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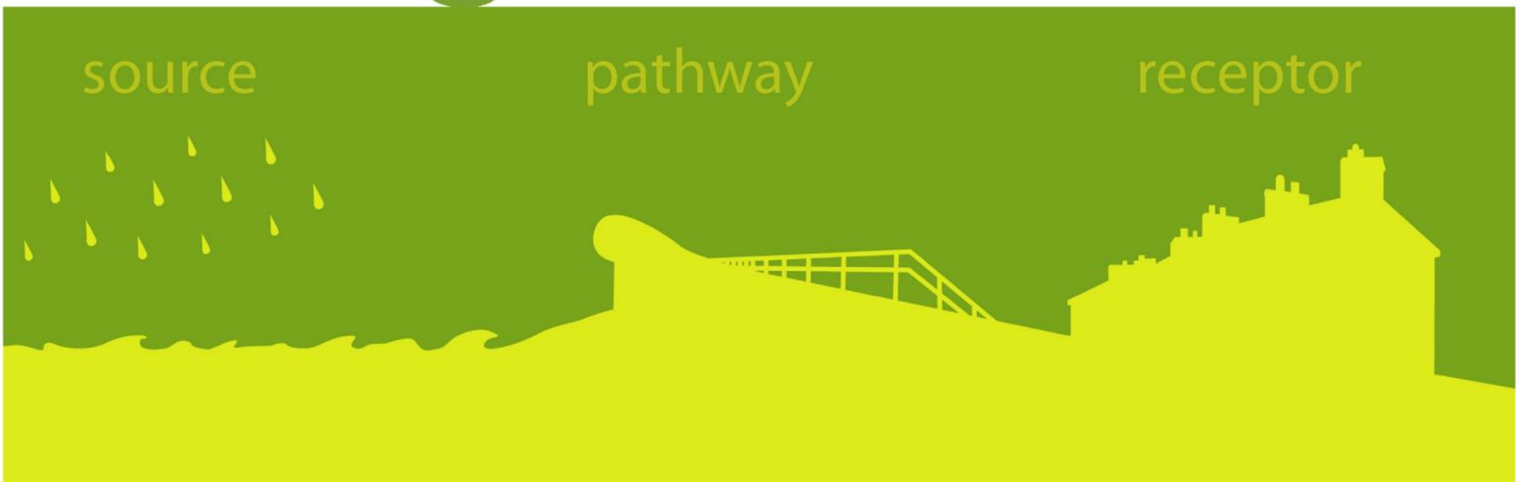

Impact of climate change on asset deterioration

Appendix D – Impact analysis

Report - SC120005/R5

Flood and Coastal Erosion Risk Management Research and Development Programme

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Contents

1 Approach and assessment

1.1 Introduction

The objectives of this project include being able to provide some identification and ranking of those flood and coastal erosion risk management (FCERM) assets that may require most attention going forward and to give some direction to be able to establish, at a high level, a measure of the total potential impact at a national level.

To address that question will require an appreciation of the total number of those assets that these impacts will affect, and the consequences of that, that is:

Total impact = (Asset impact) × (Number of those assets) × (Potential consequences)

The work described in Appendices B and C specifically addresses the first parameter, 'asset impact'. This identifies how deterioration may alter for different asset types as a result of climate change, and how to consider what the impact of that might be for those asset types.

Integration of this information with other data (e.g. asset quantity) is required to address the second component. That is information that should be available, or at least obtainable, without much difficulty, and is discussed later in this appendix.

The third parameter, potential consequences, could take different forms. It could for example relate to how the deterioration of the assets could lead to increased risk of flooding or erosion of land and property if it is not addressed. Alternatively, or additionally, the potential consequences could be the costs of addressing the increased deterioration (i.e. increased maintenance commitment or replacement). The matter of potential consequences is also assessed further in this appendix, as it is crucial to defining the most appropriate approach to take forward.

This appendix contains details of the work carried out to support these objectives, building upon the information produced and presented in Appendices B and C. It includes:

- Asset vulnerability preliminary ranking. A relative ranking based purely on qualitative assessment (High/Moderate/Low) supplemented with a very broad estimation of asset numbers.
- Appraisal of approaches to develop that further to obtain a refined impacts analysis.
- Application of a high-level method to establish the potential change in investment needed to address impacts, based upon how much maintenance costs might alter as a consequence.

1.2 Preliminary ranking

1.2.1 Approach

An initial preliminary level ranking of where attention might need to be focussed could be made just upon the relative vulnerability of asset type and total quantity of each type, without recourse to more detailed analysis.

The qualitative assessments presented in Appendix B provide an asset-by-asset type appraisal of the deterioration processes and how climate change may affect those. From that, and in that context, the assets most likely to be vulnerable to climate change and the main factors driving that have been established, with the categorisation of vulnerability defined as ‘High’, ‘Moderate’, ‘Low’ or ‘Negligible’.

Without interrogation of databases, it is also possible to quickly establish an order of magnitude quantity of each asset type, for example whether there are ‘tens’, ‘hundreds’ or ‘thousands’ of each type.

The product of these two pieces of information then enables a broad relative ranking to be established, as outlined below.

1.2.2 Outputs

Based upon the qualitative assessments and available information on asset numbers, the preliminary ranking of relative impacts was made and is presented in Table D1.1. For conciseness, only the top-ranking assets are listed in the table.

At the top end of the scale are any assets where the impacts of climate change upon their deterioration have been identified through qualitative assessment to be ‘High’. These are ranked 1 and 2, with the distinction being whether there are ‘thousands’ or ‘hundreds’ of those.

Below these, where the impact has been initially assessed to be ‘Moderate’, assets are again sorted and ranked 3, 4 or 5, depending on the broad number of each asset type.

This ranking can also be used to identify if there will be merit in developing and applying more advanced methods to quantify the impacts of climate change for those asset types. So, for example, in addition to all those identified as having ‘High’ vulnerability, those asset types with ‘Moderate’ vulnerability of which there are thousands would also likely be assessed further, as those impacts could contribute significantly to the overall vulnerability at a national level. Therefore, all of those ranked 3 here would be included.

Of the remainder (i.e. those ranked 4 and 5), particularly where numbers of assets run from tens to low hundreds, then what is practical and achievable in terms of the more detailed assessments that can be performed must also be a consideration. If the methods to quantify them are complex and cost-consuming to implement, then their inclusion may not be warranted.

It is unlikely to be valuable to focus further attention upon any of the assets where the qualitative assessment has established the impacts upon their deterioration to be ‘Low’ or ‘Negligible’, irrespective of how many of those exist. There are only four asset types at those levels which number more than 1,000, included in the table and ranked 6. All remaining asset types are fewer in number (and are not included in the table).

For this preliminary ranking, no measure of consequence is available, nor can the impacts be quantified. But it can be updated as knowledge improves and more refined assessments are carried out, to prioritise those assets that may require most attention going forward.

Table D1.1 Preliminary ranking of impacts of climate change on asset deterioration: highest ranking assets

Rank	Asset type	Setting	Impact upon deterioration	Quantity of assets
1	Embankments (protected/unprotected)	Estuary + Coastal	HIGH	1,000s
1	Embankments (turfed only)	Fluvial	HIGH	1,000s
1	Seawalls	Coastal	HIGH	1,000s
2	Beach and Barrier Beaches	Coastal	HIGH	100s
2	Saltmarshes	Estuary	HIGH	100s
3	High Ground (lined)	Fluvial	MODERATE	1,000s
3	Walls	Fluvial + Estuary	MODERATE	1,000s
3	Weirs	Fluvial + Estuary	MODERATE	1,000s
3	Groynes (Timber)	Coastal	MODERATE	1,000s
4	Embankments (protected)	Fluvial	MODERATE	100s
4	Cliffs	Coastal	MODERATE	100s
4	Outfalls	Coastal	MODERATE	100s
4	Steps	Coastal	MODERATE	100s
4	Pump Houses	Fluvial + Estuary	MODERATE	100s
4	Control Gates	Estuary	MODERATE	100s
4	Flood Gates	Coastal	MODERATE	100s
5	Ramps	Coastal	MODERATE	10s – 100s
5	Slipways	Coastal	MODERATE	10s – 100s
5	Spillways	Fluvial	MODERATE	10s – 100s
5	Control Gates (Mitre Gate)	Fluvial	MODERATE	10s – 100s
5	Demountables	Coastal	MODERATE	10s – 100s
5	Beacons	Estuary	MODERATE	10s – 100s
5	Dunes	Coastal	MODERATE	10s – 100s
5	Jetties	Fluvial + Estuary	MODERATE	10s – 100s
6	Outfalls	Fluvial + Estuary	LOW	1,000s
6	Simple Culverts	Fluvial	LOW	1,000s
6	Control Gates (other than Mitre Gate)	Fluvial	LOW	1,000s
6	Flood Gates	Fluvial + Estuary	LOW	1,000s

1.3 Incorporating consequences

1.3.1 'Ideal' approach

The ideal approach to calculate total impact would be to have a full spatial and quantified analysis of all assets individually, to establish how each responds to climate change and what the consequences of that would be for the areas that are protected, so that well informed risk-based decisions could be made upon the appropriateness of different levels of maintenance activity. This is essentially a 'bottom-up' analysis with asset-specific assessment and understanding of how each of those assets contribute to the flood management system. This would require having detailed information on:

- assets, detailed characteristics on each plus relationships between them within wider systems
- hydrodynamic data along all watercourses and coasts
- analytical methods for assessing each deterioration process
- information on settings, including bed characteristics, levels and variations
- comprehensive unit costs information for various levels of activity

The approach that could then be taken would be:

1. Run baseline case to analyse the situation without climate change.
2. Run case with hydrodynamics altered to assess impacts with climate change.
3. Analyse whether that results in excess deterioration.
4. Assess how that alters the flood/erosion risk to the areas being protected/served by those assets.
5. Calculate total impacts in terms of:
    - the change in flood or erosion damages if not addressed and/or
    - the change in benefit/cost to maintain the assets.

However, the data, information and knowledge to deliver this is not likely to be available at any point soon, and therefore other approaches are required to address the subject at a higher level.

Taking an approach which is fully asset specific is also going to potentially be more data-hungry, analytically intensive, and most costly. Therefore, consideration must also be given to proportionate approaches, and rather than attempting to quantify everything precisely, we should look not only to characterise possible impacts but also possible responses and costs for those responses.

1.3.2 Supporting data

Given the constraints that data availability present, it is logical to consider approaches that are based upon information that is available, or might reasonably be obtainable in the near future. To do so therefore requires some assessment of the availability and suitability of data, in particular asset numbers and cost rates.

Asset number data

CAMC (AIMS) contains FCERM asset data covering England and Wales. It includes information on flood defence assets owned or maintained/inspected by the Environment Agency (EA), internal drainage boards (IDBs), local authorities (LAs) and some private owners.

This database does not contain information on coast erosion assets. These may be owned or maintained by local authorities or other private owners. However, the National Coastal Erosion Risk Map (NCERM) project maintains a database for these. It does not include all 47 asset types being considered by this project, just certain structures and natural features. Nor do descriptions map exactly across between AIMS and NCERM, so some interpretation is required, but it is generally possible to combine information from both for some of the more commonly found (and more vulnerable) asset types.

Neither the AIMS nor NCERM database is 100% complete (i.e. they have not captured every asset) but they do provide a reasonable approximation of the order of magnitude number for assets of each type, which is adequate for current purposes. Indeed, it is not critical to have exact quantities as this study is considering the future, by which time these numbers are likely to have altered in any case. In conclusion, the information from these sources was considered suitable to undertake an initial high-level assessment of overall impact at the level required by this study.

In the case of several asset types, information is provided on both total length (metres) as well as total number. Therefore, it is also possible to calculate an average length per asset, which proves useful when considering maintenance costs, many of those being based upon cost per metre.

Maintenance cost data

There is no central database of asset maintenance costs, although information can be obtained on a number of the asset types from various sources. That data is both generic (as requirements vary considerably from asset to asset) and highly variable (depending upon what activities are considered within the development of those costs).

The Environment Agency is currently progressing an initiative to develop unit cost ranges for the various activities that it and others need to undertake to maintain different asset types. This is collecting information on times and rates for certain activities (e.g. inspection, grass cutting, servicing, minor repairs etc.), which can then be used for costing and planning workflow in the future. Although the initiative is in its early stages, the information that has already been collected and assessed has been provided for this study to use. However, this primarily covers the costs of labour and the plant to carry out just those activities, not the materials, equipment or time that would accompany more substantial repairs/replacement. For that reason, these costs generally appear much lower than information found in other sources which tends to include an 'all-in' typical spend on maintenance, which often includes cost of repairs.

Another key source of information to derive some of the cost rates that might be used for more substantial works, typically refurbishment and rebuilds, is data being collected by the Environment Agency after major events, and captured in its Project Cost Tool (PCT).

Among other sources are a series of joint Environment Agency–Defra publications from May 2015 including 'Cost estimation for fluvial defences – summary of evidence', 'Cost estimation for control assets – summary of evidence', and 'Cost estimation for coastal protection – summary of evidence'. It is noted however that these largely draw upon the costs provided by the Flood Risk Management Estimating Guide, Update 2010 (which in fact provides more detail and clarity on many of these costs, so was referred to instead). These guides focus on new construction costs for schemes but do include some maintenance/repair costs for certain asset types and situations. Where potentially useful, that information has been extracted for use here, although its very broad nature has to be considered in its use for this study.

Adding to this, as part of the NCERM update mentioned above, information on rates for maintenance were sought from local authorities. Where provided, these have been included.

Despite these various sources, there remain several asset types for which no data is available or only for one level of activity. For the purposes of this study, those gaps have been filled using information from similar asset types, or where the level of activity is potentially similar, but this is subjective and will inevitably contain some inaccuracies.

Notwithstanding these limitations, sufficient information was obtainable to conduct an initial high-level appraisal of impacts for this study, albeit this is identified as a key area that can still be improved upon in the future.

1.3.3 **Other approaches explored**

Quantifying the total level of additional activity (work or cost) that might be required is perhaps what really initially matters in the context of this exercise to deliver a high level view on impacts. This study is seeking to provide the knowledge and tools to help understand how climate change will affect deterioration and probably the most tangible impact is how this will alter the requirements to maintain that structure. This is consistent with the approaches that are presented in Appendices B and C.

In that context, the following subsections describe some of the approaches explored into how to deliver on the core requirements, making best use of potentially available data, to identify which assets are most impacted and the extent of those impacts and to provide some measure of the potential consequences.

Assessing which assets are most impacted and extent of those impacts

Qualitative assessment (Appendix B) has identified which assets in what settings are the most vulnerable. This is acceptable for now, but remains subjective and there will be scope to improve upon that in the following ways:

1. Establish whether it is possible to qualitatively distinguish between what is important or less important in terms of maintenance and repair activity, or costs. This will always be subjective, but may be achievable by considering further the 'what if' (or 'what if not') outcomes of acting to address the increased deterioration on different types of asset.
2. This could be better refined by using calculation methods to help to quantify the effects of climate change on the deterioration processes identified and thus the extent of additional work or cost necessary (see Appendix C), although this is currently limited by data and knowledge.
3. Another approach would be to run a series of tests (calculations for a range of possible scenarios for different asset types such as structure geometry/characteristics and a set of baseline hydrodynamic conditions) to produce some generic outcomes and thus 'rank' those relative impacts. For example, we might see that a 30% increase in flow speed makes a critical change to deterioration of a weir but not to a flood gate. Both were assessed qualitatively as being of 'Moderate' vulnerability, but this would inform us that the impacts upon one are likely to be more of an issue than on the other. This would still be fairly subjective (as actual impacts will be individually location specific) but would be informed by some quantitative examination and thus more robust than the purely qualitative assessment.

Measuring the potential consequences

There are two ways of addressing this point. One is to consider what changes in levels of operations and maintenance activity are likely to be required; the other is to consider the costs of those.

An assessment of the potential changes in operations and maintenance activity has already been made as part of the qualitative assessments.

1. This could be extracted and presented differently (e.g. by maintenance activity type), which would correspond with the manner in which the Environment Agency is seeking to capture maintenance costs. Its activity list could be adopted and used to identify possible changes.

2. The qualitative assessments of potential changes are descriptive only and some quantification still needs to be made (i.e. how much more frequently such activities might be required). This may be difficult to establish but some subjective assessment might also be made of whether the increase in activity is likely to be modest (e.g. occasional increase) or significant (e.g. doubling of effort).

Changes to maintenance costs have been determined to be one of the preferred ways to define consequences. This though is again subject to availability and quality of data.

1. One approach is to work with total (national) maintenance spend information. This can be married with the total asset population estimates and pro-rated accordingly, although it should be noted that the costs for maintaining different asset types can vary considerably.

2. It is preferable to use cost data for different asset types, or different operations that can be linked to asset types. The Environment Agency is in the process of developing this data (but the work is currently ongoing so not yet complete). This could be used in conjunction with estimated asset numbers to estimate potential cost differences to maintain (e.g. 1000s of embankments cost 10 times the costs for 1000s of outfalls) and use that directly.

3. To develop this further, where it is possible to isolate the different activities required and provide some quantified estimate of increase in those specific activities, then a more refined level of assessment can be performed using the same principles.

Another consideration will be to look at costs for rebuild/major refurbishment as follows:

1. In some instances, we have identified that a change to the structure may be required to address capacity/performance issues well before any deterioration processes have a notable effect.

2. In those instances, the response is not more maintenance but instead the futureproofing designs or upgrading of the structure. This may though also fall into the area of performance-related improvements, so any increases in costs need to be appraised with that consideration.

Measure of the total potential impact

A preliminary ranking of those assets likely to need most attention going forward has already been produced through qualitative assessment (Table D1.1). This could be improved, primarily through combining the asset numbers with the relative costs both presented in Section 1.3.2. From that, it is possible to establish whether the most vulnerable assets are also those with the greatest change in quantifiable maintenance activity or cost (i.e. impact) as follows:

1. The relationships to look for will be where the expensive maintenance costs are and how those correspond with the ranking of assets in terms of vulnerability. If for example the most vulnerable assets are also individually the cheapest to maintain, an increase in activity has only a limited impact. However, if the most vulnerable are also those that individually require most money/effort to maintain, then just those few alone may immediately indicate that overall total impacts are going to be significant.

2. The product of the two gives an order of magnitude view on total potential vulnerability (i.e. whether we expect maintenance activity/costs to go up slightly or significantly).

3. So the total potential vulnerability (impact) might for example be a doubling in maintenance activity/spend, or a modest (e.g. less than 25%) increase in maintenance activity/spend.

4. It would then be possible to re-rank assets (i.e. those requiring most attention going forward) from the above refinement to the initial ranking.

This could be produced at different stages and continually improved as follows:

1. It may for example be possible to undertake almost immediately at a broad level with some additional generic data on asset numbers and maintenance costs.

2. But, as better information develops, and possibly this work is integrated with other national level initiatives (e.g. Long Term Investment Scenarios, LTIS), this can be further refined and accuracy improved.

Potential calculation methods

There are several methods to consider for using this data to calculate the impact of climate change on the costs of maintenance for the various assets to attempt to give a high level national view, and several basic approaches were developed and tested.

Although some of the principles within those basic methods were reasonable, there are considerable limitations and those ideas could be developed further to produce a more robust calculation of the high-level impacts, albeit requiring some further refinements and manipulation of the information available.

One refinement was to make use of the different levels of cost information for different magnitudes of response, for example costs for maintaining and operating will have a different cost to minor repairs, which will be different to the cost for more substantial repairs.

Armed with such information some different types of assumption can be made in the absence of specific information on asset deterioration; so, for example, it might be assumed that all those assets categorised as being of ‘Moderate’ vulnerability will require a shift in activity from maintenance to repair.

A further refinement is to consider whether total spend (theoretically, using the assumed cost values) fits with existing budgets. This is an important consideration not accounted for in the above methods, and could be addressed through some relationship construction and factoring of cost rates to tie these together. That would also help to benchmark estimates of further investment requirements.

This is described further in Section 1.4.

1.4 Approach to impact analysis

An approach has been developed taking into account the considerations presented in Section 1.3. This was initially piloted with basic information on asset numbers and costs to establish its suitability, and then refined with further interrogation of some of that data (notably to obtain more granularity on the differences between some assets of the same type, and further information on costs for various activities). This has enabled an initial high level indication of the total potential impact of climate change upon asset deterioration to be obtained, and to identify those assets which are likely to require most attention going forward.

1.4.1 **Requirements to support analysis**

To assess the total impact of climate change upon asset deterioration, information is required to support each component of the following:

Total impact = (Asset impact) x (Number of those assets) x (Potential consequences)

Asset impact

The outcome of the qualitative assessments presented in Appendix B provides the initial means to determine which asset types are most vulnerable and require different levels of maintenance or repair to address the increase in their deterioration, categorising each as either ‘High’, ‘Moderate’, ‘Low’ or ‘Negligible’. This is sufficiently robust for the initial high-level analysis and to apply the approach presented here.

Based upon the qualitative assessments, the impacts of climate change on asset deterioration have been concluded to be ‘High’ or ‘Moderate’ for approximately one-third of asset types within fluvial settings, but approximately two-thirds of asset types on the coast and half of the asset types in estuaries.

Notably, some of the asset types categorised as having High or Moderate vulnerability are those which are also most prevalent, including Embankments and Walls across all three environments.

Number of assets

Although it is recognised that the quality of records in CAMC (AIMS) and NCERM are variable, the total asset count from those is certainly accurate to an order of magnitude level and suitable for the initial high-level analysis.

Some of the more prevalent asset types are listed in Table D1.2.

Table D1.2 Example quantities of asset types (source: AIMS and NCERM)

Asset type	Number	Length
Embankments	-	6,800km
Walls	-	1,650km
High Ground (lined)	-	1,660km
Groynes	3,700	-
Outfalls	20,600	
Control Gates	2,650	
Flood Gates	1,450	
Culverts	8,600	

Through more detailed review of this data, and cross-referencing with other information sources (e.g. RASP classifications as used by NaFRA and LTIS), it is possible to get further granularity albeit at a broad level. For example, we may be able to determine whether a defence has a protective cover layer (revetment) or not and whether that is of permeable or impermeable type, the nature of which determines the relative vulnerability to deterioration. That enables the potential impacts of climate change and associated costs to be apportioned more accurately.

Potential consequences

The qualitative assessments (Appendix B) identified that the impacts of climate change on deterioration might require one of three different response types. Each of these has a step increase in associated costs, and it is therefore possible to relate those costs to the level of vulnerability, as described later in this section. Details on the sources are given in Section 1.3.2 of this appendix, and the application of that information is described further on in this section, considering the increases required for maintenance, repairs and refurbishment corresponding to those response types.

Depending upon asset type, cost rates adopted for frequent maintenance ranged from less than £0.50 to almost £4.00 per metre per year, and approximately £25 to £350 per asset for various FCERM structures.

Repair costs adopted were more variable, but for many linear asset types lie in the range of £9.00 to £12.00 per metre per year (when annualised) , with costs for many of the non-linear structure types falling in the range of approximately £100 to £1,000 per asset.

Potential refurbishment costs were only required for certain asset types, see later. Consideration in each of those cases was also given to the nature of the deterioration processes and the sub-form of the asset (e.g. type of protection). The unit costs derived only reflect **the additional costs** estimated to address the impacts of climate change on their deterioration, not their full rebuild cost. For most of these cases that was estimated to be in the range of £500 to £1,600 per metre.

1.4.2 **Approach**

Present spend on asset maintenance

To consider the impacts of climate change upon costs to address increased deterioration, it is also necessary to understand how maintenance budgets are currently allocated and spent.

The Environment Agency report *Technical and legal background to our asset maintenance*, published in February 2014, contains useful information on expenditure, presenting information from the previous 5 years.

Over that period the average Flood Defence Grant-in-Aid (FDGiA) was:

- Capital allocation: £303 million, of which on average approximately £250 million was spent on replacement (new schemes, major repairs and refurbishment).
- Revenue allocation: £257 million, of which on average approximately £160 million was spent on maintenance activity.

With respect to revenue allocation, the reason maintenance activities account for only just over 60% is because the remainder includes many other FCERM activities such as flood warning, modelling, forecasting, incident response, contributions to wider functions such as IT support, administration, facilities etc.

The remaining £160 million per year is then further divided into direct and indirect costs. Indirect costs, comprise professional staff time to programme, plan and manage maintenance activities, revenue projects, fleet costs etc. The present allocation of direct costs on maintenance activities, which is the element of interest to this project, was most recently advised as being approximately £84 million for 2015/16, and this serves as a suitable typical baseline for making the present assessments.

In addition to the above are the costs that local authorities spend on maintaining and repairing coastal protection assets. Those costs are not centrally collated or distributed, so there is considerable variation from authority to authority. However, as part of this study data has been sought, and although data was obtained from just 10% of local authorities, this has been factored up to estimate total annual spend. This indicates the total additional spend to be approximately £8 million per year.

Maintenance categorisation

In capturing costs and allocating budgets, the Environment Agency maintenance activities are also categorised as follows:

- conveyance management
- MEICA
- operation of assets
- preventative maintenance on structures and defences

There are, however, sub-layers to these; for example, within each category there are ‘frequent’ and ‘intermittent’ activities identified. The extent of each might depend upon the level of total revenue allocations, which may differ from the levels sought. There are also activities which might be carried out concurrently (e.g. some operational inspection with conveyance management or preventative maintenance), so operational staff time also has to be apportioned appropriately across these different categories.

Because any particular asset requires a range of different activities to maintain and operate, there is no direct correlation between asset subtype and any particular category, although considerable effort by Environment Agency staff is going into collecting data on activities to improve the bottom-up development of budgets alongside the analysis of maintenance unit costs. Through that, some broad apportionment of maintenance costs for individual asset types has been made; for example, ‘weed cutting’ along open channels is 100% conveyance management, whereas ‘tree work’ for a defence is 20% conveyance management, 40% operations of assets and 40% preventative maintenance. Combining those assumptions with actual costs captured by operations delivery field teams on their activities (e.g. ‘£X million’ cost across the country to carry out weed cutting or tree work), it is possible to estimate for this study some approximate proportions of costs under those four categories for different generic asset types.

Using this data for the purposes of this initial high-level analysis it has been calculated for example that approximately 10% of the cost of ‘frequent’ maintenance on assets listed as ‘Defences’ can be attributed to conveyance management, 2% to MEICA, 48% to asset operations and 48% to preventative maintenance. Using the same approach, values for other asset groups (e.g. assets listed under ‘Structures’) have also been derived. Although this is based upon short-term data capture, and limited granularity, which could be improved upon with further work and information still being collected, it provides adequate definition to provide a first pass estimate of impacts.

It is then a question of how to utilise this information. Based upon interrogation of the data, the definitions used and the apportionment of activities to different categories, ‘preventative maintenance’ is that which best describes the main response to address asset deterioration and therefore forms the focus for our impacts analysis.

Using the data available and the assumptions made with respect to that, preventative maintenance constitutes around 40% of the total direct costs associated with frequent maintenance, and approximately 45–50% of intermittent maintenance.

Relationship between vulnerability, maintenance cost rates and budget descriptions

It is also necessary to look at the distinction made between frequent and intermittent maintenance and thus how these might be considered in terms of calculating future potential impacts.

The definitions used for activities for defence repairs or maintaining structures (two of sixteen activities) that come under ‘frequent’ maintenance include:

- *Minor repairs (replace missing flap, joint repairs in flood wall, minor revetment repairs etc) carried out during the course of frequent maintenance activities.*
- *Maintenance of non-MEICA structures such as weirs, gates, siphons, culverts, bridges, valves, pumps, basins, trash screens, walls. Removal of silt from structures, joint repairs, concrete repairs at structures.*

The definition used for repair activities (one of five listed activities) coming under ‘intermittent’ maintenance is:

- *Work involved repairing part of whole defence to reduce asset deterioration rate (more significant than those minor repairs covered by frequent maintenance).*

It can be seen from these descriptions that the natures of ‘frequent’ and ‘intermittent’ maintenance correspond well with those that describe the responses required due to climate change that have been used to categorise asset vulnerability, as shown in Table D1.3.

These also correspond well with the way in which the cost information can then be defined, that is:

1. Regular maintenance (= ‘frequent’ maintenance activities, and associated spend).
2. Repairs (= ‘intermittent’ maintenance activities, and associated spend).
3. Substantial repairs/improvement (= ‘major repairs and refurbishment’).

Table D1.3 Comparison of vulnerability and response types

Vulnerability	**Description**	**Response type**
HIGH	*Change could result in* ***a significant (large or rapid) increase in maintenance commitment and/or chance of failure*** *due to deterioration*	‘1’+‘2’+‘3’
MODERATE	*Change likely to result in* ***a notable increase in maintenance requirements or repair/replacement of elements*** *due to deterioration but without significantly increasing failure probability*	‘1’+‘2’
LOW	*Impacts* ***may result in some small increases to the level of maintenance*** *due to deterioration, e.g. the potential for some increase in the frequency of routine activities*	‘1’
NEGLIGIBLE	*The impact of climate change factors on deterioration will result in* ***little if any change to the maintenance*** *of the asset*	no change

The data sought from local authorities all pertained to the equivalent of ‘preventative maintenance’. This breaks down as approximately 40% on regular maintenance and 60% on intermittent repairs.

The unit cost information described earlier has been used to derive total cost estimates for individual asset types for each of these levels of maintenance/repair activity. In doing so, the summation of that information can then be compared with the current expenditure for these different levels of activity, and then used to consider the consequences of changes in requirements for different assets as a result of climate change.

Influence of climate change on maintenance and repair costs

In the absence of reliable individual unit costs for specific maintenance and repair activities across all asset types, or precise definition of the nature of those activities, which is specific to each individual asset, the approach taken has been to look at the collective increase in spend relating to increased levels of maintenance and repairs.

That approach has considered the reduction in return period for different events that may be encountered as a result of climate change, which can also be interpreted as the increase in frequency of exposure to those same events. Assuming deterioration rates are proportional to the level or frequency of exposure, if conditions that are currently experienced once every two years will in future be experienced annually, then it could be concluded that any deterioration resulting from those conditions may also occur twice as quickly. The extension of that is the maintenance and repair activities necessary to address those conditions would also need to take place twice as often, in other words the present annualised costs for those would double.

Ideally information on changes in flow speeds in rivers would be sought, but those do not exist. Instead, existing analysis of increases in water levels in rivers due to climate change over the next century are obtainable through LTIS. Those have been converted (by others) to estimate future return period changes, for example an event with a 1:10 year return period now having a return period of just 1:8 years by 2063. Applying that ratio to this analysis, it would indicate a 25% increase in costs should be expected.

Although changes in flow speeds are not directly in proportion to changes in water levels, this is the best information available, and to allow for such inaccuracies lower and upper bound estimates have been taken in addition to the mean to provide a range of possible increases. This also better reflects the uncertainties across the various data used in determining these results.

For the purposes of this analysis, the increases to regular maintenance activities were considered proportional to the average increase in frequency of events of less than a 1:10 year return period. The increases to repairs were considered proportional to the average increase in frequency of events in excess of the 1:10 year and up to the 1:100 year return period. Consideration was also given to the application of those same factors in tidal river and estuary settings, with adjustments made accordingly.

A variation on the approach has been adopted for assets on the open coast, reflecting both differences in the information available to conduct a similar exercise and also the much higher levels of exposure and consequences that climate change is expected to have upon accelerating deterioration. Information used was taken from the *Coastal Defence Vulnerability 2075* (CDV2075) report by HR Wallingford, which is geographically limited, covering only five points spaced around the entire coastline, but is that adopted by LTIS and currently all that is available without new analysis. CDV2075 considers joint probability events at each location and calculates the increase in overtopping volume for selected defences, from which typical reductions in return period can be determined. As there are considerable differences in results at each location, the highest and lowest 10% of results have been ignored, but the remainder can again be used to provide some factors in the same way as described above.

Tables D1.4(a) and (b) show the increases to be applied for the costs of maintenance and repairs in each of the settings in which FCERM assets are found.

Table D1.4 Cost uplift factors to take account of climate change impacts on (a) maintenance and (b) repairs

(a) Maintenance uplifts	Fluvial	Tidal River	Estuary	Coastal
Min	1.15	1.15	1.22	2.0
Mean	1.41	1.41	1.64	3.9
Max	1.82	1.82	2.43	4.7

(b) Repair uplifts	Fluvial	Tidal River	Estuary	Coastal
Min	1.22	1.22	1.28	5.0
Mean	1.64	1.64	1.84	7.1
Max	2.43	2.43	3.02	8.4

Influence of climate change on asset improvement costs

A finding of this study has been the requirement to upgrade and improve certain assets to counter the potential for increased damage to structural elements and reduced structural integrity, as the asset will have been originally designed for lesser hydrodynamic loadings. That may take the form of increasing the size or nature of any protective cover layer or extending existing protection to prevent erosion of any presently unprotected surfaces for example.

However, on the assumption that most assets are going to need major refurbishment or replacement anyway over the coming century, either due to long-term degradation in condition or raising to maintain performance standards, it would be inappropriate to consider the whole costs of refurbishment for those assets that will be incurred. Therefore, this study has estimated just the **additional** costs associated with any need to improve those assets over and above those existing requirements. This also assumes that those 'upgrades' could be carried out at the same time as any existing works, as logically that would be the approach taken to 'futureproof' those assets for any increased deterioration effects.

A two-step approach was applied to consider these impacts. Initially, published cost information was used to calculate the order of costs for all asset types categorised as High and Moderate (the latter being included initially acknowledging that some variability exists in those, e.g. in material type) to determine the order of costs associated with refurbishment of each type. The conclusion of that exercise was that just three asset types across the different environmental settings, Embankments, Walls and protected High Ground, accounted for 97% of the estimated costs for necessary improvements to deal with the impacts of climate change. Consequently, the second step assessed those in further detail, considering both greater granularity of asset type details and unit cost rates.

In fluvial, tidal river and estuary settings, most of the cost increases relate to the need to add protection to a proportion of assets in each type where the structure is simply turfed but could become vulnerable in the future, or existing protection needs to be extended (or upgraded) to include crest/rear slope protection. Existing information on water levels in rivers for different return periods (the National Fluvial Level Dataset) was analysed and compared with current information on protected extents (and form of that protection), to estimate the percentage of those assets that could require different levels of improvement. A scenario where more of those costs might also be included for 'business-as-usual' refurbishments was considered, to provide a range of outcomes.

In coastal settings, a previous paper on the impacts of climate change on coastal defence structures (*Burgess and Townend, Defra Flood and Coast Conference, 2004*) provides estimates of the increases in material volumes due to requirements to improve protection, raise crest levels and extend scour protection, for a range of different asset types and scenarios, which they then translated into cost uplifts. Where this study has identified a requirement to improve assets, the approach has been to apply those factors to the unit costs for refurbishment.

1.4.3 **Application**

Using the aforementioned information and derived relationships, the approach then applied consists of the following to determine the impacts for additional maintenance and repairs to assets:

- The total number/length of each asset type was obtained.

- Unit cost rates were identified for each asset type for response type 1 (regular maintenance) and response type 2 (repair work).
- A total cost per asset type was generated as the product of the above two sets of data, producing a total cost for both response type 1 and 2. The 'preventative maintenance' elements of these have then been extracted using the typical ratios identified from recent budget information.
- Costs have been tallied for each level of response and then factored based upon existing budgets for frequent and intermittent works. The costs for those assets which would potentially be affected by climate change have then also been isolated (i.e. for frequent maintenance all types except those categorised 'Negligible', for repairs all types categorised as 'Moderate' and 'High').
- The uplift factors for increased frequency of maintenance and repairs have been applied to those asset types potentially affected, accounting also for the numbers of assets and differences in uplifts for each setting (fluvial, coastal etc.), to provide an estimate of the potential increase in costs as a consequence of the impacts of climate change upon deterioration.

Further to this, the following approach has then been applied to determine the potential additional costs needed to improve assets to address the impacts of climate change upon their deterioration:

- Adopting a similar approach to above, the unit cost rates identified for response type 3 (improvement/refurbishment) were applied.
- Initial application of this at the pilot stage, which also considered some asset types categorised as Moderate as well as High, was used to screen out those assets where the impacts resulted in just a small proportion of the total potential impact costs.
- In the full analysis the focus has therefore been to look in greater detail, using the granularity of information on structures and more refined derivation of unit cost rates, for the three most impacted asset types.

The preliminary ranking in Section 1.2.2 has been updated with a revised ranking of impact that takes account of maintenance and repair cost increases, and a second ranking that considers the potential additional refurbishment costs.

1.5 Results of analysis

1.5.1 **Maintenance and repair**

Impacts upon specific asset groups

It is estimated that currently maintaining assets in the 'Negligible' and 'Low' vulnerability categories accounts for approximately one-third of the total preventative maintenance component of frequent maintenance expenditure.

By definition, those assets that are 'Negligible' should see no change in maintenance requirements.

With respect to the ‘Low’ assets, the impact would be increases to the regular maintenance regimes only (response type 1 activities). From analysis, the total increase in maintenance to those asset types is estimated at approximately £3–4 million per year, which is only 15% of the estimated increase in ‘frequent’ preventative maintenance. So, the overall impact on those is relatively small.

Although present preventative maintenance expenditure on the ‘Moderate’ and ‘High’ vulnerability assets accounts for around two-thirds of total frequent maintenance, these same asset types would account for around 85% of the total estimated increase to address the impacts of climate change. That is, however, consistent with them being identified as being the more vulnerable asset types.

These ‘Moderate’ and ‘High’ vulnerability asset types will also require more repairs, a response type 2 activity. At present, the asset types with ‘Moderate’ and ‘High’ vulnerability take up approximately 80% of the budget for ‘intermittent’ works, so it is not surprising therefore that a significant increase in that has been identified by this analysis.

Across different asset types, it is estimated that around 90% of the total current preventative maintenance spend on ‘intermittent maintenance’, or ‘repairs’, is on just four asset types: embankments, walls, bank protection (high ground) and timber groynes. As all of these are categorised as ‘Moderate’ or ‘High’ vulnerability, it follows that they are also expected to be the assets where the highest increases are also likely to be found.

With the inclusion of outfalls (categorised as ‘Low’), these five asset types also make up two-thirds of the preventative maintenance spend on ‘frequent maintenance’. So again, these are where the greatest increases can be expected to occur.

One other area where high increases might be seen is in the maintaining of beaches, which are expected to become more volatile, but the current information within the asset databases was inadequate to fully evaluate this.

Impacts compared to current budgets and expenditure

This analysis estimates the total increases in costs for maintenance and repairs due to the impacts of climate change to be between approximately £30 million and £75 million per year, as shown in Table D1.5.

In comparison to the current budget of approximately £92 million (£84 million Environment Agency plus £8 million local authorities), this represents an increase in required spending of between 32% and 82%.

The differences in increase between different environments are notable, with over 60% of the increase in maintenance costs and around 90% of the increase in repair costs being on coastal assets. This might be concluded to be simply attributable to the much higher uplift factors applied to coastal situations than in fluvial or estuarine settings, due to the use of a different dataset. But this outcome is not actually too surprising as there is an in-combination effect at the coast; the increase in sea levels (which is a constant and not solely event driven) also allows continual exposure to much larger waves which will be impacting upon those assets.

Table D1.5 Impacts of climate change on maintenance and repair costs

Increase in costs (£,000)		Total	Setting			
			Fluvial	Tidal River	Estuary	Coastal
Maintenance	Min	**£6,900**	£1,700	£300	£400	£4,500
	Mean	**£19,700**	£4,500	£900	£1,300	£13,000
	Max	**£30,200**	£9,000	£1,800	£2,900	£16,500
Repair	Min	**£22,100**	£600	£100	£200	£21,200
	Mean	**£34,900**	£1,700	£300	£500	£32,400
	Max	**£45,000**	£3,800	£700	£1,200	£39,300
Total	Min	**£29,000**	£2,300	£400	£600	£25,700
	Mean	**£54,600**	£6,200	£1,200	£1,800	£45,400
	Max	**£75,200**	£12,800	£2,500	£4,100	£55,800

It should be noted that the £84 million Environment Agency allocation is roughly 20% lower than the amounts submitted. The reduction results from the exclusion of uneconomic assets (i.e. where maintaining those would not return a positive benefit to cost ratio). Assuming that continues in future the analysis has been recalculated using the submission rather than allocation values. However, that indicates that the overall increases are still 27% to 70% higher than the submission value, so of a similar order of magnitude.

In addition to the above is the present annual spend on reconditioning work to maintain current design life (REC). These are costs incurred over and above the regular budgets to carry out necessary repairs. This varies year on year depending upon need, with expectations ranging from £2 to 10 million, although more recent spend has been up to £15 million per year. REC would be additional unbudgeted spend on necessary repairs, so will add to the values extracted and used by this study for intermittent maintenance. However, in comparing the potential percentage increases in costs with existing budgets this has been deliberately excluded, but should not be ignored and can be assumed to be required in future in addition to these increases. Whether that might also need to be increased by a similar percentage to these budgets is not certain, but as this can already vary by a factor of 2 to 5, it may also be assumed that the increase required in any particular year might also be within that range of present variability.

Ranking

Table D1.6 shows the proportion of the estimated increase in maintenance and repair costs likely required for different asset types.

Table D1.6 Ranking of impacts on maintenance and repair cost increases

Asset type	Setting	Proportion of additional cost
Embankments	Fluvial	26%
Coastal Embankments and Seawalls	Coastal	26%
Groynes	Coastal	20%
Embankments	Tidal River and Estuary	14%
River Walls and River Bank Protection (Lined High Ground)	Fluvial	8%
Outfalls	All	3%
Walls	Tidal River and Estuary	1%
All other asset types	All	2%

1.5.2 Refurbishment

The magnitude of response type 3 activities (much more substantial repairs and refurbishment) make it meaningless to consider and compare these against maintenance budgets, so instead comparison is made with capital works expenditure.

This analysis estimates the total costs for such improvements is going to be in the range of £2.5 to £4.5 billion due to the impacts of climate change. To put that into context, based upon a present-day capital budget of £250 million per year for replacement of FCERM assets (new schemes, rebuilds etc.), this is the equivalent of 10 to 20 years of expenditure over and above 'business-as-usual'.

These would not be annual costs, but 'one-off' improvements to safeguard against the increased deterioration due to climate change, and assumed to be carried out at the same time as any requirement to rebuild or refurbish those assets due to them becoming life expired or needing improvement to maintain the required standard of protection.

Existing estimates of total rebuild costs for the three main asset types affected, Embankments, Walls and protected High Ground, indicate their replacement would be approximately £10 to £11 billion. Accommodating the improvements needed to address the impacts of climate change on the deterioration of those same assets, would therefore increase those costs by approximately 25% to 40%.

Considered by asset type, the total cost increases for Embankments are in the range of £1.3 to £2.3 billion. Compared to the benchmark rebuild costs for embankments, this indicates an increase of approximately 30% to 50%.

The total cost increases for Walls is in the range of £0.7 to £1.1 billion, This is an increase of between 20% and 35% above the estimated benchmark rebuild costs.

Finally, the total cost increases for maintaining bank protection (High Ground) of £0.4 to £1.0 billion would indicate a 20–40% increase to the rebuild costs for those assets.

Ranking

Table D1.7 shows the estimated increase in refurbishment costs likely to be required to make the improvements necessary for the most impacted assets to be able to counter the impacts of climate change upon deterioration.

Table D1.7 Highest impacts on refurbishment costs

Asset type	Setting	Estimated cost (£ million)
Coastal Embankments and Seawalls	Coastal	£1,350–£1,625
River Bank Protection (Lined High Ground)	Fluvial	£450–£1,025
Embankments	Fluvial	£375–£620
Embankments	Estuary	£190–£740
Walls	Estuary	£50–£210
Embankments	Tidal River	£100–£155
River Walls	Fluvial and Tidal River	£25–£50

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