LCIC | UEA University of East Anglia
Low Carbon Innovation Centre

Towards a GHG Reduction Strategy for the Broads – Derivation of Emission Estimates

Technical Report Supporting Strategy Report

On Behalf of:
The Broads Authority

May 2010

UEA University of East Anglia
CARBON CO2NNECTIONS
BEST FOOT FORWARD
CRed carbon reduction

Introduction to the Broads Audit and the Technical Report

Background to the Audit

Within its overall ambition to manage the Broads in a sustainable way, the Broads Authority (BA) has identified a need to take a positive approach to the management of greenhouse gas (GHG) emissions. This need is underpinned by a number of strategic documents including the Broads Authority's Local Development Framework (LDF) Core Strategy 2007 – 2021 Development Plan Document which identifies a number of strategic objectives and policies in relation to adapting to and mitigating climate change including a Core Strategy Policy on Response to Climate Change. In addition, the Department for Environment, Food and Rural Affairs (Defra) have also clearly identified that the National Parks (of which the Boards is one) should be acting as beacons for authorities and local communities in the way they address the priorities of government in moving towards sustainable development and carbon management.

In order to achieve its ambitions and to tackle the issues of climate change for the benefit of the Broads community as a whole, the BA has identified a need to develop a carbon management strategy where such a strategy would account for current emissions from the various sources, identifying the scope for any reductions and, therein, a means by which to identify the impacts of policy and development changes on GHG emissions, how these can be mitigated or enhanced to optimise GHG reductions.

A necessary first step in the development of any carbon management strategy is a carbon footprint or audit which serves to provide information on the source, nature and magnitude of emissions and thus provides the basis for analysing mitigation options, making decisions on how best to reduce carbon emissions and how to encourage individuals, community groups land managers and businesses to co-operate in developing practical, sustainable and local projects to reduce their carbon emissions.

The development of a carbon footprint for the BA area is potentially complex, requiring not only the identification and quantification of emissions from various sources but also identifying the relevant spatial area to address and providing information at a level of detail that is sufficient to both identify optimum investment in mitigation measures and ultimately to monitor the effectiveness of these measures.

Given these complexities, the BA initially commissioned a team from LCIC/CRed and the Tyndall Centre for Climate Change Research (both based at the School of Environmental Sciences at the University of East Anglia) to scope out an approach and consider how best to structure and develop a carbon audit would provide a robust means to:

- identify and quantify emission sources;
- identify options for reducing emissions from those sources;
- appraise the performance (and relative performance) of those options;
- consider the cost effectiveness of those options; and
- consider and quantify the implications of any changes in operations or policy in other areas that might also have an impact (positive or negative) on carbon emissions.

The final report Carbon Audit of the Broads - Phase 1: Scoping Study was delivered to the BA in September 2008. On the basis of the recommendations in that report, the BA commissioned this second (and final) phase of the audit and the production of this technical report (which is accompanied by a non-technical summary and analysis). The 2008 scoping study concluded that:

- because the BA has influence in the Broads more widely, the audit/strategy needs to consider emissions beyond the 'usual', operationally restricted, sphere of an audit and also consider wider GHG emissions a larger geographical and landscape scale than the operations of the BA alone;

- when considering these wider emissions, the audit/strategy should take into account the fact that, whilst the BA has executive powers (including being a Planning Authority) to carry out its statutory duties[1], its geographical area of jurisdiction overlaps with the other jurisdictions (with other duties and executive powers). As such, the BA has greater scope to influence emissions from some sources and less scope for others. Accordingly, the audit/strategy should focus most effort on gaining sufficient detail in the areas where the BA has most influence while also taking note of the scale of other emissions sources;

- on this basis, it is desirable to categorise the emission sources into those that are broadly within the scope of the BA's influence directly (for example, from recreation, navigation, land management) and those that are less within the BA's power to influence directly[2] (such as the industrial, waste, domestic or transport emissions that are more the remit of other, overlapping, authorities). This is not to say that such emission sources should be excluded but merely that less detail is required for those emissions (or rather more detail is required for those areas/issues where the BA has most influence);

- this categorisation can be achieved by making a loose division between those emissions that are connected with the 'services' that the broads provides and those that are not (or are only distantly) 'connected';

- thus, emissions associated with Broads tourism and recreation or conservation and land use are examples of emissions that sit firmly within emissions that are 'connected with' the Broads and emissions from domestic sources or transport unrelated to the above are examples of emissions that are connected to the Broads only by geography and, hence are not directly connected to the services that the Broads provides;

- in terms of geographic boundaries, when considering the emissions that are 'connected with' the Broads (such as tourism and recreation), it is important to account for emissions that do not necessarily occur within the boundaries of the Broads Executive Area. For example, most visitors coming to the Broads do so from outside the executive area and thus one should consider emissions for the entire visit (from home to Broads and back) and not just the emissions within the Broads Executive Area;

- the scoping study also identified the importance of estimating stored carbon in soils and vegetation to ensure that the importance of the resource is reflected in the audit and conserved in the strategy.

---

[1] It is the general duty of the Authority to manage the Broads for the purposes of:

- Conserving and enhancing the natural beauty, wildlife and cultural heritage of the Broads;
- Promoting opportunities for the understanding and enjoyment of the special qualities of the Broads by the public; and
- Protecting the interests of navigation.

The Broads Act also sets down the need for the Authority to have regard to the needs of agriculture and forestry, and the economic and social interests of those who live or work in the Broads.

[2] But not totally outside of the BA's power to influence.

In this way, the scoping study proposed the following divisions between various emissions (and this was carried through into this, second, phase of study):

Emissions 'connected with' the Broads (more BA influence - more detail required)

Tourism and Recreation

- **Private boat owners**
  - Use of boats
  - Transport to/from boats
- **Hire boats**
  - Hire boat emissions
  - Boatyards
  - Visitors' transport to/from boats
- **Other tourism and recreation**
  - Accommodation
  - Food and drink
  - Recreation (spending on)
  - Travel to/from Broads
- **All visitors**
  - Travel around the Broads

Land and Land Use

- **'Natural'**
  - Woodland / dense scrub
  - Marsh / fen
  - Rivers
  - Broads
- **Agriculture**
- **Agri/semi-natural**
  - Drainage channels

Other management and activities

- **Other conservation organisations/operations**
- **Water level management**
- **BA Operations**

Broads Carbon Stores

- **Soil**
- **Vegetation**

Emissions 'NOT/Less connected with' the Broads (less BA influence – less detail required)

Emissions from industry & commerce

With the exception of some key point source emitters that the BA may be able to influence (e.g. Cantley Sugar Beet factory) which have been considered alongside Broads Connected emissions.

Emissions from domestic sources

While not outside of the BA's scope of activity, domestic sources are more the preserve of other authorities with whom the BA works

Emissions from transport

UK GHG emissions data by area provides emissions from estimated travel within that area but not travel to that area. The latter has been considered as connected with the broads and an estimate of Broads-related travel within the Broads has been estimated there.

Objectives

The aim of the second phase of study was to produce a carbon audit of the Broads area and, in the process, provide suggestions and, where possible, identify strategic options concerning the most effective action that would reduce harmful emissions and/or increase sequestration of carbon dioxide and other GHGs.

Drawing from conclusions and work in the first (scoping) phase, the audit operates at a number of levels, beginning with an audit of the BA's own operational activities and working up to the wider context of the Broads area, defined both geographically and according to the services provided by the Broads. By structuring the audit in this way the idea has been to expand the areas of consideration beyond the 'usual', operationally restricted, sphere of an audit and also consider wider GHG emissions and sequestration at a larger geographical and landscape scale. Such emissions have the potential to be much larger in scale than the operational emissions of the BA itself yet, at the same time, BA has the potential to influence them; some more significantly than others. By considering these wider emissions alongside the narrower, operational, emissions, then, BA is in a position to identify strategically how it can most (cost) effectively deliver the most significant emissions reductions across its various roles and geographical responsibilities.

Despite being undertaken prior to the publication of *English National Parks and the Broads - UK Government Vision and Circular 2010* (March 2010), the assessment of emissions and the resulting strategy (to which this Technical Report is an Annex) are entirely consistent with the delivery of this new vision. Here, for example, the 2010 vision identifies a number of general actions on the part of National Park and Broads Authorities including:

- *"the Government believes that the Parks must now place climate change as central to their objectives";*

- *"the Authorities are educators and in the area of climate change they have a vital role to play. They should spread important messages about the impacts of climate change and how individuals, especially visitors, can play their part in tackling it in ways which motivate lifelong behaviour change";*

- *"the management of the Parks can play a key role in the fight against climate change and in leading others by demonstrating best practice"; and*

- *"the Authorities also have a role to play in reducing emissions from sectors other than the land".*

Appropriate Levels of Detail

In terms of detail, the emphasis of the audit is clearly on providing sufficient information on which to base strategic and policy decisions and options identification and appraisal geared towards a reduction in (net) GHG emissions. Here one needs to be able to identify where the emissions are coming from, what the factors are that influence the scale of the emission, to what extent these can be controlled or influenced by changes in strategy and, therein, be able to identify how changes in strategy may effect the emission.

When undertaking assessments such as this, it is almost always the case that some emissions sources are easier to estimate with higher levels of accuracy than others. By extension, some potential emissions sources are exceedingly difficult and very time consuming to estimate with matching, higher levels of accuracy. Rather than investing large amounts of time, effort and investigation in estimating emissions from sources that might, in the end, be relatively small or uncontrollable, an assessment (such as this) seeks to maintain a level of detail appropriate to efficiently 'homing in' on the strategic questions in hand, namely:

- what are likely to be the most significant emission sources;
- what are the major causes of these emissions;
- what, if anything, could be done practically to curb these emissions;
- how much is this likely to reduce GHG emissions (or increase sequestration); and, therein
- what is likely to be an optimal strategy for reducing (net) emissions.

From a strategic perspective even fairly broad order of magnitude estimates can be useful initially to scope emissions and identify options for further consideration. If one subsequently identifies that further consideration of options requires more detail (for example to assess potential reductions from a given intervention for a given cost) then it can be undertaken later but it is important to first identify whether the emission is significant and, indeed, whether anything can be done about it).

Important Note on Rounding and Accuracy

It is important to note that the estimates for components of emissions categories presented in this Technical Report have not been rounded to the nearest logical unit. This should not be taken to mean that estimates are accurate to the nearest tonne (far from it). Rather, estimates are rounded once they have been aggregated to category/subcategory level. Retaining unrounded values in this way enables users of the report to better understand and dissect how numbers have been derived, combined and can be adjusted or repeated in future reviews.

Structure of the Technical Report

This Technical Report details the methods used to estimate emissions, the data on which estimates of each emission source are based, any assumptions used to fill gaps, discussion of issues associated with improvement in estimates and possible options and areas for focus for an emissions reduction strategy.

The Technical Report is divided into two distinct (and ‘standalone’) parts, each one covering a different aspect and level of assessment as follows:

- **Part A - Level 1 Audit: Emissions from Broads Authority Operations -** a carbon footprint of the Broads Authority’s (BA) operations, organised in a way that is suitable for emission elements to viewed alongside the second level, namely;

- **Part B - Level 2 Audit: Wider GHG Emissions in the Broads Executive Area – assessment of GHG emissions and sequestration for the wider Broads Area and the services provided by the Broads. The audit is divided into:**

➢ **Level 2a: emissions connected with the Broads and its services (Level 2a);**
➢ **Level 2b: emissions occurring within the Broads Executive Area but broadly unconnected with Broads services (such as emissions from industrial units, domestic emissions, etc.)**

Broads Carbon Audit

Part A - Level 1 Audit: Emissions from Broads Authority Operations

A1. Introduction

A1.1 Preamble

As noted in the main introduction to the report, the audit as a whole is divided into several different levels each denoting a different scale. The first (and smallest), of these levels relates to emissions associated with the Broads Authority's (BA) operations where here emissions relate principally to those from BA members and staff, BA premises and equipment. This part of the Technical Report (Part A) provides a description and assessment of emissions from these BA operations.

Level 1 of the audit conforms to the scale at which carbon audits are normally carried out for institutions, companies, public bodies, etc. and for which targets or other reporting requirements may soon be in the pipeline (or may already be required). It is worth noting two important issues in connection with the possibility of future reporting requirements from the outset.

Mechanisms for data collection

Firstly, where BA's intention at the outset of the project was that an audit of operational emissions might be repeated every five years (coinciding with strategic planning periods for BA), depending on any future reporting requirements from the Department for Food and Rural Affairs (Defra), it is possible that more frequent audit updates may be required. The analysis provided here represents the first attempt at calculating carbon emissions from BA operations and has been based on data provided by BA (for the Financial Year 2008/2009) as well as online surveys for staff commuting and business travel.

As would be expected, with the exception of the survey data undertaken directly for this study, the collection of financial and other data by BA is not tailored to estimation of carbon emissions but, rather, to other data reporting and record keeping requirements. This means that this first attempt to estimate emissions must bridge data gaps and extrapolate from existing data to arrive at fairly broad estimates of emissions.

As a first step this is sufficient as a means of estimating the contribution of the main sources of emissions and likely areas for improvement. However, given the potential for requirements to update audits more frequently it is worth BA considering how best to introduce data collection procedures that are more tailored to the production of more frequent (and more accurate) audits. The process of producing this audit from the existing data itself identifies a number of areas where data resolution can be improved and these are identified in the text. It will, however, be worth considering the detail of any future new reporting requirements when considering how best to implement new data gathering and management systems.

Which actions count towards target reductions?

The second issue in relation to any future reporting requirements from Defra relates to the whether or not emission reduction targets will form a part of the process and what actions count towards this. As noted in the main introduction to the report, one of the main drivers for also undertaking an audit at the higher spatial levels that comprise Level 2 (see Part B of this Technical Report) has been that, while not being directly 'responsible' for emissions in the wider Broads Executive Area, BA has some influence on the emissions and emissions reduction.

As evidenced later in the Technical Report (in Part B), these wider emissions are often orders of magnitudes higher than emissions from BA operations, and as such, successful BA intervention to reduce these wider emissions may have the potential to deliver a level of emissions reduction that is very substantially more than could be achieved by actions at the operational levels that may be the focus of future reporting requirements. In terms of cost-effective intervention, then, actions to reduce emissions at the wider scales that comprise Level 2 of this audit may deliver much greater GHG emissions reduction and, additionally, at potentially less cost than alterations to operations.

From the perspective of the wider objective to reduce emissions, then, actions that will reduce emissions in the wider area could be viewed as being of higher priority than actions at an operation level (and, owing to the scale of the emissions could even offset all emissions from BA operations). At present, however, it is unclear whether any actions in the wider area (that could even offset all operational emissions) would count towards any targets that may or may not be a part of future reporting requirements. If they are not, Defra reporting requirements may artificially skew priority towards actions at the operational level to the potential detriment of actions that may deliver much larger reductions at a wider level (even if they are more difficult to verify). As this is would in all likelihood be an unintended 'perverse' effect of any future Defra requirements these issues need to be brought to the attention of Defra before any requirements are finalised. Indeed, as the same issues of scale of emissions and influence over emissions reduction is likely to be same in other National Park Authorities, it may be worth promoting the idea of 'split level' audit that have been developed for BA to other National Parks and Defra.

A1.2 Structure of the Level 1 Assessment

As noted above, emissions associated with the Broads Authority's (BA) operations relate principally to those from BA members and staff, BA premises and equipment. The audit has been based on data provided by BA (for the Financial Year 2008/2009) as well as online surveys for staff commuting and business travel. All available data from BA operations has been provided to the study and assumptions and extrapolations have been applied as necessary where information was not available. This permits an analysis structured according to the following main emission categories:

- transport;
- utilities;
- materials; and
- waste.

For readers' convenience, each section begins with an overview of the estimated emissions for the category. This is followed by a more detailed description of the methods and data used to derive estimates, the resulting emissions and interpretation.

Part A concludes by identifying possible options for making improvements in data collection in future and by summarising the emissions and identifying those emissions sources that are responsible for the largest proportion of total emissions and, hence, where actions to reduce emissions as part of a strategy may be most fruitful. These latter strategic insights are then taken forward to the strategy document which this Technical Report supports.

A1.3 Headline emissions estimates

Resulting headline emissions estimates for BA operations (Level 1 of the assessment) are summarised by category in Table A1.1. Total emissions are estimated as being of the order of 1,900 t CO_2e. Within this, however, there is obviously some uncertainty in relation to the precision of estimates. This can be expected to vary for some sources and categories of emissions more than others. For example, parts of the analysis that must rely on Input/Output analysis are particularly uncertain. Areas/emissions where estimates are particularly uncertain are marked by orange boxes in the tables.

Table A6.2 (provided at the end of this section) provides a look-up table of all estimated emissions by source and category, expressing each emission in terms of magnitude of emission and as a percentage both of the broad category describing the emission (as set out above) and also as a percentage of the total emission from BA operations..

As noted in the main introduction to the Technical Report, identifying and estimating the magnitude of emissions is only one part of the process of developing an emissions reduction strategy. The next step is to identify from the audit what the key contributors to emissions are, therefore, where mitigation measures may provide quick and effective 'wins' and, therein, where mitigation measures may best be focussed (and what these might comprise). This is the subject of the separate Strategy Report that this Technical Report supports and further analysis of contribution of the different sources emissions to overall emissions and the issue of uncertainty is provided there. Derivation of estimates is described in the remainder of this part (A) of the report.

Table A6.1: Overview of Emissions by Category of Source

	Emissions (t CO_2e)	**Emissions % CO_2e**
Business Travel	~300	16%
Commuting	~120	6%
Utilities HQ	~85	5%
Utilities All other sites	~260	14%
Non-transport fuels	~7	0.4%
Materials	~1,000	54%
Waste	~90	5%
TOTAL EMISSIONS	**~1,900**	**100%**

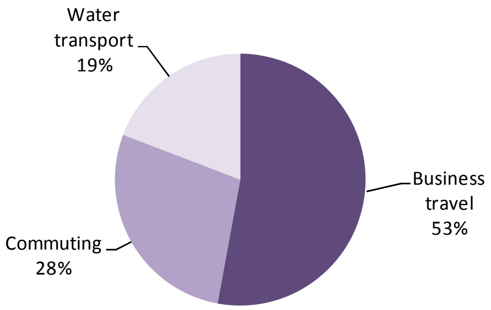
A2. Transport

A2.1 Overview of Estimated Emissions

The transport emissions component comprises emissions from business travel, staff commuting and water transport. Emissions from each represents 53%, 28% and 19% respectively of the total 411 tCO_2e estimated which, itself, represents 22% of all BA activities (i.e. Level 1).

Table A2.1 provides estimated CO_2 emissions associated with each transport component. The following sections provide both a further breakdown and a description of the methods used in estimation.

Table A2.1: Overview of Transport and Travel Emissions

Component	**Emissions (tCO_2e)**	**Emissions % CO_2e**	
Business travel	217	53%	
Commuting	115	28%	
Water transport	79	19%	
TOTAL BA TRANSPORT EMISSIONS	411	100%	

A2.2 Business Travel

Data and Calculations

Business travel has been divided into travel within and travel outside the Broads area. The following two sources of data have been used to provide estimates of emissions:

- an online survey with 25% BA staff responses; and
- data provided by BA

BA has provided data on Flights, Train travel, mileage claimed by staff and volunteers when they use their own cars, fuel consumption from vehicles own by the authorities. Survey requested about trips within the Broads and outside which has permitted partition of business travel into these two categories. The survey indicates that train and flights are only used for trips outside Broads and that 68% of car travel occurs within the Broads. Base data are summarised in Table A2.2 and derived overall travel distances are summarised in A2.3 where these assume car occupancy rate of one per vehicle.

Table A2.2: Data on Fuel Consumption and 'Mileage' for Business/Operational Travel

Mode of transport	**Quantity**	**Unit**	**CO_2e Conversion factor**
Fuel consumption by BA vehicles			
Autogas (LPG)	1,459	Litres	Defra 2009, LPG
Diesel	59,312	Litres	Defra 2009, Diesel
LPG	667	Litres	Defra 2009, LPG
Premium Diesel	841	Litres	Defra 2009, Diesel
Unleaded	3,209	Litres	Defra 2009, Petrol
V Power	264	Litres	Defra 2009, Petrol
V Power Diesel	552	Litres	Defra 2009, Diesel
Staff own vehicle 'mileage' claimed			
Mileage via Purchase Ledger	14,572	km	Defra 2009, Average car
Mileage via Payroll		km	
Casual	46,837	km	Defra 2009, Average car
Essential	95,902	km	Defra 2009, Average car
Leased	33,709	km	Defra 2009, Average car
Motorcycle	80	km	Defra 2009, Motorbikes
Rail and flights			
Train travel within UK	71,799	km	Defra 2009,National rail
One return flight Norwich/Edinburgh	944	km	Defra 2009, Domestic flight

A2.3: Derived Overall Travel Distances

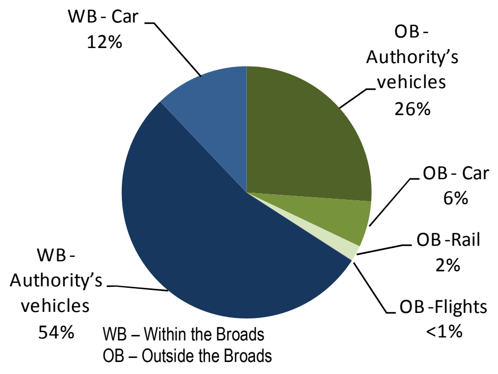
Mode of transport	**Quantity**	**Unit**
Outside the Broads		
Authority's vehicles (32%)	21,077	litres
Car (own by staff or volunteers) (32%)	60,747	km
Rail	71799	pkm
Flights	944	pkm
Within the Broads		
Authority's vehicles (68%)	45,228	litres
Car (own by staff or volunteers) (68%)	130,354	km

Calculated Emissions

Calculated emissions for business travel are provided in Table A2.4. As can be seen from the table, business travel accounts for a total of 217 tCO_2e, 12% of the total BA emissions. Emissions from business travel includes the use of vehicles owned by the Broads Authority, consumption associated with staff and volunteers private cars used for work purposes as well as rail and air travel. 80% of the emissions from business travel are from BA vehicles.

Table A2.4: Emissions from Business/Operation Travel within and outside the Broads

Mode of transport	**Emissions ($t CO_2e$)**	**Emissions % CO_2e**
Outside the Broads		
Authority's vehicles	57	26%
Car (own by staff or volunteers)	13	6%
Rail	4	2%
Flights	0.18	<1%
SUBTOTAL (outside)	74	34%
Within the Broads		
Authority's vehicles	117	54%
Car (own by staff or volunteers)	26	12%
SUBTOTAL (within)	143	66%
TOTAL EMISSIONS	217	100%



A2.2 Commuting to Work

Data and Calculations

Commuting emissions were estimated by means of an online staff survey. As the survey was completed by only 37% of responses, results have been extrapolated to the total number of BA staff (147 individuals) applying a car occupancy of one for missing data. Table A2.5 summarises data from the staff survey.

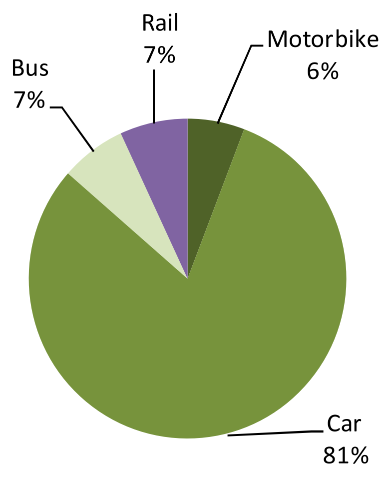
Table A2.5: Commuter Survey Data

Transport mode	**surveyed distance (km)**	**total distance - extrapolated (km)**	**CO_2e Conversion factor**
Motorbike	20,482	55,756	Defra 2009, Motorbike
Car - small petrol (<1.4l)	49,667	135,205	Defra 2009, Car - small petrol
Car - mid petrol (1.5-2l)	42,866	116,691	Defra 2009, Car - medium petrol
Car - large petrol (>2.0l)	27,713	75,440	Defra 2009, Car - large petrol
Car - small diesel (<1.7l)	4,125	11,230	Defra 2009, Car - small diesel
Car - mid diesel (1.7-2l)	25,658	69,846	Defra 2009, Car - medium diesel
Car - large diesel (>2l)	30,246	82,337	Defra 2009, Car - large diesel
Bus	25,209	68,625	Defra 2009, Bus
Rail	47,287	128,726	Defra 2009, National rail
Walk	13,386	36,439	BFF, Walk/cycle
Cycle	40,241	109,545	BFF, Walk/cycle

Calculated Emissions

Table A2.6 provides calculated emissions from commuting. As can be seen from the table, the analysis suggests that commuting emissions are around 115 tCO_2e representing 6% of the total BA carbon footprint. The analysis suggests that travel by car accounts for just over half the commuting distance travelled (55%) but is responsible for 81% of CO_2e emissions. Walking and cycling are the next most frequently used forms of transport (despite the absence of secure cycle parking at the new Dragonfly House HQ) and together account for 16% of distance travelled, followed by rail at 14%. Walking and cycling are considered zero emissions and overall car occupancy is estimated as 1.17.

Table A2.6: Emissions from Commuting

Mode of transport	**Emissions ($t CO_2e$)**	**Emissions % CO_2e**	
Motorbike	7	6%	
Car	93	81%	
Bus	8	7%	
Rail	8	7%	
Walk/cycle	0	0%	
TOTAL EMISSIONS	115	100%	

A2.3 Water Transport

Data and Calculations

BA operates a number of vessels to fulfil its functions in respect of both navigation and conservation of the Broads. BA has provided the quantity (litres) and type of fuel used by authority vessels in 2008/09 obtained from fuel cards and credit cards. Table A2.6 provides a breakdown of fuel use and conversion factors applied.

Table A2.6: BA Data on Water Transport Fuel Use

Type of fuel	Litres	Conversion factor
Diesel	6,919	Defra 2009, Diesel
Gas Oil	877	Defra 2009, Gas Oil
Gas Oil 0240 Ord	18,625	Defra 2009, Gas Oil
Unleaded	526	Defra 2009, Petrol

Calculated Emissions

Water transport emissions from the operation of BA vessels are provided in Table A2.7. The analysis suggests an annual emissions of around 79 tCO_2e, representing 4% of the total BA operational emissions.

Table A2.7: Emissions from Water Transport

Mode of transport	Emissions (t CO_2e)
Authority's vessels	79
TOTAL EMISSIONS	79

A3. Utilities

A3.1 Overview of estimated emissions

The utilities component of BA operations across all sites includes energy (i.e. electricity, natural gas, etc), and water consumption. Estimated overall emissions are summarised in Table A3.1. As can be seen from the table, with a total estimated emission of 337 tCO_2e, utilities emissions represent 18% of the total BA operational carbon emissions.

Table A3.1: Overview of Utilities Emissions

Component	Emissions (t CO_2e)	Emissions % CO_2e
(Old) Head Quarters Utilities	82	24%
Other sites Utilities	254	76%
TOTAL BA UTILITIES EMISSIONS	337	100%

A3.2 Head Quarters (HQ)

Data and Calculations

Estimation of emissions has been based on data provided by BA on energy (electricity and gas) and water. Owing to the fairly recent move, energy consumption data were not available for the current location (Dragonfly House). As such, figures are based on annual consumption at previous location (18 and 20 Colegate, Norwich). In addition, data were available only for around 10 months and it has been necessary for annual consumption has been extrapolated from this 10 month dataset. Consumption data are provided in Table A3.2.

Table A3.2: BA Data on Utilities Consumption at (OLD) Headquarters

	Days measured	Measured consumption (kWh/m^3)	Annual consumption (kWh/m^3)	Conversion factor
Electricity	249	65,903	96,605	Defra 2009, Electricity 2007
Gas at 18 Colegate building	333	61,603	67,522	Defra 2009, Natural gas
Gas at 20 Colegate building	228	46,705	74,770	Defra 2009, Natural gas
Water	249	354	519	Defra 2009, Water

Calculated Emissions

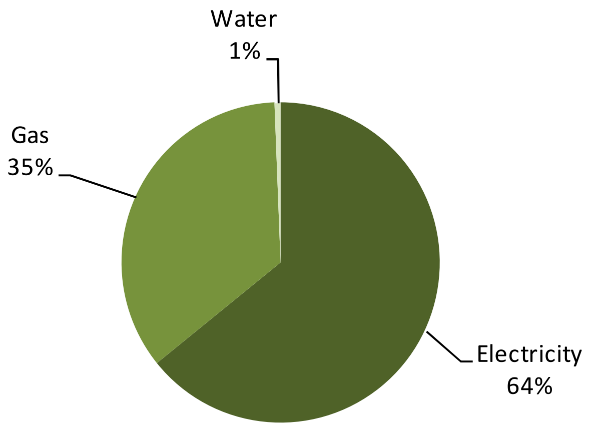
Table A3.3 provides emissions estimates for the **old** HQ building (18 and 20 Colegate, Norwich). In considering these data and associated emissions it should be noted that the new Dragonfly House HQ building is built to high energy efficiency standards incorporating a range of energy and energy efficiency technologies including solar panels, rainwater collection for toilets, etc.

As such, potentially significant improvements in estimated HQ emissions are likely to have already been made and there will be a need to update the assessment once a complete year of data are available. The data provided here therefore only represent historical emissions where this serves both to maintain a complete picture of overall emissions and also to provide a baseline from which to measure emissions from the move to Dragonfly House.

These data suggest that a total (now historical) HQ emission of 82 tCO_2e, representing 4% of the total emissions of BA operational activities and 24% of the utilities footprint for all sites. Electricity is (was) responsible for 64% of the HQ utilities emissions and water has a small contribution to the carbon emissions.

In relation to water, it should be noted that the supply of piped mains water requires a relatively small amount of energy on average in the UK. The regional/local significance of water may not be well captured by Defra data and, as a result, the data in Table A3.3. In a future assessment it will be worth considering the impacts of water efficiency measures in the new HQ both from the context of carbon emissions reduction but also in the context of longer-term availability and supply of water and the contribution of the water efficiency measures to climate change adaptation objectives. When making direct comparison between the old and new BA HQ buildings future assessments will have to address the issue that the building is shared with other executive agencies and, in addition, is owned by Defra. There is, therefore, a potential issue with double counting emissions reductions between the various agencies.

Table A3.3: Utilities Emissions from (OLD) Headquarters

Utilities	**Emissions (t CO_2e)**	**Emissions % CO_2e**	
Electricity	53	64%	
Gas	29	35%	
Water	0.5	1%	
TOTAL EMISSIONS	82	100%	

A3.3 Other BA Sites

Data and Calculations

BA operates a number of other offices and sites around the Broads and has provided data on energy and water consumed in sites other than HQ. This is summarised in Table A3.4.

Included in the data is information on the electricity consumption of Electric Charging Points on the Broads. Whilst BA does not, itself, consume this electricity (but charges consumers for it) the points are provided by the BA and for completeness consumption has been included in the data. However, it could be argued that consumption at the charging points displaces an equivalent consumption of domestic electricity. Here, whilst the BA may not itself be responsible for the emissions, if charging points were, in future, to supply electricity from renewable sources (such as wind) one might consider this to be an emissions reduction attributable to the BA. This would approximately equal to the difference between GHG emissions per unit energy average domestic electricity versus that for the supply source to the charging point.

Table A3.4: BA Utilities Consumption Data

	Fuel type	Annual consumption	Unit	Conversion factor
Other sites	Electricity	220,881	kWh	Defra 2009, Electricity 2007
	Gas	42,434	kWh	Defra 2009, Gas
	Gas Oil	30,861	litres	Defra 2009, Gas Oil
	Kerosene	8,950	litres	Defra 2009, Kerosene
	Biohydran	416	litres	EcoInvent, Vegetable oil fuel
	Water	6,234	m^3	Defra 2009, Water
Electric Charging points	Electricity	4,433	kWh	Defra 2009, Electricity 2007

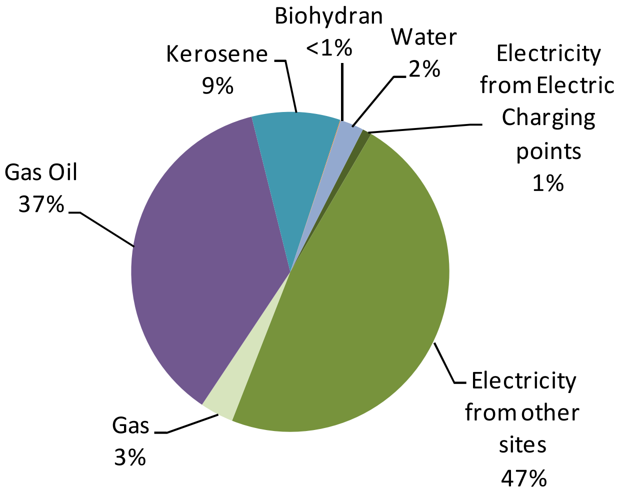
Calculated Emissions

Resulting emissions for sites other than (old) HQ are provided in Table A3.5. The analysis suggests emissions of 254 tCO_2e, representing 14% of the total carbon emissions of BA. As can be seen from the table, the vast majority of emissions are associated with both electricity and gas oil, these being responsible for 47% and 37% of the emissions respectively.

As noted above, this includes electric charging points which, it could be argued, are not directly attributable to BA (but any future emissions differential between charging point supply and average domestic supply might be claimed as a BA reduction). As charging points only account for around 1% of emissions from sites other than HQ (and 0.14% of BA emissions in total) emissions are proportionately very small.

Table A3.5: Utilities Emissions from BA sites other than Headquarters

Utilities	Emissions ($t CO_2e$)	Emissions % CO_2e
Electric Charging Points	2	1%
Electricity	121	47%
Gas	9	3%
Gas Oil	93	37%
Kerosene	23	9%
Biohydran	0.14	<1%
Water	6	2%
TOTAL EMISSIONS	254	100%



A4. Materials and waste

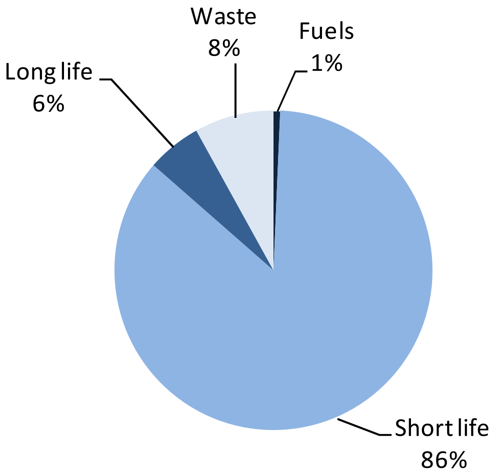
A4.1 Overview of estimated emissions

Emissions from the materials and waste category covers:

- fuels (other than those set out earlier for transport);
- short and long-life materials such as machinery, equipment, vehicles, etc.);
- various waste materials.

Overall emissions from this category are summarised in Table A4.1. Total emissions are estimated as being 1,128 tCO_2e, representing some 60% of the total emissions for BA operations of which materials is responsible for the vast majority (equivalent to 55% of the emissions for BA operations as a whole).

Within this, short life items have by far the largest carbon emissions. However, it is important to note a number of caveats here. Firstly, because estimation of emissions from short life materials had to be based on expenditure data (as opposed to physical data), the results of this component are of lower quality/resolution. Importantly, in addition, it is probable that, as the most recent year for which data are available spans the movement of BA HQ from Colegate to Dragonfly House, the year is unlikely to be a typical one from the point of view of expenditure on items such as office equipment and, indeed, waste arising. Clearly, this is a difficult problem to resolve in this and future assessments (as the increased expenditure on items in the year of the move to a new HQ is likely to reduce expenditure for a period of time into the future).

<table>
<tr><th colspan="4">Table A4.1: Overview of Emissions from Materials and Waste</th></tr>
<tr><th>Component</th><th>Emissions (t CO_2e)</th><th>Emissions % CO_2e</th><td rowspan="6">
</td></tr>
<tr><td>Fuels</td><td>8</td><td>1%</td></tr>
<tr><td>Short life items</td><td>967</td><td>86%</td></tr>
<tr><td>Long life items</td><td>62</td><td>6%</td></tr>
<tr><td>Waste</td><td>91</td><td>8%</td></tr>
<tr><td>TOTAL MATERIALS AND WASTE EMISSIONS</td><td>1,128</td><td>100%</td></tr>
</table>

A4.2 Fuels

Data and Calculations

Physical data on fuels has been provided by BA for non-transport applications (such as heaters, generators, chain saws, welders, etc). Here data have been provided as a total and no breakdown between sites/sources is available. The consumption data is provided in Table A4.2.

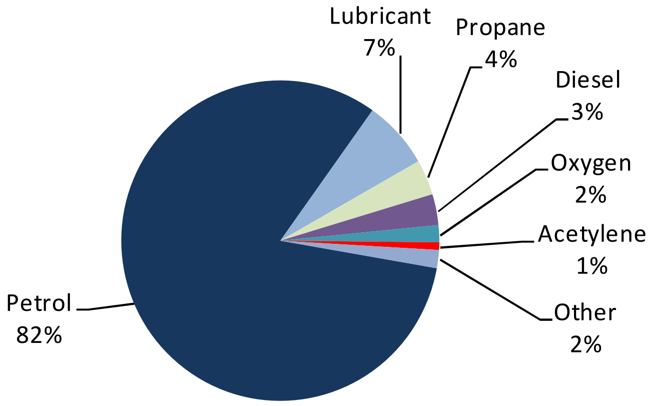
Table A4.2: BA Data on Consumption of Non-transport Fuels

Fuel	Quantity	Unit	Conversion factor
Acetone	8	kg	EcoInvent, Methyl ethyl ketone
Acetylene	26	kg	EcoInvent, Acetylene
Argon	15	kg	EcoInvent, Argon
Argoshield*	22	m3	Argon/Oxygen/CO_2 mix (calculated) [3]
Butane	36	kg	EcoInvent, Propane/ butane
Diesel	90	litres	Defra 2009, Diesel
Gas oil	14	litres	Defra 2009, Gas Oil
Kerosene	8	litres	Defra 2009, Burning Oil
LPG*	8	kg	Defra 2009, LPG
Lubricant*	205	litres	Defra 2009, Lubricants
Oxygen	318	kg	EcoInvent, Oxygen
Petrol	2,669	litres	Defra 2009, Petrol
Propane	453	kg	EcoInvent, Propane/ butane
* assumed densities: Argoshield 1.4 g/l - Lubricant 800kg/m3 - LPG 0.5187 kg/l			

Calculated Emissions

Combining consumption data with the most similar GHG conversion factor available provides the emissions estimates in Table A4.3. The analysis suggests a total emission of 7.6 tCO_2e, representing less than 1% of the total emissions from BA operations. 82% of this (relatively small) emission is associated with petrol.

Table A4.3: Emissions for Non-transport Fuels

Fuel	Emissions ($t\ CO_2e$)	Emissions % CO_2e	
Acetone	0.01	<1%	
Acetylene	0.06	1%	
Argon	<0.01	<1%	
Argoshield	0.01	<1%	
Butane	0.02	<1%	
Diesel	0.24	3%	
Gas oil	0.04	1%	
Kerosene	0.02	<1%	
LPG	0.02	<1%	
Lubricant	0.52	7%	
Oxygen	0.13	2%	
Petrol	6.22	82%	
Propane	0.27	4%	
TOTAL EMISSIONS	7.58	100%	

A4.3 Short and long life items

Data and calculations

As noted above, short and long life materials covers a wide range of sources and, with the exception of aggregates, timber and vehicles where physical data were available, the analysis has had to draw on financial expenditure (cost) data for the bulk of materials. Here emissions have been calculated using Input-Output (IO) analysis which, while it is much less accurate than analysis using physical data, provides at least some means of estimating emissions (although the

---

[3] 91.9% Argon + 3.1% Oxygen + 5% CO_2. http://www.rarespares.net.au/msds/Argoshield%20Light.pdf. Conversion factors from EcoInvent data base.

end values are subject to relatively high levels of uncertainty). This lack of accuracy, detail and associated uncertainty should be borne in mind when examining the emissions estimates.

For the I/O analysis, each item was classified in a group and each classification was converted into carbon emissions from its total cost using Input/Output tables. Only the items adding up to 95% of the footprint were included in the analysis, leaving out the less significant groups in terms of total carbon emissions. Other items represent materials which added up to 5% of the initially estimated emissions. This estimation aimed to discern the most significant contributors to then obtain more detailed information for a more accurate analysis (i.e. quantities, weight, etc). Consumption data are summarised in Table A4.4.

Table A4.4: BA data on Materials Procured

Material	Quantity	Unit	Conversion factor
Short life materials			
Aggregate	1,778	tonnes	Bath ICE 1.6 (see above)
Buoys	14,870	£	Defra 2009, Plastic products, SIC CODE: 25.2
Clothing	30,421	£	Defra 2009, Textiles, SIC CODE: 17
Electrical Equipment	14,714	£	Defra 2009, Electrical machinery, SIC CODE: 31
Equipment	12,109	£	Defra 2009, Machinery & equipment, SIC CODE: 29
IT Equipment	16,982	£	Defra 2009, Office machinery & computers, SIC CODE: 30
Machinery	27,742	£	Defra 2009, Machinery & equipment, SIC CODE: 29
Consumable materials	120,895	£	Defra 2009, Plastic products, SIC CODE: 25.2
Metals	6,099	£	Defra 2009, Iron and steel, SIC CODE: 27.1-27.3
Office Furniture	196,951	£	Defra 2009, Furniture, other manufactured goods, recycling services, SIC CODE: 36, 37
Phones	48,803	£	Defra 2009, Radio, television and communications, SIC CODE: 32
Printing	35,459	£	Defra 2009, Pulp and paper, paper products, SIC CODE: 21
Refreshments	12,256	£	Defra 2009, Food and drink products1, SIC CODE: 15
Repairs to Vessels	40,004	£	Defra 2009, Other transport equipment, SIC CODE: 35
Signs	21,102	£	Defra 2009, Plastic products, SIC CODE: 25.2
Stationery	57,588	£	Defra 2009, Pulp and paper, paper products, SIC CODE: 21
Timber	249	tonnes	Bath ICE 1.6 , Timber
Tools	25,977	£	Defra 2009, Machinery & equipment, SIC CODE: 29
Other items	53,198	£	Calculated as 5% of the total short/long life items emissions.
Long life materials			
Vehicles	4	vehicles	
Vessels	42,064	£	Defra 2009, Other transport equipment, SIC CODE: 35

Calculated Emissions

The resulting emissions estimates are provided in Table A4.5. As can be seen from the table, emissions from short and long life items are estimated as 1,030 tCO_2e for the period examined, representing 55% of the emissions from BA operations. As noted above, estimates need to be treated with care owing to their reliance on I/O data and, as such, represent order of magnitude emissions as opposed to an accurate portrayal.

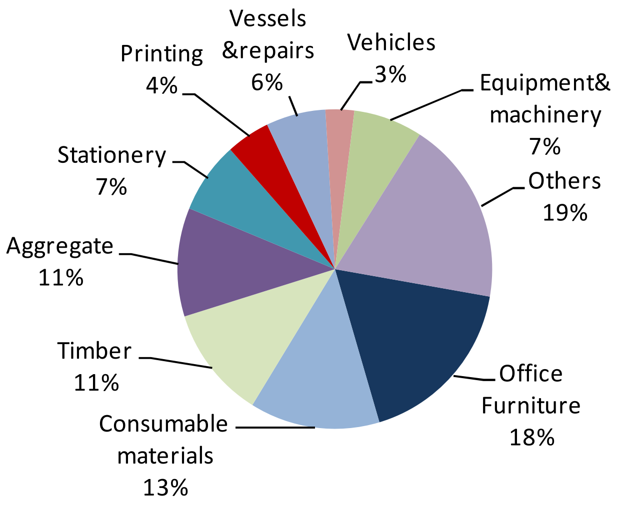
As identified in Section A4.1, in addition to the uncertainties inherent from the I/O analysis, there is also the issue that the period for which data relates coincides with the move to a new HQ. Here, expenditure on, for example, office equipment is likely to be atypical and, similarly, this will have an effect on the emissions. To gauge whether or not this is likely to be significant, the affects of adjusting data to a ‘best case’ scenario to account for the HQ move has been carried out (and the results are provided in Appendix 1a). Here, if it is assumed that ALL expenditure on IT equipment, Office Furniture, Phones and Signs is ALL associated with the move of HQ (which might be considered a ‘best case’ scenario) and that the lifetime of these items is 10 years on average (also ‘best case’), then the total emission is 21% less (220 tCO_2e) than the total given in Table A4.5 for short life materials.

Thus, under a 'best case' scenario to account for the HQ move, annual emissions for BA operations as a whole may be up to 12% less in a more typical year of annual expenditure than the year for which most recent data are available.

For the purposes of identifying options and strategies for reducing emissions, such a difference is arguably not particularly important, especially as one can build the uncertainties into decision making on a course of action. However, for the purposes of reporting emissions, the lack of physical data and records for procurement is something that will need to be addressed in future where this is likely to provide more robust data on which to base both emissions estimation and emission reduction. As such, a sustainable procurement policy with records and evidence to back it up is something that should be seriously considered by the BA particularly in the light of Defra's announcement that the National Parks Authorities will soon have to report their emissions.

Table A4.5: Emissions from Materials Procured

Material	**Emissions (t CO_2e)**	**Emissions % CO_2e**
Short life materials		
Aggregate	114	11%
Buoys	17	2%
Clothing	29	3%
Electrical Equipment	11	1%
Equipment	9	1%
IT Equipment	10	1%
Machinery	22	2%
Consumable materials	137	13%
Metals	25	2%
Office Furniture	182	18%
Phones	27	3%
Printing	46	4%
Refreshments	20	2%
Repairs to Vessels	30	3%
Signs	24	2%
Stationery	75	7%
Timber	118	11%
Tools	20	2%
Other items	51	5%
Long life materials		
Vehicles	30	3%
Vessels	32	3%
TOTAL EMISSIONS	1,030	100%



A4.4 Waste

Data and calculations

Waste data has been provided by BA. This data is largely given in terms of volume and therefore its weight has been estimated to provide a basis for calculating emissions. Table A4.6 provides the assumptions applied for weight conversion.

Table A4.6: BA Data on Waste Arisings		
Item	Weight	Unit
CRT Monitors	21	kg
Flat Screen Monitor	5.7	kg
Printer	53	kg
Computer Base Unit	8	kg
Laptop	2.7	kg
Waste, one cu yard4	0.125	tonnes
Waste, one skip	240	litres
Waste, one drum	200	litres

Calculated Emissions

Table A4.7 provides estimated emissions from waste disposal. To arrive at these figures waste disposal has been compared with materials purchases where possible to avoid double counting[5]. Thus it has been assumed that absorbents, IT, Oil and Rags have already been considered in the materials section. A part of the mixed waste footprint has probably also been accounted for in the materials purchases and as such, whilst every attempt has been made to eliminate it, there will remain some degree of double counting. Since mixed waste breakdown is unknown, office waste breakdown has been assumed for the analysis and, in addition, waste skips and drums have been assumed to have been full. A full waste audit could help to obtain better data quality as well as increase the recycling rate in waste disposal.

The estimates suggest a total carbon emissions of 91 tCO_2e, representing 5% of the total BA operational emissions. Nearly all of these emissions are associated with mixed waste.

Table A4.7: Waste Disposal Emissions		
Waste	**Emissions (t CO_2e)**	**Emissions % CO_2e**
Absorbents, IT, Oil, Rags	Included in Materials	-
Mixed waste, to landfill	91	100%
Sewage waste	<1	<1%
TOTAL EMISSIONS	91	100%

---

[4] http://www.opala.org/solid_waste/archive/conversion_tables.html

[5] Double counting takes place when the same item or component is counted as input as well as an output. Therefore the impact associated during its life cycle is considered twice. Double counting has to be avoided as much as possible, and adjustments in purchased and waste quantities have been made to reduce double counting.

A5. Options for improving data and emissions' estimation

As noted in Section A1, the audit of BA operations provided here represents the first attempt at calculating carbon emissions from BA operations. With the exception of the survey data undertaken directly for this study, the collection of financial and other data by BA is not tailored to estimation of carbon emissions but, rather, to other data reporting and record keeping requirements.

Given the potential that future requirements may necessitate regular updates to audits and, perhaps, greater accuracy in the assessment it is important to consider how data and data collection can be improved generally. At the same time it is worth bearing in mind that the detail of any future new reporting requirements will have a bearing on how best to implement new data gathering and management systems.

In terms of the overall quality of the data for this assessment, data quality has been medium compared with past experience of undertaking similar analyses. Data sources and quality for the various elements can be summarised briefly as follows:

- Utilities, Materials (long life), Materials (fuels), Water transport and Business travel components are based mainly on high quality data, with only minor assumptions required;
- the commuting component is based on a staff survey with a 37% response rate;
- most of the information for Materials (short life) was provided as financial costs which requires an alternative calculation methodology to the other components, and introduces a higher level of uncertainty; and
- the Waste component the data quality is medium because assumptions had to be made on waste weight and type.

In terms of data improvement for future audits of BA operations, reliable monitoring and data collection is essential. Without good, quality measurement, action planning is likely to be poorly focused, target-setting problematic and progress difficult to determine. When organisations seek to update audits annually, attention has to be paid to how the data is collected to allow better data comparability among annual analyses and in that way obtain the best interpretation of the results over the time. Here it is recommended that BA develop a system for accurate data collection and maintain the methods so results from different years can be comparable. As noted above, this will need to be consistent with any new requirements that will be in the pipeline.

Table A5.1 provides brief comment and suggestions on data and data gathering improvements for each of the emissions categories.

Table A5.1: Data and Data Improvements		
Business travel		Data quality was medium-high. A data collection system could help to store information during the year in the same format and physical units (i.e. litres of fuel, km, origin-destination, etc) so it is quicker and more accurate to analyse. The split between outside and inside Broads travel for this study is based on an online staff survey. This information could also be stored with other information so it is not estimated in future studies.
Commuting		Data quality was medium-high. However, data can be improved keeping a record of the commuting distances and modes of all staff during the year, or survey the 100% of all staff at the end of the year.
Water transport		Data quality was high.
Utilities		Data quality was medium. Energy and water consumption of HQ doesn't include figures from the current building as this information was not available. Energy consumption from a few sites was incomplete. Several assumptions had to be made as a result of data gaps. An energy monitoring system could improve the data quality of the consumption, not only providing an accurate annual figure but it could, depending on the system, collect data in small periods of time and in different locations. This can help to develop an effective reduction plan for energy consumption.
Materials	**Fuels**	Data quality was high.
	Long life	Data quality for vehicles was high, but low for vessels since only financial cost was available.
	Short life	Data quality was low. Most of the data provided is financial. Emissions are then calculated using Input/Output analysis which provides less accurate results which are not directly comparable with the other components For the purposes of monitoring and targeting material consumption, as well as improving data collection quality for better future analysis, it is recommended that BA establish a system to record physical data (weight, volume, type of material, % of recycled content, etc). This system could include processes and tools for capturing, recording and regularly reporting waste and consumption data.
Waste		Data quality was low. No waste breakdown (paper, plastic, etc) and end of life (landfill, recycled, incineration, etc) was provided. Data provided includes bin volumes but no volume or weight of waste. It is unknown if the bins are full, half full, etc. It is recommended that BA develop a waste audit where there is a record of the amount of waste disposed (preferably weight), type of waste and end of life. This information will create opportunities for waste and impact reduction, in addition to better footprint analysis.

A6. Overall emissions and key emissions sources

A6.1 Overview of emissions and key sources for Level 1 (BA Operations)

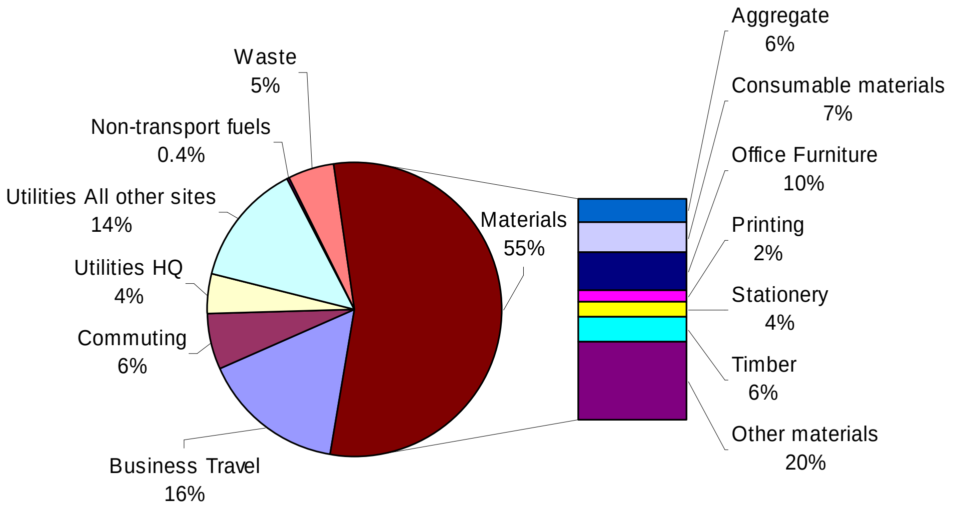
Calculated emissions for BA operations (Level 1 of the assessment) are summarised by category in Table A6.1. The figure within the table also breaks down the largest category of emissions (namely 'materials') into its key constituents. Total emissions are estimated as being of the order of 1,875 t CO_2e. Within this, however, there is obviously some uncertainty in relation to the precision of estimates. This can be expected to vary for some sources and categories of emissions more than others. For example, parts of the analysis that must rely on Input/Output analysis are particularly uncertain. Areas/emissions where estimates are particularly uncertain are marked by orange boxes in the tables.

Table A6.2 (provided at the end of this section) provides a look-up table of all estimated emissions by source and category, expressing each emission in terms of magnitude of emission and as a percentage both of the broad category describing the emission (as set out above) and also as a percentage of the total emission from BA operations.

As noted in the main introduction to the Technical Report, identifying and estimating the magnitude of emissions is only one part of the process of developing an emissions reduction strategy. The next step is to identify from the audit what the key contributors to emissions are, therefore, where mitigation measures may provide quick and effective 'wins' and, therein, where mitigation measures may best be focussed (and what these might comprise). This is the subject of the separate Strategy Report that this Technical Report supports and further analysis of contribution of the different sources emissions to overall emissions and the issue of uncertainty is provided there.

Table A6.1: Overview of Emissions by Category of Source

	Emissions (t CO_2e)	**Emissions % CO_2e**
Business Travel	296	16%
Commuting	116	6%
Utilities HQ	83	4%
Utilities All other sites	254	14%
Non-transport fuels	8	0.4%
Materials	1,029	55%
Waste	91	5%
TOTAL EMISSIONS	**1,875***	**100%**



*the total in the table is actually 1,876 owing to rounding

Table A6.2: Look-up Table of Emissions Sources – BA Operations (Level 1)

Business Transport	**t CO_2e**			**% of category total emissions**			**% of total emissions**		
	Outside Broads	Within Broads	All	Outside Broads	Within Broads	All	Outside Broads	Within Broads	All
Authority's vehicles	57	117	174	19%	40%	59%	3.0%	6.2%	9.3%
Car (owned by staff or volunteers)	13	26	39	4%	9%	13%	0.7%	1.4%	2.1%
Rail	4		4	1%		1%	0.2%	0.0%	0.2%
Flights	0.18		0.18	0%		0%	0.0%	0.0%	0.0%
Water transport (authority's vessels)		79	79		27%	27%			4.2%
Commuting	**t CO_2e**			**% of category total emissions**			**% of total emissions**		
Motorbike			7			6%			0.4%
Car			93			80%			5.0%
Bus			8			7%			0.4%
Rail			8			7%			0.4%
Walk/cycle			0			0%			0.0%
Utilities	**t CO_2e**			**% of category total emissions**			**% of total emissions**		
	HQ	Others	All	HQ	Others	All	HQ	Others	All
Electricity	53	121	174	16%	36%	52%	2.8%	6.4%	9.3%
Gas	29	9	38	9%	3%	11%	1.5%	0.5%	2.0%
Water	0.5	6	6.5	0%	2%	2%	0.0%	0.3%	0.3%
Electric Charging Points		2	2		1%	1%		0.1%	0.1%
Gas Oil		93	93		28%	28%		5.0%	5.0%
Kerosene		23	23		7%	7%		1.2%	1.2%
Biohydran		0.14	0.14		0%	0%		0.0%	0.0%
Non-transport fuels	**t CO_2e**			**% of category total emissions**			**% of total emissions**		
Acetone			0.01			0%			0.0%
Acetylene			0.06			1%			0.0%
Argon			<0.01			0%			
Argoshield			0.01			0%			0.0%
Butane			0.02			0%			0.0%
Diesel			0.24			3%			0.0%
Gas oil			0.04			1%			0.0%
Kerosene			0.02			0%			0.0%
LPG			0.02			0%			0.0%
Lubricant			0.52			7%			0.0%
Oxygen			0.13			2%			0.0%
Petrol			6.22			82%			0.3%
Propane			0.27			4%			0.0%
Materials	**t CO_2e**			**% of category total emissions**			**% of total emissions**		
Aggregate			114			11%			6.1%
Buoys			17			2%			0.9%
Clothing			29			3%			1.5%
Electrical Equipment			11			1%			0.6%
Equipment			9			1%			0.5%
IT Equipment			10			1%			0.5%
Machinery			22			2%			1.2%
Consumable materials			137			13%			7.3%
Metals			25			2%			1.3%
Office Furniture			182			18%			9.7%
Phones			27			3%			1.4%
Printing			46			4%			2.5%
Refreshments			20			2%			1.1%
Repairs to Vessels			30			3%			1.6%
Signs			24			2%			1.3%
Stationery			75			7%			4.0%
Timber			118			11%			6.3%
Tools			20			2%			1.1%
Other items			51			5%			2.7%
Vehicles			30			3%			1.6%
Vessels			32			3%			1.7%
Waste	**t CO_2e**			**% of category total emissions**			**% of total emissions**		
Mixed waste, to landfill			91			100%			4.8%
Sewage waste			<1						
TOTAL Emissions	**1,875**								

Broads Carbon Audit

Part B - Level 2 Audit: Wider GHG Emissions for the Broads and Broads Area

B1. Introduction

B1.1 Overview

The subject of Part B of this Technical Report is Level 2 of the audit which seeks to derive an estimate of emissions for the Broads and Broads Area as a whole. As noted in the main introduction of the Technical Report, the main purpose of looking at emissions over this wider area of reference is to better capture those (often much larger magnitude) emissions that BA is not necessarily responsible for, but has the power to influence when carrying out its statutory functions.

Not all emissions and emissions sources within the Broads Area are directly related to these functions (and thus BA has less scope to influence them). For example, whilst BA could use its powers to influence emissions from navigation or conservation fairly directly, its scope to influence emissions from industry or transport in the Executive Area is much less. Accordingly, Level 2 of the audit is subdivided into those emissions that are, and those that are not connected with the Broads and its services (i.e. its existence) and, therein, principal powers and functions of BA. This leads to a twin level analysis comprising:

- ***Level 2a:*** emissions connected with the Broads and its services. Here, as appropriate, the boundary is defined geographically (by the Executive Area) and more widely in terms of connection to the wider ‘ecosystem services’ provided the Broads where emissions occur both inside and outside the Executive Area (such as the road transport emissions from visitors coming to the Broads from further afield); and

- ***Level 2b:*** emissions occurring within the Broads Executive Area but broadly unconnected with Broads services (such as emissions from industrial units, domestic emissions, etc.) and hence where the scope for BA to influence emissions is much less.

It is worth noting that estimating emissions at both levels is difficult and complex and the resulting estimates are subject to uncertainty concerning exact magnitude. As is noted in the main introduction to this Technical Report, however, the intention is not to assess emissions to a very high degree of accuracy but, rather, consider what available data suggests that the overall magnitude of emissions is likely to be. Such a ‘broad and shallow’ analysis helps one to identify strategically what the largest emissions are associated with, where actions to reduce emissions might best be focussed and, therein, what the ‘quick win’ actions for a strategy to reduce emissions may be.

Estimation of emissions at each level and from each source has been achieved by means of a mixture of tailored ‘bottom up’ estimation based on the application of emissions factors to data describing the various components and also ‘top down’ estimation using available emissions data. These latter data sources include NUTS4 emissions data and the (higher resolution) National Atmospheric Emissions Inventory (NAEI) data both of which are themselves largely generated from the application of ‘bottom up’ approaches to component base data and emissions factors.

B1.2 Structure of Part B

The emissions considered in this section broadly comprise:

- emissions from tourism and recreational activities in the Broads – where these occur both within the geographical area of the Broads (in the case of the activity itself, e.g. boating) and over a wider area expanding beyond the Broads Executive area (in the case of road transport to the Broads for the purposes of undertaking the activity);

- emissions land and land use – comprising emissions of all greenhouse gases from land use as well estimating ‘stock carbon’ in soils and vegetation

- a discussion around emissions and emissions estimation for other management activities connected with the Broads including those of other actors, conservation and water level management.

The Section concludes by summarising the emissions connected with the Broads and setting these in the context of other emissions occurring within the Broads Executive Area but not connected with the Broads.

B1.2 Headline Emissions Estimates

Table B1.1 summarises the estimates of emissions ‘connected with’ the Broads and incorporating the emissions for BA operations (Level 1) calculated in Part A of this Technical Report. Also provided is the carbon stored in the biotic and abiotic environments (vegetation and soils respectively).

The data suggests emissions at the various levels with the following approximate magnitudes:

- Broads Authority operations (Level1**): ~1,900 tCO_2e;**
- Activities and operations connected with the Broads (including the above): **~131,000 tCO_2e**; and
- Other activities in the Executive Area (but not connected with the Broads itself): **~359,000 tCO_2e**.

Note that the estimates are subject to uncertainty and are intended for the purpose of focussing and developing a strategy as opposed to any other use. For the purpose intended, they are sufficient but care is required for other uses and when reporting. In terms of comparing totals for different levels, for example, there is some overlap between estimates for Levels 2a and 2b that cannot be eliminated. This means that, whilst the levels of accuracy permit broad comparison of the relative contributions of each for the purpose of context and focussing strategy, they should not be added together or expressed in precise percentage terms for any other use.

Emissions are analysed further in the separate Strategy Report (that this Technical Report supports) which seeks to consider the strategic implications of the emissions and stock carbon from the perspective of emissions reduction, enhancement of sequestration and conservation of stock carbon resources. The remainder of Part B explains the methods used to derive estimates and summarise the emissions in greater detail.

Table B1.1: Emissions 'connected' with the Broads (incorporating BA Operational Emissions)

	N_2O (tCO_2e)	CH_4 (tCO_2e)	CO_2 (tCO_2e)	CO_2e (tCO_2e)	% of Total Emission
Emissions					
Tourism and Recreation				54,104	41%
Land and Land Use	53,574	16,682	3,193	73,449	56%
Other management	2	24	3,704	3,730	3%
TOTAL	**53,576**	**16,728**	**6,897**	**131,283**	
Stored carbon					
Soils			38,803,019	38,803,019	
Vegetation			1,053,695	1,053,695	
TOTAL			**39,856,714**	**39,856,714**	

B2. Emissions from Tourism and Recreation

B2.1 Overview of Estimated Emissions

Emissions in relation to tourism and recreation on the Broads covers the following emission sources:

- private boat owners;
- hire boats;
- other visits to the Broads;
- travel around the Broads; and
- services (accommodation, food and drink, etc.)

Emissions are associated with recreational activities, tourism and recreation services and visitors transport to/from and around the Broads. Estimated emissions from each of these sources are summarised in Table B2.1 and the sections below describe the methods used in estimation.

As can be seen from the table, total emissions from tourism and recreation are estimated as being of the order of 54,104 tCO$_2$e of which 35% (18,849 tCO$_2$e) is associated with visitors transport to/from (and to a lesser extent around) the Broads.

Table B2.1: Emissions from Tourism and Recreation

		Emissions (t CO$_2$e)	***% of Transport total***	***% of non-transport total***	**% of total emissions for Tourism and Recreation**
Private boat owners	Use of boats	2,204*	*6%*		4%
	Transport to/from boats	1,208*		*6%*	2%
Hire boats	Hire boat emissions	3,259	*9%*		6%
	Boatyards	1,498	*4%*		3%
	Visitors' transport to/from boats	1,348		*7%*	2%
Other tourism and recreation	Accommodation	10,950	*31%*		20%
	Food and drink	14,417	*41%*		27%
	Recreation (spending on)	2,927	*8%*		5%
	Travel to/from Broads	15,878		*84%*	29%
All visitors	Travel around the Broads	415		*2%*	1%
Transport sub-total		**18,849**			***35%***
Non-transport sub-total		**35,255**			***65%***
Total		**54,104**			

* average mid-range predicted values derived from a high/medium/low emission scenario (see later sections)

B2.2 Emissions from Tourism and Recreational Activity and Services (non Transport

B2.2.1 Private Owner's Boat Emissions

Data and Calculations

Emissions from private boat owners under this category relate to (engine/motor) emissions associated with the use of the boats. Data for the calculations has been drawn from BA data on boat ownership for 2008 which is broadly comprised of data on postcode areas of all licensed boat owners and a separate[6] data set describing the private boat 'population' by:

- type (auxiliary yacht, motor, day boat, etc.); and
- engine (type and power if any).

The general approach taken has been:

- to generate a statistical estimate for boat emissions per day of activity (from boat data); and
- to apply an assumed frequency and duration of visit on the basis of distance from the Broads (from postcode data).

<u>Estimation of boat emissions per day of boating activity</u>

For the estimation of boat emissions per day of activity the first step was to calculate the average power rating of engines for each type of boat and type of engine (where present). Based on BA data on registered boats for 2008, Table B2.2 provides the resulting numbers of boats and average power ratings.

Table B2.2: Numbers of Boats by Type and Average Power Rating

	Petrol				Diesel		Electric		None/not stated	
Type	**Out-board (Num)**	**In-board (Num)**	**Out-board Ave Power (HP)**	**In-board Ave Power (HP)**	**Num**	**Ave Power (HP)**	**Num**	**Ave size (Kw)**	**Num**	**Ave size**
Aux Yacht	809	68	5.3	6.4	271	8.4	90	2.3	25	
Day Boat	183	10	27.1	97.3	25	22.6	11	2.0	1	
Houseboat	0	0	0.0	0.0	0	0.0		3.0	20	
Motor	1978	683	72.8	137.2	2826	83.1	167	3.0	86	62.7
O/B Dinghy	523		7.7				90	4.5	4	2.9
Rowing									1526	
Sailboard									76	
Sailing									1258	

The next step in the analysis was to calculate fuel consumption per unit time. Engine power for diesel and petrol engines on the Broads is largely only available as data expressed as Horsepower (HP). Conversion of HP to fuel use is difficult and is complicated by a number of factors, however, the following conversion factors are available[7] giving fuel consumption per unit time based on full power (i.e. full throttle):

- Fourstroke and Diesel: 0.25 L/HP/Hour
- Twostroke: 0.38 to 0.5 (mid range 0.44) L/HP/Hour

Given that speed limits on the Broads mean that full throttle is unlikely to ever be used it has been assumed that, at cruising speed, fuel consumption is 20% of the full throttle values above. In addition, since the 'old' twostroke engines are no longer manufactured (but many 'older' engines remain in use), it has been assumed that 60% of outboards are 'old' twostroke engines. Applying these assumptions provides the following fuel consumption conversion factors:

---

[6] In other words, postcode data on boats by type has not been provided and so it is assumed that ownership of boats by type is uniformly distributed between postcodes.

[7] based on factors given in http://www.boatcarbonfootprint.com/fuel/boatfuel.htm

- Outboard (petrol) – 0.073 L/HP/Hour; and
- Inboard (Petrol and Diesel) – 0.05 L/HP/Hour.

These conversion factors were applied to the average horsepower values to provide estimates of the average fuel consumption per hour of operation. These (and the kilowatt values for electric motors) were then converted to Kg CO_2e using the following Defra standard conversion factors:

	Factor	**Unit**
• Petrol (L)	2.3307	Kg CO_2e
• Diesel (L)	2.6694	Kg CO_2e
• Electric (Kwh)	0.54667	Kg CO_2e

Applying these values to the BA derived data given in Table B2 above provides estimates of fuel consumption and GHG emissions per hour of operation for boats with engines (by type). Based on the numbers of boats of different engine types, these have been aggregated to provide the weighted average emission for each type of boat. These values are provided in Table B2.3.

Table B2.3: Fuel consumption and GHG Emissions per hour of operation (for boats with motors)

	Petrol			**Diesel**			**Electric**			**Weighted average**
	Num	**L/hr**	**Kg CO_2e/hr**	**Num**	**L/hr**	**Kg CO_2e/hr**	**Num**	**Kw**	**Kg CO_2e/hr**	**Kg CO_2e/hr**
Aux Yacht	877	0.4	0.9	271	0.4	1.1	90	2.3	1.3	1.0
Day Boat	193	2.1	4.9	25	1.1	3.0	11	2.0	1.1	4.5
Houseboat										
Motor	2661	5.7	13.3	2826	4.2	11.1	167	3.0	1.7	11.8
O/B Dinghy	523	0.6	1.3				90	4.5	2.5	1.5

These fuel consumption/GHG emission values per hour of operation were then converted to average emissions per day of activity (for boats with motors) by applying assumptions concerning the number of 'motoring' hours for each boat type.

As no actual data are available on number of motoring hours per day of activity by boat type, three scenarios were applied (low, medium and high) based on expert judgement. These three scenarios and the resulting GHG emissions per day of activity are provided in Table B2.4.

Table B2.4: Assumed average 'motoring' hours per day of activity (for boats with motors)

	Assumed Motor Hours per day			**Resulting Motor emissions/day (Kg CO_2e/day)**		
Type	Low	Med	High	Low	Med	High
Aux Yacht	0.5	1	1.5	0.49	0.97	1.46
Day Boat	2	2.5	3	9.09	11.36	13.63
Houseboat				0.00	0.00	0.00
Motor	1	1.5	3	11.84	17.77	35.53
O/B Dinghy	0.75	1.5	2	1.11	2.21	2.95
Rowing				0.00	0.00	0.00
Sailboard				0.00	0.00	0.00
Sailing				0.00	0.00	0.00

As clearly not all registered boats have motors, these data have been combined with the numbers of boats without engines to provide a statistical GHG emission per day per statistical boat on the Broads for private boats, i.e. the emission per day of private boat activity measured in kgCO_2e/day/boat. This is provided in Table B2.5.

Table B2.5: Derivation of emission per day of private boat activity

Type	Boat Population		Contribution to Statistical emission per day per statistical boat (kg CO_2e/day/boat)		
	Number of Private Boats	Percentage of total Private Boats	Low	Med	High
Aux Yacht	1263	11.86%	0.1	0.1	0.2
Day Boat	230	2.16%	0.2	0.2	0.3
Houseboat	20	0.19%			
Motor	5654	53.11%	6.3	9.4	18.9
O/B Dinghy	613	5.76%	0.1	0.1	0.2
Rowing	1526	14.34%			
Sailboard	76	0.71%			
Sailing	1258	11.82%			
Wherry	5	0.05%	<0.001	<0.001	<0.001
Weighted average emission per day of activity (kg CO_2e/day/boat))			6.6	9.9	19.5

Frequency and Duration of Visit

Having calculated the CO_2 emission per day of private boat activity, the next step was to apply this to an estimate of the total number of days of private boating activity per year.

As there is no data on frequency and duration of visits to private boats there was a need to apply some assumptions where these have informed by other data describing the boat owners themselves. BA has provided data on the postcode area of licensed private boat owners. As the frequency and duration of visits to private boats is likely to be related to distance, travel distances to the Broads for each licence holder have been calculated. Here, distances to the postcode area NR12 have been calculated for all (non-NR12) area postcodes and a travel distance of 5 miles has been assumed for licence holders within the NR12 postcode.

Table B2.6 provides the assumptions used to derive estimates of the annual number of 'boating days' on the Broads by private boat owners based on the total distances from boats.

Table B2.6: Assumptions on frequency and average duration of visits

Distance range to Broads (miles)		Assumed annual visiting frequency			Assumed Average Duration (days)
From	To	Low	Medium	High	
0	9	10	15	20	2
10	19	10	15	20	2
20	39	5	10	15	2
40	59	4	6	8	3
60	99	2	4	6	4
100	149	1	2	3	5
150	199	0.5	1	2.5	7
200	999	0.5	1	2.5	7

Applying these assumptions provides estimates of both the total annual 'boating days' and also road travel distances under low, medium and high scenario assumptions used later to calculate road transport emissions from private boat owners. Resulting total boating days and total distances travelled (to and from boats) per year are estimated to be as follows:

	Low	**Medium**	**High**
• Boating Days (days/year)	110,832	182,227	258,012
• Total road distance travelled (miles/year)	2,022,018	3,581,110	5,384,930

Calculated Emissions

Based on the numbers derived above for boating days and statistical emissions for each scenario (low, medium and high), a combined scenario average has been derived based on the combination of all scenarios (i.e. low low vs low medium vs low high, etc.). This is provided in Table B2.7. From the table, predicted average boating emissions from private boats is estimated as 2,204 tCO_2e.

Table B2.7: Calculation of combined scenario average boating emissions (tonnes CO_2e/year)

			Boating Days		
			Low	**Medium**	**High**
			110,832	182,227	258,012
Statistical emission from 1 statistical day on 1 statistical boat (kg CO_2/day/boat)	**Low**	6.6	*731,491*	*1,202,698*	*1,702,879*
	Medium	9.9	*1,097,237*	*1,804,047*	*2,554,319*
	High	19.5	*2,161,224*	*3,553,427*	*5,031,234*
Scenario combined average boating emissions			2,204,284 kg CO_2e/year		
			2,204 tonnes CO_2e/year		

B2.2.2 Hire Boat Emissions

Hire boat emissions have been drawn directly extracted from Helen Colyer's dissertation on emissions associated with the hire boat industry[8] undertaken in 2008. This study provides a detailed approach to estimation by means of survey and, as such, provides a more detailed picture than could have been achieved by a coarser estimation as part of this assessment. For a detailed description of the approach used the reader is directed to the source document.

Annual hire boat emissions based on the dissertation study are estimated as being 3,259 tCO_2e per year.

B2.2.3 Other Tourism and Recreation Activities

Data and Calculations

The category of other tourism and recreation encompasses wider recreational emissions associated with tourist accommodation, food and drink, general recreation and emissions from boatyards servicing instream recreation.

Estimation and calculation of emissions for accommodation, food and drink and general recreation have been based upon data inputs and outputs from the ongoing application of the STEAM (Scarborough Tourism Economic Activity Monitor) modelling approach to Broads tourism and recreation by BA.

---

[8] A Carbon Audit of the Broads Hire Boat Industry. Helen Colyer, 2008

Unlike demand side approaches that use, for example, (resource intensive) visitor surveys, the STEAM approach measures tourism activity from the supply side (in simple terms on the basis that the levels of demand create a service supply which is both easier to monitor and indicative of demand). STEAM is not intended to provide a precise measurement of tourism in a local area, but rather to provide an indicative base for monitoring trends. This is broadly consistent with the objectives of this carbon audit in that we are interested in a broad baseline to estimate likely magnitude of emissions rather than a precise figure. Here, as with other aspects of recreational uses (such boating), the carbon audit is not concerned with annual fluctuations in participation as a result of, say good/bad summer weather but, rather, what the broad level of emissions is and how carbon intensity might be reduced as part of an emissions reduction strategy (and what impact this may have on overall emissions).

Accommodation

For estimation of emissions from accommodation, the number of guest nights has been estimated using the annual number of tourist days in serviced accommodation figure from BA STEAM statistics. Carbon emissions associated with the total guest nights is estimated using internal BFF conversion factors obtained in previous relevant projects.

Food and drink

According to the STEAM statistics, the economic expend on food and drinks in 2008 was £66,329,352 was (VAT excluded). Carbon emissions have been calculated using I/O analysis (Sector 131: Restaurants, cafes, bars, etc, SEI 2008 MRIO 19).

Recreation

According to the STEAM statistics, the economic expend on recreation in 2008 was £23,822,076 (VAT excluded). Carbon emissions have been calculated using I/O analysis (Sector 175: Recreational and cultural activities, SEI 2008 MRIO 1).

Boatyard emissions

Boatyard emissions have been drawn from Helen Colyer's dissertation on emissions associated with the hire boat industry[10] undertaken in 2008.

Calculated Emissions

Resulting emissions estimates are provided in Table B2.8.

Table B2.8: Emissions from other tourism and recreation

	t CO_2e
Accommodation	10,950
Food and drink	14,417
Recreation	2,927
Boatyards	1,498

---

[9] http://sei-international.org/?p=projects&prid=245

[10] A Carbon Audit of the Broads Hire Boat Industry. Helen Colyer, 2008

B2.3 Transport Emissions Associated with Tourism and Recreation

B2.3.2 Private Boat Owners Transport Emissions

Data and Calculations

As described in Section B2.2.1, the analysis of Private Boat owners instream (boat) emissions delivers an estimate of the distance travelled to and from boats based on postcode data on registered owners and assumptions concerning the typical annual frequency of visits given distance to boats as follows:

	Low	**Medium**	**High**
• Boating Days (days/year)	110,832	182,227	258,012
• Total road distance travelled (miles/year)	2,022,018	3,581,110	5,384,930

Calculated emissions

Applying calculated road distance travelled (above) and Defra emissions factors per unit distance travelled by car (for no fuel information) provides the estimates of road transport emissions from private boat owners given in Table B2.9.

Table B2.9: Transport Emissions from Private Boat Owners

	Low	**Medium**	**High**
Total Annual Distance Travelled (miles)	2,022,018	3,581,110	5,384,930
Emissions factor (Defra average car - no fuel information Kg CO_2e/mile)	0.3297		
Road Transport CO_2e emissions (tonnes CO_2e)	*667*	*1,181*	*1,775*
Average over scenarios	**1,208**		

B2.3.2 Transport Emissions from Visitors Hiring Boats

Data and Calculations

Transport data has been drawn directly from Helen Colyer's dissertation study[11] on emissions associated with the hire boat industry. Results on visitor travel from origin to Broads and return are based on surveys, estimating number of visitors hiring a boat as 51,602.

Calculated Emissions

Transport emissions include car, train and flights and were calculated as CO_2 only. As such, an uplift factor[12] has been applied to each mode of transport. Applying this provides an estimated emission from travel to and from hire boats of 1,348 tCO_2e.

---

[11] A Carbon Audit of the Broads Hire Boat Industry. Helen Colyer, 2008

[12] derived from the ratio CO2/CO2e of the Defra 2009 conversion factors

B2.3.3 Transport Emissions from Visitors coming for other Recreational Purposes

Data and Calculations

The number of visitors to the Broads who are not participating in boating activities has been taken from BA's STEAM statistics for 2007/08. As there is no specific information on means of transport or distances travelled, data from the dissertation study on hire boating has been applied. This is summarised in Table B3.3.

Table B2.10: base data for calculating emissions for other visitors

Data	**Quantity**	**Source**
Tourist not related with boats activities (excluding day visitors)	837,881	STEAM Broads, 2008
Visitors coming by car	97%	Broads dissertation study[13]
Visitors coming by train	3%	Assumed all other visitors use train
Visitors emissions travelling to the Broads by car (kg CO_2/visitor)	19	Broads dissertation study
Visitors emissions travelling to the Broads by train (kg CO_2/visitor)	10	Broads dissertation study
CO_2 to CO_2e uplift for car emissions	101%	Defra 2009
CO_2 to CO_2e uplift for train emissions	106%	Defra 2009

Calculated Emissions

Resulting emissions from transport to and from the Broads for recreational activity other than boating are estimated as being around 15,878 t CO_2e.

B2.3.5 Visitors Travelling around the Broads (all Recreational Visits)

Data and Calculations

As no data or estimates are available for travel around the Broads except that produced as part of Helen Colyer's dissertation, it has been assumed that all visitors have a similar pattern of travel behaviour as for those chartering a hire boat. Whilst this is likely to be a coarse estimate, it has been included for completeness.

Calculated Emissions

Resulting emissions from transport around the Broads are provided in Table B3.4.

Table B2.11: Estimated emissions from visitor's travel around the Broads

Tourism/Recreation Grouping	**Emissions (t CO_2e)**
Tourist hiring boats	20
Boat owners tourist	78
Tourist not related to boat activities	317
TOTAL	415

---

[13] A Carbon Audit of the Broads Hire Boat Industry. Helen Colyer, 2008

B2.4 Options for Improving Emissions' Estimation

Estimation of emissions across tourism and recreation is always going to be subject to variation and uncertainty and, indeed, can be expected to vary from one year to another simply on the basis that factors such as weather and macro-economic conditions influence the volume of visitors and the frequency of visits for recreational purposes.

While such uncertainty and variation affects the accuracy one can attain in emissions estimation it is not an important concern or consideration from a strategic perspective. Here, from an emissions reduction perspective, one is more interested in how one can reduce the 'intensity' of activities and services supporting them rather than reducing, say, the number of visitors engaging in those activities. The latter would not be consistent with either the functions of BA or the fact that, potentially, visitors or holidaymakers to the Broads might otherwise be travel by air to more 'far flung' destinations.

As with the rest of the audit, in order to do identify an effective strategy for reducing emissions intensity ideally one needs to be able to identify the relative significance of each component of the emissions. This, in turn, helps one to identify strategically where to focus attention and what set of actions may be most effective at delivering a cut in emissions intensity and, through this, emissions overall.

For these purposes the estimates are likely to be sufficient but, nonetheless, there are some areas where relatively simple improvements in data collection might improve and refine estimates further, for example as part of more detailed consideration of actions to reduce emissions. These areas include:

Emissions from Boats

Estimation of emissions will always depend on the numbers of participants and frequency of visits. Visitor surveys of boat usage and behaviour (for example as part of the licensing process) would, perhaps, help to improve the accuracy of emissions estimates and would be preferable to the use of assumed scenarios. However, owing to the fact that there will be variation from year to year anyway, this may not be a worthwhile undertaking as there are no (desirable) actions one would take in relation to these variables so as to reduce emissions.

Rather, in relation to boat use and reduction of emissions intensity one is far more likely to seek to improve the efficiency of the boats themselves and, therein, reduce the emissions intensity (and emissions) of the activity. Here, whilst there is a good deal of boats by size, type, etc., BA data on the size of engines is not complete and not consistently recorded. Sometimes combustion engine power is recorded as horsepower, sometimes centimetres cubed and sometimes not at all. In addition, for electric motors sometimes data are recorded as kilowatts and sometimes pounds. The analysis here has used what data there is (which covers the majority of boats) to interpolate across boat and engine types. Here, then, it would be useful for BA to refine the collection of data to consistently and completely record engine sizes.

Travel to/from and around the Broads

In terms of travel to/from and around the Broads estimates are based on location data and assumptions for some categories (such as private boats) or data from

STEAM. In both cases there is probably little that can be done (or is worth doing) to improve data collection and estimation concerning total emissions generated.

However, in the context of reducing emissions intensity from visitor travel, any actions are more likely to be focussed on creating a shift to alternative and public modes of transport. Thus, any additional surveys and monitoring might, instead, focus on collecting data on the number of visitors arriving by and travel around the Broads by such modes of transport. Depending on any strategy and actions taken to encourage this, such data could be gathered by means of an annual one day survey (perhaps timed to coincide with a hireboat changeover day) at (the few) train stations in the Broads and by bus operators. From changes in proportions travelling by these means one can interpolate (at least some idea of) likely emissions and emissions reductions.

Tourism and Recreation Services and Other Categories

In terms of emissions from services such as accommodation and food, these have been largely based on a combination of the STEAM data and input/output (I/O) analysis. I/O analysis is always going to subject to low resolution and higher uncertainty and, from the perspective of refining estimates, there is little more that can be done to assess emissions more accurately other than to undertake a survey of emissions from all tourism related businesses and services. This is not likely to be possible and, as with the transport emissions, any further refinements may be better focussed on estimating or verifying emissions reductions from actions to reduce emissions that may or may not be taken forward within a BA strategy for reducing emissions.

B3. Land and Land-use

B3.1 Overview of Approach and Emissions Estimates

Importance of Land and Land Use

Land use practices tend to produce emissions from activities associated with land use change, livestock management, or crop production; each generating varying amounts of CO_2, methane and nitrous oxide GHGs. CO_2 emissions are generally associated with the direct use of fossil fuels in everyday farming activities (e.g. agricultural off-road machinery and vehicles) as well as land use change including deforestation and the cultivation, liming and drainage of soils.

Non-CO_2 GHG emissions of nitrous oxide and methane are largely a product of microbiological processes (e.g. enteric fermentation), livestock waste production, and the combustion of organic materials, and are often organised by ecosystem components: biomass; dead organic matter; soils; and livestock.

Soils and vegetation provide an important role in sequestering and storing atmospheric carbon. For example, vegetation absorbs CO_2 from the atmosphere and fixes it into wood, fibre, and plant residues, whilst soils sequester carbon from the atmosphere, in organic form via vegetation deposition and the accumulation of recalcitrant organic matter (OM), and inorganically from parent materials via bicarbonate weathering of silicate minerals (Chadwick *et al,* 1994).

Owing to the large spatial area associated with land and land use emissions and stock carbon, GHG emissions and stock carbon (and it's loss), emissions are potentially very large indeed and, therefore, potentially small changes in management over a wide area have the potential to deliver large emissions reductions (or conversely increases).

Accordingly, the main purpose of analysing emissions from land and land use and estimating the carbon stored in soils and vegetation is to obtain data that aids consideration and identification of key areas of land/water management that might result in GHG emission reductions by, for example, changing management practices to reduce direct emissions, conserving soil and vegetation carbon stocks or promoting greater sequestration of atmospheric carbon.

Here, for example, applying fertilisers to agricultural land that drains into existing wetlands can lead to nutrient enrichment and eutrophication of water bodies, and the associated deterioration in water quality and increase in decompositional processes can lead to the formation of CH_4 and N_2O.

In terms of the importance of conserving soils, in wetland systems a significant proportion of decomposing organic matter is returned to the atmosphere as CH_4, although net soil carbon stocks may increase, decrease or remain constant over time, depending on the management and environmental controls on the overall carbon balance (IPCC, 2006).

In contrast, the sequestration of carbon in soils and vegetation can be promoted via the growth of long-lived perennial biomass, such as trees and permanent grasses. The growing importance of the agricultural, forestry and land use sector in the context of addressing climate change emphasises the need for land managers, such as the Broads Authority, to alter key environmental management strategies to help contribute towards GHG emission reductions.

Approach and Emissions Estimates

The first step to identifying strategic management actions to address such issues is to estimate the magnitude of stock carbon and GHG emissions (CO_2, methane-CH_4 and nitrous oxide-N_2O) associated with land use for overall comparison with emissions from other sectors. Here, consideration of emissions from GHGs other than (but also including) CO_2 is particularly important. Owing to the differing Global Warming Potential of different GHGs, a measure that reduces CH_4 emissions by 1 tonne is the equivalent of reducing 21 tonnes of CO_2, whilst an activity that is able to reduce 1 tonne of N_2O is equivalent to reducing 310 tonnes of CO_2.

With an area covering 30,292 ha the Broads provides a variety of habitats and landscape types, including water, fens, marshes, and woodland, which are all inter-linked to form a unique lowland wetland ecosystem (Broads Authority, 2004a; Luisetti, 2008). Given the mosaic of land uses occurring in the Broads, the land and land use emissions analysis is inherently complex. As illustrated in Figure B3.1, the cycling of CO_2 and other GHGs is complicated and very detailed assessment would require site-specific, ‘bottom-up’ calculations of emissions and cycling based on very time consuming and resource intensive sampling surveys and aggregation.

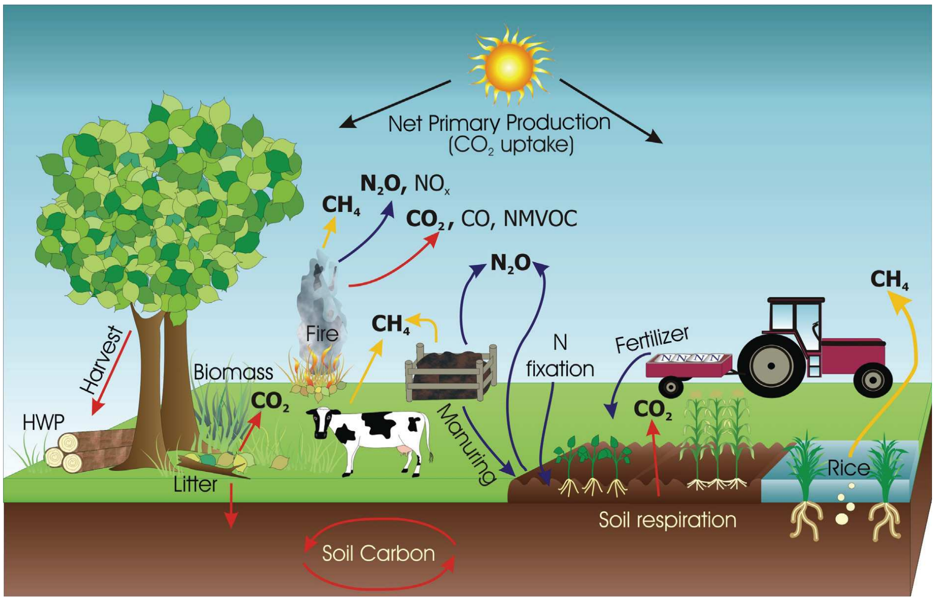


Figure B3.1: The main greenhouse gas emission sources and removals, and the processes considered in managed ecosystems. Sourced from IPCC (2006).

However, as has been noted elsewhere, rather than cataloguing every emission in great detail, the role of the audit is to help pinpoint and identify GHG emissions sources that are likely to be both significant and where intervention and management changes might either reduce emissions (or increase sequestration of atmospheric CO_2).

Accordingly the analysis focuses on the following categories:

1. **Carbon Stored in Soils and Vegetation; and**
2. **GHG Emissions from Natural Processes, Agriculture and Land Use.**

These, in turn, form the structure of this part of the report and the sections below outlines the data used in calculations, the assumptions made and work that would help improve the data and emissions estimates if desirable.

Table B3.1 provides an overview of the resulting calculated emissions in relation to land and land use.

Table B3.1: : Emissions and stores associated with agriculture, conservation and land use						
Carbon stores (tCO_2e)						
Soil Carbon Store						38,803,019
Vegetation Carbon Store						1,053,695
Total stored Carbon						**39,856,714**
Land and land use emissions associated with agriculture and natural processes						
	N_2O (tCO_2e)			**CO_2 (tCO_2e)**	**CH_4 (tCO_2e)**	**Total (tCO_2e)**
'Natural'	Woodland / dense scrub	1,245	7,887	0*	3	7,890
	Marsh / fen	4,698				
	Open water:	1,944				
	Rivers	*1,458*				
	Broads	*486*				
Agriculture			37,879	3,193	16,679	57,751
'Either'	Drainage channels		7,808	0*	0**	7,808
Total land and land use GHG emissions			**53,574**	**3,193**	**16,682**	**73,449**
* Net CO_2 emissions here may actually be slightly negative. ** Methane emissions might also be expected from ditches.						

B3.2 Carbon Stored in Soils and Vegetation

B3.2.1 Data and Assumptions

Land-based (terrestrial) carbon is that which is contained in the organic components of soils and vegetation (biomass). Climate, geology and land management practices are the main factors determining soil and vegetation type, and thus are influential controls on the amount of carbon within the terrestrial pool (Dawson & Smith, 2007).

The amount of carbon stored in the world's soils is estimated to be between 1100 to 1600 Giga tonnes (Gt), which is more than twice the carbon stored in living vegetation (560 Gt) or the atmosphere (750 Gt) (Kimble *et al* 2007; Smith 2004). For the soils of Great Britain, it has been calculated that 4,267 Million tonnes of carbon are stored within the top 100cm (Bradley *et al,* 2005), whilst the mass held in vegetation equates to 114 Million tonnes of carbon (Milne and Brown, 1997). Soils and vegetation will therefore represent a significant proportion of any regional carbon stock (and therefore inventory), and any action taken by an organisation to reduce its impact on climate change usually requires a reduction in their current greenhouse gas emissions with respect to their overall carbon store.

Estimation of terrestrial carbon stores and their spatial distribution is also important to the promotion of more diligent management of these valuable reserves as it will help highlight areas of high carbon storage, which would benefit from land management initiatives, and areas of low carbon storage that hold potential to sequester more carbon into long-term storage with the introduction of appropriate restoration initiatives. Processes influencing the fate of terrestrial carbon are also important in determining other valuable properties, such as soil fertility, quality, and health and biodiversity, as well as consequences for future environmental change scenarios (Dawson and Smith, 2007).

A ‘top-down’ estimate of the mass of carbon stored in the soils and vegetation present in the Broads Executive Area was undertaken by combining literature-derived carbon density values with geographical information systems (GIS) to help identify the spatial distribution of terrestrial carbon. In order to calculate the stock of soil carbon a copy of the 1:250,000 scale National Soil Map developed by the National Soil Resources Institute was scanned and digitised by hand, and overlain with soil-based carbon density data, sourced from the 2004 soil carbon inventory database[14] derived for the UK, for the relevant soil groups located in the Broads Executive Area. The carbon density data is provided in the form of tonnes of carbon per hectare (t C ha^{-1}) and covers the carbon stored in the 32 soil groups present in the UK between 0 and 100cm depth[15]. By digitising the soil map using ArcGIS, it was possible to extract the areal extent of each of the 9 soil groups present in the Broads Executive Area, and apply the appropriate carbon density value to estimate the total mass of carbon stored in the soil.

To calculate the mass of carbon stored in vegetation ArcGIS was again used to access the vector-based database “Land Cover Map (LCM) 2000” to identify the range and areal extent of different vegetation classes present in the Broads Executive Area. It was then possible to apply the appropriate carbon density data for each vegetation group, which was sourced from peer-reviewed UK-based studies[16]. This carbon density data was also provided in units of t C ha^{-1} and covers the biomass present in the 26 vegetation sub-classes of LCM 2000, although certain categories, such as rock, bare ground and urban areas are assumed to have no carbon by default.

By clipping the LCM 2000 database to cover the Broads Executive Area it was possible to calculate the areal extent of each of the 19 vegetation sub-classes present in the region, and apply the appropriate carbon density value[17] in order to calculate the total mass of biomass carbon. The data sourced from the 19 LCM 2000 sub-classes was then aggregated to provide vegetative carbon store estimates that fit the main habitats associated with the Broads, in an attempt to help direct future management strategies to appropriate emissions reductions and sequestration options.

In order to verify we were undertaking a suitable method of approach for this aggregation, the habitat classes generated from the LCM 2000 data were compared to the areal coverage data reported in the Broads Authority’s 2008 annual monitoring report[18], and there appears to be a suitably strong relationship between the two.

---

[14] Milne and Mobbs (2004)

[15] Soil carbon densities include carbon to a depth of 100cm or to the bedrock, whichever is the shallower for both mineral and organic/mineral soils (Milne and Mobbs, 2004).

[16] Milne and Brown (1997); Cruickshank *et al* (1998)

[17] Note: literature values were rounded to whole numbers

[18] See: Broads Authority 2008

B3.2.2 Calculated Carbon Stores

Soils

Digitising the UK 1:250,000 National Soil Map allowed the areal extent of each soil group in the Broads Executive Area to be calculated, and by overlaying the appropriate carbon density values, we were able to estimate the total stock of soil carbon to be in the region. Base data and resulting estimates of stock carbon are provided in Table B3.2 and Figure B3.2.

As can be seen from the table, total soil carbon stock is estimated at around 39 million tCO_2e. As highlighted in Table B3.2 and Figure B3.2, 95% of the soil carbon store is associated with only 2 of the 9 soil groups. The principal carbon store (65%) is found in the highly organic Earthy peat soils, which tend to be associated with the wet fen and marsh habitats so characteristic of the Broads; whilst the second largest store (30%) is associated with Alluvial gley soils, which are the dominant soil type covering over half the land surface (17,011 ha), and is expected considering the area is situated in a lowland river catchment.

This distribution of soil carbon is actually quite typical of the UK, as although raw peat soils have by far the greatest carbon density, gley and brown earth soils are equally major contributors due to their great areal extent across the country (Milne and Brown, 1997; Dawson and Smith 2007). Using ArcGIS, it was possible to map the distribution of the carbon stored in the soils of the Broads Executive Area; Figure B3.3 indentifies the spatial extent of the nine soil types, whilst Figure B3.4 highlights the variance in soil carbon stores in the region. From these two figures it is possible to see that the carbon-rich Raw peat soils tend to be located in the “upper” reaches of the five largest river catchments, whilst the Alluvial gley soils dominate the “lower” catchment, in areas typically associated with the grazing marshes.

Table B3.2: Proportioning carbon stored in the different soil groups of the Broads Executive Area

Soil Group	Area (ha)	C Density (t C ha^{-1})	C Store (t C)	CO_2 Store (t CO_2e)
Earthy peat	9,030	765	6,909,119	25,356,468
Calcareous pelosols	265	145	38,450	141,113
Brown earth	1,314	128	167,966	616,436
Brown sand	196	83	16,273	59,721
Agrillic brown earths	418	100	41,902	153,780
Stagnogley soils	43	122	5,260	19,304
Alluvial gley soils	17,011	186	3,166,020	11,619,295
Humic-sandy gley soils	266	202	53,801	197,450
Humic gley soils	621	281	174,238	639,453
Urban	812	0	0	0
Open water	202	0	0	0
Total	**30,178**	**n/a**	**10,573,030**	**38,803,019**

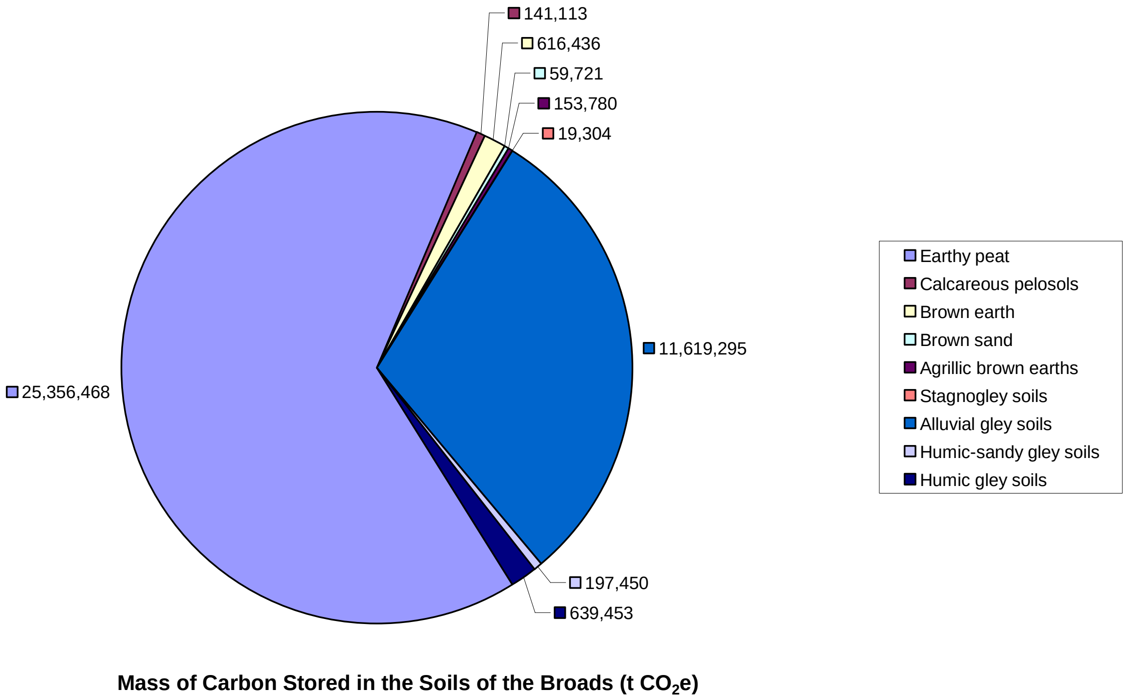


Figure B3.2: The distribution of carbon stored in the soils of the Broads Executive Area

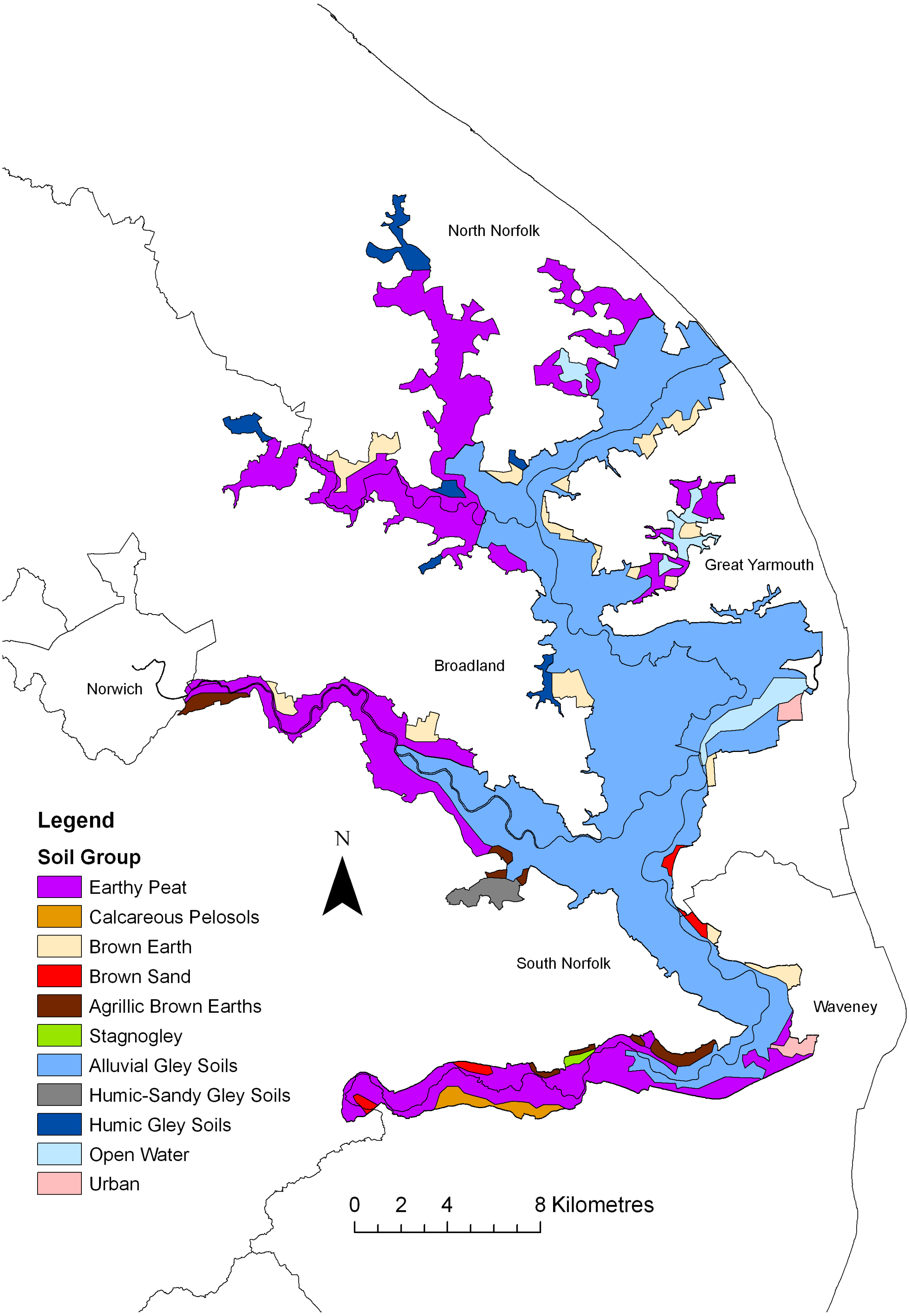


Figure B3.3: Distribution of major soil groups within the Broads Executive Area

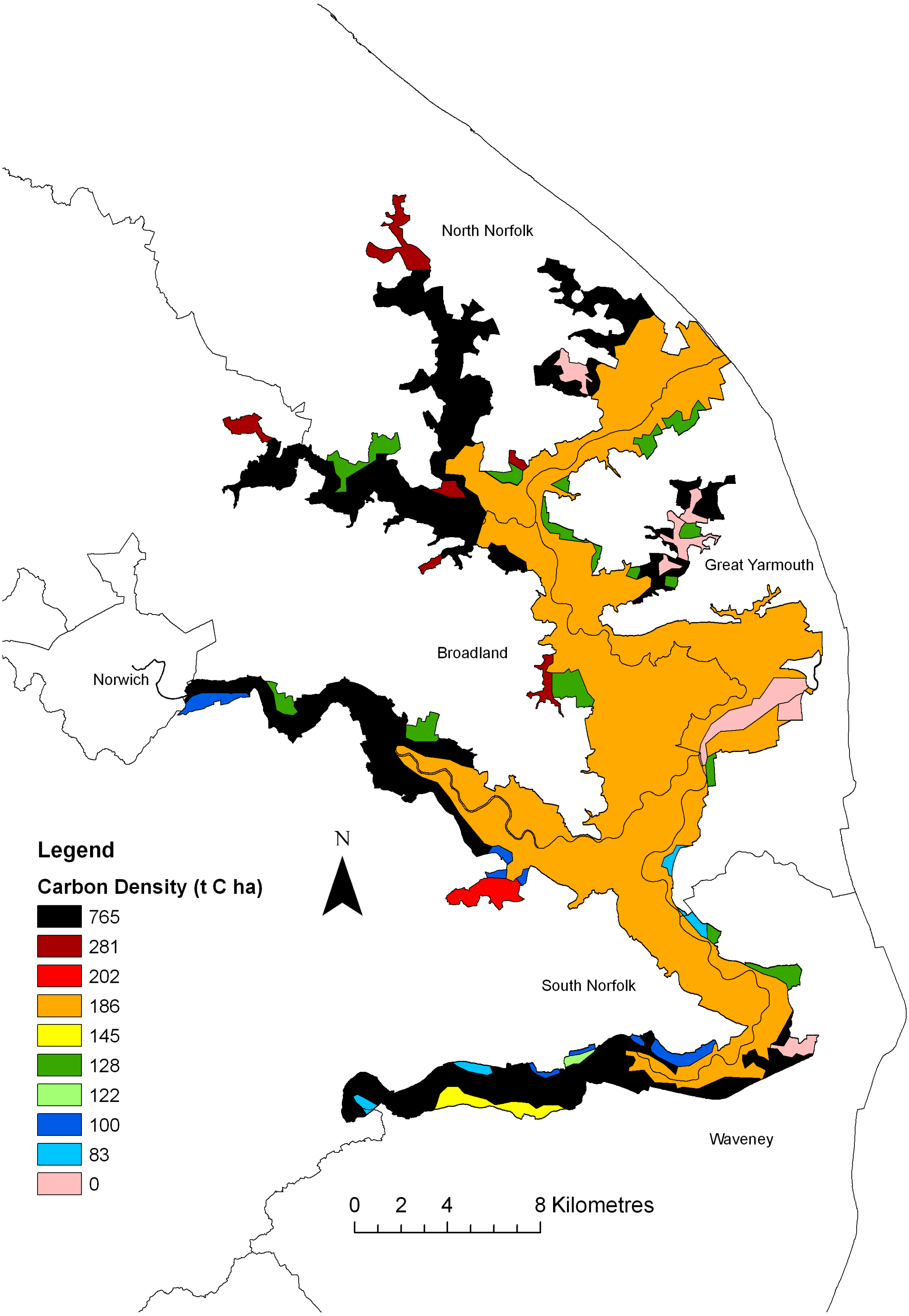


Figure B3.4: Distribution of soil carbon stores within the Broads Executive Area

Vegetation

Using the carbon density figures extracted from UK-based studies for different vegetation types, it was also possible to provide an estimate for the likely mass of carbon stored in biomass by applying these values to the aerial extent of each of the 19 LCM 2000 sub-classes represented in the Broads Executive Area. These data are provided in Table B3.3. As can be seen from the table, the data suggest that the total mass of carbon stored in vegetation is just over 1 million tCO_2e.

The largest single carbon store (88%) is located in broad-leaved and mixed woodland (929,067 t CO_2e), which occupies only 14% of the total area, and highlights the importance of this particular biomass for carbon storage and sequestration. Coniferous woodland also has a relatively high carbon density (21 t C ha), which means that, although it only covers 0.3% of the land area, it contributes nearly 1% of the total carbon for the Broads Executive Area. The remaining carbon (11%) is “fairly” evenly distributed between the nine remaining vegetation types typically associated with fenland, arable, and grassland habitats, which together account for nearly 80% of the Broads Executive Area.

Figure B3.5 shows the spatial distribution of LCM 2000 vegetation classes present in the Broads Executive Area, whilst Figure B3.6 illustrates the variance in biomass carbon stores in the region. Together, these figures demonstrate that the carbon-rich broad-leaved woodlands dominate the “upper” reaches of the Ant, Bure and Yare catchments, whereas the relatively carbon-poor vegetation associated with grassland pasture occurs in the “lower” catchment reaches.

Table B3.3: Proportioning carbon stored in the vegetation of the Broads Executive Area

LCM 2000 sub-classes	Area (ha)	C Density ($t\ C\ ha^{-1}$)	C Store (t C)	CO_2 Store ($t\ CO_2e$)
Broad-leaved/Mixed Woodland	4,090	62	253,152	929,067
Coniferous Woodland	93	21	1,953	7,168
Cereals	3,990	1	3,990	14,642
Horticulture/Non-cereal/Unknown	4,308	2	7,755	28,461
Non Annual Crop[19]	28	3	85	313
Improved Grassland	3,183	1	3,183	11,681
Set-aside Grass	463	2	925	3,395
Rough Grass	1,870	2	3,740	13,724
Calcareous Grass	6,083	1	6,083	22,326
Acid Grass	1,508	1	1,508	5,534
Fen/Marsh/Swamp	2,368	2	4,737	17,384
Inland Water	839	0	0	0
Inland Bare Ground	3	0	0	0
Suburban/rural Development	506	0	0	0
Continuous Urban	309	0	0	0
Supra-littoral Sediment	16	0	0	0
Littoral Sediment	30	0	0	0
Salt-marsh	41	0	0	0
Sea/Estuary	437	0	0	0
Total	**30,165**	**n/a**	**28,7110**	**1,053,695**

---

[19] Carbon density derived from Cruickshank *et al* (1998) for a permanent crop mix of orchard ($13.5\ t\ C\ ha^{-1}$) and grass ($1t\ C\ ha^{-1}$)

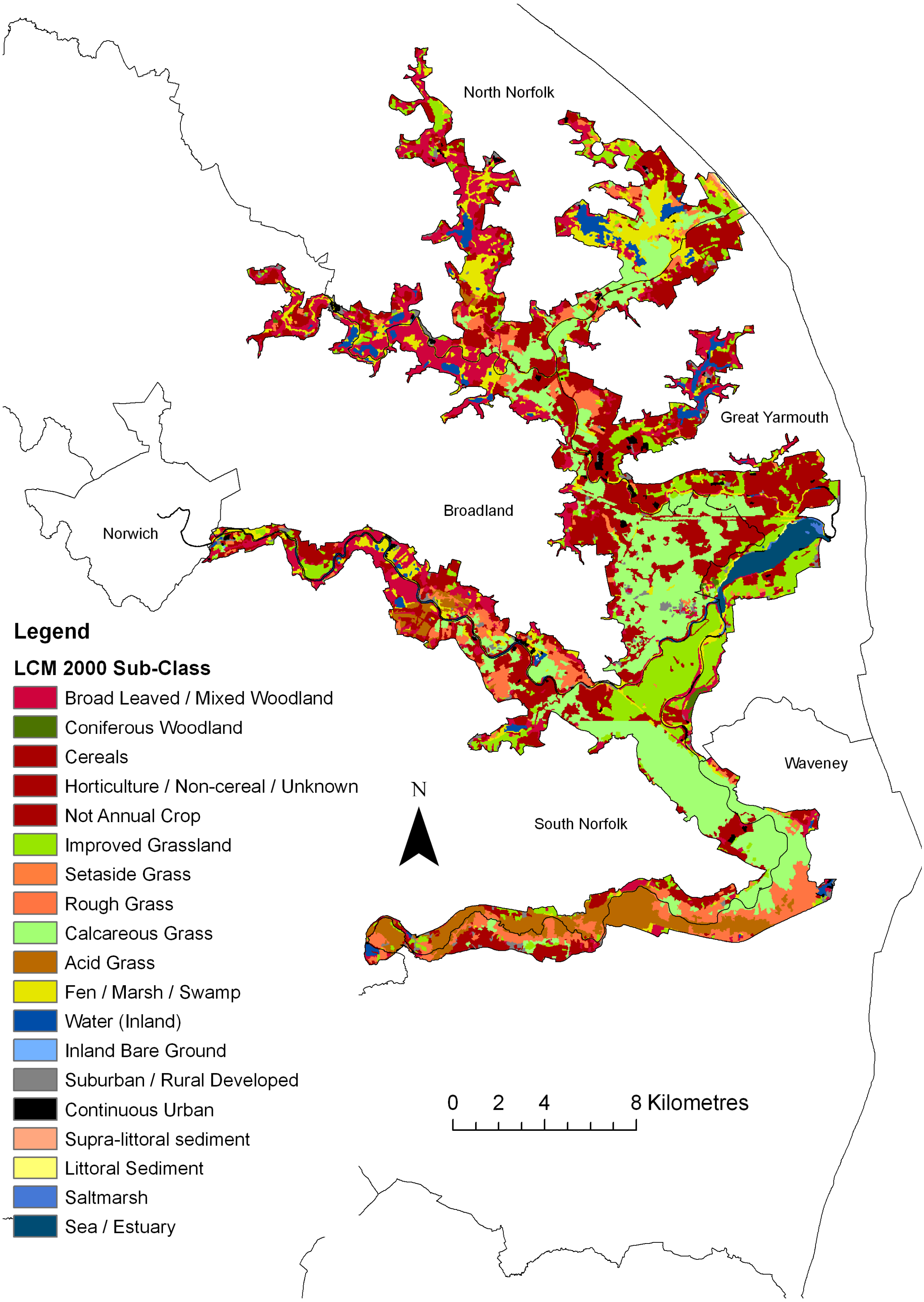


Figure B3.5: Distribution of LCM 2000 vegetation sub-classes within the Broads Executive Area

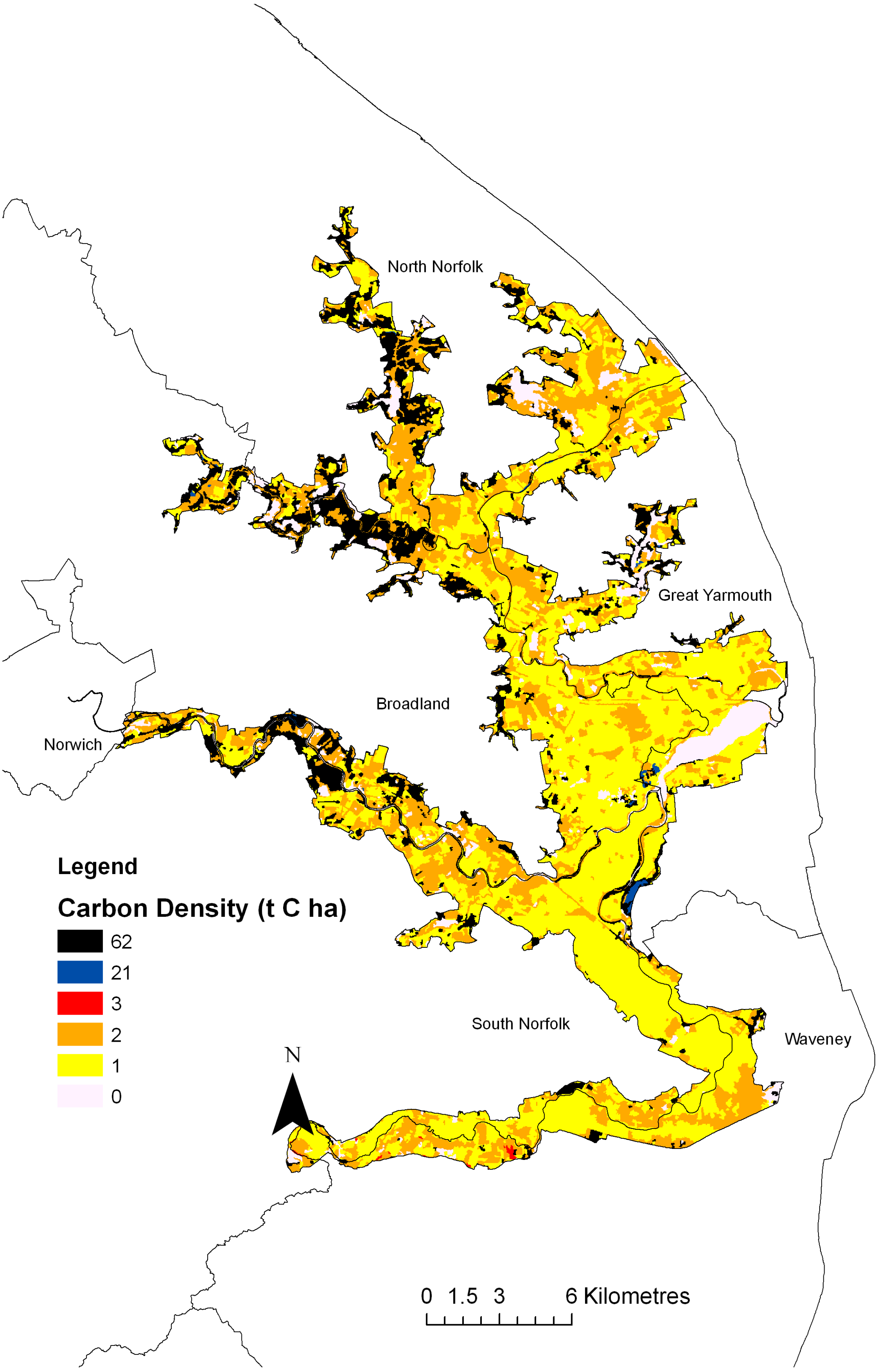


Figure B3.6: Distribution of biomass carbon stores within the Broads Executive Area

Habitats

Viewed in terms of habitats (as opposed to classes of vegetation type), Table B3.4 and Figure B3.7 provide aggregated data on carbon stored in habitats. This is plotted spatially in Figure B3.8 (which can be compared to similar areal data produced by the Broads Authority, for example, Broads Authority, 2008).

When the aggregated data (Table B3.4) is assessed the woodland habitat is clearly the largest carbon store (89%) due its high carbon density, followed by grassland pasture (5%) and arable/cultivated land (4%), primarily as a result of their large areal coverage. Although the marsh/fen habitat covers less than 8% of the total land area, it still contributes nearly 2% (17,384 t CO_2e) of the total vegetative carbon store.

Table B3.4: Estimating carbon stored in the key habitats of the Broads Executive Area.

Aggregated Land-use Type	**Area (ha)**	**C Store (t C)**	**CO_2 Store (t CO_2e)**
Grassland/Pasture[20]	13,107	15,439	56,660
Arable/Cultivated Land[21]	8,326	11,830	43,416
Woodland/Dense Scrub[22]	4,182	255,105	936,234
Marsh/Fen[23]	2,368	4,737	17,384
Open Water[24]	1,363	0	0
Urban[25]	817	0	0
Total	**30,165**	**28,7110**	**1,053,695**

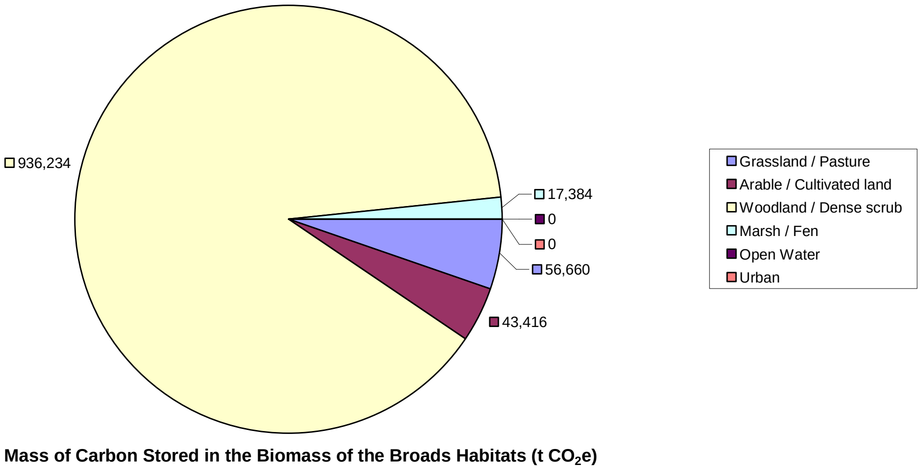


Figure B3.5: The distribution of carbon stored in the principal habitats of the Broads Executive Area

---

[20] LCM 2000 Sub classes: Improved Grassland; Set-aside Grassland; Rough Grass; Calcareous Grass; and Acid Grass
[21] LCM 2000 Sub classes: Cereals; Horticulture/Non-cereal/Unknown; and Non-annual crops
[22] LCM 2000 Sub classes: Broad-leaved/Mixed Woodland; and Coniferous Woodland
[23] LCM 2000 Sub classes: Fen/Marsh/Swamp
[24] LCM 2000 Sub classes: Inland Water; Supra-littoral Sediment; Littoral Sediment; Salt-marsh; and Sea/Estuary
[25] LCM 2000 Sub classes: Continuous Urban; Suburban/Rural Development; and Inland Bare Ground

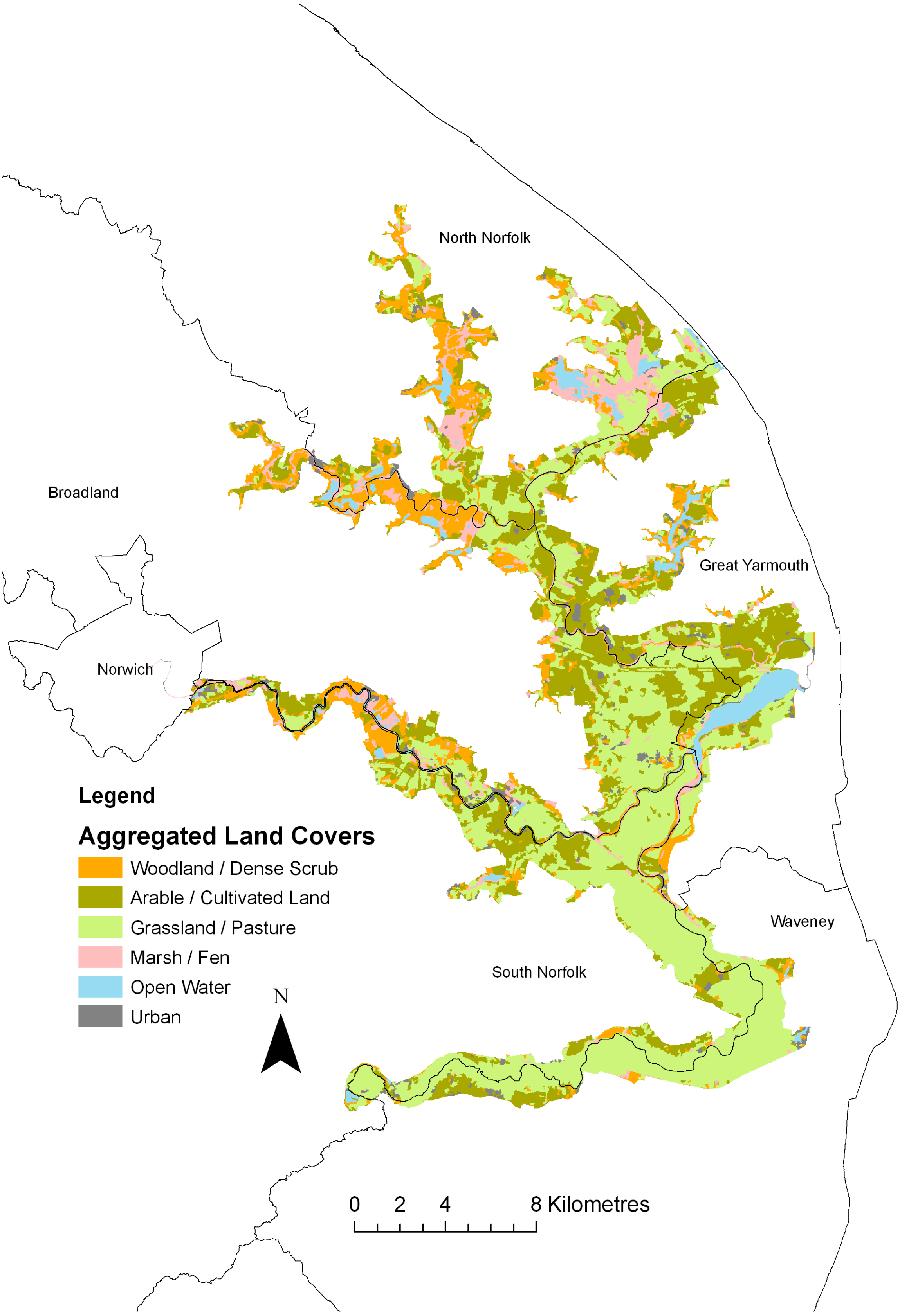


Figure B3.6: Aggregated LCM 2000 data highlighting key habitats within the Broads Executive Area

B3.2.3 Options for Improving Data and Emissions Estimation

As with all audits, estimation always depends on some assumed and default values and this audit is no exception. As noted elsewhere, however, the purpose of the audit is not to obtain a precise estimate of emissions and stock carbon for academic interest but, rather, derive estimates at a level of detail that is sufficient to inform the development of a strategy to reduce emissions and, in this case, conserve carbon stocks. For this purpose the estimates are likely to be sufficient but there are a few opportunities to improve data in future as, for example, better data becomes available or the need demands. These possible (but not essential) improvements include:

- vegetation data extracted from LCM 2000 is of good resolution (25m^2) and is of high quality, having been developed for the whole of England, Scotland and Wales by the Centre for Ecology and Hydrology (CEH). However, improvements could be made, with regard to accounting for changes in land use since this database was constructed in the mid 1990's, by using the updated Land Cover Map 2007 when it is released as a GIS vector dataset;

- as a scanned copy of the 1:250,000 UK National Soil map was digitised there is likely to be a lower level of accuracy compared with the original digital dataset. An area error of the order of 5% area error might be expected. Greater detail could be acquired from the 1:100,000 county-level soil map but this is only available for Norfolk. An option to improve the accuracy of calculating the areal extent of the soil groups would be to purchase an electronic copy of the 1:250,000 UK National Soil map from the National Soil Resources Institute (NSRI), together with a package entitled "Horizon Fundamentals" and 5km^2 gridded soil samples in order to generate more site-specific data relating to soil in the Broads Executive Area. The expected cost of this data would be in the region of £1,000. At the same time, for the purposes of identifying more general strategies to conserve stock carbon, such resolution is unlikely to be necessary at this time and this improvement might only be considered if one determined that action focussed on a subset of soil types was to be taken forward and there was a need to pinpoint the location of such soils with more precision;

- Davidson and Lefebvre (1993) raise the issue of how best to calculate soil carbon stocks and questioned the use of mean values for soil series versus mean values for major soil group, the implications of using different scale maps, and the advantages and disadvantages of making estimates using land use rather than soil type values. With the benefit of more time and resources one could undertake a detailed evaluation of the individual soil groups and series present across the Broads Executive area and apply specific soil organic carbon values that are available from the NSRI according to their individual depth, density and distribution. This could be supported by a detailed sampling campaign, similar to that undertaken by Bell and Worrall (2009) for the National Trust's Wallington Estate and incorporate data being recorded in the peat monitoring project currently being undertaken by the Broads Authority. That said, as with the above, for the purposes of identifying more general strategies to conserve stock carbon such resolution may not be necessary; and

- Although generated from studies evaluating UK soils and vegetation, the generalised carbon density values used in this analysis could be improved if more localised and site-specific data were available. However, as with the above, for the purposes of identifying more general strategies to conserve stock carbon such resolution may not be necessary.

B3.3 GHG Emissions from Natural Processes, Agriculture and Land Use

B3.3.1 Overview

As noted in Section B3.1, Land use and agricultural practices tend to produce emissions from activities associated with land use change, livestock management, or crop production; each generating varying amounts of CO_2, methane and nitrous oxide GHGs.

CO_2 emissions are generally associated with the direct use of fossil fuels in everyday farming activities (e.g. agricultural off-road machinery and vehicles) as well as land use change including deforestation and the cultivation, liming and drainage of soils.

Non-CO_2 GHG emissions of nitrous oxide and methane are largely a product of microbiological processes (e.g. enteric fermentation), livestock waste production, and the combustion of organic materials, and are often organised by ecosystem components: biomass; dead organic matter; soils; and livestock.

Applying fertilisers to agricultural land that drains into existing wetlands can lead to nutrient enrichment and eutrophication of water bodies, and the associated deterioration in water quality and increase in decompositional processes can lead to the formation of CH_4 and N_2O.

In wetland systems, a significant proportion of decomposing organic matter is returned to the atmosphere as CH_4, although net soil carbon stocks may increase, decrease or remain constant over time, depending on the management and environmental controls on the overall carbon balance (IPCC, 2006).

Approaches to Estimation

Estimation of GHG emissions from land uses is clearly complex and has employed two methods. The first of these has been the application of a ‘top down’ approach making use of available existing estimates of CO_2, N_2O and CH_4 emissions in the National Atmospheric Emissions Inventory (NAEI). This provides aggregated overall emissions of these three GHGs for agriculture and for natural processes.

To provide a second estimate and capture some elements that may not be addressed in the NAEI assessment, a broad “bottom up” approach was also applied focussing on N_2O alone. Here, owing in part to the fact that the Global Warming Potential of N_2O is some 310 times that of CO_2, the analysis of NAEI data suggested that over 65% of the total GHG emission from agricultural natural sources is associated with N_2O. In addition, because NAEI is based on land use (as opposed to water) it appears that NAEI data may not capture GHG emissions from surface water, where N_2O is likely to be the most significant of these.

In this way, the “top down” approach is intended to provide an overarching estimate of emissions and the “bottom up” provides cross checking, slightly more detail and coverage of the main sources of GHG emissions from surface water. The estimates combined provide an overall estimate of emissions.

The approaches are discussed in more detail in the sections below.

B3.3.2 'Top Down' Analysis

Data and Calculations

'Top down' estimates of CO_2, N_2O and CH_4 emissions from both natural processes and agriculture have been calculated for the Broads Executive Area using data sourced from the publically accessible National Atmospheric Emissions Inventory (NAEI), which has produced GHG emission maps at $1Km^2$ resolution at the UK Local Authority (LA) district level. NAEI data was sourced for each of the six LA districts[26] that fall within the boundary of the Broads Executive Area, and using GIS methodology the data from each $1km^2$ reference point was apportioned to fall either within or without of the Broads Executive Area boundary. Thus, in this section only the data falling inside the Broads boundary were analysed.

The NAEI datasets are consistent with the UK Greenhouse Gas Inventory (GHGI), with which they overlap. NAEI agricultural emissions are based on UK emission factors and detailed annual survey data from DEFRA's Agricultural Census, including estimates of arable production and livestock numbers and CO_2 emissions from agricultural soils. Emissions from agricultural off-road machinery and vehicles are generated using a combination of arable, pasture and forestry land use data.

NAEI 'natural' estimates are based on emission factors and regional survey data of land use, modelled to calculate GHG emissions and carbon fluxes between sources and sinks. They are distributed using $1km^2$ resolution land cover maps derived from Land Cover Map 2000 data from the Centre for Ecology and Hydrology (Bush, 2008).

'Top Down' Calculated Emissions

'Top-down' estimates of CO_2, N_2O and CH_4 emissions from agriculture and natural processes derived from the NAEI datasets are provided in Table B3.5 for the Broads Executive Area. The data suggest that agricultural activities contribute a net GHG emission of 57,751 tonnes of CO_2e, of which over 65% is attributable to nitrous oxide.

In terms of other GHGs, the data suggest that CO_2 emissions from agriculture account for approximately 6% of total emissions, whilst CH_4 contributes nearly 30%.

In terms of 'natural' processes the NAEI data suggest that, at 3 t CO_2e, the emissions profile is very much smaller than agriculture and that these emissions are wholly comprised of CH_4. However, their exact source remains obscured within the data.

Given that almost 75% (approximately 21,000 ha) of the Broads Executive Area is associated with agricultural activities, which includes land designated for grass pasture and cultivation (Broads Authority, 2008; and Table B3.4), the fact that agricultural emissions are higher than natural processes is not surprising. What is perhaps surprising is the magnitude of the difference. Here, given that from other work, it is known that there are emissions of N_2O from 'natural processes', it is possible that the NAEI data may underestimate natural process emissions and, as such, the 'bottom up' assessment of N_2O might help to refine or inform an overall estimate, where this is discussed later.

Table B3.5: GHG emissions associated with agriculture and natural processes

---

[26] Six Districts: Broadland; Great Yarmouth; North Norfolk; Norwich; South Norfolk; and Waveny.

	CO_2 (tCO_2e)	CH_4 (tCO_2e)	N_2O (tCO_2e)	Total (tCO_2e)
Agricultural emissions	3,193	16, 679	37,879	57,751
Natural emissions	0	3	0	3
TOTAL EMISSIONS	**3,193**	**16,682**	**37,879**	**57,754**
Contribution to total	*6 %*	*29 %*	*65 %*	

B3.3.3 'Bottom Up' Analysis of N_2O

Background:

As noted above, to verify, improve and provide further insight into emissions sources a fairly coarse 'bottom-up' estimate of N_2O emissions (the most potent GHG) was undertaken for land use within the Broads Executive Area.

As noted above, N_2O is a potent greenhouse gas with a global warming potential 310 times greater than that of carbon dioxide (IPCC 2006). The greatest anthropogenic source of N_2O is from agriculture (Kroeze et al. 1999). Direct N_2O emissions are considered to be those that occur as a direct result of fertiliser application onto field surfaces, whereas indirect N_2O emissions are as a result of leached nitrogen from agriculture which enters watercourses, where it is then converted to N_2O.

Natural N_2O emissions do occur from non-fertilised soils, but average atmospheric N deposition in the UK is around 17 kg N ha^{-1}, which will then enhance soil N_2O production; therefore, it is unlikely that there are 'pristine' soils that are not experiencing elevated N_2O production as a result of anthropogenic influence.

Data and Calculations

The Broads landscape is a mix of arable production, fenland, woodland, open water and drainage channels. Each one of these land uses contribute to the N_2O budget of the broadland area. For example:

- farmland due to direct N_2O emissions as a result of N-fertiliser and livestock manure application;
- fenland, which is likely to have a high N_2O flux as a result of naturally N-rich peat soils, further enhanced by atmospheric deposition and run-off from surrounding agricultural land;
- woodland, which is again likely to have a high flux as a result of peat soils, and also Alder forests tend to have higher N_2O fluxes than other types of woodland as Alder trees fix nitrogen in their roots, also enhanced by N deposition and N run-off from agriculture; and
- open water and ditches as a result of N run-off from agriculture. The drainage ditches are particularly susceptible to enhanced N_2O emissions as a result of agricultural run-off. The ditches act to lower the water table for agricultural practise and receive water from field drains throughout agricultural fields. These

therefore receive N-rich water leached directly from the fields, and then transport this water elsewhere in the catchment.

To calculate emissions, a range of emission factors sourced from scientific literature[27] were applied to the land use categories of: woodland, marsh/fen, open water, crops and fallow, improved grassland, and non-improved grassland.

Areal data for these categories was sourced using a combination of aggregated LCM 2000 data (see Table B3.4 above) and data sourced from DEFRA's 2004 Agricultural Census for the Broads[28]. N_2O Emissions were also estimated for drainage ditches, as according to Horne (2009) this is likely to be a major source as the Broads Executive Area is intrinsically 'wetter' and therefore more intensively drained than if the entire catchment area were being considered. Assumptions and calculations for each source are summarised in Box B3.1 below. It should be noted that this analysis has not considered emissions from livestock and livestock waste, which are also likely to make up a significant proportion of direct N_2O emissions.

---

[27] Couwenberg (2009); Horne (2009); and Skiba *et al* (1996)

[28] Defra Agricultural Census for the Broads available from: http://farmstats.defra.gov.uk/cs/farmstats_data/MAPS/interactive_maps/natpark_map.asp?natpark1_id=6#results

Box B3.1: Assumptions and Calculations Applied to ‘land use’ categories and open water

Woodland: The woodland in Broadland is principally broad-leaved deciduous and it was assumed that all woodland constituted carr woodland and, therefore, contained a mixture of alder, sallow and birch. Published N_2O fluxes from Skiba *et al* (1996) were used, which gives a separate flux values for birch and alder forests. Alder trees have one of the highest N_2O fluxes of all temperate woodland types because the roots are able to fix atmospheric nitrogen. No data was available as to the proportion of the woodland made up by each type of tree; therefore an equal mix of alder and birch trees was assumed in this calculation.

Marsh/fen: It was assumed that all marsh/fen occurred on peat soils, and if fen peat is left unmanaged then it leads to natural creation of carr woodland, containing alder trees. Therefore, a published N_2O flux for temperate drained nutrient-rich forested peat soils from Couwenberg 2009 was used for this category.

Open water: Open water includes the Broads themselves and the interconnecting river channels. N_2O fluxes from the broads and river in the Upper Thurne catchment in Broadland were estimated in Horne (2009). These values, expressed as kg of N_2O emitted per hectare of open water were used in this study. Using the LCM 2000 data, it was unclear exactly how much of the open water category used in the ‘Bottom-up’ N_2O estimates was attributable to broads and how much was attributable to rivers. However, the Broads Authority provided habitat data that suggested the split should be approximately 50:50, which was used in this study. The appropriate flux value from Horne (2009) was used for each of the estimated surface areas of broads and rivers, rivers having a slightly higher N_2O flux per hectare of surface water.

Whilst these figures give a good ballpark estimation of the N_2O flux from open water in the BA Executive Area, caution must be used as there are several factors that influence the amount of nitrogen that is likely to be produced by a wetland or river. For example, N_2O production is directly related to the dissolved inorganic nitrogen in the water column (nitrate, nitrite and ammonium), which is largely derived from agricultural practices. Therefore, the broads in the Upper Thurne catchment where the data from Horne (2009) was sourced may not be wholly representative in the amount of dissolved inorganic nitrogen in the water column and so using these flux values could result in either an over or under-estimation of N_2O depending on the specific nitrogen input of each catchment. More research is needed in this area as it is likely that all of the broads are emitting significant amounts of N_2O, and there is not currently much data detailing N_2O fluxes from temperate freshwater wetlands.

Drainage channels: There was little data available regarding the area of drainage channels in the BA executive area. However, Horne (2009) used OS Mastermap to estimate the surface area of drainage channels in the Upper Thurne catchment and found that for the Upper Thurne catchment as a whole, drainage channels occupied 1.7% of the land, but when just the Broads Executive Area within the Upper Thurne catchment was considered, the drainage channels made up 5% of the land. Therefore, 5% was used in this study to estimate the areal extent of drainage channels in the Executive Area.

The annual N_2O flux for drainage channels as reported in Horne (2009) was used to estimate emissions from drainage channels in the Broads Executive Area. As mentioned above, care must be taken when extrapolating these values, developed in the Upper Thurne catchment, across the larger catchment area. Again, more research is needed as if these N_2O fluxes from drainage channels in the Upper Thurne catchment are representative of all drainage channels in the Broads, then they form an important part of the greenhouse gas budget for the region, and indeed the national N_2O inventory (Horne, 2009).

Crops and fallow: The crops and fallow land use data derived from DEFRA did not provide any detail of crop type. N_2O emissions vary significantly depending on crop type; they are higher, for example, from leafy crops like potatoes and sugar beet than from cereals. Thus, the proportion of main crop types from Horne (2009) was taken to be representative of the crops found in the Broads Executive Area, so that this land use category could be broken down into crop type. Specific fertiliser application rates could then be used for each crop type (taken from the British Survey of Fertliser Practise, DEFRA), which were combined with annual atmospheric Nitrogen (N) deposition to work out the total mass of N applied to each crop type. Specific emission factors were taken from Skiba *et al* (1996) to estimate the proportion of fertiliser applied that is likely to be lost as N_2O.

Temporary grassland, permanent grassland, rough grazing and set-aside: Fertiliser rates from the British Survey of Fertliser Practise or N-fixing rates for rough grazing and set-aside sourced from Johnes (1996) were combined with atmospheric N deposition rates to calculate the total mass of N applied to each land use. Emission factors from Skiba *et al* (1996) were used to estimate the likely proportion of N applied that is lost as N_2O.

Calculated Emissions

Table B3.6 and Figure B3.9 provide estimated N_2O emissions based on the 'bottom-up' analysis described. Using this approach, the total N_2O emissions in the Broads Executive Area are estimated to be 80,099 kg of N_2O-N, equivalent to nearly 25,000 tonnes of CO_2.

The data suggest that the areas considered the most 'pristine' (e.g. the woodland) contribute the least N_2O to the annual budget (approximately 1,245 t CO_2e). In contrast, although assumed to cover only 5% of the surface area, the analysis suggests that drainage channels are the single largest source of N_2O, emitting approximately 7,800 t CO_2e (~30% of total).

Crops and fallow, and fen marsh are also significant N_2O sources, primarily as a result of significant fertiliser inputs and water-logged anaerobic conditions, respectively.

Table B3.6: 'Bottom-up' assessment of N_2O emissions in the Broads Executive Area

	Area (ha)	**N_2O Emissions (kg N_2O-N)**	**CO_2 Emissions (t CO_2e)**
Grassland / pasture	13,107	14,502	4,496
Arable / cultivated land	8,326	14,971	4,641
Woodland / dense scrub	4,182	4,015	1,245
Marsh / fen	2,368	15,155	4,698
Open water	1,363	6,270	1,944
Rivers	*681.5*	*4,702*	*1,458*
Broads	*681.5*	*1,567*	*486*
Subtotal	**30,165**	**n/a**	**n/a**
Drainage channels (5%)	1,508	25,186	7,808
Total	**30,165**	**80,099**	**24,831**

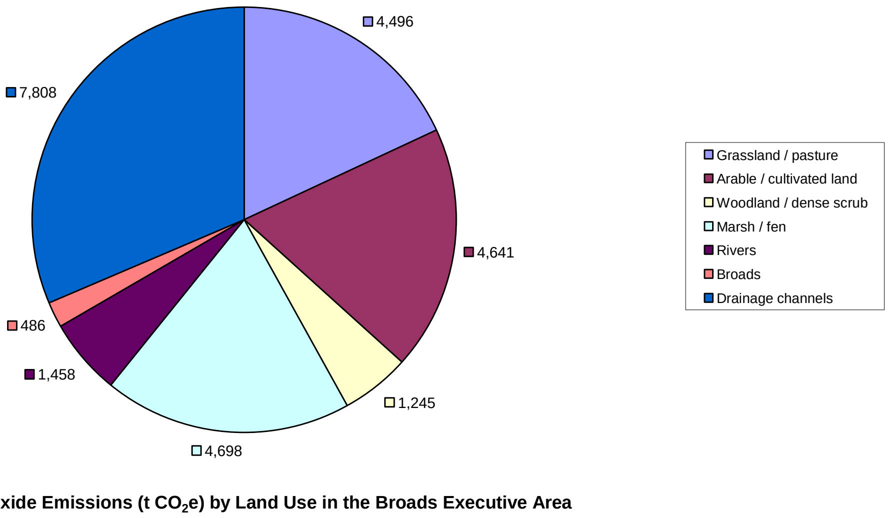


Figure B3.9: N_2O production from different land use classes with the Broads

B3.3.4 Combined estimate of Emissions from Natural Processes, Agriculture and Land Use

As noted in Section B3.3.1, the 'top down' estimates provide an overarching estimate of emissions and the 'bottom up' provide cross checking, more detail and greater coverage of the main sources of GHG emissions from surface water. In this way, while both approaches may have limitations, the two approaches combined can be used to provide a better insight into what emissions are likely to be.

From the discussion above, a limitation of the NAEI based 'top down' approach is that it may underestimate the contribution of 'natural' emissions of GHGs and, in particular, N_2O and also surface water emissions (it being land based).

In contrast, while based on slightly coarse data and assumptions, the 'bottom up' assessment of N_2O emissions may provide greater insight into emissions from 'natural processes' but, owing to the fact that it does not consider emissions from livestock, is likely to be weaker as far as emissions from agriculture are concerned.

A possible 'grey area' is the N_2O emissions from drainage channels identified in the 'bottom up' analysis. Here it is not clear whether emissions from drainage channels are or are not included in the NAEI data as part of emissions from agriculture. As drainage ditch emissions are related to fertiliser application and rates of fertiliser application are used to model emissions in the NAEI it is likely that the NAEI data does, in part, consider some of the emission. At the same time, it is unlikely that the NAEI data calculations adequately consider the larger potential for N_2O emissions from exposure routes such as N applied to field, leached to field drain, flows to ditch, released to atmosphere. Clearly, in an area such as the Broads, drainage ditches are frequent and, as such NAEI data may substantially underestimate or even omit emissions from ditches. NAEI data almost certainly does not consider the associated route from ditches to open water.

In terms of developing a combined estimate, Table B3.6 summarises the differences in N_2O estimates between the two approaches. As already noted, the 'top down'

NAEI approach records zero N_2O emissions for 'natural' processes and as such it seems better here to rely on estimates from the 'bottom up' approach.

Table B3.6: 'Bottom-up' assessment of N_2O emissions in the Broads Executive Area

Category	**Source**	**N_2O Emissions (t CO_2e)**				
		'Bottom up'		**NAEI 'Top down'**	**Difference in estimates approaches**	**Probable Explanation**
'Natural'	**Woodland / dense scrub**	1,245	7,887	0	7,887	NAEI calculations not sensitive enough
	Marsh / fen	4,698				
	Open water	1,944				
	Rivers	*1,458*				
	Broads	*486*				
Agriculture	**Grassland / pasture**	4,496	9,137	37,879	28,742	In 'bottom up': difference attributable to omission of livestock from analysis
	Arable / cultivated land	4,641				
'Either'	**Drainage channels (5%)**	7,808	7,808		7,808	In NAEI analysis: possibly omitted/almost certainly underestimated NAEI

In terms of agriculture, the 'bottom up' estimates are less than half of the NAEI 'top down' estimates. The main reason for this is likely to be that livestock emissions are not included in the 'bottom up' analysis. As such, the NAEI estimates would seem more reliable. In terms of drainage ditches, as already noted, NAEI may or may not capture some of the emissions but, even if it does, is likely to underestimate them. As such it seems sensible to treat these as an additional emission source in the combined estimates.

Grouping the results together into a combined estimate suggests the emissions in Table B3.7.

Table B3.5: GHG emissions associated with agriculture and natural processes

	N_2O (tCO_2e)			**CO_2 (tCO_2e)**	**CH_4 (tCO_2e)**	**Total (tCO_2e)**
'Natural'	Woodland / dense scrub	1,245	7,887	0*	3	7,890
	Marsh / fen	4,698				
	Open water:	1,944				
	Rivers	*1,458*				
	Broads	*486*				
Agriculture			37,879	3,193	16,679	57,751
'Either'	Drainage channels (5%)		7,808	?*	?**	7,808
TOTAL			**53,574**	**3,193**	**16,682**	**73,449**

* Net CO_2 emissions here may actually be slightly negative.

** Methane emissions might also be expected from ditches, which provides an additional reason to assume that the drainage emissions of N_2O are additional to NAEI agriculture estimates.

B3.3.5 Options for Improving Data and Emissions Estimation

As identified in the discussion, whilst the data are likely to be sufficient for the purpose of developing strategic options, there are a number of refinements that could be made to future analyses. These include:

- in this study, the 'bottom-up' N_2O estimates have not included any emissions associated with livestock or livestock waste, which are likely to make up a significant proportion of direct N_2O emissions, and would thus be a key area to focus future efforts for expanding these more bespoke estimates;

- 'bottom-up' N_2O estimates assume that the Broads woodland habitat consists of equal proportions of Alder and Birch trees. An improvement to this calculation would be species level data, because if in reality there is a higher proportion of alder trees than birch trees, then the N_2O flux from woodland could be far greater than the estimate provided here;

- 'bottom-up' N_2O estimates for the marsh/fen habitat utilised an emission factor derived for drained nutrient-rich forested peat soils. GHG estimates could be improved further if data were available that allowed a proportional split to be made between the area of fen peat that is drained/un-drained, and additionally the proportion of each category that is forested/un-forested;

- using the LCM 2000 data, it was unclear exactly how much of the open water category used in the 'Bottom-up' N_2O estimates was attributable to broads and how much was attributable to rivers. However, the Broads Authority provided BAP habitat data that suggested the split to be approximately 50:50, which was used in this study. If available, more precise data originating from the impending LCM 2007 database could be used; and

- more field-level research is required detailing N_2O fluxes from drainage channels in the Broads Executive Area as, if the data derived for the Upper Thurne catchment is to be taken as representative of all the drainage channels in the Broads, they contribute very greatly to emissions. Potential emissions reduction measures, particularly in relation to seeking changes in agricultural practice, may require further evidence gathering and greater detail. Data are, however, sufficient to suggest that this is an area where very significant emissions reduction is likely to be possible.

B4. Other emissions Connected with the Broads and its Management

B4.1 Introduction

B4.1.1 Context of the Emissions within the Analysis

As noted in Section B1.1, the purpose of Level 2 of the audit is to consider scale of emissions for the Broads and Broads Area as a whole so as to better capture those (often much larger magnitude) emissions that BA is not necessarily directly responsible for, but has the power to influence by means of strategic interventions.

As noted elsewhere, the purpose here is to assess emissions and, in the process, help identify possible measures that BA might consider as part of a strategy to produce a reduction in emissions. Given limitations on the scope of BA's influence, as much as possible, the analysis seeks to divide emissions into:

- ***Level 2a:*** emissions connected with the Broads and its services; and

- ***Level 2b:*** emissions occurring within the Broads Executive Area but broadly unconnected with Broads services (such as emissions from industrial units, domestic emissions, etc.).

Here, BA scope to influence is likely to be much greater in the former (Level 2a) than the latter (Level 2b).

In terms those emissions that are connected with the Broads (Level 2a), earlier sections in the part of the report have considered emissions (and stock carbon) associated with (what is likely to be) the most significant categories of emissions in terms of both magnitude and, therein, potential opportunities to produce larger reductions. These categories are:

- tourism and recreation; and
- land and land use.

There are, however, a number of other emissions within the Broads Area that, though often likely to be much smaller, could be considered as being connected with the Broads and its management where these include (but are not necessarily limited to):

- emissions from other conservation organisations with an involvement in the Broads;
- conservation management activities; and
- flood protection and drainage.

B4.1.2 Complexity and Predictive Uncertainty

When seeking to derive an overall estimate of aggregate emissions from these sources across the Broads Area as a whole there are a number of complexities that intervene to make estimation both extremely difficult and also highly uncertain. These complexities principally revolve around the fact that the management activities involve a number of actors (including BA) and, unlike other emissions from a number of actors (such as agriculture) there is no standard data on either scope/scale of activities or standard emission factors for activities to base an analysis on.

In terms of the number and range of actors, in addition to BA, other conservation organisations such as the Norfolk Wildlife Trust (NWT) undertake conservation management activities such as scrub clearance and woodland management over a relatively significant area. Indeed the net can be cast much wider to include farmers undertaking conservation management activities as part of agri-environment schemes, conservation volunteers, contractors, etc.

This, in turn, makes it difficult to pinpoint which methods being used to undertake work of a given type and, also, the amount of work being done within the Broads Executive Area. An additional complexity in this particular assessment is that fuel and transport emissions associated with BA conservation work are already accounted for in the assessment of BA operational emissions that comprises the Level 1 analysis (provided as Part A to this Technical Report). As such, the emissions associated with, say, chainsaws or boats, are embedded within the more general data (and are not amenable to being separated out from data collected to date by BA).

B4.1.3 ‘Normal’ Operations and Timescales

Additional sources of complexity (for some activities) include the extent to which the nature or scale of some activities can be taken as representing ‘normal operations’ within a given year of ‘business’ and, within this, the duration over which these activities may take place. Here, projects such as the Broadland Flood Alleviation Project (BFAP) provide a good example. Calculation of emissions elsewhere focuses on ‘normal’ operations and associated (annual) GHG emissions. The BFAP, however, is a longer duration project that is being carried out over a 20 year period.

Whilst one could, in principle, attempt to calculate an average annual emission associated with the BFAP, because the BFAP replaces the works and maintenance schedule associated with the previous defences, one would also have to subtract the emissions that would otherwise have occurred – which means also calculating emissions associated with the previous flood defence arrangements and maintenance schedule. Needless to say, this makes assessment very complicated and, in the case of BFAP, the assessment is further complicated by the fact that, because BFAP is replacing existing ‘hard’ defences with flood banks and measures made from natural materials, it is accompanied by a switch to the use of materials with much less embedded carbon (c.f. mud banks versus steel piling). Thus, BFAP is also likely to affect the nature and emissions from maintenance schedules far into the future (and because, broadly, it replaces man-made materials with natural ones, in all likelihood with a new reduction in emissions compared to the previous incarnation). Thus, to arrive at a suitable aggregate emission from flood defence works and the BFAP, one would have to consider the impact of changes on maintenance schedules well beyond the 20 years of the BFAP’s lifetime.

B4.1.4 Estimating a Total Value versus Actions to Reduce Emissions

Clearly, all of these complexities act to increase the uncertainties associated with estimation significantly such that, in the context of an analysis that is intended to aid in the production of a strategy for emissions reduction, one must question whether calculating an annual emissions estimate for these emissions is a worthwhile undertaking (particularly given that the wider objective is to identify means of reducing emissions). As such it is useful to reflect upon the additional value that an overall total emissions estimate (particularly one that is likely to be relatively small and uncertain) gives us when seeking to identify strategic options compared to the alternative.

For an emissions reduction strategy, the alternative is to focus more on identifying the means of delivering an emissions reduction. As many of the management activities on the Broads could be considered ‘essential works’ one is more interested in how one can improve the GHG efficiency of the undertakings rather than eliminate the activity altogether. At the same time, this requires that one analyses the activities in some detail in order to identify areas for improvement which, as noted, can be very complex. There are a potentially large number of activities and actors using different methods to do different things over different areas. Accordingly what emissions reduction actions are likely to be most effective in each case depends on the individual circumstances.

As such individual circumstances are likely to be best assessed by those carrying out the activities, rather than seeking to arrive at a highly uncertain aggregate estimate of emissions (of questionable use), the best option for a wider BA strategy to reduce emissions in the Broads Executive Area is probably to focus on more general strategic actions that may encourage (or require) the various actors to put in place processes to appraise their own activities and identify improvements.

Appraisal of such processes, it should be noted, includes the operational activities of BA itself as well as other key actors. Importantly, such appraisal need not necessarily focus on the minutiae of emissions associated with every aspect of the activity but, rather, identifying where obvious efficiency improvements can be made relatively easily and then implementing them. In the case of BA activities in relation to conservation management, for example, appraisal or efficiency actions could be embedded within the 24 existing Environmental Standard Operating Procedures for different activities.

B4.1.5 Issues/emissions Considered

In the light of the issues associated with deriving an estimate of the aggregate emissions, then, this section considers a few of the more significant and widespread activities/emissions and, in the process, illustrates both the importance of engaging different actors in delivering efficiency savings and some opportunities for making changes in to reduce emissions by means that may be less obvious.

In terms of the importance of getting other actors ‘on board’ with the ethos of reducing emissions within the context of the wider Broads area, Section B4.2 provides a very rough estimate of potential scale of emissions from other conservation organisations’ work in the Broads.

Section B4.3 examines emissions from perhaps the largest scale conservation management activity, fen harvesting, illustrating trade-offs between conservation objectives and GHGs and also the importance of considering the fate of harvested material in the emission’s and efficiency savings equation.

Section B4.3 briefly considers drainage and pumping as an emissions source generally and trends in water level management on the Broads that look also seem likely to act reduce emissions over time.

B4.2 Other Conservation Organisations

As is highlighted above, the Broads Authority is not the only organisation/body undertaking work in the Broads and the Broads executive area. Norfolk Wildlife Trust (NWT), for example, owns and maintains some 1,294 ha of reserves within the Broads, representing some 45% of the total reserves area owned and maintained by NWT. Similarly, Suffolk Wildlife Trust (SWT) owns and maintains an, albeit smaller, reserves area in the Broads of at least 74 hectares.

Other organisations involved in the Broads and with work overlapping to a greater or lesser extent with BA include:

- Natural England;
- RSPB;
- National Trust;
- English Heritage; and
- the Environment Agency.

In common with the BA, all of the activities of these organisations will be associated with (some level) of GHG emissions from buildings, vehicle fleets as well as conservation and other management activities, both within and outside the Broads Area.

Clearly, undertaking a detailed analysis of operational emissions from all of the organisations involved (to a greater or lesser extent) in the management Broads (as well as areas outside) cannot be reasonably be performed in this audit. However, as is noted in Section 4.1, getting such organisations 'on board' with both the ethos of this audit and also a wider strategy for the Broads would encourage such organisations to undertake their own audit of operations and thus produce operational changes that would deliver GHG reductions. Given that the geographical scope of these other organisations is far greater than the Broads alone, this would have benefits far beyond those of emissions associated with the Broads Area alone.

Whilst a detailed analysis is not possible/reasonable, a flavour of the scale of emissions are can be imputed from BA's operational emissions. Here, for example, applying the emissions from BA operations per unit of BA Full Time Equivalent (FTE) staff to the number of FTEs in NWT and SWT suggests total emissions from these organisations of:

- 677 tCO_2e for Norfolk Wildlife Trust (53 FTEs); and
- 1,002 tCO_2e for Suffolk Wildlife Trust (79 FTEs).

Clearly, the nature and emphasis of the operations of these organisations is likely to be different from BA's and so the actual figure will be different. In terms of making a division in these emissions between those that are associated with the Broads and those which are not, a very rough cut according to the proportion of reserve are within:outside the Broads area gives some idea of emissions connected with the Broads where this would suggest emissions of 307 and 52 tCO_2e for NWT and SWT activities in the Broads, making a total of 359 tCO_2e for these organisations combined.

If, further, one assumes that the other organisations' emissions associated with the Broads together add up to the same at NWT and SWT combined, then the rough order of magnitude of emissions for the Broads Area would be around 700 tCO_2e. As noted, however, this is a very uncertain estimate and, should efforts be made to encourage these organisations to follow BA's suit, emissions reductions over a much wider area would be achievable.

B4.3 Conservation Management Emissions Incorporating Biomass – the Illustrative Case of Fen management

B4.3.1 Overview

As noted in Section B4.1, conservation management works (which could be regarded as 'essential works') are carried out by a number of different actors in the Broads where this includes BA but also includes other conservation organisations, conservation volunteers, farmers, contractors and others. As such, developing an aggregate estimate of emissions in the Broads Area as a whole is plagued by problems of not knowing what activities take place, covering what areas, using what methods and how frequently.

As also noted in Section B4.1, in terms of BA's own emissions from conservation management activities, these are already embedded in the estimates of fuel use, etc. that comprise a component of BA's operation emissions.

Given these issues, Section B4.1 has identified that the most appropriate strategic action here is to encourage those undertaking such activities to review and appraise the methods used and consider opportunities for improvements in the emissions profile of carrying out works. Such appraisal does not need to focus on deriving an estimate of the emissions associated with a given activity but, rather, focus on areas of likely improvement. In this respect, given that a large number of conservation related activities involve the 'harvesting' of biomass, it is important to consider the extent to which the fate of that harvested biomass can contribute to emissions and, therein, the extent to which emissions reductions can be achieved by altering the methods used.

Fen management provides a good illustrative example of these issues.

B4.3.2 Fen Management

Direct emissions

As part of its land management activities, BA is responsible for a variety of semi-natural habitats surrounding the waterways, which include fens, carr woodland and grazing marsh. The BA uses several different land management techniques to restore and conserve the fens, which includes scrub clearance, fen harvesting and reed and sedge cutting. BA undertook its own carbon audit[29] of land management techniques in 2006, which evaluated emissions generated from the direct usage of fossil fuels for the different land management activities (mainly from the machinery used for digging, cutting, chopping and shredding, and for transportation of the machinery and cut material) and indirect energy used in inputs (such as energy used in the construction of machinery).

Based on this 2006 work, the direct GHG emissions associated with the management of the Broad fens are given in Table B4.1 for four main categories of

---

[29] Olloqui (2006)

activity: conservation cutting with volunteers; cutting via the Fen Harvester machine; commercial reed and sedge cutting; and rotating scrub clearance.

Table B4.1: GHG Emissions associated with fen conservation

	Area (ha)	CO_2 Emissions (kg CO_2e)	CO_2 Emissions (t CO_2e)	CO_2 Emissions per ha (t CO_2e/ha)
Conservation cutting	6	3,034	3.03	0.51
Fen harvester	12	13,157	13.16	1.10
Commercial reed and sedge cutting	79	3,172	3.17	0.04
Rotating scrub clearance	14	51,861	51.86	3.70
Total	**111**	**71,224**	**71.22**	

As can be seen from the table, considering only the more direct emissions associated with fen management suggests a total emission of 71 t CO_2e for annual clearance of 111ha.

As is also clear from the table, the scale of emissions per ha of clearance varies significantly from one method to another where this implies, for example, that commercial reed and sedge cutting may result in significantly lower emissions per ha than the fen harvester. At the same time, however, it is known that the fen harvester has a much lower 'ecological' footprint as far as disturbance to fenland habitats is concerned and, therefore, there is a trade-off between increased emissions of GHGs and other conservation objectives.

In terms of GHG emissions, then, an analysis of the direct carbon emissions of, say, fen harvesting and scrub clearance would suggest relatively small GHG emissions and relatively little scope for making significant cuts in emissions given other conservation priorities. However, the analysis above does not take into account the fate of harvested biomass which, as detailed below, has a much greater bearing on overall emissions than the direct emissions associated with undertaking the harvesting itself.

Fate of Harvested Biomass

Here, based on the 111 ha of fen managed on an annual basis, and applying data sourced from the literature[30] on the approximate mass of vegetation harvested per ha (1.56 t ha^{-1}) suggests a total annual yield of 173t of harvested biomass from the operations in Table B4.1. Applying this mass of biomass to emissions data sourced from Lineback *et al* (1998) (see Table B4.2), suggests that, depending on the end-use of the material, the GHG emissions generated from harvested biomass might range between 138 and 1,090 t CO_2e.

---

[30] Broads Authority, 2004b; Sanderson and Prendergast, 2002

Table B4.2: GHG Emissions associated with each tonne of biomass[31]

	CO_2 ($t\ CO_2e$)/t biomass	CH_4 ($t\ CO_2e$) /t biomass	N_2O ($t\ CO_2e$) /t biomass	Total ($t\ CO_2e$) /t biomass	Total emission for 111ha of biomass clearance ($t\ CO_2e$)
Natural decay[32]	1.49	0.14	0.01	1.64	284
Burning [33]	1.49	0.14	0.01	1.64	284
Landfill[34]		6.3		6.3	1,090
Landfill[35]	0.8			0.8	138

Comparing this with the estimated direct GHG emissions associated with undertaking the harvesting alone (71 tCO_2e) reveals that the biomass emissions are potentially of the order of 2 to 15 times those of the direct emissions in this example.

This, of course, serves to illustrate that the fate of the harvested biomass has by far the dominant influence on resulting overall emission and, as such, considering options for how to best dispose of/use the harvested biomass provides the greatest scope for emissions reductions.

In terms of a likely total annual emissions under current management, a broad estimate of biomass emissions would suggest that, assuming all is burned if these emissions are split evenly between burning and decay, total annual emissions from biomass would equal 284 tCO_2e which, when added to the direct emissions of 71 tCO_2e, suggests an emission of 355 tCO_2e for fen management.

Scope for emissions reductions

Given that other conservation management activities also often involve the harvesting of biomass (such as woodland management and weed cutting), the same is likely to apply for other conservation management activities whether undertaken by BA or by other conservation organisations, etc. As such, when appraising methods and emissions from carrying out activities so as to identify the means of delivering emissions reductions, the first place to start may, in fact, often be to consider the fate of harvested biomass rather than small changes in the way in which the management activities are carried out mechanically. Here, when considering the optimal fate for biomass from an emissions perspective, one should be focussed on ‘locking’ the carbon in the biomass away for the longest time possible while seeking to limit the production of decomposition by products such as methane and nitrous oxide.

The separate Strategy Report that this Technical Report supports considers the role of biomass further in relation to delivering net reductions in GHG emissions. It also examines the potential for conservation management to both increase the sequestration of carbon from the atmosphere and also conserve stock carbon.

---

[31] Emissions data sourced from Lineback et al (1999) and Feinstein et al (1998)

[32] Including pilings of material, composting and use in thatch roofing

[33] Including open fires and use as fuel for bioenergy (open burning is less efficient than combustion, so less GHG emissions may be expected in the short-term, but over time the unburned residue will degrade).

[34] Landfill with no flaring of CH_4

[35] Landfill where there is combustion of CH_4 either by flaring it off or capturing it as an energy source

B4.4 Flooding and Water Level Management

In relation to flooding and flood risk management, Section B4.1 has discussed the Broadland Flood Alleviation Project (BFAP) and concluded that, for the purposes of this audit and the wider goal of a strategy geared towards emissions reductions, deriving an emissions estimate for BFAP is inappropriate on a number of levels. Here, for example, estimation of annual emissions is complicated by the need to compare the 20 year project (and the post-project maintenance schedules) with actions that would otherwise have taken place. Even were this to be carried out, to be consistent with other emissions in this audit, one would need to express the emissions on an annual basis. This, in turn, requires one to average out the emissions over a timescale dictated not only by the lifetime of the project, but, because the changes wrought by the project, far beyond that.

In addition to the methodological problems, the shift away from hard, man-made structures (with significant embedded carbon) towards the use of natural materials, although requiring considerable front end work to undertake, probably represents a beneficial shift from an emissions perspective in the longer term. Given such issues, a detailed audit of the BFAP is of questionable use to this analysis, the emphasis of which is on providing information to aid the development of a wider strategy in the Broads and for BA.

That said, there are always likely to be opportunities to reduce emissions in the BFAP but any analysis to aid this needs to be able to focus on key points and processes across the lifetime of the project itself rather than the need to derive an overall estimate of annual emissions and account for the work that it substitutes. This is work that better suited to a separate study.

The BFAP is not, however, the only aspect of flood alleviation that may have emissions associated with it. More general water level management and, in particular, drainage pumps is an emissions source which we considered could be potentially high and where emissions reductions might be possible and would therefore be worthy of consideration within the analysis.

Water Level Management

The Broads Area is at considerable theoretical risk of river flooding and inundation from the sea. The actual risk is substantially reduced by the work of the Internal Drainage Boards (IDBs) that, working in partnership with Local Authorities, the Environment Agency and Natural England, monitor and manage water levels, in simple terms, by means of level gauges and pumps.

Initially it was thought that, owing to their isolation, pumps might be diesel driven at present and, hence, there was the potential to deliver large reductions by means of changing fuels used or by means of wind pumps. Discussions with the Broads IDB suggest that this is not quite the case and, indeed, the need to keep pump operating costs to a minimum combined with a trend towards management at smaller catchment levels may already be serving to limit emissions and providing opportunities for emissions reductions.

Broads IDB operates 34 pumping stations all of which are electric. Owing to the need to keep costs to a minimum, during ‘normal’ conditions (between low and high settings) these pumps are programmed to run at night (i.e. on lower tariffs). As such, pumps automatically wait until the lower tariff before switching on except in extreme cases where levels are going too high.

In terms of electricity consumption, each pumping station has its own contract and bill and, hence, its own tariff and, as such, it is difficult to determine actual consumption over recent sample years. However, the IDB has nearly completed the installation of smart meters to send back meter readings automatically so in future this should be relatively easy. At present there isn't a complete year of data but, even if there were, given the annual variation in rainfall (and hence pumping), ideally a few years of data would be required to calculate an average.

The average budget for electricity is £110,000 per year but this is difficult to convert to anything like a reliable estimate of energy consumed and carbon emissions owing to differences in tariffs and energy prices. In addition, as the vast majority of the electricity purchased is on lower tariffs dictated by smart meters, in theory there is a carbon saving from the use of electricity during periods of low demand. However, the collective effect of grid smoothing and redistributing energy consumption to periods of low demand on carbon emissions is not something that considered within, for example, Defra emissions factors (which report average grid electricity alone). Thus, despite the fact that pumps probably operate at the most optimum time from an energy/carbon efficiency perspective, this is difficult to capture in an estimate of carbon emissions.

As such, only a very broad order of magnitude estimate is possible at present. Here, if one assumes 10 pence per kwh, then £110,000 of consumption equals approximately 1.1 million kwh. Applying the Defra grid averaged emission factor of 0.54418 kg CO_2e per kWh suggests an emission of the order of around 600t CO_2e for the 34 pumps in the Broads IDB. With an additional 12 pumps in the adjoining IDB, an overall emission for the Broads Area is (very roughly) of the order of 800 t CO_2e.

In terms of opportunities to reduce emissions, as already noted, the use of smart metering is likely to have some benefits and these will not be captured in the very approximate emissions estimate above. However, clearly emissions from electricity consumption are quite significant and could, in principle, be reduced by a shift to the use of renewables via the grid or by solar/wind generation in situ. In considering in situ methods, however, one would have to take into account the need for security of electricity supply.

An alternative is the use of direct pumping by wind. Whilst wind pumps will never offer a 'drop in' substitute for the high pump volume electric pumps, according to the Broads IDB, wind is an option and is very effective and efficient for 'trickle' pumping when combined with backup from electric pumps with greater volumes. Indeed, Broads IDB recently installed a wind pump (servicing Calthorpe Broad) which pumps up to a reservoir and a second stage pump (also wind) draws from the reservoir and is run by Natural England.

Broads IDB predicts a trend towards management within smaller catchments over time as there is a need to provide varying water levels at smaller spatial scales. Wind trickle pumps provide a good means of achieving this and so could be considered alongside upcoming decision making concerning the replacement of pumps installed in 1970's (pump lifetime is typically 50 years).

B5. Overview and context of 'Broads related' emissions

B5.1 Summary of Estimated Emissions 'Connected with' the Broads

Table B5.1 summarises the emissions and emissions categories 'connected with' the Broads as calculated above and incorporating the emissions for BA operations (Level 1) calculated in Part A of this Technical Report. Also provided is the carbon stored in the biotic and abiotic environments (vegetation and soils respectively)

The total estimated emission for activities and actions connected with the Broads and considered in this audit (including BA operations) is of the order of 102,000 tCO_2e. In terms of stored carbon, total carbon stores in the BA executive area are estimated to be in the range of 40 million tCO_2e. As such, annual emissions connected with the Broads are equivalent to the loss of around 0.25% of stock carbon annually.

As noted above, the audit cannot hope to include each and every emission connected with the Broads owing to the range of actors involved. However, the estimate is likely to cover the vast majority of the emissions and provides a good starting point for considering actions to reduce emissions and the focus/priorities that such a strategy might adopt.

Table B5.1: Emissions 'connected' with the Broads (incorporating BA Operational Emissions)

	N_2O (tCO_2e)	CH_4 (tCO_2e)	CO_2 (tCO_2e)	CO_2e (tCO_2e)	% of Total Emission
Emissions					
Tourism and Recreation				54,104	41%
Land and Land Use	53,574	16,682	3,193	73,449	56%
Other management	2	24	3,704	3,730	3%
TOTAL	**53,576**	**16,728**	**6,897**	**131,283**	
Stored carbon					
Soils			38,803,019	38,803,019	
Vegetation			1,053,695	1,053,695	
TOTAL			**39,856,714**	**39,856,714**	

For the purposes of developing such a strategy, emissions summarised at category level do not provide sufficient detail. As such, Tables B5.2 and B5.3 provide look-up tables of all emissions and stock carbon by source. These data are analysed further in the separate Strategy Report that this Technical Report supports, where this seeks to consider the strategic implications of the emissions and stock carbon from the perspective of emissions reduction, enhancement of sequestration and conservation of stock carbon resources.

Table B5.2: All emissions 'connected with' the Broads by Category and Source

Emissions Category	Emissions Source	N_2O (tCO_2e)	CH_4 (tCO_2e)	CO_2 (tCO_2e)	CO_2e (tCO_2e)	% of Category Total	% of Total Emission
Tourism and Recreation							
Private boat owners	Use of boats			2,204	2,204	4.1%	1.7%
	Transport to/from boats			1,208	1,208	2.2%	0.9%
Hire boats	Hire boat emissions			3,259	3,259	6.0%	2.5%
	Boatyards			1,498	1,498	2.8%	1.1%
	Visitors' transport to/from boats			1,348	1,348	2.5%	1.0%
Other tourism and recreation	Accommodation			10,950	10,950	20.2%	8.3%
	Food and drink			14,417	14,417	26.6%	11.0%
	Recreation (spending on)			2,927	2,927	5.4%	2.2%
	Travel to/from Broads			15,878	15,878	29.3%	12.1%
All visitors	Travel around the Broads			415	415	0.8%	0.3%
Land and Land Use							
'Natural'	Woodland / dense scrub	1,245	13		1,258	1.7%	1.0%
	Marsh / fen	4,698	7		4,705	6.4%	3.6%
	Rivers	1,458	2		1,460	2.0%	1.1%
	Broads	486	2		488	0.7%	0.4%
Agriculture		37,879	16,679	3,193	57,751	78.6%	44.0%
Agri/semi-natural	Drainage channels	7,808	0	0	7,808	10.6%	5.9%
Other management and activities							
Other conservation organisations				700	700	18.8%	0.5%
Fen example (Biomass 50:50 burning:decay)		2	24	258	284	7.6%	0.2%
Fen example (Direct emissions)				71	71	1.9%	0.1%
Water level management				800	800	21.4%	0.6%
BA Operations (Level 1)				1,875	1,875	50.3%	1.4%
Total		**53,576**	**16,727**	**61,001**	**131,304**		
% Distribution of GHGs		**41%**	**13%**	**46%**			
Non CO_2 contribution to total =		**54%**					

Table B5.3: Stored carbon		
		Stored CO_2e (tCO_2e)
Abiotic environment (Soils)	Earthy peat	25,356,468
	Calcareous pelosols	141,113
	Brown earth	616,436
	Brown sand	59,721
	Agrillic brown earths	153,780
	Stagnogley soils	19,304
	Alluvial gley soils	11,619,295
	Humic-sandy gley soils	197,450
	Humic gley soils	639,453
	Urban	0
	Open water	0
Biotic environment (Habitats)	Grassland/Pasture	56,660
	Arable/Cultivated Land	43,416
	Woodland/Dense Scrub	936,234
	Marsh/Fen	17,384
	Open Water	0
	Urban	0

B5.2 Comparison with other Emissions within Broads Executive Area

As noted above, total emissions ‘connected with’ the Broads and the Broads Area are estimated to be of the order 131,000 tCO_2e.

For the purposes of comparison, as discussed in Section B1, emissions occurring within the Broads Executive Area but ‘unconnected’ with the Broads and its services have also been considered. This constitutes Level 2b of the audit and the estimated emissions are provided in Table B5.4.

The estimates have been derived by using GIS interpretation of NAEI datasets (as discussed in Section B2 above). Point source emissions for large industrial units are compiled from a variety of official UK sources, which include the Environment Agency, the Scottish Environmental Protection Agency, and Local Authorities (LA)[36].

It should be noted that for the analysis to arrive at a value for the Level 2b emissions one must deduct emissions sources already estimated in Level 2a above (and, in principle, Level 1 for BA operations as well). For a number of the emission source categories in the data this is a relatively easy task (for example large industrial point sources, domestic sources, etc.). However, for emission sources reported in the data under the general category of ‘industry and commerce’ and also ‘transport’ a split must be made between emissions connected with and not connected with the Broads.

Here, in principle, one would simply deduct the appropriate emissions calculated in Levels 1 and 2a but, as these are calculated in a number of ways using both ‘bottom up’ and ‘top down’ approaches, their calculation is different from that used in the NAEI data and it is not possible to accurately extract these from the NAEI data. In addition, in relation to the transport emissions, those recorded in the NAEI database

---

[36] See Bush *et al* (2008) for the full NAEI methodology.

relate to transport within the Broads Executive Area alone and thus do not include the wider transport emissions from visitors travelling to the Broads that have been included in the analysis of emissions connected with the Broads.

These caveats explained, the data still provide some point of reference for comparison where the data suggest that emissions occurring within the Broads Area but NOT connected with the Broads and Broads services are of the order of 359,000 tCO_2e. As noted above, emissions that ARE connected with the Broads and its services are estimated as being of the order of 131,000 tCO_2e – in other words significantly smaller than the other emission sources within the Executive Area.

Table B5.4: Emissions from the Broads Executive Area that are NOT connected with the Broads

	CO_2 (tCO_2e)	CH_4 (tCO_2e)	N_2O (tCO_2e)	Emissions (tCO_2e)
Emissions from industry & commerce*	34,703	38,181	1,665	74,548
Emissions from domestic sources	54,515	0	0	54,515
Emissions from transport	74,284	84	1,352	75,720
Point source emissions	154,131	1	59	154,191
TOTAL EMISSIONS	**317,633**	**38,265**	**3,075**	**358,974**

References from Land and Land Use Section of Part B

AEA (2009). Local and Regional CO_2 Emissions Estimates for 2005 – 2007 for the UK. Report to Department of Energy and Climate Change, September 2009. Available from: http://www.decc.gov.uk/en/content/cms/statistics/climate_change/climate_change.aspx

BFAP, (2009). Broadland Flood Alleviation Project – Review of Progress, April 2009. Available from: http://www.bfap.org/uploads/docs/FAP_review2009_website.pdf

Bradley, R.I., Milne, R., Bell, J., Lilly, A., Jordan, C., Higgins, A., (2005). A soil carbon and land use database for the United Kingdom. *Soil Use and Management* **21:** 363 – 369.

Broads Authority, (2002). *Biofuel Energy Plant* – Executive Report. Prepared for the Broads Authority on behalf of Hunston Engineering Ltd.

Broads Authority, (2004a). *Broads Plan 2004: A Strategic Plan to Manage the Norfolk and Suffolk Broads*.

Broads Authority (2004b). *Supplement to the Fen Management Strategy*. Available from: http://www.broads-authority.gov.uk/managing/land/fen/strategy.html

Broads Authority, (2008). Annual Monitoring Report 2007-2008. Local development framework. Autumn 2008.

Bush, T., Tsagatakis, I., King, K., Passant, N., (2008). *NAEI UK Emission Mapping Methodology 2006.* AEA Technology report. Available from: http://www.naei.org.uk/report_link.php?report_id=536

Cruickshank, R.W., Tomlinson, R.W., Devine, P.M., and Milne, R., (1998). Carbon in the vegetation and soils of Northern Ireland. *Biology and Environment; Proceedings of the Royal Irish Academy* **98B**: No 1, 9-21

Collison, M., Collison, L., Sakrabani, R., Tofield, B., & Wallage, Z.E.,(2009). Biochar & Carbon Sequestration: A Regional Perspective. East of England Development Agency Report. Reference 7049. Available from: http://www.uea.ac.uk/lcic/Biochar

Couwenberg, J., (2009). *Methane Emissions from Peat Soils (organic soils, histosols): Facts, MRV-ability, Emission Factors*. Wetlands International Report. Available from: http://www.imcg.net/docum/09/couwenberg_2009b.pdf

Davidson, E.A., Lefebvre, P.A.,(1993). Estimating Regional Carbon Stocks and Spatially Co-varying Edaphic Factors using Soil Maps at Three Scales. *Biogeochemistry* 22, 107–131.

Dawson, Q.L., (2006). Low-lying Agricultural Peatland Sustainability under Managed Water Regimes. PhD thesis. National Soil Resources Institute, Cranfield University.

Dawson, J.J.C., and Smith, P., (2007). Carbon Losses from Soil and its Consequences for Land-use Management. *Science of the Total Environment* **382:** 165 – 190.

Eggelsman, R. (1976). Peat Consumption under Influence of Climate, Soil Condition and
Utilization. *Proceedings of the Fifth International Peat Congress,* I, pp. 233-247. Poznan.
Poland.

Feinstein, C., Odil, T.P., Mendis, M., Gowen, M., Hargrave, T., Openshaw, K., Dang, M., Brackett, N., and Braatz, B., Leining, C., Ebert, C., (1998). Greenhouse Gas Assessment Handbook: A Practical Document for the Assessment of Project-level Greenhouse Gas Emissions. Report prepared for the Environment Department of the World Bank. Paper No: 064. Available from: http://www-wds.worldbank.org/servlet/main?menuPK=64187510&pagePK=64193027&piPK=64187937&theSitePK=523679&entityID=000094946_02081604154234

Heathwaite A. L. (1993) Disappearing Peat-Regenerating Peat? The Impact of Climate
Change on British Peatlands *The Geographical Journal*, Vol. 159, No. 2. pp. 203-208.

Horne, F., (2009). *Nitrogen Dynamics within the Upper Thurne Catchment.* PhD Thesis, University of East Anglia

Gauci, V., Matthews, E., Dise, N., Walter, B., Koch, D., Granberg, G., and Vile, M., (2004). Sulphate Suppression of the Wetland Methane Source in the 20th and 21st Centuries. *Proceedings of the National Academy of Sciences USA*, 101, 12583-12587

Gauci, V (2008). Carbon Balance and Offset Potential of the Great Fen Project. Report funded by the East of England Development Agency for the Great Fen Project. July 2008.

Grønlund, A., Hauge, A., Hovde, A., Rasse, D.P., (2008) Carbon Loss Estimates from Cultivated Peat Soils in Norway: A Comparison of Three Methods. *Nutrient Cycling in Agroecosystems* **81**: *157 -167*

Intergovernmental Panel on Climate Change (IPCC) 2000. Special report on Land use, Land-use Change and Forestry. Prepared by Watson, R.T., Noble, I.R., Bolin,B., Ravindranath, N.H. Verardo, D.J., Dokken, D.J (eds). Cambridge University Press

Intergovernmental Panel on Climate Change (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.

Intergovernmental Panel on Climate Change (IPCC) (2006). The 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).Published: IGES, Japan

Jackson, J., Li, Y., Murrells, T., Passant, N., Sneddon, S., Thomas, J., Thistlethwaite, G., Dyson, K., Cardenas, L., (2009) Greenhouse gas inventories for England, Scotland, Wales and Northern Ireland: 1990 – 2007. AEA Report for DECC. Accessed October 2009 and available from:

http://www.airquality.co.uk/reports/cat07/0909231418_DA_GHGI_report_2007_maintext_Issue_1.pdf

Johnes, P., (1996). *Nutrient Export Modelling - River Bure, Norfolk*. Environment Agency Report, Anglian Region, O1581.

Kasimir Klemedtsson, A., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J., Oenema,
O., (1997). Greenhouse gas emissions from farmed organic soils: a review. Soil Use Manage.
13, 1–6.

Kelly, A (2008a) Broads Lake Restoration Strategy – Appendix 5: History of lake restoration measures, Broads Authority Report.

Kelly, A (2008b) Broads Lake Restoration Strategy – Appendix 3: Review of sediment removal, Broads Authority Report.

Kimble, J.M., Rice., Reed, D., Mooney, S., Follett, R.F., Lal, R. (2007). Soil carbon management: Economic, environmental and societal benefits. CRC Press.

Krishnan, P., Bourgeon, G., Lo Seen, D., Nair, K.M., Prasanna, R., Srinivas, S., Muthusankar, G., Dufy, L., Ramesh, B.R., (2007). Organic carbon stock map for soils of Southern India: a multifactorial approach. Current Science 93 (5), 706–710.

Kroeze, C., Mosier, A., and Bouwman, L., (1999): Closing the Global N_2O Budget: A Retrospective Analysis 1500 - 1994. *Global Biogeochemical Cycles*: **13**, 1 - 8.

Lal R. (2004) Climate Change and Food Security Soil Carbon Sequestration Impacts on
Global *Science* 304, 1623

Lineback, N., Dellinger, T., Shienvold, L.F., Witcher, B., Reynolds, A., Brown, L.E., (1999). Industrial greenhouse gas emissions: Does CO_2 from combustion of biomass residue for energy really matter? *Climate Research* **13**: 221-229

Luisetti, T., (2008) Broads Lake Restoration Strategy – Appendix 6: An ecosystem services approach for the Broads, Broads Authority Report.

Maltby, E and Immirzi, C.P. (1993) Carbon dynamics in peatlands and other wetland soils -
regional and global perspectives. *Chemosphere*, 27 (6), pp 999 - 1023

Milne, R., and Brown, T.A., (1997). Carbon in the Vegetation and Soils of Great Britain. *Journal of Environmental Management* **49**: 413-433

Milne, R., and Mobbs, D.C., (2004). UK Emissions by Sources and Removals by Sinks due to Land Use, Land Use Change and Forestry Activities. Defra Report. Defra Contract CEPG 1/GA01054. Accessed September 2009 and available from:
http://www.edinburgh.ceh.ac.uk/ukcarbon/docs/DEFRA_Report_2004_Section0.pdf

Mobbs, D.C., and Dyson, K., (2009). Mapping carbon emissions and removals for the land use, land use change and forestry sector. Final report to AEA Technologies – May 2009. Accessed September 2009 and available from:

http://www.decc.gov.uk/en/content/cms/statistics/climate_change/climate_change.aspx

Morris, J., Hess, T.M., Gowing, D.J., Leeds-Harrison, P.B., Bannister, N., Wade, M. and Vivash, R.M. (2004). Integrated Washland Management for Flood Defence and Biodiversity. *Report to Department for Environment, Food and Rural Affairs and English Nature, March 2004*. Cranfield University at Silsoe, Bedfordshire, UK..

Olloqui, E., (2006). *Greenhouse Gas Emissions Measurement and Reporting for different Land Management Techniques used by the Broads Authority.* MSc Thesis: Environmental Impact Assessment, Auditing and Management Systems. University of East Anglia.

Parish, F., Silvius, M., Reed, M.S., Stringer, L.C., Joosten, H., Suryadiputra, N., and Lin, C.K., (2007)Management of peatlands for biodiversity and climate change. In: Parish, F., Sirin, A., Charman, D., Joosten, H., Minaeva, T., and Silvius, M., (eds.) *Assessment on peatlands, biodiversity and climate change*. Global Environment Centre, Kuala Lumpur and Wetlands International, Wageningen.

Sanderson, H., and Prendergast, H.D.V., (2002). *Commercial Uses of Wild and Traditionally Managed Plants in England and Scotland.* http://www.kew.org/science/ecbot/commusesreport.pdf

Schwartz, D., Namri, M., (2002). Mapping the total organic carbon in the soils of the Congo. Global and Planetary Change 33, 77–93.

Shepherd, D., Burgess, D., Jickells, T., Andrews, J., Cave, R., Turner, R. K., Aldridge, J., Parker, E. R., and Young, E. (2007). "Modelling the effects and economics of managed realignment on the cycling and storage of nutrients, carbon and sediments in the Blackwater estuary UK." *Estuarine, Coastal and Shelf Science*, 73, 355-367.

Skiba, U.M., McTaggart, I.P., Smith, K.A., Hargreaves, K.J and Fowler, D. (1996). Estimates of Nitrous Oxide Emissions from Soil in the UK. *Energy Conversion Management*, **37(6-8):** 1303-1308.

Smith, P., (2004). Soils as carbon sinks: the global context. Soil Use and Management 20, 212–218.

Wakelin, T. & Kelly, A. (2007) Sediment Management Strategy for the Broads. Broads Authority Report.

Watterson, J., and Thistlethwaite, G., (2009). Summary of differences between geographical coverages of reported GHG emissions. AEA Report for DECC. Accessed October 2009 and available from:http://www.airquality.co.uk/reports/cat07/0905261531_ED45322_GeographicalCoverage_GHG_Inventories_Final.pdf

Whiting, G.J., and Chanton, J.P., (2001), Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration *Tellus* 53B, 521–528

Zhi-Yao, S., Yong-Mei, X., Jian-Yun, Z., Yong-Chang, Y., Mai, Y., (2006). Soil organic carbon content and distribution in a small landscape of Dongguan, South China. Pedosphere 16 (1), 10–17.