red), greenbelt (light blue), Core Economic Development Area (blue dashed line) and redevelopment opportunity site (vertical brown line)

Specific issues with area identified for managed realignment:

Much of the development is very close to the coast, including housing and areas earmarked for significant economic centres which may be at risk from predicted sea-level rise.

The area highlighted by the council for potential managed realignment is divided by the railway. This could provide significant issues, including the need for a culvert under the line to allow ingress to the landward side.

[3] http://www.west-dunbarton.gov.uk/media/2589474/west_dunbartonshire_proposed_local_development_plan.pdf

Inner Clyde South

Baseline

The Inner Clyde south site is adjacent to the Inner Clyde protected area which is designated as an SPA, Ramsar and SSSI[4]. The designation extends along the shoreline, incorporating all of the intertidal zone from just above Bowling, up, and extends seawards past the mouth of the River Leven.

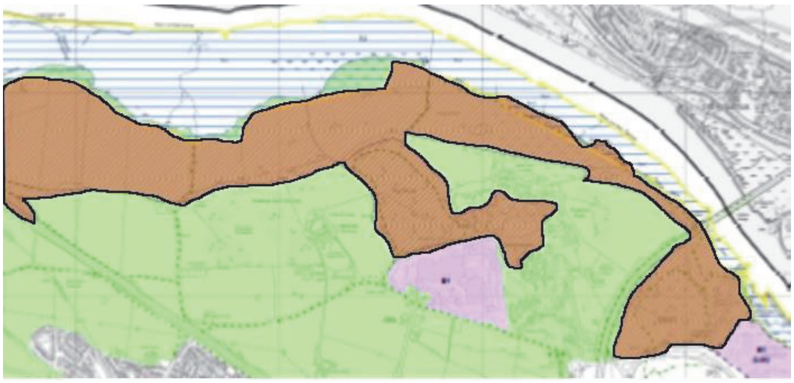

Figure 4. Extract from Renfrewshire LDP map C, showing: Site of Interest for Nature Conservation (brown); Inner Clyde SPA (blue hashed area); Economic Investment Area (purple); and greenbelt (green).

Figure 4 is an extract from the Renfrewshire LDP map C[5]. The majority of the area, about 1 field's width from the shore forms part of the Erskine – West Ferry Site of Interest for Nature Conservation (SINC). This is designated for swamp and saltmarsh communities and estuarine mudflats with ornithological interest[6]. The purple shape ~800m from the shoreline is an identified economic investment area. The Erskine – West Ferry SINC forms part of Renfrewshire councils green network (Figure 5), a link of which follows the route of the south bank of the Clyde.

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[4] See Inner Erskine North baseline data for specific designations

[5] http://www.renfrewshire.gov.uk/article/2478/Renfrewshire-Local-Development-Plan

[6] Renfrewshire Council email response, November 2014

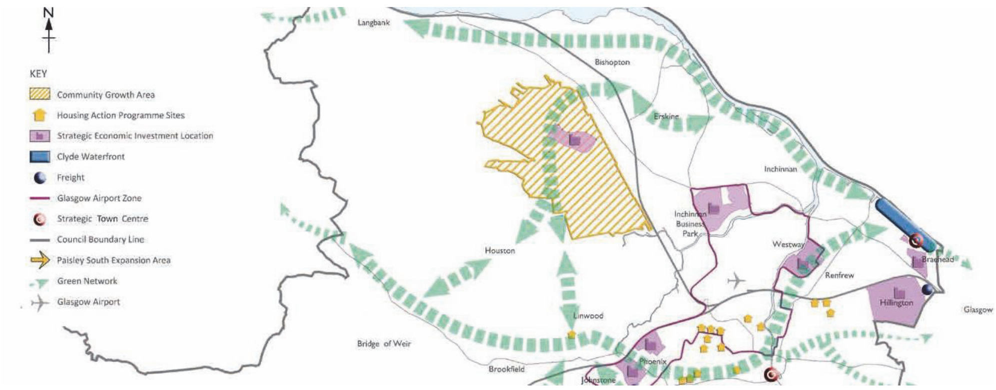

Figure 5. Renfrewshire councils green network

Specific issues with area identified for managed realignment:

The proposed phase 1 managed realignment has as category B listed building on its southern edge which could be an issue to consider, and any works must ensure that the SINC onshore or the SPA within the estuary are not negatively impacted.

The proposed second and third phases of managed realignment will impact the Erskine – West Ferry SINC and any negative impacts will need to be mitigated. The realignment may also change views from the Golf Course (converting rough scrub to saltmarsh) or necessitate a change in the Golf Course layout. The impact to these receptors is expected to be limited but needs to be considered.

Newshot Island

Baseline

Newshot Island is adjacent to the Inner Clyde SPA, Ramsar and SSSI. Designation extends along the shoreline, incorporating all of the intertidal zone from just above Bowling, up, and extends seawards past the mouth of the River Leven.

Newshot Nature reserve was a proposed 73ha local nature reserve which never made it past the planning stage. The whole Island was identified as a SINC by the Mid Clyde River Valleys Project due to its swamp vegetation and ornithological value. It is an important area for wildfowl, especially redshank and adds ecological value to the adjacent SPA. It is outlined in green in figure 6.

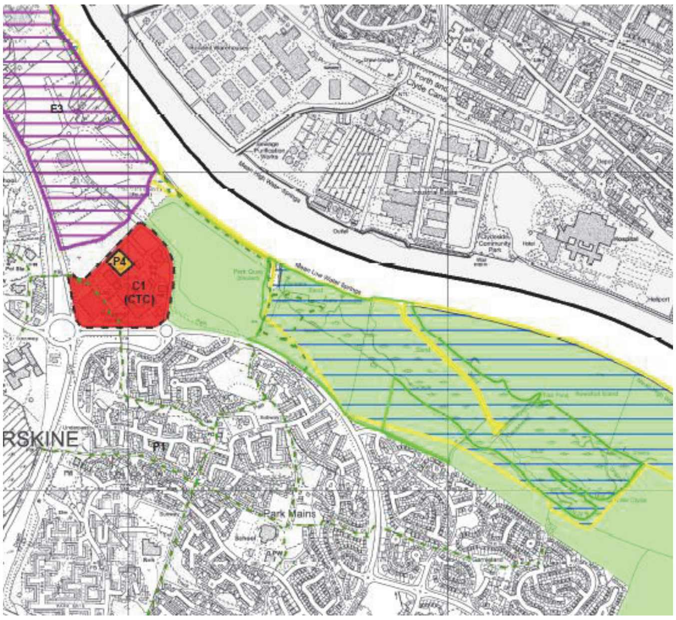

Figure 6. Extract from Renfrewshire Council LDP, showing: SPA (yellow lines); SSSI (blue diagonal lines); proposed LNR (solid green outline); greenbelt (green fill); Core Town Centre (red fill); and transitional areas (purple diagonal lines).

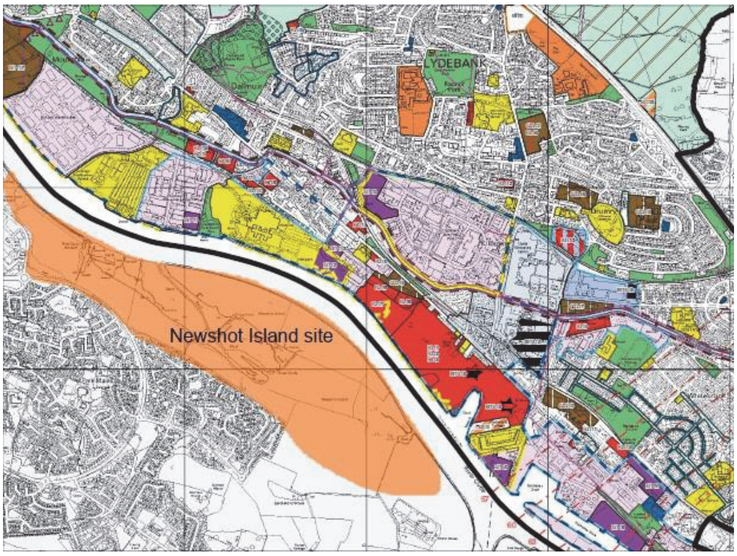

Figure 7. Extract from West Dunbartonshire Council LDP showing Queens Quay (red) with Newshot Island proposed managed realignment site marked.

Queens Quay, marked in red on figure 7, on the northern bank of the Clyde, has been identified by West Dunbartonshire Council as one of its ‘changing places’[7]. It has been earmarked primarily for housing (~1500), along with some business and financial services, and life sciences development. The council hopes to develop a leisure centre, coffee shops, restaurants and hotels clustered around the docks. The LDP wants the site to take into account the water front location and to encourage recreational and wildlife use of the area; there are regular mentions of the waterfront and views of the river. Smaller scale projects such as they have in Europe designed with flood defence in mind could have traction as the risk of flooding at the site is also a key consideration in the LDP.

On the south side of the river into Renfrewshire, the majority of land is green belt and it is anticipated that the council may well be amenable to managed realignment at the site.

Specific issues with area identified for managed realignment:

No specific issues obviously arise from the managed realignment proposals if the SPA is not negatively impacted, i.e. as long as the area of land inundated is not a valuable foraging habitat for SPA species.

[7] http://www.west-dunbarton.gov.uk/council/strategies-plans-and-policies/local-development-planning/local-plan/

Holy Loch

Baseline

The northern coastline of the bay forms the boundary of Loch Lomond and the Trossachs National Park. Holy Loch Local Nature Reserve (LNR) sits within the western sector of the delimited area skirting the saltmarsh. Holy Loch is a newly designated nature reserve of 8.49ha with the long term objective of maintaining and improving the quality of the local shoreline habitat (saltmarsh, mudflats, gravel beds and estuarine scrub) and the semi-natural broad-leaved woodland. It also aims to promote and enable use of the reserve by the public for recreation and education[8].

The River Eachaig to the north east of the site is classed as a Heavily Modified Water Body (HMWB) by SEPA and has a current status of poor ecological potential as a result of the impoundment at Loch Eck. Excluding the impact of the impoundment, the river is classified as high status for the majority of physico-chemical and biological metrics and pass for specific pollutants and priority substances.

The Little Eachaig River is also classed as a HMWB with a current status of bad ecological potential. This classification is as a result of morphological and bankside alterations relating to intensive forestry, abstraction and flow regulation associated with renewable energy production. Again it appears that most metrics of water quality are high/ good but the river is hydrologically and morphologically impacted.

Large portions of the potential site are already at risk from a 1 in 10yr flood event[9]. Risk to those areas already susceptible may be increased and areas currently not at risk i.e. certain parts of Orchard Farm and Dalinlongart Cottage could be made more susceptible. On the other hand strategically designed managed realignment may be able to reduce flood risk.

There are numerous listed buildings and one scheduled monument (Kilmun Colligiate Church Tower and Burial Ground) associated with the area around Holy Loch. The majority are associated with the coastal route within the Loch Lomond and the Trossacs National Park and these should be safeguarded by the existing sea wall, at least in the short term.

There is a strategic industrial and business location marked to the south of the identified area where the A815 meets Ferry Road.

Specific issues with area identified for managed realignment:

The proposed phase 1 realignment would complement the majority of the Holy Loch LNR. However, some of the site is broad-leaved and if this is impacted compensation planting may be required.

The proposed phase three MR could impact Inverech, a category B-grade listed building to the west of A815 and potentially Rashfield Cottages to the north of the A815.

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[8] http://www.spanglefish.com/holylochlocalnaturereserve/index.asp
[9] http://map.sepa.org.uk/floodmap/map.htm

ANNEX 5: POTENTIAL AREAS AT RISK - 1 IN 200 YEAR TIDAL FLOOD EXTENT

Drawing	Receptor	Location	Extent of impact
Those sites where potential impacts are greatest are highlighted.			
12B	Indicative housing site	Greenock, NS 28589 75945	Sea could potentially inundate this housing site at the quay.
12B	Industrial estate	Greenock, NS 28185 76267	Sea inundates large sections of industrial estate up to A8.
12B	Development opportunities	Greenock, NS 29743 75760	Area surrounding quay, incorporating LDP development opportunities and indicative housing sites inundated.
12B	Residential / industrial	Greenock, NS 29549 75685	Residential properties along James Watt Way inundated as is industrial area between Quay and A8.
12B	A8	Greenock, NS 28905 75653	A8 inundated along with lower lying retail areas to the north.
12B	Railway	Gourock, NS 24356 77697	Sea extends to/ beyond railway line, inundating sections of ferry terminal and low lying residential areas around A771.
12B	Residential	Gourock, NS 24970 77296	Sea inundates residential properties around Steel Street, and properties lining Cove Road.
12B	Proposed road	Gourock, NS 24158 77935	Sea covers area suggested for new road, and swimming pool area up the coast.
12B	Industrial estate	Gourock, NS 25448 77855	Sea floods seaward boundary of Fort Matilda Industrial Estate, inundating a building or two. Recreation ground to the south west almost totally inundated.
12B	Esplanade, residential	Gourock, NS 26658 77704	Sea extends inland covering the esplanade along its entire length flooding the gardens of residential properties, and potentially a couple of buildings.
1B	Town centre	Campbeltown, NR 71940 20758	Sea could inundate large area, extending beyond the B842 and A83 and inundate retail area and parkland. Shore area around quay inundated.
3B	A83	Lochgilphead, NR 86356 86897	Sea encroaches just inland of A83.
3B	Residential property and A83	Lochgilphead, NR 86434 87733	Sea inundates residential properties seaward of A83 and extend just inland of the road.
3B	Town centre	Lochgilphead, NR 86212 87946	Sea extends just inland of A83 inundating residential and retail properties which about it.

3B	Caravan park and A83	Lochgilphead, NR 85861 88150	Sea extends beyond A83 submerging the majority of the caravan park and residential properties closest to the Burn.
3B	A83 and residential properties	Lochgilphead, NR 85575 87252 and NR 85360 86706	Sea extends inland beyond A83 inundating residential properties.
4B	A884	Ascog, NS 10727 62995	Sea encroaches just inland of A884.
5B	Residential	Toward, NS 13588 67707	Sea encroaches inland inundating a property and threatening others.
5B	Residential	Toward, NS 13591 67277	Sea encroaches inland inundating a property and threatening others.
5B	Residential	Toward, NS 12911 67655	Sea encroaches inland to A815, inundating at least one property and threatening others.
5B	A886	Port Bannatyne, NS 06544 67775	Sea encroaches inland of A886 inundating small area of agricultural land beyond.
5B	A886	Port Bannatyne, NS 07107 67296	Sea encroaches inland of A886 inundating residential and retail buildings.
5B	Residential	Port Bannatyne, NS 07749 67342	Sea inundates areas of residential property between Shore Road and High Road.
5B	A884	Port Bannatyne, NS 08388 66468	Sea inundates areas beyond A844 threatening residential property.
6B	A815	Bullwood, NS 16704 75218	Sea encroaches onto and just inland of A815.
6B	A815	Bullwood, NS 16470 74261	Sea encroaches onto and just inland of A815.
7B	A815 and Residential	Dunoon, NS 16821 76240	Sea extends beyond A815 inundating lots of residential properties seaward of Clyde Street and those inland along Glenmorag Avenue and Glenmorag Crescent.
7B	A815	Dunoon, NS 17828 77222 to NS 17606 77035	Sea extends beyond A815 inundating a few properties inland.
8B	Residential	Holy loch, NS 18454 80884	Sea inundates residential properties at this point and inundates gardens of properties just up the coast.
8B	A880	Holy loch, NS 17750 81218	Sea inundates or is abutting road along the majority of the shore.
8B	A880	Holyloch, NS 16752 81956	Sea extends inland of A880, threatening properties on the other side.

8B	Static Caravan park	Holyloch, NS 15406 83016	Sea moves inland along River Eachaig, inundates large portion of caravan park.
8B	Camping ground & A815	Holyloch, NS 14958 83127	Sea extends inland along River Eachaig, inundating large areas of agricultural land and a caravan park.
8B	A815	Holyloch, NS 14871 81855	Sea extends inland, just breeching the A815 putting pressure on properties lining it.
8B	A815	Holyloch, NS 15288 81444 to NS 15752 80954	Sea extends inland beyond A815, potentially impacting residential properties between these points.
8B	Residential and A815	Sandbank, NS 16419 80303 to NS 18168 79724	Sea extends inland beyond A815, inundating residential properties.
8B	A815	Sandbank, NS 18507 79102	Sea extends onto A815.
9B	HMNB Faslane	Faslane, NS 24582 88749	Buildings close to the shore will be inundated, as will any static (non floating) moorings.
9B	Faslane bay	Faslane, NS 23786 91126	Sea inundates residential properties seaward of Old School Road.
9B	B833	Faslane, NS 23426 90937	Sea extends inland past B833, gardens of residential buildings along a 450m section of B833 are at risk.
10B	A814 and residential	Helensburgh, NS 27938 83270	Sea extends past A814, submerging a large section of the boating facilities car park and inundating some residential properties beyond.
10B	Port/ Quay	Helensburgh, NS 27566 83468, NS 27188 83483	Sea submerges large terrestrial areas of both Port/ Quays/ piers. Waters breach A814 at certain points.
10B	A814	Helensburgh, NS 27425 83557	Sea extends beyond A814 into gardens.
10B	A814 and residential	Helensburgh, NS 26832 83895	Sea extends beyond A814, inundating residential and commercial properties.
10B	Minor road	Helensburgh, NS 26615 83901	Small access road inundated, one property may be impacted.
10B	A814	Helensburgh, NS 26436 84508	Sea extends beyond A814 inundating several residential properties.
10B	A 814	Shandon, NS 25485 86341	Sea abuts large section of A814 close to Shandon inundating in a couple of places, NS 25318 86978, NS 25785 85682

11B	Special PA & Railway line	Helensburgh, NS 32579 79105, NS 32816 78381, NS 32044 80169	Sea extends inland beyond the trainline at these three points. Inner Clyde SPA, Ramsar (aggregations of non breeding birds) SSSI (Saltmarsh) impacted, sea almost cuts off headland.
11B	Railway and Road	Helensburgh, NS 31460 81136	Sea extends inland beyond railway and past A814. Low lying residential areas around Moore Drive may also be impacted if hydrologically connected.
11B	Railway station	Helensburgh, NS 30912 81341	Sea inundates station and gets very close to residential properties on Middleton Drive just up the coast
11B	A814	Helensburgh, NS 30052 82135	Sea encroaches inland past A814, inundating a few retail (along A814) and residential properties.
12B	A770 and coastal route	Gourock, NS 23390 77221	Sea abuts A770 along most of the shoreline in this section of map.
13B	Harbour and SINC	Inverkip, NS 20736 72428	Sea extends beyond harbour to flood grass land and puts some pressure on a SINC.
13B	Coastal route	Inverkip, NS 20437 73345, NS 20197 74752	Sea engulfs coastal route.
13B	Scheduled monument	Cloch Lighthouse, NS 20318 75882	Area around lighthouse inundated.
13B	A770 and coastal route	nr Cloch lighthouse, NS 20277 75606	Sea abuts A road and coastal route at several points along the coast.
14B	A78	Skelmorlie, NS 19226 67127	Sea abuts A78.
14B	Disused power station	Wemyss Bay, NS 19356 70855	Sea inundates low lying area of Inverkip power station.
15B	A78	St Fillans Bridge, NS 19129 63745	Sea extends inland beyond A78, Sea abuts A78 along large areas of the coastline in this map.
16B	Residential and retail	Largs, NS 20203 59113	Sea extends inland along Gogo Water beyond B7025, inundating lower residential areas (esp roads). Water may aso extend to junction of B7025 with A78 inundating lower areas around it.
16B	A78 and residential area	Largs, NS 20244 59883	Sea extends beyond A78, inundating residential property here and just up the coast NS 20015 60337 along Noddsdale Water.
16B	A78	Largs, NS 19476 61194	Sea abuts A78.
17B	A78	Fairle, NS 20771 54161	Sea abuts A78 inundating some residential areas seaward of it.
17B	railway	Fairle, NS 19944 54095	Railway on thin strip of land under pressure as SLR.

17B	B896	Millport, NS 15190 54350	Sea extends inland around southern shore of Great Cumbrea Island, extending beyond the B896 and threatening to residential and retail properties which adjoin it. NS 15678 54591, NS 16113 54839, NS 17245 54945
18B	Residential	Porten cross, NS 17596 48860	Sea abuts residential property next to coast.
18B	Power station	Hunterston, NS 17596 48860; NS 19322 52132	Sea inundates few low lying areas close to shore, few buildings/ car park and access road.
19B	Holiday development	West Kilbride, NS 20711 46095	Sea reaches A78 inundating areas of a holiday park.
19B	A78	West Kilbride, NS 21994 44408	Sea extends beyond A78, inundating small area of land beyond and putting pressure on those properties seaward of the road.
20B	B780 and railway line et al	Stevenson, NS 25661 41265	Sea may extend inland of railway line, potentially flooding area between railway and B780, including football pitch and static caravan park.
20B	Residential	Saltcoats, NS 24273 41258	Low lying areas of Saltcoats near shore are inundated.
20B	Residential	Ardrossan, NS 22974 42458	Low lying residential areas of Adrossan up to and just beyond B780 inundated.
20B	Railway	Ardrossan, NS 22446 42112	Sea putting pressure on railway line to Adrossan Harbour station.
20B	Residential	Ardrossan, NS 22919 43172	Residential properties along North Crescent Road inundated. Inundation extends up shore putting pressure on A738 at NS 22658 43458.
21B	Railway line and SSSI	Irvine, NS 31279 39799	Sea extends inland along River Irvine and River Garnock. It inundates the majority of Bogside Flats SSSI (Saltmarsh and Mudflats) extending inland of the railway at two points, also putting pressure on the A78 and A737. Residential properties next to River Irvine inundated between low Green Road and A737. Residential properties along Harbour Street also impacted.
21B	Bridges	Irvine, NS 32496 38142	Rising of River Irvine puts pressure on bridges over it.
22B	SSSI	Gailes, NS 32054 35480	Seaward edge of Western Galies SSSI (Invertebrate assemblage and sand dunes) inundated.
22B	Residential	Barassie, NS 32490 33195	Sea inundates beach road and extends into residential properties next to it.

23B	B746 and residential properties	Troon, NS 32506 32411	Sea inundates B746 as it hugs the shore and some properties landward of it.
23B	Town centre	Troon, NS 32127 31094	Large area in the centre of Troon susceptible to inundation, including residential and retail.
24B	Holiday park	Prestwick, NS 34514 27931	Area of holiday park inundated as levels in Pow Burn increase.
24B	Railway line	Prestwick, NS 35022 26834	Inundation extends inland beyond railway line, flooding area of Dow's burn, putting pressure on Prestwick International Airport Railway Station and potentially inundating the airport car park.
24B	Residential	Prestwick, NS 34193 24948	Sea abuts residential property and inundates the esplanade which follows the coast.
24B	Railway	Ayr, NS 33665 23041	Sea abuts railway line.
25B	Railway and road bridge	Ayr, NS 34225 21641	Water levels in river Ayr put pressure on capacity of bridges crossing it.
25B	Retail and residential properties	Ayr, NS 33854 22226	Commercial properties adjacent to river inundated along River Street, as are residential properties along Strathayr Place.
25B	Retail and residential properties	Ayr, NS 33536 22594	Low lying areas, especially roads of industrial estate inundated, on other side of river, sections of Harbour Street and South Harbour Street also inundated impacting area of residential properties.
25B	Residential	Ayr, NS 32736 20102	Significant areas of residential area between shore and A719 partially inundated, sea inundates all of the esplanade.
25B	A719	Ayr, NS 33059 19743	Sea rises to abut A719, approximately 500m inland flooding rough grazing/ wet grassland.
25B	Residential	Ayr, NS 32633 19317	Significant areas of residential area between shore and A719 partially inundated, sea inundates all of the esplanade.
25B	Residential	Ayr, NS 32003 19330	Sea abuts Castle Walk putting pressure on residential area.
25B	Residential	Ayr, NS 32765 18895	Areas on banks of River Doon, residential properties along Mount Charles Crescent Road inundated, as is grassy area on opposite bank. Capacity of bridge upstream also in question.

26B	Caravan park, golf course, B road	Girvan, NX 18427 98319	Large section of Golf Course inundated, as is area of static caravan park adjacent to river. Parts of Golf Course Road inundated putting pressure on residential properties lining it.
26B	Railway and road bridge	Girvan, NX 19017 98537, NX 19310 98891	Water levels rising in Water of Girvan, putting pressure on capacity of bridges.
26B	Retail, residential, infrastructure	Girvan, NX 18640 98156	Water extending to inundate low areas within the town centre adjacent to the Water of Girvan, including majority of bay/ port area.
26B	Residential	Girvan, NX 18231 97374	Water abutting Edmiston Drive putting pressure on road.
27B	A77 and SSSI	Kilranny Bridge, NX 16029 94160	Girvan to Ballantrae Coast Section SSSI (stratigraphy) is almost completely inundated. Sea abuts road, potentially having a significant erosive impact on at least 6 discrete sections of road: NX 13641 91105, NX 14639 92848, NX 15057 93289, NX 17375 95240, NX 17869 95699.
8B	SSSI	Bann ane, NX 09752 87450	Sea encroaches onto Girvan to Ballantrae Coast SSSI (stratigraphy).
28B	A77	Whilk Cottage, NX 11742 88899	Sea moves onto A77.
28B	A77	Whilk Cottage,NX 12617 89422	Sea moves onto A77.
29B	SSSI	Ballantrae, NX 08408 82653	Sea inundates majority of Ballantrae Shingle Beach SSSI. Flooding extends inland beyond A77 along River Stinchar and across agricultural land towards Ballantrae. Farm out buildings at risk of inundation.
12B	Residential and docks	Gourock, NS 27383 77101	Sea inundates residential properties beyond Campbell Street and seaward boundary of cargo loading port. This is in theLDP as a business and development opportunity.
4B & 5B	Town centre	Rothesay, NS 08656 64769	Sea encroaches inland past A884 inundating residential and retail properties.
4B & 5B	A884	Rothesay, NS 09912 65394	Sea encroaches just inland of A884.
5B & 6B	A815	Newton Park, NS 14390 69591	Sea encroaches inland of A815, inundating gardens of several properties.
10B & 11B	Car park/ Storage facility	Helensburgh, NS 29503 82169	Car park/ storage facility submerged, along with some retail properties adjoining it.

10B & 11B	A814	Helensburgh, NS 29178 82392 to NS 28070 82818	Long section of the A814 inundated, impacting residential properties on the landward side.
16B & 17B	A78 and railway	Kelburn, NS 20976 55988, NS 21088 57278	Sea extends beyond A78, inundating area between it and the railway. Port/ quay areas also have significant inundation.
17B & 18B	SSSI	Hunterston, NS 19387 52663	Sea inundates large area of Southannan Sands SSSI (sandflats).
20B & 21B	Railway line	Stevenson, NS 26648 41196	Sea extends in land beyond railway line, impacting the residential properties beyond.
23B & 24B	SSSI	Prestwick, NS 33896 28348	Large area of Troon Golf Links and Foreshore SSSI (sand dunes) inundated.

ANNEX 6: POTENTIAL FURTHER CASE STUDY SITES

Drawing	Receptor	Location	Extent of impact
26B	Caravan park, golf course, B road	Girvan, NX 18427 98319	Large section of Golf Course inundated, as is area of static caravan park adjacent to river. Parts of Golf course Road inundated putting pressure on residential properties lining it.
25B	A719	Ayr, NS 33059 19743	Sea rises to abut A719, approximately 500m inland flooding rough grazing / wet grassland.
24B	Railway line	Prestwick, NS 35022 26834	Inundation extends inland beyond railway line, flooding area of Dow's Burn, putting pressure on Prestwick International station and potentially inundating the airport car park.
21B	Railway line and SSSI	Irvine, NS 31279 39799	Sea extends inland along River Irvine and River Garnock. It inundates the majority of Bogside Flats SSSI (saltmarsh and mudflats) extending inland of the railway at two points, also putting pressure on the A78 and A737. Residential properties next to River Irvine inundated between Low Green Road and A737. Residential properties along Harbour Street also impacted.
17B	B896	Millport, NS 15190 54350	Sea extends inland around southern shore of Great Cumbrea Island, extending beyond the B896 and threatening residential and retail properties which adjoin it. NS 15678 54591, NS 16113 54839, NS 17245 54945.
13B	Harbour	Inverkip, NS 20736 72428	Sea extends beyond harbour to flood adjacent grassland.
29B	SSSI	Ballantrae, NX 08408 82653	Sea inundates majority of Ballantrae Shingle Beach SSSI. Flooding extends inland behind A77 along River Stinchar and across agricultural land towards Ballantrae. Farm out-buildings at risk of inundation.

ANNEX 7: MAPPED OUTPUTS

This annex can be downloaded from the SNH website as a separate file.

ANNEX 8: MANAGED REALIGNMENT BENEFITS

Managed Realignment

This short note will introduce what is meant by managed realignment and why it is being considered as a long term coastal management tool.

The decline of coastal habitats

In Europe coastal habitats have been exploited with ever increasing intensity since the Palaeolithic and are now considered some of the most degraded coastal temperate systems worldwide[1]. It is estimated that there has been a loss of approximately two thirds of European coastal wetlands that existed at the beginning of the twentieth century[2]. The UK is thought to have lost >50% of its saltmarshes since Roman times and >913km^2 of estuary area[3].

Those areas of coastal habitat which remain are fragmented and frequently degraded, show changes in structure and function and a loss of biodiversity. This loss of habitat through increasing exploitation is compounded by the current trend in sea-level rise. The latest estimates suggest that global sea-levels will rise between 04-0.6m by AD 2100, even if strong mitigation is put in place to reduce the impacts of global warming; in an unmitigated scenario that increases to between 0.7-1.2m[4]. As a result of this sea-level rise the intertidal zone is shrinking as the low water mark migrates landward towards a high water mark fixed by flood defence, this process is termed coastal squeeze.

Ecosystem services of coastal habitats

Coastal systems provide a raft of ecosystem services on which we rely and the loss or degradation of these habitats negatively impacts their ability to provide these key services. Salt marshes provide raw materials and food, coastal protection, erosion control, water purification, nursery habitat which helps to maintain fisheries, carbon sequestration, education and research, and tourism and recreation[5]. A reduction in the provision of these services relates to real economic losses. Costanza *et al* (2008) [6] estimate that the value of saltmarshes for coastal defence in the USA is US\$8236ha^{-1}yr^{-1} and the UK National Ecosystem Assessment (NEA)[7] estimated that coastal wetlands provide £3,730ha^{-1}yr^{-1} in storm buffering and flood control. Flood control is not the only economic benefit, biodiversity supported by UK coastal wetlands is estimated to be worth £2,786 ha^{-1}yr^{-1} in use value as a result of the contribution it makes to food production and recreation, see table 1. If the current trend in UK coastal habitat loss continues there will be significant loss in capacity of CO_2 sequestration in the region of £0.25 billion between 2000 and 2060[8].

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[1] Lotze *et al*. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science*, 312, 1806–1809.

[2] EEA, 2006. The Changing Faces of Europe's Coastal Areas. EEA Report 6/2006. Luxembourg: OPOCE.

[3] Airnoldi, L. & Beck, M. W. 2007. Loss status and trends for coastal marine habitats of Europe. *Oceanography and Marine Biology: An Annual Review*, 45, 345-405.

[4] Horton *et al*. 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300, *Quaternary Science reviews*, 8, 1-6.

[5] Baribier *et al*. 2011. The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81(2), 169–193.

[6] Costanza *et al*. 2008. The value of coastal wetlands for hurricane protection. *Ambio*, 37, 241-248.

Table 1. Estimated use values for a selection of ecosystem services provided by UK Coastal wetlands. Data taken from UK NEA

Ecosystem service related goods	Estimated value (£/ha/yr)
Biodiversity	2, 786
Water quality improvement	2, 676
Surface and groundwater supply	16
Flood control and storm buffering	3,730
Amenity and aesthetics	2,080

Salt marshes play a key role in flood defence through attenuating wave energy. Moller *et al* (2002)[9] found energy dissipation rates of 89% over saltmarsh compared to 20% over bare sands. Several studies have illustrated that this attenuating capacity of saltmarshes reduces the height required of man-made defences and the costs associated with building them. For example, a site with an 80m width of saltmarsh buffer would need a 3m high sea wall, if the salt marsh was removed a 12m sea wall would be required to provide the same protection[10] see Figure 1.

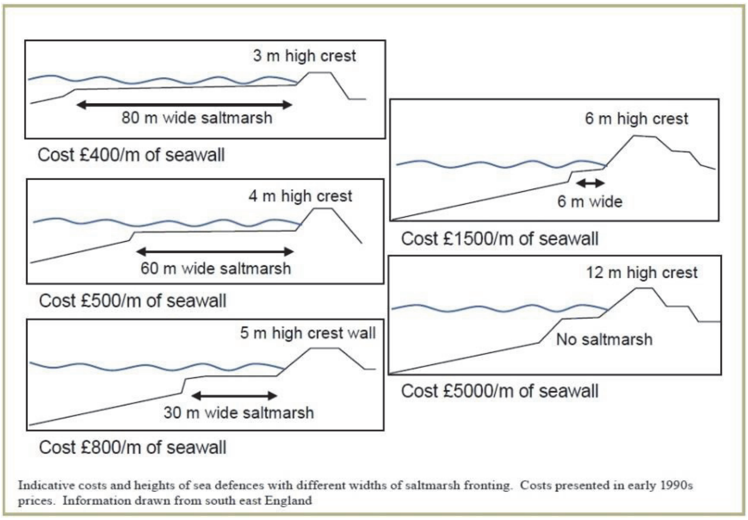

Figure 1. The cost of sea defences with different widths of saltmarsh buffer. Reproduced from Linham and Nicholls (2014).

[7] UK National Ecosystem Assessment, 2011. The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge.

[8] Beaumonta *et al*. 2014. The value of carbon sequestration and storage in coastal habitats. *Estuarine, Coastal and Shelf Science*, 137, 32–40.

[9] Möller *et al*. 2002. Spatial and temporal variability of wave attenuation over a UK East-coast saltmarsh. Proceedings of the 38th International Conference on Coastal Engineering, London: Thomas Telford Publishing, 362pp.

[10] King, S. & Lester, J.N. 1995. The value of saltmarsh as a sea defence. *Marine Pollution Bulletin*, 30, 180-189.

[11] Linham, M.M. & Nicholls, R.J. n.d. Managed realignment, ClimateTechWiki, Available at: http://www.climatetechwiki.org/content/managed-realignment. Accessed 3 June 2016.

Managed realignment

What is it?

Managed realignment is a 'soft' engineering technique where river, estuary and/ or coastal waters are deliberately allowed to extend beyond current flood defences. In the UK, the first deliberate managed realignment site was an area of 0.8ha at Northey Island in the Blackwater Estuary, Essex, which was flooded in 1991. This was done by breaching an existing embankment and was chosen as a demonstration project for habitat creation. Subsequently, approximately fifty different sites have been completed and more are planned[12].

Figure 2. Illustration of managed realignment reproduced from Linham and Nicholls (2014)

Types of managed realignment

There are several managed realignment techniques which are appropriate for different sites and purposes[13].

- Removal of defences – An entire section of sea defences are removed with no new defences built. Natural processes are allowed to dominate in the newly flooded area.
- Breach of defences – Parts of a defensive structure are removed allowing seawater incursion but retaining some protection from the erosive action of waves and tides.
- Realignment of defences – Coastal defences are rebuilt further inland prior to removal of original defences. Natural processes are allowed to dominate up to the new line of defence.
- Controlled tidal restoration – Enclosed areas behind hard sea defences are connected to the sea by inflow/ outflow pipes. Produces areas of flood storage and creates new habitat. Often used in highly developed coastal areas.
- Managed retreat – Long-term solution involving shifting land use wholesale, sometimes meaning moving valuable structures and allowing the shoreline to respond dynamically to sea-level rise.

[12] Pendle, M. 2013. Estuarine and coastal managed realignment sites in England. A comparison of predictions with monitoring results for selected case studies, HR Wallingford.

[13] Esteves, L. 2014. Managed realignment: A viable long-term coastal management strategy? SpringerBriefs in Environmental Science. New York: Springer.

Potential benefits of managed realignment
Improving habitats – Managed realignment sites can provide significant areas of habitat for valuable and protected species such as wading birds and fish. Using the abundance of juvenile sea bass Fonseca (2009)[14] showed that managed realignment sites in the Blackwater estuary can contribute 1.65kg of juvenile bass per hectare of saltmarsh and Luisetti *et al*[15] estimated that it contributed between £7.43-11.33ha^{-1} yr^{-1} to the commercial fishing industry.

Habitat offsetting – The demand for coastal land is high and often leads to damage to or loss of internationally designated coastal sites. Managed realignment has the potential to compensate for this by creating new areas of valuable habitat.

Positive impacts for recreation and tourism – New habitat created increases the amenity value of a site and the increase in biodiversity can spark an increase in nature tourism. The Blackwater realignment made a contribution of between £4, 429 and 8,348yr^{-1} to tourism and nature watching in the area[15].

Carbon sequestration – Net carbon burial values of between 0.266 and 0.347 tonnes ha^{-1}yr^{-1} were recorded for the Blackwater estuary site depending on sedimentation rates suggesting it was providing a significant carbon sequestration service[15].

Flood defence – Inter tidal buffer zones reduce the size and maintenance requirements of sea wall defences. Costs of implementing realignment in England have been predicted by the adaptation sub-committee (2013) to be £10-£15m yr^{-1}, this would be more than offset by the financial savings on flood defence of £180 to £130 million, (excluding flood storage benefits) as well as the environmental benefits predicated to be between £80 and £280 million[16].

Managed realignment of the coastline can also mediate the impact of tidal surges by creating space for the water to move into. Allowing the sideways movement of the tidal surge, alleviates pressure on flood defences elsewhere in the system[17].

Potential issues with managed realignment
Loss of Land – Land currently protected by flood defences will be lost. Compensation payments need to be made to land owners which can be expensive as land protected is valuable agricultural land. There is also an associated loss of overall agricultural productivity, however the adaptation sub-committee suggested that losses of agricultural land are more than compensated for by provision of other ecosystem services such as aquaculture, fish nursery and grazing[16].

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[14] Fonseca, L. 2009. Fish utilisation of managed realignment areas and saltmarshes in the Blackwater Estuary, Essex, S.E. England. PhD Thesis, Queen Mary University of London.
[15] Luisetti *et al*. 2011. Coastal and marine ecosystem services valuation for policy and management: managed realignment case studies in England. *Ocean & Coastal Management*, 54, 212-224.
[16] Esteves, L. 2014. Managed realignment: A viable long-term coastal management strategy? SpringerBriefs in Environmental Science. New York: Springer.
[17] EEA, 2014. A sustainable coastal defence re-creating wildlife habitats alongside economic farming methods, Abbott's Hall Farm UK. Available at: http://ec.europa.eu/ourcoast/index.cfm?menuID=8&articleID=5 Accessed 30 October 2014.

Stakeholder engagement – the change in land use associated with managed realignment has significant implications for the local population and wider stakeholders. There is often initial public opposition to realignment proposals and bad feeling where there is insufficient consultation[18].

Loss of Habitat – The incursion of saltwater has meant the loss of several valuable, internationally designated freshwater and terrestrial habitats. Thus far this has been dealt with on a case by case basis and sites have been able to mitigate this loss through habitat creation elsewhere[16].

Habitat quality – Habitat created through managed realignment is not equivalent to natural intertidal habitat. Vegetation tends to be dominated by pioneer species[19] and despite providing good habitat for a range animals such communities are missing key species[20]. The science behind managed realignment is still developing and it appears that several of the issues relating to the quality of the habitat are being resolved[21].

Example sites:

Tollesbury – An experimental managed realignment in Essex, UK. New sea defences, in the form of low embankments, were constructed behind the existing sea wall and surrounding approximately 21ha of low-lying agricultural land adjacent to Tollesbury Creek. Following the completion of the new sea defences, the existing sea wall was breached on 4 August 1995 and the enclosed area of agricultural land behind it exposed to tidal inundation for the first time in at least 150 years.
http://www.uea.ac.uk/~e130/Tollesbury.htm

Abbots Hall Farm – A project on the Blackwater Estuary, in England. Sea defences were moved inland in order to create a sustainable coastal defence, 80ha of arable land was returned back to saltmarsh, mudflat, coastal grassland and transition habitat.
http://ec.europa.eu/ourcoast/index.cfm?menuID=8&articleID=5

Niggbay - The first planned realignment in Scotland. Promoted by the Royal Society for the Protection of Birds (RSPB) and the Scottish Environmental Protection Agency (SEPA) with the aim of creating important habitats for wildlife at Meddat and also reducing maintenance requirements for the existing and failing defenses. Two 20m-wide breaches were made in existing sea defenses to allow the top of the tide to flood a 25ha field a secondary sea wall was already in place. The site is owned and managed by the RSPB, and forms part of its wider Nigg Bay reserve. This reserve incorporates extensive areas of mudflat, saltmarsh and wet grassland.
https://restorerivers.eu/wiki/index.php?title=Case_study%3ANigg_Bay_Managed_Realignment_Scheme

[18] DEFRA / Environment Agency, 2002. Flood and Coastal Defence R&D Programme, Managed Realignment Review Project Report
[19] Mossman *et al.* 2012. Does managed coastal realignment create saltmarshes with 'equivalent biological characteristics' to natural reference sites? *Journal of Applied Ecology*, 49, 6, 1446-1456.
[20] Atkinson *et al.* 2004. Managed realignment in the UK – the first 5 years of colonization by birds *Ibis*,146, (Suppl.1), 101– 110.
[21] Esteves, L. 2014. Managed realignment: A viable long-term coastal management strategy? SpringerBriefs in Environmental Science. New York: Springer

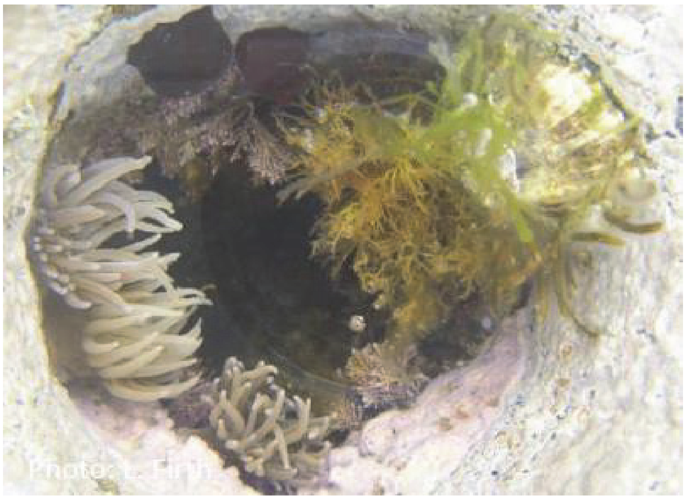
ANNEX 9: BIOENGINEERING SOLUTIONS

Hard enhancements

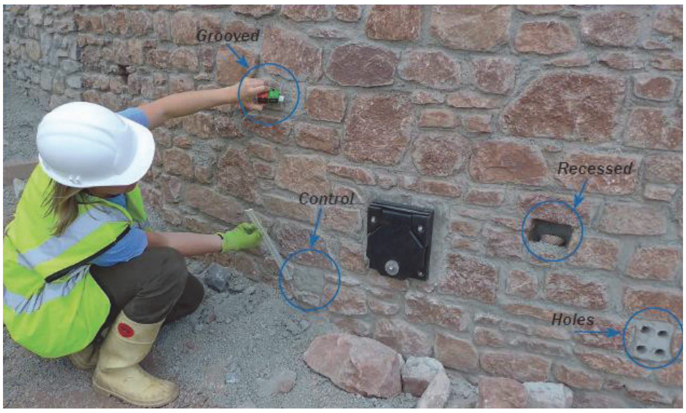
Cracks and cavity features can be cast into concrete for ecological enhancement such as these 'bioblocks' (Firth et al., 2012). Similar features could be reproduced for any replacement structures as part of realignment works e.g. at the Bowling railway wall.

Artificial rock pool created in a vertical seawall in Sydney Harbour (Chapman & Blockley, 2009).

Holes drilled into granite boulders (Tywyn, Wales)



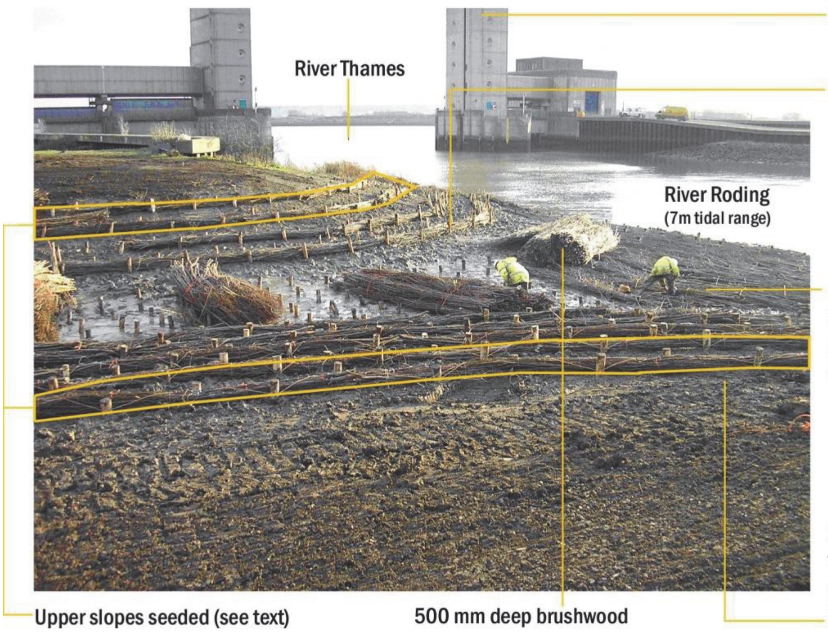
Diverse range of species present in a hole (c. 5 cm width) in a limestone block (Plymouth Breakwater, Devon). (from Firth et al., 2012).



Niche habitat enhancement at Shaldon, Devon, before exposure to the sea.

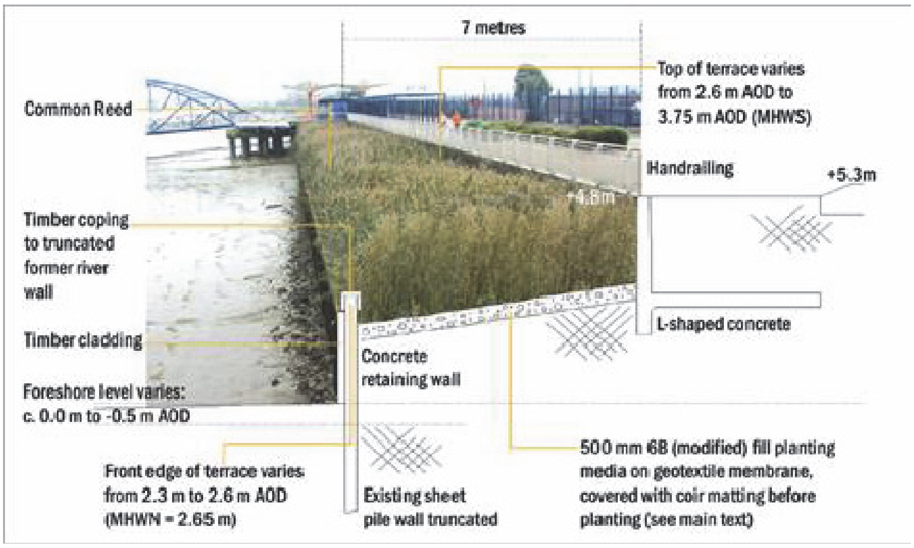
Shaldon, Devon, niche enhancement

Connectivity



Barking Creekmouth

https://restorerivers.eu/wiki/index.php?title=Case_study%3ABarking_Creekmouth



Greenwich peninsula, Environment Agency 2009

http://evidence.environment-agency.gov.uk/FCERM/en/SC060065/MeasuresList/M7/M7T2.aspx?pagenum=2

An artificial vegetated berm or terrace fronting a hard engineered structure provides space for marginal habitat to link to adjacent habitats both parallel and normal to the shore orientation. The design of the terrace will depend on several factors, including: Available space - the more limited the space available, the steeper the terrace will need to be; Sediment particle size distribution - steep slopes with cobbles and large gravel may not be suitable for vegetation growth, but may still provide refuge for invertebrates; some flat fish (e.g. flounder) appear reluctant to cross over submerged terrace steps and a possible solution is to ensure that terraces are sloping in two planes to encourage to the passage of flat fish onto the terrace.
Estuary Edges: Ecological Design Guidance (Environment Agency, 2008).

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