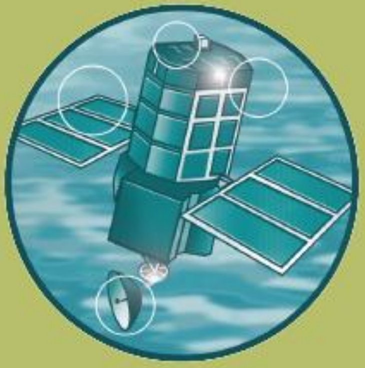
Joint Defra/EA Flood and Coastal Erosion
Risk Management R&D Programme

Understanding the Impact of Flood and Coastal Erosion Risk Management on the Causes of Climate Change

R&D Technical Report FD2622/TR



Environment Agency

defra
Department for Environment
Food and Rural Affairs

Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Understanding the Impact of Flood and Coastal Erosion Risk Management on the Causes of Climate Change

R&D Technical Report FD2622/TR

Produced: March 2010

Authors:
Economics for the Environment Consultancy (eftec)
Enviros Consulting Ltd
Philip Williams and Associates (PWA)

Statement of use: Final technical report of the project 'Understanding the Impact of Flood and Coastal Erosion Risk Management on the causes of Climate Change' (FD2622).

Dissemination status: Publically available

Keywords: Carbon footprint, climate change, flood risk management

Research contractor: Economics for the Environment Consultancy (eftec), Enviros Consulting Ltd. and Philip William and Associates (PWA)

Defra Project Officer: Victor Aguilera

Publishing organisation
Department for Environment, Food and Rural Affairs
Flood Management Division,
Ergon House,
Horseferry Road
London SW1P 2AL

Tel: 020 7238 3000 Fax: 020 7238 6187

www.defra.gov.uk/environ/fcd

Published by the Department for Environment, Food and Rural Affairs (March 2010).

Executive summary

Introduction

The purpose of this research project is to improve understanding of the climate change impact of flood and coastal erosion risk management (FCERM) policy in England. Establishing an accurate picture of how FCERM contributes to emissions of GHGs – in effect its ‘carbon footprint’ - is critical to facilitating effective policy responses for reducing future emissions. In addition, mitigating the drivers of climate change now can reduce the potential costs of adaptation in the future.

The research aims of the project are to:

- Provide an evidence base to support the current best estimate of the contribution of FCERM policy to GHG emissions;
- Investigate and evaluate the impact of different FCERM policy options on GHG emissions;
- Identify the FCERM policy areas most likely to present significant threats and opportunities for the release/abatement of GHG emissions and the extent of these impacts in terms of contributing to UK GHG reduction targets; and
- Facilitate understanding of the consequences of current and potential Government intervention in FCERM policy on climate change.

The approach to addressing the research aims is that of a desk-based assessment. No primary data collection has been undertaken; all evidence is collated from secondary sources. The main elements of the assessment are: (i) a conceptual review of the policy context for the project, which informs the scope and subsequent framework for the analysis; and (ii) collation and analysis of currently available data to estimate as best possible the carbon footprint of FCERM policy. With respect to (ii), the availability of data can represent a significant challenge to carbon footprinting exercises. This is often the case when a subject area is addressed for the first time as is the case for the entirety of FCERM policy.

Methods and Scope

The term ‘carbon footprint’ is shorthand for an inventory of the GHG emissions that result from an activity, event, organisation, product or geographical area. It typically measures the emissions of each of the basket of six greenhouse gases (CO_2; CH_4; N_2O; PFCs; HFCs; SF_6) expressed in terms of carbon dioxide equivalent (CO_2e) to enable the comparison of emissions of the different gases on a like-for-like basis.

Basic principles for developing a transparent and robust carbon footprint are:

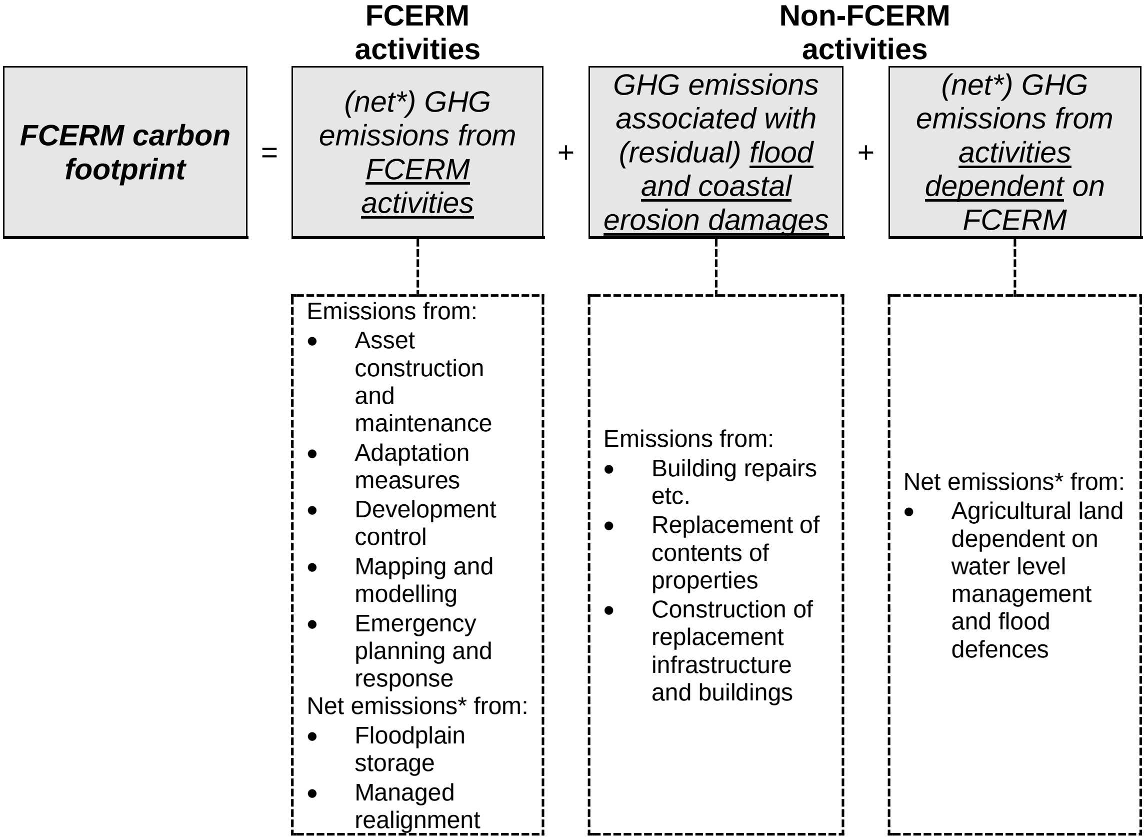
- *Establish project boundaries:* In particular determine the scope of activities to be included in the analysis.

- *Determine calculation methodology:* the “first best” approach to calculating emissions is to take primary consumption data and multiply this by a GHG emissions factor.
- *Present results:* it is important that the results are presented in a way that facilitates ‘like for like’ comparison with existing studies and also highlights any limitations and caveats associated with the results.

In addition the approach to a carbon footprint should facilitate future updating as new or previously unavailable information becomes available.

The basic formulation of the FCERM policy carbon footprint is summarised in Figure ES1. ‘FCERM activities’ are defined as actions or interventions that arise as a direct result of FCERM policy that are intended to reduce the risk of flooding (including coastal, river and surface water flooding) or coastal erosion. In general FCERM activities are intended to either reduce the likelihood of flooding or coastal erosion, or reduce the impacts of flooding and coastal erosion. ‘Non-FCERM activities’ are defined as actions, interventions or activities that are consequences of FCERM policy, but that are not directly controlled by FCERM. For example repair and rebuilding construction activities in response to flooding damages or agricultural land use protected by flood defences.

Figure ES1 Basic formulation of the FCERM policy carbon footprint



Notes: *Net emissions = GHG emissions – carbon sequestration

The research considers a number of ‘scenarios’ to assess the GHG emissions implications of current and future policy options. This involves comparison of the carbon footprint of a baseline scenario with the carbon footprints of alternative scenarios that reflect different policy focus. These alternative scenarios may be considered as ‘*what if*’ scenarios. For example, what would the net GHG emissions implications be, if current rates of maintenance, asset construction and residual damages continued?

The baseline for the assessment is a ‘business as usual’ (BAU) scenario that assumes a continuation of the current policy focus and levels of investment. The main emphasis of data collection has been to establish the BAU situation; i.e. collate data on existing assets and maintenance and planned infrastructure that reflect the current policy circumstances. Two alternative policy scenarios are considered:

- Increased investment in river and coastal flooding (‘*BAU plus*’): typically expenditure in the ‘traditional’ FCERM policy areas represent a good return on public investment. EA (2009) reports that benefit cost ratios for river and coastal flooding schemes are around 8:1. This scenario assesses the carbon footprint implications of increased expenditure from the BAU case, weighing increased emissions from FCERM activity (i.e. more construction and maintenance schemes) against the decrease in emissions associated with residual flooding damages.
- Addressing surface water flooding (‘SWF’): Surface water management represents a developing policy area under the current draft Flood and Water Management Bill (Defra, 2009b). This scenario assesses the implications of increased expenditure on surface water flooding schemes, weighing increases in emissions from asset construction against the decrease in emissions associated with surface water flooding.

A further scenario to be assessed is that of ‘policy-off’, which describes the counterfactual to FCERM intervention and associated net GHG emissions; i.e. the carbon footprint implications of no active FCERM intervention.

Details of data requirements, current data availability, and assumptions entailed in estimating the carbon footprints for the BAU, policy-off and alternative policy scenarios are set out in the Technical Report (see in particular Sections 2.4 and 3.2).

Data and results

Estimated carbon footprints for the BAU, policy-off, BAU-plus and SWF scenarios are presented in Table ES1 in terms of annual average tonnes of CO_2e per year. The annual estimate is calculated from the assumed profile of emissions over a 50-year time horizon.

With respect to Figure ES1, but based on data availability, the estimated carbon footprints include:

- Emissions associated with FCERM activities - asset construction and maintenance only.
- Emissions associated with flood and coastal erosion damages - reparations to properties and possessions.

The analysis does not estimate emissions associated with adaptation measures, development control, mapping and modelling, emergency planning and response, flood storage or managed realignment. In addition emissions from activities dependent on FCERM are not accounted for in the analysis (e.g. agriculture).

Table ES1: Estimate of FCERM carbon footprint for alternative policy scenarios (Mt CO_2e per year)

Scenario	***Emissions arising from:***		***Total***
	FCERM activities	*Flood and coastal erosion damages*	
BAU	0.53	1.89	2.41
Policy-off	n/a	2.89	2.89
BAU plus	0.70	1.67	2.36
SWF	0.55	1.62	2.18

The current 'best' estimate of net emissions from FCERM policy and investments is 2.41 Mt CO_2e per year. As detailed in the main report, the greatest contribution to the BAU carbon footprint estimate comes from surface water flooding damages. River and coastal flooding contribute similarly to the overall BAU carbon footprint in terms of FCERM activities (each approximately 10% of the overall estimate). In both cases estimated emissions arising from flood damages outweigh estimated emissions arising from flood alleviation activities. Estimated emissions associated with coastal erosion are relatively minor (0.04 Mt CO_2e per year), representing less than 2% of the total BAU footprint.

Analysis

The current climate change impact of FCERM activities can be viewed from two perspectives. First, in terms of the overall level of emissions - on the basis of the results presented in Table ES1 - FCERM activities are a net contributor to GHG emissions with respect to the business as usual (BAU) scenario (estimated emission of approximately 2.41 Mt CO2e per year).

The second perspective considers the impact of FCERM activities in relation to the counterfactual of no FCERM activities (represented by the policy-off scenario and estimated emissions of approximately 2.89 Mt CO2e per year). The analysis here suggests that FCERM activities largely represent a net reduction in emissions due to flood alleviation actions which reduce damages from flooding and consequential GHG emissions associated with those damages. In other words, without FCERM activities, net emissions resulting from FCERM policy would likely be greater due to impacts of greater flood damage. This interpretation therefore suggests that, in the short term at least, the net contribution of FCERM activities to climate change *mitigation* is positive.

Longer term however the marginal impact of FCERM is more difficult to assess because FCERM policy influences the baseline situation against which changes to emissions are calculated. Therefore, while FCERM avoids emissions resulting from flooding in the shorter term, it may in the long term perpetuate activities (land uses or patterns of development) that have higher carbon emissions, and higher avoided emissions due to avoided flooding, than would otherwise be the case. It has, however, not been possible to account for the more dynamic aspect of FCERM policy in this regard in this analysis. This is primarily limited by the current scope for specifying parameters of alternative policy scenarios (as detailed in the main report).

Conclusions

Drawing together the findings of the research, the key themes that emerge are:

- Current FCERM *activities* result in net emissions of GHGs but, in general, these emissions are lower than the counterfactual level of GHG emissions that would arise in the short-term in their absence as a result of flood and coastal erosion *damages* (i.e. the policy-off scenario and no active intervention);
- Some sources of emissions and all sources of sequestration are not included in this result. The net effect of their inclusion is not known at present;
- Compared to the net emissions from other sectors, the role of FCERM policies is relatively minor (current UK GHG emissions are in the region of 630 Mt CO_2e per year), not withstanding unquantified emissions and data limitations;
- There is potential to enhance sequestration of GHG emissions via land use management (e.g. managed realignment activities and changes in land use in order to be compatible with flood storage). The outcomes will be case specific and dependent on a variety of environmental factors and, in general, are unlikely to substantially ‘offset’ GHG emissions that arise in relation to flood alleviation activities and flood damages;
- All analysis and findings are subject to significant assumptions and caveats that reflect the current extent of the evidence base on the carbon footprint of FCERM.

Gaps in available evidence and suggestions for moving forward the estimate of the FCERM carbon footprint are presented in the main report.

Contents

Figures

Tables

1. Introduction

1.1 Background

Current flood and coastal erosion risk management (FCERM) policy in England recognises the need to address the challenges and pressures from climate change. The majority of effort is focused on adapting to the main impacts of climate change on flood and coastal erosion risks. However, there may be scope for FCERM to contribute to mitigation of climate change by developing policies and strategies that avoid an increase of, or lead to a reduction, in greenhouse gas (GHG) emissions.

The purpose of this research project is to improve understanding of the climate change impact of FCERM policy; in effect, to provide an assessment of its 'carbon footprint'. Establishing an accurate picture of how FCERM contributes to emissions of GHGs is critical to facilitating effective policy responses for reducing future emissions. In addition, mitigating the drivers of climate change now can reduce the potential costs of adaptation in the future.

1.2 Objectives

The Terms of Reference (ToR)[1] sets out the research aim of the project as to:

- Provide an evidence base to support the current best estimate of the contribution of FCERM policy to GHG emissions;
- Investigate and evaluate the impact of different FCERM policy options on GHG emissions;
- Identify the FCERM policy areas most likely to present significant threats and opportunities for the release/abatement of GHG emissions and the extent of these impacts in terms of contributing to UK GHG reduction targets; and
- Facilitate understanding of the consequences of current and potential Government intervention in FCERM policy on climate change.

Overall the intention is that the project develops as far possible, given the current evidence base, the necessary tool(s) for policy-makers to weigh up and present evidence of the positive and negative effects of FCERM policy on climate change. This also provides an opportunity to identify gaps within the current evidence base and scope for opportunities for addressing them.

Within the overall research aims for the project, the ToR identifies a set of specific policy questions to be addressed (Table 1.1).

---

[1] Defra (2008) *Understanding the Impact of Flood and Coastal Erosion Risk Management on the causes of Climate Change*, FD2622 Specification.

Table 1.1 Defra policy questions to be addressed by research

Policy Question	***Defra Requirement***
I. What is the current net climate change impact of FCERM activities?	The likely impact: neutral, negative or positive?
II. What is the best estimate of net GHG emissions from FCERM policy and investments?	Quantitative estimate of GHG emission: *tonnes of carbon dioxide equivalent per year* ($t\ CO_2e/yr$)
III. Which FCERM activities and policies provide significant positive mitigation of net GHG emissions through sequestration of carbon?	Identification of '*carbon negative*' activities and policies
IV. What are the FCERM policy areas likely to make the biggest contribution to UK GHG policy under different future scenarios?	Identification of policy areas (e.g. coastal flooding, coastal erosion, fluvial flooding, surface water flooding) that *provide greatest scope for contributing to reductions in GHG emissions*
V. What are the key opportunities to reduce GHG emissions and/or enhance carbon sequestration in terms of future FCERM policies?	Identify the implications of the findings to Questions I-IV

Addressing both the research aims and specific policy questions requires an appreciation of FCERM policy and investment as well as the science and methods – carbon footprinting - of estimating GHG emissions. The influence of FCERM policy is not limited to the protection of people and property via construction and maintenance of defences; it also can have considerable influence on land use management and development, which in turn may have significant implications for emissions of GHG. Moreover, the scientific understanding underlying measurement of GHG emissions is complex and still developing, particularly with respect to sequestration of carbon by terrestrial and coastal ecosystems, a key aspect of land use management directly or indirectly influenced by FCERM policy.

The approach to addressing the research aims and policy questions is based on: (i) a conceptual review of the policy context for the project, which informs the scope and subsequent framework for the analysis; and (ii) collation and analysis of currently available data to estimate as best possible the carbon footprint of FCERM policy. With respect to (ii), the availability of data can represent a significant challenge to carbon footprinting exercises. This is often the case when a subject area is addressed for the first time as is the case for the entirety of FCERM policy.

Finally, a requirement of this project is that the analysis is compatible, as far as possible, with emerging UK and wider guidance on emissions reporting[2]. This will ensure that the study provides outputs that can be used in wider Government and land use management reporting initiatives.

---

[2] For example the GHG protocol (http://www.ghgprotocol.org/) and Carbon Disclosure Project (http://www.cdproject.net/).

1.3 Report Structure

Sections 2-5 of the report are structured as follows:

- *Section 2* provides an overview and description of the methods to analyse net greenhouse gas emissions/sequestration from FCERM activities;
- *Section 3* summaries currently available data and presents the estimated FCERM carbon footprint;
- *Section 4* presents the analysis of the results and an assessment in gaps in the current evidence base; and
- *Section 5* sets outs key conclusions and highlights the opportunities to improve our understanding of the impact of FCERM on the causes of climate change.

Three annexes also accompany the report:

- Annex 1: Land use management and the FCERM carbon footprint
- Annex 2: Description of TE2100 carbon multiplier
- Annex 3: FCERM carbon footprint (spreadsheet model)
- Annex 4: Case studies that ‘test the FCERM carbon footprint framework at the project level.

2. Methods and Scope

Section 2 focuses on the methodology and scope of analysis in assessing the carbon footprint of FCERM policy. An overview of the methodological approach to the project is provided in Section 2.1, while Section 2.2 reviews the policy context from the perspective of UK climate change policy and flood and coastal erosion risk management policy in England. Section 2.3 details the scope and framework for analysis, including conceptual and practical considerations and data requirements.

2.1 Approach

The main methodological steps and tasks of this 'desk-based' assessment are summarised in Table 2.1. No primary data collection has been undertaken; all evidence is collated from secondary sources. As described in Section 1.2 the project approach primarily consists of a review of the policy context (in order to establish the scope and framework for the analysis) followed by the collation and analysis of available evidence.

Table 2.1 Approach to project – methodological steps

Step	***Tasks***	***Purpose***
1. Establish a framework for analysing the impacts of FCERM policy on climate change	a. Review of GHG emissions and FCERM policy context; b. Identify FCERM policy scenarios, including current policy baseline, to facilitate comparative analysis of future policy options; c. Outline data requirements methods for calculating GHG emissions and carbon sequestration from FCERM policy.	The framework for analysis is structured to address all research aims and policy questions as outlined in Section 1.2.
2. Identify and collate available evidence based on data requirements outlined in the framework.	a. Review of relevant research and data sources b. Consultation with relevant stakeholders (e.g. Environment Agency) to determine extent of currently available evidence and to request data.	To address the research aim to '*provide an evidence base to support the current best estimate of the contribution of FCERM policy to GHG emissions'*.

Table 2.1 Approach to project – methodological steps (cont.)

Step	***Tasks***	***Purpose***
3. Analyse available data to estimate net GHG emissions from FCERM policy	a. Calculate GHG emission associated with FCERM policy[a] b. Review and calculate/analyse data for comparative scenario analysis as outlined in the analysis framework.	To address the research aim to '*investigate and evaluate the impact of different policy options*' and policy questions I and II[b].
4. Provide high-level assessment of FCERM policy impact on climate change	a. Interpret analysis and results	To address research aims to '*identify FCERM policy areas presenting significant threats and opportunities to contribute to GHG emissions reductions*' and '*facilitate understanding of consequences of current and future policy options*' and policy questions III and IV[b].
5. Provide suggestions moving forward and conclusions	a. Reporting results and identify opportunities for reducing the FCERM carbon footprint	To address policy question V[b].

Notes:
[a] See section 2.2.4 for further detail; [b] See Table 1.1.

Steps 1 – 4 in Table 2.1 detail the process for providing a high-level assessment of the GHG implications of the overall FCERM policy circumstances. The research also includes a series of case studies (presented in Annex 4) that apply the framework for analysis set out in Section 2.3 at an individual FCERM scheme level, attempting to establish the carbon footprint of a selection of recently implemented or appraised coastal and inland flood alleviation projects. Outcomes from the case studies also inform the conclusions and suggestions for moving forward under Step 5 in Table 2.1.

2.2 Policy context

The brief review of the policy context for the project focuses on three main themes of the research: UK climate change policy; carbon footprint reporting requirements; and flood and coastal erosion risk management policy in England. The section concludes by providing an overview of the role of FCERM policy in contributing to GHG emissions.

2.2.1 UK climate change policy

Climate change

'Climate change' is a term commonly applied to describe an observed and expected continuation of increased average temperature of the Earth's near surface and air since the mid-20th century, which is largely the result of anthropocentric emissions of GHGs.

Basis of current UK policy

The UK has committed to GHG emission reductions of at least 80% by 2050, and initially to reductions in carbon dioxide emissions of at least 26% by 2020, against a 1990 baseline[3]. The reduction target was defined in the Climate Change Bill which became law in November 2008[4].

The Climate Change Bill also resulted in the creation of the Climate Change Committee, an independent expert body to advise Government on the level of carbon budgets and where cost-effective savings can be made. The Committee will submit annual reports to Parliament on the UK's progress towards targets and budgets. The Government must respond to these annual reports, thereby ensuring transparency and accountability on an annual basis. The Committee has recommended that a carbon reduction of 34% on 1990 levels should be achieved by 2020[5].

An 80% reduction of total greenhouse gas emissions against a 1990 baseline equates to about 618 million tonnes carbon dioxide equivalent (Mt CO_2e). Between 1990 and 2008 a reduction of annual emissions of 136 million t CO_2e has been achieved[6].

Under the Kyoto Protocol the UK must reduce its greenhouse gas emissions by 12.5% below 1990 levels over the 2008 to 2012 commitment period.[7] The UK is currently on track to double the Kyoto target[8].

2.2.2 UK greenhouse gas reporting

Annual statement of UK emissions

As part of the Climate Change Act 2008, the Secretary of State has an annual duty to lay before Parliament a statement reporting the amount for the year of UK emissions, UK removals and net UK emissions of each greenhouse gas[9].

---

[3] 2020 target is currently being reviewed to reflect the move to all greenhouse gases and the increase in the 2050 target to 80%.

[4] Climate Change Act 2008 – Department of Energy and Climate Change (http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx)

[5] UK Carbon Budgets – Committee on Climate Change (http://www.theccc.org.uk/carbon-budgets/)

[6] Based on data from UK Greenhouse Gas Emissions 1990-2007 (http://www.defra.gov.uk/environment/statistics/globatmos/download/xls/ghg_annex_a_20090203.xls)

[7] Progress towards national and international targets – Defra (http://www.defra.gov.uk/environment/climatechange/uk/progress/index.htm)

[8] 05 Jun 09 – Press Release – UK on track to double Kyoto target – DECC (http://www.decc.gov.uk/en/content/cms/news/pn058/pn058.aspx)

[9] Climate Change Act 2008, c. 27 Public Acts 2008 (http://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080027_en.pdf

In addition to the national GHG inventory (see below) and the annual statement of UK emissions, Defra and National Statistics report annually on sustainable development and energy sector indicators respectively[10].

National inventory report

Following ratification of the Kyoto Protocol as an Annex I party, the UK is required to submit information on its national GHG inventory annually to the United Nations Framework Convention on Climate Change (UNFCCC). National inventories are prepared by all Annex I countries which have ratified the Kyoto Protocol using comparable methodologies and good practices agreed upon by the Conference of the Parties[11]. Inventories must report on six major emission source categories:

- Energy;
- Industrial processes;
- Solvent and other product use;
- Agriculture;
- Land use, land-use change and forestry (LULUCF); and
- Waste.

As a minimum, inventories are required to report on the 'basket of six GHGs': carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); perfluorocarbons (PFCs); hydrofluorocarbons (HFCs); and sulphur hexafluoride (SF_6). Inventories should also contain information on the indirect greenhouse gases: carbon monoxide (CO); nitrogen oxides (NOX) and non-methane volatile organic compounds (NMVOCs); and are further encouraged to provide information on sulphur oxides (SO_2).

National emissions estimates for the UK are available for 1990-2007. Table 2.2 sets out the GHG emissions per source category in CO_2e terms for 2003 to 2007 from the UK and Crown Dependencies. Total UK inventory GHG emissions in 2007 were approximately 636 Mt CO_2e, representing a 3% reduction compared to the 2003 estimate[12].

---

[10] Climate Change – the UK Programme 2006, HM Government

[11] Annex 1 Greenhouse Gas Inventories – UNFCCC (http://unfccc.int/national_reports/annex_i_ghg_inventories/items/2715.php)

[12] The Kyoto target is based on 1990 emissions.

Table 2.2 Aggregated emissions trends per source category in the UK[1] (Mt CO_2e)

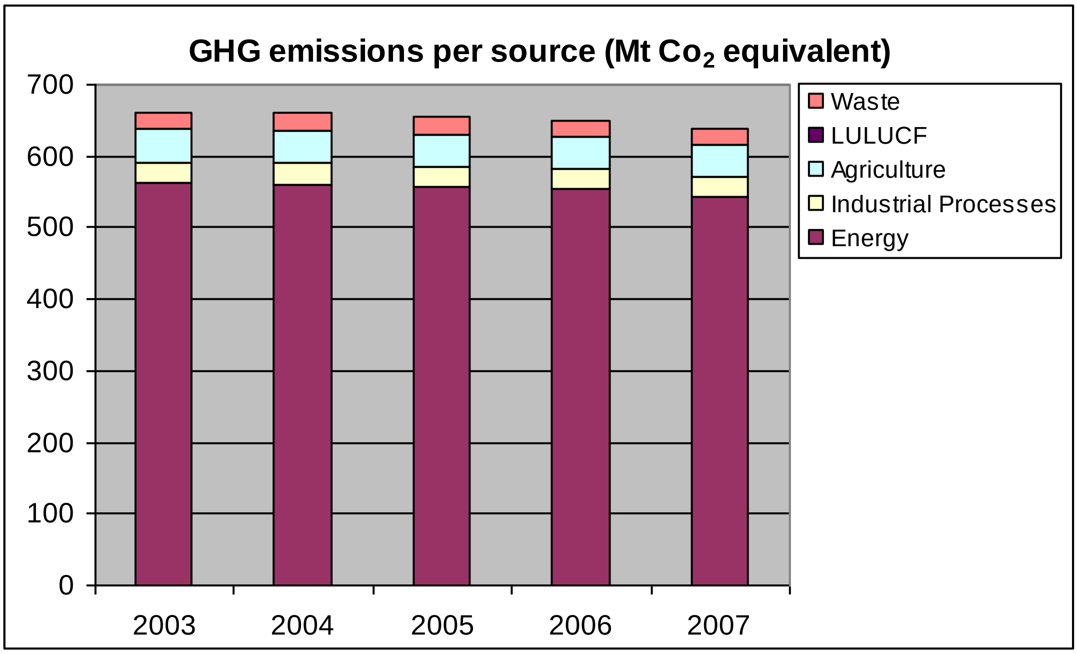
Source category	***2003***	***2004***	***2005***	***2006***	***2007***
Energy	561.67	561.28	557.26	554.9	543.98
Industrial processes	29.09	28.74	28.21	26.91	27.86
Agriculture	46.66	46.56	45.69	44.57	43.32
Land use, land use change and forestry	-0.98	-1.73	-1.88	-1.75	-1.75
Waste	24.59	23.07	22.84	22.84	22.83
Total (net emissions)	661.04	657.93	652.12	647.48	636.24

Source: UK Greenhouse Gas Inventory 1990 to 2007: Annual Report for Submission under the Framework Convention on Climate Change, DECC (2009)

Notes: [1]Comprises of emissions from England, Wales, Scotland, Northern Ireland and Crown Dependencies (Jersey, Guernsey and the Isle of Man); excludes emissions from Overseas Territories (the Cayman Islands, Falkland Islands, Bermuda, Montserrat and Gibraltar).

Figure 2.1 provides a graphical representation of Table 2.2, illustrating the magnitude of difference between the emissions from the energy source sector (approximately 85% of emissions) compared to all other sectors. As is evident from Table 2.2, the Land Use, Land Use Change and Forestry (LULUCF) sector contributes a small net reduction in emissions (less than 1% of total emissions).

Figure 2.1 UK GHG emissions per source category from 2003 to 2007 (Mt CO_2e)



Source: Based on Table 2.2.

2.2.3 Basic principles of carbon footprinting

Definition of 'carbon footprint'

The term 'carbon footprint' is shorthand for an inventory of the GHG emissions that result from an activity, event, organisation, product or geographical area. It typically measures the emissions of each of the basket of six greenhouse gases (CO_2; CH_4; N_2O; PFCs; HFCs; SF_6) expressed in terms of carbon dioxide equivalent (CO_2e) to enable the comparison of emissions of the different gases on a like-for-like basis.

Estimating a carbon footprint and establishing the contribution of different activities to it enables the key drivers of emissions to be identified. It also shows where to focus efforts to reduce emissions and facilitates the measurement of the impact of a GHG emissions reduction strategy.

The Greenhouse Gas Protocol

There is no single accepted methodology for deriving a carbon footprint. However the GHG Protocol[13] is a widely recognised approach. Under the protocol, GHG emissions are classified as either:

- *Scope 1 emissions*: these are ‘direct’ GHG emissions which occur from sources that are owned or controlled by an organisation and can arise from on-site energy generation, fugitive emissions, or transport that the organisation is responsible for; or
- *Scope 2 emissions*: these are ‘indirect’ GHG emissions arising from the consumption of purchased energy (typically electricity), or energy associated with generation and transmission of electricity within material purchased; or
- *Scope 3 emissions*: this includes the treatment of all other indirect emissions, and may include emissions arising from business travel, water consumption, etc.

In addition to classifying emissions, the GHG Protocol also provides guidance on the calculation of emissions from different sources and covers considerations such as the use of renewable energy.

Publicly Available Specification (PAS) 2050

The Carbon Trust and Defra have co-sponsored the publication by the British Standards Institution of PAS 2050[14], a carbon footprint standard for products. PAS 2050 provides a method for assessing the GHG emissions arising from products across their life cycle, from initial sourcing of raw materials through manufacture, transport, use and ultimately recycling or waste. This new standard is the first widely accepted and published method that provides a framework for understanding the carbon footprint of goods and services. PAS 2050 may be used for a variety of formal and informal processes for improving and communicating the GHG performance of products and services.

---

[13] GHG Protocol (http://www.ghgprotocol.org/)

[14] BSI Group – Assessing the life cycle greenhouse gas emissions of goods and services (http://www.bsigroup.com/en/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050/)

Developing a robust carbon footprint

Basic principles for developing a transparent and robust carbon footprint are:

- *Establish project boundaries:* In particular determine the scope of activities to be included in the analysis. Consideration of the project boundaries in relation to FCERM policy is provided in Sections 2.2.4 and 2.3.

- *Determine calculation methodology(ies):* the “first best” approach to calculating emissions is to take primary consumption data and multiply this by a GHG emissions factor[15]. For example consumption of energy (kWh) and GHG emissions per unit of consumption (t CO_2e/kWh).

  Standard emissions factors exist for some of the emissions sources that this project addresses, such as energy and materials (e.g. t CO_2e/tonne)[16]. For other emission sources, such as land use changes (e.g. conversion of agricultural land to wetland) the availability of standard emissions factors is limited due to the wide range of impacts such activities have.

- *Present results:* it is important that the results are presented in a way that facilitates ‘like for like’ comparison with existing studies and also highlights any limitations and caveats associated with the results.

In addition the approach to a carbon footprint should facilitate future updating as new or previously unavailable information becomes available.

2.2.4 Flood and coastal erosion risk management policy

The overall aim of flood and coastal erosion risk management policy in England is to reduce risks to people, property and the natural environment from flooding and coastal erosion. A key aspect of current and future policy is adaptation to changing risk caused by natural processes (e.g. isostatic sea level change), natural processes enhanced by human activity (particularly climate change) and anthropocentric processes (e.g. land-use change and development) (Defra, 2005).

The FCERM policy remit covers all forms of flooding and coastal erosion:

- *River flooding*: results from heavy or sustained rainfall exceeding the capacity of rivers and streams.

- *Coastal flooding*: results from a combination of high tides and storm conditions flooding coastal and estuary areas. Severe flooding results when

---

[15] An emissions factor defines the average emission rate of pollutant from or a given source, relative to the intensity of a specific activity.

[16] See for example - energy: http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm; and embodied carbon: http://www.bath.ac.uk/mech-eng/sert/embodied/

low atmospheric pressure coincides with a high tide, resulting in a tidal surge.

- *Surface water flooding*: results from heavy or sustained rainfall exceeding capacity of drainage systems, particularly in urban areas[17].

- *Groundwater flooding*: results from rising groundwater levels particularly in low lying areas underlain by permeable rocks (aquifer).

- *Coastal erosion*: loss of land and removal of beach or dune sediments caused by wave action, tidal currents and drainage.

The Environment Agency (2009a) estimates that approximately 5.2 million properties in England are at risk from flooding; this equates to one in six properties. Of this total, approximately 2.4 million properties are at risk from river and coastal flooding and 2.8 million are susceptible to surface water flooding. Around 1 million properties are susceptible to both surface water flooding and river or coastal flooding. The number of properties at risk from coastal erosion is considerably smaller – the current ‘working estimate’ is that approximately 200 properties may be lost nationally over the next 20 years (Defra, 2009a) – but this is likely to rise over time as a result of climate change.

Defra has national policy responsibility for England for flood and coastal erosion risk management and provides funding through grant in aid to the Environment Agency (EA), which also administers grant for capital projects to Local Authorities (LAs) and Internal Drainage Boards (IDBs). All three organisations are referred to as Operating Authorities (OAs) and are responsible for the delivery of FCERM (such as construction of flood defences). Defra does not build or manage flood defences nor direct the authorities on which specific projects to undertake. Table 2.3 sets out the responsibilities of OAs. Defra also provides grant aid to OAs and is therefore part-responsible for the effects of FCERM activities carried out by operating authorities.

---

[17] Note that sewer flooding that occurs as a result of failure of equipment or blockages and results in raw sewage flooding land and properties is outside the FCERM policy remit.

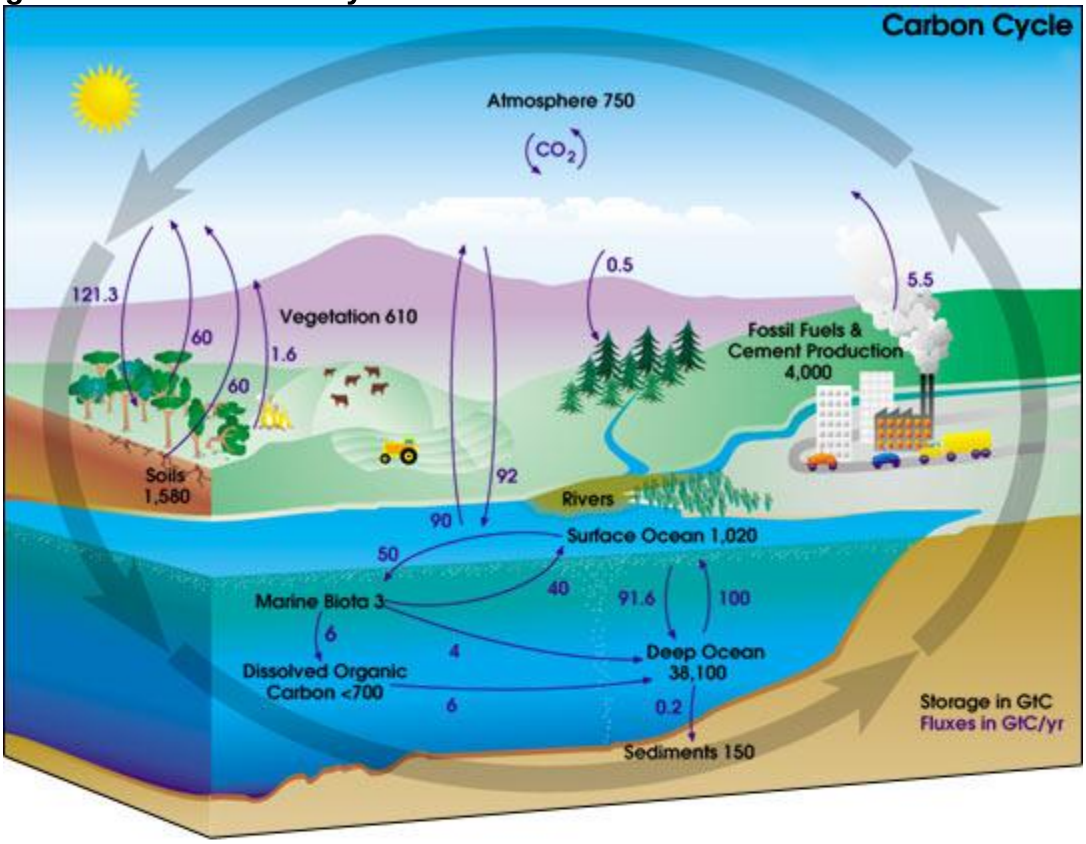
Table 2.3 FCERM operating authorities and related responsibilities

Operating Authority		***Responsibilities***
Environment Agency (EA)		• Management of flood risk from designated main rivers and water courses and the sea • Construction and maintenance of defences and other management measures • Flood forecast and warning • Floodplain development control advice • Raising public awareness of flood risk • Management of central Government grants for LA and IBD capital projects
Local authorities (LAs)	Inland local authorities	• Management of flood risk from ordinary water courses (non designated main rivers) including construction and maintenance of defences • Flood emergency planning • Response to flooding events (e.g. providing emergency housing) and clean-up • Developing responsibility for managing surface water flooding
	Coastal local authorities	• Management of risk from ordinary water courses (non designated main rivers), coastal erosion and some areas of flood risk from the sea - construction and maintenance of defences • Flood emergency planning • Response to flooding events (e.g. providing emergency housing) and clean-up • Developing responsibility for managing surface water flooding
Internal drainage boards (IDBs)		• Independent bodies responsible for management of land drainage in some low-lying areas

2.2.4 Contribution of flood and coastal erosion risk management to emissions of GHGs

FCERM policy primarily influences the direct exchange of GHGs (particularly CO_2, CH_4 and NO_X) between the terrestrial biosphere and the atmosphere as well as playing a role in the exchange of carbon between the terrestrial biosphere and oceans (in terms of dissolved organic carbon) (Figure.2.2).

Figure 2.2 The carbon cycle



Source: NASA http://earthobservatory.nasa.gov/Features/CarbonCycle/carbon_cycle4.php

The roles and responsibilities detailed for OAs in Table 2.3 give rise to a number of routes by which activities, investments and outcomes of FCERM policy may generate GHG emissions or sequester carbon. In summary the principle sources of emission/sequestration are the following.

Embodied carbon within materials

Embodied carbon measures GHG emissions associated with the manufacture of a product (or material). A full account of embodied carbon measures GHG emissions from the entire product life cycle. Based on the GHG Protocol (Section 2.2.3) these are Scope 1, 2 and 3 emissions. With respect to FCERM, embodied carbon is relevant to:

- Use of materials in asset construction and maintenance activities (i.e. defences and associated infrastructure as well as adaptation, resilience and resistance measures for individual properties), such as concrete and metal; and
- Use of materials in flood and coastal erosion damage reparations, e.g. repair of building fabric and structures, rebuild of properties, replacement of possessions, etc.

Energy use in operations

FCERM activities give rise to GHG emissions from use of electricity from the national grid and also on-site consumption of fossil fuels, in buildings and facilities (e.g. pumping stations). These are Scope 1, 2 and 3 emissions.

Energy use in transport

Energy use also includes GHG emissions associated with fuel (petrol, diesel and biofuels). These are Scope 1, 2 and 3 emissions. The two main transport emission sources are:

- Transport of materials (e.g. for asset construction and maintenance); and
- Transport of people (e.g. for survey, inspection, maintenance, construction, etc. activities).

Land use and land use change

FCERM may influence land use management and consequently GHG emissions from this sector, either directly or indirectly. In the ‘direct’ case FCERM activities include the creation of floodplain areas designed for flood water storage and managed realignment to accommodate changing coastal processes. These can result in habitat creation, restoration or maintenance, particularly in terms of wetland habitats, which in turn can lead to storage of carbon in floodplain soils or coastal sediment as depicted in Figure 2.2 (see also: Thompson, 2008).

In the ‘indirect case’, FCERM may be a critical factor to GHG emissions that arise from development of household, commercial and agricultural sectors, particularly if land-use changes as a consequence of FCERM activity; i.e. development is allowed as a result of areas being protected by defences. This may lead to GHG emissions in terms of embodied carbon from construction and energy use (e.g. housing and commercial developments) and also changes in agricultural land use management. The principle consideration in relation to indirect land use GHG emissions is ‘additionality’ and whether in the absence of FCERM the emissions would arise[18].

FCERM activities and GHG emissions

Table 2.4 links the sources of GHG emissions outlined above to FCERM and non-FCERM activities as explained below:

---

[18] A distinction is drawn between FCERM influencing the location of a particular activity as opposed to its overall economic viability and hence existence. For example, flood defences may permit development on floodplains, but the counterfactual (i.e. ‘no defences’) does not imply that properties built on floodplains would not be constructed. Most likely they would be situated in lower risk areas in the absence of defences. However, water level management is critical to the viability agriculture in some areas; e.g. the Fens where the scale of activity and reliance on flood defences is significant and production would not be transferred to other locations in England in the absence of FCERM.

- *FCERM activities*: actions or interventions that arise as a direct result of FCERM policy that are intended to reduce the risk of flooding or coastal erosion. In general FCERM activities are intended to either reduce the likelihood of flooding or coastal erosion, or reduce the impacts of flooding and coastal erosion.

- *Non-FCERM activities*: actions, interventions or activities that are consequences of FCERM policy, but that are not directly controlled by FCERM. For example repair and rebuilding construction activities in response to flooding damages or agricultural land use protected by flood defences.

On this basis Table 2.4 sets out the component parts of the FCERM carbon footprint and the requirements to quantify the *net* contribution of FCERM policy to GHG emissions. The framework for calculating the carbon footprint and data requirements and availability are discussed in Sections 2.3 and 2.4 respectively.

Table 2.4 FCERM policy and sources of GHG emissions

Activity	*Description*	*Embodied carbon*	*Energy*	*Transport*	*LUC*[a]	*Notes*
FCERM activities						
Asset construction and enhancements	Actions to reduce likelihood of flooding: construction of and improvements to raised defences (e.g. embankments and walls) and structures (e.g. weirs, sluices) to control flow of water and protect multiple properties and/or area of land. Surface water management actions include SUDS[b] (e.g. filter strips, swales, drains, permeable surfaces and infiltration devices, basins and ponds)	✓	✓	✓	✓	GHG emissions associated with works on coastal and inland defences in response to coastal, river and surface water flooding and coastal erosion GHG emissions associated with land-use change are likely to be minor resulting from land take for schemes
Asset operation, maintenance and refurbishment	Actions to reduce likelihood of flooding: pumping, upkeep of raised defences and structures to maintain standard of protection, including inspection, vegetation removal, repairs, renovation and modifications	✓	✓	✓	-	
Adaptation measures	Actions to reduce impacts of flooding at individual property level: ▪ Resilience measures[c]: construction techniques or modifications on standard practice to ensure no permanent damage is caused, structural integrity is maintained and drying and cleaning are facilitated	✓	✓	✓	-	GHG emissions associated with interventions at individual property level in response to coastal, river and surface water flooding
	▪ Resistance measures[d]: construction measures/techniques additional to standard practice to prevent flood water entering properties	✓	-	✓	-	

Table 2.4 FCERM policy and sources of GHG emissions (cont.)

Activity	***Description***	***Embodied carbon***	***Energy***	***Transport***	***LUC***[a]	***Notes***
Floodplain storage	Actions to reduce likelihood of flooding (in populated areas): creation or restoration of flood plain areas adjacent to rivers for flood water storage; typical habitat types include seasonally (or controlled) flooded grassland or pasture, or arable land or amenity land (e.g. sports fields)	-	✓	✓	✓	GHG emissions and sequestration of carbon associated with FCERM land management actions in relation to river flooding GHG emissions associated with energy and transport arise at construction stage and are likely to be minor
Managed realignment	Actions to reduce likelihood of flooding (in populated areas): Creation or restoration of (tidal flooded) wetland habitats in estuarine and coastal areas to accommodate coastal geomorphology processes; typical habitats include saltmarsh and mudflat	-	✓	✓	✓	GHG emissions and sequestration of carbon associated with FCERM coastal land management actions GHG emissions associated with energy and transport arise at construction stage and are likely to be minor
Development control	Actions to reduce likelihood of flooding: inclusion of flood and coastal erosion risk considerations within overall land planning process	-	-	-	✓	Primarily influences land use (residential or commercial) through the planning system and hence GHG emissions associated with development (e.g. house building) including adaptation measures (see above) to address residual flood risk
Flood and erosion mapping and modelling	Actions to inform decision-making: analysis of data and primary survey work (e.g. aerial surveys and LIDAR[e] data collection)	-	-	✓	-	GHG emissions from survey activities in relation to all types of flooding and coastal erosion
Emergency planning and response	Actions to reduce impacts of flooding: analysis of data to identify areas and infrastructure at risk, flood warning systems and actions required in event of flooding	✓[f]	✓	✓	-	GHG emissions from emergency response activities in relation to all types of flooding.

Table 2.4 FCERM policy and sources of GHG emissions (cont.)

Activity	*Description*	*Embodied carbon*	*Energy*	*Transport*	*LUC*[a]	*Notes*
Non-FCERM activities						
Response to flood and coastal erosion property damages	Actions resulting from flood and coastal erosion damages: includes repairs to infrastructure and properties (fabric, fixtures and fittings), replacement of household equipment and goods, use of air blowers and dehumidifiers and also construction of new properties	✓	✓	✓	-	GHG emissions arising from reparation of damages from all types of flooding and coastal erosion
Land use dependent on FCERM	Actions dependent on FCERM activities: agricultural land use made viable due to flood defences and the management of water levels	-	-	-	✓	GHG emissions and sequestration of carbon associated with land uses dependent on FCERM activities

Notes:

[a] Land use change

[b] Sustainable drainage systems

[c] See: Improving the flood performance of new buildings – Ciria (http://www.ciria.org.uk/flooding/flood_performance.htm) and http://www.ribabookshops.com/site/viewtitle.asp?sid=&pid=7568&HID

[d] See: Flood Management – MSW Increased Resilience to Flooding (Defra) (http://www.defra.gov.uk/environ/fcd/policy/strategy/rf1rf2.htm) and National SUDS Working Group (2004) (http://www.ciria.org.uk/suds/pdf/nswg_icop_for_suds_0704.pdf)

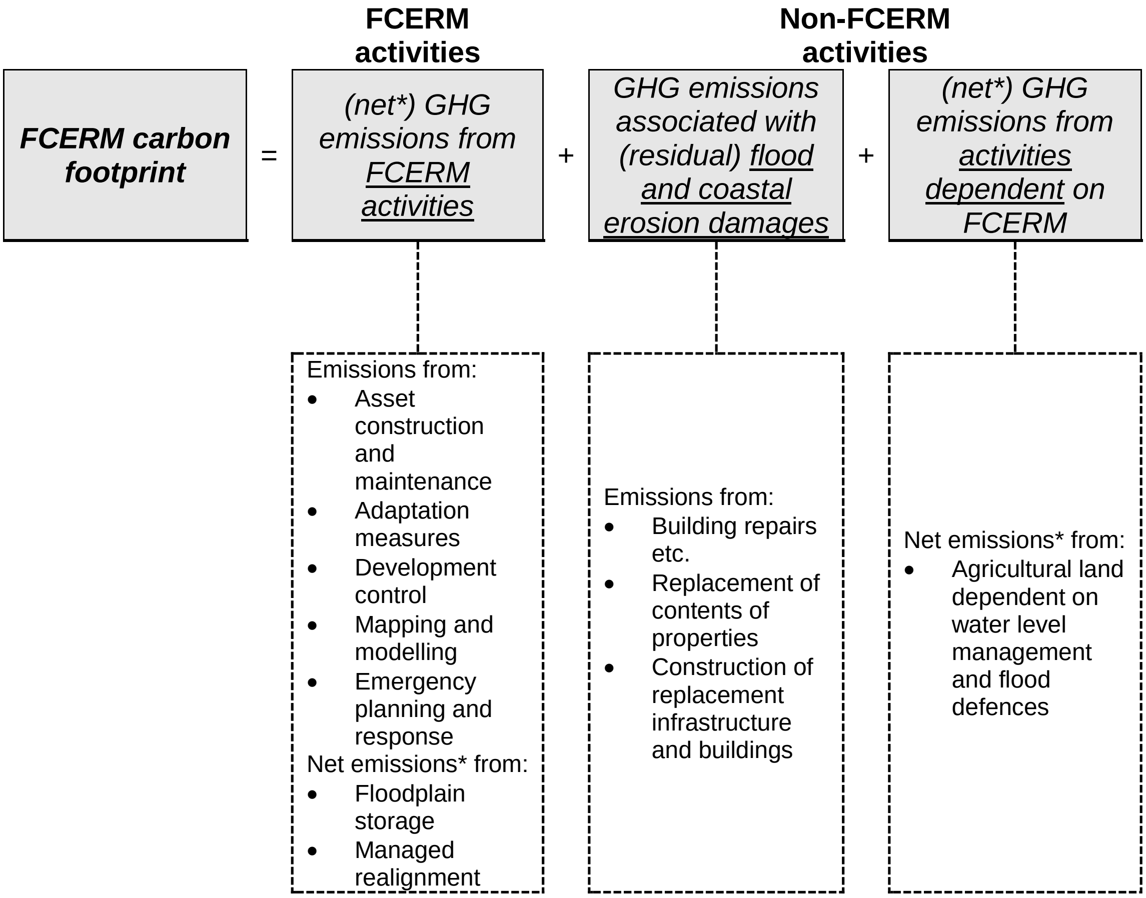
[e] Light detection and ranging: airborne Lidar survey measures the height of the ground surface and other features in large areas of landscape;

[f] Minimal linked to telemetry equipment and warning signs/systems.

2.3 Framework for analysis

The basic formulation of the FCERM policy carbon footprint builds on the activities and sources of emissions identified in Table 2.4. This is summarised in Figure 2.3, covering FCERM activities and FCERM dependent activities arising from actions to address coastal, river and surface water flooding and coastal erosion. Note that GHG emissions associated with 'non-FCERM' activities are separated into those associated with: (i) response to flood and coastal erosion damages; and (ii) land use – primarily agricultural activity – dependent on FCERM intervention(s)[19].

Figure 2.3 Basic formulation of the FCERM policy carbon footprint



Notes: *Net emissions = GHG emissions – carbon sequestration

Sections 2.3.1 – 2.3.3 address key parameters of the approach to estimating the carbon footprint of FCERM policy, including coverage of GHGs, geographical scope and the appropriate time horizon. Section 2.3.4 discusses

---

[19] For the purposes of the report, only agricultural land dependent on water level management and flood defences is considered with the 'activities dependent' on FCERM. While housing and commercial development may also be relevant, it is assumed that these are not 'additional' and would proceed in the absence of FCERM, albeit in alternative locations. Furthermore housing and commercial development is addressed via the development control remit of the EA's FCERM responsibilities.

definition of policy scenarios to enable recommendations as to the GHG emissions consequences of current and potential FCERM policy options.

While the formulation of the FCERM carbon footprint in Figure 2.3 is specified in terms of a high-level assessment of the GHG implications of the overall FCERM policy, it is also relevant to the individual FCERM scheme level as demonstrated by the case studies (Annex 4).

2.3.1 Greenhouse gases

Greenhouse gases are defined as gases that absorb and emit radiation within the thermal infrared range. As detailed in Section 2.2.3 a carbon footprint typically measures emissions from the basket of six GHGs (CO_2; CH_4; N_2O; PFCs; HFCs; SF_6) in a common metric of carbon dioxide equivalent (CO_2e). While there are other greenhouse gases, these six are relevant to the issue of anthropogenic climate change due to the human influence on their presence and quantity in the atmosphere, their lifetime and their radiative forcing potential[20]. Table 2.5 lists the long-life GHGs relevant to anthropogenic climate change and their global warming potential[21], calculated over a 100 year time horizon.

Table 2.5 Greenhouse gases and their global warming potential (GWP) over a 100 year horizon[1]

Greenhouse gas	***GWP for 100 year time horizon***	***Percentage of total GHG emissions in UK (2007)[2]***
Carbon dioxide (CO_2)	1	85.3%
Methane (CH_4)	21	7.7%
Nitrous Oxide (N_2O)	310	5.4%
HCFC-22	1,500	1.5%
HCFC-141b	(not given)	
HCFC-142b	1,800	
HFC-125	2,800	
HFC-134a	1,300	
HFC-152a	140	
HFC-23	11,700	
SF_6	23,900	0.12%
CF_4 (PFC-14)	6,500	0.03%
C_2F_6 (PFC-116)	9,200	

Notes: [1]Amalgamated from Table 2.1 and Table 2.14 of the IPCC Fourth Assessment Report (2007); [2]Based on Table 2.2 UK inventory emissions (in CO_2e terms).

As Table 2.5 illustrates, in terms of quantity of UK emissions, the key GHG is CO_2. Relatively small contributions to the total quantity of emissions come

---

[20] The term ‘radiative forcing’ has been employed in the IPCC Assessments to denote an externally imposed perturbation in the radiative energy budget of the Earth's climate system. Such a perturbation can be caused by changes in the concentrations of greenhouse gases (termed ‘radiatively active species’), Definition adapted from IPCC (2001).

[21] Global warming potential (GWP) is a measure of how much a given mass of GHG contributes to global warming (defined as the increase in the average temperature of near-surface air and oceans since the mid-20th century and its projected continuation). GWP is a relative scale which compares the gas in question to that of the same mass of CO_2.

from HFCs, SF_6 and PFC (less than 2% of annual emissions combined), even though most of these have substantial GWPs. As such the project scope focuses on the three main GHGs (CO_2; CH_4; and N_2O), but in practice current data availability permits only quantification of CO_2 emissions from select aspects of FCERM.

2.3.2 Geographical scope

The geographical scope of the study is England, reporting the FCERM carbon footprint in terms of tonnes of carbon dioxide equivalent per year for FCERM policy in England. This corresponds to the current extent of Defra's policy remit, but the framework set out allows for a carbon footprint estimate for the whole area under Defra's policy responsibility in the future.

2.3.3 Time Horizon

The activities set out in Table 2.4 and Figure 2.3 may result in differing levels of emissions[22] or sequestration[23] of GHGs over time. This implies that a 'life-cycle' approach that accounts for the profile of emissions over time from FCERM policy is required. This is particularly pertinent with respect to land use management options, i.e. flood storage and managed realignment, where carbon sequestration benefits may not be realised for a number of years.

Net GHG emissions (emissions minus sequestration) for the various scenarios can be estimated in annual terms, calculating a figure per year for a profile of emissions over the time frame of the analysis. This implies that calculated emissions can be provided as a 'snapshot' (e.g. calculated emissions in year X) or in more formal terms such as base year value.

The choice of the time frame for the analysis is dependent on a number of FCERM policy considerations:

- Timescales for committed investment (5 years for the EA) and longer term investment strategies;
- FCERM economic appraisal horizons of 40-60 years; and
- Longer time horizons for considering avoided damages and environmental effects, such as 50-100 years.

None of the above time frames is regarded as the 'most appropriate', but for the purposes of the analysis emissions profiles are presented over 50 years. The choice of time horizon also represents a parameter that can be subject to sensitivity analysis, particularly where policy options may entail different timings of effects. However this sensitivity is not assessed in the current analysis.

Assessing carbon emissions profiles over time also raises the issue of discounting and whether it is appropriate to discount future outcomes in terms

---

[22] Defined as release of GHG emissions.

[23] Defined as the long-term capture and storage of GHG emissions.

of emissions and sequestration. As Box 2.1 explains discounting is not applied in the analysis on the basis that a carbon footprint represents a physical inventory of emissions rather than an explicit assessment of the consequential impacts of emissions.

2.3.4 Developing policy scenarios

Defining policy scenarios

Comparative scenario analysis is used to consider GHG emissions implications of current and future policy options – policy questions IV and V in Table 1.1. This involves comparison of the carbon footprint of a baseline scenario (see below) with the carbon footprints of alternative scenarios that reflect different policy focus.

In the context of this project, policy scenarios may be considered as '*what if*' scenarios. For example, what would the net GHG emissions implications be, if current rates of maintenance, asset construction and residual damages continued? In the context of FCERM, alternative policy options are likely to entail differing scales of emphasis on the different types of flooding (coastal, river and surface water) and coastal erosion. In particular national level policy-making typically needs to prioritise between aspects such as actions to address flood alleviation in general versus coastal erosion, and/or actions to address frequent but low consequence river flooding versus low frequency but high consequence coastal flooding, and/or investment in a developing policy area such as surface water flooding versus traditional investment policy areas of coastal and river flooding.

The key rationale for a scenario-based approach is that different policy emphasis will require different 'quantities and types of FCERM activities resulting in different carbon footprints. For example, increased emphasis on coastal erosion may entail significant investment in 'hard engineering' schemes, implying significant quantities of embodied carbon in construction via the use of material such as concrete and quarried aggregates. In addition, policy-making may also address 'technological' choices in terms of how objectives may be achieved; e.g. hard engineering (raised defences) versus soft engineering (managed realignment). Hence a given policy area prioritisation may imply differing carbon footprints depending on how interventions are delivered.

Box 2.1: Assessing carbon emissions over time and discounting

Discounting is a technique that is ordinarily applied in project appraisal to allow comparison of costs and benefits that occur in different time periods. In most cases – which includes FCERM appraisal - it is the monetary value of flows of costs and benefits that are subject to discounting in order to estimate present values.

With respect to carbon footprint type assessments, there is no established practice for discounting physical (rather than monetary) measures of impact (e.g. emissions). Whether the underlying principle of discounting, that of ‘social time preference’ should be extended to flows of physical impacts such as carbon over time requires consideration of several points:

- Social time preference recognises that society as a whole prefers to receive benefits sooner rather than later and to defer costs to future generations. Hence if two land use management options result in similar levels of carbon sequestration but are subject to different timings, preference would ordinarily be accorded to the option that delivers sequestration earlier (all else equal). Not discounting in this situation would leave little incentive to pursue the option that delivers earlier sequestration since it is not weighted sufficiently to recognise a preference for earlier delivery of benefits.

- In appraisal, discounting of non-monetised impacts can be viewed as inappropriate where the physical measure of impact is a poor proxy for outcomes such as damages. GHG emissions in actual fact provide a good example; measuring tonnes of emissions can be a long way away from the actual effects of interest (e.g. changes in risk of flood, drought, food shortages etc.) since much depends on the subsequent changes in global temperature over time, sea level and other physical environment variables. In turn, changes in temperature depend on the magnitude of emissions of all greenhouse gases over time and their radiative forcing (see Section 2.3.1). In addition impacts of climate change may depend not only on the absolute levels of these effects but also the rate at which they occur.

On balance the general preference for earlier ‘benefits’ (i.e. reduced or avoided GHG emissions) over later ones should apply to policy responses concerned with mitigating the climate change impact of FCERM. However given the aim of this research to estimate the carbon footprint of FCERM policy in terms of a physical GHG inventory, rather than to provide an economic analyses concerned with the ultimate impact endpoints of climate change (i.e. actual costs and benefits), it is not considered appropriate to apply discounting. Furthermore from a practical perspective, discounting future GHG emissions and carbon sequestration would imply a further set of assumptions that are not necessarily desirable given the current limitations of analysis due to data availability that in itself requires substantial caveats (as discussed below).

The ability to quantify the carbon footprint of alternative policy scenarios is dependent upon data availability regarding the activities and sources of emission set out in Table 2.4. As Section 2.4 reveals the analysis presented in this report is limited to an approach largely based on proxy measures linked to investment expenditure and damages. This implies that detailed specification of policy scenarios is not currently possible, particularly in terms of distinguishing between different types of FCERM activity that might be pursued under alternative policy scenarios.

The gap analysis (Section 4.2) and guidance (Section 5.2) describe requirements for enhanced data availability and quality for more sophisticated estimation of the carbon footprint of different FCERM policy options.

Baseline Scenario

A baseline for the analysis is required so that alternative policy scenarios can be evaluated consistently. For this project, the most obvious baseline is a 'business as usual' (BAU) scenario that assumes a continuation of the current policy focus and levels of investment. Thus, the main emphasis of data collection has been to establish the business as usual situation; i.e. collate data on existing assets and maintenance and planned infrastructure that reflect the current policy circumstances.

Alternative policy scenarios

In conjunction with the definition of a baseline, specification of alternative policy scenarios provides the basis for advice as to how FCERM policy can mitigate its climate change impact (as required by policy question IV in Table 1.1). As noted alternative policy scenarios are regarded as '*what if*' scenarios that can assist in identifying the trade-offs at the national policy level; i.e. establishing priorities in terms of reducing GHG emissions between interventions for coastal, river and surface water flooding and coastal erosion.

In the subsequent analysis, two alternative policy emphases are considered:

- Increased investment in river and coastal flooding ('*BAU plus*'): typically expenditure in the 'traditional' FCERM policy areas represent a good return on public investment. EA (2009) reports that benefit cost ratios for river and coastal flooding schemes are around 8:1. This scenario assesses the carbon footprint implications of increased expenditure from the BAU case, weighing increased emissions from FCERM activity (i.e. more construction and maintenance schemes) against the decrease in emissions associated with residual flooding damages.

- Addressing surface water flooding ('SWF'): Surface water management represents a developing policy area under the current draft Flood and Water Management Bill (Defra, 2009b). This scenario assesses the implications of increased expenditure on surface water flooding schemes, weighing increases in emissions from asset construction against the decrease in emissions associated with surface water flooding.

Details of the assumptions entailed in specifying the BAU plus and SWF scenarios are set out in Section 3.2.

Policy-off scenario

A further scenario to be assessed is that of ‘policy-off’, which describes the counterfactual to FCERM intervention and associated net GHG emissions; i.e. the carbon footprint implications of no active FCERM intervention. This is similar to assessments of flooding damages that have investigated the implications, in terms of annual average damages, of cessation of investment in flood and coastal defences and the consequential increasing likelihood of failure of defences and a declining standard of protection over time (see for example Halcrow, 2001).

Comparison of the BAU and policy-off scenarios permits an assessment of the significance of FCERM in terms of *avoiding GHG emissions* at the national level (Figure 2.4); i.e. emission that would arise in the absence of FCERM policy intervention. In this sense estimating the policy-off carbon footprint provides an indication of the current level of GHG emissions mitigation provided by FCERM policy in these terms.

Figure 2.4 Business as usual carbon footprint versus policy-off scenario carbon footprint

FCERM carbon footprint *(from Fig. 2.3)*	=	*(net) GHG emissions from FCERM activities*	+	*GHG emissions associated with flood and coastal erosion damages*	+	*(net) GHG emissions from activities dependent on FCERM*
BAU scenario *carbon footprint*	=	*Net GHG emissions from current and planned activities*	+	*GHG emissions associated with residual damages from current standard(s) of protection*	+	*GHG emission from current level of activity dependent on intervention*
Policy-off scenario *carbon footprint*	=	*No FCERM activities; i.e. zero emissions*	+	*GHG emissions associated with flood and coastal erosion damages (equivalent to avoided BAU damages plus residual damages)*	+	*No FCERM implies no activities dependent on intervention; i.e. zero emissions*

In the policy-off scenario GHG emissions from FCERM activities is zero (since there is no FCERM[24]), as is the case for emissions arising from activities dependent on FCERM. Emissions associated with policy-off 'damages' correspond to avoided damages plus residual damages under the business as usual scenario.

2.4 Data requirements

2.4.1 Overview

The framework for analysis detailed in Section 2.3 establishes significant data demands to estimate the carbon footprint for FCERM policy under the BAU, alternative policy scenarios (BAU plus and SWF) and policy-off. This section reviews data requirements in terms of the categorisation of FCERM and non-FCERM activities detailed previously in Table 2.4. These desiderata are then confronted with the available data to set the practical considerations alongside the conceptual ideals.

As detailed in Section 2.2.3 the ideal approach to estimating GHG emissions associated with a given activity or process is to combine primary consumption data by the relevant GHG emission factor. For the sources of emissions/sequestration relevant to FCERM identified in Section 2.2.4 this implies the following data requirements:

- *Embodied carbon within materials*: quantity of material(s) used (e.g. kg, tonnes, or similar) and emissions factors for each type of material (e.g. concrete, metal, timber).
- *Energy use in operations*: consumption of energy (e.g. kWh, litres, etc.) and emissions factors for each energy source (e.g. grid electricity, on-site generation, etc.).
- *Transport*: distance transported (km) and emissions factor for fuel type (e.g. petrol, diesel, biofuel)[25].
- *Land use and land use change:* area of land (e.g. hectares) and habitat type(s) (e.g. grassland, arable, wetland) and emission/sequestration rate for habitat type(s).

Table 2.6 summarises the data requirements and current data availability for estimating net GHG emissions from the FCERM and non-FCERM activities set out in Table 2.4 and Figure 2.3. In practice there are significant gaps in the current evidence base that preclude the 'ideal approach' to estimating the carbon footprint of FCERM. In a number of cases where required data for an activity are unavailable, proxy approaches to estimating GHG emissions have been reviewed and adopted. In other cases, it is not possible at present to estimate emissions associated with activities. Table 2.6 details the extent of

---

[24] Strictly in the absence of publicly funded FCERM, some activity may be undertaken by private individuals and organisations but this is beyond the policy scope of Defra and this project.

[25] Ideally the volume of the fuel used would be obtained.

coverage within the present research. Gaps in available evidence are reviewed in Section 4.2.

Following Table 2.6, brief discussion of data availability and proxy approaches for estimating emissions from asset construction and maintenance and emissions associated with flood and coastal erosion damages are set out in Sections 2.4.2 and 2.4.3. Evidence and discussion relating to land use management aspects (flood storage, managed realignment, development control and agricultural land) of the FCERM carbon footprint is provided in Annex 1.

Table 2.6 FCERM carbon footprint – data requirements and availability

Activity	***Data requirements***	***Data availability***	***Comment – estimating carbon footprint***
FCERM activities			
Asset construction and enhancements	Number and type of assets built or upgraded each year (e.g. number of structures, length of raised defence) and a breakdown of materials used.	*River and coastal flooding and coastal erosion*: recent schemes (>£250K) available from EA NCMPS data; planned schemes detailed in Medium Term Plan; EA Construction Carbon Calculator provides details of materials used and GHG emissions from a small sample of recent schemes *Surface water flooding*: limited information at national level in terms of expected expenditure on capital schemes	Data availability allows for proxy approach to estimating GHG emissions from asset construction, based on expenditure and carbon intensity factors (t CO_2e/£) estimated from EA Construction Carbon Calculator
Asset operation, maintenance and refurbishment	Type of maintenance activity for each asset type and frequency of activity, breakdown of materials used, energy in operations	*River and coastal flooding and coastal erosion*: major schemes (>£250K) detailed in EA NCMPS, Medium Term Plan and EA Construction Carbon Calculator data as above; details of schemes <£250k not collated in national database (information held by EA regions); summary detail of asset inspections available from EA; limited information on energy use from operation available at national level *Surface water flooding*: no information available at national level	Information on major capital works covers both asset construction (as above) and maintenance/refurbishment of assets. Information on other maintenance activities and operational energy use is limited.
Adaptation measures (see Table 2.4)	Types of measure and frequency of installation	No data available	Not included in analysis
Floodplain storage	Area of floodplain and land converted to floodplain, land use/habitat types (in frequency of flooding), estimate carbon	Available evidence is fragmented and incomplete for the purposes of providing a high level carbon footprint assessment	Not included in carbon footprint estimates - summary provided in Annex 1

Table 2.6 FCERM carbon footprint – data requirements and availability

	storage and sequestration rate for land/use habitat types		
Managed realignment	Area of accommodation space and land converted to accommodation space, habitat types, estimate carbon storage and sequestration rate for habitat types	Available evidence is fragmented and incomplete for the purposes of providing a high level carbon footprint assessment	Not included in carbon footprint estimates - summary provided in Annex 1
Development control	Number of properties/development on flood plains, risk of flooding and damage, estimates of GHG emissions associated with damages	Information is available on planning application consultation by the EA (including applications permitted and those that proceed against EA advice	Not included in carbon footprint estimates - summary provided in Annex 1
Flood and erosion mapping and modelling	Type and frequency of activities and GHG emissions associated with these	No data available	Not included in analysis – GHG emissions expected to be relatively minor
Emergency planning and response	Type and frequency of actions and GHG emissions associated with these	No data available	Not included in analysis – GHG emissions expected to be relatively minor
Non-FCERM activities			
Response to flood and coastal erosion property damages	Estimates of energy use, materials, waste, etc. resulting from flood and coastal erosion damages	*Flooding*: damage multiplier (links GHG emissions to economic damage estimates) and national assessments of economic damages (e.g. NaFRA) *Coastal erosion*: estimates of properties lost to erosion and emissions associated with construction	Data availability allows for proxy approach to estimating GHG emissions associated with flood damages based on economic cost estimates and a damage multiplier. Emissions associated with coastal erosion estimated from property losses.
Land use dependent on FCERM	Area of land at risk of flooding, habitat types, estimate carbon storage and sequestration rate for habitat types	Available evidence is fragmented and incomplete for the purposes of providing a high level carbon footprint assessment	Not included in carbon footprint estimates - summary provided in Annex 1. Potentially very significant (e.g. drainage of peat soils)

2.4.2 FCERM activities - asset construction and upgrades; asset maintenance and refurbishment

This section identifies the data requirements for these FCERM activities and then reports on the data availability separately for coastal and river flooding, coastal erosion and surface water flooding.

Data requirements

Asset construction and upgrades (enhancements) activities are intended to improve the standard of protection in an area (e.g. by controlling the flow of water entering an area via construction of flood defence walls, raising existing defences and other structures such as sluices). Asset maintenance activities are concerned with maintaining the standard of protection in an area, including inspection, repair and modification to defences and structures. Both these types of activities result in GHG emissions via embodied carbon in material, use of energy and transportation (e.g. of materials) in relation to construction and operation of assets.

Preferably GHGs emissions resulting from asset construction and maintenance would be measured directly. This implies measuring emissions from a range of activities such as material production (e.g. concrete) and energy use (e.g. fuel combusted in vehicles used or pumping of water).

However, such data cannot realistically be obtained under the constraints of most research projects. Instead, the second best approach involves:

- Characterising asset types:
  - Assets constructed: the number and type of assets built or upgraded every year (e.g. number of structures, length of raised defence) and a breakdown of materials used and
  - Assets maintained: type of maintenance activity for each asset type.
- Measuring amount of materials and energy used for each type of asset;
- Calculating GHG emissions factor for each asset type or maintenance activity based on primary data using a sample of assets or maintenance projects;
- Taking note of the annual completion rate of assets to calculate the total GHG emissions associated with construction and maintenance activities for each asset type.

In terms of assets a standard classification would distinguish between the type of infrastructure; for instance differentiating between types of raised defence (e.g. concrete walls and earth embankments) and structures (e.g. pumping stations, weirs, sluices, barrages). Drawing this classification together with different policy areas can provide a grouping of scheme types that are relevant to coastal defence (coastal flooding and coastal erosion) and inland defence (particularly river flooding). For example:

- Coastal defence works: involving extensive concrete walls/revetments, rock armouring etc.
- Coastal management works: e.g. groynes, beach recharge and recycling.
- Inland flood defence works: e.g. concrete walls/revetments.
- River control structures: e.g. sluices and weirs.
- Drainage and culvert works: e.g. concrete channels.

In practice GHG emissions should vary by scheme types – based on different materials and energy use and also transportation requirements – and such a classification, or a similar, provides an approach to specifying alternative policy scenarios by ‘parameterising’ the activities entailed in terms of intensity of material and energy use (covering the GHG implications of the construction, maintenance and operation of assets).

Data requirements in relation to surface water flooding are addressed below in conjunction with data availability in this area.

Data availability – coastal and river flooding and coastal erosion

Asset construction and maintenance data related to coastal and river flooding and coastal erosion are principally kept by the EA, though LAs and IDBs also own and maintain assets. The EA records all assets in the National Flood Coastal Defence Database (NFCDD). In addition, information relating to FCERM projects and schemes costing more than £250,000 (normally comprising of a number of assets) is kept in the National Capital Programme Management Service (NCPMS) database. EA projects with more modest expenditure are managed at local level, with relevant data being held across the EA region and area offices.

Overall current data availability is limited in terms of requirements for estimating GHG emissions associated with FCERM asset construction and maintenance. The main limitations are:

- Construction and maintenance works are not categorised by ‘type’ by the EA since most flood and coastal defence schemes consist of a number of elements (e.g. raised defences and beach recharge in the case of a coastal scheme) that are specifically designed for a particular level of risk and location; i.e. there is no ‘typical’ design solution which makes generalisations, particularly in terms of GHG emissions, difficult;
- EA databases are fragmented at least in two levels based on scheme-budget, i.e. national database for projects >£250,000 and locally held for projects <£250,000, and

- Maintenance, upgrades and construction activities are not necessarily recorded separately and it is difficult to split the schemes accordingly.

Available data do however include estimated carbon emissions for a small sample of projects from the EA's Construction Carbon Calculator[26]. This is a spreadsheet used to assess the carbon footprint of construction works in terms of embodied carbon of materials and the CO_2 emissions associated with their transportation. Its use has been mandatory for all EA major construction projects since November 2007. Ideally these data would enable carbon emissions factors to be calculated for different asset or maintenance types as outlined above. However, there are limitations to its use for this project:

- Data obtained from the Construction Carbon Calculator refer only to emissions for construction aspects of asset construction and maintenance schemes;
- The Construction Carbon Calculator records only CO_2 emissions[27];
- The ability to estimate emissions factors is subject to the data sample available;
- The schemes are not categorised and available data provides limited detail of the works entailed;
- The project stage varies and data cover both schemes already completed and also those at the planning stage with the potential for design changes.

With respect to energy use from operation, the EA's annual corporate reporting provides detail on overall use of energy for pumping, in terms of the EA's overall carbon footprint.

Data availability – surface water flooding

Surface water management represents a developing policy area. Current proposals under the draft Flood and Water Management Bill (Defra, 2009b) will designate LAs as the lead operating authority for local flood risk management. LAs will be responsible for local flood risk assessment, mapping and planning in relation to ordinary watercourses, surface run-off and groundwater. LAs will also lead development of local surface water management plans (SWMPs) and associated programmes of capital work.

At present no central database of existing and planned assets exists for surface water management schemes. Moreover major capital investment in the future will be determined following a case specific appraisal of costs and benefits following from the identification of needs by SWMPs.

---

[26] For further detail see: http://www.environment-agency.gov.uk/business/sectors/37543.aspx

[27] It was considered that these can skew a factor considerably and the aim of the Construction Carbon Calculator, where possible, is to use data which represent the fossil CO_2 associated with a material, without the contribution of non-CO_2 GHGs.

Currently available data are fragmented due to the variety of parties which may construct and/or maintain assets from LAs and developers (e.g. sustainable drainage systems (SUDs)) to the EA, the Highways Agency and local highways authorities and water companies. Indeed an initial task for LAs under the Bill's proposals is to map local flood risk management assets and their ownership. 'Ideal' data requirements comprise of:

- Number and types of schemes or assets constructed or upgraded to manage surface water runoff (e.g. SUDS schemes – of which a large number of techniques are available with different carbon footprints -, sewer upgrades, improved treatment works, etc); and
- Data on maintenance of surface water drainage networks (e.g. EA, LAs, IDBs, privately owned/riparian ownership).

The developing evidence base with respect to local flood risk management allows a preliminary assessment of the likely scale of intervention required to address surface water flooding (see Section 3.1.3.

Approach to estimating GHG emissions

In light of the data available the following approach to estimating GHG emissions from asset construction and maintenance is adopted:

1. The level of asset construction and maintenance activities is proxied to high level estimates of investment expenditure for each policy area (river flooding, coastal flooding, coastal erosion and surface water flooding).
2. A carbon intensity factor (kg CO_2 / £) is estimated for asset construction and maintenance activities is calculated. This is applied to convert expenditures on FCERM construction and maintenance projects into GHG emissions. At present it represents 'best available' approach to the analysis in the absence of complete data.

2.4.3 Non-FCERM activities - response to flood and coastal erosion property damages

Data requirements

The key sources of carbon emissions as a result of flood and coastal erosion damage are:

- Damage to building fabric / fixtures / fittings / repairs;
- Replacement of household goods;
- Energy use for hot air blowers / dryers / de-humidifiers;
- Carbon associated with transport / travel of trades and homeowners; and
- Carbon emissions as a result of impacts on soil.

For estimating the carbon footprint of FCERM ideally primary data of the properties damaged by flooding would be collated on an annual basis. This would include data on: the energy used to repair flood damages (by fuel type), the materials used to replace/ repair damaged goods (by type of material), the waste streams caused by flood damage (by type of waste), and the land changes (by soil type). These data would provide an estimate of the annual emissions associated with the residual damage. Such data could then be used to model GHG emissions associated with damages under alternative policy scenarios using estimates of the damage to each property type.

Data availability

The primary data as described above are not recorded currently and its collection would require substantial resources. However, there exist considerable data on the economic costs of flooding in England, which offers a proxy approach to calculating GHG emissions from flood damages.

For example, as part of the Thames Estuary 2100 (TE2100) project, an approach was developed to link economic damage costs to carbon emissions. The EA commissioned a study to determine a broad-scale ‘multiplier’ (suitable for strategic appraisal) to be used to adjust monetary estimates of direct damage to property to account for GHG emissions (see Halcrow, 2008). The multiplier can be used to convert the damage costs provided by economic damage cost studies into carbon emissions. A description of the multiplier approach used in the TE2100 project is provided in Annex 2.

Approach to estimating GHG emissions

For the purpose of this study GHG emissions associated with flood and coastal erosion property damages are estimated via a proxy approach based on the TE2100 multiplier. This approach is recognised as limited and is applied in order to estimate the likely magnitude of emissions and should not be interpreted as anything other than a high level assessment.

Estimated annual damages under the BAU scenario for river and coastal flooding are drawn from reporting of residual damages from the National Flood Risk Assessment (NaFRA) undertaken on behalf of the EA (Environment Agency, 2009a). NaFRA is based on a ‘Risk Assessment for Strategic Planning’ (RASP) methodology which uses a risk-based probabilistic approach to factor the location, type, condition and performance of flood defences into the assessment of flood damages. It provides the current best available flood risk assessment at the national level. Residual damages incurred under alternative policy are based on a series of assumptions linked to the effectiveness of capital investment in asset construction and maintenance. These are presented in Section 3.1.7.

Assumptions concerning policy-off damages are based on earlier work (pre-NaFRA) for the National Appraisal of Assets at Risk (NAAR) (Halcrow, 2001). This provides the most recent assessment of 'do-nothing' damages based on an assumption of no further FCERM investment.

Estimates of damages arising from surface water flooding are drawn from recent analysis for Defra's Impact Assessment of SWMPs (Defra, 2009c). Information provided by Defra includes details of supporting analysis (undertaken by Halcrow, 2009) and provides estimates of BAU damages as well as the basis for assumptions for alternative policy scenarios. These are presented in Section 3.1.7

Finally, damages associated with coastal erosion are estimated by applying previously reported carbon footprints for repair and refurbishment of properties or replacement of properties (based on GHG emissions associated with construction of new housing stock)[28]. Rates of property loss arising from coastal erosion are sourced from recent Defra reporting (Defra, 2009a) although this indicates that further and more detailed analysis will be available in the future.

---

[28] Note that the net difference in emissions arising from occupancy of the 'average' UK housing stock (assumed to be lost to coastal erosion) and new housing stock (assumed to replace lost stock) is not considered in the estimation of this aspect of the carbon footprint

3. Data and results

This section summarises data[29] and results in terms of GHG emissions from FCERM policy scenarios as defined in Section 2.3.4.

3.1 Data

3.1.1 Data sources

The key data and information sources used in this study for estimating emissions from FCERM activities (asset construction and maintenance) and emissions associated with flood and coastal erosion damages are presented in Tables 3.1 and 3.2 respectively.

Table 3.1: Data and information sources – emissions from FCERM activities

Data source	***Description and use***
Construction Carbon Calculator data provided by the Environment Agency (June 2009)	Estimates of CO_2 emissions from sample of recently completed or planned schemes. Used to estimate the GHG emissions from asset construction and maintenance
Medium Term Plan – funded plan for new and improved flood and coastal defences for 2009/10 – 2013/14 provided by the Environment Agency (April 2009)	Data on expenditures for asset construction and maintenance schemes by type of operating authority. Used to calculate carbon intensity factors
List of schemes completed since Summer 2007[1] provided by the Environment Agency (April 2009)	Data on expenditures for asset construction and maintenance. Used to calculate carbon intensity factors
National Flood Coastal Defence Database (NFCDD) – data on asset elements provided by Environment Agency (July 2009)	Data on defences and structures (type, length, and number). Used to attribute GHG emissions to river and coastal flooding and coastal erosion policy areas
Environment Agency Asset Management Data Factsheet: Version 2.2 (May 2009)	Reports number of inspections of assets. Used to estimate GHG emissions associated with inspections
Supporting analysis for Defra SWMP Impact Assessment (September 2009)	Data to support assumptions on surface water flooding investments

---

[29] The project team acknowledges the input of David Richardson (expert advisor to the project steering group) in assisting with the interpretation and analyses of various data concerning FCERM activities and damages.

Table 3.1: Data and information sources – emissions from FCERM activities (cont.)

Data source	*Description and use*
Arup (2008) Thames Estuary 2100 Cost Integration. Phase 3 Studies, Work Element 5.4. Stage 1 Report – document provided by the Environment Agency (May 2009)	Details of carbon emissions from capital works for TE2100 strategy. Used as 'sense check' on calculated carbon intensity factors

Notes: [1]This document primarily records the number of properties protected by completed schemes (no. of houses with reduced flood risk).

Table 3.2: Data and information sources – emissions associated with flood and coastal erosion damages (non-FCERM activities)

Data source	*Description and use*
National Flood Risk Assessment (NaFRA) 2008 – data on weighted annual average damages and properties at risk provided by Defra and Environment Agency (September 2009)	Estimate of residual damage costs from river and coastal flooding. Used to estimate GHG emissions associated with BAU damages
Halcrow (2001) National Appraisal of Assets at Risk (NAAR) from Flooding and Coastal Erosion, including the potential impact of climate change, Final Report	Estimate of damage costs associated with river and coastal flooding and coastal erosion. Provides basis for assumptions concerning estimate of GHG emissions associated with policy-off damages. Also provides an assessment of agricultural land at risk from flooding
Halcrow (2008) Thames Estuary 2100 GHG implications of flood damages. Phase 3 Studies, Work Element 2.11a – document provided by Environment Agency (May 2009)	Provides methodology for proxy estimate of GHG emissions associated with flood damages based on calculated damage costs. The estimated multiplier is applied in the analysis to convert damage costs into GHG emissions
Defra (2009a) Consultation on Coastal Change Policy provided by Defra (July 2009)	Provides estimate of rate of property loss from coastal erosion
Supporting analysis for Defra SWMP Impact Assessment (September 2009)	Data to support assumptions on damages from surface water flooding
EHA (2008)	Provides estimate of carbon emissions associated with repair and refurbishment of properties, and construction of new properties

3.1.2 Current FCERM asset portfolio

The reported value of EA flood risk management assets is approximately £20 billion (Environment Agency, 2009b). The starting point for the analysis is to 'characterise' the business as usual portfolio of assets. This information coupled with information on planned schemes and material used in construction, maintenance activities and GHG emissions associated with these can provide the basis for developing the carbon footprint from FCERM activities.

As established in Sections 2.3, detailed analysis in terms of scenario specification is beyond current data availability. However it is useful to set out available data to identify the gaps and recommendations for updating and enhancing estimates of the carbon footprint of FCERM. For this purpose Table 3.3 provides a typology of FCERM assets based on the EA's reporting in its Annual Report and Accounts.

Table 3.3: FCERM asset typology

Asset/activity	***Description***	***River defence assets***	***Coastal defence assets***
Embankments	Creation, improvement or heightening of embankments along the watercourses to keep water within the river channel	Concrete revetment Concrete wall (and equivalent) Earth/clay flood embankment Masonry wall Rock revetment Timber revetment	Concrete faced embankment Earth/clay embankment Shingle bank Timber faced embankment Wetland
Culverts and channel improvements	Repair or replacement of culverts under land, roads and properties and channel improvements that assist the flow of watercourses	Channel Concrete channel Delph ditch	Channel
Rock groynes and sea walls	Defences typically used in conjunction with beach recharge activity to prevent sea flooding	N/A	Concrete sea wall Masonry breakwater Masonry sea wall Rock revetment
Piling	Installation of piles (typically steel) along the to strengthen river banks secure adjacent land, preventing landslips into the water course causing obstructions	Steel piling	Steel piled wall

Table 3.3: FCERM asset typology (cont.)

Asset/activity	*Description*	*River defence assets*	*Coastal defence assets*
Beach recharge	Shingle replacement on beaches to retain integrity of a sea defence.	N/A	Foreshore recharge Timber groyne
Structures and other	Other waterway and coastal defence improvements	Debris screen/collector Gates Manhole Outfall Penstock Pumping station Stop log Weir Other unclassified defences	Debris screen/collector Gates Manhole Outfall Penstock Pumping station Stop log Weir Other unclassified defences

Notes: Typology adapted from reporting in EA Annual Report and Accounts 2008-09.

In conjunction with the typology set out in Table 3.3, information made available from the Environment Agency with the NFCDD data details material and elements that comprise individual assets and structures. These are summarised in Table 3.4. In addition, the information presented in Tables 3.2 to 3.4 may be useful in considering aspects such as carbon intense material in relation to the 'carbon hierarchy' (see Section 4.1) and understanding the elements of schemes that are likely to have significant GHG emissions implications.

Table 3.4 FCERM assets – materials and elements

Asset	*Materials/elements*
Hard defences: Embankments, culverts and channel improvements, rock groynes and sea walls, and piling	Aluminium, asbestos cement, bagwork, blockwork, brickwork, cobbles, complex, concrete (poured), concrete (precast), gabions, geogrids, masonry, piling, plastic, rock, spilling, steel (corrugated/armco), steel (piling) steel/concrete, steel/iron
Soft defences: Embankments, culverts and channel improvements, beach recharge	Clay, earth, faggoting, geotextile fabric, mud/silt, sand, sand/gravel, shingle, timber, timber (hardwood), timber (softwood), timber piling
Gates: Structures	Gate (flood), gate (sluice), gate (opening), gate valve
Manholes: Structures	Manholes, chambers
Outfalls: Structures	Flap, outfall, outfall (inwards), outfall (outwards), outfall protection
Stop logs: Structures	Stop logs, dropboards

Table 3.4 FCERM assets – materials and elements

Asset	***Materials/elements***
Weir: Structures	Weir (adjustable), weir (fixed)
Debris screen/collectors: Structures	Debris collector deflector/boom, screen, screen (debris), screen (weed)

Source: Environment Agency, NFCDD (July 2009)

Data on the current asset portfolio of FCERM defences and structures were obtained from the Environment Agency's NFCDD database. A summary of river and coastal defences (types and, length) based on analysis of the NFCDD data is provided in Table 3.5. Note that calculated lengths of defences differ from those typically reported[30] since they are summed from reported asset *element* lengths where individual assets (e.g. an embankment) are comprised of a number of elements (e.g. front face, crest and back face of an embankment[31]). The analysis of defences accounts for approximately 95% of assets reported by NFCDD for river defences and approximately 90% of assets reported for sea defences; the residual corresponds to assets that could not be attributed to the typology set out in Table 3.3.

Table 3.5 FCERM assets – length of defences (km)

Length of river defences (km)	***EA***	***LA***	***Private***	***Total km***
Culverts & channel improvements	789	29	184	1001
Channel	*760*	*29*	*184*	*973*
Concrete channel	*8*	-	-	*8*
Delph ditch	*21*	-	-	*21*
Embankments	1438	23	492	1953
Concrete revetment	*32*	-	*26*	*58*
Concrete wall (and equivalent)	*111*	-	*50*	*160*
Earth/clay floodbank	*1119*	*23*	*321*	*1462*
Masonry wall	*101*	-	*96*	*197*
Rock revetment	*70*	-	-	*70*
Timber revetment	*6*	-	-	*6*
Piling	22	0	24	47
Steel piling	*22*	-	*24*	*47*
Other	25	0	25	50
Unclassified defences	*25*	-	*25*	*50*

---

[30] For example in Environment Agency (2009b) Asset Management Data Factsheet: Version 2.2.
[31] Pers. comm. D. Richardson (August 2009).

Table 3.5 FCERM assets – length of defences (km) (cont.)

Length of coastal defences (km)	***EA***	***LA***	***Private***	***Total km***
Beach recharge	152	25	34	212
Foreshore	*152*	*23*	*32*	*207*
Timber groyne	*-*	*2*	*2*	*5*
Culverts & channel improvements	70	4	13	87
Channel	70	*4*	*13*	*87*
Embankments	327	37	76	441
Concrete face embankment	*42*	*30*	*11*	*82*
Earth/clay embankment	*255*	*5*	*59*	*318*
Shingle bank	*14*	*3*		*17*
Timber faced embankment	*3*	*-*	*-*	*3*
Wetland	*13*	*-*	*7*	*20*
Piling	11	0	3	14
Steel piled wall	*11*	*-*	*3*	*14*
Rock groynes & sea walls	54	49	70	172
Concrete sea wall	*24*	*14*	*36*	*74*
Masonry breakwater	*-*	*3*	*-*	*3*
Masonry sea wall	*6*	*21*	*23*	*49*
Rock revetment	*25*	*10*	*11*	*46*
Other	0	34	0	34
Unclassified	*-*	34	*-*	34

Source: Length of defences calculated from NFCDD data provided by the EA (July 2009)

Table 3.6 reports NFCDD data that summarise the current number of river and sea defence structures.

Table 3.6 FCERM assets – number of structures

River structures	***EA***	***LA***	***IBD***	***Private***	***Uncl.***	***Total***
Debris screen/collector	1541	441	50	859	16	2907
Gates	1567	65	34	616	1	2283
Manhole	529	27	41	383	3	983
Outfall	14014	1979	1082	8484	193	25752
Penstock	187	19	9	75	1	291
Pumping station	574	7	109	81	-	771
Stop log	203	-	8	75	-	286
Weir	2287	211	129	3384	7	6018
Coastal defence structures	***EA***	***LA***	***IBD***	***Private***	***Uncl.***	***Total***
Debris screen/collector	114	7	4	24	-	149
Gates	568	117	7	95	1	788
Manhole	114	8	1	34	-	157
Outfall	1704	291	138	835	4	2972
Penstock	19	1	-	3	-	23
Pumping station	30	1	11	11	-	53
Stop log	30	58	-	7	-	95
Weir	11	1	-	5	-	17

Source: Number of structures reported in NFCDD data provided by the EA (July 2009)

3.1.3 FCERM investment – asset construction maintenance and expenditure

Details of planned investment in FCERM assets, in terms of expenditure on construction and maintenance schemes are primarily reported by the EA's Medium Term Plan (MTP). The MTP details schemes that are intended to address river or coastal flooding or coastal erosion that have approved funding from Defra. In addition supporting information on historic and proposed investment is available, including headline numbers reported in the EA's National Assessment of Flood Risk (EA, 2009a) as well as a number of other sources as detailed below.

Table 3.7 summarises analysis of the MTP, primarily for the purpose of attributing investment expenditure to river or coastal flooding or coastal erosion policy areas. This is based on a review of the MTP that has categorised schemes funded for the period 2009-12 by operating authority type.

Table 3.7 Breakdown of MTP expenditure 2009-2012 by policy area (£m)

Policy area and operating authority	***2009/2010***	***2010/2011***	***2011/2012***	***Total*** *(2009-12)*
River flooding	95	122	113	330
EA schemes	*92*	*120*	*111*	*323*
LA schemes	*3*	*1*	*2*	*7*
Coastal flooding	113	135	148	395
EA schemes	*91*	*112*	*121*	*323*
LA schemes	*22*	*24*	*26*	*72*
Coastal erosion	19	17	18	54
LA schemes				
Other	9	7	6	21
IDB schemes				
Total	235	281	284	

Source: Analysis of EA MTP (April 2009)

Based on Table 3.7 and accounting only for EA and LA schemes, for the period 2009-12 approximately 42% of FCERM expenditure is attributed to river flooding, 51% to coastal flooding and 7% to coastal erosion.

Headline figures report that 65% of the flood and coastal risk management for the EA is spent on asset construction and maintenance. For 2008-09 this amounted to £427 million. This expenditure is set to increase to £570 million by 2010-11, comprising of:

- EA construction programme: £270m
- EA maintenance programme: £160m
- LA revenue grant support: £87m
- LA and IDB construction programme: £52m

Comparison of the headline expenditure figures to Table 3.7 reveals considerable discrepancy in total expenditure amounts, but this is to be expected. The MTP is largely relevant to 'major works' schemes and collates currently available scheme information from a variety of sources including regional offices, LAs and IDBs, but it is recognised that it does not provide complete coverage of all proposed FCERM asset construction and maintenance activities.

Analysis of the MTP has also sought to establish the primary asset types for schemes funded for the period 2009-12. As reported in Section 2.4.2, schemes generally comprise of a series of elements and are generally not classified in terms of a typology. However, an initial assessment of the nature of schemes is useful with respect to implications for GHG emissions. As such Table 3.8 provides a summary of a partial analysis of the MTP that categorises schemes, based on expert judgement into likely asset types.

Table 3.8 Partial analysis of asset types and elements in MTP expenditure 2009-2012 by policy area (no. of schemes)

Asset 'type'	***River flooding***		***Coastal flooding***		***Coastal erosion***	***Other***
	EA schemes	LA schemes	EA schemes	LA schemes	LA schemes	IDB schemes
Embankment	130	36	25	-	-	13
Culverts and channels	40	6	2	-	-	-
Sea walls and groynes	-	-	36	14	40	-
Tidal barriers/sluices	-	-	24		-	-
Piling	3	-	-	-	-	-
Beach recharge/recycling	-	-	7	4	13	-
Pumping stations	4	2	3	-	-	43
Other/undetermined	31	13	4	6	19	4

Source: Analysis of EA MTP (April 2009)

Overall reporting in Tables 3.7 and 3.8 should be treated as 'indicative', with the purpose of characterising the business as usual status of FCERM for informing the development of the carbon footprint. Supporting detail on the asset construction and maintenance expenditure can also be obtained from the EA's Annual Report and Accounts. Table 3.9 details expenditure for 2006-09 reported for capital works.

Table 3.9 Environment Agency capital works expenditure 2006-09 by flood and coastal defence asset/activity (£m)

Asset/activity	**2006-07**	**2007-08**	**2008-09**
Embankments	56.0	47.6	37.9
Culverts and channel improvements	16.3	24.4	26.6
Rock groynes and sea walls	18.8	21.1	18.7
Piling	20.4	20.4	18.8
Beach recharge	17.0	11.8	29.9
Repair and refurbishment	43.2	33.3	54.6
Flood mapping[1]	*7.0*	*6.2*	*7.7*
Flood risk management strategies[1]	*15.8*	*15.6*	*33.7*
Other	13.4	15.8	19.9
Total	202.4	196.2	247.8

Source: EA Annual Report and Accounts 2008-09 and 2007-08.

Details of surface water flooding assets and expenditure are limited. As noted in Section 2.4, there is no central database of existing surface water flooding defence assets. Planned expenditure for capital investment is reported to be £14.7 million per year by Defra, based on funding of £100,000 per year for each LA, over all 147 LAs in England (Defra, 2009c) for activities such as re-profiling roads to manage flood flows, maintenance of ditches and watercourses (Halcrow, 2009).

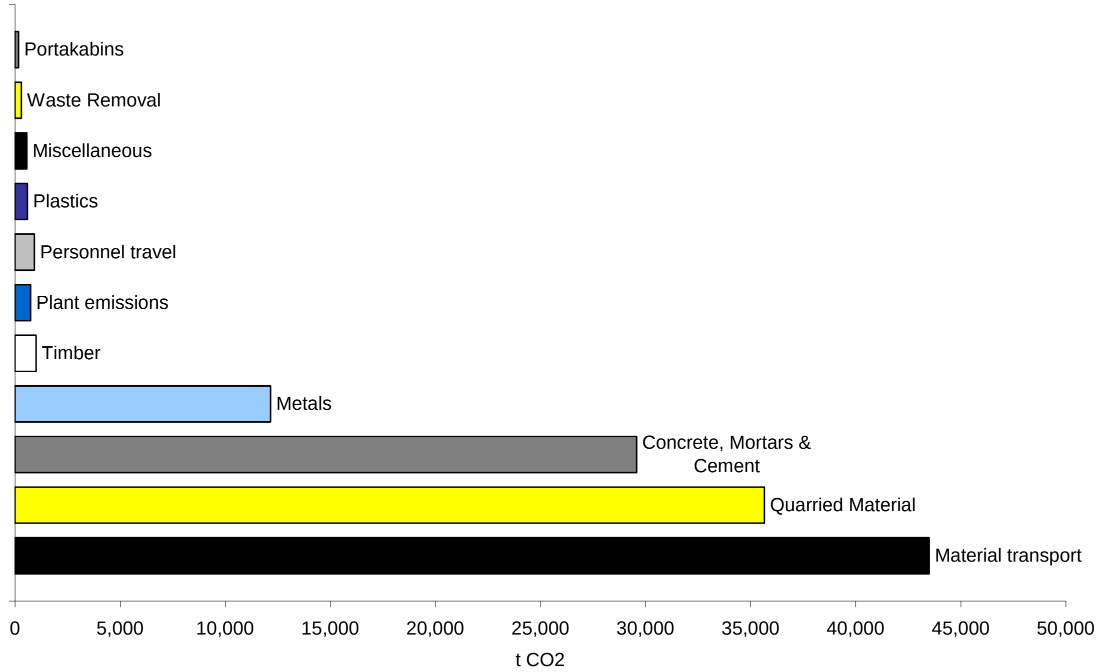
3.1.4 Construction carbon calculator data

The EA provided the currently available sample of data on carbon emissions from 31 schemes for which the Construction Carbon Calculator had been completed. A high level overview of the main emissions sources from the sample reveals that approximately 97% of the total emissions can be attributed to four emissions sources:

- Material transport;
- Quarried material;
- Concrete, mortars & cement; and
- Metals.

This is illustrated in Figure 3.1 which presents the breakdown of total emissions by source for the 31 schemes.

Figure 3.1 Breakdown of the carbon emissions associated with sample of projects



Source: Enviros calculations based on data provided by the Environment Agency

The Construction Carbon Calculator data do not provide detailed information on the scheme type and elements; for example it is not possible to link the data to the typology of asset types set out Table 3.3. Analysis of the data has however sought to classify schemes in terms of: coastal defence works (e.g. concrete walls/revetments, rock armouring etc.); coastal management works (e.g. groynes, beach recharge and recycling); inland flood defence works (e.g. concrete walls/revetments); river control structures (e.g. sluices and weirs); and drainage and culvert works (e.g. concrete channels). This provides a basis for assessing if distinctions in terms of GHG emissions can be identified between schemes likely to be developed in different policy areas. A summary of the analysis of individual schemes by policy area is provided in Table 3.10.

In general the summary of data set out in Table 3.10 reveals too few observations per type of policy area to calculate meaningful descriptive statistics such as average emissions per source material. For example calculations could be subject to skew by variation caused in the data by schemes that are potentially atypical interventions (a concern which, of course, would be reduced by a larger sample size and more scheme observations).

Table 3.10 Categorisation of Construction Carbon Calculator sample of schemes by policy area

Scheme	*Total CO_2*	*Transport Materials*	*Quarried Material*	*Concrete, Mortars & Cement*	*Metals*	*Timber*	*Plant emissions*	*Personnel travel*	*Plastics*	*Misc*	*Waste Removal*	*Porta-kabins*	*Operating emissions*
	Tonnes	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*	*%CO_2*
Major coastal defence works involving extensive concrete walls/revetments													
Dymchurch Frontage A Permanent Works - Conservative Estimate	28,107	3.1	2.6	65.6	26.4	1.2	0.0	1.1	0.0	0.0	0.0	0.0	0.0
Coastal Management works - groynes, beach recharge and recycling													
Winchelsea Beach Groynes & Associated Works (Pett Frontage Sea Defences Year 6 Works)	573	23.1	50.3	1.0	2.5	13.9	3.5	3.6	0.0	0.0	1.0	1.0	0.0
Denge Annual Beach Recharge	520	9.8	86.9	0.0	0.0	0.0	1.9	1.3	0.0	0.0	0.0	0.0	0.0
Winchelsea Beach Groynes & Associated Works (Pett Frontage Sea Defences Year 5 & 6 Works)	964	16.8	24.3	1.0	7.5	42.2	3.1	3.8	0.0	0.0	0.0	0.9	0.0
Medium scale inland flood defence works													
Cobbins Brook	33,667	1.3	90.6	3.8	2.1	0.0	1.0	0.0	0.1	0.0	0.0	0.0	0.0
Glynneath FAS	2,781	6.0	30.0	53.3	8.8	0.0	2.1	1.5	0	1.0	0.0	0.1	0.0
Smeeth Bridge	257	18.7	16.2	14.3	28.7	1.6	16.3	3.4	0.0	0.0	0.0	0.0	0.0
Flexbury Flood Defence Scheme	669	7.9	16.1	52.9	15.3	0.1	0.0	3.1	1.8	0.0	0.0	2.4	0.0
Minor inland flood defence works													
Lewes Cliffe FAS: Approved PAR Option	585	3.3	22.2	54.6	8.5	3.5	2.1	1.5	2.0	1.0	1.0	0.0	0.0
Exwick Scheme Improvements	124	5.0	8.5	39.3	7.5	0.0	32.2	5.5	0	0	1.0	1.0	0.0
Major control structures													
Boston Waterways Link	3,272	3.1	3.8	43.9	40.3	0.0	0.0	2.2	2.0	0.0	0.0	0.0	4.4
Rainham Tidal Sluice Frontage	364	0.0	0.1	5.5	90.8	0.0	1.6	0.9	0.0	0.0	0.0	0.0	0.0

Table 3.10 Categorisation of Construction Carbon Calculator sample of schemes by policy area (cont.)

Scheme	***Total CO_2** Tonnes*	***Transport Materials** %CO_2*	***Quarried Material** %CO_2*	***Concrete, Mortars & Cement** %CO_2*	***Metals** %CO_2*	***Timber** %CO_2*	***Plant emissions** %CO_2*	***Personnel travel** %CO_2*	***Plastics** %CO_2*	***Misc** %CO_2*	***Waste Removal** %CO_2*	***Porta-Kabins** %CO_2*	***Operating emissions** %CO_2*
Small Control structures													
Lancing Brook Outfall	773	3.4	62.3	9.5	22.8	0.0	0.1	0.0	0.0	0.0	1.0	0.0	0.0
North Wessex FSRs - Curry Moor - IMSW001322	346	1.0	28.3	63.7	3.9	0.4	1.4	1.0	0.1	0.0	0.0	0.0	0.0
North Wessex FSRs - Lysander Road - IMSW001323	247	1.5	23.0	44.7	18.0	7.2	1.9	1.4	1.7	0.2	0.0	0.0	0.0
North Wessex FSRs - South Perrott - IMSW001324	130	16.0	14.8	33.4	7.4	15.1	3.4	2.5	6.2	0.3	1.0	0.0	0.0
Drainage and culvert works													
North Wessex FSRs - Westford - IMSW001325	705	1.0	76.2	18.4	0.5	1.8	0.6	0.4	1.0	0.0	0.0	0.0	0.0
Heacham, Lavender Corner Junction Improvement Scheme	98	9.3	12.6	9.3	18.4	3.7	16.3	8.0	20.3	0.0	1.0	1.4	0.0
Unclassified													
Bruton Dam IMSW 000822 & 1132	2,540	8.3	1.3	7.8	5.2	0.0	1.3	0.9	0.0	4.8	0.0	0.0	0.0
Warren Dam Discontinuance	1,188	17.8	15.0	48.2	3.4	0.4	0.8	0.6	0.6	0.0	13.0	0.0	0.0

Source: Scheme data provided by EA Construction Carbon Calculator (June 2009).

3.1.5 Carbon intensity factors

Schemes from the Construction Carbon Calculator data sample were matched to reported expenditure data from several sources including the MTP and other information provided by the EA, including a list of schemes completed since Summer 2007 and other NCPMS data. This information was used to calculate carbon intensity factors for each scheme (i.e. kg CO_2 / £ spent), as detailed in Table 3.11. These data can be used as a proxy to convert FCERM expenditure (for construction, maintenance and operation) as presented in Section 3.1.3 into carbon emissions.

Given the variety of data sources used, three sets of carbon intensity factors were calculated, with weighted average values derived from each. The resulting average carbon intensity factors range between 0.91 kg CO_2/£ to 0.98 kg CO_2/£[32]. Carbon intensity factors for individual schemes range between 0.07 kg CO_2/£ and 4.18 kg CO_2/£. Estimated values are dependent on the reported cost of the scheme, which in some instance can be seen to vary between source (for example the cost data from the Construction Carbon Calculator may only cover construction elements, cost data from the MTP may include broader elements of a strategy).

Comparison to analysis reported elsewhere, indicated broad consistency between the average carbon intensity factors estimated here and those calculated for FCERM measures (0.2-2.0 kg CO_2/ £) within the TE2100 strategy by Arup (2008).

The analysis also sought to establish average carbon intensity factors for the groups of schemes in different policy areas as set out in Table 3.10. However, given the scarcity of observations no discernable distinctions in the data were found as illustrated by the scatter plot graph in Figure 3.2.

---

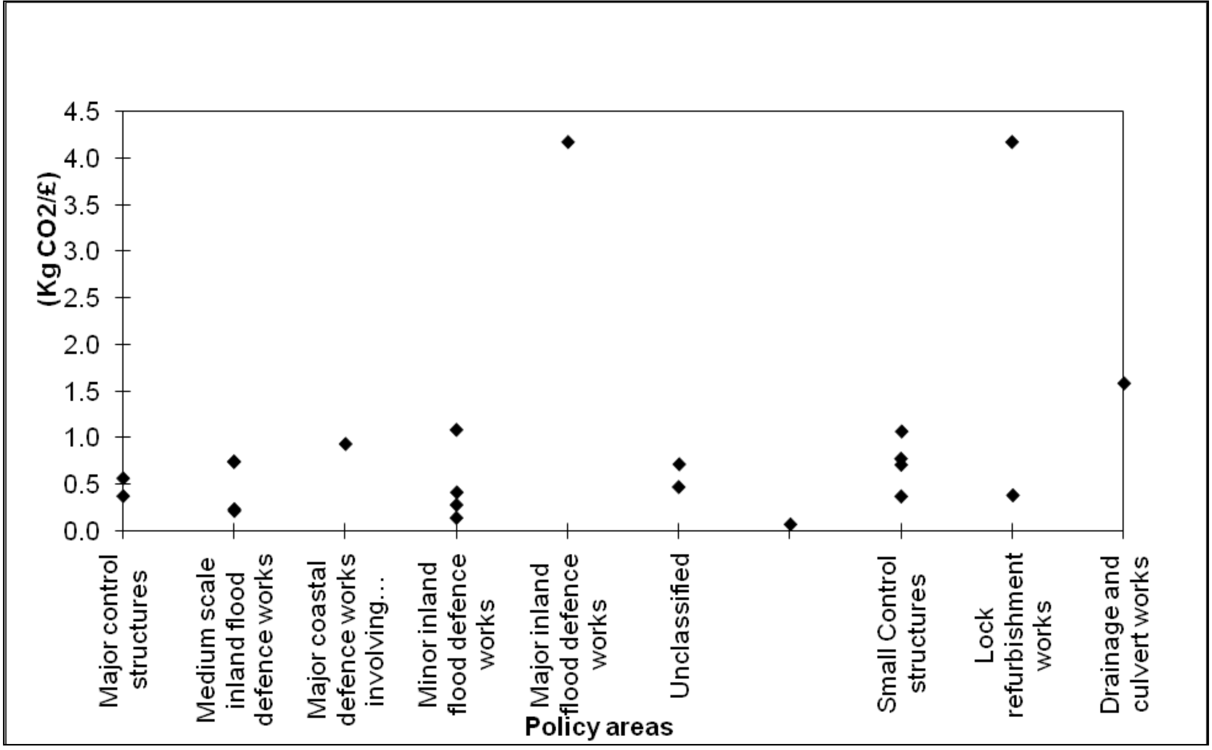
[32] Note that one scheme in the Construction Carbon Calculator sample was dropped from the analysis due to the extreme outlier nature of the estimated carbon intensity factor.

Table 3.11: Calculated carbon intensity factors for sample of schemes

Scheme	***CO$_2$ tonnes***	***Summary of cost data***			***Calculated range of carbon intensity factors***		
		Scheme Cost (£) [MTP]	*Scheme Cost (£) [CCC]*	*Scheme Cost (£) [NCPMS]*	*kg CO$_2$ / £ [MTP]*	*kg CO$_2$ / £ [CCC]*	*Kg CO$_2$ / £ [NCPMS]*
Boston Waterways Link	3,271	-	-	8,860,000	-	-	0.369
Flexbury Flood Defence Scheme	753	3,163,000	-	3,577,500	0.238	-	0.210
Dymchurch Frontage A Permanent Works - Conservative Estimate	28,107	27,207,000	-	30,249,900	1.033	-	0.929
STM 16, 18 & 21; Demountable Defences	436	-	-	1,865,500	-	-	0.234
Exwick Scheme Improvements	124	989,000	132,613	303,200	0.125	0.94	0.409
St Ives Flood Scheme	41,836	-	-	10,027,000	-		4.172
Glynneath FAS	2,781	-	2,720,000	3,775,000	-	1.02	0.737
Glynneath FAS (with soil nailing)	2,797	-	2,720,000	3,775,000	-	1.03	0.741
Bruton Dam IMSW 000822 & 1132	2,540	-	1,679,743	3,570,500	-	1.51	0.711
Winchelsea Beach Groynes & Associated Works (Pett Frontage Sea Defences Year 5 & 6 Works)	964	-	1,200,000	14,767,700	-	0.80	0.065
Smeeth Bridge	257	-	1,000,000	-	-	0.26	-
North Wessex FSRs - Curry Moor - IMSW001322	346	245,000	136,741	325,300	1.412	2.53	1.064
Denge Annual Beach Recharge	520	900,000	1,300,000	-	0.578	0.40	-
Heacham, Lavender Corner Junction Improvement Scheme	98	-	410,000	-	-	0.24	-
Eldridges Lock & Sluice	644	-	658,000	1,704,100	-	0.98	0.378
Lancing Brook Outfall	773	368,000	314,000	996,900	2.102	2.46	0.776
Lewes Cliffe FAS: Approved PAR Option	585	-	800,000	2,087,300	-	0.73	0.280
North Wessex FSRs - Lysander Road - IMSW001323	247	-	178,543	351,100	-	1.38	0.704
Moorland House Improvement Works	753	-	-	696,400	-	-	1.081
Winchelsea Beach Groynes & Associated Works (Pett Frontage Sea Defences Year 6 Works)	573	-	1,000,000	-	-	0.57	-
Rainham Tidal Sluice Frontage	407	717,000	300,000	718,700	0.567	1.36	0.566
North Wessex FSRs - South Perrott - IMSW001324	130	-	136,519	349,100	-	0.95	0.373
Thatchers Arms Improvement Works	75	515,000	-	517,400	0.146	-	0.145
Teston Lock Refurbishment	301	-	658,000	72,000	-	0.46	4.178
Warren Dam Discontinuance	1,188	1,854,000	1,000,000	2,517,800	0.641	1.19	0.472
North Wessex FSRs - Westford - IMSW001325	705	326,000	178,407	446,200	2.163	3.95	1.580
East Farleigh Lock Refurbishment	301	-	658,000	-	-	0.46	-
Weighted average carbon intensity factor					**0.91**	**0.95**	**0.98**

Source: Total CO$_2$ for schemes provided by EA Construction Carbon Calculator (June 2009). Scheme cost estimates sourced from EA Medium Term Plan (April 2009), the EA Construction Carbon Calculator (June 2009) and further information provided by NCPMS, including details of schemes completed since Summer 2007 (provided July 2009).

Figure 3.2 Estimated carbon intensity factors by policy area



Overall data from EA Construction Carbon Calculator allow for a limited approach to estimating GHG emissions associated with asset construction and maintenance. In particular it is not possible to differentiate GHG emissions between scheme type which would permit flexibility in specifying alternative policy scenarios; i.e. reflecting different portfolio of schemes and GHG emissions in comparison to the BAU situation. Given this estimation of this aspect of the FCERM carbon footprint relies on a proxy approach of relating investment expenditure to GHG emissions, based on a relatively small sample of recent and planned schemes. There is however scope in the future to refine this aspect of the analysis as more EA schemes report GHG emissions via the mandatory Construction Carbon Calculator. Initiatives relating to other aspects of EA maintenance and operating activities are detailed in Section 4.2.

3.1.6 Energy use from operations - pumping

Basic high-level information is available from the EA in relation to GHG emissions from energy use for pumping. For 2008/09 total CO2 emissions from all EA activities are estimated at 56,700 tonnes. Of this 32% (approximately 18,000 tonnes CO_2) is attributed to electricity use for pumping[33]. This information however is not applied in the subsequent analysis of the FCERM, due to the broad approach that does not permit consideration of operation details such as the requirement for energy use for pumping under alternative policy scenarios.

---

[33] Pers. comm. J. Feasby, Environment Agency (March 2010).

3.1.7 Emissions associated with flood and coastal erosion damages – estimates of annual damages

As detailed in Section 2.4.2 a proxy approach to estimating GHG emissions associated with flood and coastal erosion damages is adopted, linking estimates of economic damage costs to carbon emissions, based on the ‘multiplier’ calculated for TE2100 (see Halcrow, 2008).

Estimates of economic damage costs are applied from a variety of sources. The most comprehensive data on damages from river and coastal flooding are provided by NaFRA. Other sources of information include earlier work on NAAR (Halcrow, 2001) and recent analysis for Defra in relation to the SWMP Impact Assessment (Defra, 2009a and Halcrow 2009). Table 3.12 summarises these damage estimates at the national level in relation the policy scenarios set out in Section 2.3.4.

Table 3.12: Annual average damage estimates for policy scenarios (£ million)

Source	***Description***	***Annual Average Damages (£m)***	***Policy Scenario***
NaFRA (2008)	Residual damages from river and coastal flooding	Total: 1,326 Residential: 664 Non-residential: 572	BAU
NAAR (2001)	Do-nothing damages from no further investment in river and coastal flooding and coastal erosion	Total: 3,030 River: 1,419 Coastal: 1,528 Erosion: 84	Policy-off
Defra SWMP IA (2009); Halcrow (2009)	Do-nothing damages from surface water flooding and residual damages from intervention in surface water flooding	2009: 1,174 – 2,280 2060: 1,195 – 3,796	BAU
		2009: 1,174 – 2,280 2060: 1,526 – 4,788	Policy-off

Source: NaFRA (2008) data provided by Defra and the Environment Agency (September 2009); NAAR data provided by Defra (August 2009) and SWMP Impact Assessment supporting analysis provided by Defra (September 2009), including Halcrow (2009).

Data provided by NaFRA do not split flooding damages between river and coastal flooding, instead a categorisation is provided between residential and non-residential damages at EA region, LA and river basin district levels. Damages associated with the BAU plus and SWF scenarios are derived from the damage estimates set out in Table 3.12. Assumptions regarding these are provided in Section 3.2.

3.1.8 Emissions associated with flood and coastal erosion damages – estimates of properties damaged

Table 3.13 details estimates of properties affected by coastal erosion. More recent estimates (e.g. Defra, 2009a) reflect improved modelling.

Table 3.13: Properties affected by flooding and coastal erosion (£ million)

Source	***Description***	***No. of properties per year***	***Policy Scenario***
NAAR (2001)	Estimate of properties lost to coastal erosion	141 – 695 per year	Policy-off
Defra (2009a)	‘Working estimate’ of properties lost to coastal erosion (national figure)	200 properties over 20 years	BAU

Average estimates of 15t CO_2 for refurbishment and 50t CO_2 for rebuilding a property are applied in the calculation of emissions associated with coastal erosion damages. These estimates are based on figures provided by EHA (2008), which presents a number of case studies comprising various types of houses (i.e. newly built and existing old housing stock) and investigated the emissions related to refurbishing and rebuilding the houses after a non-specific damaging event (e.g. fire).

3.2 Results – estimates of GHG emissions from FCERM

3.2.1 Carbon footprints for policy scenarios

Estimated carbon footprints for the BAU, policy-off, BAU-plus and SWF scenarios are presented in Tables 3.14 to 3.17 in terms of annual average tonnes of CO_2e per year. The annual estimate is calculated from the assumed profile of emissions over a 50-year time horizon; details of scenarios and sensitivity analysis are presented in Annex 3 (spreadsheet model). With respect to Figure 2.3, but based on data availability, the estimated carbon footprints include:

- *Emissions associated with FCERM activities - asset construction and maintenance only*. The analysis does not estimate emissions associated with: adaptation measures, development control, mapping and modelling, emergency planning and response, flood storage or managed realignment.
- *Emissions associated with flood and coastal erosion damages - reparations to properties and possessions*. The analysis is based largely on the damage multiplier approach described previously.

Emissions from activities dependent on FCERM are not accounted for in the analysis.

Descriptions of calculations and assumptions for each scenario are provided below.

BAU carbon footprint

Table 3.14 reports an estimated carbon footprint for the BAU scenario of approximately 2.41 Mt CO_2e per year. The BAU scenario is intended to characterise the current FCERM policy stance, reflecting the present distribution of investment between the four policy areas of interest; river flooding, coastal flooding, surface water flooding and coastal erosion.

Table 3.14: Estimate of FCERM carbon footprint for BAU scenario (Mt CO_2e per year)

BAU scenario	***Emissions arising from:***			***Total***
Policy area	*FCERM activities*	*Flood and coastal erosion damages*	*Activities dependent on FCERM*	
River flooding	0.22	0.36	*Not estimated*	0.58
Coastal flooding	0.26	0.54		0.80
Coastal erosion	0.04	0.00		0.04
Surface water flooding	0.01	0.99		1.00
BAU TOTAL	**0.53**	**1.90**	**-**	**2.41**

The key assumptions in estimating the BAU carbon footprint are:

- Expenditure on asset construction and maintenance is assumed constant over the 50 year time horizon from 2010/11 headline expenditure reported by the EA (2009a). Expenditure (£520m per year from 2011) is apportioned between river flooding (42%), coastal flooding (51%) and coastal erosion (7%) based on analysis of the MTP of proposed projects and expenditure for the period 2009-11. A further £14.7m per year (as reported in Section 3.1.3) is attributed to surface water management, which is assumed to commence in 2014 following completion of SWMPs.

- A carbon intensity factor of 0.91 kg CO_2e / £ is applied across all asset construction and maintenance activities. This is expected to over-estimate emissions from a subset of activities that are not adequately reflected by the sample of schemes from the Construction Carbon Calculator data.

  Sensitivity analysis considers a lower carbon intensity factor (0.2 kg CO_2e / £) based on the low estimate reported by Arup (2008) for the TE2100 strategy. A higher value is also considered (0.98 kg CO_2e / £) reflecting the higher estimate from the Construction Carbon Calculator (see Table 3.10). The sensitivity range results in a lower and upper set of estimates for emissions from FCERM activities of 0.11 – 0.55 million tonnes CO_2e per year.

- Emissions associated with river and coastal damages are calculated from NaFRA 2008 residual damage estimates as reported in Table 3.11 and are assumed constant over the time horizon. Emissions are attributed between river (40%) and coastal flooding (60%) on the basis of NAAR (Halcrow, 2001), since NaFRA data does not provide this split.

The damage multiplier applied to river and coastal flooding (2.25%) is based on a calculated mid-point (2.0% - 2.5%) for the range presented by Halcrow (2008). As detailed in Annex 3, the range reflects differences between damages in short and long duration flooding events. The conversion from damage (£) to carbon emissions (tonnes) is based on a carbon price of £25.50 per tonne CO_2e with a sensitivity of £60 per tonne of CO_2e [34]. The effect of the higher unit value is to reduce the estimate of emissions associated with damages, for example BAU emission for coastal flooding damages are 0.23 million tonnes CO_2e per year (compared to 0.54 million tonnes CO_2e per year reported in Table 3.14).

- Emissions associated with surface water flooding are calculated from the BAU damage estimates reported in Table 3.12. These are assumed to increase over time following Halcrow (2009); the low estimate from Halcrow (2009) is applied in the analysis, with the high estimate tested for sensitivity analysis[35]. This gives a range of 0.99 – 1.13 million tonnes CO_2e per year.
- The damage multiplier applied to surface water flooding is based on the short duration (2.0%) factor from Halcrow (2008), reflecting the difference between this type of flooding and river and coastal flooding.
- Emissions associated with damages from coastal erosion are based on Defra (2009a) as detailed in Table 3.12. A number of sensitivities have been tested, including higher rates of property loss based on NAAR (Halcrow, 2001) – see Annex 2). An emissions factor of 15 t CO_2e per property is applied (strictly this based on repair rather than rebuild but it provides a lower bound conservative estimate) with a sensitivity of 35 t CO_2e per property (based on rebuild). Overall the various sensitivities provide a range of 350 – 7,000 tonnes CO_2e per year; note that these estimates are several orders of magnitude lower than those presented for emissions from flooding damages.

BAU-plus carbon footprint

Table 3.15 reports an estimated carbon footprint for the BAU-plus scenario of approximately 2.36 Mt CO_2e per year. This scenario presents a case of increased investment in the ‘traditional’ FCERM policy areas of river and coastal flooding. It assesses the trade-off between increased GHG emissions from

---

[34] The value of £25.50 per tonne specified by Halcrow (2008) is based on guidance (at the time) provided by Defra (2007) for the shadow price of carbon guidance. UK Government guidance regarding carbon valuation has been updated since by DECC (2010) which now specifies initially separate but then converging schedules over time for traded and non-traded carbon. Unit values for central estimates range from approximately £20 to £70 per tonne CO_2e for the period up to 2030, with values beyond rising to approximately £270 per tonne by 2060.

[35] As noted in Section 3.1 this damage estimate is assumed to double-count properties at risk from both surface water flooding and coastal and river flooding.

asset construction and investment, versus decreased GHG emissions from flood damages due to enhanced flood protection.

Table 3.15: Estimate of FCERM carbon footprint for BAU-plus scenario (Mt CO_2e per year)

BAU-plus scenario	***Emissions arising from:***			***Total***
Policy area	*FCERM activities*	*Flood and coastal erosion damages*	*Activities dependent on FCERM*	
River flooding	0.29	0.26	*Not estimated*	0.55
Coastal flooding	0.36	0.42		0.77
Coastal erosion	0.04	0.00		0.04
Surface water flooding	0.01	0.99		1.00
BAU-plus TOTAL	**0.70**	**1.45**	**-**	**2.36**

The key assumptions in estimating the BAU plus carbon footprint are:

- The treatment of coastal erosion and surface water flooding (both emissions from asset construction and maintenance and damages) is identical to the BAU scenario.

- Expenditure on asset construction and maintenance is assumed to increase from the BAU level in 2011 (£570m) at a rate of 2% per year. The increase in investment is apportioned between river flooding (45%) and coastal flooding (55%) based on analysis of the MTP.

- The resultant decrease in river and coastal flooding damages – due to increased investment – is calculated on the basis of a 2:1 ratio; i.e. £1 invested in flood defence reduces flood damages by £2. While the EA (2009) reports higher benefit-cost ratios for investments a lower value is applied in the analysis to reflect the fact that as investment increases, the return on schemes will inevitably decrease[36]. The reduction in emissions is calculated over the 50 year time horizon, with a 5 year lag between increased investment and reduced damages (to reflect planning and construction phases of schemes). The effect of the 5-year lag is potentially conservative (i.e. it under-estimates the reduction in emissions, assuming other factors do not change).

---

[36] As detailed in Section 2.3.4, EA (2009) reports benefit cost ratios for river and coastal flooding schemes around 8:1. However, in general these will be in relation to a do-nothing or do-minimum baseline rather than BAU and damages also include aspects such as business losses and environmental and social impacts, not accounted for in the analysis here (which is limited to property damages). Note that sensitivity testing of this aspect of the analysis is not formally presented in Annex 3, although the effect of assuming a higher ratio (e.g. 4:1) is relatively marginal in terms of overall scenario footprint estimates (differences are in the order of 100k rather than 1,000k).

- Two sensitivities reported for the BAU scenario, regarding the carbon intensity factor for asset construction and maintenance (0.2 - 0.98 kg CO_2e / £) and the conversion from flood damage (£) to carbon emissions (tonnes) (£25.50 - £60 per tonne) are also tested. Overall these give a range of 1.53 – 7.51 million tonnes CO_2e per year for the BAU plus scenario.

SWF carbon footprint

Table 3.16 reports an estimated carbon footprint for the SWF scenario of approximately 2.18 Mt CO_2e per year. This scenario presents a case of increased investment in addressing surface water flooding. It assesses the carbon implications of increased investment in surface water flooding protection.

Table 3.16: Estimate of FCERM carbon footprint for SWF scenario (Mt CO_2e per year)

SWF scenario	***Emissions arising from:***			***Total***
Policy area	*FCERM activities*	*Flood and coastal erosion damages*	*Activities dependent on FCERM*	
River flooding	0.22	0.36	*Not estimated*	0.58
Coastal flooding	0.26	0.54		0.80
Coastal erosion	0.04	0.00		0.04
Surface water flooding	0.04	0.72		0.76
SWF TOTAL	**0.55**	**1.62**	**-**	**2.18**

The key assumptions in estimating the SWF carbon footprint are:

- The treatment of river and coastal flooding and coastal erosion (both emissions from asset construction and maintenance and damages) is identical to the BAU scenario.

- Assumptions as to capital investment in surface water management schemes are drawn from Halcrow (2009) which considers two cases of increased investment above £14.7m per year: £44.1m per year and £64.7m per year.

  The sensitivity range of carbon intensity factors applied in the BAU scenario are also applied here, giving a range of 0.11 – 0.55 million tonnes of CO_2e per year.

- The decrease in surface water flooding damages – due to increased investment – follows the analysis of Halcrow (2009), which projects a reduction for both the low and high estimate case.

These are assumed to increase over time following Halcrow (2009); the low estimate from Halcrow (2009) is applied in the analysis, with the high estimate tested for sensitivity analysis. This gives a range of 0.73 – 1.79 Mt CO_2e per year.

Policy-off carbon footprint

Table 3.17 reports an estimated carbon footprint for the policy-off scenario of approximately 2.89 Mt CO_2e per year. This scenario assumes no further active intervention in flood and coastal erosion risk management.

Table 3.17: Estimate of FCERM carbon footprint for policy-off scenario (Mt CO_2e per year)

Policy-off scenario	***Emissions arising from:***			***Total***
Policy area	*FCERM activities*	*Flood and coastal erosion damages*	*Activities dependent on FCERM*	
River flooding	n/a	0.81	*Not estimated*	0.81
Coastal flooding	n/a	0.94		0.94
Coastal erosion	n/a	0.01		0.01
Surface water flooding	n/a	1.13		1.13
Policy-off TOTAL	-	**2.89**	**-**	**2.89**

The key assumptions in estimating the policy-off carbon footprint are:

- No asset construction or maintenance investment is undertaken.

- GHG emissions arising from flood and coastal erosion damages progress overtime from BAU damages in 2009 to full policy-off damages in 2058, based on NAAR estimate for river and coastal flooding and coastal erosion and Halcrow (2009) estimates for surface water flooding, as reported in Table 3.11.

  A number of sensitivities concerning the profile of damages overtime have been assessed (Annex 3), including ‘constant’ policy-off damages overtime. This is expected to result in an over-estimate of GHG emissions since in reality failure of defences as a result of no further investment will be progressive, rather than immediate. For example emissions for policy-off coastal flooding damages are estimated to be 1.3 Mt CO_2e per year (compared to 0.93 Mt CO_2e per year as reported in Table 3.17).

  Sensitivity analysis concerning the conversion from flood damage (£) to carbon emissions (tonnes) (£25.50 - £60 per tonne) and the emission factor for repair/rebuild (15 - 50 t CO_2e per property) for coastal erosion gives a range of 1.2 – 3.0 Mt CO_2e per year for the policy-off carbon footprint.

4. Analysis

The analysis set out in this section focuses on implications of the estimated carbon footprints for different policy scenarios and assessing gaps in evidence and future opportunities for enhancing the estimate of GHG emissions and understanding of the climate change impact of FCERM.

4.1 Answering the policy questions and understanding the climate change impact of FCERM

This section returns to the specific policy questions I-V set out in ToR (see Table 1.1) to be addressed by the research.

I. What is the current net climate change impact of FCERM activities?

The current climate change impact of FCERM activities can be viewed from two perspectives. First, in terms of the overall level of emissions - on the basis of the results presented in Section 3.2 - FCERM activities are a contributor to GHG emissions with respect to the business as usual (BAU) scenario.

The second perspective considers the impact of FCERM activities in relation to the counterfactual of no FCERM activities (represented by the policy-off scenario). The analysis here suggests that FCERM activities largely represent a net reduction in emissions due to flood alleviation actions which reduce damages from flooding and consequential GHG emissions associated with those damages. In other words, without FCERM activities, net emissions resulting from FCERM policy would likely be greater due to impacts of greater flood damage. This interpretation therefore suggests that, in the short term at least, the net contribution of FCERM activities to climate change *mitigation* is positive.

The two perspectives highlight the care needed in interpreting results from this research. A key point is the trade-off particularly between flood alleviation and flood damages. Both aspects in isolation contribute to GHG emissions, but the marginal impact of increasing FCERM activities is positive; increased investment in flood alleviation results in reduced damages. This gives net emissions savings in the short term because the emissions savings from the reduced flood damages are greater than the increased emissions from the FCERM activity.

Longer term however the marginal impact of FCERM is more difficult to assess because FCERM policy influences the baseline situation against which changes to emissions are calculated. Therefore, while FCERM avoids emissions resulting from flooding in the shorter term, it may in the long term perpetuate activities (land uses or patterns of development) that have higher carbon emissions, and higher avoided emissions due to avoided flooding, than would otherwise be the case. It has, however, not been possible to account for the more dynamic aspect of FCERM policy in this regard in this analysis. This is primarily limited by the current scope for specifying parameters of alternative policy scenarios.

The assessment of the net climate change impact of FCERM activities is also subject to caveats that have been identified earlier in this report:

- Estimation of FCERM BAU carbon footprint is only possible to the extent allowed by existing information sources. Limited data availability means that not all of the emissions associated with FCERM activities and non-FCERM activities arising due to FCERM (Figure 2.3) can be quantified.

- Carbon footprint analysis accounts for emissions from asset construction and maintenance only in terms of FCERM activities.

- At present, it is not possible to calculate emissions associated with adaptation measures, development control, mapping and modelling, emergency planning and response, flood storage or managed realignment. Qualitative consideration of the potentially significant carbon footprint implications of land use management is provided in Annex 1.

- The omitted activities have implications for both emissions and sequestration of GHGs, implying that the net effect on the BAU carbon footprint at present comprises a significant degree of uncertainty.

Overall the resulting carbon footprint estimates should be interpreted with caution, representing indications of order of magnitude rather than precise estimates. Sensitivity testing of component parts of the carbon footprint estimates indicates relatively large ranges based on different sets of assumptions; in general however this is expected given the high-level nature of the analysis.

Establishing the carbon sequestration potential of land use management activities (flood storage and managed realignment) in aggregate is a key avenue for further research.

II. What is the best estimate of net GHG emissions from FCERM policy and investments?

The current ‘best’ estimate of net emissions from FCERM policy and investments is 2.41 Mt CO_2e per year (see Table 3.14). Over 50 years, total emissions from the BAU scenario are estimated to be approximately 121 Mt CO_2e (see Annex 3). Some notes on comparing the estimate of GHG emissions from FCERM policy to other UK sectors are provided in Box 4.1.

The greatest contribution to the BAU carbon footprint estimate comes from surface water flooding, with virtually all emissions arising from flood damages (approximately 0.99 Mt CO_2e per year). A ‘sense check’ on this estimate is possible using an alternative approach to estimate emissions arising from surface water flood damages, as demonstrated in the case studies (see Annex 4). Halcrow (2009) estimate that between 2.8 – 3.8 million properties are susceptible to surface water flooding, with approximately 50,000 – 76,000 properties at an annual risk of flooding. Taking those properties at annual risk of flooding only and assuming a range of 15 t CO_2e per property to 35 t CO_2e per property for GHG emissions arising from flood damages (see Annex 4) gives an expectation of 0.75 – 2.66 Mt CO_2e per year. Although this calculation is subject to its own limitations the order of magnitude and range of values is consistent with the carbon footprint estimate for damages from surface water flooding in Table 3.16.

Box 4.1: Comparing FCERM's carbon footprint to other sectors

Direct comparison of the estimated BAU and alternative policy scenario carbon footprints with other sectors is difficult. Foremost, no evidence of 'aggregate' carbon footprint analysis has been identified for other UK Government policy areas (e.g. the carbon footprint of transport infrastructure, housing development, etc.); reporting that is available focuses on component level (e.g. footprints of carbon efficient homes versus standard construction). In addition, comparison to UK GHG reporting (Section 2.2.2) can only be viewed as 'indicative' given the different accounting methods and scope of emissions considered.

As detailed in Table 2.2, current UK GHG emissions are in the region of 630 Mt CO_2e per year. The current emissions estimate for BAU and other policy scenarios (Tables 3.15 – 3.17) are two orders of magnitude lower and on this basis represent around 0.3 – 0.5% of annual UK emissions. In these overall terms, the magnitude of emissions estimates indicate that FCERM is not hugely significant in contributing to emissions on the national scale, notwithstanding the current omissions from the analysis.

River and coastal flooding contribute similarly to the overall BAU carbon footprint in terms of FCERM activities (each approximately 10% of the overall estimate). In both cases estimated emissions arising from flood damages outweigh estimated emissions arising from flood alleviation activities. For coastal flooding the estimated emissions from damages are over double those estimated for flood alleviation.

Estimated emissions associated with coastal erosion are relatively minor (0.04 Mt CO_2e per year), representing just under 2% of the total BAU footprint. FCERM activities generate 99% of these emissions, with the remainder attributed to damages from coastal erosion. This simply reflects the fact that based on Defra (2009a) very few properties are lost to coastal erosion each year (see Table 3.13).

The 'best' estimate of net emissions from FCERM policy and investments corresponds to the BAU scenario. This assumes that the level of activities and policy focus (between river and coastal flooding, surface water flooding and coastal erosion) remains constant over the time horizon for the analysis. The estimate should also be viewed in light of the sensitivity analysis undertaken

(Annex 3), which provides an upper – lower bound of 0.92 – 3.53 Mt CO_2e per year, as well the caveats detailed in (I) above.

The BAU scenario can also be compared to the BAU-plus (increased investment in river and coastal flooding protection), SWF (increased investment in surface water management) and policy-off scenarios (no FCERM activities). Overall, the analysis is limited to varying only the high level indicators of GHG emissions associated with FCERM activities (investment expenditure) and flood and coastal erosion damages (economic cost). More nuanced approaches should be possible as the evidence base improves.

As noted in (I) above, the BAU scenario (Table 3.14) gives rise to lower emissions than the policy-off scenario (Table 3.17)[37], suggesting that 'no active intervention' in flood and coastal risk management would have detrimental carbon implications in addition to economic damages. Although this is relatively minor in terms of overall UK GHG emissions (see Box 4.2), these 'avoided emissions' can be viewed as FCERM's major contribution to UK carbon reduction efforts.

The finding with regards to avoided emissions also provides the intuition for results with regards to the BAU-plus and SWF scenarios. The net change in emissions in both scenarios compared to BAU are the result of (i) increased GHG emissions from increased capital investment in flood alleviation minus (ii) reductions in emission that result from lower levels of economic damages. In both of these scenarios (Tables 3.15 and 3.16) the net effect is to reduce the overall scenario footprint below the BAU estimate: 2.36 Mt CO_2e per year for BAU-plus, and 2.18 Mt CO_2e per year for SWF (compared to 2.41 Mt CO_2e per year for BAU). On this basis one extra tonne of CO_2e per year emitted as a result of river and coastal flood alleviation activities results in a reduction of 1.3 t CO_2e per year from river and coastal flooding damages. One extra tonne CO_2e per year emitted as a result of surface water flooding management activities results in a reduction of 10.8 t CO_2e per year from surface water flooding[38].

These results are driven by the strong assumption that the relationship between investment and damages is constant. In practice this is unlikely to be the case, since actual benefit-cost ratios will depend on a variety of scheme specific factors that cannot be accounted for in a high level assessment as provided here. More refined scenario specifications, particularly with regards to distinguishing the carbon implications of different types of capital investment (and different types of activity), would improve upon this assessment.

---

[37] Avoided emissions in the BAU scenario is equal to the net difference between emissions arising in policy-off and BAU damages (3.0 Mt CO_2e/yr minus 1.9 Mt CO_2e/yr = 1.1 Mt CO_2e/yr). Emissions associated with BAU FCERM activities are estimated as 0.53 Mt CO_2e/yr, giving a positive mitigation effect of 0.57 Mt CO_2e/yr.

[38] Note that these ratios are simply calculated from the difference between estimated emissions for the BAU scenario compared to the BAU-plus and SWF scenarios.

III. Which FCERM activities and policies provide significant positive mitigation of net GHG emissions through sequestration of carbon?

As noted, estimation of the FCERM carbon footprint has not included activities with the potential to sequester carbon due to data limitations. However, supporting qualitative discussion and a summary of available data is set out in Annex 1 in relation to land use management activities. With respect to flood storage and managed realignment options, key carbon management conclusions are:

- There is potential to re-sequester carbon within coastal lowlands through managed realignment, with associated reactivation of geomorphic processes and the creation of accommodation space for accumulation of carbon-bearing sediments.

- Restoration of wetlands in saline environments (saltmarshes and mudflats) have a net carbon sequestration potential. Restoration of freshwater and brackish tidal wetlands will sequester carbon (more than saltmarsh and mudflat) but the production of methane will likely offset the carbon sequestration benefits over time (for example a 100 year timeframe). A possible exception is the restoration of seasonally flooded grasslands, which as well as sequestering carbon in soils, if drained through summer months are likely to emit only marginal quantities of methane.

- It may be possible to create managed freshwater wetlands to fill some available accommodation space with organic rich soils while reducing methane emissions and therefore creating net positive carbon sequestration potential, an approach that is being experimentally trialled in the USA.

- Erosion of saltmarsh will release significant quantities of sequestered carbon back in to estuarine circulation with potential for likely conversion to carbon dioxide.

- Drainage of peat soils will release significant quantities of sequestered carbon into the atmosphere.

- From a regional perspective, restoration of saltmarsh will be most effective in carbon sequestration terms in estuaries with high sediment availability, notably the Severn Estuary and Humber Estuary. Restoration of saltmarshes in ‘sandy’ estuaries (e.g. Solway Firth, Morecambe Bay, outer Wash) will sequester less carbon than in relatively ‘muddy’ estuaries. It is anticipated that saltmarshes in the Outer Thames Basin (Essex and North Kent) will continue to be highly sensitive to sea level rise and the erosion will continue to release carbon in to circulation. Because of limited sediment availability and high rates of relative sea level rise it is anticipated that saltmarsh restoration will have limited capacity for carbon sequestration in this region.

- Carbon sequestration potential can come at a cost of biological diversity. From an ecological perspective, restoration should include a mix of habitats across the landscape, only some of which will be net sequesters of GHGs in the long term.

Under the Biodiversity Action Plan (BAP) the EA has a commitment to produce 200 hectares of wetland habitat per year as a result of FCERM activities (see Annex 1), with at least 100 hectares of saltmarsh and mudflat. However, this creation or restoration largely offsets losses arising from development, land reclamation or coastal squeeze due to sea level rise suggesting that any net gain is currently marginal[39].

In carbon footprint terms available evidence indicates that potential for carbon accumulation in restored wetlands could be in the region of 370 – 6,000 t CO_2e per hectare over a timescale of 50 – 100 years, depending on soil type, elevation and vegetated cover. Losses of habitat such as saltmarsh can in contrast result in release of accumulated carbon in the range of potentially 180 – 5,500 t CO_2e per hectare of depending primarily on the depth of erosion. On this basis a rough assumption would be that, over a sufficiently long time horizon (e.g. greater than 50 years) current habitat creation/restoration activities should cancel out the release of accumulated carbon as a result of habitat loss. Given this, net sequestration from FCERM land use management activities, particularly with respect to inter-tidal habitats, requires net habitat gain; i.e. in excess of the current BAP driven target.

The total BAU scenario carbon footprint was calculated as 120.1 Mt CO_2e over 50 years. Achieving levels of carbon sequestration that represent 1% of this (12.01 Mt CO_2e) could require between 220 – 6,700 hectares of net habitat gain, depending on the assumed unit value of tonnes CO_2e per hectare[40]. As with other aspects of the analysis this is a very ‘high-level’ assessment that should be viewed as indicative of potential orders of magnitude; indeed the upper end of this range implies extensive managed realignment similar to a scenario investigated by Lee (2001) (see also Annex 1).

IV. What are the FCERM policy areas likely to make the biggest contribution to UK GHG policy under different future scenarios?

Results presented in Section 3.2 and discussed in I - III above broadly establish the policy areas that provide greatest scope for contributing to reductions in GHG emissions. In particular a significant result is the role of flood alleviation activities in reducing potential GHG emissions associated with flood damage. Here a potential policy issue is the extent to which investment should be prioritised between coastal flooding, coastal erosion, fluvial flooding and surface water flooding.

---

[39] See for example details of targets for saltmarsh under the BAP reporting system: http://www.ukbap-reporting.org.uk/plans/national_2008.asp?HAP={4AA1049D-37BB-4D92-98CB-AB8AE240EB51}&SAP

[40] For example: 180 t CO2e per hectare over a net gain of 6,700 hectares gives potentially 1.2 Mt CO_2e (over a timescale of 50 – 100 years); and 5,500 t CO2e per hectare over a net gain of 220 hectares gives 1.2 Mt CO_2e (over a timescale of 50 – 100 years).

Comparing the ‘effectiveness’ in carbon terms of flood alleviation investment in river and coastal flooding to surface water flooding suggests the latter results in greater gains; i.e. avoided emissions. As detailed above, one extra tonne CO_2e per year emitted as a result of surface water flooding management activities results in a reduction of 10.8 t CO_2e per year from surface water flooding (compared to a reduction of 1.3 t CO_2e per year from river and coastal flooding damages). In contrast the result with respect to coastal erosion suggest that investment in this policy area is not ‘effective’ in carbon terms; one extra tonne of CO_2e per year emitted as a result of investment activities results in a reduction of 0.3 t CO2e per year from coastal erosion damages[41].

Again caution is required in interpreting these results as anything more than indicative, given limitations of the data, but the simple comparison illustrates the GHG emissions trade-offs that can be factored into both strategic level policy decisions and individual project appraisals within specific policy areas. Undoubtedly both levels of policy analysis would benefit from improved data and evidence and more consistent carbon footprint assessments on the basis of the framework set out in Figure 2.3. The gap analysis (Section 4.2) and conclusions (Section 5) provide an initial review of the key areas of the evidence base to be developed, building on existing and developing initiatives such as the EA’s construction carbon calculator that are required to underpin a more systematic assessment GHG implications of FCERM decision-making.

V. What are the key opportunities to reduce GHG emissions and/or enhance carbon sequestration in terms of future FCERM policies?

Drawing together the findings under questions I-IV, the key themes that emerge are:

- Current FCERM *activities* result in net emissions of GHGs but, in general, these emissions are lower than the counterfactual level of GHG emissions that would arise in the short-term in their absence as a result of flood and coastal erosion *damages* (i.e. the policy-off scenario and no active intervention);
- Some sources of emissions and all sources of sequestration are not included in this result. The net effect of their inclusion is not known at present;
- Compared to the net emissions from other sectors, the role of FCERM policies is relatively minor, not withstanding unquantified emissions and data limitations;
- There is potential to enhance sequestration of GHG emissions via land use management (e.g. managed realignment activities and changes in land use in order to be compatible with flood storage). The outcomes will be case specific and dependent on a variety of environmental factors and, in general, are unlikely to substantially ‘offset’ GHG emissions that arise in relation to flood alleviation activities and flood damages;

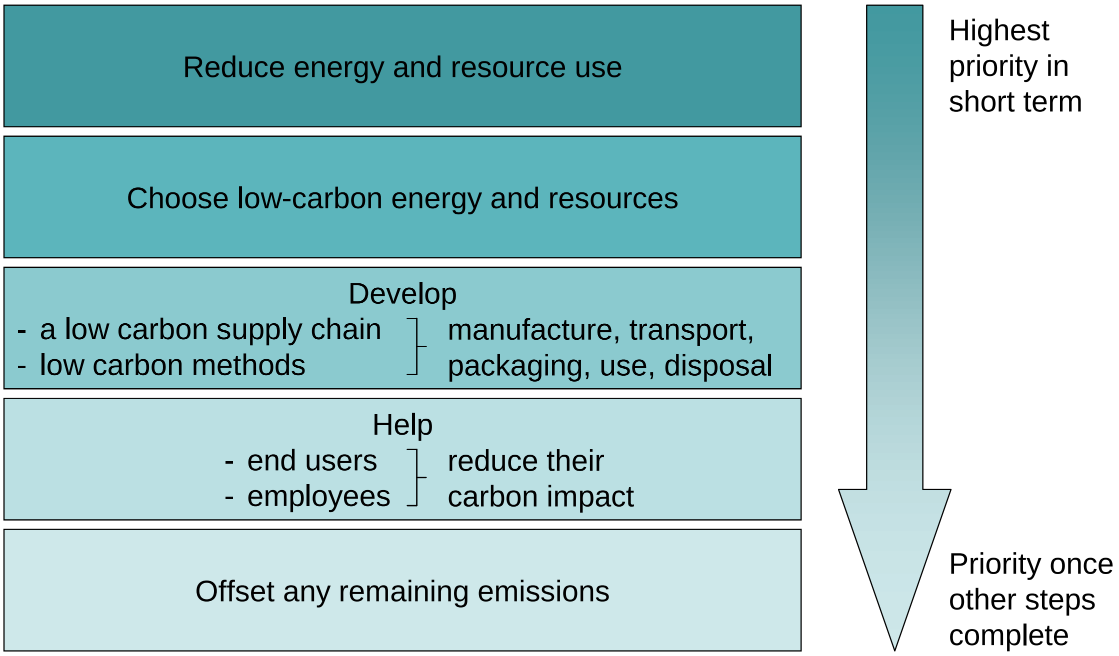
---

[41] i.e. a ratio of less than 1. This is based on a comparison of the BAU and policy-off scenarios.

- All analysis and findings are subject to significant assumptions and caveats that reflect the current extent of the evidence base on the carbon footprint of FCERM.

In assessing the key opportunities to reduce the carbon footprint of future FCERM policy, it is useful to outline the prioritisation of actions in terms of a ‘carbon hierarchy’. This provides a structured approach to carbon management, first concentrating on emissions directly associated with the activities under consideration, then assessing wider and more indirect effects. Figure 4.1 illustrates the basic steps associated with the carbon hierarchy, while the following discusses each stage in the hierarchy and how it relates to reducing the carbon footprint of FCERM activities.

Figure 4.1 Basic carbon hierarchy



Source: Enviros (August 2009)

- *Reduce energy and resource use***:** within the basic formulation of the FCERM policy carbon footprint energy and resource use is relevant both to emissions from FCERM activities and emissions associated with (residual) flood and coastal erosion damages.

  With respect to FCERM activities – in particular asset construction and maintenance – much depends on scheme design and engineering. As the Construction Carbon Calculator data shows 97% of the total from the data sample can be attributed to four emissions sources: material transport; quarried material; concrete, mortars & cement; and metals. Given this the main opportunities are likely to lie in relation to sourcing local materials (reducing material transport), efficient use of high carbon materials (reducing overall resource/energy use) and also good design principles that entail effective use of natural land formations (again this can assist in reducing overall material use – i.e. less requirement for earthworks).

The Construction Carbon Calculator provides a tool for comparing GHG implications in terms of the embodied carbon in materials and the CO_2 emissions associated with their transportation. From the sample of data available it appears that it is however used as an ‘accounting’ tool rather than an appraisal tool to compare different options for a scheme. Making carbon footprint assessments a routine element of scheme appraisal would serve to enhance the link between such a tool and scheme design considerations.

In addition to asset construction and maintenance, energy use from operational sites (pumping stations, barriers, locks, etc.) can be subject to both short term measures such as ensuring that an existing plant is operated efficiently, and longer term measures such as replacement of equipment with more energy efficient machinery (e.g. for pumps) when asset renewal is required.

On the basis of results set out in Section 4.1, flood alleviation itself represents a way in which energy and resource use can be reduced in relation to emissions associated with (residual) flood and coastal erosion damages. As set out in Table 2.4, GHG emissions associated with flood damages arise in relation to: materials used for repairs of building fabric, fixtures, fittings and replacement of household goods; energy use from hot air blowers, dryers and de-humidifiers; and associated transport. In particular estimates of avoided emissions from coastal, river and surface water from the alternative BAU plus and SWF scenarios are around 4 – 13% of the estimated overall BAU carbon footprint. In contrast, addressing coastal erosion appears to represent a case where emissions from investment are disproportionately large relative to avoided emissions from damages reductions.

- *Choose low carbon energy and resources*: Once options to reduce the amount of resources used have been considered, the next step is to ensure that the materials and energy used are low carbon wherever possible. In relation to asset construction the key choices are in relation to embodied materials with the trade-off between material strength and longevity and total quantity required and carbon intensity, not only from production but whole-life cycle (e.g. accounting for transportation). Input data to Construction Carbon Calculator presents embodied carbon estimates for various materials illustrating the carbon ‘implications of different material types. For example embodied carbon for timber is in the region of 0.5 t CO_2 per tonne, steel 1.8 t CO_2 per tonne, and cements, mortars and concrete 0.1 – 2.0 CO_2 per tonne.

  A further example is moving to lower carbon energy sources for the provision of energy on-site. Often temporary or standby generation uses oil which is more carbon intensive than natural gas. Renewables are often the lowest carbon energy option. The feasibility of their use, either through onsite generation or importing green electricity or heat from elsewhere, should be considered. In fact, some FCERM assets have the potential to provide energy for local supply, for example hydroelectricity from dams.

- *Develop low carbon methods*: FCERM schemes are likely to comprise of a number of asset types and elements as detailed in Section 3.1.3. The scope for implementing ‘low carbon’ options such as managed realignment directly in place of hard defence assets such as sea walls or embankments (which require the use of carbon intensive materials and future maintenance) can be limited particularly in developed areas. However options such as managed realignment and flood storage can potentially extend the life of existing assets and structures delaying asset renewal or replacement. Likewise alternatives such as rock revetments may prolong the useful life of concrete sea walls in a more carbon efficient manner than direct renewal.

  While general observations such as selecting options that minimise maintenance activities and that require the least future repairs and upgrades can be made with respect to ‘low carbon methods’, overall appropriate decisions can only be made on a case-by-case basis. This point further highlights how routine inclusion of carbon footprints in scheme appraisal can contribute to reducing GHG emissions from FCERM schemes.

- *Develop a low carbon supply chain*: The next step in reducing the carbon footprint of FCERM activities should be to review the supply chain in order to identify carbon savings. This includes reviewing the impact of the raw materials and labour over their life cycle, from their sourcing to their transport to site to their disposal. Since each supply chain is unique, organisations should work with their suppliers to see whether collaboration can establish additional carbon savings. For instance, if the moisture content of different materials affects their functionality, then it is worth working with suppliers to establish the best stage in the process to either dry or wet the materials (water incurs additional energy if transported and equally drying can be carbon intensive). Given that FCERM involves ongoing activities such as building and repairs to existing flood and coastal erosion defences[42], this is an area where lessons learned can be passed on from project to project, and one that we would expect to influence the footprint on an ongoing basis.

- *Help end users and employees***:** More generic actions relate to individuals’ behaviour. This covers relatively modest actions such as switching off the lights, to putting waste in a recycling bin or just ‘thinking carbon’ when purchasing materials. To achieve the best outcome (i.e. the greatest carbon reduction), an awareness of the issues, an understanding of the changes required and an enthusiasm to participate are essential[43]. One way to support such activities in the workplace is to reach out more widely to employees or to the communities that are affected by the FCERM activities. A simple example is encouraging employees to use public transport where

---

[42] Maintenance activities have a carbon footprint associated with the use of machinery and raw materials, transport of materials and personnel, the disposal of waste etc.

[43] The Defra ‘4 E’s’ model sets out that this can be achieved through encouraging, exemplifying, enabling and engaging.

possible, helping them choose a low-carbon company vehicle and/or allowing them to work flexibly close to home. Even though an employee's domestic emissions are not necessarily a core part of the FCERM carbon footprint, initiatives that raise awareness of cutting carbon in the home[44] mean carbon is considered much more regularly at work and so can help support the behavioural change required to reduce the FCERM footprint.

A different perspective on 'end-users' can be related to FCERM dependent activities, such as agriculture and other land uses. For example, FCERM provision enables the drainage of peat soils in areas such as the Fens and Somerset Levels and Moors. This drainage oxidises stored soil carbon and is estimated to be resulting in loss of 1.4Mt $C0_2$e/yr in the Fens. Wastage of peat in the Somerset Levels and Moors is estimated to result in 20,000 tonnes of carbon loss per year (73,400 t $C0_2$e/yr) (Brown, 2009). There is scope here for FCERM policy to consider implications in terms of consequential carbon implications of activities and attempt to reduce effects in these terms.

- *Offset remaining emissions*: The term 'carbon neutral' is used to describe an organisation or set of activities for which carbon emissions are counterbalanced by carbon savings. This can be achieved internally to the activity (for example, if sequestration in a new wetland balances emissions from its construction), or through external compensation. Compensation requires that the carbon footprint is calculated and then an equivalent amount of carbon savings or 'offsets' are bought from a third party. In line with best practice guidance, e.g. from the Carbon Trust[45], offsetting should be the final step of carbon management to complement an organisation's own actions to reduce its footprint. Any offsetting of the activities from FCERM should be considered in conjunction with Government's targets for public sector carbon reductions. The Government Carbon Offsetting Fund has been established to facilitate the purchase of allowances for Government Departments that have targets to offset their emissions.

In summary, the carbon hierarchy establishes that the balance of measures to reduce a carbon footprint depends on the time horizon over which the reductions need to be made, the willingness of the organisation and individuals involved to change, the procedures and incentives in place, and, importantly, the funding available.

Finally while the focus is on reducing the FCERM carbon footprint, it is important to note that it may not always be appropriate to consider carbon in isolation. For instance, using local materials can support local employment, reduce the burden on the transport infrastructure and deliver a solution that is in keeping with its surroundings. Local options may therefore be favoured (even where they are not the lowest carbon option) in order to satisfy other objectives.

---

[44] As supported by the DEFRA Act On CO_2 campaign.

[45] The Carbon Trust (2006) 'The Carbon Trust three stage approach to developing a robust offsetting strategy' publication CTC62 at: http://www.carbontrust.co.uk/publications/publicationdetail?productid=CTC621

It is nonetheless important to understand the trade-off that is made and to at least account for (and mitigate elsewhere) any negative impact on GHG emissions.

4.2. Gap analysis

This gap analysis focuses on key areas of the evidence base for calculating the carbon footprint of FCERM. It is structured in terms of the basic formulation of the FCERM policy carbon footprint set out in Figure 2.3.

4.2.1 Emissions from FCERM activities

Asset construction, maintenance and operation

With regards current evidence, data available on FCERM activities and policies are at present fragmented and of low quality as there are no complete datasets, nor is there a systematic process of collecting homogeneous data across the country. Data are disaggregated and incomplete across geographical areas, organisations, and FCERM activities. Thus a complete quantitative analysis to calculate GHG emissions derived from FCERM policy and activities is not possible at present.

However, a number of initiatives are expected to improve the evidence base:

- *The Construction Carbon Calculator*: the key gap with this information is the small sample size presently available. Since use of the calculator is now mandatory for all NCPMS schemes evidence on GHG emissions associated with capital investment should grow. Analysis of a larger dataset may allow for categorisation of projects – as initially explored in Sections 3.1.2 and 3.1.4 – and carbon 'benchmarks' to be estimated in these terms. That said, consultation with the EA suggests that in general benchmarking exercises (for example with regards to scheme costs) can be challenging given the individually-specific nature of works involved.

  If a larger dataset does permit distinction between some categorisation of scheme types, there is then likely to be greater scope for addressing policy questions such as identifying opportunities to reduce carbon emissions.

- *Maintenance activity carbon calculator*: consultation with the EA[46] indicates that a tool is currently being developed to estimate GHG emissions associated with FCERM maintenance and operations activities (such as number of staff and hours spent maintaining soft embankments, dredging channels, desilting, etc.). It is expected that the tool will be applied at the EA area level, possibly by the end of 2010. Eventually data will be collated nationally to provide high level figures of the EA's maintenance activity.

---

[46] Pers. comm. J.Naylor, Environment Agency (June 2009).

The initiative to develop an evidence base with regards to maintenance activities will permit wider distinction within the types of FCERM activity. Even with a proxy approach to estimating emissions associated with FCERM activities based on carbon intensity factors, this would represent a significant advancement of the analysis undertaken to date which used the same intensity factor (based on analysis of the construction carbon calculator data) uniformly across all types of expenditure.

- *GHG emissions from pumping stations*: Consultation with the EA indicates that work is being undertaken to assess the carbon footprint of pumping facilities at the local level. This is being led by the Regional Environmental Management Advisors for the eight EA regions[47].

  As with the maintenance activity this evidence would permit further refinement of the approach used here.

Overall, there is clear impetus within the EA for understanding the GHG implications of its FCERM activities. However, given the nature of flood and coastal erosion risk management, these initiatives are necessarily focused on the local level. As the evidence base develops, considerable coordination effort is likely to be required to draw together data for the purposes of improving estimates of the overall carbon footprint.

Surface water flooding

Outside of the EA's remit, the developing policy area of surface water management represents an opportunity for addressing carbon footprint issues from a strategic level. Development of a carbon calculator tool for SUDs and similar interventions are examples of this and could draw on the EA's development of the Construction Carbon Calculator. Evidence of this nature would help improve understanding of trade-offs between investment in one policy area (e.g. river and coastal flooding) and another (e.g. surface water flooding); i.e. given a certain level of investment, do the carbon implications offset traditional benefit-cost measures that drive decisions?

Carbon sequestration

Turning to activities omitted from the estimation of the FCERM carbon footprint, a key issue of interest is the potential for carbon sequestration. While this report provides a broad assessment of sequestration potential of land use management options based on a review of available evidence, developing a national level assessment would likely prove challenging. While the basis of datasets for habitat types and flood risk areas is available, broad assumptions as to net gain or loss of carbon would likely be required for different land uses, implying an inherent level of uncertainty in estimates. Moreover determining the counterfactual situation, i.e. net emissions or sequestration in the absence of FCERM intervention, adds an additional layer of complexity.

---

[47] Pers. comm. A. Fitton, Environment Agency (July 2009).

As an alternative, evidence in this area may be improved by a case study approach, requiring a specifically focused 'land use management' scientific study which may provide a fuller assessment of existing data from a flood and coastal erosion risk management perspective. Beyond this there is the monitoring of actual flood storage and managed realignment sites which would doubtless improve the evidence base in this regard.

Other considerations

FCERM activities under adaptation measures, mapping and modelling, and emergency planning have been omitted from the analysis in general since it is expected that the carbon footprint implications of these are relatively minor in comparison to other areas. While a complete analysis would seek to account for these too, no coherent data or evidence has been identified at present.

4.2.2 Emissions associated with flood and coastal erosion damages

The analysis of GHG emissions arising from responses to damages is based on a high-level assessment applying a 'damage multiplier' value. This represents a proxy approach which is subject to strong assumptions in apportioning emissions to damages and converting the value of damages to emissions (using carbon values; i.e. £ per t CO_2e).

In the analysis, application of the damage multiplier follows from previous work, but doubtless the approach could be refined with respect to estimating the FCERM carbon footprint. For example estimating a multiplier for surface water flooding damages, since damages associated with this form of flooding are expected to differ as result of its typical shorter duration (in comparison to river and coastal flooding).

Further refinement of this aspect of the FCERM carbon footprint could be made by expanding the approach applied for coastal erosion and applied in a number of the case studies in Annex 4. Here a damage multiplier approach has not been applied; instead an estimate of number of properties affected per year has been used in conjunction with an estimate of GHG emissions associated with rebuilding (or refurbishing a property). In practice data from NaFRA and similar assessments could readily be applied to estimate the number of properties per year affected by flooding. Given data on GHG emissions arising per property (and even type of property; i.e. residential, non-residential) in response to flood damages (some basis of which is available from the damage multiplier approach) an estimate of the carbon footprint of flooding (conceivably of different types and severity if data permit) could be calculated.

Following an approach to estimating emissions associated with flood and coastal erosion damages based on properties rather than the value of damages would provide a 'sense check' to the damage multiplier approach, and with respect to developing policy scenarios offer an alternative to assumptions based on benefit-cost ratios in determining how increased investment may reduce emissions from flood damage.

Overall, given the significance of the emissions associated with flood and coastal erosion damages (as indicated in Tables 3.14 to 3.17), refinement of the calculation of this aspect of the carbon footprint is warranted. It is also likely that this could be achieved in a relatively short time span in a specifically targeted research project, potentially advancing the approach set out in the case studies.

4.2.3 Emissions associated with activities dependent on FCERM

This project has taken the stance that for the most part flood and coastal erosion risk management may determine where other activities and land uses, such as residential housing, commercial properties, etc., may be situated but not whether or not they are built. As reviewed in Annex 1, the considered exception to this is some areas of agriculture that are dependent on defences and water level management and in their absence would not be able to relocate and so would cease to exist. However, a quantitative assessment of impacts in this area has not been undertaken.

In general net GHG emissions associated with agricultural land can be treated similarly to the land use management activities gaps addressed in Section 4.2.1. In fact flood storage space may serve a dual purpose for agriculture and flood risk attenuation; i.e. seasonally flooded grazing land. On this basis it is expected that work to improve carbon sequestration from flood storage options would also provide an assessment of the GHG emissions implications of agricultural land protected by defences. However, as noted in Annex 1 and Section 4.1 the complexity of processes that determine carbon sequestration and the production of methane implies that producing national level estimates is likely to remain challenging. Furthermore, the impacts of different locations for different forms of agricultural activities on GHG emissions then come into consideration, adding a significant additional level of complexity.

5. Conclusions and Suggestions Moving Forward

5.1 Summary

This report describes the outputs of a research project intended to improve understanding of the climate change impact of flood and coastal erosion risk management in England. In summary this comprises of:

- Review of the background to measuring GHG emissions and estimating carbon footprints;
- Developing a conceptual framework within which sources of GHG emissions and carbon sequestration within the FCERM policy remit are identified;
- Establishing data needs and collating available evidence on GHG emissions that arise as a result of FCERM;
- Estimating the carbon footprints for a set of scenarios to compare carbon implications of alternative policy options; and
- Assessing keys gaps in the current evidence base and identifying further avenues of research that would refine the estimation of the FCERM carbon footprint.

Necessarily the project provides a broad view of flood risk management and the science and methods of measuring GHG emissions and carbon sequestration. In practice, many of the component areas of the FCERM footprint could warrant detailed investigation; especially developing the evidence base related to land use management and carbon sequestration, estimating emissions from asset construction and maintenance activities, or estimating emissions associated with flood and coastal erosion damages.

Drawing together the available evidence has permitted a partial estimate of the contribution of FCERM policy to GHG emissions. This suggests that FCERM plays a small role in contributing to national level emissions (estimated to less than 1% of total annual emissions) and that increases and decreases in the level of emissions are likely to have relatively slight implications for the attainment of UK GHG reduction targets.

The analysis undertaken also indicates that it is likely that intervention in flood and coastal erosion risk management plays a mitigation role in terms of avoided GHG emissions (that would arise in the absence of active intervention). However key gaps remain, particularly in relation to providing a detailed account of threats and opportunities for the release/abatement of GHG emissions from FCERM policy.

Overall the research has enabled each of the specific policy questions (Table 1.1) to be addressed by the project. As the evidence base for estimating the carbon footprint develops, these assessments can be refined and improved enabling a fuller account to be made of the current and potential carbon implications of FCERM policy.

5.2 Conclusions and opportunities to improve understanding of the climate change impact of FCERM

The challenges in collating data and estimating the FCERM carbon footprint imply that this research represents a ‘starting point’ rather than a complete and detailed assessment. However the conceptual framework provides a basis for developing the required evidence base further in a systematic and coherent manner.

The research reveals that relevant evidence has to be drawn from a wide variety of sources, where, in virtually all cases, the intended use of the data is not to facilitate a high level assessment of the FCERM carbon footprint. A pertinent example is the Construction Carbon Calculator data which provides scant detail on asset types and elements that are part of the design due to the ‘individual’ nature of each scheme. However, from the perspective of estimating an overall footprint, inevitably some form of generalisation is required. In practice with an increased sample of schemes, scrutiny of the data will likely permit judgements as to scheme types and improved distinction in emissions arising from these.

Proposals arising from the project include:

- Foremost it is suggested that the estimate of the FCERM carbon footprint be reviewed and revised as more data becomes available. New data should serve to both increase the coverage of the analysis (by providing an account of currently omitted areas) and permit for a more nuanced approach in terms of the specification of alternative policy scenarios and assessing their carbon implications.

- The gap analysis (Section 4.2) reveals that work is already taking place within the Environment Agency that will improve the evidence base for estimating the FCERM carbon footprint. This includes assessments of emissions associated with maintenance and operations, and pumping stations. In addition increased use and familiarity of the Construction Carbon Calculator should improve this aspect of the evidence base, both in terms of quality and quantity of data available. However, from the perspective of estimating the FCERM carbon footprint, the Environment Agency in particular would benefit from the integration of data already being collated by these on-going but separate initiatives.

- The Environment Agency’s experience in developing approaches to measuring GHG emissions from FCERM activities could usefully inform assessments of the carbon footprints of the other Operating Authorities (Local Authorities and Internal Drainage Boards) activities. In particular the development of surface water management plans is likely to identify the need for significant investment in SUDs and other measures. Here there is an opportunity to ensure GHG emissions and sequestration potential are assessed at the planning stage and accounted for in decision-making. An initiative of calculating carbon from these types of schemes would also improve the evidence base for estimating the overall FCERM footprint, and provide for greater distinction in the specification of alternative policy scenarios; for example in understanding the carbon implications of investment in river and coastal flooding versus surface water management.

- Use of carbon calculators for FCERM (i.e. for EA schemes, LA schemes and surface water flooding) actions should be used more widely, and as their use is extended there should be some review and quality assurance applied to their results. Review should establish typical ranges of emissions for different types of projects, and if results fall outside expected ranges, they should be further scrutinised.

- Appraisal of FCERM projects could routinely calculate carbon savings resulting from reduction of flooding to properties (i.e. avoided emissions that would be generated in response to flooding incidents). At present the approach detailed in the report, primarily via the damage multiplier, but also in term of properties affected as addressed in the case studies, allows for little distinction as to differences in emissions that arise from differences between property types. Hence further work that improves estimates of GHG emissions associated with damages is required, since this would permit greater distinction between alternative options being appraised.

- Further research is required to understand the potential for carbon sequestration from FCERM activities such as flood storage and managed realignment, as well as the influence of FCERM on emissions and sequestration from land protected by defences (e.g. agricultural land). The general conclusions presented by this project note that a long term view is required and that understanding local environmental factors is crucial in determining whether carbon sequestration benefits are realised.

- Finally it is recommended that a desk-based assessment of secondary data, as undertaken by this study, allow for sufficient time to liaise with relevant organisations for improved data collection. Contacting multiple sources within one organisation – such as the Environment Agency – to ascertain the availability and status of relevant information entails considerable effort in search, and the task in ensuring coherency of data for the purpose of estimating the carbon footprint for FCERM policy should not be under-estimated.

6. References

Arup, 2008. *Thames Estuary 2100 Cost Integration. Phase 3 Studies – Work Element 5.4*. Stage 1 Report

Brown A. G. (2009) *Carbon Storage and Sequestration in the Somerset Levels, UK.* Report for Somerset County Council.

BSI Group Website: Assessing the life cycle greenhouse gas emissions of goods and services (http://www.bsigroup.com/en/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050/)

CIRIA Website: Improving the flood performance of new buildings (http://www.ciria.org.uk/flooding/flood_performance.htm)

Committee on Climate Change Website: UK Carbon Budgets (http://www.theccc.org.uk/carbon-budgets/)

DECC, 2010. *Valuation of energy use and greenhouse gas emissions for appraisal and evaluation*, Department of Energy and Climate Change and HM Treasury.

DECC Website: Climate Change Act 2008 (http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx)

DECC Website: 05 Jun 09 – Press Release – UK on track to double Kyoto target (http://www.decc.gov.uk/en/content/cms/news/pn058/pn058.aspx)

Defra, 2005. *Making space for water: Taking forward a new Government strategy for flood and coastal erosion risk management in England, First Government response to the autumn 2004,* March 2005

Defra, 2007. *Flood and coastal erosion risk management*, Flood Management Division, November 2007.

Defra, 2008. *Understanding the Impact of Flood and Coastal Erosion Risk Management on the causes of Climate Change*, FD2622 Specification.

Defra, 2009a. *Consultation on Coastal Change Policy, June 2009*

Defra, 2009b. *Draft Flood and Water Management Bill*, April 2009

Defra, 2009c. *Draft Full Impact Assessment for Local Flooding*, Version 16, August 2009.

Defra Statistics Worksheet: UK Greenhouse Gas Emissions 1990-2007 (http://www.defra.gov.uk/environment/statistics/globatmos/download/xls/ghg_annex_a_20090203.xls)

Defra Website: Business & Sustainability – Business support – Environmental Reporting (http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm)

Defra Website: Flood Management – MSW Increased Resilience to Flooding (http://www.defra.gov.uk/environ/fcd/policy/strategy/rf1rf2.htm)

Defra Website: Progress towards national and international targets (http://www.defra.gov.uk/environment/climatechange/uk/progress/index.htm)

EHA, 2009. *New Tricks with Old Bricks*, The Empty Homes Agency Ltd.

Environment Agency, 2007. *Flood Risk Data Report for England and Wales. An analysis of the National Flood Risk Assessment 2006 and the Flood Map for England and Wales*

Environment Agency, 2008. *Asset Management Data fact sheet about our assets: Version 1.0 August 2008*.

Environment Agency, 2009. *Flooding in England: National Flood Risk Assessment*, June 2009

Environment Agency Website: Environment Agency – Carbon calculator for construction activities (http://www.environment-agency.gov.uk/business/sectors/37543.aspx)

GHG Protocol Website (http://www.ghgprotocol.org)

Halcrow, 2001. *National Appraisal of Assets at Risk from Flooding and Coastal Erosion, including the potential impact of climate change* Final Report July 2001

Halcrow, 2008. *Thames Estuary 2100. Greenhouse gas implications of flood damages. Phase 3 Studies – Work Element 2.11a*

Halcrow, 2009. *Impact Assessment of Local Flood Risk Management Supplementary Evidence Base*, Draft, August 2009

HM Government, 2006. Climate Change – the UK Programme 2006

HM Government, 2008. Climate Change Act 2008, c27 Public Acts 2008

IPCC, 2001. *Climate Change 2001: The Scientific Basis. IPCC Third Assessment Report.* UNEP/GRID Arendal Publications. (http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/212.htm)

IPCC, 2003. *Good Practice Guidance for Land Use, Land-Use Change and Forestry.* Kanagawa, Japan, Institute for Global Environmental strategies (IGES) for the Intergovernmental Panel on Climate Change

IPCC, 2007. *Climate Change 2007 - The Physical Science Basis*. IPCC Fourth Assessment Report. Cambridge University Press, New York.

National SUDS Working Group, 2004. *Interim Code of Practice for Sustainable Drainage Systems.* (http://www.ciria.org.uk/suds/pdf/nswg_icop_for_suds_0704.pdf)

Thompson, D., 2008. *Carbon Management by Land and Marine Managers. Natural England Research Reports*, Number 026.

University of Bath website: Embodied Energy & Carbon (http://www.bath.ac.uk/mech-eng/sert/embodied/)

UNFCCC Website: Annex 1 Greenhouse Gas Inventories (http://unfccc.int/national_reports/annex_i_ghg_inventories/items/2715.php

Annexes

A1 Land use management and the FCERM carbon footprint

A1.1 Overview

Flood and coastal erosion risk management policy influences land use and land use management activities, and hence both GHG emissions and carbon sequestration from this sector. While the analysis in the main report does not attempt to provide a quantitative assessment of net emissions associated with aspects such as flood storage, managed realignment, development control and land use activities dependent on defences, this Annex draws together various evidence and information. It reviews the following:

- Habitat restoration and creation;
- Carbon sequestration potential from land use management;
- Agricultural land at risk from flooding; and
- Development control.

An appendix to this Annex also provides further material on the carbon sequestration potential of tidal wetlands.

A1.2 FCERM and habitat restoration and creation

Background

Information on areas of land affected by FCERM schemes (whether land for habitat creation or ‘sacrificed’ for flood water storage) is generally recorded at the project level and only summary data is available from databases. For example the Environment Agency’s Medium Term Plan records hectares of Biodiversity Action Plan (BAP) habitat restored or created by scheme[48], but does not distinguish habitat type and whether it is restored or created (or converted from some other habitat/land use type).

Current policy requires that the UK mitigate for habitat loss, but whether compensatory rates are being achieved or not is a matter of debate. For example, in the case of coastal areas, even if restoration occurred at the same rates as loss, this may not fully compensate for the loss as it takes time to re-establish wetland functions, and there is also the loss of the historic carbon reservoir associated with the erosion of a marsh that took centuries to build up – see Section A1.2 below.

---

[48] In terms of Defra’s Outcome Measure 5 (OM5), which is the creation of BAP habitat. This requires 800 hectares of priority BAP habitat be created by March 2011, including 200 hectares of intertidal habitat. Of this, the EA must deliver 600 hectares.

The situation in relation to habitat restoration in freshwater systems is less clear, with uncertainties such as whether agricultural land and urban land on floodplains can be restored to freshwater habitats such as lowland wet grassland, and the speed with which this process would happen. Other uncertainties include the response of existing land uses. For example, in a ‘policy-off’ scenario where flood defences failed through neglect, or overtopping by more frequent higher magnitude flood events resulting from climate change, would land managers allow land to be flooded and revert to natural systems, and move their activities to higher ground, or would they restore or upgrade defences as a way to adapt to a changing climate.

BAP habitats

The three habitat types that are covered under the UK’s biodiversity action plan (BAP) that the Environment Agency’s FCERM remit influences are:

Intertidal habitats

- Mudflats are sedimentary intertidal habitats created by deposition in low energy coastal environments, particularly estuaries and other sheltered areas. Their sediment consists mostly of silts and clays with a high organic content. The mud surface plays an important role in nutrient chemistry.

- Coastal salt marshes comprise the upper, vegetated portions of intertidal areas, lying approximately between mean high water neap tides and mean high water spring tides. Salt marshes develop principally around our major estuaries where fine silt and other sediments are trapped by salt-tolerant plants.

Intertidal habitats dissipate wave energy, thus reducing the risk of eroding and damaging coastal defences and flooding low-lying land.

Coastal and floodplain grazing marsh

- Coastal and floodplain grazing marsh is defined as pasture or meadow containing standing brackish or fresh water. Almost all areas are grazed and some are cut for hay and silage. Grazing marshes are especially important for the breeding of birds such as snipe, curlew, Bewick swans and whooper swans.

Upland flushes, fens and swamps

- Upland flushes, fens and swamps are defined as peat or mineral based wetlands in upland situations, which receive water and nutrients from surface and/or groundwater sources as well as rainfall. This habitat overall supports a rich flora of vascular plants with many rare species, and may also be an important nesting site for waders such as snipe, curlew and redshank.

Under the BAP, the EA has a commitment to create or restore 200 hectares of thee habitats per year as a result of FCERM activities (Environment Agency, 2008). Of this, at least 100 hectares should be salt marsh and mudflat.

Table A1.1 reports current and target levels (area) for BAP habitats in England and Wales.

Table A1.1: BAP targets for FCERM influenced habitats

Habitat	***2005 Level (ha)***	***2010 Target (ha)***	***2015 Target (ha)***	***2020 Target (ha)***
England				
Mudflats (coastal and inland)	206,900	209,060	No data	No data
Coastal and floodplain grazing marsh	170,000	173,750	177,500	185,000
Fens	8,000	8,750	9,500	10,250
Wales				
Mudflats (coastal and inland)	14,320	14,560	No data	No data
Coastal and floodplain grazing marsh	39,858	42,108	44,358	48,858
Fens	6,200	6,225	6,250	6,275

Source: Data from BAP website (www.ukbap.org.uk).

The National GHG Inventory

The National GHG Inventory is the primary source for statistics on the UK's greenhouse gas emissions. This includes a section on land use changes and carbon emissions Mobbs and Thomson (2006). The Inventory takes into account the carbon emissions associated with land use changes such as conversion of grassland to cropland and is in line with the IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry (IPCC, 2003). The change in carbon stocks of living biomass, dead biomass and soil organic matter must be reported for each activity together with other relevant non-carbon changes. All land in a country must to be classified as one of six classes. The six land classes are:

A. Forest Land;
B. Cropland;
C. Grassland;
D. Wetlands;
E. Settlements; and
F. Other land.

For the National Inventory, estimates of emissions and removals for this category are made using the Countryside Survey Land Use Change matrix approach, with biomass densities weighted by expert judgment. Changes in carbon stocks in biomass due to land use change are based on the same area matrices used for estimating changes in carbon stocks in soils. The biomass carbon density for each land type is assigned by expert judgment based on the work of Milne and Brown (1997).

Five basic land uses are assigned initial biomass carbon densities, then the relative occurrence of these land uses in the four countries of the UK are used to calculate mean biomass carbon densities for each of the IPCC types:

cropland, grassland and settlements. The mean biomass carbon densities for each land type are then weighted by the relative proportions of change occurring between land types in the same way as the calculations for changes in soil carbon densities. Changes between these equilibrium biomass carbon densities are assumed to happen in a single year.

Wetlands, which are of most relevance to FCERM, are categorised as either saturated land (e.g. bogs, marshes) or open water. Due to the classifications used in the Countryside Survey these areas either fall into the Grassland category (C) or into the Other Land category (F). The Other land category includes lakes, rivers, reservoirs and rocky coastal land etc. It is assumed that there are very few, if any, transitions of land to a type that is classified as 'Other' and no emissions or removals are reported for this category.

Details of wetlands included in Grasslands are not reported separately and estimates for wetland conversions cannot be retrieved from the National Inventory. The main source for the calculations reports on emissions or removals from wetlands conversions (both land to wetland and wetland to land) is CEH (2008). Table A1.2 presents the CEH results for land conversion:

Table A1.2: Land use transition matrix for the UK, 2005-2006 (ha)

To **From**	Forest	Cropland	Grassland	Wetlands	Settlements	Other Land
Forest	2,420,004	961	6,658	-	534	-
Cropland	-	5,529,899	95,948	-	942	-
Grassland	741	83,447	12,541,792	-	4,662	-
Wetlands	-	-	-	-	-	-
Settlements	417	2,475	13,462	-	2,097,428	-
Other Land	-	-	-	-	-	1,633,621

Source: CEH (2008).

A1.2 Assessment of carbon sequestration potential from FCERM land use management

This section provides a scoping assessment of the impacts of coastal erosion and flood management practice on GHG sequestration / emissions from tidal wetlands (including, salt marshes, mudflats and reed bed). The appendix to this Annex provides supporting material.

Carbon sequestration potential of tidal wetlands

Coastal wetlands sequester carbon dioxide as soils accumulate build up with sea level rise. Sequestered soil carbon may be buried for centuries or millennia. In many coastal areas sequences of organic bearing sediments 10 meters or more in depth have accumulated. The capacity for wetlands to store carbon in soils increases within freshwater conditions. However, in brackish (less that around 18 ppt) and freshwater settings wetlands also produce methane (CH_4). While the lifespan of methane in the atmosphere is short, around 10 to 12 years, it is a potent GHG with a warming potential of 20 to 25 times that of carbon dioxide, as normalized over a 100 year time frame. For this reason, methane emissions must be taken into account when considering the carbon sequestration potential of wetland systems when planning to address climate change in coming decades. A third global warming gas of concern is nitrous oxide (N_20), which is produced by all wetlands as part of the nitrogen cycle from ammonia and nitrate, and is a 310 times as potent a GHG as carbon dioxide. The levels of nitrous oxide produced by wetlands is directly related to the amount of nitrogen pollution derived from agricultural and industrial sources.

Estimate of carbon loss from UK reclaimed floodplains

Historic land-use change has dramatically altered the carbon sequestration potential of the UK's coastal lowlands. One detailed study assessed the carbon budget associated with reclamation and drainage of 87,000 ha coastal floodplains in the Humber Estuary over the past 300 years has released 0.5 billion tonnes of organic carbon (1.8 x 10^9 $tC0_2e$) (Andrews et al, 2000). This study also calculated that the carbon sequestration capacity of the estuary had decreased by over 99% from 3.2 x 10^5 tC (1.2 x 10^6 $tC0_2e$) to 2.5 x 10^3 tC (9.2 x 10^3 $tC0_2e$).

It is most likely that similar emissions of GHGs have occurred with historic reclamation of coastal lowlands in other parts of the UK, notably the Severn Estuary (84,000 ha), The Wash and Fens (180,000 ha), and outer Thames Basin (40,000 ha), as well as elsewhere. Such large numbers for GHG emissions with tidal floodplain reclamation are likely not uncommon and have been documented elsewhere in the world (Crooks, 2009 and Miller et al, 2008). The magnitude of the carbon loss from UK coastal lowlands provides an indication of the potential capacity for future sequestration.

FCERM activities enable the drainage of floodplains such as Somerset Levels and Moors and the Fens. Drainage is usually undertaken to enable agricultural production, but also facilitates other activities (e.g. terrestrial transport links) that may develop on the drained land. Drainage allows release and oxidisation of carbon. Emissions from peat soils are most significant in this respect, as peat contains significant concentrations of stored organic carbon.

A study in the Fens (Holman, 2009) tentatively estimates the carbon stored in the areas peat soils is 150Mt of $C0_2e$. Based on estimates of loss or wastage of peat soils at between 1.5 – 2.1 cm/yr for different thickness of peat soils, annual carbon emissions due to peat drainage in the Fens are estimated at 1.4 Mt $C0_2e$ (note that this arises from a range of activities, not only water level management actions).

A study of peat in the Somerset Levels and Moors (Brown, 2009) estimated that wastage results in 20,000 tonnes of carbon loss per year (73,400 t $C0_2e$/yr). The top 1 metre of the peat soils are identified as most vulnerable to erosion and wastage, and therefore loss of carbon. Both carbon loss and CO_2 exchange are dependent on water table management, with higher water tables limiting carbon losses. Finally the study also identifies a risk of increasing carbon loss from drained areas as a result of climate change.

Estimate of carbon accumulation within wetlands soils

In a study of UK salt marsh soils (Crooks, 1996), carbon content was found to be variable depending upon constituent sedimentology (see Appendix to this Annex, Table 5.2). Broadly, salt marshes can be classified as those built with predominantly coarse silts and sands, "sandy" marshes, and those comprised of silts and muds, "muddy" marshes. Sandy marshes tend to occur in open coastal high energy areas (Morecambe Bay, Solway Firth, Northumberland coast, The Wash) and possess soils that are well drained and as a consequence store limited amounts of carbon below the active root zone (carbon content c.1-2 g/g dry sediment). Muddy marshes are found within many estuaries in sheltered or lower energy coastal areas. Due to natural poor soil drainage, they hold carbon buried beneath the active root zone (carbon content c.5-10 g/g dry sediment). For all marshes, carbon content is higher within the root zone than in sub-root zone deposits.

The carbon content of salt marsh soils within salt marsh of the Humber, analysed by Andrews et al. (2000) lies within the range found in other muddy estuaries, as described by Crooks (1996). Andrews et al. (2000) further quantify carbon content of mudflats (c. 1 g/g dry wt), coastal reedbeds (12-20 g/g dry wt) and alder car (c. 15 g/g dry wt) (Table A1.3).

Table A.1.3: Comparison of area, organic carbon content, yearly sediment and organic carbon deposition in the palaeo-Humber (3-2 cal yrs BP) and modern Humber Estuaries.

Environment	*Area (km^2)*	*Average C_{org} Content (g/g dry wt)*	*Sediment deposited in one year (tonne)*	*C_{org} deposited in one year (tonne)*	*C_{org} deposited per ha (tonne)*
3-2cal.ka BP estuary					
Raised bog*	21	30	2187	656	0.3
AC	918	15	1837080	275562	3
HSM	117	10	233280	23328	2
LSM	129	4	262440	10498	0.8
Intertidal flats	305	1	612360	6124	0.2
Total	1490		2,947,347	316,167	316,167
Modern estuary					
Raised Bog	neg	30	0	0	0
AC	neg	15	0	0	0
HSM	neg	10	0	0	0
LSM	5	4	10000	400	0.8
Intertidal flats	106	1	212000	2120	0.2
Total	111		222,000	2,520	2,520

*The value for raised bog is poorly constrained, based on an assumed bulk density of 100 kg m3.

Source: Table 6 from Andrews et al. (2000). Estimates for carbon accumulation assume sea level rise of 1 mm/yr.

Coastal lowland soils behind flood defences may be either progressively loosing carbon through oxidation associated with drainage, or have reached a net equilibrium. By contrast salt marshes, as long as they do not erode, accrete with sea level rise and sequester carbon. The rate of surface carbon sequestration likely increases with sea level rise as the rate of burial will commensurately increase. An estimate of carbon sequestration potential per hectare is provided in Tables A1.4 and A1.5.

Table A1.4: Upper and lower bounds for carbon content by marsh type

Type	*Lower (g/cm^3)*	*Upper (g/cm^3)*	*Note*
Muddy Marsh	0.05	0.1	Equivalent to 5-10% carbon by weight
Sandy Marsh	0.01	0.03	Equivalent to 1-3% carbon by weight
Mudflat	0.01	0.01	Equivalent to 1% carbon by weight

Notes: Carbon content by unit volume estimated assuming a typical bulk density of 1.6 g cm^3. This is equivalent to a dry density of approximately 1.0 g/cm^3 calculated from an empirical relationship based on data from Crooks (1996): *dry density* = (*bulk density* – 0.925)/0.6427. For a dry density of 1.0 g/cm^3 carbon content in g/cm^3 equals percent carbon by weight (from laboratory analysis). Carbon contents listed representative lower and upper ranges based on field samples taken from UK marshes (Crooks 1996). Calculations assume adequate sediment supply to keep pace with sea level rise of 3 mm/yr^1. As sediment accumulates on marsh surface, carbon is sequestered at depth through burial. Assumed carbon content for muddy and sandy marsh as given above.

Table A1.5: Rate of carbon sequestration in established wetlands soils

	Carbon (tC/ha/yr)		***Carbon (tCO_2e/ha/yr)***	
Type	***Low***	***High***	***Low***	***High***
Muddy	1.5	3.0	5.5	11.0
Sandy	0.3	0.9	1.1	3.3
Note: Mass of carbon in tC/ha converted to tCO_2e/ha using conversion factor of 3.67.				

Estimate of total carbon accumulation in restored wetland soils

Managed realignment results in the building of mudflats and salt marshes on former drained wetlands. Because these lands are subsided, sediment is required, through natural processes, to build wetlands back up to mudflat elevations. Evolution of the subsided site from subtidal or low intertidal mudflat to vegetated salt marsh will depend upon adequate availability of sediment from the estuary.

As sediments accumulate they will sequester organic carbon. Table A1.6 provides estimated ranges of carbon sequestered within an accumulating marsh, on a per hectare basis. A range is provided each for muddy and sandy marshes based upon assumptions of carbon accumulation within soil types, elevation of flooded lands and elevation at which mudflat transitions to vegetated saltmarsh (dependant upon tidal range at site). For muddy marshes over the full life of the project, a lower range for the total carbon accumulation during restoration of saltmarsh would result in the accumulation of 300 tC/ha (1,100 $tC0_2e$/ha), while at the upper range around 1,650 tC/ha (6,050 $tC0_2e$/ha). In a sandy system the range of sequestration values will be lower because of oxidation of carbon with an estimated range between 100 tC/ha (367 $tC0_2e$/ha) to 600 tC/ha (2,200 $tC0_2e$/ha). These values do not include the carbon accumulation associated with the development of an organic-bearing active root zone when the marsh fully matures.

Table A1.6: Potential for carbon accumulation in restored wetlands

	Carbon (tC/ha)		***Carbon (tCO_2e/ha)***	
Type	***Low***	***High***	***Low***	***High***
Muddy	300	1,650	1,100	6,050
Sandy	100	600	367	2,200

Note: Mass of carbon in tC/ha converted to tCO_2e/ha using conversion factor of 3.67. Restoration of subsided areas represents a potential for carbon sequestration. Assumes dyked marsh has subsided by approximately 1 to 3 m and that sedimentation within dyked areas would first create mudflat (1.0 +/- 0.5 m) subsequently overlain by vegetated salt marsh (1.0 +/- 0.5 m). Assumed carbon content for muddy and sandy marsh and mudflat as given in Table A1.4. Lower and upper bounds of potential carbon sequestration determined by combining range of values for mudflat depth (0.5-1.5 m), marsh depth (0.5-1.5 m), and carbon content of muddy (0.05-0.1 g cm-3) and sandy (0.01-0.03 g cm-3) marshes.

Brackish marshes and freshwater reed swamp will likely sequester greater of quantities of carbon that salt marsh, but will also produce methane gas. The net balance between GHG sequestration and emissions is not known. Based upon studies overseas, emissions will likely mitigate some if not all carbon sequestration over the centennial timescale (Andrews et al, 2006 and Crooks et al, 2009).

There is potential to establish managed freshwater wetlands to fill accommodation space with carbon rich soils, and through management of water reduce methane emissions. This mechanism is being explored in the United States by the U.S. Geological Service and others as a potential mechanism to restore subsided areas while sequestering carbon dioxide from the atmosphere.

Estimate of carbon emissions with salt marsh erosion

With rising sea level, as well as a response to some engineering-induced impacts, erosion of salt marshes will release reservoir carbon that has accumulated and been stored within soils for a number of centuries.

Table A1.7 provides broad estimates of carbon release from salt marshes, per hectare, based upon an estimated range of depth of erosion of between 0.5 and 1.5 metres. Erosion depth will vary based upon tidal range at site and could vary beyond these estimates.

Table A1.7: Carbon loss from salt marsh erosion

	Carbon (tC/ha)		***Carbon (tCO$_2$e/ha)***	
Type	***Low***	***High***	***Low***	***High***
Muddy	250	1,500	917	5,500
Sandy	50	450	183	1,650

Notes: Calculation of carbon released due to salt marsh erosion assumes height of eroding marsh edge of 1.0 m +/- 50% (range of 0.5 to 1.5 m). Carbon released due to erosion of salt marsh calculated for lower and upper ranges of carbon content for muddy (0.05-0.1 g/cm^3) and sandy (0.01-0.03 g/cm^3) marshes and range of eroding marsh edge heights (0.5-1.5 m).

For muddy marshes, each hectare of salt marsh loss would result in the release of between approximately 250 tC/ha (917 tC0$_2$e/ha) and 1,500 tC/ha (5,500 tC0$_2$e/ha), depending upon depth of erosion. In a sandy system the same erosion would release between 50 tC/ha (183 tC0$_2$e/ha) to 450 tC/ha (1,650 tC0$_2$e/ha). These values do not include the carbon accumulation associated with the development of an organic-bearing active root zone and the loss of standing biomass.

Flood and coastal erosion risk management projections

To provide a scoping assessment of the impacts of FCERM strategies on coastal sinks of carbon and GHG emissions projections of habitat changes developed by Lee (2001) for the Environment Agency, English Nature (now Natural England) and Countryside Council of Wales are applied. Though Lee's estimates of habitat change are based upon lower levels of sea level rise than predicted by the IPCC 2007 and subsequent studies, and are limited to Special Protection Areas in England and Wales, they do provide a first cut of projected landscape change based upon policy scenarios. In consultation with staff from UK agencies, the following policy actions were considered:

- *Do Nothing*. Carry out no defence works except for safety measures. This could lead to continued erosion or breaching of dykes.

- *Hold the line*. Holding the defence line in its present location could result in further coastal squeeze in front of defences whilst protecting freshwater and brackish habitat inland.

- *Advance the line*. Moving defences seaward could result in the loss or degradation of intertidal habitats.

- *Retreat the line (managed realignment)*. Move the existing defence line landwards could result in loss or degradation of freshwater habitats, grasslands and farmland behind the current defence, but creating accommodation space for sediment accumulation, geomorphic processes and intertidal wetland restoration.

A summary of habitat changes per management scenario are provided in Table A1.9 and estimates of the relative carbon content in each soil type in Table A1.8.

Table A1.8: Carbon content by habitat type

Habitat	***Carbon (g/cm^3)***
Intertidal	0.01
Saltmarsh[1]	0.075
Shingle Bank	0
Sand Dune	0.01
Wet Grassland[2]	0
Coastal Lagoon	0.01
Reed Bed[3]	0.16

Notes: [1]Assumes median carbon content for muddy salt marsh of 0.075 g/cm^3 (Crooks 1996); [2]Assumes grassland has attained equilibrium carbon storage; Assumes median carbon content of 0.16 g/cm^3 (25th to 75th percentile range is 0.12-0.20 g/cm^3 (Andrews et al. 2000))

Source: Andrews et al. (2000), Crooks (1996).

Table A1.9: Estimated habitat loss/gain for SAC/SPA and Ramsar sites in England for four flood defence scenarios

	Do nothing			***Hold the line***			***Advance the line***			***Managed Realignment***		
Habitat	***Loss (ha)***	***Gain (ha)***	***Net (ha)***	***Loss (ha)***	***Gain (ha)***	***Net (ha)***	***Loss (ha)***	***Gain (ha)***	***Net (ha)***	***Loss (ha)***	***Gain (ha)***	***Net (ha)***
Intertidal	9,792	245	-9,547	1,517	6,651	5,134	50	0	-50	100	6,095	5,995
Salt marsh	245	23	-222	6,651	1,517	-5,134	0	50	50	100	6,095	5,995
Shingle Bank	19	0	-19	119	20	-99	0	0	0	100	90	-10
Sand Dune	204	269	65	301	113	-188	0	0	0	0	0	0
Wet Grassland	0	0	0	0	0	0	0	0	0	3,214	0	-3,214
Coastal Lagoon	0	0	0	0	0	0	0	0	0	530	30	-500
Reed Bed	0	0	0	0	0	0	0	0	0	172	0	-172
Total	**10,393**	**537**	**-9,856**	**8,588**	**8,301**	**-287**	**50**	**50**	**0**	**4,216**	**12,310**	**8,094**

Source: Lee, M. (2001)

Table A1.10: Estimated release or sequestration of carbon dioxide (Mt CO_2) for four flood defence scenarios

	Do nothing			***Hold the line***			***Advance the line***			***Managed Realignment***		
Habitat	***Loss***	***Gain***	***Net***	***Loss***	***Gain***	***Net***	***Loss***	***Gain***	***Net***	***Loss***	***Gain***	***Net***
Intertidal	3.59	0.09	-3.50	0.56	2.44	1.88	0.02	0.00	-0.02	0.04	2.23	2.20
Saltmarsh[2]	0.67	0.06	-0.61	18.29	4.17	-14.12	0.00	0.14	0.14	0.28	16.76	16.49
Shingle Bank	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sand Dune	0.07	0.10	0.02	0.11	0.04	-0.07	0.00	0.00	0.00	0.00	0.00	0.00
Wet Grassland[3]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coastal Lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.01	-0.18
Reed Bed[4]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01	0.00	-1.01
Total (Mt CO_2)	**4.3**	**0.3**	**-4.1**	**19.0**	**6.7**	**-12.3**	**0.0**	**0.1**	**0.1**	**1.5**	**19.0**	**17.5**

Notes: [1]Assumes median carbon content for muddy salt marsh of 0.075 g cm-3 (Crooks 1996); [2]Assumes grassland has attained equilibrium carbon storage; [3]Assumes median carbon content of 0.16 g cm^3 (25th to 75th percentile range is 0.12-0.20 g cm-3 (Andrews et al. 2000)).

Estimates of GHG emissions from wetlands based upon FCERM projections

Table A1.10 summarises estimates of GHG emissions coastal habitats based upon management scenarios described in Lee (2001). The results suggest that scenario, 'do nothing' would result in the net emission of 4.1 Mt $C0_2$e, 'hold the line' in net emission of 12.3 Mt $C0_2$e, 'advance the line' in net sequestration of 0.1 Mt $C0_2$e, and managed realignment in 17.5 Mt $C0_2$e. Therefore the different between the coastal wetland management choices of 'hold the line' and 'managed realignment' is 29.8 Mt $C0_2$e.

These projections carbon sequestration/emissions are spread roughly over a 50 year time horizon, but do not account for increased rates of sea level rise described in recent projections. These projections are also based on a reasonable assumption that soils on flooded lands do not release carbon when buried beneath saline sediments. Nor do these projections include construction of managed freshwater wetlands behind flood defences actively operated to sequester carbon. Finally, production of nitrous oxide has not been included in these calculations. An assumption has been made that were managed realignment and wetland restoration not undertaken, nitrous oxide would still be produced on existing intertidal and subtidal mudflats as it is primarily the consequence of nitrogen levels present in the water cycle, rather than of the area of habitats.

Carbon sequestration potential - conclusions

Overall, the key conclusions from the scoping assessment are:

- There is potential to re-sequester carbon within coastal wetlands through managed realignment, with associated reactivation of geomorphic processes, and the creation of accommodation space for accumulation of carbon-bearing sediments.

- Restoration of wetlands in saline environments (saltmarshes and mudflats) have a net carbon sequestration potential.

- Restoration of freshwater and brackish tidal wetlands will sequester carbon (more than saltmarsh and mudflat), but the production of methane will likely offset the carbon sequestration benefits over the 100 year timeframe. A possible exception is the restoration of seasonally flooded grasslands, which as well as sequestering carbon in soils, if drained through summer months is likely to emit only marginal quantities of methane, and therefore result in net sequestration.

- It may be possible to create managed freshwater wetlands to fill some available accommodation space with organic rich soils while reducing methane emissions so creating net positive carbon sequestration potential, as being experimentally trialled in California.

- Erosion of saltmarsh will release significant quantities of sequestered carbon back in to estuarine circulation with potential for likely conversion to carbon dioxide.

- Restoration of salt marsh will be most effective in estuaries with high sediment availability, notably the Severn Estuary and Humber Estuary.

- Restoration of salt marsh in ‘sandy’ estuaries (e.g. Solway Firth, Morecambe Bay, outer Wash) will sequester less carbon that in relatively ‘muddy’ estuaries (e.g. Severn Estuary, Humber Estuary, Mersey Estuary, Thames Estuary).

- It is anticipated that salt marsh in the Outer Thames Basin (Essex and North Kent) will continue to be highly sensitive to sea level rise, and therefore the expected erosion will continue to release carbon into estuarine circulation. However, it is anticipated that salt marsh restoration has limited capacity for carbon sequestration in this region, due to limited sediment availability and high rates of relative sea level rise.

A1.3 Agricultural land at risk from flooding

Type of activity at risk

The National Assessment of Assets at Risk (NAAR) (Halcrow, 2001) estimated that approximately 1.5 million hectares of agricultural land was at risk from flooding. A breakdown of area at risk by region and type of flooding is provided in Table A1.11. Based on NAAR the greatest area of land at risk is that in the Anglian region, both in terms of total area and areas of Grade 1 and 2 land, which are characterised by arable crops and high yields. Grade three to five are characterised by land that produces lower yields and thus is used primarily for livestock rearing (MAFF, 1988).

Combining NAAR data with Defra’s annual agricultural and horticultural survey enables an assessment of the type of agricultural activity at risk[49]. The survey details the number of holdings per agricultural type in a given region, split between three groups: arable (cereals, horticulture and general cropping), livestock (specialist pigs, specialist poultry, dairy, grazing livestock, lowlands grazing livestock) and mixed farming. In Table A1.12 the total area at risk in each region (from Table A1.11) is broken down on the basis of the number of types of holding per region, for arable and livestock (no calculations are made for mixed farming since no data is available on types of holding, and this typically represents less than 5% of holdings per region).

---

[49] Assuming no significant changes in the area of land at different grades per region since NAAR.

Table A1.11: Agricultural land at risk of flooding and coastal erosion

Flooding	***Grade***	***Anglian***	***Midland***	***North East***	***North West***	***South West***	***Southern***	***Thames***	***Wales***	***Total***
River	1,2	305	17	26	3	12	4	9	6	1024
	3,4,5	143	120	101	31	85	33	58	71	
Coastal	1,2	54	33	34	20	1	31	1	2	432
	3,4,5	57	44	40	27	12	47	1	28	
Total (Flood)	All	559	214	201	81	110	115	69	107	1456
Coastal erosion	All	1	0	0.2	1	0.2	2	0	1	5
Overall Total	All	560	214	201	82	110	117	69	108	1461

Source: Halcrow (2001*) National Appraisal of Assets at Risk from Flooding and Coastal Erosion*, page 24

Table A1.12: Type of agricultural activity and area of land at risk by region

Flooding	***Grade***	***Agriculture Type***	***Anglian***		***Midland***		***North East***		***North West***		***South West***		***Southern***		***Thames***		***Wales***	**Total**
			000's ha	%	000's ha	%	000's ha	%	000's ha	%	000's ha	%	000's ha	%	000's ha	%	000's ha	
River flooding	1,2	Cereals	180	59%	10	61%	18	69%	1	38%	6	52%	2	57%	5	57%	-	-
	1,2	General Cropping	83	27%	4	21%	5	20%	1	27%	1	11%	0	10%	1	10%	-	-
	1,2	Horticulture	42	14%	3	18%	3	12%	1	35%	4	37%	1	32%	3	32%	-	-
	1,2	*Total*	*305*		*17*		*26*		*3*		*12*		*4*		*9*		*6*	*382*
	3,4,5	Specialist Pigs	18	13%	4	3%	5	5%	1	2%	3	3%	2	5%	3	5%	-	-
	3,4,5	Specialist Poultry	35	25%	13	11%	10	10%	2	7%	8	9%	4	13%	7	13%	-	-
	3,4,5	Diary	7	5%	18	15%	11	11%	7	23%	16	19%	3	8%	4	8%	-	-
	3,4,5	Grazing Livestock (LFA)	0	0%	20	17%	44	44%	11	36%	11	12%	0	0%	0	0%	-	-
	3,4,5	Grazing Livestock (lowlands)	83	58%	64	54%	32	31%	10	32%	48	56%	25	75%	44	75%	-	-
	-	*Total*	*143*		*120*		*101*		*31*		*85*		*33*		*58*		*71*	*642*
Coastal flooding	1,2	Cereals	32	59%	20	61%	23	69%	8	38%	1	52%	18	57%	1	57%	-	-
	1,2	General Cropping	15	27%	7	21%	7	20%	5	27%	0	11%	3	10%	0	10%	-	-
	1,2	Horticulture	8	14%	6	18%	4	12%	7	35%	0	37%	10	32%	0	32%	-	-
	1,2	*Total*	*54*		*33*		*34*		*20*		*1*		*31*		*1*		*2*	*176*
	3,4,5	Specialist Pigs	7	13%	1	3%	2	5%	1	2%	0	3%	2	5%	0	5%	-	-
	3,4,5	Specialist Poultry	14	25%	5	11%	4	10%	2	7%	1	9%	6	13%	0	13%	-	-
	3,4,5	Diary	3	5%	7	15%	4	11%	6	23%	2	19%	4	8%	0	8%	-	-
	3,4,5	Grazing Livestock (LFA)	0	0%	8	17%	17	44%	10	36%	1	12%	0	0%	0	0%	-	-
	3,4,5	Grazing Livestock (lowlands)	33	58%	24	54%	13	31%	9	32%	7	56%	35	75%	1	75%	-	-
	-	*Total*	*57*	-	*44*		*40*		*27*		*12*		*47*		*1*		*28*	*256*
Total (Flood)	All	All	559	-	214		201		81		110		115		69		107	1,456
Coastal Erosion	All	All	1	-	0		0		1		0		2		0		1	5
Overall Total	All	All	560	-	214		201		82		110		117		69		108	1,461

GHG emissions from agricultural land

The Country Land and Business Association (CLA)[50] provides estimates of GHG emission and sequestration from agricultural land types. These are reported in Table A1.13 in tonnes CO_2e per hectare.

Table A1.13: GHG emission and sequestration from agricultural land types (t CO_2e per ha)

Farm Type	*GHG emissions*	*CO_2 sequestered*	*Net GHG emissions*
Cereals	3.16	0.42	2.74
Dairy	11.44	0.63	10.81
General Cropping	5.22	0.37	4.85
Horticulture	61.94	0.13	61.81
Grazing (LFA)	2.5	0.24	2.26
Lowland Grazing	7.05	1.16	5.89
Mixed	4.21	0.46	3.75
Nature Reserve	2.46	3.24	-0.78

Source: CALM calculator (http://www.calm.cla.org.uk/)

Cost of flooding on agriculture

Posthumus et al. (2009) provide an assessment of the cost of the Summer 2007 floods on the agriculture sector, based on survey of 78 farmers. Details of area flooded and estimated cost for different types of activity are provided in Table A1.14.

Table A1.14: Costs of 2007 floods on agriculture

	Horticulture (n=4)	General Cropping (n=20)	Cereals (n=22)	Mixed (n=11)	Dairy (n=9)	Grazing Livestock (n=9)	Pigs (n=3)	All Farms (n=78)
Flooded area per farm (ha)	18	84	76	71	70	76	88	74
Proportion of total farm flooded (%)	13.2	21.6	27.5	32.4	38.3	44.5	33.3	29.4
Total Cost (£ per ha flooded, weighted avg)	6,879	2,028	850	411	1,058	612	948	1,207

Source: Posthumus et al (2009), page 186.

Based on Table A1.14, the greatest economic cost of flooding is to horticulture production (£6,879 per hectare), with the least impact experienced by grazing livestock (£612 per hectare). Posthumus et al. note that the majority of costs incurred on pig farmers were crop losses. Overall, 82% of damage was to crops, the remaining 18% was farm assets and other costs that cannot be directly attributed to flooded areas. Average total cost to farmers was £89,415 per farm.

---

[50] The CALM calculator: http://www.calm.cla.org.uk/

Posthumus et al. also investigated farmer's perception of future flood risks and measures that would be considered to mitigate against flood damages. An immediate response was to change the crop rotation, since fields stayed waterlogged for a long period of time and as a result crops were relocated to another field.

Thirty three of the 78 farmers interviewed stated they were considering some form of flood mitigation, including: change in land use on the floodplain (e.g. no more potatoes or winter cereals, or converting arable land into grassland); improvement of drainage and/or flood defences; securing a sufficient stock of forage for livestock (by harvesting hay or silage on fields not prone to flooding); reduction in herd size and hence need for grass; or entering an Environmental Stewardship Scheme agreement (an agri-environment scheme).

Interactions between flooding, agriculture and GHG emissions

The issues reviewed in this section illustrate the different interactions between flooding and agricultural land uses. Agricultural is both an influence on flood risk and determined by flood management. The data used to illustrate these interactions show that the scale of the effect can vary across a broad range, typically by a factor of ten between different land uses.

The generalised national data is too coarse to draw significant conclusions about land use, flood management and GHG emissions. They would benefit from refinement, especially in terms of assumptions necessary about displacement of agricultural production. However, they highlight some points that may be worthy of further research.

All the agricultural uses identified in Table A1.13 are net GHG emitters, but feasible changes between land uses could potentially reduce emissions significantly. The data also identifies net sequestration potential for 'nature reserves', although these can involve a wide range of habitats and associated land uses (including grazing regimes identified as net emitters). Modelling of land use changes as a result of flood management adaptation to climate change could help identify how these changes might be distributed across fluvial and coastal flood plains in England and Wales, the expected changes to GHG emissions and opportunities to reduce emissions and maximise sequestration.

A1.4 Development control

Development control refers to the inclusion of flood and coastal erosion risk considerations within the overall land planning process. This primarily influences land use (residential or commercial) through the planning system and hence GHG emissions associated with development (e.g. house building) including adaptation measures to address residual flood risk.

Assessing the carbon footprint of different levels of development control requires information on the number of developments on floodplains and the number of residential and non-residential properties as well as the level of flood risk and consequential GHG emissions associated with flood damages.

The baseline development control situation can be assessed by comparing the number of planning applications for new development and re-development, although a series of assumptions would be required to account for the Environment Agency influencing the design of large developments regarding management of surface water runoff[51]. For developments on high flood risk areas, further assumptions would be required to calculate the footprint of all positive planning outcomes resulting from negotiation and permitting/allowing development with modifications in design (e.g. raised floor levels, construction of sustainable drainage systems etc.), which incidentally, may incur an additional carbon footprint.

Considering alternative development control policy scenarios requires estimating GHG emissions from damages that arise from variants of, or an absence of, development control policy, i.e. Planning Policy Statement 25, in place. Challenges in this regard include:

- *The calculation of specific carbon implications of development allowed by FCERM activity (including development control policy):* more development happens behind defences, and this has implications for the carbon footprint of indirect FCERM activity than would naturally occur without FCERM activity. Hence assessing a ‘policy off’ development control scenario, requires assumptions as to whether communities would build elsewhere, would repair flood defences themselves, or go ahead with all development plans with little or no consideration for flood risk. This would entail uncertainties and could have implications for the carbon footprint associated with construction, as well as potential repairs and reconstruction of new developments and re-developments located in flood risk areas. So, for example, if the current damage is X when a defence fails or is overtopped, damage without development control policy in place will be greater than X accounting for emissions from new development/re-development made possible in flood risk areas.

- *The ‘indirect’ benefits of development control policy, i.e. the benefits that go beyond the number of developments objected to by the EA*: Available data on planning and flood risk includes the number of flood risk consultations received by the EA, the number of permitted cases dealt with by condition, the number of objections, and the number of developments built against advice. However, a crucial element associated to having Development Control policy in place not captured in these data is that of the policy’s main goal: to influence development design to deal with flood risk and residual risk[52] (i.e. the number and type of planning applications being made). This is

---

[51] Note that Local Authorities, rather than the Environment Agency, provide Standard Advice on Flood Risk for small developments.

[52] In particular, Current Development Control policies PPS25 (England) and TAN15 (Wales) are intended to stop development in areas at high risk of flooding by re-directing development to lower risk areas, and avoid inappropriate development; i.e. by advising and influencing design, for example on how to deal with surface water runoff from large developments. For a large

achieved via negotiation with developers and LAs, and hence, a number of assumptions would have to be made to account for this process. These assumptions would be significant given the fact that planning applications on which the EA is consulted regarding flood risk vary in complexity and scale.

Notwithstanding uncertainties and issues outlined above, some data are readily available from the Environment Agency on the number of planning applications consulted on regarding flood risk, how many are objected to, how many applications are permitted with conditions to deal with EA concerns, and how many developments go ahead against EA advice (Table A1.15).

Table A1.15: Total number of planning applications considered and objections

	2003/4	***2004/5***	***2005/6***	***2006/7***	***2007/8***
Planning consultations on which the Environment Agency responded on all issues	52,379	41,481	32,142	31,850	38,401
Consultations which required detailed consideration on flood risk grounds	22,067	13,937	11,403	10,854	9,123
Total Environment Agency objections made on flood risk grounds	5,077	4,634	4,201	4,750	6,232
Local Planning Authority (LPA) decision notices received by the Environment Agency relating to Environment Agency objections on flood risk grounds[1]	2,811	3,047	2,922	2,719	3,689
Sustained objections on flood risk grounds where the outcome is known[2]	1,437	1,438	1,160	1,067	1,264
Applications refused, or approved with conditions, by LPAs in line with Environment Agency advice[3]	931	998	889	829	1021
Applications refused by LPAs for other reasons	183	192	135	128	119
Applications permitted by LPAs contrary to Environment Agency advice[4]	323	248	136	110	124
Notes: [1]Decision notices received from LPAs during the monitoring period do not correlate with objections made. Many decisions will relate to objections made in the previous accounting period, while LPAs will not yet have made a decision on those objections made late in the monitoring period; [2]Sustained objections do not include applications withdrawn by developers or Environment Agency objections resolved through negotiations, before a formal decision is made by the LPA; [3]This includes applications refused in line with Environment Agency advice plus those approved with conditions attached that fully mitigate Environment Agency concerns; [4]Including those with conditions only partly mitigating/meeting Environment Agency concerns.					

Source: Environment Agency (2009).

---

proportion of cases, the EA responses to consultations received do not lead to outright objections, but rather a process of negotiation leading to designs that avoid flood risk and minimise impacts so that development proposals become acceptable. Hence, the benefits of PPS25 and TAN15 policies at present cannot be measured only in terms of the number of developments at risk of flooding avoided by means of EA objections. In order to encapsulate the usefulness and full effectiveness of current policy, there is also a need to account for the EA positive responses via conditions, negotiation and influencing development layout, design and land-use, as these responses mean that the damage associated with flooding is considerably avoided or reduced.

A1 References

Andrews, J.E., Burgess, D., Cave, R.R., Coombes, E.G., Jickells, T.D., Parkes, D.J., and Turner, R.K., (2006). “Biogeochemical value of managed realignment, Humber Estuary, UK”. *Science of the Total Environment,* 371: pp. 19-30.

Andrews, J.E., Samway, G., Dennis, P.F. and Maher, B.A. (2000). ‘Origin, abundance and storage of organic carbon and sulphur in the Holocene Humber Estuary: emphasizing human impacts on storage change’. In: Shennan, I., and Andrews, J.(eds) *Holocene Land-Ocean Interactions and Environmental Change Around the North Sea.* Geological Society, London, Special Publication, 166: pp. 145-170.

Brown, A. G. (2009). *Carbon Storage and Sequestration in the Somerset Levels, UK.* Report for Somerset County Council.

CEH (2008). Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry. A. M. Thomson and M. A. Van Oijen. Edinburgh, CEH.

Crooks, S. (1996). *Sedimentological Controls on the Geotechnical Properties of Saltmarsh and Mudflat Deposits*. University of Reading, unpublished thesis.

Crooks, S. (2009). Carbon Sequestration in Tidal Wetlands. White paper for the Resources Legacy Fund by Philip Williams and Associates, Ltd. San Francisco. February, 9th 2009. PWA Reference 1944.

Crooks, S., Finden, J., Igusky, K., Orr, M.K. and Brew, D. (2009).*Greenhouse Gas Mitigation Typology Issues Paper: Tidal Wetlands Restoration*. Report by PWA and SAIC to the California Climate Action Registry. Philip Williams and Associates, Ltd., PWA Reference 1957.

Environment Agency (2008). *Deliver habitat creation requirements through flood risk management*, Operation Instruction 908_08 (June 2008).

Environment Agency (2009). *High Level Target 5 Development and flood risk in England*, Report to Defra and CLG (February 2009).

Halcrow (2001*). National Appraisal of Assets at Risk from Flooding and Coastal Erosion*, page 24.

Holman, I.P. (2009). An estimate of peat reserves and loss in the East Anglian Fens Commissioned by the RSPB, Cranfield University.

IPCC (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. Kanagawa, Japan, Institute for Global Environmental strategies (IGES) for the Intergovernmental Panel on Climate Change.

Lee, M. (2001). “Coastal defence and the Habitat Directive: projections of habitat change in England and Wales”. *The Geographical Journal*, 167: pp. 39-56.

MAFF (1988). *Land classification of England and Wales*.

Miller, R., Fram, M., Fujii, R. and Wheeler, G. (2008). ‘Subsidence reversal in a re-established wetland in the Sacremento-San Joaquin Delta, California, USA’. *San Francisco Estuary & Watershed Science.* Available from: http://repositories.cdlib.org/jmie/sfews/vol6/iss3/art1.

Milne, R. and Brown, T.A. (1997). "Carbon in the vegetation and soils of Great Britain." *Journal of Environmental Management* 49(4): pp.413-433.

Mobbs, D.C. and Thomson, A. (2006). *Mapping Carbon Emissions & Removals for the Land Use*, Land Use Change & Forestry Sector.

Posthumus, H., Morris, J., Hess, T.M., Neville, D., Philips, E. and Baylis, A. (2009). “Impacts of the summer 2007 floods on agriculture in England”*, Journal of Flood Risk Management*, pp. 182 – 189.

UK Biodiversity Action Plan, Priority Habitat Descriptions at www.ukbap.org.uk

Appendix to Annex 1: GHG emissions and carbon sequestration in wetlands

This Appendix to Annex 1 presents a note on GHG emissions and carbon sequestration in wetlands, originally submitted for review by the project steering group in June 2009.

Background

This appendix provides a review of scientific evidence concerning GHG emissions and carbon sequestration from wetland habitats, for the project ‘Understanding the impact of flood and coastal erosion risk management (FCERM) on the causes of climate change’. The summary is primarily drawn from a study for the California Climate Action Registry (now the Climate Action Reserve) in 2009 by PWA with SAIC to review of the potential for tidal wetland restoration to be developed into a greenhouse gas (GHG) mitigation offset protocol (PWA and SAIC 2009). That study outlined the status of the science and information gaps to be filled for a US national protocol to be developed. The following builds on that study as is updated to include UK specific data, as available.

The following is structured as:

- Section 1 provides an overview of the processes giving rise to sequestration and emissions of GHGs in wetlands;
- Section 2 provides an account of factors influencing whether wetlands are net carbon sinks or sources;
- Section 3 discusses the effect of climate change on sequestration and emissions from wetlands; and
- Section 4 considers the available evidence and implications for UK wetlands.

1. Overview

Wetlands act both as a reservoir for carbon, ultimately sequestered from the atmosphere, and producers of methane (CH_4) and nitrous oxide (N_2O) through biogeochemical processes. The capacity of wetlands to provide an offset for anthropogenic GHG emissions will depend upon landscape settings as variations in these determine both the rate of carbon sequestration and GHG production.

1.1 Wetlands as carbon reservoirs

Coastal wetlands

Wetlands accumulate carbon directly from the atmosphere as plants capture CO_2 during photosynthesis, as well as by directly trapping organic matter carried with flooding waters. The bulk of carbon stored within wetlands is derived from below-ground biomass, the accumulation of roots and rhizomes associated with standing above-ground crop of vegetation. Some of the above ground biomass is accumulated within the soil but much is recycled within the estuary.

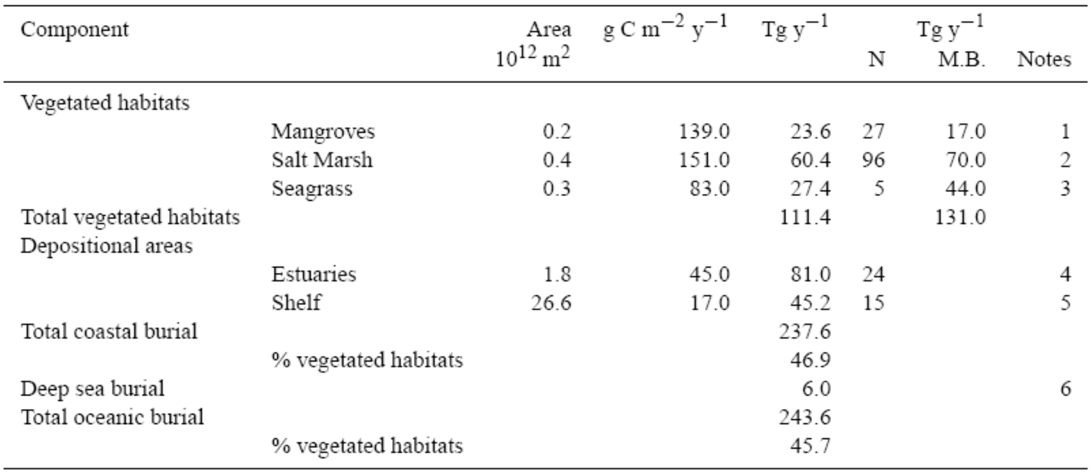
The living standing crop of vegetation and the build up of roots and rhizomes in near-surface soils create a standing pool of carbon in the marsh. Once a steady state is achieved this standing pool will remain constant unless the vegetation changes or the health of the wetland is impacted.

Below the standing crop, microbial degradation of organic matter occurs, and is not compensated by new production. Consequently, below the surface the amount of soil carbon generally diminishes with depth. There is some indication that below a permanent water table this rate of decomposition decreases and long-term sequestration occurs. The depth of this permanent water table may be a few decimeters to meters depending upon tidal range. A fair approximation of this depth would be the local mean tide elevation. In many coastal settings accumulations of organic bearing soils have built up that date back to the mid Holocene (around five thousand years old) (Andrews et al, 2003).

The capacity of coastal wetlands to accumulate carbon has been the focus of several review studies. Gathering together data from 154 marshes, mainly from the United States, but also from overseas, Chmura *et al.* estimated that salt marshes and mangroves accumulated, on average 150-250 gC/m^2/yr (550-916.7 g CO_2e/m^2/yr) , though the range varied over an order of magnitude (Chmura et al, 2003). In a similar summary assessment, Duarte *et al.*, (2005) reviewed the contribution of vegetated and unvegetated coastal wetlands to carbon sinks in coastal areas and estimated that salt marshes, mangroves and sea grass areas store 151, 139 and 83 gC/m^2/yr (553.7, 509.7, 304.3 g CO_2e/m^2/yr), respectively; while unvegetated areas of estuaries (mudflats) and the open continental shelf respectively accumulate 45 and 17 gC/m^2/yr (165, 62.3 g CO_2e/m^2/yr) (Table 1.1) (Duarte et al, 2005).

A key factor in assessing carbon accumulation and greenhouse gas emission rates from tidal wetlands is the coastal setting of the tidal wetlands. Carbon accumulation estimates in tidal wetlands (primarily U.S. data) range over two orders of magnitude, reflecting interactions between climate, vegetation type, salinity (a primary control of vegetation type), and soil type (capacity to store carbon in soils) (Table 1.2).

Table 1.1: Estimates of Organic Carbon Burial Rates in Coastal Systems (Duarte *et al.*, 2005)



Component		Area 10^{12} m^2	g C m^{-2} y^{-1}	Tg y^{-1}	N	Tg y^{-1} M.B.	Notes
Vegetated habitats							
	Mangroves	0.2	139.0	23.6	27	17.0	1
	Salt Marsh	0.4	151.0	60.4	96	70.0	2
	Seagrass	0.3	83.0	27.4	5	44.0	3
Total vegetated habitats				111.4		131.0	
Depositional areas							
	Estuaries	1.8	45.0	81.0	24		4
	Shelf	26.6	17.0	45.2	15		5
Total coastal burial				237.6			
	% vegetated habitats			46.9			
Deep sea burial				6.0			6
Total oceanic burial				243.6			
	% vegetated habitats			45.7			

Notes:
10^{12}m^2 = million sq km.
1) Area covered from Valieia *et al.*, (2001), organic burial data from Chmura *et al.*, (2003); 2) Area covered from Woodwell *et al.*, (1973), organic burial from Chmura *et al.*, (2003); 3) Area covered calculated from original extent of seagrass and reported fraction relative long-term decline rates (Green and Short, 2003; Duarte et al, 2005), Organic burial data from Garcia *et al.* 2002, Romero *et al.* 1994, Mateo et al, 1997; 1995, and Barron *et al.*, 2004; 4) Area covered by Costanza *et al.*, (1997), organic burial data from Heip *et al.*, (1995) and Widdows *et al.* (2004); 5) Area covered from Costanza *et al.*, (1997) assuming that depositional area covers 10% of the shelf area, organic burial from Middelburg *et al.* (1997a) and; 6) Berner (1982). M.B: Mass balance approach, this is the former method for estimating carbon content of ocean sediments but did not account for updated carbon content estimated derived from soil analysis– provided for comparison of change.

Table 1.2: Summary of Carbon Sequestration and Methane Production Across the Salinity Interface (PWA and SAIC, 2009)

Wetland Type	Carbon Sequestration Potential ($gC/m^2/yr$, $gCO_2e/m^2/yr$)	Methane Production Potential ($gCH_4/m^2/yr$, $gCO_2e/m^2/yr$)	Net balance
Mudflat (saline)	Low (<50, 183.3)	Low (<2, 50)	Low C sequestration
Salt Marsh	High (50-250, 183-917)	Low (<2, 50)	High C sequestration
Mangrove	High (50-250, 183-917)	Low – High	Depends on salinity
Brackish Tidal Marsh	High (250-450, 183.3-1650)	High (5-100, 125-2,500)	Unclear[53]
Freshwater Tidal Marsh	Very High (500-1000, 1,833.3)	High- Very High (40-100+, 1,000-2,500+)	Unclear – potential very high C sequestration[54]
Estuarine Forest	High (100-250, 366.7-916.7)	Low (<10, 250)	High C sequestration
Note: 1gC ≡ 3.67 gCO_2e; $1gCH_4$ ≡ 25 gCO_2e			

---

[53] Too few studies to draw firm conclusions. Potentially CH_4 emissions brackish wetlands may negate carbon sequestration within soils. Further research required.

[54] Too few studies to draw firm conclusions. Potentially CH_4 emissions from freshwater tidal wetlands may partially or fully negate carbon sequestration within soils.

Freshwater wetlands

Moving from the saline environment to freshwater tidal wetlands there is potential to accumulate over 500 gC/m^2/yr (1,833 g CO_2e/m^2/yr), perhaps over 1000 gC/m^2/yr (3,667 g CO_2e/m^2/yr) on long-term restoration projects (Feijtel et al, 1985 and Miller, 2008). It appears from the literature that organic matter accumulation is limited by salinity and has a maximum threshold; freshwater wetlands are able to accrete at rates greater than sea level rise, until an elevation threshold relative to water elevations is reached. For this reason restoring freshwater wetlands potentially offer higher capacity to store carbon than restoring saline wetlands.

Freshwater tidal marshes are prolific accumulators of carbon, with potential to store in excess of 500 gC/m^2/yr (1,833 g CO_2e/m^2/yr). One notable example of high carbon accumulation rates is in experimental managed freshwater tidal wetlands. Managed wetlands (built on subsided former marsh areas) have through water management practices demonstrated the capacity to raise marsh surface at rates far in excess of rates of sea level rise. Now in its 10th year of monitoring a USGS study in the Sacramento-San Joaquin Delta has documented marsh surface accumulation of over 5 cm/yr [55]. With an average soil carbon content of about 0.2 gC/cm^3 such accretion rates would equate to an accumulation of about 1,000 gC/m^2/yr (3,667 g CO_2e/m^2/yr). These marshes are vegetated with tule (*Schoenoplectus*) and cattails (*Typha*) species which have capacity to grow prolifically.

Less prolific, but still significantly productive is the freshwater and brackish salinity tolerant common reed (*Phragmites Australis*) which builds wetlands including those known as reedbeds and coastal reedswamp in the UK. Though the authors are unaware of any UK studies that directly document the carbon burial associated with these reed, studies in New Jersey (a State subject to hot summers and freezing winters) suggests that the carbon sequestration potential of this plant in brackish settings is at least double that of saltmarsh (Windham, 2001).

Estuarine scrub / shrub and forested wetlands were once common features of the landscape at the margin of estuaries. Less work has been done to characterize their soil carbon storage potential, though one estimate by Yu *et al.* (2006), suggests the storage potential could be in comparable range to salt marsh (Yu, 2006).

1.2 Emissions of greenhouse gases

Developing a carbon budget for wetlands requires that we not only consider carbon sequestration potential but also account for the release of carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (N_2O), which are by-products of organic decomposition by bacteria in wetland soils. Table A1.3 summarizes

---

[55] *Ibid*

the overall the global atmospheric contribution of GHGs to radiative forcing that recycle through wetland biogeochemical pathways.

Table 1.3: Greenhouse Gases Emitted from Wetlands (Forster *et al.*, 2001)

Gas	Current (1998) Amount by Volume	Global Warming Potential	Percent increase Since 1750	Radiative forcing (W/m²)
Carbon dioxide, CO_2	365 ppm	1	31%	1.46
Methane, CH_4	1,745 ppb	25	150%	0.48
Nitrous Oxide, N_2O	314 ppb	310	16%	0.15

2. Tidal wetlands as active GHG sinks or sources

2.1 Background

All tidal marshes are generally net sinks for atmospheric CO_2 through burial of organic matter in sediment. Some portion of this carbon is recycled and consequently emitted as CO_2 to the water column and directly to the atmosphere at low tide (Abril and Borges, 2004).

CH_4 formation occurs in low salinity or non-saline environments and requires strictly anaerobic conditions. Methane production is generally intense in brackish and freshwater tidal flats and marshes because of the high organic matter content of the soils at anoxic depths. Methane production decreases by two orders of magnitude as salinity increases due to the availability of sulphate, which in anoxic sediments feeds sulphate-reducing bacteria that outcompete methanogenic bacteria.

In many wetlands some of the methane produced in subsurface soils is oxidized and denatured as it diffuses to the atmosphere through the oxygenated soil surface (Megonigal and Schlesinger, 2002). In freshwater and brackish marshes (vegetated by tule, common reed, and sedge) this pathway is short-cut by a route through deep soils and by air passages in the plant to the atmosphere (Van Der Nat and Middleburg, 2000). Seasonally flooded forested and scrub shrub wetlands produce less CH_4 than fully tidal marshes because of the periods of prolonged drying and lowered water table. Such systems may even be net sinks for CH_4.

N_2O in oceanic environments is mainly formed as a by-product during nitrification (the breakdown of ammonia to nitrate and nitrite) and as an intermediate during denitrification (conversion of nitrate to nitrous oxide and nitrogen) (Bange, 2006). Both nitrification and denitrification are microbial processes that can happen in the water column and in sediments, mediated by bacteria living in low oxygen environments. Ammonia and nitrate are natural constituents in estuarine waters, but are now found at heightened levels in wetlands due to agriculture and other anthropogenic sources such as air pollution.

While estuaries overall are very effective systems for the recycling of nitrogen, the capacity of estuaries to do so has been degraded by the loss of tidal wetlands (Jickells, 1998). Denitrification is not confined to intertidal sediment, but continues in organic bearing continental shelf sediments beyond the estuary. As a consequence, while restored wetlands do contribute to the production of small amounts of N_2O, this compound would be produced elsewhere in the estuarine or on the adjacent continental shelf, even without the presence of the wetland. As a result, the presence of the N_2O precursor compounds and their associated emissions would likely remain unchanged regardless of whether the wetlands are there or not. However, further research is required to confirm this.

Overall, tidal wetlands are a net sink for carbon even though they release a percentage of that as CO_2 to the atmosphere or in particulate or dissolved form to the estuary. In brackish and freshwater tidal systems, large amounts of CH_4 are released, which from a GHG mitigation perspective may exceed their carbon sequestration value. Tidal wetlands also contribute a small amount of N_2O production, but this is a function of nitrogen pollution in coastal areas, and these emissions would most likely occur regardless of the presence of the wetland.

2.2 Carbon fluxes of all wetlands

Bridgham *et al.* (2006) estimated that the current wetlands of the conterminous US and Alaska are net carbon sinks of 9.5 and 13.3 Tg C/yr (34.8, 48.8 Tg $CO_2e/m^2/yr$), respectively (total 22.8 Tg/yr, 83.6 Tg $CO_2e/m^2/yr$), and emit methane to the atmosphere at rates of 3.1 Tg $CH_{4/}$yr and 1.7 Tg CH_4/yr (11.4, 6.2 Tg $CO_2e/m^2/yr$), respectively (total 4.8 Tg CH_4/yr, 17.6 Tg $CO_2e/m^2/yr$) (Bridgham et al., 2006). Though the error bars are large, the Bridgham *et al.* study finds wetlands overall to have a net negative GHG offset balance. However, when looking only at saline tidal marsh, mangroves and mudflats, the low CH_4 emissions and relatively high carbon sequestration potential resulted in these specific wetlands having a positive GHG offset balance.

The managed freshwater wetlands on deeply subsided dyked former coastal floodplains in California appear to have capacity to sequester very strong net positive amounts of GHG (2000 g $CO_2e/m^2/yr$) because of the capacity, through water management to lower CH_4 emissions during the summer season. Currently agricultural soil oxidation in the Sacramento – San Joaquin Delta is, over an area of 180,000 ha, releasing an estimated 13 Mt CO_2 in to the atmosphere, not including accounting for N_2O production from agricultural fertilizer. While the net GHG offset potential of natural freshwater wetlands is under investigation is it clear that reversal of delta island subsidence through wetland growth could over decades sequester 2,000 Mt of CO_2 within this region.

Similarly in the Fens in the UK, drainage and wastage of peat soils is estimated to be producing annual carbon emissions of 1.4 $MtC0_2e$ (Holman, 2009). While the sequestration potential using common reed , and likely less prolific that tule, in the UK is currently unquantified, the potential to sequester significant quantities of carbon within managed freshwater tidal wetland (reedswamp) soil should be investigated.

2.3 Carbon sequestration and soil chemistry

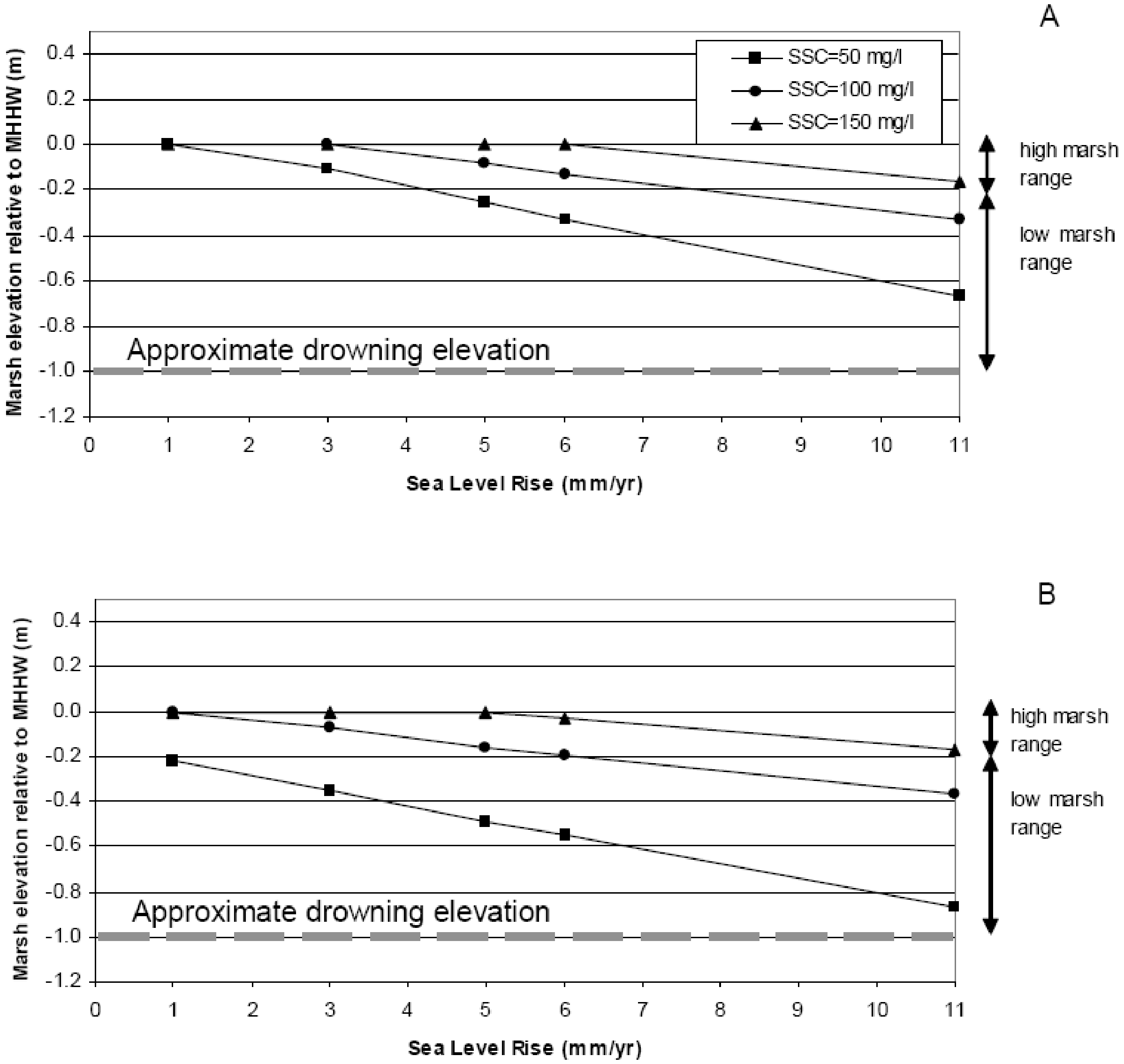
Microbial activity in freshwater wetland soils transforms considerable amounts of CO_2 into CH_4, which is then released into the atmosphere. In contrast to freshwater wetlands, tidal saline marshes release negligible amounts of CH_4 to the atmosphere, due to the presence of abundant sulphate which inhibits CH_4 production. As CH_4 has a greenhouse warming potential greater than CO_2, each unit of carbon sequestered in tidal saline marshes will have a greater impact than freshwater wetlands in reducing greenhouse warming.

2.4 Carbon sequestration and sedimentation

Sediment deposition enhances carbon sequestration by burying organic matter. The nature of the sediment influences the rate at which buried organic material breaks down. Relatively ‘sandy’ sediments have a higher permeability than more ‘muddy’ sediments. With higher soil permeability the flow of water, as well as the potential for desiccation, provides conditions for organic oxidation and release of carbon; i.e., lesser carbon sequestration will occur. Therefore, carbon sequestration will be regionally variable depending upon the nature of sediments that are building tidal wetlands.

The capacity of saltmarshes to respond resiliently to sea level rise depends upon mineral sediment availability. Modelling studies in San Francisco Bay (spring tide range 6ft) suggest that established ‘mature’ saltmarshes must be fed by tidal waters sediments in concentrations of 100 mg/l for their surfaces to accrete at rates that match relative sea level rise up to 3 mm/yr. For rates of relative sea level rise of 6 mm/yr the amount of sediment in suspension that must be brought by tidal waters increases to 150 mg/l for marshes to be resilient (Figure 2.1).

Figure 2.1: 100 Year Projections of Saltmarsh Elevations as a Function of Sea Level Rise and Suspended Sediment Concentrations, San Pablo Bay (Orr et al., 2003)



Notes:
(a) Initially starting at natural marsh plain elevations (equivalent to tidal datum Mean Higher High Water, M.H.H.W); (b) initially starting at low marsh (-0.5 m M.H.H.W). Calculations based upon model by Krone (1987) modified to include constant organic accumulation of 1 mm/yr. Dry Density of inorganic accretion = 500 kg/m^3. Tides for Petaluma River Mouth, San Francisco Bay.

Sediment is required to raise the surface of restoring marshes on managed realignment sites to the elevation of vegetated saltmarsh. The elevation of coastal floodplains is typically lower than those of natural marshes because of soils subsidence associated with drainage as well as the consequences of ongoing sea level rise. As a consequence, the time table to restore tidal wetlands depends upon the degree of subsidence on the dyked former wetlands as well as the availability of sediment (Figure 2.2).

2.3 Carbon Sequestration and Wetland Drainage

Historically, many tidal wetlands have been drained and converted to terrestrial uses, principally agriculture and urban development. The direct impact of ditching and drainage is the lowering of the water level, which results in oxidation of organic matter in soil and the release of CO_2 to the atmosphere. Hence, former wetlands that are currently drained for agricultural use may either be losing their historically stored carbon or have lost their carbon stores in surface soils.

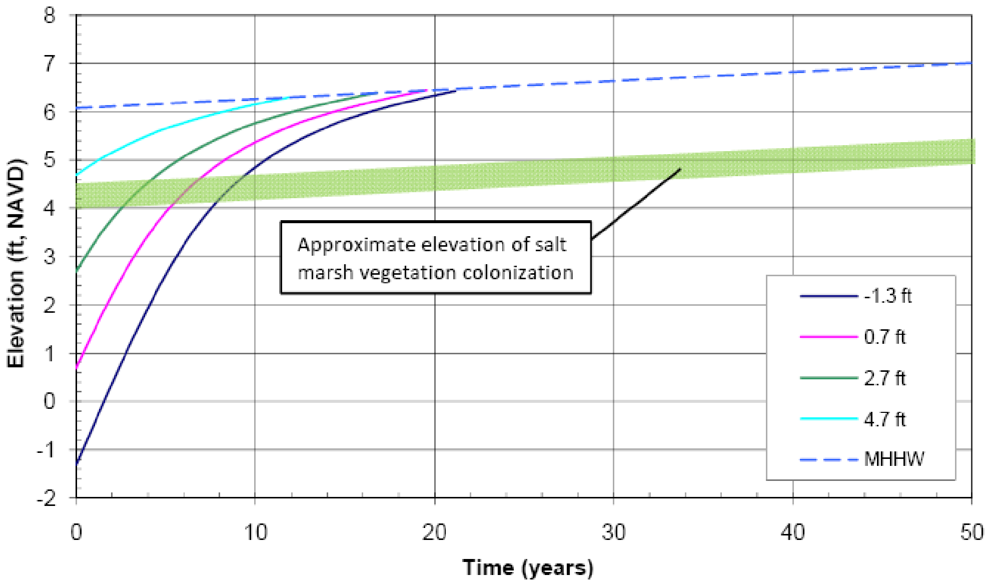
In natural tidal wetlands it is likely, but not scientifically quantified, that the depth of the water table influences carbon sequestration potential. Wetlands in microtidal or low mesotidal settings, potentially offer a higher percentage of carbon within soils than relatively well drained marshes in coastal areas with high tidal ranges.

2.6 Sequestration over Time

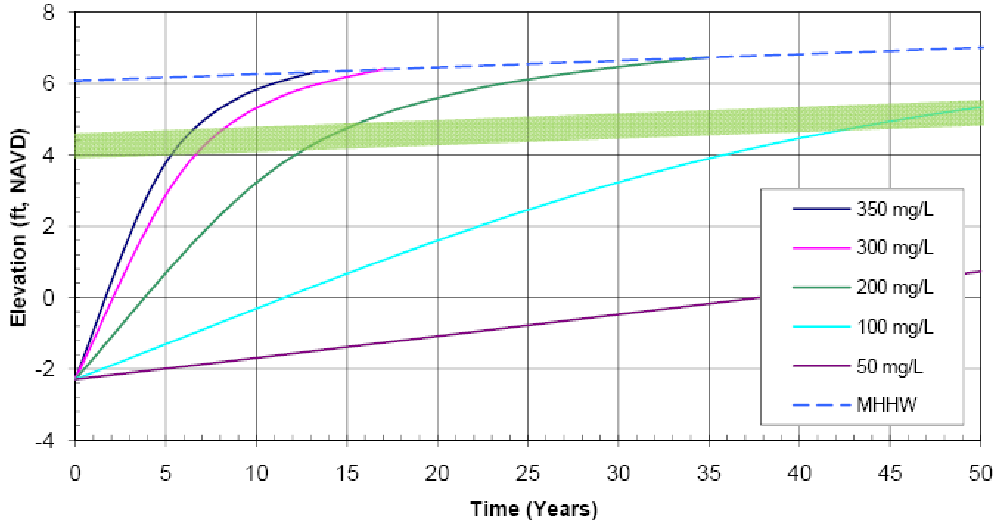
Wetlands restoration projects typically follow an evolutionary trajectory from an unvegetated or partially vegetated state to a fully vegetated state. Thus, over time, the capacity of wetlands to sequester carbon evolves at a rate dependant upon the time it takes to achieve a fully vegetated wetland. There is some indication that once wetlands have achieved a fully vegetated state (often less that 10 years after the pioneering vegetation establishes) that carbon accumulation rates are equivalent to that of natural reference marshes (Craft et al, 2003 and Cornell et al, 2007). In a subsided site with limited sediment supply it may take several decades, if at all, to build mudflat areas to elevations where vegetation will begin to colonize.

Figure 2.2: Predicted Sedimentation Rates for Saltmarshes Restored as Defined by Initial Elevation or Available Sediment Supply, San Pablo Bay.

(a) Sedimentation curves for range of initial mudflat bed elevations



(b) Sedimentation curves for range of suspended sediment concentrations



Notes: (a) Ambient sediment concentration of 250 mg/L
(a) and (b) Mean monthly tide from Petaluma River Entrance (NOAA #9415252), Rate of sea level rise = 5.67 mm/yr.
Source: MARSH98 Sedimentation Model

figure 1
Tidal Wetland Carbon Sequestration

Predicted Sedimentation Curves

PWA Ref# 1944 PWA

3. Carbon sequestration and climate change

Climate change will likely affect the process of carbon sequestration in tidal wetlands, but the impacts are difficult to predict. Climate change scenarios predict warming, changes in precipitation, and water levels (tidal and groundwater), which could affect the carbon cycle in wetlands. Increased CO_2 in the atmosphere will result in higher temperatures and increased plant growth in most wetlands, but also increased decomposition rates in wetland soils, increasing CH_4 emissions (Megonigal and Schlesinger, 2002).

The primary impact of climate change on tidal wetlands will relate to their capacity to respond to sea level rise. Freshwater tidal marshes consisting of common reed may be resilient to rising water levels with capacity to build marsh vertically at a rate of several centimetres per year. As long as freshwater marshes are maintained in a low salinity environment (<0.5 ppt) they have the capacity to build under relatively high rates of sea level rise.

Saline and brackish marshes depend on a supply of mineral sediment to maintain accretion rates. It appears that in these marshes, carbon production is relatively constant in healthy marshes but that the contribution of organic matter to marsh building is sufficient to balance only 1-2 mm of sea level rise, at most. As a consequence these marshes may be subject to decay and breakdown if the mineral supply is insufficient to balance sea level rise, and / or lateral erosion as deepening waters adjacent to intertidal areas allow larger waves to attack the marsh edge. Examples exist around the US of marsh breakdown including around 100 km^2 of marsh loss per year in the Mississippi Delta (Day et al, 2007), the loss of vegetated wetlands in Elkhorn Slough (Van Dyke and Wasson, 2005) , as well as loss of marshes in Chesapeake Bay.

In the UK the widespread breakdown of saltmarsh in the Thames basin (estuaries of south Suffolk, Essex and north Kent) to mudflat similarly appears characteristic of inadequate mineral sediment supply to maintain vegetated marshes. The loss of these vegetated marshes and the release of stored carbon is likely to continue unless the supply of sediment to these marshes is substantially increased, which will not happen in the absence of artificial placement or similar intervention. In such sediment-starved areas ongoing dredging activities (with sediment exported from the estuary) and additional levee set-back act to increase the accommodation space to be filled by limited sediment supplied and likely exacerbates rates of regional saltmarsh loss.

With respect to tidal saline wetlands, climate change is important because of changes in wetland area with potential accelerated sea-level rise, and the subsequent changes in sequestration capacity associated with any change in area. If tidal saline wetlands are able to maintain their elevation with accelerated sea-level rise, then the capacity of carbon sequestration will be sustained. However, if sediment supply to the wetland and organic matter accumulation cannot maintain the elevation of the wetland relative to sea-level rise, there is the potential for the wetland to drown. The soil surface is submerged and the wetland edge may erode releasing stored carbon. Also, tidal saline wetlands may expand inland over former terrestrial land which has a lower sequestration capacity than the wetlands. To avoid future loss of wetlands from GHG offsets projects, it would be important to specify certain long-term management practices at tidal saline wetlands to ensure they will be sustained over time.

5 Carbon Sequestration Potential of Tidal Wetlands in the UK

5.1 Available data

The carbon sequestration potential of tidal wetlands in the UK has received little direct attention, and far less than agricultural soils and peatland. We can draw some conclusions from carbon storage and greenhouse emissions estimates from studies overseas, but these where possible should be calibrated based upon UK botany, climate and other local conditions.

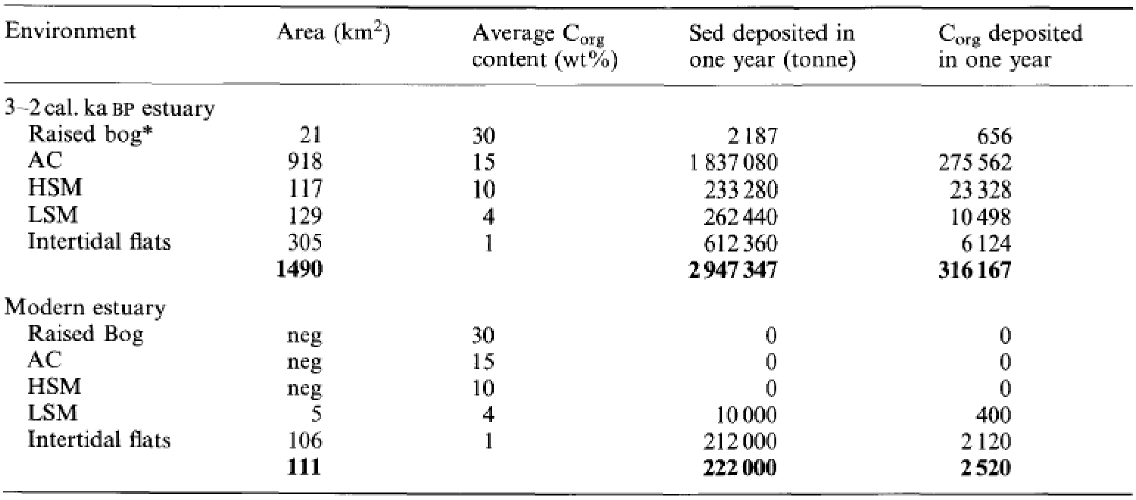
To assist in this calibration we have the following information.

1. As part of the Land Ocean Interaction Study (LOIZ) Andrews et al (2000) quantified the carbon accumulation within a range of historic and present day freshwater and saline wetlands across the Humber estuary and levels.
2. A Ph.D. Thesis investigation of salt marsh soils with field data from 26 natural, dyked and restored marshes across the UK and north France (Crooks, 1996).
3. Projections of wetland change under conditions of sea level rise documents in a series of regional Coastal Habitat Management Plans.

The Andrews et al. (2000) study provides a systematic synthesis of carbon accumulation in coastal wetlands across a single large UK estuary. The findings are broadly transferable to other large estuaries with dyked expansive coastal plains (such as the Severn Estuary). The study estimate the annual carbon storage (not including GHG emissions) from wetland landscape prior to human disturbance, 3000 years ago, to have been 3.2×10^5 tC/yr (1.2×10^6 tCO_2e/yr), an amount now reduced by 99% by diking to 2.5×10^3 tC/yr (2.2×10^3 tCO_2e/yr) today. Lost are a range of freshwater, brackish and saline wetlands, leaving a limited fringe of saltmarsh and mudflat. Based on measurements of soil carbon content it is possible to estimate the net carbon accumulation rates of various UK habitat types, including alder car, coastal reedswamp, saltmarsh and mudflat (Table 5.1).

In this study, Andrews et al. estimate modern Humber saltmarshes accumulate carbon at a net rate of 48 – 80 $gC/m^2/yr$ (176 – 293 $gCO_2e/m^2/yr$). This number is based upon marsh carbon contents of 4%.

Table 5.1: Comparison of area, carbon content, and annual carbon accumulation rates in palaeo and modern habitats in the Humber Estuary



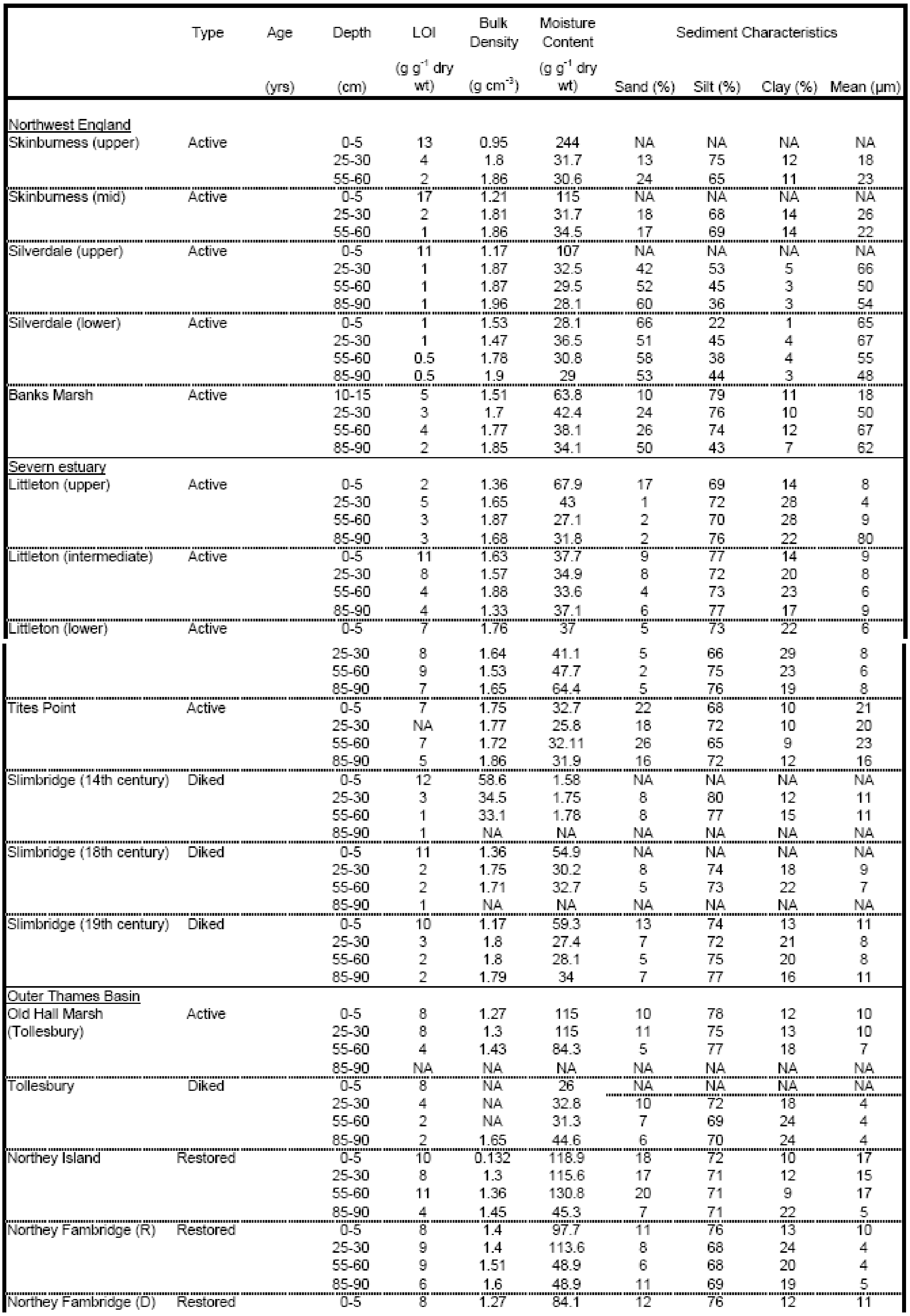
Environment	Area (km^2)	Average C_{org} content (wt%)	Sed deposited in one year (tonne)	C_{org} deposited in one year
3–2 cal. ka BP estuary				
Raised bog*	21	30	2 187	656
AC	918	15	1 837 080	275 562
HSM	117	10	233 280	23 328
LSM	129	4	262 440	10 498
Intertidal flats	305	1	612 360	6 124
	1490		**2 947 347**	**316 167**
Modern estuary				
Raised Bog	neg	30	0	0
AC	neg	15	0	0
HSM	neg	10	0	0
LSM	5	4	10 000	400
Intertidal flats	106	1	212 000	2 120
	111		**222 000**	**2 520**

Notes: AC – Alder Carr; HSM, High Salt Marsh, LSM Low Salt Marsh.

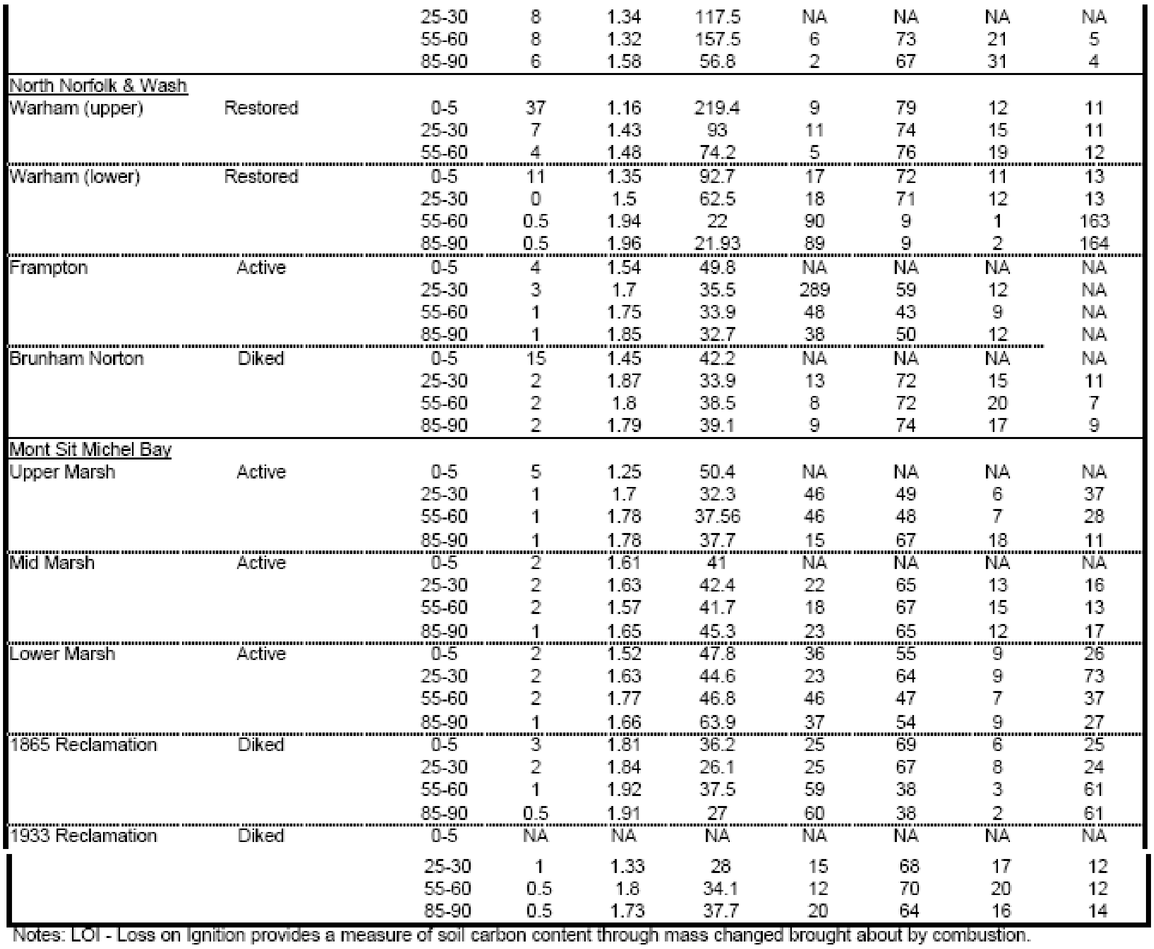
The sedimentological investigation by Crooks (1996) sampled the top 0.75-1.25 m of active, land-claimed and restored saltmarshes at selected locations around the UK coast (as well as marshes in Mont Saint Michelle Bay, France) (Table 5.2). Though limited in extent to 26 sample locations this study provides insights into the variability of saltmarsh carbon sequestration as defined by coastal setting. Broadly, marsh soils with a high sand content possess a carbon content beneath the root zone that is lower than marshes with a low sand content, presumably because heightened oxidation processes in well drained soils (Table 5.2). As a consequence saltmarshes built up ‘sandy; sediments around Morecambe Bay and the Solway Firth (and presumably other marshes around the Irish Sea) possess lower soil carbon (around 1-3 g/g dry weight) that marshes around the Outer Thames basin and Severn Estuary (both around 7-9 g/g dry weight).

We know very little about the carbon sequestration potential of UK freshwater tidal wetlands, beyond the geological analysis by Andrews et al. Potentially, these marshes possess the carbon accumulation capacity of similar common reed marshes investigated in the US. As such likely sequester carbon at a rate higher than saltmarshes but, this increased gain is offset partially or fully by methane emissions. Moreover, as far as the authors are aware no studies have been published that quantify methane emissions from tidal wetlands in the UK.

Table 5.2: Soil carbon content of UK saltmarshes (summary data from Crooks 1996)



	Type	Age	Depth	LOI	Bulk Density	Moisture Content	Sediment Characteristics			
		(yrs)	(cm)	(g g^{-1} dry wt)	(g cm^{-3})	(g g^{-1} dry wt)	Sand (%)	Silt (%)	Clay (%)	Mean (µm)
Northwest England										
Skinburness (upper)	Active		0-5	13	0.95	244	NA	NA	NA	NA
			25-30	4	1.8	31.7	13	75	12	18
			55-60	2	1.86	30.6	24	65	11	23
Skinburness (mid)	Active		0-5	17	1.21	115	NA	NA	NA	NA
			25-30	2	1.81	31.7	18	68	14	26
			55-60	1	1.86	34.5	17	69	14	22
Silverdale (upper)	Active		0-5	11	1.17	107	NA	NA	NA	NA
			25-30	1	1.87	32.5	42	53	5	66
			55-60	1	1.87	29.5	52	45	3	50
			85-90	1	1.96	28.1	60	36	3	54
Silverdale (lower)	Active		0-5	1	1.53	28.1	66	22	1	65
			25-30	1	1.47	36.5	51	45	4	67
			55-60	0.5	1.78	30.8	58	38	4	55
			85-90	0.5	1.9	29	53	44	3	48
Banks Marsh	Active		10-15	5	1.51	63.8	10	79	11	18
			25-30	3	1.7	42.4	24	76	10	50
			55-60	4	1.77	38.1	26	74	12	67
			85-90	2	1.85	34.1	50	43	7	62
Severn estuary										
Littleton (upper)	Active		0-5	2	1.36	67.9	17	69	14	8
			25-30	5	1.65	43	1	72	28	4
			55-60	3	1.87	27.1	2	70	28	9
			85-90	3	1.68	31.8	2	76	22	80
Littleton (intermediate)	Active		0-5	11	1.63	37.7	9	77	14	9
			25-30	8	1.57	34.9	8	72	20	8
			55-60	4	1.88	33.6	4	73	23	6
			85-90	4	1.33	37.1	6	77	17	9
Littleton (lower)	Active		0-5	7	1.76	37	5	73	22	6
			25-30	8	1.64	41.1	5	66	29	8
			55-60	9	1.53	47.7	2	75	23	6
			85-90	7	1.65	64.4	5	76	19	8
Tites Point	Active		0-5	7	1.75	32.7	22	68	10	21
			25-30	NA	1.77	25.8	18	72	10	20
			55-60	7	1.72	32.11	26	65	9	23
			85-90	5	1.86	31.9	16	72	12	16
Slimbridge (14th century)	Diked		0-5	12	58.6	1.58	NA	NA	NA	NA
			25-30	3	34.5	1.75	8	80	12	11
			55-60	1	33.1	1.78	8	77	15	11
			85-90	1	NA	NA	NA	NA	NA	NA
Slimbridge (18th century)	Diked		0-5	11	1.36	54.9	NA	NA	NA	NA
			25-30	2	1.75	30.2	8	74	18	9
			55-60	2	1.71	32.7	5	73	22	7
			85-90	1	NA	NA	NA	NA	NA	NA
Slimbridge (19th century)	Diked		0-5	10	1.17	59.3	13	74	13	11
			25-30	3	1.8	27.4	7	72	21	8
			55-60	2	1.8	28.1	5	75	20	8
			85-90	2	1.79	34	7	77	16	11
Outer Thames Basin										
Old Hall Marsh	Active		0-5	8	1.27	115	10	78	12	10
(Tollesbury)			25-30	8	1.3	115	11	75	13	10
			55-60	4	1.43	84.3	5	77	18	7
			85-90	NA	NA	NA	NA	NA	NA	NA
Tollesbury	Diked		0-5	8	NA	26	NA	NA	NA	NA
			25-30	4	NA	32.8	10	72	18	4
			55-60	2	NA	31.3	7	69	24	4
			85-90	2	1.65	44.6	6	70	24	4
Northey Island	Restored		0-5	10	0.132	118.9	18	72	10	17
			25-30	8	1.3	115.6	17	71	12	15
			55-60	11	1.36	130.8	20	71	9	17
			85-90	4	1.45	45.3	7	71	22	5
Northey Fambridge (R)	Restored		0-5	8	1.4	97.7	11	76	13	10
			25-30	9	1.4	113.6	8	68	24	4
			55-60	9	1.51	48.9	6	68	20	4
			85-90	6	1.6	48.9	11	69	19	5
Northey Fambridge (D)	Restored		0-5	8	1.27	84.1	12	76	12	11



		25-30	8	1.34	117.5	NA	NA	NA	NA
		55-60	8	1.32	157.5	6	73	21	5
		85-90	6	1.58	56.8	2	67	31	4
North Norfolk & Wash									
Warham (upper)	Restored	0-5	37	1.16	219.4	9	79	12	11
		25-30	7	1.43	93	11	74	15	11
		55-60	4	1.48	74.2	5	76	19	12
Warham (lower)	Restored	0-5	11	1.35	92.7	17	72	11	13
		25-30	0	1.5	62.5	18	71	12	13
		55-60	0.5	1.94	22	90	9	1	163
		85-90	0.5	1.96	21.93	89	9	2	164
Frampton	Active	0-5	4	1.54	49.8	NA	NA	NA	NA
		25-30	3	1.7	35.5	289	59	12	NA
		55-60	1	1.75	33.9	48	43	9	NA
		85-90	1	1.85	32.7	38	50	12	NA
Brunham Norton	Diked	0-5	15	1.45	42.2	NA	NA	NA	NA
		25-30	2	1.87	33.9	13	72	15	11
		55-60	2	1.8	38.5	8	72	20	7
		85-90	2	1.79	39.1	9	74	17	9
Mont Sit Michel Bay									
Upper Marsh	Active	0-5	5	1.25	50.4	NA	NA	NA	NA
		25-30	1	1.7	32.3	46	49	6	37
		55-60	1	1.78	37.56	46	48	7	28
		85-90	1	1.78	37.7	15	67	18	11
Mid Marsh	Active	0-5	2	1.61	41	NA	NA	NA	NA
		25-30	2	1.63	42.4	22	65	13	16
		55-60	2	1.57	41.7	18	67	15	13
		85-90	1	1.65	45.3	23	65	12	17
Lower Marsh	Active	0-5	2	1.52	47.8	36	55	9	26
		25-30	2	1.63	44.6	23	64	9	73
		55-60	2	1.77	46.8	46	47	7	37
		85-90	1	1.66	63.9	37	54	9	27
1865 Reclamation	Diked	0-5	3	1.81	36.2	25	69	6	25
		25-30	2	1.84	26.1	25	67	8	24
		55-60	1	1.92	37.5	59	38	3	61
		85-90	0.5	1.91	27	60	38	2	61
1933 Reclamation	Diked	0-5	NA	NA	NA	NA	NA	NA	NA
		25-30	1	1.33	28	15	68	17	12
		55-60	0.5	1.8	34.1	12	70	20	12
		85-90	0.5	1.73	37.7	20	64	16	14

Notes: LOI - Loss on Ignition provides a measure of soil carbon content through mass changed brought about by combustion.

5.2 Restoration potential of tidal wetlands in the UK

The restoration potential of UK salt marshes is variable and can be summarized in general terms and on a regional basis. We would expect that restored marshes in high sediment availability settings would respond more resiliently than those low sediment availability settings. Transferring these principles we would expect that marsh restoration potential is very high in settings such as the Severn Estuary (typical suspended sediment concentrations of over 1000 mg/l), the Humber Estuary (>100 mg/l) and estuaries around the Irish Sea, but very low in the estuaries of south Suffolk, Essex and north Kent where suspended sediments appear to be available at levels of only about 50 mg/l. Consequently, there appears not only to be insufficient sediment available for existing marshes in Essex and North Kent to keep pace with sea level rise but also that additional restoration would further extract sediment from circulation.

Examining the responses of natural marshes, and where available the responses of managed realignment wetlands, to modified hydrology this is indeed what we find. Natural marshes in the Severn Estuary, Morecambe Bay and Ribble Estuary have accreted rapidly when conducive for sediment deposition (Crooks, 1996). By comparison, natural marshes in south Suffolk, Essex and North Kent, are breaking down internally and managed realignment marshes have been slow to recover (Davy et al., 2009).

5.3 Tidal wetland carbon sequestration – UK regional trade-offs

Comparing regions, we find that slightly higher rates of carbon sequestration in poorly drained muddy soils of the Outer Thames Basin salt marshes than in better drained muddy soils of marshes in the Severn Estuary. Moreover, the carbon sequestration potential of restoring ‘sandy’ marshes is low because of the post depositional oxidation of soil carbon. When we look at the restoration potential we find that managed realignment marshes in the Thames Basin are unlikely to be resilient to rising sea level, while managed realignment marshes in the Severn Estuary, the Humber Estuary and estuaries around the Irish Sea are likely to be more resilient. The marshes in the Severn Estuary are likely to be most resilient of all; potentially capable of rapidly building restored wetlands were extensive areas to become available through dyke breaching, even under high rates of sea level rise.

5.4 Managed versus natural wetlands – trade-offs

Because of dependence on mineral sediment supply it is not possible to restore saltmarshes under impaired hydrological conditions (e.g. muted tide marshes) unless a source of mineral sediment is actively supplied. Similarly, active intervention through artificial sediment delivery may be required to maintain some limited extent of vegetated wetlands in the Outer Thames Basin under conditions of accelerated sea level rise.

However, managed freshwater wetlands can be created in inner estuarine settings (such as on the Humber Levels, Somerset Levels, or dyked areas of the inner Wash.) which have potential to sequester carbon, as well as build up marshes’ surfaces at rates that exceed existing and possibly future rates of sea level rise. It may be possible, that through managing seasonal water levels, methane emissions can be reduced to make such managed wetlands a positive contribution to UK GHG mitigation. However, there may be conflicts between this management and the water levels required to achieve nature conservation objectives (e.g. with wading birds requiring standing water in early summer to rear young). The future benefit of such managed wetlands reflects their independence from mineral sediment supply, and so increased GHG mitigation is achieved in a short time frame (compared with saltmarsh restoration) and may over longer time scales lead to the restoration of expansive wetland areas or future soils of high agricultural value.

Appendix to Annex 1 – References

Abril, G., Borges, A.V. (2004). Carbon Dioxide and Methane Emissions from Estuaries. In: Tremblay A, Varfalvy L, Roehm C, Garneau M, editors. Green House Emissions: Fluxes and Processes, Hydroelectric Reservoirs and Natural Environments New York: Springer.

Andrews, J.E., Samway, G., Dennis, P.F. and Maher, B.A. (2003). Origin, abundance and storage of organic carbon and sulphur in the Holocene Humber Estuary: emphasizing human impact on storage change. In Shennan, I. & Andrews. J.E. (Eds.) *Holocene Laond-Ocean Interaction and Environmental Change Around the North Sea*. Geological Society, London, Special publication, pp.166, 145-170.

Barron, C., Marba, N., Terrados, J., Kennedy, H., Duarte, C.M. (2004). “Community metabolism and carbon budget along a gradient of seagress (Cymodocea nodosa) colonization”. *Limnology and Oceanography* 49(5):pp. 1642-1651.

Bridgham, S.D., Megonigal,J.P., Keller, J.K., Bliss, N., B. and Trettin, C. (2006). “The Carbon Balance of North American Wetlands”. *Wetlands*: 26, pp. 889-916.

Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Chmura, G.L., Anisfield, S.C., Cahoon, D.R. and Lynch, J.C. (2003). “Global carbon sequestration in tidal, saline wetland soils”. *Global Biogeochemical Cycles*: 1111, doi:10.1029/2002GB001917.

Craft, C., Megonigal, P., Broome, S., Stevenson, J., Freese, R., Cornell, J., Zheng, L., Sacco, J. (2003). “The Pace of Ecosystem Development of Constructed Spartina Alterniflora Marshes”. *Ecological Applications* 13(5): pp. 1417-1432.

Crooks, S. (1996). *Sedimentological Controls on the Geotechnical Properties of intertidal Saltmarshes and Mudflats*. Unpublished Ph.D. Thesis, University of Reading.

Cornell, J.A., Craft, C.B., Megonigal, J.P. (2007). ”Ecosystem gas exchange across a created salt marsh chronosequence”. *Wetlands* 27(2): pp. 240-250.

Costanza, R., d'Arge, R., De Groot, R., Fraber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J. and others (1997). “The value of the world's ecosystem services and natural capital”. *Nature* 387: pp. 253-260.

Day, J.W. Jr., Boesch, D.F., Clairain, E.J., Kemp, G.P., Laska, S.B., Mitsch, W.J., Orth, K., Mashriqui, H., Reed, D.J., Shabman, L. and others (2007). Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. Pp. 1679-1684.

Duarte, C.M., Middelburg, J.J., Caraco, N. (2005). “Major Role of Marine Vegetation on the Oceanic Carbon Cycle”. *Biogeosciences* 2: pp. 1-8.

Feijtel, T.C., Delaune, R.D., Patrick, W.H. (1985). “Carbon Flow in Coastal Louisiana”. *Marine Ecology-Progress Series* 24(3): pp. 255-260.

Forster, P., Ramaswamy, V., Artaxo, P. Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulz, M. and Van Dorland, , R. (2007):

Garcia, E., Duarte, C., Middelburg, J.J. (2002). “Carbon and nutrient deposition in the Mediterranean seagrass (Posidonia oceanica)”. *Limnology and Oceanography* 47: pp. 23-32.

Green, E. and Short, F. (2003). World Atlas of Seagrasses: California University Press.

Heip, C.H.R., Goosen, N., Herman, P.M.J,, Kromkamp, J,, Middelburg. J.J., Soetaert, K. (1995). ”Production and consumption of biological particles in temperate tidal estuaries”. *Oceanography Marine Biology Annual Review* 33: pp. 1-150.

Holman, I.P. (2009). An estimate of peat reserves and loss in the East Anglian Fens Commissioned by the RSPB. Cranfield University.

Jickells, T. (1998). “Nutrient Biogeochemistry of the Coastal Zone”. *Science* 271(5374): pp. 217-222.

Mateo, M., Romero, J., Perez, M., Littler, M., Littler, D. (1997). “Dynamics of millenary organic deposits resulting from the growth of the Mediterranean seagrass Posidonia oceanica”. *Estuarine, Coastal, and Shelf Science* 44: pp. 103-110.

Megonigal, J.P., Schlesinger, W.H. (2002). “Methane-limited methanotrophy in tidal freshwater swamps”. *Global Biogeochemical Cycles* 16(4).

Miller, R., Fram, M., Fujii, R., Wheeler, G. (2008). Subsidence reversal in a re-established wetland in the Sacremento-San Joaquin Delta, California, USA. San Francisco Estuary & Watershed Science. : Available from: http://repositories.cdlib.org/jmie/sfews/vol6/iss3/art1.

PWA, Associates HT Harvey, Second Nature, Thornton E, Monismith S. 2008. Elkhorn Slough Tidal Wetland Project: Hydrodynamic modelings and morphologic projections of large-scale restoration actions. Prepared for The Elkhorn Slough Tidal Wetlands Project.

PWA and SAIC (2009). Greenhouse Gas Mitigation Typology Issues Paper: Tidal Wetlands Restoration. Report to the California Climate Action Registry, February 4, 2009, PWA Reference 1957.

Romero, J., Perez, M., Mateo, M., Sala, E. (1994). “The below-ground organs of the Mediterranean seagrass Posidonia oceanica as a biogeochemical sink”. *Aquatic Botany* 47:pp. 13-19.

Van Der Nat, F.J. and Middelburg, J.J. (2000). “Methane emission from tidal freshwater marshes”. *Biogeochemistry*: 49, pp. 103-121.

Van Dyke, E., and Wasson, K. (2005). “Historical Ecology of a Central California Estuary: 150 Years of Habitat Change”. *Estuaries* 28(2): pp. 173-189.

Widdows, J., Blauw, A., Heip, C.H.R., Herman, P.M.J., Lucas, C.H., Middelburg, J.J., Schmidt, S., Brinsley, M.D., Twisk, F., Verbeek, H. (2004). “Role of physical and biological processes in sediment dynamics (sedimentation, erosion and mixing) of a tidal flat in Westerschelde estuary, S.W. Netherlands”. *Marine Ecology-Progress Series* 274:pp. 41-56.

Windham, L. (2001). “Comparison of biomas production and decomposition between *Phragmites astralis* (common reed) and *Spartina* patens (salt hay grass) in brackish tidal marshes of New Jersey”. *Wetlands* 21: pp. 179-188.

Woodwell, G., Rich, P. and Mall, C.S.A. (1973). Carbon in estuaries. In: Woodwell GM, Pecan EV, editors. Carbon and the Biosphere: United States Atomic Energy Commission.

Yu, K.W., Faulkner, S.P., Patrick, W.H. (2006). “Redox potential characterization and soil greenhouse gas concentration across a hydrological gradient in a Gulf coast forest”. *Chemosphere* 62(6):pp. 905-914.

Valiela, I., Bowen, J. and York, J. (2001). “Mangrove forests: one of the world threatened major tropical environments”. *Bioscience* 21: pp. 807-815.

A2 Description of TE2100 carbon multiplier

As part of the Environment Agency’s Thames Estuary 2100 (TE2100) strategy Halcrow (2008) estimates a broad-scale “multiplier” (suitable for use in strategic appraisal) to be used to adjust monetary estimates of direct damage to property to account for greenhouse gas (GHG) impacts. This Annex describes the scope, approach, assumptions and results of the model, and some caveats related to its use.

A2.1 Scope

The key flood damage parameters identified by Halcrow (2008) are associated with:

- Building fabric / fixtures / fittings / repairs;
- Replacement of household goods;
- Energy use for hot air blowers / dryers / de-humidifiers; and
- Carbon associated with transport / travel of trades and homeowners.

A2.2 Approach

The carbon calculation for building fabric / fixtures / fittings and household inventory items was based on the embedded carbon of materials within each of these items. The approach taken for the study was to assess the overall weight of items and sub-divide these into the proportion by weight of constituent components. The embedded carbon for these materials was then applied to these totals to provide an overall kg CO_2e. To offset the fact that the embedded carbon within the materials did not include manufacturing, a multiplier was applied to take this into account.

The carbon cost associated with energy consumed by hot air blowers / dryers / de-humidifiers was directly converted from energy consumed in kWh into kg CO_2e using conversion factors. The carbon associated with vehicle emissions is converted from kg CO_2e / km.

A2.3 Assumptions

A number of assumptions lie behind the model:

- Replacement of building materials and household items on a like-for-like basis;
- Replacement by more energy efficient devices was ignored - in some instances, replacement of items may be more energy efficient than the originals, and it may be significant over the lifetime of the product e.g. a fridge or washing machine;

- Life of appliances - the embodied CO_2e per year within appliances depends on the length of the product life, and this variable was not considered; and
- No saving in domestic energy use during repairs - although the property might be unoccupied, there would be domestic energy use associated with alternative (e.g. temporary) accommodation and thus no net change.

Only the carbon associated with the direct effects of flooding were considered, i.e. direct tangible losses for flooded households – damage to building fabric, damage to inventory items, clean-up and drying, and transport associated with these. No account was taken of intangible losses and indirect losses both to flooded and non-flooded households (e.g. increased travel necessary for commuting to work).

The value of carbon applied by Halcrow (2008) is based on guidance for the shadow price of carbon from Defra (2007). The value increases from £25 / t CO_2e in 2007 to almost £60 / t CO_2e in 2050.

Use of the damage multiplier used in the main report includes two sensitivities: (i) application of £25 / t CO_2e; and application of £60 / t CO_2e. In both cases the value is assumed constant across the time horizon. Use of a higher carbon value from 2009 is intended to reflect revisions to guidance for valuing carbon that has been made available by DECC (2009) since Halcrow (2008).

A2.4 Results

The recommended broad-scale ‘multipliers’ (suitable for use in strategic appraisal) to be used to adjust monetary estimates of direct damage to property over time to account for greenhouse gas (GHG) impacts are:

- +2% for short duration flooding of residential and non-residential properties, and
- +2.5% for long duration flooding of residential and non-residential properties.

The multipliers can be applied to undiscounted estimates of direct property damage (e.g. event damages or Annual Average Damage). This applies in Year 0 of an economic appraisal, and can be increased by 2% year-on-year in line with Defra guidance.

A2.5 Main caveats

Modelling a complex issues like the impacts of property flooding on carbon emissions inevitably requires assumptions and simplifications, and therefore the results are subject to a number of caveats. The main caveats of the Halcrow approach are that:

- The multiplier is based on residential properties only, but used for both residential and commercial;
- An average house was the basis for the assessment rather than a representative sample of residential properties;
- The estimated carbon emissions of household goods replacement only includes the embodied carbon of materials, and excludes the manufacturing process of the items (the carbon emissions were scaled up to reflect this but this was based on assumptions); and
- No account is taken of intangible losses and indirect losses both to flooded and non-flooded households (e.g. increased travel necessary for commuting to work).

A2 References

Defra (2007). *How to use the shadow price of carbon in appraisal*. See: http://www.defra.gov.uk/environment/climatechange/research/carboncost/pdf/HowtouseSPC.pdf

DECC (2009). *Carbon Valuation in UK Policy Appraisal: A Revised Approach*, (July 2009). See: http://www.decc.gov.uk/en/content/cms/what_we_do/lc_uk/valuation/valuation.aspx

Halcrow (2008). Thames Estuary 2100. Greenhouse gas implications of flood damages. Phase 3 Studies – Work Element 2.11a

A3 FCERM carbon footprint (spreadsheet model)

[See separate file]

A4 Case studies

A4.1 Overview

This Annex presents a series of case studies that illustrate the application of the framework for analysis set out in the main report at an individual FCERM scheme level. In particular the formulation of the FCERM carbon footprint in Figure 2.3 is specified in terms of a high-level assessment of the GHG implications of the overall FCERM policy, but it also relevant to the individual FCERM scheme level.

Moreover, the gap analysis (Section 4.2) and conclusions (Section 5) identify opportunities to make carbon footprint assessments a routine element of FCERM project appraisal. These case studies provide an initial attempt in this regard, drawing on available information and data and fitting this within the carbon footprint framework.

The case studies are based on a selection of recently implemented or appraised coastal and inland flood alleviation projects:

- Alkborough managed realignment (Section A4.2);
- Lower Derwent flood risk management strategy (Section A4.3)
- Dymchurch coastal defence scheme (Section A4.4); and
- Cobbins Brook flood alleviation scheme (Section A4.5).

Source material has primarily been provided by the Environment Agency. The coverage of the case studies is by no means comprehensive, with the main focus on inland and coastal flood alleviation schemes as well as broad summary of a managed realignment example. Examples covering alternative FCERM activities types such as coastal erosion or schemes involving significant pumping and water level management activities would enhance the coverage and help distinguish further data requirements for different FCERM policy areas. However the scope to develop case studies in these areas has been limited by data availability.

A4.2 Alkborough managed realignment

A4.2.1 Introduction

The Alkborough Flats is a 440-hectare (ha) site at the confluence of the Rivers Trent and Ouse in the Humber Estuary, North Lincolnshire (Figure A4.1). As part of the response to extensive tidal flooding in the Humber in 1953, a flood embankment was built to protect the boundary between the low-lying agricultural land on the flats, which sit below the village of Alkborough, and the rivers. Following this initial tidal-flood-defence construction, about 375ha of Grade-2 agricultural land remained behind the defences (EA *undated*).

Figure A4.1: Alkborough Flats Site (EA et al., "The Alkborough Flats Project")

The majority of current flood defences in the Humber Estuary were built in response to the 1953 flooding. Now 50 years on they are coming to the end of their lifecycle and a new flood-defence strategy has been developed and is being implemented by the Environment Agency for England and Wales (EA 2008).

At Alkborough Flats, the flood embankments are experiencing bank settlement and erosion, and with the additional concern of rising sea levels, would be compromised in the future. As such, the site was considered and agreed on as a site for managed realignment (Coastal Futures, *undated*).

In Autumn 2006 modifications to the flood embankment were carried out, that included:

- A 20-metre breach in the existing defence;
- A 1,500-metre length of lowered embankment or spillway; and
- A new section of flood bank to protect assets at the edge of the site.

After these modifications had taken place, a 6.4km embankment remained at the site, designed to meet the dual objectives of the scheme as set out in the Environment Agency Project Appraisal Report (PAR) (EA, 2005):

- To provide flood storage to reduce peak tide levels in the estuary during extreme events, resulting in approximately £12 million savings from deferring works to improve existing defences elsewhere in the estuary; and
- To contribute to habitat creation responsibilities under the EU Birds and Habitats Directives, by creating up to 170ha of new inter-tidal habitat and approximately 200ha of assorted other natural habitats, including grazing marsh, grassland and reedbed.

The managed realignment scheme cost £10.2 million[56] to carry out (EA, *undated*) and has a lifetime of 30 years (EA, 2008)

4.2.2 Carbon footprint assessment

Following the methodology set out in the main Technical Report, the carbon footprint assessment of the 2006 managed realignment at Alkborough Flats is dependent on three primary aspects:

- Carbon from FCERM activities;
- Carbon associated with flood and coastal erosion damages; and
- Carbon from dependent activities.

Assessment of carbon from FCERM activities

The Technical Report details the estimation of a carbon intensity factor that relates the cost of asset construction to carbon emissions. It is not possible to determine how suitable it is to apply the carbon intensity factor in this case study. For example:

- Review of Table 3.10 (see Technical Report) reveals that no managed realignment schemes within the sample of 31 available. This suggests that

---

[56] It was funded by the Environment Agency "via the Department for Environment, Food and Rural Affairs (Defra,) Yorkshire Forward, the Heritage Lottery Fund and the European Union (EU) through the Interreg programme." (EA, *undated*).

the construction activities of interest here - primarily concerning earth embankments (which can comprise a variety of materials use; e.g. clay, earth, sand, gravel, timber and fabrics) and the movement of embankment material on-site - may not be well represented by the mix of defences and structures that comprise the set of schemes in the construction carbon calculator data.

- Breakdown of the construction carbon calculator data (Figure 3.1 and Table 3.10) indicates that materials transport is often a significant contributor to the carbon footprint of scheme construction. No information is available on the material transport aspect of the managed realignment scheme and removal of breach material.

Taking the reported cost of the managed realignment scheme at Alkborough Flats (£10.2 million) and applying the mid-range estimate carbon intensity factor (0.91 kg CO_2e / £) gives an estimate of 9,282 t CO_2e emissions associated with construction activities. Basic sensitivity analysis using the range of carbon intensity estimates from the Technical Report gives a range of emissions of approximately 2,000-10,000 t CO_2e (Table A4.1)[57].

Table A4.1: Estimated GHG emissions associated with construction of Alkborough Flats managed realignment scheme

Scenario	Carbon intensity factor (kg CO_2e / £)	Source	Associated emissions (t CO_2e)
Low	0.20	Arup (2008)	2,040
Medium	0.91	Technical Report	9,282
High	0.98	Technical Report	9,996

Comparison to the schemes for which construction carbon calculator data is available indicates that estimated range for Alkborough Flats places this in the upper end of schemes in terms of emissions. This result is of course driven only by scheme cost; Table 3.11 (Technical Report) shows that cost of most schemes in the available sample is less than £4 million.

Uncertainty as to the estimated range for carbon would be reduced by applying a carbon intensity factor estimated from earthwork construction or alteration activities to the relevant proportion of costs for the scheme. However, it is likely that an improved estimate would likely fall within the estimated range and be in the same order of magnitude, so the assessment here should be broadly interpretable as a ‘ballpark’ estimate of carbon from construction activities.

---

[57] A fuller breakdown of scheme costs would permit an assessment of how a managed realignment scheme such as Alkborough compares to more typical hold the line works. For example managed realignment may have more site analysis input to manage habitat/land use change on area to be flooded. Reasonably this can be expected to have lower carbon emissions than use of machinery.

Assessment of carbon associated with FCERM damages

The primary benefit arising from the scheme is the provision of flood accommodation space at Alkborough Flats, which assists with lowering the water level across the Humber Estuary during extreme events. For example, for the most extreme event (i.e. 1 in 200 events), the scheme is expected to lower water levels by 150mm (EA, *undated*). This effect means it is possible to defer the construction of £12 million worth of flood river defences in the tidal rivers upstream of the site[58].

Following from this the Alkborough scheme assists in reducing the flood and coastal erosion damages upstream, and consequently emissions associated with refurbishing or rebuilding damaged properties. This reduction, however, is indirect and it is difficult to attribute specific emissions reductions associated with reduced damages to the Alkborough defences. As a result emissions for this aspect for the carbon footprint of the scheme are not estimated.

Assessment of carbon from dependent activities

The greatest effect of managed realignment at Alkborough Flats in terms of carbon footprint overtime is likely to be associated with land use change. Approximately 370ha of cultivated agricultural land were converted to 170ha of inter-tidal habitat with an additional 200ha converted to a mix of other natural habitats, including 50ha of freshwater reedbed and 100ha of wet grassland (EA, 2009). Additionally, 5ha of inter-tidal habitat was lost elsewhere in the Humber (as a direct result of the Alkborough scheme), meaning the net change in inter-tidal habitat is an increase of 165ha.

Each of these land uses has a different level of carbon emissions or sequestration associated with it. Previous use of the land for agriculture is assumed to have resulted in net GHG emissions. For example as Grade 2 agricultural land it is likely the land was used for a mix of crop cultivation (see Annex 1, Section A1.3). Net emissions from cereals cultivation and general cropping have been estimated throughout the UK as 2.74 and 4.85 t CO_2e per ha per year[59], respectively, which provide lower- and upper-bound carbon factors to

---

[58] Here there is another potential aspect to the carbon footprint of the Alkborough scheme. Deferring other defence works implies deferring carbon emissions associated with their construction and maintenance. This aspect is not quantified within the analysis here but a fuller assessment of how emissions arise over time across the estuary strategy area could address questions as to how land use management can contribute to the carbon footprint implications of defence across a spatial area. For example, the basic comparison that can be made is that the cost of scheme (approximately £10m) is less than the savings to works elsewhere (approximately £12m). In this sense there is likely to be a net reduction in carbon emissions in the present, dependent on the types of works and for on how long they are deferred. Coupled with this there is also reduction in carbon compared with a baseline of no managed realignment and other works in relation to a reduced residual damages.

[59] Sourced from Carbon Accounting for Land Managers (CALM): http://www.calm.cla.org.uk/

estimate avoided emissions under the Alkborough scheme[60]. Applying these estimates, the net GHG emissions from the agricultural land prior to conversion for managed realignment is estimated to be 1,014 - 1,795 t CO_2e per year, averaging 1,404 t CO_2e per year (Table A4.2).

Table A4.2: Estimated net annual GHG emissions from agricultural land prior to Alkborough Flats managed realignment

Estimate	**Area (ha)**	**Net GHG emissions per hectare (tCO_2e/yr)**	**Total annual GHG emissions (tCO_2e/yr)**
Lower (cereals)	370	2.74	1,014
Upper (general cropping)	370	4.85	1,795
Average	370	3.80	1,404

In addition to avoiding agricultural emissions, the realignment has converted land to a state where it sequesters carbon. Based on research of modern Humber inter-tidal habitat, the new inter-tidal habitat can potentially sequester carbon at an annual rate of approximately 8.1 t CO_2e per ha (Andrews et al, 2000). For the other habitat types created, it is not specified how much of each has been created. As such, it is difficult to estimate the level of carbon sequestration associated with them. It is estimated, however, that the average annual net GHG emissions associated with land in the UK set aside as a “nature reserve” is -0.78 t CO_2e per ha[61], which can be applied here as a proxy. Applying these emissions factors, the habitat created from managed realignment is estimated to sequester approximately 1,493 t CO_2e per year (Table A4.3).

Table A4.3: Estimated net GHG emissions from habitat created during Alkborough Flats managed realignment

Habitat Type	**Net area (ha)**	**Net GHG emissions per hectare (t CO_2e per yr)**	**Total annual GHG emissions (t CO_2e per yr)**
Inter-tidal Habitat	165	-8.1	-1337
Other Habitat	200	-0.78	-156
Of which.... Reedbed	*50*	*-0.78*	*(-39)*
Wet grassland	*100*	*-0.78*	*(-78)*
Total	365	n/a	-1493

Based on the simple calculations here using readily available data, the conversion of agricultural land to inter-tidal and other habitats has resulted in a

---

[60] In practice all agricultural land is not totally lost to the scheme but for simplicity this is assumed to be the case here.

[61] Sourced from Carbon Accounting for Land Managers (CALM): http://www.calm.cla.org.uk/

change of GHG emissions of around -2,897 t CO_2e per year (i.e. sequestration of up to 3,000 t CO_2e per year from the site). Over the estimated 30-year lifetime of the project, this totals to net GHG emissions of -86,895 t CO_2e (Table A4.4).

Table A4.4: Estimated total change in GHG emissions from land use associated with Alkborough Flats managed realignment

Estimate	Change in net annual emissions (t CO_2e)	Total change in net emissions (t CO_2e over 30 years)
Lower	-2,506	-75,189
Upper	-3,287	-98,610
Average	-2,897	-86,895

The figures in Table A4.4 should be regarded as crude estimates of the likely net carbon sequestration from the land-use changes due to the managed realignment of Alkborough. In particular, the result is sensitive to assumptions about the type and intensity of farming methods on the land prior to realignment, and the carbon flux of the intertidal habitat created (which is dependent on environmental factors such as estuary water silt content and salinity) (see Annex 1 for further detail). These assumptions should be further refined before specific claims about the level of carbon emissions reduction associated with the land use changes resulting from the project are made.

A4.2.3 Summary

For the managed realignment scheme at Alkborough Flats, it is currently feasible to provide a broad-based estimate of the emissions from FCERM activities and other dependent activities associated with the scheme. Using a carbon intensity factor based on expenditures that was calculated from the Environment Agency Construction Carbon Calculator, emissions from FCERM activities at the site were approximately 9,282 t CO_2e. The change in activities dependent on the choice of flood management strategy at the site was a replacement of 370 ha of agricultural land with inter-tidal and other restored natural habitats. The approximate change in net annual emissions associated with this land use change was -2,897 t CO_2e (with roughly half from avoided agricultural emissions and half from sequestration within the habitats created), which aggregates to -86,895 t CO_2e over the 30-year lifecycle of the scheme. Overall, the scheme appears to make a net contribution to climate change mitigation of the order of approximately 80,000 t CO_2e over a 30 year period (Table A4.5).

Table A4.5: Estimated total net GHG emissions associated with managed realignment at Alkborough Flats

Estimate	**Emissions (t CO$_2$e over lifetime of project)**				
	FCERM Activities (total)	*Associated with flood and coastal erosion damages*	*From dependent activities*		*Total*
			Annual	*Over 30 years*	
Lower	+9,996	(-)	-2,506	-75,189	< -65,193
Middle	+9,282	(-)	-2,897	-86,895	< -77,613
High	+2,040	(-)	-3,287	-98,610	< -96,570

Although this assessment provides a reasonable estimate of the net emissions associated with the scheme, there are a number of ways it could be improved if certain data were available:

- *Assessment of carbon from FCERM activities*: carbon intensity factors, to estimate the emissions associated with construction and maintenance of a scheme, that are based on expenditures are an accessible tool to assess carbon emissions associated with future projects. In this case, however, the intensity factors would be more appropriate if one were developed based specifically on similar projects (i.e. managed realignment, or earthworks more generally) than on all previous projects. Due to this data gap, this aspect of the assessment is subject to a reasonable amount of uncertainty. However it is nearly an order of magnitude smaller than the estimated potential sequestration capacity associated with the current land-use, so should not significantly affect the overall results of the assessment presented here.

- *Assessment of carbon associated with flood and coastal erosion damages*: emissions associated with flood and coastal erosion damages avoided by the managed realignment scheme at Alkborough Flats are difficult to estimate due to the *indirect* nature of flood management benefits associated with an *accommodation space* such as the flood storage at this site. Estimating the damage avoided attributable to this scheme would increase the estimate of carbon emissions avoided by its implementation.

- *Assessment of carbon from dependent activities*: greater specification of the area and types of natural habitat created by the managed realignment would make the estimate of sequestration capacity of the land after implementation of the scheme more accurate, but likely not change the direction of net emissions (i.e. that the area should now be a carbon sink overtime). Similarly, greater specification of the area and types of agricultural area lost through managed realignment would make the estimation of emissions avoided more accurate, but would not change the direction of net emissions avoided (i.e. that previous agricultural land was a net carbon emitter).

Although, more detailed information is always desirable, this case study illustrates that reasonable broad based estimates of the carbon emissions associated with a managed realignment scheme are feasible to assess based on basic project information. In the absence of site-specific studies of change in carbon emissions/sequestration associated with land-use change, carbon factors developed as UK averages for a land-use or based on site studies for similar land-types can be used to facilitate carbon assessment at the site of interest.

Most importantly, however, the study illustrates the difficulty in determining the avoided emissions associated with avoided property damages (i.e. avoided carbon associated with flood and coastal erosion damages) for schemes designed to provide *accommodation space* in order to lower water levels in areas outside the site of interest.

A4.2.4 References

Andrews, J. E., Samways, G., Dennis, P. F. and Maher, B. A., 2000. Origin, abundance and storage of organic carbon and sulphur in the Holocene Humber Estuary: emphasising human impact on storage changes. In Shennan, I. and J. Andrews, J. (Eds), *Holocene Land-Ocean Interaction and Environmental Change around the North Sea*. Geological Society Publishing House, Bath, UK. Geol. Soc. Spec. Publ. 166: 145-170.

Arup, 2008. *Thames Estuary 2100 Cost Integration. Phase 3 Studies – Work Element 5.4*. Stage 1 Report

Coastal Futures, *undated*. Case Study 3: Alkborough Flats, North Lincolnshire. Available online at: [http://www.coastalfutures.org.uk/benefits.html#3].

Environment Agency (EA), *undated*. *The Alkborough tidal defence scheme*. Available online at: [http://www.environment-agency.gov.uk/research/planning/108978.aspx].

Environment Agency (EA), 2008. *The Humber Flood Risk Management Strategy: Planning for the rising tides*. Available online at: [http://www.environment-agency.gov.uk/homeandleisure/floods/31704.aspx].

Environment Agency (EA), 2009. *MRMoToWFO – Final report to LIFE+*. Available online at: [http://www.environment-agency.gov.uk/homeandleisure/floods/31704.aspx].

A4.3 Lower Derwent flood risk management strategy

A4.3.1 Introduction

There is a history of river flooding in the Derwent catchment. The last major event occurred in 1965 when nearly 700 properties flooded, although since 2000 several events have resulted in inundation of properties and traffic disruption (Environment Agency, 2008a; Environment Agency, 2008b). The impact of flooding is significantly higher in the lower regions and while there are a number of permanent flood defences throughout the Derby area some of these are coming to the end of their design life leading to lower protection against flooding.

The Lower Derwent Flood Risk Management Strategy (LDFRMS) sets out the preferred flood risk management (FRM) option to address flooding in the catchment. The ‘typical’ FRM objectives are evident:

- Reduce risk to life, protect and enhance people’s social well-being;
- Protect property (commercial and residential) and existing infrastructure;
- Protect and enhance biodiversity, cultural heritage and landscape; and
- Allow the river to be an integral part of the urban environment.

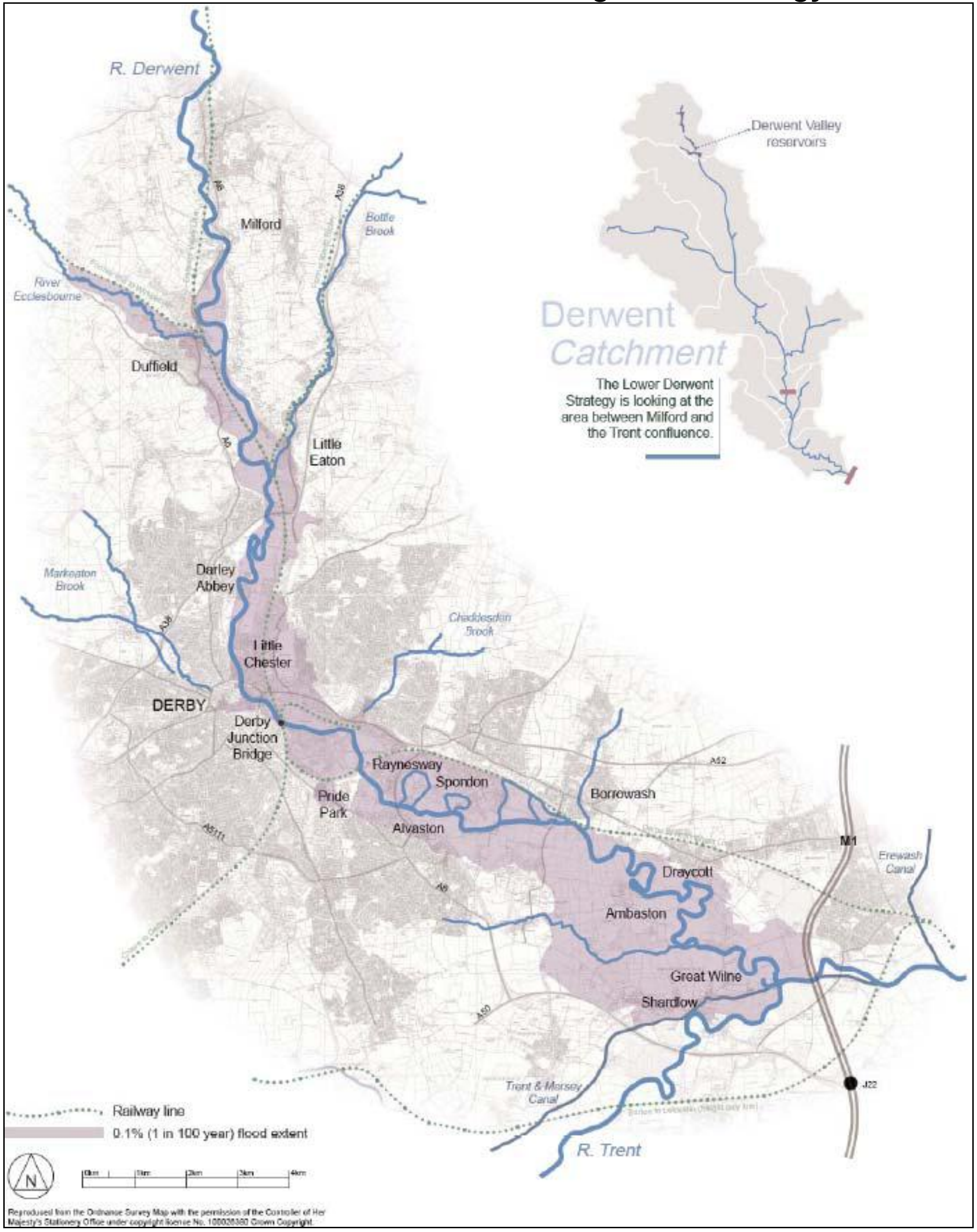
The LDFRMS covers 32km of the River Derwent from the village of Milford, 10km north of Derby, to the River Trent confluence (Figure A4.2). As noted, incidents of flooding are higher in the lower reaches of the catchment hence the main concentration of FRM options are within this area. The source of the River Derwent is in the Peak District National Park. Key tributaries include the River Ecclesbourne, Markeaton, Bottle and Chaddesden Brooks.

Another project - ‘Moors for the Future’ - conducted within the Peak District also has a potential influence on flood risk in the Derwent catchment. In particular restoration of upland moors can increase upstream water storage resulting in reduced flood risk in areas such as Derby.

Current flood defences

There are currently 28km of flood defences maintained by the Environment Agency within the catchment, made up of walls and earth embankments. These defences protect Derby, upstream villages of Duffield and Little Eaton, and downstream villages of Ambaston, Draycott, Great Wilne and Shardlow (Environment Agency, 2008b). Most of these defences are grade 3 or greater. However, at three locations within Derby, temporary urgent works were carried out between March and August 2007 to reduce risks of sudden failure, loss of life and injury (Environment Agency, 2008b). In addition to these flood defences there is an early warning system that home owners can sign up to. This provides warnings to those within Flood Zone 2[62] throughout the study area, although the public take up is low at 21% (Environment Agency, 2008b).

Figure A4.2: Lower Derwent Flood Risk Management Strategy area



The Lower Derwent Strategy is looking at the area between Milford and the Trent confluence.

Reproduced from the Ordnance Survey Map with the permission of the Controller of Her Majesty's Stationery Office under copyright license No. 100026380 Crown Copyright.

Source: Reproduced from (Environment Agency, 2008b)

---

[62] Flood zones (Zone 2 = moderate risk) indicate the risk of flooding from rivers, the sea and tidal sources and ignore the presence of existing defences, since these can be breached, overtopped and may not be in existence for the lifetime of a residential or commercial development, (Communities and Local Government, 2006).

Current flood risk

Table A4.6 establishes that there are currently 2,900 residential and 750 commercial properties at risk of a 1% (1 in 100 years) annual exceedance probability (AEP) flood event, across 36 flood cells assessed in the LDFRMS. The majority of properties at risk (2,150) are in the Derby area. In addition, there are several pieces of infrastructure that are also at risk of flooding including:

- Sewage treatment works at Duffield, Spondon and Great Wilne;
- Sewage pumping station and water treatment works at Little Eaton;
- Electricity substation at Silk Mill within Derby;
- Mainline railway between Birmingham and Sheffield;
- Control of major hazards (COMAH) sites at Rolls Royce (Raynesway) and Courtaulds (Spondon).
- A number of communities are also considered to be vulnerable including: sheltered accommodation for elderly people along City Road in Derby; ring-banked villages at Ambaston and Great Wilne; and isolated properties within the floodplain that are not currently protected by flood defences in the upper and lower reaches of the study area.

Table A4.6: Summary of existing flood defences, flood risk and condition grades

Flood cell	No. properties at risk	Onset of flooding (AEP)	Existing flood defences	Condition grades	Residual life (years)	FRM options
Milford LB	3	4%	Agricultural defences	4	10	FW
Milford RB	8	1%	None	None	None	FW
Duffield RB	63	4%	None	None	None	FW, CHFV
Ecclesbourne LB1	51	1.3%	Earthworks	1 – 3	20 – 30	FW, AR, RD
Ecclesbourne + Duffield RB1	475	4%	Concrete flood walls	2 – 3	20 – 30	FW, AR, RD, CNDA
Duck Island	2	1.3%	Earthworks	3 – 4	10 – 20	FW, AR
Edge Hill	4	4%	None	None	None	FW
War Memorial	3	4%	None	None	None	FW
Bottle Brook LB1	0	>0.5%	Concrete and masonry structures	2 – 3	20 – 30	FW, AR, RD
Bottle Brook LB2	29	1.3%	Masonry and earthworks	2 – 3	20 – 30	FW, AR, RD
Bottle Brook RB	223	4%	Earthworks and concrete	3	20	FW, AR, RD, CNDA
Little Eaton Jct	0	>0.5%	None	None	None	FW
Little Eaton RB	1	4%	Agricultural defences	4	10	FW
Breadsall	0	>0.5%	None	None	None	FW
Darley Abbey Park RB	10	4%	None	None	None	FW
Darley Fields RB	8	0.5%	None	None	None	FW

Flood cell	**No. properties at risk**	**Onset of flooding (AEP)**	**Existing flood defences**	**Condition grades**	**Residual life (years)**	**FRM options**
Darley Fields LB	0	>0.5%	None	None	None	FW
Darley Abbey	69	1.3%	Concrete, masonry and earthworks	2 – 4	10 – 30	FW, AR, RD
Derby City RB	334	2%	Masonry, earthworks and concrete	2 – 5	10 – 30	FW, AR, RD, CNDA
Derby Left Bank	2,160	2%	Masonry, earthworks and concrete	2 – 5	10 – 30	FW, AR, RD, CNDA
Pride Park and Wilmorton	5	1%	Earthworks (private)	2 – 4	10 – 30	FW
Derby sand and gravel	-	>0.5%	Earthworks (private)	-	-	FW
Chaddesden	37	2%	Earthworks	3	20	FW
Derby Landfill	36	0.67%	Earthworks	3	20	FW, AR, RD
Raynesway	9	0.5%	Earthworks (private)	-	-	FW
Spondon	22	2%	Earthworks (some private)	3	20	FW
Spondon Sluice	-	>0.5%	Earthworks (private)	-	-	FW
Alvaston Loop	0	>0.5%	Earthworks (private)	-	-	FW
Alvaston RB	197	0.5%	Earthworks	3	20	FW
Borrowash LB1	0	>0.5%	Earthworks	-	-	FW

Flood cell	No. properties at risk	Onset of flooding (AEP)	Existing flood defences	Condition grades	Residual life (years)	FRM options
			(private)			
Borrowash LB2	0	>0.5%	Earthworks (private)	-	-	FW
Elvaston	17	4%	Agricultural defences	4	10	FW
Draycott	53	4%	Earthworks and concrete	4	10	FW, AR, RD
Ambaston	48	4%	Earthworks	3	20	FW, AR, RD
Great Wilne	20	1.3%	Earthworks and concrete	2-4	10-30	FW, AR, RD
Shardlow	480	4%	Earthworks and concrete	1-2	10-30	FW, AR, RD

Source: Adapted from Environment Agency (2008b). Options: FW = flood warning and provide flood resilience; AR = asset management replacement; RD = raise Defences to optimum standard of protection (SoP); CNDA = construct new flood defences along new alignment; CHFV = Construction of headwall and flap value.

A4.3.2 Carbon footprint assessment

Following the methodology set out in the Technical Report, the carbon footprint assessment of the LDFRMS is dependent on three primary aspects:

- Carbon from FCERM activities;
- Carbon associated with flood and coastal erosion damages; and
- Carbon from dependent activities.

Available data permits for a broad assessment of the above. This includes:

- Establishing a business as usual (BAU) baseline case;
- Establishing the FRM options considered within the strategy;
- Identifying costs of FRM options in terms of maintenance and capital costs to provide a basis for estimating carbon associated with these activities;
- Identifying the residual damages under each FRM option to estimate carbon associated with flood damages; and
- Establishing details of any land use management options.

From this the case study contrasts carbon emissions that arise from construction and maintenance activities that increase the standard of protection (SoP) in the catchment to carbon associated with residual damages under different SoPs. Due to lack of data, no assessment is made of carbon arising from dependent activities.

Business as usual case

For the purpose of this case study, the BAU case applied is ‘do minimum’, which the LDFRMS presents as the existing situation with ‘patch and repair’ to slightly prolong the life of current defences until they reach the end of their design life.

Flood risk management options

The following options were considered as part of the initial screening process in the LDFRMS.

- *Flood warning and flood resilience*: maintain and improve current flood warnings, and improve public up take of the service. The carbon footprint of this option is not assessed here.

- *Asset replacement*: renewal or replacement of assets as they reach the end of their design life (this is based on the condition grade identified during asset inspections in 2006), assuming that no work is carried out to raise defences to maintain current SoP, and that all construction is carried out along the existing line of defence.

- *Replacing and raising existing defences (outside of Derby city centre):* improvements in existing defences were assessed to improve the standard of protection (SoP) to 1.3%, 1% and 0.67%. In some cases, raising existing defences to the optimum level along with undertaking repair on existing defences to improve their condition was also considered (it is assumed that if an existing defence cannot withstand additional loading these would be demolished and a new flood defence constructed).

- *Improving conveyance*: changing how new bridges are constructed over the River Derwent, as well as considering options to improve conveyance through existing bridges. The carbon footprint of this option is not assessed here as this option was dropped from the LDFRMS due to the high costs associated with implementation.

- *Realign defences*: realigning defences too a new line through Derby City centre to the optimum standard of protection.

- *Additional defences:* Construction of headwall structure on minor watercourses.

As shown in Table A4.6 (see above) a number of these options were considered for each flood cell. This allows for the calculation of the carbon emissions related to three different SoP, defined as:

- Option 1 (O1) with a SoP of 1.3%;
- Option 2 (O2) with a SoP of 1%; and
- Option 3 (O3) with a SoP of 0.67%.

For the carbon footprint assessment, only schemes that were considered beyond the initial screening phase of the LDFRMS are considered.

Assessment of carbon from FCERM activities

Capital and maintenance costs

Table A4.7 presents costs associated with the construction and maintenance activities required to achieve different SoPs across a selection of flood cells for which schemes were considered beyond the initial screening phase.

Table A4.7: LDFRMS annual construction and maintenance costs (2008 £) (£,000s)

Flood Cell	No. properties at risk	Onset of flooding (AEP)	BAU		O1 (1.3%)		O2 (1%)		O3 (0.67%)		FRM options
			Construction	Maintenance	Construction	Maintenance	Construction	Maintenance	Construction	Maintenance	
Duffield RB	63	4%	0	0	0.7	4.5	1.06	4.5	1.42	4.5	FW, CHFV
Ecclesbourne LB1	51	1.30%	1	1.4	38.26	6.34	47.1	6.34	52.42	6.34	FW, AR, RD
Ecclesbourne + Duffield RB1	475	4%	0	1.18	137.92	10.9	168.28	10.9	201.14	10.9	FW, AR, RD, CNDA
Duck Island	2	1.30%	0.02	0.98	4.32	4.42	5.18	4.42	5.74	4.42	FW, AR
Bottle Brook LB1	0	>0.5%	0	0.76	0	3.44	0	3.44	0	3.44	FW, AR, RD
Bottle Brook LB2	29	1.30%	0	0.62	0.24	1.48	2.14	1.48	4.48	1.48	FW, AR, RD
Bottle Brook RB	223	4%	0.72	3.28	59.06	5.28	70.18	5.28	86.18	5.28	FW, AR, RD, CNDA
Darley Abbey	69	1.30%	1.96	1.06	51.12	4.86	62.52	4.86	101.36	4.86	FW, AR, RD
Alvaston RB	197	0.50%	0	0	0	0	0	0	0	0	FW
Draycott	53	4%	0	1	42.78	4.56	45.32	4.56	49.46	4.56	FW, AR, RD
Great Wilne	20	1.30%	0	1.08	31.3	4.92	36.7	4.92	37.52	4.92	FW, AR, RD
Shardlow	480	4%	0	2.82	43.48	12.86	50.02	12.86	62.22	12.86	FW, AR, RD
New flood defence alignment (Derby city RB and Derby LB)	2494	2%	0	4	518.62	47.18	586.34	47.18	747.88	47.18	CNDA

Notes:
Costs are undiscounted; BAU = do minimum; O1 = Option 1, FRM measures result in a SoP of 1.3%; O2 = Option 2, FRM measures result in a SoP of 1%; O3 = Option 3, FRM measures result in a SoP of 0.67%; FW = flood warning and provide flood resilience; AR = asset management replacement; RD = raise defences to optimum standard of protection (SoP); CNDA = construct new flood defences along new alignment; CHFV = Construction of headwall and flap value.

Using the cost estimates presented in Table A4.7 carbon emissions resulting from construction and maintenance activities to achieve different SoPs in the catchment are estimated by applying carbon intensity factors (kg CO2e / £):

- *Carbon from construction activities*: estimated using the mid-range estimate carbon intensity factor (0.91 kg CO_2e / £) detailed in the Technical Report (see Table 3.10). The sample of schemes available in construction carbon calculator data include a number of inland flood risk management works hence it assumed that it is reasonable to apply this intensity factor here.
- *Carbon from maintenance activities*: estimated using a lower carbon intensity factor (0.20 kg CO_2e / £). Use of this lower value is somewhat arbitrary but is drawn from the evidence presented in the Technical Report. This aspect of the analysis would be improved if more information was available as to the nature of maintenance activities associated with options.

Table A4.8 presents estimates of the annual carbon emissions associated with construction and maintenance:

- Estimated total carbon emitted annually for achieving different SoPs is:

    - BAU = 7 t CO_2e per year;
    - O1 (1.3%) = 866 t CO_2e per year;
    - O2 (1%) = 1,000 t CO_2e per year; and
    - O3 (0.67%) = 1,250 t CO_2e per year.

  As would be expected the highest estimate for carbon emissions is for Option 3 (O3), which provides a greater level of protection and consequential higher construction costs. Defences are required to be higher/longer to protect properties subject to infrequent but significant flood events. The increase in the carbon emitted between options is entirely driven by construction costs as maintenance costs remain constant after an initial increase from BAU.

- Results are as expected with options for flood cells relating to higher numbers of 'at risk' properties costing more and thus resulting in a higher estimated carbon footprint, although these increases are not linear.

- The individual flood cells with the highest footprint across different SoPs are Ecclesbourne and Duffield RB1, and Shardlow, both of which aim to protection of more than 450 properties. The 'new defence' alignment which stretches across two flood cells (Derby city RB and Derby LB) has the greatest footprint (since construction costs are approximately ten times greater than for options relating to other flood cells), however, there are approximately five times more properties at risk within this combined cell than at Ecclesbourne and Duffield RB1, and Shardlow.

- Flood cells in which high construction costs are prevalent tend to rely on the application of a number of the flood risk management options described in above. The 'new defence' strategy in particular involves all aspects of these described options. In contrast most options relating to flood cells with lower carbon footprints rely on asset replacement and the raising of defences.

Land use management

In addition to asset construction and maintenance activities the LDFRMS also recommends the addition of 43 hectares of wetland (BAP habitat) to lower river levels in Derwent catchment. This habitat may serve as a net sequester of carbon and contribute to reducing the overall carbon footprint of the FRM options as a whole.

The type of wetland habitat to be created/restored is inland freshwater marsh. However, at present there is limited information relating to the carbon sequestration potential of inland marsh, meaning it is not possible to estimate a net carbon for this aspect of the LDFRMS. To enable an account for the carbon budget associated with the increased inland marsh account is required for all processes that release (for example methanogenesis) or take-up carbon.

Further land use management activity that may potentially influence flooding in the Lower Derwent Catchment includes the Moors for the Future project (Box A4.1).

Table A4.8: Assessment of annual carbon footprint associated with construction and maintenance activities within LDFRMS

Flood cell	No. properties at risk	Onset of flooding (AEP)	Estimated carbon emissions from construction (t CO2e/yr)				Estimated carbon emissions from maintenance (t CO2e/yr)			
			BAU	O1	O2	O3	BAU	O1	O2	O3
Duffield RB	63	4%	0.00	0.64	0.96	1.29	0.00	0.90	0.90	0.90
Ecclesbourne LB1	51	1.30%	0.91	34.82	42.86	47.70	0.28	1.27	1.27	1.27
Ecclesbourne + Duffield RB1	475	4%	0.00	125.51	153.13	183.04	0.24	2.18	2.18	2.18
Duck Island	2	1.30%	0.02	3.93	4.71	5.22	0.20	0.88	0.88	0.88
Bottle Brook LB1	0	>0.5%	0.00	0.00	0.00	0.00	0.15	0.69	0.69	0.69
Bottle Brook LB2	29	1.30%	0.00	0.22	1.95	4.08	0.12	0.30	0.30	0.30
Bottle Brook RB	223	4%	0.66	53.74	63.86	78.42	0.66	1.06	1.06	1.06
Darley Abbey	69	1.30%	1.78	46.52	56.89	92.24	0.21	0.97	0.97	0.97
Alvaston RB	197	0.50%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Draycott	53	4%	0.00	38.93	41.24	45.01	0.20	0.91	0.91	0.91
Great Wilne	20	1.30%	0.00	28.48	33.40	34.14	0.22	0.98	0.98	0.98
Shardlow	480	4%	0.00	39.57	45.52	56.62	0.56	2.57	2.57	2.57
New flood defence alignment (Derby city RB and Derby LB)	2494	2%	0.00	471.94	533.57	680.57	0.80	9.44	9.44	9.44
Total	4156	-	3	844	978	1,228	4	22	22	22

Notes:
Annual emissions are calculated as annual average over 50 years.

Box A4.1: Moors for the Future

The objective of the 'Moors for the Future' project is to manage change and restore areas of the Peak District upland moors. Activities taking place under the project are wide-ranging but include some aspects of particular relevance to downstream flood risk management:

- *Re-vegetating bare peat*: this includes the re-vegetation of 4km^2 of bare peat in the Dark Peak (MFTFP, 2007) in addition to a little over 6km^2 restored within the Kinder Scout/Bleaklow plateau (eftec, 2009).
- *Gully blocking and hydrological restoration*: the blocking of particular gullies may help prevent peat land erosion ensuring the effective functioning of a carbon sink and the reduction of downstream flood risk.

The LDFRMS identifies the Moors for the Future as a project that may decrease the flood risk associated with the Lower Derwent catchment. The Strategy Approval Report in particular states that the Environment Agency has contributed £5 million towards this particular project. A pilot project to determine the impact of peat land restoration and its affect on downstream flooding is being set-up[1].

Improved evidence as to the carbon budget of peat land, both in restored and degraded states can help inform assessments of the carbon footprint of FCERM, where linkages between upland management and downstream flood risk can be established. However upland peat restoration projects are typically promoted as providing multiple benefits - including river water quality improvements, carbon sequestration, flood risk attenuation, enhancement of biodiversity, as well as cultural, landscape and recreation amenity – hence there is a requirement to establish extent to which carbon sequestration can be fully attributed to flood risk management objectives. This should largely be informed by the main policy driver for the project.

[1] See Environment Agency (2008b)

A4.3.3 Assessment of carbon associated with flood and coastal erosion damages

Available data permits comparison of two contrasting approaches to estimating carbon emissions associated with residual damages in relation to residential property[63]:

1. Applying a damage multiplier to estimated residual damages under different SoP options; and
2. Estimating carbon emissions from a ‘per property basis’ by identifying those at risk of flooding under different SoP options.

Approach 1: Damage multiplier

Table A4.9 presents estimated annual residual damages for flooding under the BAU case and different SoPs (O1-O3). Estimated carbon emissions associated with the residual damage of each option are calculated by multiplying the residual damage by a damage multiplier (see Technical Report, Section 2.4.2).

Combining estimated residual damages and the damage multiplier value entails a series of caveats:

- The assessment is limited to emissions arising only from refurbishment and repair of residential properties.
- Estimated emissions do not include those arising from commercial property damage, emergency services, or transport disruption.
- Avoided damages are calculated on an annual basis using the highest value of the potential damage that ‘may’ occur under BAU.

Table A4.10 presents estimates of the annual carbon emissions associated with the residual damage under the BAU case and different SoPs.

---

[63] To simply the analysis, the assessment considers residual residential property damages only.

Table A4.9: Residual annual damages for BAU and different SoP (2008 £) (£,000s)

Flood Cell	No. properties at risk	Onset of flooding (AEP)	Residual damages				FRM options
			BAU	O1 (1.3%)	O2 (1%)	O3 (0.67%)	
Duffield RB	63	4%	48	25	21	16	FW, CHFV
Ecclesbourne LB1	51	1.3%	29	14	12	9	FW, AR, RD
Ecclesbourne + Duffield RB1	475	4%	384	193	151	110	FW, AR, RD, CNDA
Duck Island	2	1.3%	0.73	0.65	0.57	0.49	FW, AR
Bottle Brook LB1	0	>0.5%	N/A	N/A	N/A	N/A	FW, AR, RD
Bottle Brook LB2	29	1.3%	C	C	C	C	FW, AR, RD
Bottle Brook RB	223	4%	386	98	76	56	FW, AR, RD, CNDA
Darley Abbey	69	1.3%	21	12	9	6	FW, AR, RD
Alvaston RB	197	0.5%	67	N/A	N/A	N/A	FW
Draycott	53	0	114	25	18	13	FW, AR, RD
Great Wilne	20	0	17	8	6	4	FW, AR, RD
Sharlow	480	0	3390	183	132	96	FW, AR, RD
New flood defence alignment (Derby city RB and Derby LB)	2,494	2%	2000	788	703	410	CNDA

Notes:

Residual damages are totalled annually and are undiscounted; BAU = do minimum; O1 = Option 1, FRM measures result in a SoP of 1.3%; O2 = Option 2, FRM measures result in a SoP of 1%; O3 = Option 3, FRM measures result in a SoP of 0.67%; FW = flood warning and provide flood resilience; AR = asset management replacement; RD = raise defences to optimum standard of protection (SoP); CNDA = construct new flood defences along new alignment; CHFV = Construction of headwall and flap value. N/A = data not available; C = only commercial property at risk. Additional assumptions regarding the properties values obtained for residential property are detailed within (Environment Agency, 2008b)

Table A4.10: Estimated annual carbon emissions associated with the residual damages (t CO_2e per year) – *damage multiplier approach*

Flood Cell	No. properties at risk	Onset of flooding (AEP)	Carbon associated with damages				FRM options
			BAU	O1 (1.3%)	O2 (1%)	O3 (0.67%)	
Duffield RB	63	4%	42	22	19	14	FW, CHFV
Ecclesbourne LB1	51	1.30%	26	12	11	8	FW, AR, RD
Ecclesbourne + Duffield RB1	475	4%	339	170	113	97	FW, AR, RD, CNDA
Duck Island	2	1.30%	1	1	1	1	FW, AR
Bottle Brook LB1	0	>0.5%	N/A	N/A	N/A	N/A	FW, AR, RD
Bottle Brook LB2	29	1.30%	C	C	C	C	FW, AR, RD
Bottle Brook RB	223	4%	341	86	67	49	FW, AR, RD, CNDA
Darley Abbey	69	1.30%	19	11	8	5	FW, AR, RD
Alvaston RB	197	0.50%	59	N/A	N/A	N/A	FW
Draycott	53	4%	101	22	16	115	FW, AR, RD
Great Wilne	20	0	15	7	5	4	FW, AR, RD
Sharlow	480	0	2,991	161	116	85	FW, AR, RD
New flood defence alignment (Derby city RB & LB)	2494	2%	1,765	695	620	362	CNDA
TOTAL	4,156		5,697	1,188	996	635	

Notes:

BAU = do minimum; O1 = Option 1, FRM measures result in a SoP of 1.3%; O2 = Option 2, FRM measures result in a SoP of 1%; O3 = Option 3, FRM measures result in a SoP of 0.67%; FW = flood warning and provide flood resilience; AR = asset management replacement; RD = raise defences to optimum standard of protection (SoP); CNDA = construct new flood defences along new alignment; CHFV = Construction of headwall and flap value. N/A = data not available; C = only commercial property at risk. Additional assumptions regarding the properties values obtained for commercial and residential property are detailed within (Environment Agency, 2008b)

As expected – since the damage multiplier is only scaling estimated residual damages - the results show that the highest SoP (O3 - 0.67%) has the lowest carbon footprint across all of the flood cells. As with the cost element of the calculations, flood cells with a higher number of properties at risk of flooding have the greatest carbon footprint associated with them. A shift from BAU to O1 results in the largest (incremental) reduction in carbon emissions arising from residual flood damages.

Approach 2: Carbon per property at risk of flooding

The contrasting approach to estimating carbon associated with residual damages takes a ‘bottom-up’ approach. The LDFRMS documentation details the number of properties at risk of flooding under the BAU case and different SoPs. Generic estimates of carbon emissions associated with repair and refurbishment of properties are sourced from EHA (2008) (see Technical Report, Section 3.1.1). To reflect uncertainty as to the types of properties at risk and uncertainty as to the severity of damage a range of values are applied:

- 15 t CO2e per property;
- 35 t CO2e per property; and
- 50 t CO2e per property.

The highest value of 50t CO2e per property represents the carbon cost of completely rebuilding a property outside the floodplain and is therefore included as a ceiling for CO2e emissions. The lower figure of 15t CO2e per property is based on the carbon cost associated with a major domestic refurbishment for energy efficiency rather than the repair of flood damage per se. Thus the figure serves as a useful bench mark in terms of the order of magnitude of carbon emissions.

The mid-point of the range (35 t CO2e per property) is calculated from the estimates provided by EHA (2008). Estimates of carbon per property for repair and refurbishment are multiplied by the likelihood of flooding per year. Hence for a given flood cell in a given year:

Carbon from repair and refurbishment = likelihood of flooding × number of properties × carbon per property

The main caveats in this aspect of the assessment are:

- The assessment is limited to emissions arising only from refurbishment and repair of residential properties.
- It is assumed that the number of properties within the ‘at risk’ categories of 5% through to 0.67% remain unchanged across flooding events of different severities; i.e. a flood event does not increase the area effected as its severity

increases (this is to enable a consistent comparison between different SoPs and with the BAU)

- Emissions are calculated on an annual basis for the BAU case up to the point where the likelihood of flooding is 100%[64].

Table A4.11 reports estimates of carbon emissions associated with repair and refurbishment of properties within each flood cell under the BAU case and each of the possible SoP options (O1-O3).

Overall, as expected the carbon footprint associated with the BAU case is the highest across all flood cells as this option is likely to result in the refurbishment and repair of a greater number of properties than for the other three options (even accounting the point at which it is uneconomical to continue to repair properties in this scenario). The number of properties to be repaired and refurbished decreases as the SoP increases. The carbon footprint varies in size depending on the generic estimate applied to the number of properties at risk at a level of ±43%.

---

[64] Note that this contrasts with the damage multiplier approach which will be influenced by the capping of estimated damages before the probability of flooding reaches 1.0.

Table A4.11: Estimated annual carbon emissions associated with the repair and refurbishment of properties (t CO_2e per year) – *carbon per property approach*

Flood Cells	No Properties at risk	Onset of flooding	Carbon associated with damages										
			BAU			O1 (1.3%)			O2 (1%)			O3 (0.67	
			15	35	50	15	35	50	15	35	50	15	35
Duffield RB	63	4%	870	2030	2,900	10	24	34	10	24	34	9	20
Ecclesbourne LB1	51	1.30%	555	1295	1,850	0.9	2.1	3	0.5	1.2	1.8	0	0
Ecclesbourne + Duffield RB1	475	4%	6,225	14,525	20,750	71	165	235	67	157	224	66	153
Duck Island	2	1.30%	30	70	100	0.08	0.2	0.3	0.08	0.2	0.3	0	0
Bottle Brook LB1	0	>0.5%	0	0	0	0	0	0	0	0	0	0	0
Bottle brook LB2	29	1.30%	0	0	0	0	0	0	0	0	0	0	0
Bottle Brook RB	223	4%	3,030	7,070	10,100	79	184	262	78	182	259	76	177
Darley Abbey	69	1.30%	375	875	1,250	0	0	0	0	0	0	0	0
Alvaston	197	0.50%	30	0	0	0	0	0	0	0	0	0	0
Draycott	53	4%	735	1,715	2,450	22	50	72	21	50	71	21	49
Great Wilne	20	0	375	630	900	0	0	0	0	0	0	0	0
Shardlow	480	0	5,760	13,440	19,200	214	500	715	214	499	713	213	498
New defence (Derby city RB and Derby LB)	2494	2%	27,570	64,330	91,900	159	371	530	141	329	471	131	306
Total	4,156	-	45,555	105,980	151,400	555	1,296	1,852	532	1,241	1,774	516	1,204

Notes:

Carbon footprint of each flood risk ‘option’ using three different estimates of carbon emissions associated with repair and refurbishment of properties, i.e., (15, 35 and 50 t CO2e per property); BAU = do minimum; O1 = Option 1, FRM measures result in a SoP of 1.3%; O2 = Option 2, FRM measures result in a SoP of 1%; O3 = Option 3, FRM measures result in a SoP of 0.67%.

Comparing two approaches to estimating carbon from residual damages

Except in the BAU case, the two approaches to estimating carbon emissions associated with residual damages result in total estimates of emissions in the same order of magnitude:

- BAU: the damage multiplier estimate is less than 15% of the low end estimate calculated using carbon emissions ‘per property’ (see below);
- Option 1: the damage multiplier estimate is within the estimated range of the carbon per property approach and close to the mid point estimate (using 35 t CO2e per property);
- Option 2: the damage multiplier estimate is within the estimated range of the carbon per property approach, between the low and mid point estimates (using 15t and 35t CO2e per property respectively); and
- Option 3: the damage multiplier estimate is within the estimated range calculated using the carbon per property and close to the low estimate (using 15t CO2e per property).

The contrasting BAU estimates show a significant disparity between the two approaches. In particular the damage multiplier approach is subject to the capping of damages that was applied in the LDFRMS assessment, since at some point it becomes uneconomical to maintain properties that are subject to frequent flooding. The effect of this is to lower the BAU estimate of emissions in comparison to the carbon per property approach, which does not control for capping nor write-off of properties. Overall it is likely to be the case that the two different approaches ‘bracket’ BAU emissions associated with residual damages.

Notwithstanding the above point in relation to the BAU estimates, the approximate consistency of both approaches in evaluating the carbon footprints of different options suggests that, while subject to significant caveats and assumptions, both provide workable proxies for calculating emissions associated with FCERM damages, provided that sufficient data is available. Moreover both can be applied using information readily available from standard project appraisal analysis.

A4.3.4Summary

The Environment Agency (2008b) details the recommended strategy to address flooding in the Lower Derwent catchment as:

- Improve flood risk warnings;
- Continue the maintenance of existing defences;
- Construct new defences and improve protection in the options highlighted above, i.e., Duffield right bank, Bottle brook left and right bank, Alvaston right bank, Draycott right bank, Sharlow right bank and the new flood defence alignment.

- Develop in partnership changes in upstream catchment land use management; and
- Influence planning decisions with regard to FRM.

The assessment set out in this case study provides a broad-brush estimate of the potential carbon footprint for fourteen flood cells in which a number of different FRM options are considered. Table A4.12 presents a summary of the annual carbon emissions associated with the construction and maintenance costs and residual damages from achieving different SoPs. The overall carbon footprint over 50 years for each option across all flood cells is estimated to be:

- BAU: 285,206 – 7,570,350 t CO_2e
- O1 (1.3%): 71,073 – 135,875 t CO_2e
- O2 (1%): 76,602 – 138,675 t CO_2e
- O3 (0.67%): 88,300 – 148,500 t CO_2e

The greatest influence on the estimated footprints is carbon emissions associated with residual damages; in annual terms these significantly outweigh emissions associated with construction and maintenance:

- BAU: 5,697- 151,407 t CO_2 e,
- O1 (1.3%): 1,421 - 2,718 - t CO_2e,
- O2 (1%): 1,532 - 2,773- t CO_2e, and
- O3 (0.67%): 1,766 - 2,970- t CO_2e.

Therefore options that increase the SoP give rise to lower footprints in relation to the BAU, to the extent that the highest SoP presents the lowest estimate carbon footprint range. This result is particularly sensitive to the treatment of emissions arising from residual damages in the BAU case.

Overall, the information available for the LDFRMS enables a rudimentary assessment of carbon emissions associated with the construction, maintenance and avoided damages, applying the proxy carbon intensity and allowing a comparison of the damage multiplier detailed in the Technical Report to an alternative ‘per property’ approach. The comparison shows a certain amount of consistency between the two approaches, although further work concerning the carbon implications of damages under BAU would improve this assessment.

Sufficient information is not available to assess carbon emissions and sequestration associated with land management aspects of the LDFRMS; this is a key gap in the available data. This represents an area of significant uncertainty, particularly in relation to inland marsh where there is potential for both sequestration and storage of carbon and release of methane depending on site specific factors.

A4.3.5 References

Communitiees and Local Government 2006, *Planning Policy Statement 25: Development and Flood Risk*.

eftec 2009, *Economic Valuation of Uplands Ecosystem Services*, Report to Natural England.

EHA 2009, *New Tricks with Old Bricks*, The Empty Homes Agency Ltd.

Environment Agency 2008a, *Lower Derwent Flood Risk Management Strategy - Public consultation summary*.

Environment Agency 2008b, *Strategy approval report*.

Environment Agency 2009a, *Appendix E - Economic Appraisal, part of the Lower Derwent Management Strategy*.

Environment Agency 2009b, Annex E – All FCDPAG3 spreadsheets relating to flood option cost and avoided damage calculations.

Table A4.12: Summary of the annual carbon footprint for LDFRMS

Flood Cell	No. properties at risk	Onset of flooding (AEP)	BAU (t CO2e/yr)		O1 (t CO2e/yr)		O2 (t CO2e/yr)		O3 (t CO2e/yr)	
			Cons. & main.	Residual damage	Cons. & main.	Residual damage	Cons. & main.	Residual damage	Cons. & main.	Residual damage
Duffield RB	63	0	0.0	42-2,900	1.5	22-34	1.9	19-34	2.2	14-29
Ecclesbourne LB1	51	1	1.2	26-1850	36.1	3-12	44.1	1.8-10	49.0	0-8
Ecclesbourne + Duffield RB1	475	0	0.2	339-20750	127.7	170-235	155.3	113-224	185.2	97-219
Duck Island	2	0.02	0.2	0.64-100	4.8	0.3-0.57	5.6	0.3-0.5	6.1	0-0.43
Bottle Brook LB1	0	0	0.2	0	0.7	0	0.7	0	0.7	0
Bottle brook LB2	29	0	0.1	0	0.5	0	2.2	0	4.4	0
Bottle Brook RB	223	0.72	1.3	340-10,100	54.8	86-262	64.9	67-259	79.5	49-253
Darley Abbey	69	1.96	2.0	19-875	47.5	0-11	57.9	0-8	93.2	0-5.29
Alvaston	197	0	0.0	0-59	0.0	0	0.0	0	0.0	0
Draycott	53	0	0.2	100-1715	39.8	22-72	42.2	16-71	45.9	71-114.7
Great Wilne	20	0	0.2	15-630	29.5	0-7	34.4	0-5	35.1	0-3.5
Shardlow	480	0	0.6	2,991-13,440	42.1	161-715	48.1	116-713	59.2	85-711
New defence (Derby city RB and Derby LB)	2494	0	0.8	1,764 – 64,330	481	530-695	543	471-620	690	361-437
SUM of schemes	4,156	-	7.0	5,697 – 105,980	866	1852-1188	1,000	996-1,774	1,250	635-1,720

Notes:
BAU = do minimum; O1 = Option 1, FRM measures result in a SoP of 1.3%; O2 = Option 2, FRM measures result in a SoP of 1%; O3 = Option 3, FRM measures result in a SoP of 0.67%

A4.4 Dymchurch coastal defence scheme

A4.4.1 Introduction

Dymchurch and extensive areas of Romney Marsh are at risk of rapid flooding if a breach of current sea defences were to occur (EA, 2004a). There has been a long history of damage to the sea wall during storm events. Recent damages occurred from overtopping[65] during the winter of 2004 and in 1999 the A259 was closed during storms due to shingle and spray coming over the sea wall preventing safe access (EA, 2004b).

A failure of the defences along the frontage at Dymchurch could have significant safety implications for the low lying property located behind them. Current sea defences in the area only offer a standard of protection (SoP) from wave overtopping of less than 1 in 10 years leading to the development of the Dymchurch coastal defence scheme (CDS) (2004). The CDS main aim is *"to reduce the risk of flooding from the sea to people, property and the natural environment by providing effective defences and awareness"* (EA, 2004a).

In order to meet this aim and the wider criteria of sustainability the following objectives were considered for each CDS option proposed for the area:

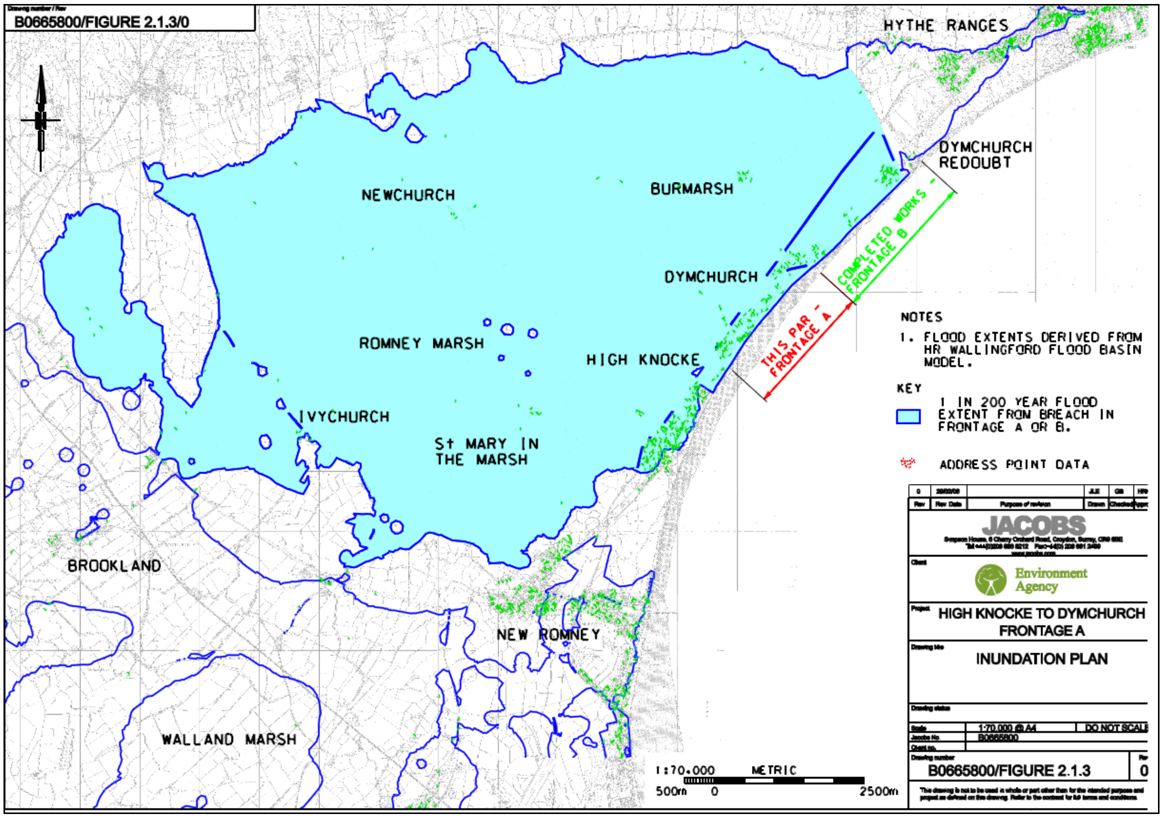
- To maintain a minimum SoP of 1 in 100 years for a period of 100 years;
- To reduce the risk of breach of the defences;
- To provide minimal adverse effects on the coastal zone in construction, operation and decommissioning of the scheme;
- To include suitable measures to mitigate against identified environmental impacts; and
- To maintain the recreational amenity value of the frontage.

Dymchurch lies between the settlements of Hythe to the north and St Mary's Bay to the south (see Figure A4.3). These form part of a discontinuous line of settlements along the coast between Dungeness and Folkestone. In the southern part of the study area, properties in Dymchurch are located on the seawall itself, and are at particular risk from overtopping. The sea defences along this frontage also protects the low-lying area of Romney Marsh inland, populated with the smaller settlements of Burmarsh, St Mary in the Marsh and isolated farmsteds (EA, 2004a).

---

[65] Overtopping is water taken over the top of a sea defence as a result of wave run up exceeding the crest height of the sea defence

Figure A4.3: Dymchurch and surrounding area, the extent of a 1 in 200 year flooding event following a breach in the frontage area



Source: Environment Agency (2004b)

Current flood defences

Current flood defences in the area consist of seawalls of concrete and masonry with seaward sloping aprons in concrete or masonry blockwork. The beach and foreshore are sandy although the former is only present over the southern half of the frontage. There are old timber groyne fields, which are generally in poor condition (EA, 2004b).

Current flood risk

There are currently 2471 residential properties at risk of a 10% (1 in 10 years) annual exceedance probability (AEP) flood event (see Table A4.13).

Table A4.13: Number of predicted properties at risk from flooding under business as usual (BAU)

Economic asset	**Size / number**
Residential properties	2471 dwellings (post code areas TN29 0)
Caravans	927
Recreational assets	3 holiday camps excl. caravans
Agricultural Land	7672 hectares
Martello towers	4 incl. 2 designated as Scheduled Ancient Monument (SAM)
A259	Main access road across marsh
Romney Marsh SSSI	113 hectares

Source: Adapted from EA (2004b).

A4.4.2 Carbon footprint assessment

Following the methodology set out in the Technical Report, the carbon footprint assessment is dependent on three primary aspects:

- Carbon from CDS activities;
- Carbon associated with flood and coastal erosion damages; and
- Carbon from dependent activities.

Available data permits for a broad assessment of the above. This includes:

- Establishing a business as usual (BAU) baseline case;
- Establishing the CDS options considered within the strategy;
- Identifying costs of CDS options in terms of maintenance and capital costs to provide a basis for estimating carbon associated with these activities; and
- Identifying the residual damages with the CDS option to estimate carbon associated with flood damages.

From this the case study contrasts carbon emissions that arise from construction and maintenance activities that increase the standard of protection (SoP) to 1% in the Dymchurch area for different options. The carbon associated with residual damages is assumed to remain constant under all potential options. Due to lack of data, no assessment is made of carbon arising from dependent activities.

Business as usual case

For the purpose of this case study the BAU case applied is ‘do minimum’. The Dymchurch CDS presents this as the existing situation; i.e., continuing the current annual maintenance works to the sea wall. The SoP afforded by this practice is assessed at 1 in 10 years on the basis that such patch repairs remain vulnerable to progressive failure (EA, 2004b).

Flood risk management options

The following alternative options were considered for the frontage at Dymchurch:

- Structural work on the existing sea wall structure including raising the wall and adding new groynes;
- Strengthening the current wall and rock revetment;
- Recharging either shingle or sand along with structural work to the upper part of the current sea wall;
- Building an offshore breakwater; and
- Upgrading the current sea wall incorporating either a rock berm or step work.

All of the proposed options deliver a SoP of 1%, thus the selection of the preferred options is based on a *'least cost'* approach.

Assessment of carbon from FCERM activities

Capital and maintenance costs

Table A4.14 presents the costs associated with the construction and maintenance activities required for each of the options to achieve a SoP of 1% across the Dymchurch area. Options are split into two groups: (i) those concerned with the frontage from High Knocke to Martello Tower 23, the south side of the beach (termed frontage A); and (ii) those concerned with Martello Tower 23 to Dymchurch Redoubt, the north side of the beach (termed frontage B).

Table A4.14: Dymchurch CDS annual construction and maintenance costs (2008 £) (£, 000s)

Frontage Option	**Capital**	**Maintenance**	**Total**
Frontage A			
BAU	0	33	33
Option 1: Structural work to maintain toe/wall and raise crest	363	51	51
Option 2: Structural work to maintain toe/wall, raise crest level and new groynes	411	43	454
Option 3: Rock revetment and strengthen wall	369	17	386
Option 4: Shingle recharge on beach and structural work to upper wall and terminal rock groynes	544	29	573
Option 5: Sand recharge and structural work to upper wall and groynes with periodic enourishment	1114	57	1171
Option 6: Offshore break water	503	37	541
Frontage B			
BAU	0	36	36
Option 1: Upgrade seawall, incorporating rock berm	497	30	527
Option 2: Upgrade seawall, incorporating concrete stepwork	504	122	626
Option 3: Offshore break water	575	40	615
Preferred option	1119	70	1032

Notes:
Costs are undiscounted and show the average annual cost over a 50 year period; BAU = do minimum.

Available data permits comparison of two contrasting approaches to estimating carbon emissions associated with the construction and maintenance of flood risk management options:

1. Applying carbon intensity factors (see Technical Report, Section 3.1) to estimated construction and maintenance costs for each option; and
2. Use of the EA Construction Carbon Calculator (see Technical Report, Section 2.4.2) that accounts for different carbon intensity factors based on the materials used within the construction of each option. Note however that data is only available for the preferred Dymchurch CDS option (see below).

Approach 1: Applying a general carbon intensity factor to construction and maintenance costs

Using the cost estimates presented in Table A4.14 carbon emissions resulting from construction and maintenance activities to achieve the SoP of 1% in the Dymchurch area are estimated by applying carbon intensity factors (kg CO_2e / £):

- *Carbon from construction activities*: estimated using the mid-range estimate carbon intensity factor (0.91 kg CO_2e / £) detailed in the Technical Report (see Table 3.10).
- *Carbon from maintenance activities*: estimated using a lower carbon intensity factor (0.20 kg CO_2e / £). Use of this lower value is somewhat arbitrary but is drawn from the evidence presented in the Technical Report. This aspect of the analysis would be improved if more information was available as to the nature of maintenance activities associated with options.

Table A4.15 presents estimates of the annual carbon emissions (averaged over 50 years) associated with construction and maintenance:

- Estimated total carbon emitted annually for achieving the desired SoP of 1% for each option for frontage A are:

    - Option 1 = 340 t CO_2e per year;
    - Option 2 = 382 t CO_2e per year;
    - Option 3 = 339 t CO_2e per year;
    - Option 4 = 501 t CO_2e per year;
    - Option 5 = 1025 t CO_2e per year; and
    - Option 6 = 466 t CO_2e per year.

- Estimated total carbon emitted annually for achieving the desired SoP of 1% for each option for frontage B are:

    - Option 1 458 t CO_2e per year;
    - Option 2 483 t CO_2e per year; and
    - Option 3 532 t CO_2e per year.

The lowest estimates for carbon emissions for frontage A and B are Option 3 and Option 1 respectively. The maintenance costs of Options 2 and 3 for frontage B are significantly greater than for all other options. However the increase in the carbon emitted between options is mostly driven by construction costs. The preferred options for frontage A and B were Option 4 and Option 3 respectively. Option 4 was chosen because it maintained or improved the amenity value of the beach, met all the project objectives and has the least impact upon the environment, while Option 3 for frontage B was chosen as it provided the defence standards at least cost (EA, 2004b).

Table A4.15: Assessment of annual carbon footprint associated with construction and maintenance activities within CDS (t CO2e/yr)

Frontage Option	Capital	Maintenance	Total
Frontage A			
BAU	0	7	7
Option 1: Structural work to maintain toe/wall and raise crest	330	10	340
Option 2: Structural work to maintain toe/wall, raise crest level and new groynes	374	9	382
Option 3: Rock revetment and strengthen wall	335	3	339
Option 4: Shingle recharge on beach and structural work to upper wall and terminal rock groynes	495	6	501
Option 45: Sand recharge and structural work to upper wall and groynes with periodic enourishment	1014	11	1025
Option 6: Offshore break water	458	7	466
Frontage B			
BAU	0	7	7
Option 1: Upgrade seawall, incorporating rock berm	452	6	458
Option 2: Upgrade seawall, incorporating concrete stepwork	459	24	483
Option 3: Offshore break water	523	8	532
Preferred option	1018	14	1032

Notes: Annual emissions are calculated as annual average over 50 years. BAU = do minimum; N/A – not applicable.

Approach 2: EA Construction Carbon Calculator results

The Construction Carbon Calculator estimates carbon emissions associated with FCERM schemes from standard data associated with the carbon impacts based on construction material used; i.e., the tonnage, transport distance and mode of transport. Table A4.16 shows a breakdown of the construction materials used and the associated CO_2 emissions for the Dymchurch 'preferred option'[66].

---

[66] The Construction Carbon Calculator datasheet for Dymchurch CDS does not explicitly state the details of the 'preferred option'; however based on the PAR (EA, 2008b) it is assumed that this is the combination of Option 4 for frontage A and Option 3 for frontage B. In addition, some inconsistency in the Construction Carbon Calculator spreadsheet and report where identified. Here data from the spreadsheet are reported.

Table A4.16: Outputs from the construction calculator for the preferred CDS option, emissions shown as tonnes CO_2 for all construction costs.

	CO_2 tonnes	%
Quarried material	1,807	4%
Timber	438	1%
Concrete, mortars & cement	26,862	58%
Metals	9,872	21%
Plastics	176	0%
Miscellaneous	13	0%
Plant emissions	1,055	2%
Waste removal	1	0%
Portakabins	58	0%
Material transport	5,311	12%
Personnel travel	558	1%
Total	46,154	100%

Source: Reproduced from EA (2004c).

As shown by Table A4.16 the concrete, mortar and cement (58%) represents the greatest embodied carbon element of the Dymchurch preferred option, reflecting the nature of the asset construction activities (e.g. rock revetment and sea wall strengthening, offshore break water). Embodied emissions from metals (primarily steel bar and rod and sheet piling) are also significant (21%).

Comparing EA Construction Carbon Calculator results to the carbon intensity factor approach

A direct comparison of the results from Table A4.15 (carbon intensity factor approach) and Table A4.16 (EA Construction Carbon Calculator results) can be made only after the annual values for asset construction calculated for the carbon intensity approach are total over the 50 year time period. Emissions from asset maintenance estimated from the carbon intensity factor approach are not included in the comparison (since this is not covered by the EA Construction Carbon Calculator).

Converting the annual emission for the preferred option in Table A4.15 to the total amount over 50 years gives an estimate of 51,600 tonnes of CO_2 for asset construction. The EA Construction Carbon Calculator reports a slightly lower amount of approximately 46,200 tonnes.

The difference is explained by the fact that the carbon intensity factor applied is ‘weighted’ by the sample of schemes from which the average is calculated. Table 3.11 in the Technical Report shows that the carbon intensity factor for the Dymchurch scheme alone is greater than the 0.91 kg CO_2e / £ value applied here (it is closer to 1.0 kg CO_2e / £).

A greater test of the consistency of the carbon intensity factor approach would be provided by comparing EA Construction Carbon Calculator results for a scheme that is not within the sample used to estimate factor. As noted in Sections 4.2 and 5.2 of the Technical Report wider use of the Construction Carbon Calculator should permit such assessments and estimation of carbon 'benchmarks'.

Assessment of carbon associated with flood and coastal erosion damages

Available data permits the estimation of carbon emissions associated with residual damages in relation to residential property by applying a damage multiplier (see Technical Report, Section 2.4.2) to an estimate of residual damages under the BAU and with the CDS (see Box 4.2).

Box 4.2: Estimating carbon associated with Dymchurch coastal flooding damages

The original Dymchurch PAR (EA, 2004b) calculates that the total value of assets at risk is £413 million. As each option was assumed to provide the same SoP detailed modelling of damages was not undertaken and the assessment conducted for CDS was based on a 'least cost' method on basis that each option met acceptable technical, social, safety and environmental considerations. Using the value of assets as risk and the BAU and CDS SoPs as a proxy for potential damages gives:

- BAU annual damages: 413 × 0.1 = £41.3 million
- CDS annual damages: 413 × 0.01 = £4.1 million

It is recognised that these proxy estimates are likely to be 'high' in relation to a detailed assessment of damages that account for write-off values for assets at risk or the capping of damages.

Estimated carbon emissions associated with the residual damage across options as detailed in Box 4.2 are calculated by multiplying the residual damage by a damage multiplier (see Technical Report, Section 2.4.2). Combining estimated residual damages and the damage multiplier value entails a series of caveats:

- Property damage was assessed based on:
  - Type, age and social class of houses and householders in the benefit area and the estimation of an 'average' home value;
  - Detailed standard data for type, age and social class of houses and householders;
  - This does not include estimates of the values of 'intangibles'; e.g. re-locating after a flood, stress and disruption.
- The assessment is limited to emissions arising only from refurbishment and repair of residential properties;

- Estimated emissions do not include those arising from caravan, commercial property damage, emergency services, or transport disruption; and
- Avoided damages are calculated on an annual basis of the potential damage that ‘may’ occur under BAU.

The avoided annual damage to residential property is calculated by subtracting £4.13 million from £41.3 million (£2004). Applying the damage multiplier gives:

- CO_2 emissions BAU: 36,406 t CO_2e per year
- CO_2 emissions for all other options: 3,641 t CO_2e per year

The shift from BAU to an SoP of 1% (across all options) results in a decrease of 90% in carbon emissions arising from residual flood damages.

A4.4.3 Summary

The Dymchurch CDS feasibility study recommends Options 4 (frontage A) and 3 (frontage B) with an SoP of 1% to address the risk of flooding of Dymchurch:

- Frontage A: structural work to strengthen the existing seawall and raising of the crest level. Stabilisation of the beach with new timber groynes;
- Frontage B: rock revetment and strengthening works to the existing seawall.

The assessment set out in this case study provides a broad-brush estimate of the potential carbon footprint of the Dymchurch CDS. Table A4.18 provides a summary of the total carbon emissions (over 50 years) associated with the construction and maintenance costs and residual damages from achieving a SoP of 1% for each of the options considered.

The greatest influence on the estimated footprints is carbon emissions associated with residual damages. For the preferred option carbon from residual damages accounts for 77 – 79% of the footprint, depending on whether carbon associated with construction and maintenance is estimated on the basis of the carbon intensity factor or taken from the construction carbon calculator.

In addition the carbon associated with construction and maintenance is more than offset by the reduction in carbon from damages as a result of moving from the BAU to the SoP of the preferred option (over 50 years a total reduction in emissions arising from damages in the region of 1.6m tonnes). However, given the basic estimate of the value of damages to which the damage multiplier is applied (as detailed in Box 4.2), this should be interpreted as an indicative finding that is likely to be an over-estimate of the possible ‘carbon saving’. That said, it is probably reasonable to expect that the general result will hold (construction carbon < avoided damages carbon) even if a more detailed assessment of damages was available, given the magnitude of orders difference. In particular this is a conclusion that is consistent with discussion of results in the main report (see Technical Report, Section 4).

A4.4.4 References

Environment Agency, 2004a. *High Knocke to Dymchurch Redoubt Coastal Defence Scheme Environmental Statement*.

Environment Agency, 2004b. *Project Appraisal Report High Knocke to Dymchurch Redoubt Sea Defences*.

Environment Agency, 2004c. *Project Appraisal Report Annex E: Construction Carbon Calculator*.

Table A4.18: Summary of the total carbon footprint of the Dymchurch CDS over 50 years

Frontage Option	**CCal[1]**	**C intensity factor[2]**			**Residual Damage**	**Total t CO_2e**
		Capital	**Mainten-ance**	**Total CMC[3]**		
BAU	N/A	N/A	695	695	1,820,294	1,820,989
Frontage A						
Option 1: Structural work to maintain toe/wall and raise crest	N/A	16,500	510	17,010	182,029	199,039
Option 2: Structural work to maintain toe/wall, raise crest level and new groynes	N/A	18,688	434	19,122	182,029	201,151
Option 3: Rock revetment and strengthen wall	N/A	16,770	173	16,942	182,029	198,972
Option 4: Shingle recharge on beach and structural work	N/A	24,745	294	25,039	182,029	207,068
Option 5: Sand recharge and structural work with periodic renourishment	N/A	50,678	573	51,251	182,029	233,280
Option 6: Offshore break water	N/A	22,903	373	23,276	182,029	205,305
Frontage B						
Option 1: Upgrade seawall, incorporating rock berm	N/A	22,592	300	22,892	182,029	204,921
Option 2: Upgrade seawall, incorporating concrete stepwork	N/A	22,944	1217	24,161	182,029	206,190
Option 3: Offshore break water	N/A	26,175	402	26,577	182,029	208,606
Preferred option	46,154	50,920	696	51,616	182,029	228,183 - 233,645

Notes: total CO_2emissions over 50 years; N/A not available; [1]C.Cal – construction calculator output (see Table A4.16); C intensity factor – carbon intensity factor estimate for capital and maintenance (see Table A4.15); [3]CMC – construction and maintenance costs does not include any outputs from the C.Cal; T. CO_2e – total CO_2 emissions (CMC plus residual damages).

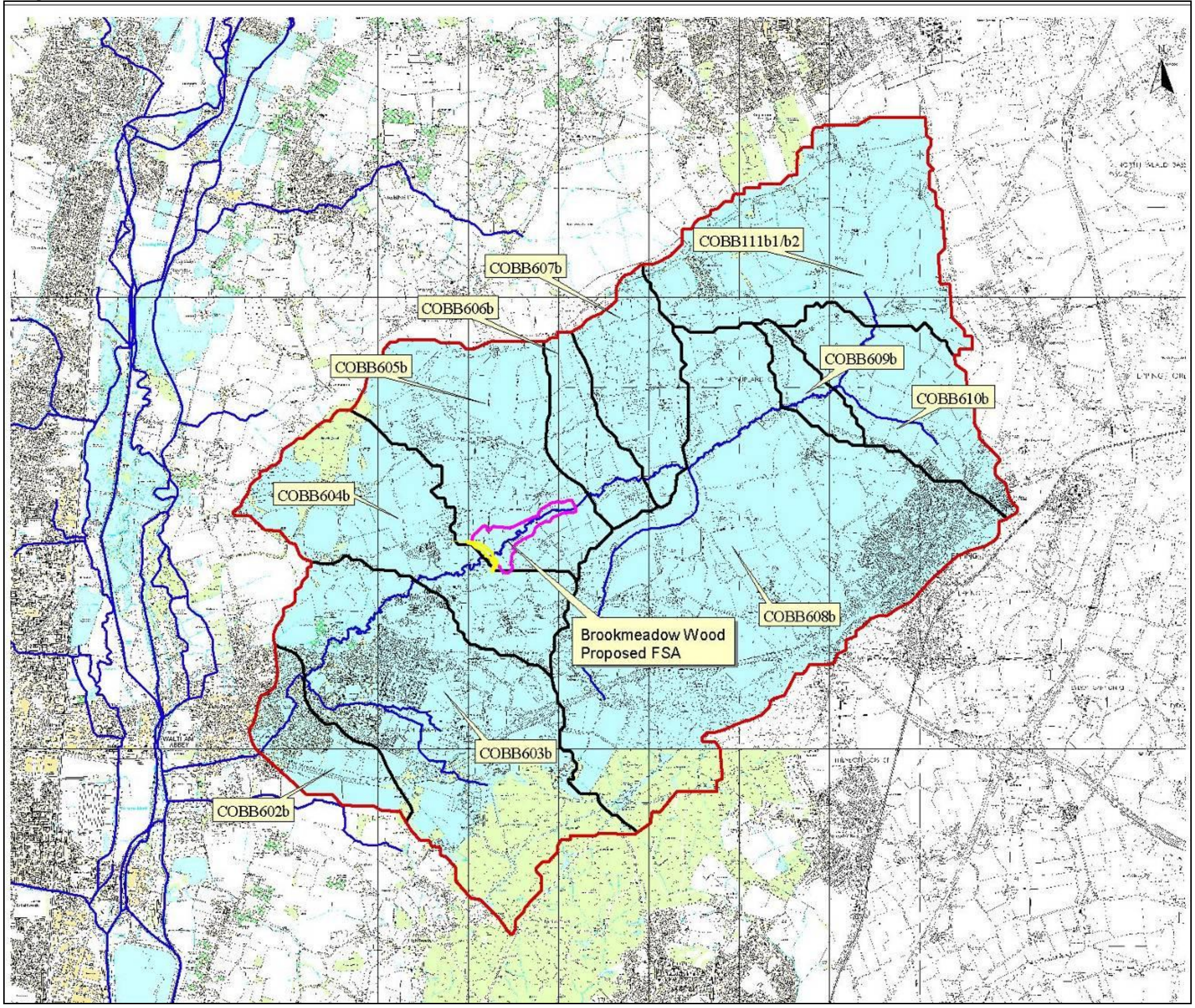
A4.5 Cobbins Brook flood alleviation scheme

A4.5.1 Introduction

There is a history of river flooding in the Lower Lee catchment area. Waltham Abbey in Essex in particular has been subjected to flooding from Cobbins Brook on a number of occasions. The most recent flood event occurred in 2000 where 97 properties were flooded and serious damage to the entire Lee Catchment was caused (Environment Agency, 2004). Past events in 1947, 1968 and 1974 initiated flood risk management activities in the area including the remodelling of Cobbins Brook and the construction of a relief channel within the area. As part of the overall Lower Lee Flood Risk Management Strategy (LLFRMS), the Cobbins Brook Flood Alleviation Scheme (CBFAS) feasibility study was initiated (Environment Agency, 2004) to establish a preferred flood risk management (FRM) option to address flooding in the catchment.

Cobbins Brook, is a major tributary of the Lower River Lee, and is located in the Epping Forest District in south-east Essex. The Cobbins Brook valley is bounded by Nazeing Long Green and Epping Long Green to the north and by Epping Forest Ridges in the south, a catchment of approximately 38km^2 (see Figure A4.). Cobbins Brook covers a distance of about 24km. The catchment includes part of the town of Waltham Abbey, half the urbanised area of Epping Town and the village of Epping Green. The Brook flows for most of its length through the rural areas adjacent to Epping Forest but its final length flows through a heavily urbanised/residential area. The main channel of the Cobbins Brook is joined by several tributaries, including Honey Lane Brook, Copped Hall Brook, Bury Farm Brook and Wintry Wood Brook (Environment Agency, 2004).

Figure A4.4: Cobbins Brook catchment area



Source: Reproduced from Environment Agency (2004)

Current flood defences

There are few permanent flood defences in the area consisting of a lined channel. In addition there are three weirs upstream of Waltham Abbey but two are in poor condition and no longer in use whilst the third, at Brookmeadow Wood, serves no flood defence purpose. Most sections of the Cobbins Brook, as it runs through Waltham Abbey, have been re-sectioned and many have been canalised to increase channel capacity and reduce flood risk, there is also an automated flood warning system in place for the Waltham Abbey area (Environment Agency, 2004).

Current flood risk

There are currently 341 residential and 30 commercial properties at risk of a 0.5% (1 in 200 years) annual exceedance probability (AEP) flood event. In addition, there are several pieces of infrastructure that are also at risk of flooding including:

- A nursery;
- Shops;
- Auctioneers;
- A school;
- School playing fields;
- Electricity substation at Hill House;
- Waltham Abbey Football Club (stand, pitch, and clubhouse);
- Several halls;
- A public house; and
- The possible closure of the M25 motorway as a result of flooding.

Table A4.19: Number of predicted properties at risk from flooding under business as usual (BAU)

Flood Risk	Residential	Non Residential	Total
20%	7	3	10
10%	72	10	82
5%	137	19	156
2%	229	24	253
1.3%	260	24	284
1%	276	25	301
0.5%	341	30	371

Source: Adapted from Environment Agency, 2004

A4.5.2 Carbon footprint assessment

Following the methodology set out in the Technical Report, the carbon footprint assessment of the CBFAS Feasibility Study is dependent on three primary aspects:

- Carbon from FCERM activities;
- Carbon associated with flood and coastal erosion damages; and
- Carbon from dependent activities.

Available data permits for a broad assessment of the above. This includes:

- Establishing a business as usual (BAU) baseline case;
- Establishing the FRM options considered within the strategy;
- Identifying costs of FRM options in terms of maintenance and capital costs to provide a basis for estimating carbon associated with these activities;
- Identifying the residual damages under each FRM option to estimate carbon associated with flood damages; and
- Establishing details of any land use management options.

From this the case study contrasts carbon emissions that arise from construction and maintenance activities that increase the standard of protection (SoP) in the catchment to carbon associated with residual damages under different SoPs. Due to lack of data, no assessment is made of carbon arising from dependent activities.

Business as usual case

For the purpose of this case study, the BAU case applied is ‘do minimum’, which CBFAS presents as existing situation with ‘patch and repair’, i.e. *“continuing with existing maintenance and replacing structures and defences ‘like for like’ as they fail”* (Environment Agency, 2004).

Flood risk management options

The following options were considered as part of the feasibility study.

- *Provision of upstream attenuation (UA)*: an ‘on-line’ storage area that will allow Cobbins Brook to flow through at low flows and be impounded behind an embankment during high flows.

- *Provision of downstream attenuation (DA)*: by way of flood storage areas.

- *Flood defence works (FDW)*: along Cobbins Brook in and around the Waltham Abbey area.

- *Raising/replacement of channel walls (RW)*: along Broomstick Hall Road to provide sufficient flood defences based on the levels of service selected.

Combinations of these options were tested as part of the feasibility study as independently these measures would not resolve the issue of flooding along Cobbins Brook. Of the original 29 options specified only four were viable and compared with both the ‘do nothing’ and ‘do minimum’ cases:

- Option 1: on-line flood storage upstream of Brookmeadow Wood with Parklands ‘off-line’ FSA Site and some minor Wall Raising along Broomstick Hall Road, (i.e., UA; DA and RW);

- Option 2: on-line flood storage upstream of Brookmeadow Wood with Wall Raising along Broomstick Hall Road, (i.e., UA; RW), Option 2 is split up into to two further options due to differences in how the relief channel will be replaced in the future, the options are:
    - 2A: includes flood attenuation at Brookmeadow Wood and the complete replacement of the Broomstick Hall Road concrete channel, and
    - 2B: includes flood attenuation at Brookmeadow Wood with wall raising along Broomstick Hall Road followed by channel replacement.

- Option 3: on-line flood storage upstream of Brookmeadow Wood with by-pass culvert under Eastbrook Road and minor Wall Raising along Broomstick Hall Road, (i.e., UA; RW; ; and FDW); and

- Option 4: on-line flood storage downstream of Spratt’s Hedgerow Wood with Parklands ‘Off-line’ FSA Site and minor Wall Raising along Broomstick Hall Road, (i.e., UA; DA and RW).

A number of different variants of the above options, in terms of the standard of protection (SoP) delivered were considered for the area. This allows the calculation of GHG emissions arising from four different SoP’s for each option, defined as:

- SoP of 2%;
- SoP of 1.3%;
- SoP of 1%; and an
- SoP of 0.5%.

The preferred option presented within the CBFAS feasibility study is Option 2 at an SoP of 2% (at this SoP options 2A and 2B are identical).

Assessment of carbon from FCERM activities

Capital and maintenance costs

Table A4.20 presents costs associated with the construction and maintenance activities required to achieve the four different SoPs across the Waltham Abbey area for the four options and the BAU case considered as part of the CBFAS Feasibility study. No other costs are accounted for within this assessment.

As per the previous case study (see Section A4.4) available data permits comparison of two contrasting approaches to estimating carbon emissions associated with the construction and maintenance of flood risk management options:

1. Applying carbon intensity factors (see Technical Report, Section 3.1) to estimated construction and maintenance costs under different SoP options; and
2. Use of the EA Construction Carbon Calculator (see Technical Report, Section 2.4.2) that accounts for different carbon intensity factors based on the materials used within the construction of each option.

Table A4.20: CBFAS annual construction and maintenance costs (£,000s)

FRM option	BAU		SoP 2%		SoP 1.3%		SoP 1%		SoP 0.5%	
	Construction	Maintenance	Construction	Maintenance	Construction	Maintenance	Construction	Maintenance	Construction	Maintenance
BAU	0	64	N/A							
Option 1 (including upstream attenuation; downstream attenuation and raising/reworking walls)	N/A	N/A	232	96	232	96	233	96	256	96
Option 2A (including upstream attenuation and raising/reworking walls)			27	85	70	50	87	50	89	50
Option 2B (including upstream attenuation and raising/reworking walls)			27	85	50	85	67	85	73	85
Option 3 (including upstream attenuation; raising/reworking walls and flood defence works)			111	85	117	85	126	85	140	85
Option 4 (including upstream attenuation; downstream attenuation and raising/reworking walls)			231	96	232	96	232	96	258	96

Notes:
Costs are undiscounted and show the average annual cost over a 50 year period; BAU = do minimum; Option 1: On-line flood storage upstream of Brookmeadow Wood with Parklands 'Off-line' FSA Site and some minor Wall Raising along Broomstick Hall Road; Option 2: On-line flood storage upstream of Brookmeadow Wood with Wall Raising along Broomstick Hall Road; Option 3: On-line flood storage upstream of Brookmeadow Wood with by-pass culvert under Eastbrook Road and minor Wall Raising along Broomstick Hall Road; and Option 4: On-line flood storage downstream of Spratt's Hedgerow Wood with Parklands 'Off-line' FSA Site and minor Wall Raising along Broomstick Hall Road. SoP – standard of protection; N/A – not applicable.

Approach 1: Applying a general carbon intensity factor to construction and maintenance costs

Using the cost estimates presented in Table A4.20 carbon emissions resulting from construction and maintenance activities to achieve different SoPs in the catchment are estimated by applying carbon intensity factors (kg CO2e / £):

- *Carbon from construction activities*: estimated using the mid-range estimate carbon intensity factor (0.91 kg CO_2e / £) detailed in the Technical Report (see Table 3.10).
- *Carbon from maintenance activities*: estimated using a lower carbon intensity factor (0.20 kg CO_2e / £). Use of this lower value is somewhat arbitrary but is drawn from the evidence presented in the Technical Report. This aspect of the analysis would be improved if more information was available as to the nature of maintenance activities associated with options.

Table A4.21 presents estimates of the annual carbon emissions associated with construction and maintenance:

- Estimated total carbon emitted annually (average over 50 years) for achieving the minimum SoP of 2% are:

    - O1 = 230 t CO_2e per year;
    - O2A = 42 t CO_2e per year;
    - O2B = 42 t CO_2e per year;
    - O3 = 118 t CO_2e per year; and
    - O4 = 229 t CO_2e per year.

The lowest estimate for carbon emissions is for the variants of Option 2 (O2A and O2B), (since these have the lowest construction costs). Increasing the SoP beyond 2% results in a step change with regard to the costs of Option 2 (both variants), this increase in costs is as a result of the need to replace or raise the channel now as opposed to in the future. However, the costs associated with both Options 2A and 2B are lower than those of Options 1, 3 and 4 at all SoP's, thus their estimated carbon emissions are the lowest of all of the options. The increase in the carbon emitted between options is mostly driven by construction costs as maintenance costs remain relatively constant after an initial increase from BAU.

Table A4.21: Assessment of annual carbon footprint associated with construction and maintenance activities within CBFAS

Flood Risk Management Option	Estimated carbon emissions from construction (t CO2e/yr)					Estimated carbon emissions from maintenance (t CO2e/yr)				
	BAU	**SoP 2%**	**SoP 1.3%**	**SoP 1%**	**SoP 0.5%**	**BAU**	**SoP 2%**	**SoP 1.3%**	**SoP 1%**	**SoP 0.5%**
BAU	0	N/A				13	N/A			
Option 1 (including upstream attenuation; downstream attenuation and raising/reworking walls)	N/A	211	211	212	233	N/A	19	19	19	19
Option 2A (including upstream attenuation and raising/reworking walls)		25	64	79	81		17	10	10	10
Option 2B (including upstream attenuation and raising/reworking walls)		25	46	61	66		17	17	17	17
Option 3 (including upstream attenuation; raising/reworking walls and flood defence works)		101	106	115	128		17	17	17	17
Option 4 (including upstream attenuation; downstream attenuation and raising/reworking walls)		210	211	211	235		19	19	19	19

Notes:

Annual emissions are calculated as annual average over 50 years. BAU = do minimum; Option 1: On-line flood storage upstream of Brookmeadow Wood with Parklands 'Off-line' FSA Site and some minor Wall Raising along Broomstick Hall Road; Option 2: On-line flood storage upstream of Brookmeadow Wood with Wall Raising along Broomstick Hall Road; Option 3: On-line flood storage upstream of Brookmeadow Wood with by-pass culvert under Eastbrook Road and minor Wall Raising along Broomstick Hall Road; and Option 4: On-line flood storage downstream of Spratt's Hedgerow Wood with Parklands 'Off-line' FSA Site and minor Wall Raising along Broomstick Hall Road. SoP – standard of protection; N/A – not applicable.

Approach 2: EA Construction Carbon Calculator results

The Construction Carbon Calculator estimates carbon emissions associated with FCERM schemes from standard data associated with the carbon impacts based on construction material used; i.e., the tonnage, transport distance and mode of transport. Table A4.22 shows a breakdown of the construction materials used and the associated CO_2 emissions for the preferred FAS option (Option 2A or 2B at an SoP of 2%).

Table A4.22: Outputs from the construction calculator for the preferred option, emissions shown as tonnes CO_2 for all construction costs

Sub-totals	**CO_2 tonnes**	**%**
Quarried material	30,507	91%
Timber	19	0%
Concrete, mortars & cement	1,291	4%
Metals	718	2%
Plastics	298	1%
Miscellaneous	4	0%
Plant emissions	344	1%
Waste removal	7	0%
Portakabins	19	0%
Material transport	424	1%
Personnel travel	36	0%
Total	33,667	100%

As shown by Table A4.22, the dominant embodied carbon from the preferred FAS option arises from quarried material (91% of total emissions). This is primarily arises from use of clay (some 152,000 tonnes of material as detailed in Construction Carbon Calculator data, with an embodied carbon content of 0.2 t CO_2 per tonne, which results in 30,400 tonnes CO_2), quarried aggregate (approximately 4,500 tonnes of material) and recycled aggregate (3,800 tonnes of material).

Comparing EA Construction Carbon Calculator results to the carbon intensity factor approach

A direct comparison of the results from Table A4.21 (carbon intensity factor approach) and Table A4.22 (EA Construction Carbon Calculator results) can be made only after the annual values for asset construction calculated for the carbon intensity approach are total over the 50 year time period. Emissions from asset maintenance estimated from the carbon intensity factor approach are not included in the comparison (since this is not covered by the EA Construction Carbon Calculator).

Converting the annual emission for the preferred option in Table A4.21 to the total amount over 50 years gives an estimate of 3,950 tonnes CO_2 for asset construction. This estimate is substantially less than the amount reported by the EA Construction Carbon Calculator of approximately 46,200 tonnes CO_2. In fact in comparison to the carbon intensity factors reported for the sample of schemes in Table 3.11, Cobbins Brook represents an 'outlier' with an estimated carbon intensity factor of approximately 11 kg CO_2e / £ compared to the weighted averages over all schemes in the range 0.91 – 0.98 kg CO_2e / £. In line with the suggestions for moving forward in the Technical Report (Section 5.2), this apparent discrepancy highlights point made concerning scrutiny of carbon calculators and review of results to establish 'typical' ranges of emissions for different types of projects

Land use management

In addition to asset construction and maintenance activities for the preferred option, approximately 1.5 hectares of land comprising of arable farmland and woodland would be lost to cater for flood storage. However, as part of the overall scheme additional wetland would be created (although the details to the exact size of this are unavailable). At present there is limited information relating to the carbon sequestration potential of inland wetlands, this in addition to missing details relating the exact size of the wetland to be created mean it is not possible to estimate a net carbon for this aspect of the Cobbins Brook FAS.

Assessment of carbon associated with flood and coastal erosion damages

Available data permits the estimation of carbon emissions associated with residual damages in relation to residential property by applying a damage multiplier (see Technical Report, Section 2.4.2) to estimate residual damages under different SoP options. The carbon emissions associated with the residual damages for other impacts including those relating to commercial property are not calculated here.

Table A4.23 presents annual estimated residual damages for flooding under the BAU case and different SoPs (from 2% to 0.5%). Estimated carbon emissions associated with the residual damage of each option are calculated by multiplying the residual damage by a damage multiplier (see Technical Report, Section 2.4.2).

Table A4.23: Residual annual damages for BAU and different SoP (£,000s)

Flood Risk Management Option	Residual damages				
	BAU	**SoP 2%**	**SoP (1.3%)**	**SoP (1%)**	**SoP (0.67%)**
BAU	301	N/A			
Option 1 (including upstream attenuation; downstream attenuation and raising/reworking walls)	N/A	18	4	3	3
Option 2A (including upstream attenuation and raising/reworking walls)		29	6	5	4
Option 2B (including upstream attenuation and raising/reworking walls)		29	6	5	4
Option 3 (including upstream attenuation; raising/reworking walls and flood defence works)		24	5	4	4
Option 4 (including upstream attenuation; downstream attenuation and raising/reworking walls)		15	12	4	3

Notes:

Residual damages are totalled annually and are undiscounted; BAU = do minimum; Option 1: On-line flood storage upstream of Brookmeadow Wood with Parklands ‘Off-line’ FSA Site and some minor Wall Raising along Broomstick Hall Road; Option 2: On-line flood storage upstream of Brookmeadow Wood with Wall Raising along Broomstick Hall Road; Option 3: On-line flood storage upstream of Brookmeadow Wood with by-pass culvert under Eastbrook Road and minor Wall Raising along Broomstick Hall Road; and Option 4: On-line flood storage downstream of Spratt’s Hedgerow Wood with Parklands ‘Off-line’ FSA Site and minor Wall Raising along Broomstick Hall Road. SoP – standard of protection; N/A – not applicable.

Table A4.24: Estimated annual carbon emissions associated with the residual damages (t CO_2e per year)

Flood Cell	Carbon associated with damages				
	BAU	SoP 2%	SoP 1.3%	SoP 1%	SoP 0.5%
BAU	266	N/A			
Option 1 (including upstream attenuation; downstream attenuation and raising/reworking walls)	N/A	16	4	3	3
Option 2A (including upstream attenuation and raising/reworking walls)		26	5	4	4
Option 2B (including upstream attenuation and raising/reworking walls)		26	5	4	4
Option 3 (including upstream attenuation; raising/reworking walls and flood defence works)		21	4	4	4
Option 4 (including upstream attenuation; downstream attenuation and raising/reworking walls)		13	11	4	3

Notes:

BAU = do minimum; Option 1: On-line flood storage upstream of Brookmeadow Wood with Parklands ‘Off-line’ FSA Site and some minor Wall Raising along Broomstick Hall Road; Option 2: On-line flood storage upstream of Brookmeadow Wood with Wall Raising along Broomstick Hall Road; Option 3: On-line flood storage upstream of Brookmeadow Wood with by-pass culvert under Eastbrook Road and minor Wall Raising along Broomstick Hall Road; and Option 4: On-line flood storage downstream of Spratt’s Hedgerow Wood with Parklands ‘Off-line’ FSA Site and minor Wall Raising along Broomstick Hall Road. SoP – standard of protection; N/A – not applicable.

Combining estimated residual damages and the damage multiplier value entails a series of caveats:

- Property damage was assessed based on:
    - Type, age and social class of houses and householders in the benefit area;
    - Detailed standard data for type, age and social class of houses and householders;
    - Detailed standard data on commercial properties; and
    - Intangibles e.g. re-locating after a flood, stress and disruption.

The assessment here is limited to emissions arising only from refurbishment and repair of residential properties. Estimated emissions do not include those arising from commercial property damage, emergency services, or transport disruption and avoided damages are calculated on an annual basis of the potential damage that may occur under BAU.

Table A4.24 presents estimates of the annual carbon emissions associated with the residual damage under the BAU case and different SoPs. As expected – since the damage multiplier is only scaling estimated residual damages - the results show that the highest SoP (0.5%) has the lowest carbon footprint across all of the flood risk management options. A shift from BAU to an SoP of 2% (across all options) results in the largest (incremental) reduction in carbon emissions arising from residual flood damages.

A4.5.3 Summary

The Cobbins Brook feasibility study recommends Option 2A or 2B with a SoP of 2% to address flooding of Cobbins Brook; i.e. on-line flood storage upstream of Brookmeadow Wood with Wall Raising along Broomstick Hall Road, as this option has the highest cost benefit ratio of all of the options tested (Environment Agency, 2004).

The assessment shown in this case study provides a broad-brush estimate of the potential carbon footprint for the Waltham Abbey area in Essex where a number of different FRM options have been considered. Table A4.25 provides a summary of the annual carbon emissions associated with the construction and maintenance costs and residual damages from achieving different SoPs for each of the options considered within the feasibility study. The overall carbon footprint over 50 years for each SoP across the range of options is estimated to be:

- BAU: 13,919 t CO_2e,
- SoP 2%: 3,358 - 12,310 t CO_2e,
- SoP 1.3%: 3,390 - 12,045 t CO_2e,
- SoP 1%: 4,119 - 11,694 t CO_2e, and
- SoP 0.5%: 4,348 - 12,831 t CO_2e.

The greatest influence on the estimated footprints is carbon emissions associated with the construction and maintenance cost of options; in annual terms these significantly outweigh emissions associated with residual damage costs except in the case of the BAU scenario (where the opposite is the case). Options that increase the SoP give rise to lower footprints as a result of decreasing residual damages however, in this example the additional cost of moving from a SoP of 2% to 1.3% or greater means that the carbon footprint of each option begins to increase, to the extent that for most options a SoP of 2% results in the lowest carbon footprint estimates.

Overall, the information available for the Cobbins Brook FAS feasibility study enables a rudimentary assessment of carbon emissions associated with the construction and maintenance costs, including a comparison of results from applying a generic carbon intensity factor to the Construction Carbon Calculator. This suggests that there is need for scrutiny and review of construction carbon estimates as more schemes are subject to the assessment in appraisal.

Sufficient information is not available to assess carbon emissions and sequestration associated with land management aspects of the feasibility study; this is a key gap in the available data. This represents an area of significant uncertainty, particularly in relation to inland wetland where there is potential for both sequestration and storage of carbon and release of methane depending on site specific factors.

Table A4.25: Summary of the annual carbon footprint for Cobbins Brook FAS

Flood Risk Management Options	**BAU (t CO2e/yr)**			**SoP 2% (t CO2e/yr)**			**SoP 1.3% (t CO2e/yr)**			**SoP 1% (t CO2e/yr)**			**SoP 0.5% (t CO2e/yr)**		
	Cons. & main.	Res. damage	Sum	Cons. & main.	Res. damage	Sum	Cons. & main.	Res. damage	Sum	Cons. & main.	Res. damage	Sum	Cons. & main.	Res. damage	Sum
BAU	13	266	278	N/A											
Option 1	N/A	N/A	N/A	230	15.9	246	230	3.5	234	231	2.6	234	252	2.6	255
Option 2A				42	25.6	67	74	5.3	79	89	4.4	94	91	3.5	95
Option 2B				42	25.6	67	63	5.3	68	78	4.4	82	83	3.5	87
Option 3				118	21.2	139	123	4.4	128	132	3.5	135	144	3.5	148
Option 4				229	13.2	243	230	10.6	241	230	3.5	234	254	2.6	257

Notes:

BAU = do minimum; Option 1: On-line flood storage upstream of Brookmeadow Wood with Parklands ‘Off-line’ FSA Site and some minor Wall Raising along Broomstick Hall Road; Option 2: On-line flood storage upstream of Brookmeadow Wood with Wall Raising along Broomstick Hall Road; Option 3: On-line flood storage upstream of Brookmeadow Wood with by-pass culvert under Eastbrook Road and minor Wall Raising along Broomstick Hall Road; and Option 4: On-line flood storage downstream of Spratt’s Hedgerow Wood with Parklands ‘Off-line’ FSA Site and minor Wall Raising along Broomstick Hall Road. SoP – standard of protection; N/A – not applicable.

A4.5.4 References

Environment Agency, 2004a. *Cobbins Brook FAS Feasibility Study Final Report*.