Oxford to Cambridge Arc flood risk investment study

Economics technical report

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Oxford to Cambridge Arc flood risk investment study

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1 Introduction

The OxCam economic evidence study for investment in flood resilience and adaptation aims to find the optimum **level** and **timing** of investment in flood resilience across the Oxford-Cambridge Arc. Our high-level method uses existing river level data and new 2D floodplain modelling combined with an assessment of impacts to represent the effect of a range of interventions over time under a series of climate change and development scenarios.

This technical report describes our approach to quantifying the economic impacts of flooding (and therefore benefits of interventions) and the costs of interventions. As shown in Figure 1.1, these technical reports are accompanied by a cross-cutting summary report which describes the overarching approach and findings.

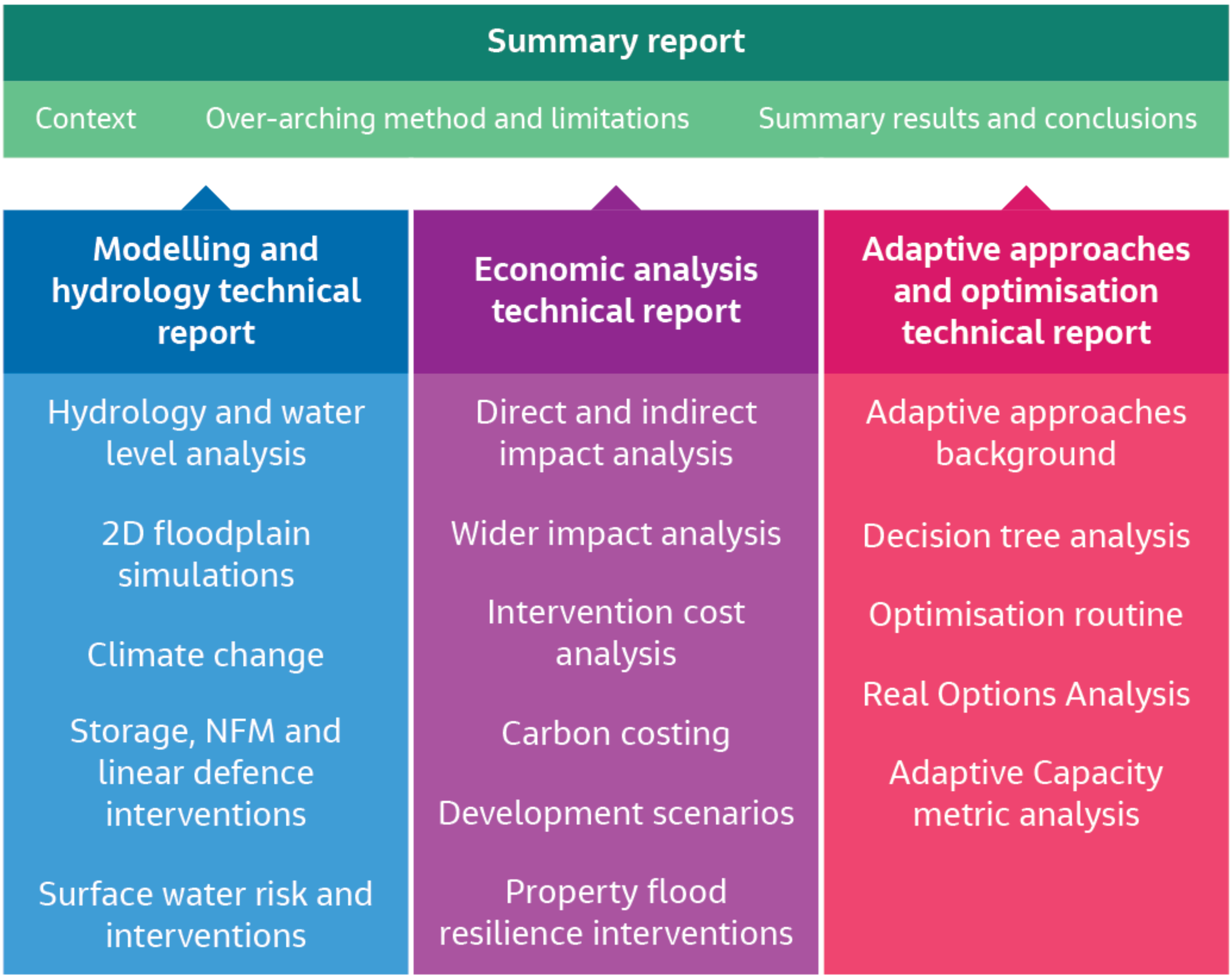

Figure 1.1. OxCam flood economics project reporting structure and content.

Figure 1.2 outlines our overall approach to the economic analysis. Whilst the subsequent sections provide detail on the approach to assessing specific economic impact streams, the overarching analysis is underpinned by the following key assumptions:

- We consider impacts (both positive and negative) for the combination of investment scenarios and development scenarios; for different climate change scenarios.

- We report net present value metrics in **2020** prices and values throughout the report, unless otherwise stated. These use data for costs and impacts produced by our modelling. Where necessary, these data are extrapolated to represent the likely trajectory of future risk, if the lifespan of an intervention extends beyond the available modelled data, applied consistently with the approach to transitioning between climate change epochs.
- Discounting is undertaken in line with HM Treasury Green Book (HM Treasury, 2018) principles, i.e. 3.5% per annum discount rate for most impact categories to start with (1.5% adopted for life and health impacts) reducing over time at the HM Treasury Green Book prescribed rates.
- The appraisal period for an investment pathway is consistent across all pathways to ensure a fair comparison between pathways. Within each pathway, specific flood interventions are represented with a corresponding assumed lifespan appropriate to the type of intervention. For new development related impacts, a shorter lifespan is used to reflect best practice (e.g. ten years of persistence for GVA linked to jobs created at new development, land value uplift accruing in year of release to market).
- All cost and benefit values are produced at factor or market prices. As noted above all prices are presented in 2020 price base (real prices) with the effects of inflation removed. We therefore assume that the present-day costs and impacts are applicable over the length of the study period.

Figure 1.2 outlines an illustrative set of impacts considered in this study. Note that these impacts are economic impacts that are presented in monetary values, rather than local financial impacts.

Figure 1.2. Illustrative impacts to be considered in the Economic Analysis and the NPV process.

2 Costs

We have considered costs slightly differently for different types of intervention, due to their varying natures and readily available data.

We have applied the data and costing approach developed by the **long term costing tool for flood and coastal risk management** (JBA Consulting, 2015), updated for inflation. This tool provides data and calculation approaches for capital and maintenance costs for:

- Linear defences (walls, embankments and sheet piling).
- Property flood resilience (described as household flood protection and resilience).
- Natural flood management (described as land use and run-off management).
- SuDS.

The tool includes multiple approaches (of varying complexity) for each intervention type. In general, we are applying the **simplest available method** from the tool – the sections below provide more detail on the assumptions.

For flood stage we have used data directly from the Thames Valley flood scheme.

2.1 Flood storage

We felt that the optimal approach to costing the flood storage would be to transpose data from the Thames Valley flood schemes. This is a comparable scheme and would therefore provide a closer estimation of likely outturn costings than modelled data. We were able to include data for:

- **Capital costs**. Cost incurred during the initial project implementation including materials and source of material;
- **Enabling costs**. Enabling costs represent professional fees, consultation and licences/consent costs and land acquisition costs;
- **Operation and maintenance (O&M) costs**. O&M costs are applied as a percentage of capital costs.

2.2 Natural flood management

Estimating the costs of NFM is challenging at a catchment scale. LTIS 2019 (Clarke, Hardwick, Old, & Kay, 2018) explored available evidence from the Working with Natural Processes Evidence Directory (Burgess-Gamble, et al., 2018) and its case studies to identify relationships between cost and peak flow reductions – but the variability of catchments means these relationships are difficult to form with the small number of available case studies. Conversely, the long-term costing tool (JBA Consulting, 2015) provides more specific estimates of, for example, the cost per hectare of establishing floodplain woodland – although this is also based on limited data. Land acquisition costs was also considered.

Through this project, we have sought to marry the best-available data from these sources, along with analysis of the Working with Natural Processes mapping, to assess likely costs of achieving NFM outcomes in our 4 catchments[1]. Costs are based on an equivalent volume of

[1] The 3 catchments relate to the Oxcam region and are the Thames. Ouse, Nene and Cambridge.

storage, but we recognise some variability in individual NFM interventions that may not be accounted for.

2.3 Linear defences

We assigned existing defences to the most appropriate category (walls, embankments and sheet piling) based on their AIMS asset type. We have assumed that existing defences will be replaced with the same type of defence. New defences (i.e. locations where the current asset type is 'high ground') are assigned one of the other defence types for the purpose of cost estimation – because of the scale of this study, this will be a high-level assumption and not based on local knowledge.

We applied the following:

- Capital costs. We applied the height band (<1.2m, 1.2-2.1m, 2.1-5.3m or >5.3m) and assumed a 50%ile (i.e. average) cost estimate to obtain a cost per m length, which are combined with the length of defence in a given (Flood Risk Management System) FRMS to obtain a total capital cost. A range of defence heights were defined through an analysis of water level data.
- Enabling costs. We assume that the interventions explored by this project are developed 'from scratch' – we therefore include enabling costs to represent professional fees, consultation and licences/consent costs. These were applied using the available assumptions based on Environment Agency scheme data, which are calculated as a percentage of total capital costs, but with a percentage which is dependent on the scheme size (<£200k: 32%, £200k-£1m: 26%, >£1m: 9%).
- O&M costs. We apply the **weighted** method to estimating O&M costs, which uses a series of factors (such as whether a wall is prone to vandalism, or an embankment is home to protected species) and the defence length to provide an estimate of the expected annual maintenance costs.

We also apply this approach to raising existing defences, to represent the adaptive approach of investing in lower height defences early and raising later, rather than the precautionary approach of investing in larger defences early. These raisings are treated as separate capital investments, with defence costs calculated using the above approach – this means the adaptive approach to linear defence investment (as opposed to the overall adaptive approach to catchment resilience) might have a higher **cash** cost, but with discounting may have a lower present value cost.

2.4 Property flood resilience

LTIS 2019 (Clarke, Long Term Investment Scenarios: Additional Analysis. Topic 5 technical report: Property level resistance and resilience, 2019) built on previous work to identify viable packages of interventions for residential properties, based on:

- Resistance measures: Interventions to reduce the likelihood of water entering a property (such as flood resistance doors and airbrick covers).
- Resilience measures: Interventions to reduce the impact of water entering a property (such as moving electrics and replacement of kitchen units with waterproof alternatives).
- A combination of resistance and resilience measures.

LTIS 2019 also collated available cost information for these packages of interventions. Through its optimisation process, LTIS 2019 found that a single package of interventions was universally found to be the most cost beneficial. For this project, we have therefore reduced the complexity of the analysis by adopting a single package to represent PFR. We believe this is appropriate and proportional to the scale of analysis, given the available data. In reality, property-specific characteristics may mean that different packages of interventions are viable and better-suited, but we use the single package which is likely to perform best economically. This is discussed in more detail in Section 3.6.

2.5 Surface water flood risk management

Community-scale surface water flood risk management interventions are underpinned by an outcome-led analysis. SUDS in a given location is assumed to achieve a certain volume reduction in surface water. Baseline volumes have been calculated using the Risk of Flooding from Surface Water depth data (assuming that any volume of surface water *not* included in those results is already handled by existing drainage systems). Benefits are therefore represented by removing volumes of water from the baseline data. We have then developed a representative cost per volume of surface water management.

We have assumed that new developments include mitigation for increases in surface water risk resulting from that development. We considered additional investment in SuDS to reduce risk from its baseline level – which could apply to either existing developments or future developments. We also assume that property flood resilience would be effective at managing surface water flood risk (see above).

Costs are based on an equivalent volume of storage, but we recognise some variability in individual SuDS interventions that may not be accounted for.

2.6 Approach to costing of schemes

This section describes the approach to deriving unit cost and carbon models that were used to support the optimisation approach. A high-level approach to costing was used which is consistent with projects to inform regional planning. Appendix B sets out the specific values for the different models that were used.

2.6.1 Format of asset life cycle unit cost and carbon models

A series of cost models were developed in a format that enabled them to be automated in the optimisation process.

Each model was defined as a function in one of two forms to represent generalised relationships between cost and an explanatory variable (yardstick). The cost models were of the form:

1. $Linear\ where\ Cost = ax + b$
2. $Power\ where\ Cost = bx^a$

Where a, b and x relate to calculated values based on carbon data and long term costing tool as described below. Yardstick values for the models are set out in Appendix B.

2.6.2 Source of cost data

Data to build the cost models was sourced from the series of evidence documents that were developed to support the Environment Agency Long Term Costing Tool. This summary of evidence provides indicative costs and guidance for range of flood mitigation measures.

2.6.3 Source of carbon data

We obtained the Carbon emissions data from the Environment Agency Carbon Modelling Tool (CMT) version 7.3.

2.6.4 Cost and carbon model categories

Category	Model	Notes
Linear defences	Earth embankment	Assumes 1in3 side slopes and 3m crest width.
Linear defences	High ground	Use embankments.
Linear defences	Vertical wall	(all materials).
Linear defences	Vertical wall raising	(all materials).
Catchment storage	Flood storage	
Natural Flood Management	NFM	Ponds and wetland establishment. Provision of woodland in floodplains, hedgerows, ponds and wetland establishment.
Property Flood Resilience	Residential flood resilience.	Provision of flood-proof doors, external renders and air bricks.
Sustainable urban drainage	SUDs	Filter drains, soakaways, infiltration basin, retention and detention ponds.

2.7 Base year indexing of source cost data

The base year of the source cost data was used to index costs to current year (2020) using Construction Output Price Indices available from the Office for National Statistics.

2.8 Optimism bias

Optimism bias adjustment was applied to account for the systematic tendency for project appraisers to be overly optimistic.

An optimism bias of 35% was applied which falls in the upper end of the recommended range of 3% to 44% for standard civil engineering projects, though we note optimism bias could be as much as 60%.

3 Impacts / benefits

3.1 Introduction

Section 3.2 describes how we have included standard appraisal impacts in this analysis. In addition, we have considered four further categories of benefits:

- Benefits from existing economic activity (see section 3.2.2).
- Benefits from future economic activity (see section 3.4).
- Benefits from uplifts in property values due to flood protection (see section 3.5).
- Carbon impacts, including the carbon costs of flood recovery (see chapter 3.7).

3.2 Standard appraisal impacts

3.2.1 Overall approach

Standard appraisal impacts are assessed in accordance with:

- HM Treasury Green Book (HM Treasury, 2018).
- Flood and Coastal Erosion Risk Management: Appraisal Guidance (FCERM-AG) (Environment Agency, 2010).
- Multi Coloured Manual (MCM) (Penning-Rowsell, et al., Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal, 2013).
- Multi Coloured Handbook 2020 (MCH 2020) (Penning-Rowsell, et al., Flood and Coastal Erosion Risk Management: Handbook for Economic Appraisal, 2020).

Following the guidance in FCERM-AG, economic assessments should adopt a **proportionate** approach. This is to ensure enough information has been collected to make a robust and defensible decision but to remain proportionate so as not to expend resource on collecting data that that will not have a material impact on the assessment. We have followed a proportionate approach in undertaking our assessment and determining the methods we have applied to calculate benefits.

A high degree of automation is required due to the large number of scenarios / hydraulic model runs anticipated. Automated approaches have been successfully used on a number of projects, including the Thames Valley Flood Scheme. Jacobs have also developed the Damage Calculator software which is used for almost all projects in the UK, and our assessment of the 'ease of automation' in Table 3.1 is based on our knowledge of our existing tools and their application on past projects. Further efficiency was obtained via automation by directly loading and batching run scenarios.

Table 3.1 outlines the full range of impacts specified in the MCH and specifies, based on ease of automation and complexity of analysis versus value, which impacts are considered within this study.

Table 3.1. MCH Damage categories included in our analysis and related approaches.

Type	Sub-type	Ease of automation	Included in OxCam study?	Summary approach
Residential	Building, content and clean up (direct)	Easy	Yes	Uses MCH data and capped at Land Registry average market values.
	Health: intangible	Complex	No	Based on Environment Agency guidance. This has been excluded due to the complexity of the analysis and the expected added value.
	Vehicle damages	Easy	Yes	Uses MCH data.
	Temporary and alternative accommodation	Easy	Yes	Uses MCH data.
	Socio-economic equity	Complex	No	The approach would be based on DeFRA guidance. We have selected to exclude this due to the complexity of the analysis and the expected added value.
	Mental health costs	Easy	Yes	Based on Environment Agency guidance.
Non-residential	Building, content and clean up (direct)	Easy	Yes	Uses MCH data for depth damage, capping and write-off.
	Indirect	Easy	Yes	Uses specified percentage of Direct Damages in accordance with MCH.
Risk to life		Complex	No	This would be based on DeFRA guidance. We have excluded this due to the complexity of the analysis and the expected added value.
Other flood losses	Infrastructure damages	Complex	No	Proposed for potential inclusion as non-monetised impact metrics to support the benefits narrative, rather than economic benefits. See Section 3.4 for more details.

Type	Sub-type	Ease of automation	Included in OxCam study?	Summary approach
	Transport delay damages	Moderate	Yes	MCH approach, detailed local data or modelling of effect on transport network (roads). See section 3.5 for more details.
	Emergency response and recovery	Easy	Yes	Uses MCH data.
Recreation		Complex	No	MCH approach, detailed local data on attendance figures, and whether comparable alternative recreation facilities are available elsewhere may be required. We have excluded this due to the complexity of the analysis and the expected added value. (see Section 3.7 for more details)
Agricultural		Moderate	Yes	See section 3.8 for more details.
Environmental		Complex	Yes	See section 3.6 for more details.
Changes in property prices		Moderate	No	Research in this area relating to long term property prices is inconclusive
Carbon		Moderate	Yes	Estimating the quantity and value of carbon emissions associated with investments and provision of flood resilience interventions and estimating carbon emissions associated with disruption, repair and replacement as a result of flood damages

3.2.2 Capping and write-off

Capping and write-off are applied as part of the analysis process for fluvial and surface water independently. However, limitations to the computational complexity mean that is has not been possible to apply capping and write-off **across** sources. i.e. total PV impacts for a property would not be capped based on the combined fluvial and surface water impacts, and the fluvial analysis may not pick up that the surface water analysis has written off a property (or vice versa). In regard to future properties in different parts of the impact / benefit analysis – in particular where the scope of this analysis goes beyond the scope of current appraisal guidance – we have been careful to ensure any new development does not result in any imminently written-off properties.

3.2.3 Infrastructure (utilities) impacts

Representing true utilities infrastructure impacts is a complex process at any scale. A number of considerations were necessary including:

1) **Data** providing a suitable representation of infrastructure sites and assets that identified individual infrastructure assets
2) **Resilience** of individual sites or assets and related impact from flooding
3) **Redundancy** of the infrastructure network. Translating site or asset failure to system failure
4) **Linking networks to users**. Failure of an infrastructure site which leads to a loss of service then needs to be linked to the users (e.g. homes and businesses) who are affected.

The Multi-Coloured Manual (MCM) provides guidance on flooding costs to infrastructure including electricity, gas, telecommunications, water and water treatment assets. It additionally states: 'Proportionality is a key feature of infrastructure assessment. The effort in the assessment of any type of loss should be proportional to its impact and although it may be technically feasible to assess the potential of loss to many assets, it may not be effective or necessary to do so'. It then recommends proportionality tests for each infrastructure type.

Ultimately, we found that there was no viable solution in which to include the infrastructure damage impacts in a defensible manner for economic damages avoided. This is an area where further research could benefit future assessments.

3.2.4 Road transport delay damages

3.2.4.1 Selection of an approach

Three potential approaches to calculating road delay damages were considered for the OxCam scheme:

1) A simple percentage uplift based on data from historical flood events.
2) The **Delayed Hour method**, a more sophisticated approach described in the MCM. This approach uses readily available data in the form of depth grids from the hydraulic modelling which is to be undertaken, traffic flow data available from the Department for Transport (DfT), and a road network map also available from the DfT. Costs of flooding are then obtained by multiplying number of vehicles delayed at a range of locations by cost per vehicle and duration of flooding. DfT's Transport Appraisal Guide may also be used to define appropriate values of time for diverted or otherwise delayed vehicles, as necessary.
3) The **Diversion Value method**, a yet more sophisticated approach also described in the MCM. This approach uses the data described above for the Delayed Hour Method, but also makes use of GIS routines to find alternative routes to flooding, rather than assuming a delay cost per vehicle.

Through discussions with the Environment Agency project team and Jacobs appraisal experts, we have agreed to adopt the Delayed Hour Method, as it provides greater granularity than a simple damage uplift factor, yet is still proportionate to the scale of analysis. The Diversion Value Method would involve significant additional GIS work which was considered excessively complex for a study of this nature, especially given uncertainty in the future transport network.

3.2.4.2 Our process for quantifying impacts

Our approach is as follows:

1) Ordnance Survey OpenRoads data. This provides a spatially accurate routable network at an appropriate level of detail for this scale of analysis (compared with the more complex Ordnance Survey MasterMap Highways Network dataset).
2) Annual Average Daily Flow (AADF) traffic data from the Department for Transport (Department for Transport, 2020). This is tabular data accompanied by a major road link network spatial dataset – however, this was not suitably spatially accurate to apply in the analysis.
3) Attribution of traffic data to the spatially accurate network dataset. For this, we have:
    a) Identified the start and end points of each link on the road network for which AADF data is available.
    b) Used ArcGIS routing tools and the OpenRoads data to find the route between the start and end points of the link, generating a spatially accurate road link between those points.
    c) Attributing tabular AADF data to those links.
4) Developed a processing tool which accepts flood depth grids as an input, and:
    a) Intersects the attributed road network with the flood depth grids to find the road links disrupted due to flooding.
    b) Applies the MCM Delayed Hour method to quantify the cost of disruption **per hour of disruption** to each road link based on the traffic data. This includes consideration of the different classes of vehicle and their typical speeds.
5) Cataloguing these impacts (alongside others) in the results database against each simulated model output.
6) As part of the annualisation process when results are extracted, estimating the duration of disruption based on the AEP of each event.

3.2.4.3 Application of the Delayed Hour approach

The Delayed Hour method uses the following equation:

CD = VD x AC x D

Where:

- CD is the estimated costs incurred during disruption (£).
- VD is the number of vehicles delayed per hour. For each road link, this is generated from the AADF daily flow divided by 24 for an hourly figure. While traffic flows are variable over the course of a day, this gives an average hourly vehicle count based on an assumption that flooding is equally likely to occur at any point in the day.
- AC is the additional cost per vehicle (£). This is taken from Table 6.11 of the Multi-Coloured Handbook (Penning-Rowsell, et al., Flood and Coastal Erosion Risk

Management: Handbook for Economic Appraisal, 2020), which provides “pence per km” disruption values categorised by a) speed and b) vehicle type. We have assumed typical speed values for vehicle classes and road classes.

- D is flood duration (hours). As noted above, the initial calculation calculates values per hour of disruption for a specific simulation, which was then be multiplied by an estimated duration at the point where results are annualised. This is taken from Table 6.12 of the Multi-Coloured Handbook, which provides an indicative delay duration at different AEPs.

3.2.4.4 Uncertainty

There are 2 main uncertainties resulting from this approach:

- The forecast increases in traffic may create an over-estimate in damages as the vehicles per hour may not fit on the existing road network.
- New roads are excluded. However, they would carry some of the increased traffic flows described above, and may also be subject to flooding – so it could be assumed that these uncertainties dampen the effect of each other.

3.2.5 Environmental and Ecosystem Service Impacts

As stated in the Multi Coloured Handbook (MCH) (Penning-Rowsell, et al., Flood and Coastal Erosion Risk Management: Handbook for Economic Appraisal, 2020), “In principle, all environmental costs and benefits that can be valued in monetary terms should be included in the benefit-cost analysis.” Exceptions are made for when valuation is likely to be very difficult or disproportionately expensive, where sensitivity testing can demonstrate that it would not impact the choice of scheme/option, or where no meaningful monetary valuation is possible (in which case environmental costs and benefits should be fully described).

Defra’s newly published guidance on outcome measure 4 (OM4) (Environment Agency, Partnership funding: Supporting guidance for Outcome Measure 4, 2020) in the partnership funding calculator provides default values for capturing benefits related to a net change in hectares of habitats created or improved. OM4A provides values per broad habitat type (£/ha/year) covering intertidal, terrestrial and river habitats, and are provided based on poor, moderate, and good condition. OM4B provides values for projects that enhance habitats, physical features and natural functioning of watercourses.

While the guidance values are intended to target environmental gains, in theory the default values could be applied to capture environmental losses under the do nothing scenario – for example where the current status of habitats is expected to deteriorate from good to moderate or moderate to poor as a result of inundation. Care has to be taken not to double count with the agricultural assessment in considering arable land.

To assess impacts under OM4A, habitat data was sourced from the Priority Habitat Inventory (Natural England, Priority Habitat Inventory, 2020) and matched to the broad habitat types outlined in the OM4 guidance using the UK National Ecosystem Assessment (UKNAE) classification. These habitat layers were intersected with flood extents under the Do-Nothing and Do Something scenarios. The hectares flooded under each scenario were multiplied by the default values in Table 3.2 to estimate the gains/losses resulting from permanent changes in condition as a result of flooding.

Estimating habitat condition is challenging at a catchment scale. Different habitats have different tolerance and resilience to flooding. This depends on factors such as flood frequency, duration, timing (e.g. season), water depth, soil drainage, water quality and water temperature. According to research undertaken by the Environment Agency, wet woodlands have a recovery period of greater than 6 years for a short term flood event and would not recover from a medium or long duration event. However, semi-improved grasslands have a recovery period of 3 years from a short duration flood event, 6 years for a medium duration event and would not recover from a long duration event (Environment Agency, 2009). As this is a high-level strategic assessment, the habitat values applied to each intervention are taken as difference between the value of a habitat's moderate and poor habitat condition as a per annum value to be conservative. We treated damages as one-off impacts and presented them as avoided costs.

Table 3.2. Default OM4A habitat values (uplifted to 2020 prices/ha/year).

	Poor	Moderate	Good	Moderate to poor
Intertidal	£ 1,938	£ 6,679	£ 11,430	£ 4,741
Woodland	£ 1,146	£ 3,584	£ 6,721	£ 2,438
Wet Woodland	£ 1,146	£ 3,584	£ 6,721	£ 2,438
Wetlands/ wet grassland	£ 698	£ 2,126	£ 3,553	£ 1,427
Grassland	£ 63	£ 115	£ 511	£ 52
Heathland	£ 94	£ 1,459	£ 2,834	£ 1,365
Arable not included so as not to double count with agricultural land assessment				

To assess impacts under OM4B, we have applied the default values in Table 3.3 as benefits to all options which would result in improvements to the physical features and natural processes of watercourses above the current baseline. Interventions which were not considered to result in restoration were excluded from the analysis.

Table 3.3. Default OM4B values for length of river habitat enhanced (Uplifted to 2020 prices/km/year).

OM4B Categories	(£/km/yr) (£2020 prices)
Comprehensive restoration of natural processes, habitats and removal of physical modifications	£13,754
Partial restoration of natural processes, habitats and partial removal of physical modifications	£6,877
A single major physical or habitat enhancement	£3,438

3.2.6 Recreation

We have not included recreational benefits in the impact assessment for OxCam.

The Multi Coloured Handbook (MCH) (Penning-Rowsell, et al., Flood and Coastal Erosion Risk Management: Handbook for Economic Appraisal, 2020) sets out an approach for capturing recreational gains/losses which are calculated by multiplying the £ value per recreational visit (often a small number) by the number of visits or beneficiaries (often a large number). As noted in the MCH "the crucial stage in estimating recreational benefits is usually the estimation of the number of visits or beneficiaries."

MCH recommends an initial study stage for projects and for strategy studies. Data is provided on annual visitor numbers from example sites ranging from 30,000 pa (local park – low estimate) to 250,000 pa (honeypot site – high estimate). This can be combined with £ value of losses and gains per visit for various changes at river sites such as low flows and full river restoration ranging from £2.57 to £5.19 per visit.

The approach set out in the MCH does not account for the creation / generation of new visits that may result from a scenario – rather it relies on capturing changes from the 'value of enjoyment' (VOE) of existing visitor numbers.

We have excluded recreational benefits for the following reasons:

- The value of recreational gains/losses is likely to be dwarfed by other impact categories. As noted in Appendix 8 of MCH 2020, "Flooding along rivers will usually cause only a temporary loss of recreation and amenity to those using rivers and riversides for recreation… Thus, usually there will be too few visitors and recreation benefits to justify protecting undeveloped riverside sites".
- 'Do something' interventions may result in recreational benefits for example, flood storage areas providing a new recreational resource, raised embankments providing enhanced views and/or safer access. However, at the strategic level of the OxCam investment study it is not possible to identify the number and nature of such interventions at specific locations in order to meaningfully estimate recreational benefits.
- The approach set out in MCH does not consider effects on non-river recreational sites that may be impacted within the flood envelope.
- Recreation and tourism benefits were partially captured under 'environmental benefits' by applying the generic values under OM4a and OM4b.

It would be possible to undertake an additional task to look at recreational gains/losses at existing sites as well as potential creation of new sites using the ORVal (Outdoor Recreation Valuation) tool. ORVal maps the location and extent of recreational resources including nature reserves, country parks, golf courses, core paths and PROW etc along with estimated annual visitor numbers and associated welfare values (£). The data in ORVal could be intersected with the flood envelope for various events to assess temporary losses in recreational use as a result of flooding. Careful consideration of the availability of alternative sites would be required to capture the transfer of recreational use from one site to another which is not a true economic cost.

ORVal could also be applied to estimate the change in visitor numbers / welfare values as a result of interventions for example altering the landcover at existing sites to enhance natural flood protection or create a new flood storage site altogether with associated recreational benefits. However, the level of assumptions that would be required based on the very high-level development of intervention scenarios may not be appropriate for this type of analysis.

3.2.7 Agricultural Impacts

As stated in the MCH (Penning-Rowsell, et al., Flood and Coastal Erosion Risk Management: Handbook for Economic Appraisal, 2020) "At a broad catchment scale, appraisals will at least require information on categories of land use, and the extent to which these might be affected by a change in flood frequency." However, any estimates are likely to be dwarfed by other impact categories "…for major flood events in the UK, agricultural losses tend to be a relatively small proportion of total damage costs" [ranging from 3-8% based on major recent flood events]. Given the prevalence of high-quality agricultural land in the OxCam Growth Arc, we have undertaken a high-level assessment of agricultural benefits.

There are three scenarios which reflect the nature of impacts on agricultural land from flooding:

1) Permanent loss of agricultural land (3.2.7.1).
2) One-off damages arising from infrequent flood events (3.2.7.2).
3) A permanent change in agricultural land type/productivity as a result of flood risk management standards (3.2.7.3).

The consideration of each scenario is explained below. It should be noted that due to the scale of the analysis, some high-level assumptions have been applied to the assessment. For example, individual schemes will not all impact on the duration and depth of flooding on agricultural land in the same way so a simplification was required. Similarly, conditions that can affect soil quality such as salt water have not been considered. It is also assumed that the land is used at 100% capacity within one season of the event occurring and that drainage conditions are of average condition across the study area.

In addition, we need to ensure that we correctly reflect the loss of agricultural land over time due to urbanisation in the study area, so we do not over-estimate / double count agricultural benefits in future years (3.2.7.4).

3.2.7.1 Scenario 1: Permanent loss of agricultural land

The assessment of permanent loss of agricultural land considered land that is abandoned or no longer fit for agricultural use for the foreseeable future due to a high frequency of inundation. For this assessment, we overlaid Agricultural Land Classification (ALC) data from Natural England (Natural England, Provisional Agricultural Land Classification, 2020) with flood extents under the Do Nothing and Do Something scenario for each intervention. As per Defra guidance, the avoided permanent loss of land was valued at its market value, less £600/ha to reflect the subsidy effect of farm income support. We treated damages as one off write-off damages and included in the PV calculation as avoided costs. Average land values for each ALC grade have been adapted from Savills Farmland Values Survey (Savills, Rural Land Values, 2020) and uplifted to 2020 prices as per Table 3.4.

Table 3.4. Cost per hectare of agricultural land by ALC grade and land type.

Land Type	2019 £/hectare	Equivalent ALC Grade	Value applied (less farm income support subsidy of £600) Inflated to £2020
Prime Arable	£21,535	1	£21,376
Prime Dairy	£16,721	2	£16,464
Grade 3 Arable	£18,021	3	£16,856
Poor Arable	£16,190	3	
Grade 3 Livestock	£13,304	4	£12,977
Poor Livestock	£10,084	5	£9,691

3.2.7.2 Scenario 2: One off damage from infrequent flood events

The assessment of one-off damages refers to situations where there is a reduction in yield for a temporary period. We have taken the seasonally-weighted cost of a single annual flood event by land use type from Table 9.7 of the MCH and mapped to ALC grades as seen in Table 3.5. The cost of a single annual flood has been averaged to take into account varying drainage conditions across the study area. Values are uplifted to 2020 prices to calculate the cost of a single annual flood event by ALC grade. Whilst the MCH takes into account drainage condition, estimating drainage conditions at a catchment scale is challenging. We have therefore considered all agricultural land to have average drainage conditions.

Table 3.5. Cost of a single annual flood by land use and ALC grade.

Land Type	ALC Grade	2019 cost of single annual flood (£/ha)	Cost of a single annual flood (£/ha) inflated to 2020 prices
Horticulture	Grade 1	£ 1,154	£ 1,178
Intensive arable including sugar beet and potatoes	Grade 2	£ 1,154	£ 1,178
Extensive arable: cereals, beans, oil seeds	Grade 3	£ 357	£ 364
Intensive grass: improved grass, usual dairying	Grade 4	£ 113	£ 115
Extensive grass, usually cattle and sheep	Grade 5	£ 75	£ 77

We adapted the minimum acceptable flood frequency for each ALG grade from Table 9.1 of the MCH, taking into account flood probability during the whole year and summer season. The maximum annual event probability suitability per ALC grade is shown in Table 3.6.

Table 3.6. Proposed Annual Event Probability suitability for ALC grade types.

Proposed ALC Grade	Agricultural land use type	Common minimum acceptable flood frequency: annual	Common minimum acceptable flood frequency: annual probability – Summer-April-October	Assigned maximum AEP from modelling
1	Horticulture	5%	1%	3%
2	Intensive arable including sugar beet and potatoes	10%	4%	5%
3	Extensive arable: cereals, beans, oil seeds	10%	10%	10%
4	Intensive grass: improved grass, usual dairying	50%	20%	20%
5	Extensive grass, usually cattle and sheep	>100%	33%	50%

As per scenario 1, we overlaid ALC data from Natural England with flood extents under the Do Nothing and Do Something scenario to calculate the hectares of each ALC grade affected by each intervention. Application of these values to calculate average annual damages is explained below.

3.2.7.3 Scenario 3: A permanent change in agricultural land type due to a change in flood management standards

The basis of this calculation is a permanent loss of agricultural output and hence net margin. The proposed net margin per hectare is taken from Table 9.5 in the MCH. As per scenario 1, land use types have been mapped to ALC grades and uplifted to 2020 prices to calculate the net margin per hectare per year as seen in Table 3.7. For the purposes of the assessment, the horticulture land use category is treated as grade 1 and assumed to achieve the same net margin as the intensive arable and winter wheat categories.

Table 3.7. Net margin per hectare per year by ALC grade.

	Proposed ALC grade	Proposed net margin (per ha per year) (£2019)	Proposed net margin (£/ha/y) Inflated to 2020 prices
Horticulture	1	£187	£ 191
Intensive arable	2	£187	£ 191
Winter wheat	3	£187	£ 191
Extensive arable	3	£166	
Dairy Cows	4	£187	£ 191
Beef and Sheep	5	£17	£ 17

The loss of net margin is calculated as follows:

$$\begin{aligned} &Loss\ of\ net\ margin \\ &\quad = Net\ margin_{OLD}\ (based\ on\ orginal\ ALC\ grade) \\ &\quad - Net\ margin_{NEW}\ (based\ on\ ALC\ grade\ with\ new\ flood\ probability) \end{aligned}$$

As seen in Table 3.7, there is no change in net margin for ALC grades 1-4. Therefore, this scenario was not considered in the calculation of average annual damages.

3.2.7.4 Calculation of average annual damages and Net Present Value under scenario 2&3

Table 3.8 summarises the proposed value per hectare under each annual event probability, considering the three scenarios presented above. For scenarios 2&3, the average annual flood damage was calculated by multiplying the cost of a single annual flood by the maximum annual event probability under each intervention.

Table 3.8. Proposed value per hectare under each annual event probability by ALC grade.

Proposed ALC grade	Proposed value per hectare for each annual event probability						
	0.5	0.2	0.1	0.04	0.02	0.01	0.005
1	*Written off*	*Grade 1 to 4*	*Grade 1 to 2*	*Grade 1 to 1*			
	£21,376	£115	£1,178	£1,178	£1,178	£1,178	£1,178
2	*Written off*	*Grade 2 to 4*	*Grade 2 to 2*				
	£16,464	£115	£1,178	£1,178	£1,178	£1,178	£1,178
3	*Written off*	*Grade 3 to 4*					
	£16,856	£115	£364	£364	£364	£364	£364
4	*Written off*	*Grade 4 to 4*					
	£12,977	£115	£115	£115	£115	£115	£115
5	*Written off*	*No change*					
	£9,691	£77	£77	£77	£77	£77	£77

Further explanation of each scenario and their treatment in this assessment are explained below in Table 3.9.

Table 3.9. Flood scenarios and their treatment for the calculation of agricultural damages.

Scenarios and their treatment	
1	Scenario 1 – Assumes that both arable and pastoral land with an onset of flooding greater than a 1 in 2 year event will be abandoned. Land is written off at the estimated land value, less subsidy of farm income support as per Table 3.4.
2&3	Scenario 2 & 3 – considers a change in gross margin as a result of land moving from a high value ALC grade to a low value ALC grade. Based on the proposed values in Table 3.8 the assessment assumes there is no change in net margin between ALC grade 1-4.
2	Scenario 2 – considers the loss of gross margin as a result of a single flood event, taking into account the minimum acceptable flood frequency (see Table 3.6).

3.2.8 Mental health costs

The contribution of mental health costs to the economic damage caused by flooding has recently been recognised – there are higher rates of anxiety, depression and post-traumatic stress disorder (PTSD) after flooding has occurred. The costs associated with these illnesses include treatment costs and loss of employment This was assessed and monetised in accordance with the Environment Agency guidance 'Advice for Flood and Coastal Erosion Risk Management Authorities - Mental Health Costs of Flooding and Erosion' (Priest & Viavattene, 2020). Implementation of this guidance makes use of available flood depth and property type data to assign monetized mental health damages to residential properties. These values are then converted to annual average damages and discounted in accordance with the 'Health' discount rates in the Treasury Green Book.

Mental Health costs per adult for a range of flood depths is shown in Table 3.10

Table 3.10. Mental health cost per adult at different flood depths

Depth (m)	Losses Per Adult (£)
0	1,878
0.3	3,028
1	4,136

The average number of adults for a range of residential property types is shown in **Error! Reference source not found.**

Table 3.11. Average adult occupancy per property

Property Type	Average Adult Occupancy
Detached	2.01
Semi	2
Terrace	1.95
Flat	1.45

The total mental health costs for a range of residential property types and a range of flood depths is shown in **Table 3.12**

Table 3.12. Losses per property type by depth

Depth (m)	Total Losses per Property Type (£)			
	Detached	Semi	Terrace	Flat
0	3,775	3,756	3,662	2,723
0.3	6,086	6,056	5,905	4,391
1	8,313	8,272	8,065	5,997

The data was combined with the impact of individual interventions to assess the economic benefit from avoided mental health costs.

3.3 Existing economic activity

Using methodologies broadly aligned with FD2662 'Flood and coastal erosion risk management and the local economy' (Frontier Economics, 2014), we undertook economic analysis to forecast the level of economic activity (measured in terms of full-time equivalent jobs and gross value added [GVA]) impacted by temporary and permanent closure of businesses in response to flood events.

Specifically, the analysis is based on the following steps:

- Combined National Receptor Dataset (NRD) information with flood modelling outputs to understand the number, size and type of non-residential properties inundated across various flood extents under the baseline and intervention scenarios.
- For each flood extent and scenario, we used floorspace data in the NRD dataset to translate property data into employment data using workforce density benchmarks sourced from the Homes and Community Agency's 'Employment Density Guide'. Note that the broad land use categories identified in the NRD data and the associated employment density benchmarks are outlined in the table below:

Table 3.13. Employment density by NRD category.

MCM Code	Land Use/ Property Type	Employment Density (sq m per employee)	Note
2	Retail	17.5	Mid-point of High Street Retail and Foodstore benchmarks
3	Offices	12	Professional Services benchmark
4	Warehouses	77	Regional Distribution Centre benchmark
5	Leisure and Sport	100	Approximate average across all D2 Leisure benchmarks
6	Public Buildings	45	Recognising range of potential uses, pivots from the office and other attractions benchmarks in Employment Density Guide, plus other Non-B Use classes within Wiltshire's 'Workspace and Employment Land Strategy'
8	Industry	36	B2 Industrial and Manufacturing benchmark

- Monetised the employment data using sector-specific annual GVA per employee data derived by combining aggregate GVA data[2] with aggregate employment data[3] at sector and local authority level, as noted in the table below:

Table 3.14. GVA per employee per annum by NRD category.

MCM Code	Land Use/ Property Type	GVA per Employee per Annum (2020 Prices)	Note
2	Retail	£43,615	Based on wholesale and retail trade and accommodation and food service sector benchmarks

[2] Regional gross value added (balanced) by industry: local authorities by NUTS 1 region
[3] ONS Jobs density split into sectors using Business Register and Employment Survey data

MCM Code	Land Use/ Property Type	GVA per Employee per Annum (2020 Prices)	Note
3	Offices	£80,449	Based on information and communication, financial and insurance, real estate, professional/scientific/technical admin and support service and public administration and defence sector benchmarks
4	Warehouses	£47.856	Based on transport and storage sector benchmarks
5	Leisure and Sport	£41,540	Based on art, entertainment and recreation sector benchmarks
6	Public Buildings	£38,720	Based on education and human health and social activities sector benchmarks
8	Industry	£83,671	Based on manufacturing sector benchmark

- Converted the annual estimate of GVA per Employee to 'per flood event' estimate, using sector-specific business downtime durations based on data obtained from academic and an industry literature review. These duration assumptions are listed in the table below.

Note that in the absence of specific data for two year flood events, the business downtime duration has been interpolated. Similarly, for two hundred and thousand year flood events, the business downtime duration benchmark for a one hundred year flood event has been applied.

Table 3.15. Business downtime per flood event by NRD category.

MCM Code	Land Use/ Property Type	Business Downtime by Flood Event (years)					
		5	10	20	50	75	100
2	Retail	0.04	0.09	0.13	0.18	0.27	0.59
3	Offices	0.04	0.09	0.13	0.18	0.27	0.59
4	Warehouses	0.04	0.09	0.13	0.18	0.27	0.36

MCM Code	Land Use/ Property Type	Business Downtime by Flood Event (years)					
		5	10	20	50	75	100
5	Leisure and Sport	0.04	0.09	0.13	0.18	0.27	0.59
6	Public Buildings	0.04	0.09	0.13	0.18	0.27	0.59
8	Industry	0.04	0.09	0.13	0.18	0.27	0.60

This provides an insight into lost productivity resulting from the temporary closure of businesses under baseline and intervention scenarios. The differential between the scenarios represents the wider economic benefit of intervening.

Note that the temporary closure analysis is being undertaken net of potential permanent business closures in response to flooding. Based on FD2662, a proportion (1-5%) of economic activities defined as having low adaptive capacity are assumed to shut down, resulting in a permanent loss of employment and GVA. Further, a proportion (1-5%) of economic activities defined as having medium/high adaptive capacity and low geographic dependency will relocate, resulting in permanent loss of employment and GVA for the OxCam Arc economy (albeit, not necessarily for the national economy). For the purposes of the current assessment, the high end of this range, i.e. 5% is applied to qualifying businesses. The tables below demonstrate the potential business responses for relevant NRD categories:

Table 3.16. Business characteristics and response to flooding by type/size.

MCM Code	Land Use/ Property Type	Micro Businesses		Small/Medium Businesses		Large Businesses	
		Adaptive Capacity	Location Dependence	Adaptive Capacity	Location Dependence	Adaptive Capacity	Location Dependence
2	Retail	Low	High	Low	High	High	High
3	Offices	Low	Medium	Low	Medium	High	Medium
4	Warehouses	Low	High	Low	High	High	High
5	Leisure and Sport	Low	Low	Low	High	High	High
6	Public Buildings	Low	High	Low	High	High	High
8	Industry	Low	Low	Low	High	High	High

Table 3.17. GVA per Employee per Annum by NRD Category.

Adaptive Capacity	Location Dependence	Response Scenario
Medium	Low	Business Relocates
High	Low	Business Relocates
Low	n/a	Business Closes
n/a	n/a	Business Stays

The outputs from the above analysis were an assessment of:

i. Number of jobs and associated GVA permanently lost to the OxCam Arc economy in the absence of intervention.

ii. Annual average number of jobs and associated GVA temporarily disrupted within the OxCam Arc economy in the absence of intervention. This impact was profiled across the full 100-year appraisal period.

The economic impacts described above relate to sub-regional level impacts across the OxCam Arc only. Recognising that in the event of flood-related disruption, consumers could transfer demand and some businesses could transfer activity to other unaffected locations, the sub-regional impacts are converted to national scale economic impacts through consideration of spatial displacement and substitutability of economic activity. At a sector-level, analysis was applied to determine the spatial distribution and importance of key economic activities through metrics such as location quotients and sector densities.

This provided a series of sector-specific factors that translate sub-regional GVA losses into national scale GVA losses, accounting for the relative ability of consumer demand and business activity in each sector to switch from the OxCam Arc to other parts of the UK. Displacement was higher for sectors that comprise businesses with national operations or that allows demand to shift relatively easily (e.g. retail), but lower for sectors with businesses with niche operations (e.g. science and technology activities).

This approach has allowed us to forecast wider economic impacts (and consequently secure significant partnership funding) on a number of previous studies including, Avonmouth-Severnside Enterprise Area Flood Alleviation Scheme.

The table below outlines the adopted assumptions relating to spatial displacement of business activity at a national level:

Table 3.18. Spatial displacement at a national level.

MCM Code	Land Use/ Property Type	Displacement Potential	Displacement Factor
2	Retail	High	100%
3	Offices	Low	25%
4	Warehouses	Low	25%
5	Leisure and Sport	High	100%
6	Public Buildings	Low	25%
8	Industry	Low	25%

Current guidance outlined by central government and key departments (including HM Treasury Green Book, Department for Transport's Transport Appraisal Guide and MHCLG's Appraisal Guide) all identify the importance of capturing national scale economic impacts within value for money metrics such as net present values and benefit cost ratios. Simultaneously, there is ongoing interest in understanding local impacts from the perspective of organisations tasked with unlocking regional and sub-regional economic growth and development (e.g. Local Enterprise Partnerships, Combined Authorities etc). Hence, net present value metrics were prepared reflecting local GVA impacts.

3.4 Future economic activity

It is recognised that the Government's aspirations for economic growth in the OxCam Arc include development of hundreds of thousands of new homes and jobs. These aspirations are articulated in 'The Oxford-Cambridge Arc Economic Prospectus'. The ability of the investment proposals to support these aspirations and unlock development in the Arc was undertaken via the following steps:

- **Identify scale and extent of proposed development:** Utilising spatial data relating to the OxCam development scenarios (developed by ITR, see Section 2.7.2). Specific detail on the type, form and sector of development were influenced by the findings of the Oxford-Cambridge Arc Economic Prospectus, where relevant.
- **Utilising the ITR model, a number of options exist to determine the ability of flood interventions to unlock development:**
  - Option 1: Simplistic approach: Cross-referencing development proposals from the ITR model with the EA's Flood Zone definitions, we determined the number of homes (and on a pro-rata basis, the quantum of employment development) that is earmarked for grid squares currently in flood zones 2 or 3. Although the development model considers flood risk as a disincentive to development, we can assess the scale of development that would be accelerated, enabled or benefitting directly from interventions, based on those grid squares that move from flood zones 2 or 3 to flood zone 1.
  - Option 2: Development incentivisation approach: Explicitly recognising the disincentive to development created by flood risk built into the development model, we can apply the average development differential between grid squares in flood zone 1 versus flood zones 2/3 to understand the additional capacity of grid squares in flood zone 2/3 if interventions upgrade the flood risk to flood zone 1. For example, if the development scenarios demonstrate that there are typically x (more) dwellings per ha earmarked for flood zone 1 grid squares but y (less) dwellings per ha earmarked for flood zone 2/3 grid squares in the Do Nothing/Do Minimum scenario, by moving grid squares from flood zone 2/3 to flood zone 1 in the intervention scenario we could unlock additional residential development in the order of x-y per grid square. Employment supporting commercial development was forecast on a pro-rata basis.
  - Option 3: Planning-based approach: allied to the ITR outputs, we can look at flood risk planning policy for all local planning authorities in the OxCam area to understand their approach to development control. For example, we know that Oxford City Council strongly recommend against development in flood zone 3. Based on a synthesis of OxCam wide policy information, we can understand the scale of land moved from flood zone 2 or 3 (as appropriate) into flood zone 1, which then becomes more attractive and acceptable to development.

  We engaged with the EA economics team in finalising our approach.
- **Monetising the economic impact of unlocking dependent development:** For dependent development quantums identified through the above processes, the quantum of homes was estimated, alongside number of jobs (based on application of plot ratios and employment densities as necessary) and associated GVA (based on application of GVA per employee data). This analysis was informed by the findings of the Oxford-Cambridge Arc Economic Prospectus, where appropriate. Such outputs were viewed as attributable to intervention. Further, land value uplift, associated with converting land from one land use

(e.g. greenfield/agricultural to housing/commercial), will also be estimated for dependent development, utilising MHCLG's land value benchmarks.

- **Estimating inward investment into the OxCam Arc**: by combining BCIS benchmarks for residential/non-residential unit construction costs with the identified quantum of dependent development.

As per the discussion above, all analysis was presented in terms of local and national scale impacts, through consideration of appropriate additionality factors including displacement and leakage. Net present value metrics were prepared reflecting local GVA impacts and national GVA impacts separately. Attribution rates for land value uplift were considered in the context of how much wider public sector expenditure may be required to unlock sites (e.g. through transport infrastructure).

Also note that at this stage, development financial viability has not been considered within the economic analysis. Viability analysis could demonstrate that certain developments could afford to contribute partially or fully towards flood defence infrastructure required to mitigate flood impact relating to an individual or specific set of sites. Whilst it is important to recognise and be aware of potential opportunities for partnership funding (particularly with private sector/developer partners) as the project progresses, the focus of the current analysis is around identifying total investment costs and economic benefits that might result from a holistic set of flood defence infrastructure initiatives. Detailed analysis of development affordability and viability should be considered at the partnership funding stage.

3.5 Property value impacts

3.5.1 Introduction

Research demonstrates that provision of flood defence infrastructure can have variable impacts on property prices depending on the characteristics of properties and their locations. For example, properties directly protected and benefitting from reduced flood impact due to flood defence infrastructure can experience an uplift in value. However, peripherally located properties, particularly in rural areas, can experience a reduction in property value due to perception of increased risk away from flood defences. Further, the impact of flood events on property values could vary temporally, with short term reduction in prices in the wake of a specific event cancelled out by a reversion to original prices in line with wider property market trends.

Within this context we reviewed the following papers to determine if it was possible to identify any robust observable relationships between flood risk and property values:

- (Beltrán, Maddison, & Elliot, Assessing the Economic Benefits of Flood Defenses: A Repeat-Sales Approach, 2018)
- (Beltrán, Maddison, & Elliot, The impact of flooding on property prices: A repeat-sales approach, 2019)

Our review determined that the data was too inconclusive to allow us to take a defensible position around the property value impacts from flooding events. Further detail is set out below.

3.5.2 Beltrán, Maddison, & Elliot, Assessing the Economic Benefits of Flood Defenses: A Repeat-Sales Approach, 2018

The study uses data on 12 million property sales combined with geospatial analysis to identify the impact of constructing flood defences on a property's price over the period of 1995 – 2014. The study uses a Difference In Difference repeat sales methodology to undertake the analysis.

To undertake the econometric analysis, the study obtained data on house prices from the England and Wales Land Registry which included the following information:

- Sale price.
- Date of transaction.
- Address.
- Household characteristics.

This was supplemented with house sale data for the area in question. Within the sample size, on average a property was sold 2.5 times. In order to take into account the role of inflation, all house prices were converted to 2014 prices using the property price index.

Geospatial data describing the spatial location and main characteristics of fluvial and tidal flooding was sourced from the Environmental Agency.

Using post code data, through geospatial analysis, the flood defence measures were mapped to an approximate location. The data captured flood defence structures across the following; floodwalls, embankments, bridges, abutments, high ground, floodgates and demountable flood defences, with each type of flood defence having their own benefits.

Following the run of a regression analysis, the study found that when looking at 5 digit postcode as opposed to 6 digit areas, the benefits generated by larger flood defences, which offer a higher standard of protection, are diminished. This suggests the presences of dis-amenities, whereby the construction of large infrastructure reduces the value of the property.

The result of the regressions are presented below in Table 3.19:

Table 3.19. Capitalisation of flood defences into property prices in England, 1996-2014. 95% confidence interval and mean capitalisation rate in parentheses. Reproduced from (Beltrán, Maddison, & Elliot, Assessing the Economic Benefits of Flood Defenses: A Repeat-Sales Approach, 2018).

	Type of property		Fluvial risk	Coastal risk
6-digit postcode	House	Urban	£28,829 [£12,676 – £45,029] (12.6%)	£45,420 [£20,521 – £70,675] (16.7%)
		Rural	£14,804 [-£2,768 – £32,399] (6.5%)	£28,784 [£2,736 – £54,723] (10.5%)
	Flat	Urban	-£8,290 [-£17,340 – £760] (-4.4%)	-£576 [-£14,165 – £13,006] (-0.3%)

	Type of property		Fluvial risk	Coastal risk
5-digit postcode	House	Urban	£3,203 [-£6,635 – £13,042] (1.4%)	£15,048 [£1,833 – £28,511] (5.5%)
		Rural	-£11,509 [-£22,125 – -£915] (-5.0%)	-£2,326 [-£16,937 – £12,230] (-0.8%)
	Flat	Urban	-£10,819 [-£15,858 – -£5,780] (-5.7%)	-£2,852 [-£9,127 – £3,460] (-1.5%)

The findings of the study show that the impact of flood defence schemes varies by type of flooding, the location of the house and the postcode classification. For instance, when looking at a house at risk of fluvial flooding, construction of a flood defence scheme could increase the property prices by 12.6% as opposed to 1.4% when looking at the 5-digit postcode, a similar trend can be seen for houses at risk of coastal flooding.

The study concludes that in rural areas, the dis-benefits of a flood defence scheme outweigh the benefit it brings as a result of its protection. The study goes on to further state that flood defences constructed also do not seem to benefit flat owners. The rationale provided for this is that, unless the flat is on the ground floor, the flats above would not benefit from flood risk reduction. However, they would still experience the negative dis-amenity impact of the flood defence measures that have been constructed, it is estimated that this leads to a reduction in the price of flats between 0.3 – 5.7%.

The study proposes that further research should be undertaken to assess the impacts of flood defences on house prices in greater depth, such as evaluating the role of multi-function flood defences in helping to reduce the dis-amenity impacts associated with traditional flood defences.

3.5.3 Beltrán, Maddison, & Elliot, The impact of flooding on property prices: A repeat-sales approach, 2019

The study sets out to evaluate the impact of flooding on house prices between the years of 1995 and 2014 using a repeated sales model. From within the sample data, properties on average were sold at least once.

To model the impacts, a hedonic pricing model was set up based on house sales data from England and Wales Land Registry data set which captures all residential and house sales data from 1995 onwards. The data also includes general characteristics around the property such as its age, freehold or leasehold.

Following a data cleansing process which included removing any Wales housing data from the sample size, the data set included 12 million transactions which correspond to 4.8 million properties in England. To ensure a valid comparison, all house prices were converted to a 2014 price year using relevant inflation metrics. The study finds that from the sample size the average transaction value of a house was £234,129. On average, properties were sold 2.5 times during the time frame being evaluated.

Using data from the Recorded Outline of Individual Flood Events in England, the study was able to map out individual areas that have been impacted by flooding. The data set was also able to provide granular data such as the type of the flood; costal or inland and the cause of flooding. Combined with ONS data, the data are dis-aggregated into 6-digit level post code areas that were impacted by the flooding.

Running the hedonic model with the aforementioned data sets, the study finds that inland flooding can reduce a property's value by 31.3%. This figure represents a reduction in price for a property sold immediately after a flooding event. A possible explanation for this is that no repairs have been undertaken at the property and it has been sold with its damages, therefore getting a lower price. The study finds that after 8-9 years, the effect is no longer statistically significant.

Similarly, for properties impacted by coastal flooding, the study finds that the price of detached properties decreases by 40.1%. However as was with the case for inland flooding, after 8-9 years it appears that the price reduction is no longer significant.

The study concludes by finding that even properties that have been significantly impacted by flooding, the reduction in price is only short lived, with even properties in the lowest price quartile recovering in price after 6-7 years. Further research is suggested by the authors around how the impact on insurance premiums for properties located within the flood zones over time.

3.5.4 Conclusion

Given the above research, we did not believe that it was defensible to include any long-term economic benefit related to property prices in flood risk zones.

3.6 Representation of the risk reduction benefits of interventions

Interventions are represented as follows:

- Storage and natural flood management are represented by modifying the water level associated with a given scenario based on catchment hydrology. For a given scenario, different simulations (and their event impacts) are therefore selected as part of the calculations based on the water levels corresponding to the requested intervention scenario. This is described in more detail in the modelling and hydrology technical report.
- Linear defences are represented by explicit modifications to asset crest levels, with flood simulations run to represent those modified crest levels. For a given scenario, the simulations (and their event impacts) corresponding to the requested linear defence scenario. This is described in more detail in the modelling and hydrology technical report.
- Surface water risk management is represented by modifying the AEP of available surface water outputs based on the volume of water on the floodplain. This is described in more detail in the modelling and hydrology technical report.
- Property flood resilience is represented by modifying depth-damage curves to reflect the presence of property interventions. This is described below.

3.6.1 Property flood resilience

A wide variety of 'property flood resilience' (PFR) interventions are possible, ranging from measures which act to keep water out of a property (such as flood proof doors and flood guards) to measures which act to reduce impacts if a property floods (such as raising electrical sockets, waterproof kitchens and waterproof flooring). Each intervention could be brought together in various combinations to create a package of measures most appropriate for a particular property.

LTIS 2019 (Clarke, Long Term Investment Scenarios: Additional Analysis. Topic 5 technical report: Property level resistance and resilience, 2019) explored a range of PFR packages, in turn adapted and updated from previous studies:

a) Flood guards (and accompanying measures, such as non-return valves).
b) Flood-proof doors (and accompanying measures, as above).
c) Resilience measures, excluding flood resilient flooring.
d) Resilience measures, including flood resilient flooring.
e) Flood guards + resilience measures, excluding flood resilient flooring.
f) Flood-proof doors + resilience measures, including flood resilient flooring.

The LTIS 2019 study indicated that (so long as a flood warning service is provided), flood guards (and accompanying measures) provide the most cost-efficient (i.e. highest NPV) property intervention. While this does not reflect the complexity of different properties (in particular due to the limitations of the LTIS 2019 approach) and what the right intervention or set of interventions might be at a local level, adopting a single package of measures should provide sufficient detail to fit the needs of this project: i.e. to find the optimal level and timing of investment. This simplification is also necessary because of the constraints of this project, and because of the scale and complexity of the analysis. While it should not have a significant impact on the overall economic analysis, the main limitation of focussing on flood-proofing rather than wider flood resilience measures is that the approach may not reflect the potential benefits of PFR for properties with significant high-depth flooding (above which protection measures would not be effective). However, the results database is set up to enable a wider range of interventions to be explored within the analysis framework in future.

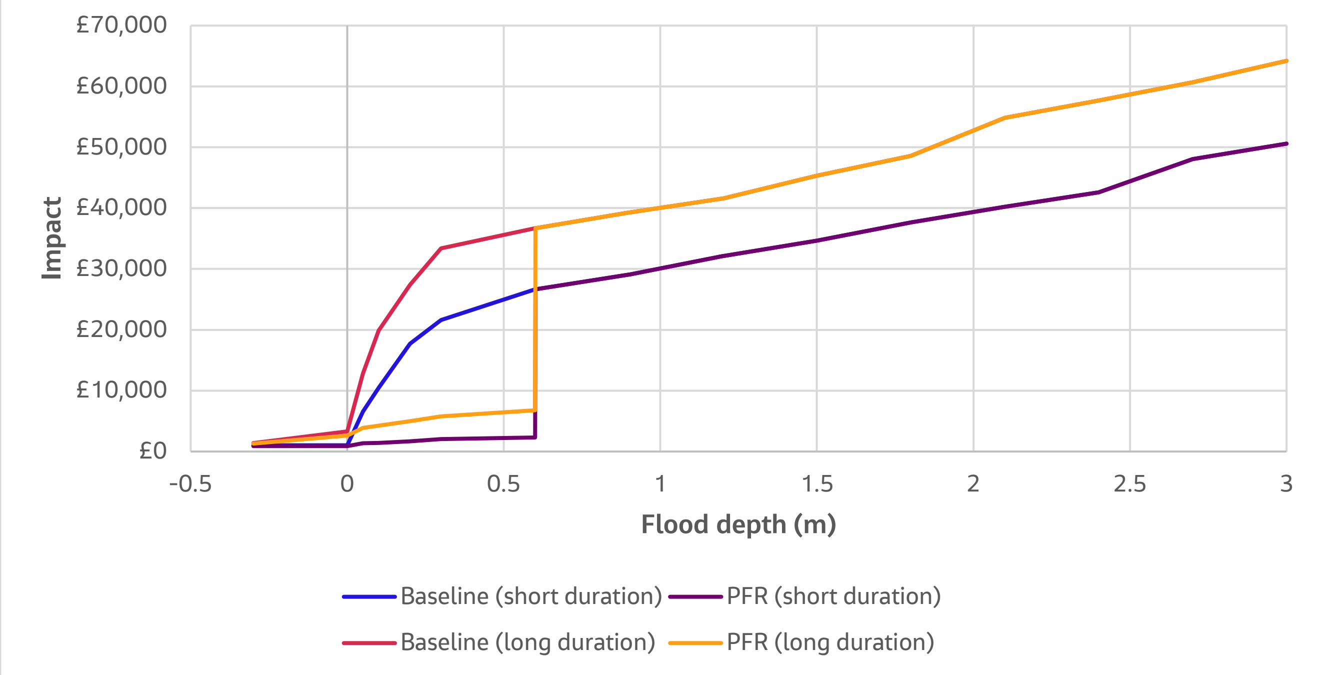

Figure 3.1. Depth-damage curve modifications for property flood resilience.

Figure 3.1 shows the modifications to depth-damage curves applied to represent property flood resilience measures. As the graph shows, it assumes that they are effective up to 0.6m, with no effectiveness above. Damages below 0.6m are not £0, rather the approach breaks down the MCM depth-damage curve into its constituent parts (internal and external; building fabric and inventory; clean-up):

- Flood guards and accompanying measures prevent damage to internal building fabric and inventory up to their effective depth.
- Some seepage is known to occur even when flood guards are in place, so clean-up costs are reduced (to the cost of cleaning up a 5cm flood) but not zero.
- External building fabric and inventory are assumed not to benefit.

These depth-damage curve modifications have been applied to the top-level residential property type (MCM code 0 or 1) – for which we were able to access to fully detailed MCM depth-damage data. From this, the percentage damage reduction at each depth has been calculated, and in turn applied to the depth-damage curves for every **residential** property type.

While there is evidence that there is some take-up of PFR in non-residential properties, there is limited evidence to support the costs and expected benefits for a range of non-residential property types.

3.7 Carbon

3.7.1 Background

The Environment Agency has set itself the aim of becoming a net zero organisation by 2030 – ensuring that its own activities and its supply chain are taking as much carbon out of the atmosphere as it is putting into it. Meeting this goal, which is based on the internationally recognised Science Based Target Initiative methodology, would see the Environment Agency go beyond what was set out in the Paris Climate Change Agreement. It will seek to meet the goal by reducing the emissions of its own activities and supply chain by 45%, with the remaining emissions addressed through tree planting or other measures.

To support the Environment Agency's aim of becoming a net zero organisation by 2030 we wish to include carbon emissions in the benefit assessment for the OxCam.

3.7.2 Approach

This outline methodology describes steps that we undertook to include carbon in the economic analysis in two ways:

- Estimating the quantity and value of carbon emissions associated with investments and provision of flood resilience interventions. These emissions were associated with the 'do something' scenarios.
- Estimating carbon emissions associated with disruption, repair and replacement as a result of flood damages (and hence the potential of carbon benefits for flood resilience schemes on the basis of damages and impacts avoided). These emissions were associated with all scenarios, and highest in the baseline 'do nothing' scenarios.

This is one of the first live projects that incorporates carbon in the economic appraisal in this way, and pathfinding activities were required across the project team.

3.7.3 Carbon associated with investments and provision of flood resilience

3.7.3.1 Scope of types of activity

Table 3.20**Error! Reference source not found.** shows the types of activity at flood risk management system (FRMS) or catchment scale interventions, and whether we assessed carbon emissions.

Table 3.20. Carbon-generating activities for different types of intervention.

Spatial Granularity	Intervention type	Size / amount	Activity		
			Construct and renew	Midlife maintenance	Annual maintenance
Catchment wide	Catchment storage	No storage			
		Small storage	✓	✓	✓
		Medium storage	✓	✓	✓
		Large storage	✓	✓	✓
	Natural flood management	No NFM			
		Some NFM	✓		✓
		Widespread NFM			
FRMS	Linear defences	No linear defences			
		Defences at current levels	✓	✓	✓
		Small raised defences	✓	✓	✓
		Medium raised defences	✓	✓	✓
		Large raised defences	✓	✓	✓
	Property flood resilience	No PFR			
		Some PFR			
		Widespread PFR			

3.7.3.2 Method of quantification

Carbon 'unit emissions factors' were developed to mirror the capital and revenue cost factors that are being developed for cost aspects of the intervention net present value (NPV) analysis. We developed a three-point (low, medium, high) carbon unit emissions factors for each activity type. The three-point estimates could be used to test the sensitivity to carbon emissions uncertainty. The factors quantified carbon emissions in tonnes of Carbon Dioxide Equivalent (tCO2e).

We used the Environment Agency Carbon Calculator to align carbon unit emissions factors with cost factors. We used a bottom-up carbon assessment to create three-point estimate for each activity type.

For some sources of carbon emissions there may be time varying carbon intensities to reflect in the analysis.

3.7.4 Carbon associated with flood damages

The Environment Agency Carbonomics report provides the most recent source of guidance and evidence for including carbon impacts associated with the disruption, repair, and replacement of assets that is required to restore communities following flood events. The information and data tables provided by the Carbonomics report was be used to support evaluating the potential carbon benefit that could be realised by provision of flood resilience schemes.

The scope of the most recent iteration of the Carbonomics work is:

- Residential property carbon impact – detailed look up tables.
- Non-residential property carbon impact – review of methods.
- Non-property carbon impacts – identification of potential sources of emissions.

3.7.4.1 Residential property carbon impacts

The Carbonomics report provides two methods for assessing carbon:

1) Detailed assessment using the carbon depth-damage table appraisal using a Multi-Coloured Manual type analysis.
2) Rule of Thumb approach that estimates carbon emission quantities using ratios based on damage costs.

We used the detailed carbon depth-damage approach because it is well-aligned with the core flood damage calculations being carried out for economic impacts. We have automated the carbon quantification using machine readable tables and calculated the carbon quantities alongside the depth-damage cost. The carbon quantities were monetised in a further step.

The analysis supports the assessment of carbon associated with non-residential damages.

3.7.4.2 Carbon associated with non-residential property damages

Detailed depth-damage tables are not provided in the Carbonomics report for non-residential damages. We created a conversion from residential damages to tCO2e and apply the same conversion to non-residential property losses. We used the comparison information in the Carbonomics report to inform this work.

3.7.4.3 Carbon associated with non-property impacts

Carbon emissions can result from the loss of utilities, infrastructure or services. The emissions were associated with repair, replacement or changes in service from flood impacts. We did not include non-property carbon impacts in the analysis because there is insufficient data and understanding of the impacts to quantify them.

3.7.5 Including carbon in the economic assessment

The output of the calculations above is tCO2e. To include the carbon quantities in the economic assessment, we monetised the impacts. Carbon quantities were converted from tCO2e to £s following government guidelines on EU Emissions Trading System (ETS) or Non-ETS carbon (as applicable) with median and upper limits. The carbon valuations, including time-varying aspects, were included in the NPV and optimisation, and discounted for the analysis. We followed the best available guidance on monetisation from the Department for Business, Energy, and Industrial Strategy (BEIS).

We have presented results from the optimisation with and without carbon included in the NPV outputs, to enable us to understand the effect that carbon has on the optimal level and timing of investment in flood resilience for the OxCam Arc.

3.7.6 Summary

Figure 3.2**Error! Reference source not found.** summarises the proposed method.

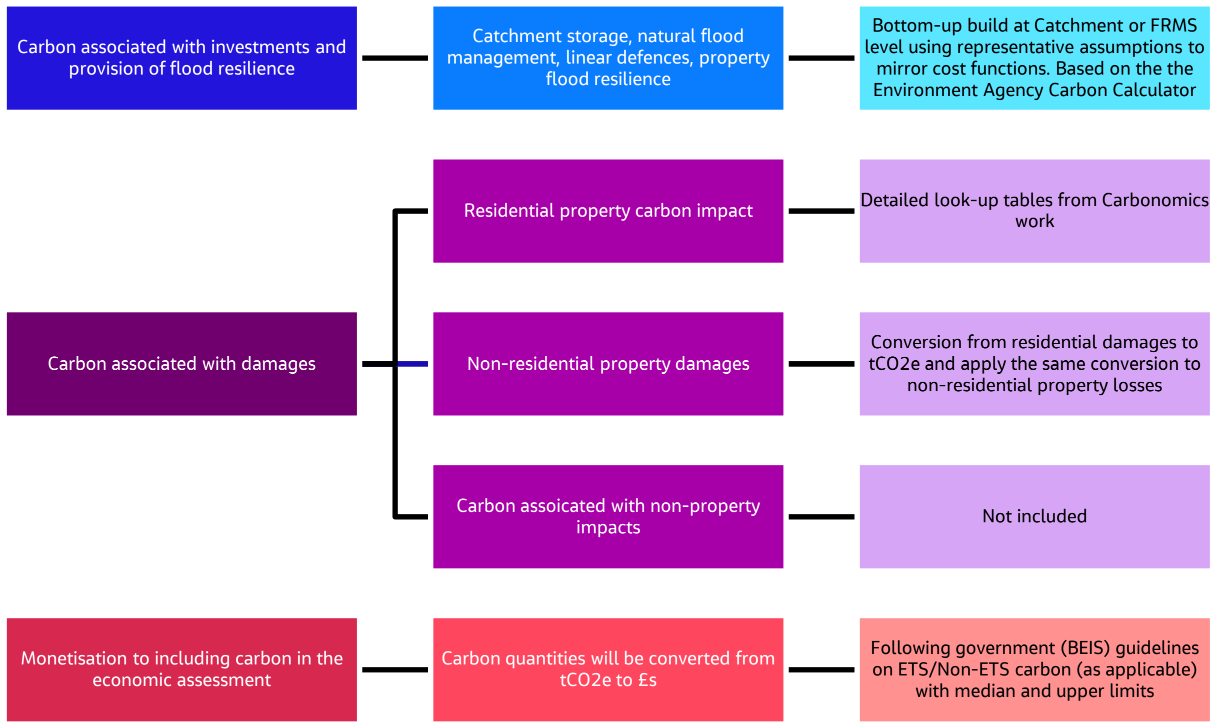

Figure 3.2. Method summary.

4 Development scenarios

4.1 Introduction

This project has adopted development scenarios developed by members of the Infrastructure Transition Research Consortium (ITRC) at Newcastle University. The ambition for these scenarios is to provide a broadly representative range of future development scenarios, rather than explicitly representing local development plans. Within the project, we have processed these scenarios into a form that fits with the needs of our analysis.

4.2 Generation of development scenarios

4.2.1 High-level approach

The high-level approach is as follows:

1) Generation of high-level housing growth statistics (23,000, 30,000 and 43,000 homes per year).
2) Distribution of regional housing growth to local spatial units.
3) Feeding population growth estimates into the Urban Development Model (UDM, developed by ITRC at Newcastle) to predict the spatial pattern of housing development.
4) Applying assumptions of spatial patterns of housing and non-residential development to translate housing density to simulated property point locations.

4.2.2 Housing growth

A Savills report the property market within the Cambridge – Milton Keynes – Oxford corridor (Savills, 2016) produced for the National Infrastructure Commission (NIC) identified 3 scenarios of housing and economic growth, and estimated the population, employment and GVA growth associated with them (Table 4.1).

Table 4.1. Estimated housing and economic growth in OxCam under different scenarios.

Scenario	Population growth	Employment growth	GVA growth	Housing growth
	From 3,341k in 2014 to 2050	From 1,833k in 2014 to 2050	From £90,484m in 2014 to 2050, 2011 prices	New homes per year
Baseline (business as usual)	986k	335k	£85,621m	15,000
Incremental (meeting local need)	1,177k	720k	£123,576m	20,000
Transformational	1,551k	1,104k	£163,151m	30,000*
*23,000 to meet local demand + 7,000 to meet need from connected economies				

The partnering for prosperity report (National Infrastructure Commission, 2017) summarised the housing need for transformational growth as:

"Estimates prepared for the Commission suggest that meeting the needs of the arc's future population and workforce could require 23,000 – 30,000 net new homes per year. While completion rates at the lower end of this range (around 23,000 net new homes per year) may be sufficient to meet the needs of the arc's own future workforce, further development may be required to mitigate the impact of growth and under-delivery of homes in neighbouring, land-constrained markets such as London."

These estimates form the basis of the three housing growth scenarios adopted in this project:

1) 23,000 homes per year.
2) 30,000 homes per year.
3) 43,000 homes per year. This scenario was added as an additional extreme growth scenario, and does not represent the expected level of growth in the OxCam Arc. We have excluded this from the 'multiple futures' optimisation (see the optimisation and adaptation technical report).

4.2.3 Predicting growth

The Urban Development Model (UDM) was developed by researchers at Newcastle University as part of the Infrastructure Transitions Research Consortium (ITRC).

The model predicts the spatial pattern of housing development associated with the population statistics – based on two drivers:

- 'Attractors' which increase or decrease the likelihood of development occurring in a given area, such as availability of transport links – positive or negative factors that encourage or deter growth.
- 'Constraints' – areas where development cannot occur.

The model predicts – for a given rate of housing development – where those homes will be built, based on a 100m x 100m (1 hectare) grid.

Defining different attractors and constraints allows the model to represent different hypothetical planning and growth policies. For example, previous work compared existing planning policy ('grey' scenarios attracting development towards roads) with 'green' planning (attracting development towards public transport and constraining development of high natural capital areas). In this project, we focus on the 'shape' of development – described in the following sections.

The output of the UDM model (at the time of writing) is a 100m x 100m (1 hectare) grid showing a) areas predicted to be developed, and b) the expected density of housing in each grid cell.

4.2.4 Influence of flood risk

For this project, the influence of flood risk is important as the location of new development relative to flood risk could have a large effect on future impacts.

There are a number of possible approaches – within the confines of the development model:

1) Using flood risk – or specifically flood zones – as a constraint on development.

2) Applying flood zones as a 'negative attractor' to discourage development in the floodplain unless other attractors outweigh that negative.

Both of these approaches could arguably represent planning policy – i.e. not allowing development in the locations at highest risk of flooding in (1), or allowing development in the floodplain but only when there are significant drivers for doing so that outweigh the risk in (2). In practice, the latter could for example be because under the National Planning Policy Framework (Ministry of Housing, Communities and Local Government, 2019), no suitable sites can be found in lower risk areas. The Newcastle University model has followed (1) – applying Flood Zone 3 as a constraint to development, but not (2).

Limitations in the approach mean that changes in flood risk cannot be shown to result in changes in development – the development scenarios are an input to the analysis not part of the analysis process itself. This also means that the constraint (Flood Zone 3) is static, so does not reflect changing risk over time.

4.2.5 OxCam growth scenarios

The *Cambridge, Milton Keynes and Oxford future planning options project* (5th studio, 2018) produced for the NIC explored seven different expansion scenarios that aligned with a total population growth of 1.9 million[4] by 2050, including:

- A single large city of c. 1.9 million people.
- Two medium-sized cities of c. 950,000 people.
- Six small cities of c. 320,000 people.
- 50 towns of c. 38,000 people.
- 200 villages of c. 9,500 people.
- Expansion of the eight largest settlements in the corridor ('continuous concentric expansion').
- Concentrated development around and between two (or more) existing settlements to create a single combined settlement ('conurbia') similar to the Birmingham/West Midlands conurbation.

The report translates these scenarios to a series of nine 'development typologies' that may be relevant to the Arc – but concludes that there is no 'one-size-fits-all' development form that fits the Arc, although it recognises that to achieve the 'transformational' growth scenario, larger-scale new settlements are likely to be needed.

4.2.6 Adopted scenarios

The growth scenarios in this project are broadly similar to two of the scenarios above:

1) Expansion of existing settlements. Similar to the continuous concentric expansion scenario described above, but allowing the UDM model to dynamically grow settlements through the adopted attractors and constraints, rather than explicitly directing growth towards a pre-defined set of eight settlements.

4 It is unclear why this population growth estimate of 1.9 million does not align with the 1.55 million described in the Savills report.

2) Creation of new settlements. The model is seeded with – in this case – 5 settlement locations. These are existing settlements around which growth is focussed to the extent where they become new towns / new cities. From West to East:
   a) Bicester.
   b) Winslow.
   c) Cranfield.
   d) St. Neots / Sandy.
   e) Cambourne.

An additional third scenario provides:

3) A hybrid of the settlement expansion and new settlement scenarios.

These scenarios are defined through a series of attractors and constraints, including the influence of flood risk described above. In this application, the model assumes linear growth of housing numbers, i.e. a constant rate of 23,000, 30,000 and 43,000 homes in OxCam, although because of variable housing density, this does not necessarily translate to linear spatial growth.

Results have been produced at 2030, 2040 and 2050 (in addition to our assumed present day of 2020 based on property points in the National Receptor Dataset).

4.2.7 Adopted attractors and constraints

The model described above could be applied with a range of different attractors and constraints to reflect different drivers of housing growth. The adopted attractors and constraints are described in full in 9A, but in summary, the model applied to OxCam uses the following attractors:

- Current Development Proximity.
- Road Proximity.
- Rail Proximity.
- Employment Access by Road (for the settlement expansion scenario).
- Employment Access by Rail (for the settlement expansion scenario).
- Natural Capital Minimum Score.

The model applies a range of constraints – including Flood Zone 3, as described in 4.2.4 above. They are largely the same for all scenarios (see 9A), with the exception of green belts, which are only a constraint in the 'new settlement' scenarios.

4.2.8 Translating spatial housing density to property locations

4.2.8.1 Approach

As noted above, the output of the UDM model is a raster grid describing housing density for a 100m x 100m grid. To apply this data in this analysis, we have used these outputs to generate simulated property points for both residential and non-residential properties which mirror the format of National Receptor Dataset (NRD) points, which means they can (for example) be used in standard depth-damage calculations.

Our process was as follows:

1) Generating a 100m x 100m grid providing full coverage of the OxCam study area.
2) Sampling present day NRD against that grid to quantify the density of a) residential and b) non-residential properties in each grid cell.
3) Grouping each grid cell by residential density (grouped into density categories) and producing statistics describing the average distribution of housing types (detached, semi-detached, terraced or flat, classified as ground floor or upper floor) and the average count and floor area of non-residential properties by property type (based on Multi-Coloured Manual property classification) in each residential density category. See Section 4.2.8.2 below for a summary of these statistics.
4) Estimating the total number and floor area of future non-residential properties by type expected across the OxCam Arc by looping through each grid cell to get an expected average number of non-residential properties by type (given the housing density), then producing a 'list' of simulated non-residential properties assigned with a type and floor area that can then be distributed across the OxCam Arc in the steps below.
5) For each of the nine development scenarios (23,000, 30,000 and 43,000; expansion, new settlement and hybrid):
    a) For each UDM model grid cell in the 'final' (i.e. 2050) outputs:
        i. Estimating the number of ground floor residential properties by looking up the assigned density in the housing type statistics from 3) to get an average proportion of addressable properties which are ground floor, multiplied by the UDM density to get a total count of ground floor properties.
        ii. Creating NRD records for all simulated residential properties, including the classification of housing type and floor level, based on the UDM density entry in 3).
        iii. Randomly assigning upper floor properties to corresponding ground floor property records.
        iv. Estimating the number of non-residential properties expected in the grid cell using the statistics from 3) and picking at random from the list of available properties generated by 4), filtered by the non-residential property types found in the density category. Once 'picked' from the master list of non-residential properties, they are removed from the list.
        v. Produce randomly-generated points within the bounds of the grid cell equal to the count of ground floor properties plus the count of non-residential properties.
        vi. Assign a property record (or for flats, a series of property records) to each of these points.
    b) Writing out these results as a single OxCam-wide point vector dataset containing NRD-like property points for 2050 (for each development scenario).
    c) Sampling this data against the 2030 and 2040 UDM model grids. This identifies the period in which each property is developed, enabling the final step of producing a 2030, 2040 and 2050 additional properties dataset to be produced.

4.2.8.2 Residential property types by density

Table 4.2 and Figure 4.1 show the distribution of residential property types in each residential density category – calculated as described in point 3) above. As would be expected, low density cells are dominated by detached properties. As density increases, semi-detached then terraced houses become most prominent. The most dense grid cells are populated by upper-floor properties (and the corresponding ground floor flats).

Table 4.2. Residential property type distribution by density category.

Residential properties per grid cell	Detached	Semi-detached	Terraced	Ground floor flat	Upper floor
0 to 10	55%	25%	11%	4%	6%
10 to 20	37%	35%	17%	4%	6%
20 to 30	15%	38%	29%	7%	11%
30 to 40	6%	25%	38%	11%	19%
40 to 50	3%	13%	38%	17%	29%
50 to 60	2%	7%	37%	20%	34%
60 to 70	1%	5%	29%	23%	42%
70 to 80	1%	3%	25%	25%	46%
80 to 100	1%	2%	16%	27%	54%
100+	0%	1%	6%	24%	69%

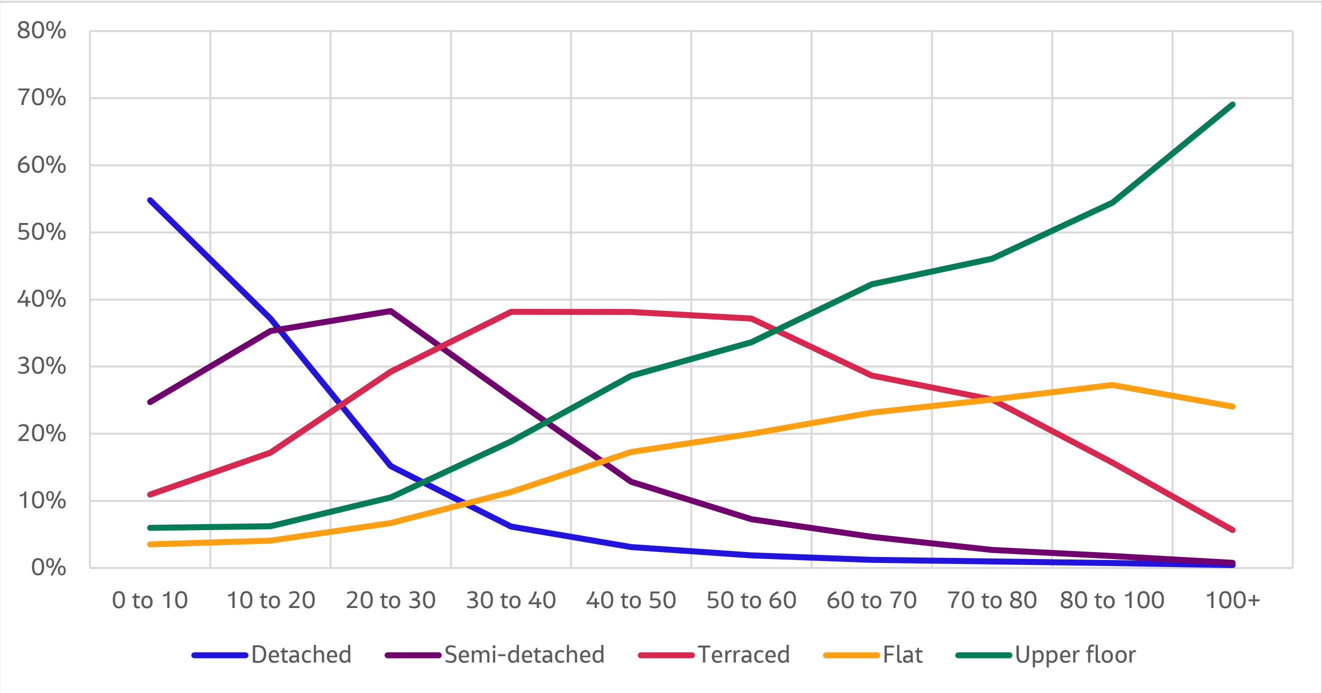

Figure 4.1. Plot of residential property type distribution by density category.

4.2.8.3 Generation of non-residential properties

Non-residential properties are defined slightly differently to residential properties. While the residential property categories are used to classify a pre-defined (from the UDM model) number of properties, the non-residential data is focussed on enabling the analysis to estimate the number and type of non-residential properties that should be added alongside those residential properties.

In the National Receptor Dataset (NRD), non-residential properties are classified by Multi-Coloured Manual property type codes, as described in Table 4.3.

Table 4.3. Non-residential property types (and their MCM codes) used in NRD.

MCM code	Non-residential property type
2	Retail
3	Offices
4	Distribution/logistics
51	Leisure
523	Sports and leisure centres
525	Football ground and stadia
6	Public buildings
8	Industry
9	Miscellaneous
910	Car park
960	Electricity sub-station
999	Unclassified

Table 4.4 shows the average number of non-residential properties per grid cell by non-residential property type in each residential property density category, and Table 4.5 shows the average floor area per property by non-residential property type in each residential property density category. As described in point 4) above, these averages are multiplied by the number of total number cells in each residential property density category across the OxCam Arc to create a 'pick list' of simulated non-residential properties, which are then assigned a location.

Table 4.4. Average number of non-residential properties per grid cell by non-residential property type (MCM code) in each residential property density category.

Residential properties per grid cell	Non-residential property type											
	2	3	4	51	523	525	6	8	9	910	960	999
0 to 10	0.13	0.06	0.03	0.01	0.01		0.08	0.06	0.06	0.02	0.01	1.71
10 to 20	0.41	0.13	0.03	0.01	0.01		0.10	0.03	0.08	0.00	0.04	1.73
20 to 30	0.55	0.15	0.02	0.01	0.00		0.10	0.05	0.12	0.00	0.06	1.51

Residential properties per grid cell	Non-residential property type										
	2	3	4	51	523	525	6	8	9	910	960	999
30 to 40	0.97	0.15	0.02	0.03	0.01		0.14	0.07	0.16	0.00	0.09	1.41
40 to 50	1.21	0.18	0.02	0.03	0.01	0.00	0.19	0.11	0.21	0.01	0.11	1.73
50 to 60	1.46	0.29	0.03	0.02	0.01		0.22	0.11	0.26	0.02	0.12	1.76
60 to 70	1.84	0.33	0.05	0.03	0.01		0.28	0.18	0.29	0.01	0.14	1.87
70 to 80	2.06	0.29	0.04	0.05	0.01		0.22	0.18	0.33	0.05	0.20	2.00
80 to 100	2.37	0.37	0.04	0.07	0.01		0.34	0.14	0.49	0.05	0.22	2.61
100+	3.11	0.56	0.05	0.11	0.03		0.38	0.22	0.68	0.14	0.19	2.94

Table 4.5. Average floor area (m^2) per property by non-residential property type (MCM code) in each residential property density category.

Residential properties per grid cell	Non-residential property type											
	2	3	4	51	523	525	6	8	9	910	960	999
0 to 10	215	171	176	224	387		656	213	131	333	39	90
10 to 20	156	145	465	610	312		367	174	77	371	25	67
20 to 30	142	100	287	202	126		324	293	83	648	29	59
30 to 40	112	151	342	272	635		397	153	71	825	19	62
40 to 50	109	126	154	320	181	47	351	128	62	289	18	71
50 to 60	112	141	234	633	242		298	162	63	116	28	79
60 to 70	107	130	217	315	271		274	133	75	262	24	78
70 to 80	106	147	152	282	408		222	102	90	89	42	82
80 to 100	92	135	237	331	74		216	117	92	106	22	86
100+	96	128	123	238	377		294	108	82	47	69	97

4.3 Development scenario results

4.3.1 Density distributions

The following graphics show the distribution of housing growth under each development scenario (shapes and rates), and the distribution of housing density (homes per hectare grid cell) in each. These results are for 2050 (2030 and 2040 results include a subset of the properties shown here).

- Figure 4.2 shows the high-level shape of development under the different shapes and rates of development across the OxCam Arc, colour-coding developed areas by the density of housing.
- Figure 4.3 shows a more local view for an example location, in this case Winslow in Buckinghamshire.

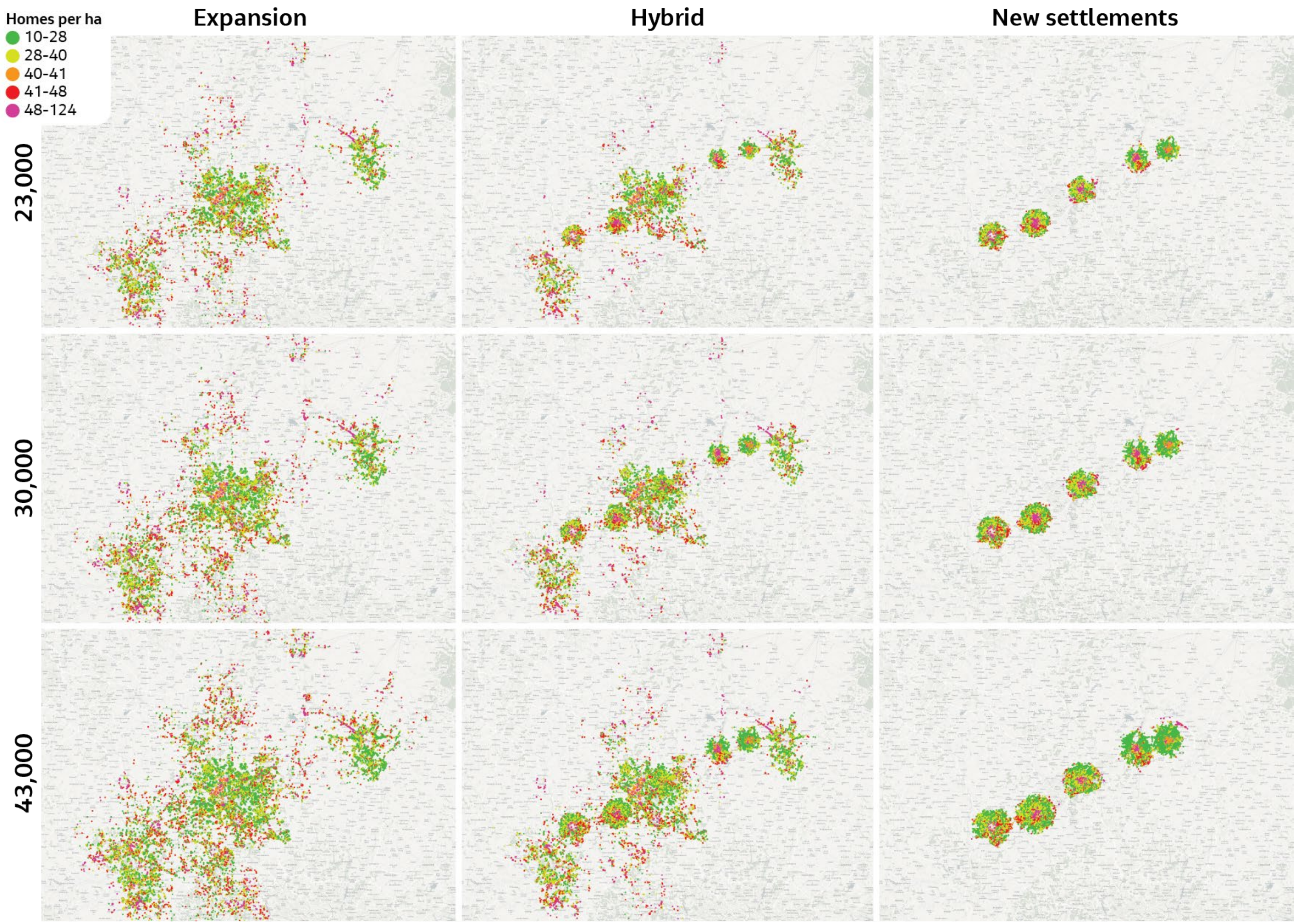

Figure 4.2. Housing density distributions under each development scenario.

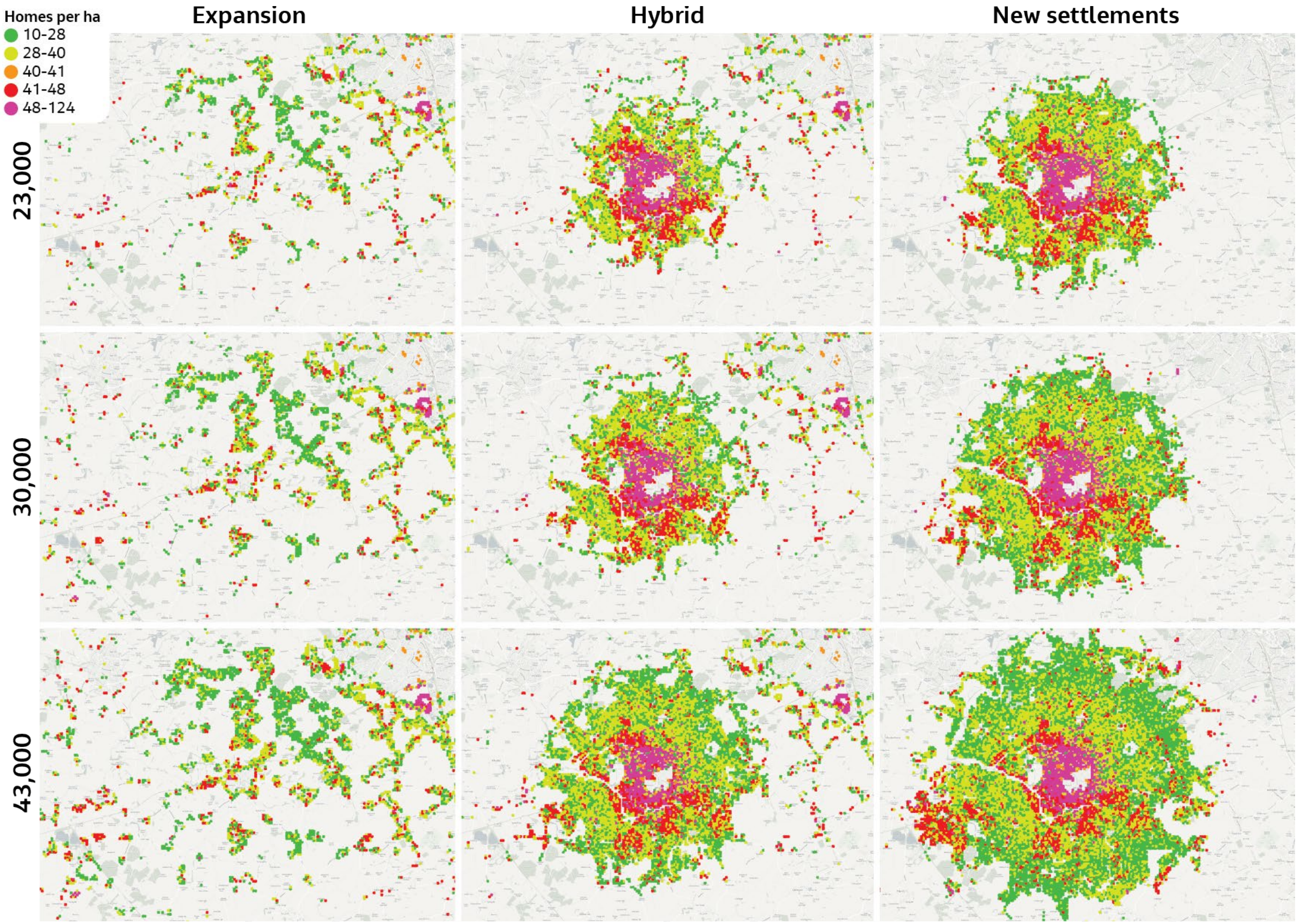

Figure 4.3. Housing density distributions under each development scenario at an example location (Winslow).

4.3.2 Development growth

In the previous section, the maps all show different densities of development in 2050 under the different scenarios. The following maps do not visualise the density of development, instead colour-coding development areas by the year in which they are developed (2030, 2040 and 2050). The overall shape of development in each scenario mirrors that in the previous section.

- Figure 4.4 shows high-level development across the OxCam Arc for the different rates and shapes of development, colour-coded based on development year.
- Figure 4.5 shows a more local view for an example location (Winslow).

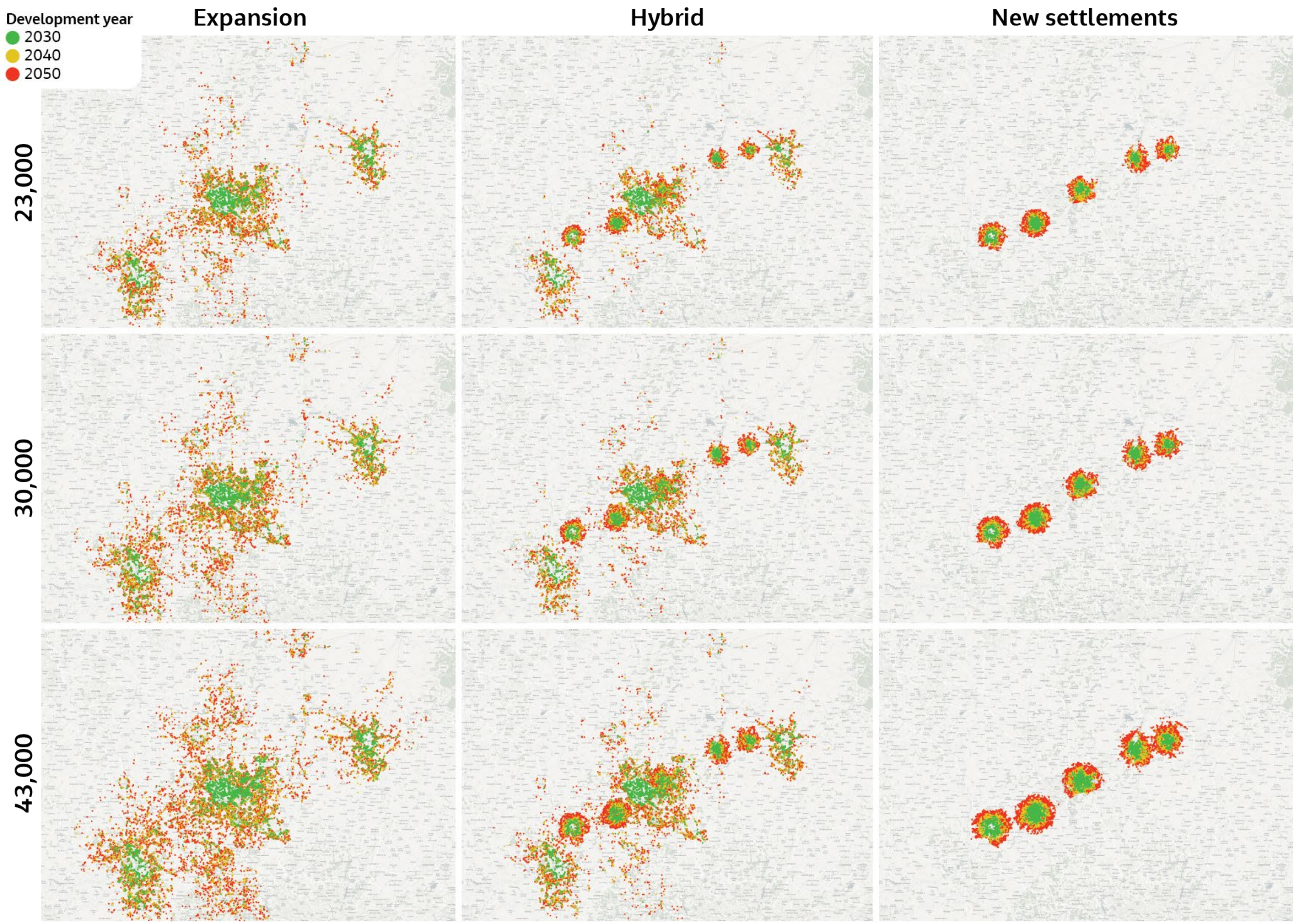

Figure 4.4. Housing growth patterns by development year under each development scenario

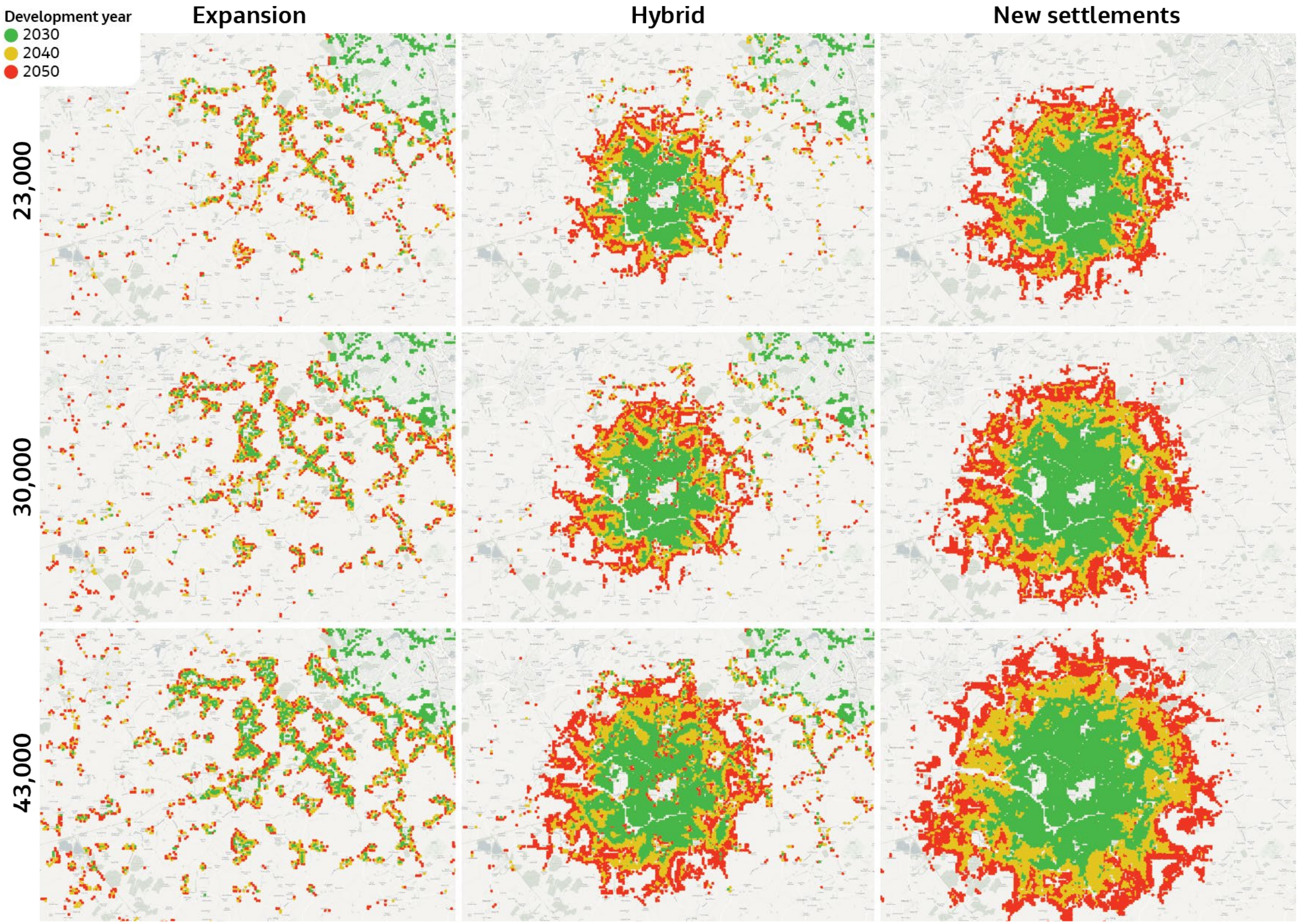

Figure 4.5. Housing growth patterns by development year under each development scenario at an example location (Winslow).

4.3.3 Translation to property points

At an OxCam scale, graphics showing the distribution of property points looks the same as the gridded results shown in the examples above. **Figure 4.6** shows how the property density information translates to generated property points. In line with the National Receptor Dataset (NRD) data, the generated property points use a combination of MCM codes (e.g. where 1 is residential, 2 is a shop, etc.) and a ‘house type’ field (detached, semi-detached, etc.) to classify properties. The figure shows how the generated points are classified using these fields. Note that for the ‘zoomed out’ view, the colour-coding is difficult to interpret, because the density of points means that the visualisation is dependent on the rendering order of those points – hence why the top-right map is largely blue, while in the ‘zoomed in’ view you can see the correct distribution of house types.

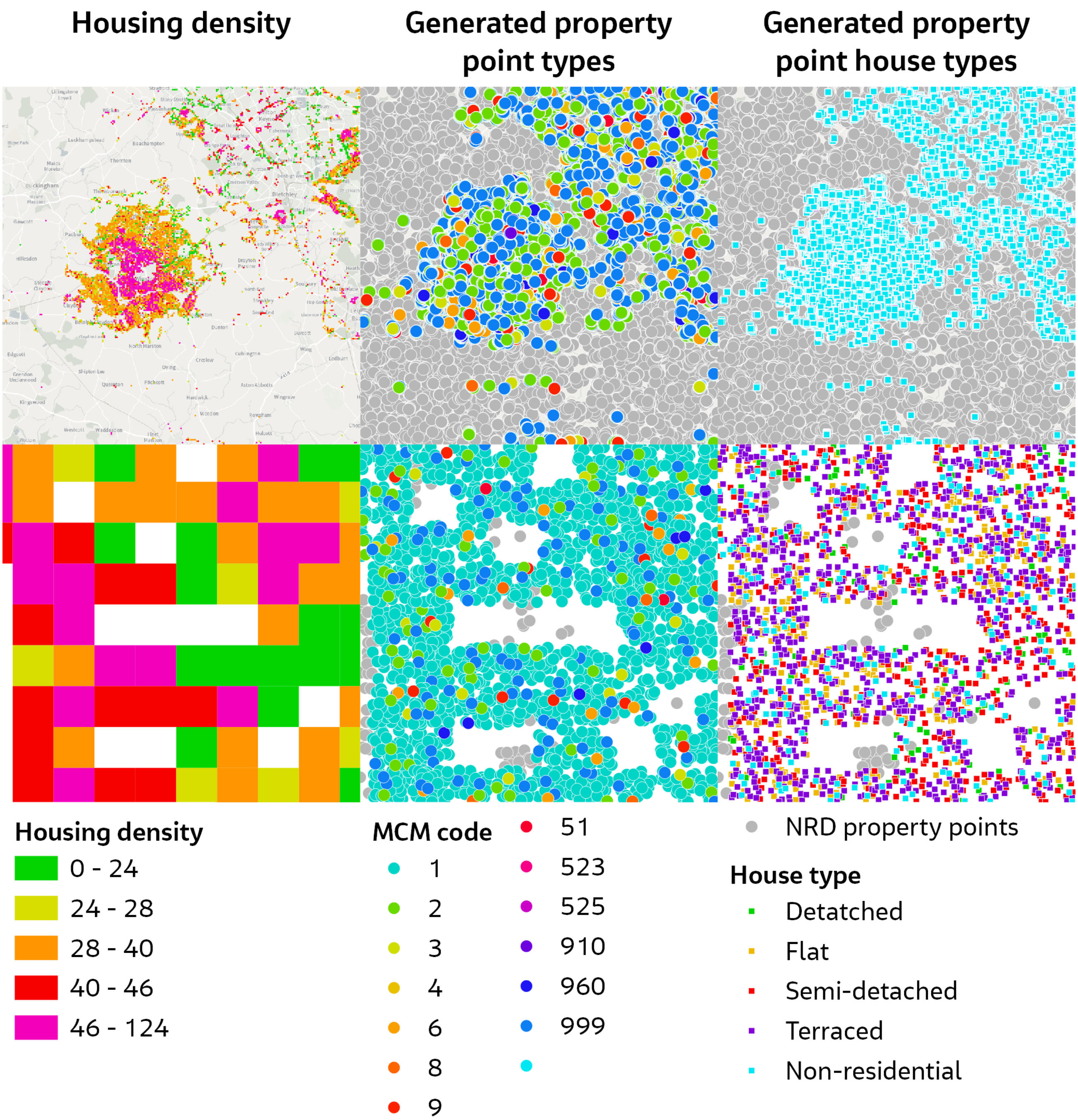

Figure 4.6. Generated property points for a sample area (Winslow) in the upper row of images, and local detail for an example location within that area in the lower row.

4.4 Limitations of this approach

4.4.1 Static relationship between flood risk and development

The key limitation of this approach is in its application as part of the wider analysis. Because the development scenarios are effectively a static input dataset to our analysis (in the same way that climate change scenarios are), we don't have a way to represent the dynamic relationship between flood risk and development. i.e. we have to assume that development is the same whether or not investment in flood resilience interventions is made.

4.4.2 Non-residential properties

The current iteration of the UDM model produces housing density grids only. It therefore does not provide information about the potential growth of non-residential properties. We therefore developed the approach described in 4.2.8.3 to address this limitation. The key assumptions of this approach are that:

a) The housing densities described in the UDM outputs leave 'space' for non-residential development within each grid cell.

b) Non-residential development takes place in grid cells with at least 1 residential property. We have not appended additional non-residential grid cells in addition to those modelled by UDM.

c) The balance of non-residential property types, and the ratio of non-residential properties to residential properties remains constant, and equal to that of the OxCam Arc in the present day.

4.4.3 Land available for development

The grid cell approach has limitations in its representation of land available for development. It identifies any 'empty' land available for development. This means that at a local level, it may identify unrealistic development locations based on available green space areas (which are not officially designated).

This appears to be a particularly noticeable issue in Milton Keynes (shown in Figure 4.7), whose large green space areas (in particular the green space provided alongside roads) are picked up by the model, and are developed on – this is unlikely to reflect reality. We do not believe this is likely to have a material impact on the model results at a macro level, but it is an important limitation to note at a micro scale.

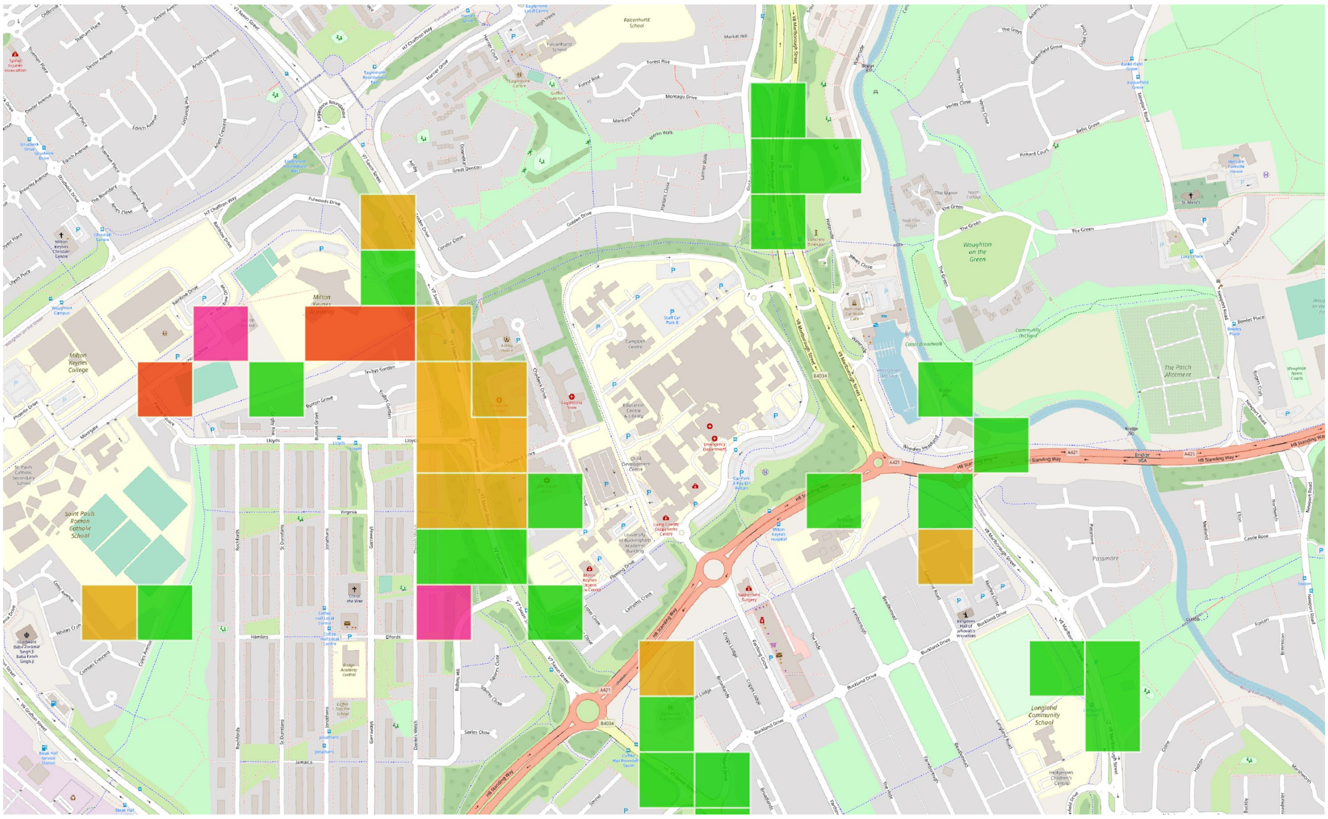

Figure 4.7. Example of development scenario outputs in Milton Keynes.

4.4.4 Apolitical

While the model includes assumptions around the type of land that is likely to be developed on through its constraints and attractors, which are in turn a reflection of planning policy, it does not reflect current local development plans.

5 Method implementation

We have implemented the methods described in Section 2 and 3 using a database system and appropriate coding including Python and SQL. The functionality to query the database is implemented as a Python Class ("CustomScenario"), which enables annual average and present value impacts to be extracted for:

- A given flood area.
- A defined climate change and development scenario.
- A defined combination of interventions.
- A specified series of analysis parameters.

The overall workflow is as follows:

- Each modelled simulation is indexed in the database, accompanied by pre-calculated economic damages for each simulation (and for each development scenario – as property damages are dependent on the development scenario).
- When a specific scenario is requested, the combination of simulations required for that scenario are identified and simulation economic damages extracted.
- The impact extraction and annual average damage calculation process includes calculation of economic damages for specific scenarios – i.e. those which are dependent on the AEP.
- Finally, we calculate present value impacts using a profile of annual average damages, with additional processing to apply capping and write-off – i.e. aspects which are dependent on the present value impacts. This is implemented in a *Calculate_PV* function, which is used by the optimisation routine to access present value impacts (see the optimisation and adaptation technical report).

The key elements of the modelling implementation are set out below.

5.1 Economic damages for each modelled simulation

These are pre-calculated and stored in a database:

- Direct and indirect property damage and carbon costs are calculated using Jacobs Damage Calculator, which applies Multi-Coloured Manual standard approaches and depth-damage data, with depths sampled from flood simulation outputs at property points from National Receptor Dataset.
- Transportation disruption damages are calculated based on the flood extent, Major roads database (https://roadtraffic.dft.gov.uk/downloads) and traffic data (https://roadtraffic.dft.gov.uk/downloads) with assumed flooded duration of 1hour using MCM Delayed-Hour method, equation 6T.1 pg 84.
- Gross Value Added (GVA) damages are calculated based on the outputs of damage calculator for non-residential properties following the method described in chapter 4. It assumes that upper floor properties which share a TOPOFID with a ground floor are the same business and increases the floor area based on the number of upper floors. Upper flood properties without a matching ground floor property are ignored.

- Since GVA is dependent on AEP, but our simulation results are decoupled from AEP, the damages are stored as a relationship between AEP and GVA damage so they can be used for different events/scenarios.
- Agricultural and habitat damages are both entirely event-dependent. The hectares flooded by land use category (ALC grade for agriculture, habitat classification for habitat) are pre-calculated, with impacts calculated for specific scenarios.

5.2 Economic damages for specific scenarios

These are calculated during individual runs. The specific components of each run include:

- Running queries for impacts:
  - To support in the calculation of impacts for a single scenario and AEP.
  - To assess property, transport, GVA impacts via our pre-calculated database.
  - Agriculture one-off costs.
  - Habitat impacts (only used in write off assessments based on a 0.1% AEP impacts).
- Calculate AAD:
  - Impacts queried for a set of AEPs, using the ‘running queries for impacts’ process described above.
  - The AAD is calculated for each impact category.
  - Values for written off agricultural and habitat land, plus info AEP at which properties first flood is included in the scripting calculations.
- Calculate PV:
  - Based on an appraisal period, calculation interval, scenario pathway plus other economic parameters. This provides a full range of AAD values by category for each year, using the ‘calculate AAD’ process described above.
  - The AAD is calculated at intervals (e.g. every 10 years) defined as a parameter, then interpolated to intervening years. This interval is set dynamically by the optimisation routine, using different values for the different iterations.
  - Present value damage (PV) is assessed by summing and discounting the AADs.
  - Property write off, Agriculture and habitat write off and capping is applied during the PV calculations.

6 Economic Results

6.1 Introduction

The focus of this chapter is to provide summary outputs for the OxCam for the total economic benefits that might be achieved should the various interventions be implemented universally across the region from year 0 and throughout the study period where a need is identified. This chapter does not present details of the optimisation process (see the optimisation and adaptation technical report) that is used to select the optimum levels and timing of investment in interventions for a given future scenario. The results in this chapter are therefore only illustrative of the type of impact a type of intervention may have on economic benefits.

As described in Section 3.6, the analysis includes a number of available flood risk management interventions:

- Linear interventions (fluvial), with 'small', 'medium' and 'large' defence raising per flood area.
- Natural flood management (fluvial), per sub-catchment.
- Storage (fluvial), with 'small', 'medium' and 'large' storage volumes per catchment.
- Property flood resilience for properties at risk of fluvial flooding (per flood area) and properties at risk of surface water flooding (per flood risk management system).
- Sustainable urban drainage systems (SuDS) (surface water), per flood risk management system.

The modelling has been undertaken to allow the different options to be selected based on the overall NPV of a particular option. The optimisation and adaptation technical report provides additional details.

6.2 Selected sample for result presentation

In order to present the results we have determined to present that for the Oxcam region and for a number flood areas around Winslow. This is located in Buckinghamshire. Winslow was selected as it is representative of a typical region within the Oxcam area. The specific flood areas that were considered as part of the results presentation are set out below in table 8.1 below. The flood areas represent specific geographic locations within the Winslow area.

Table 6.1. Flood areas related to Winslow

Flood Area					
330200094	330200124	330299184	330200201	330200219	330200231
330200289	330200323	330200324	330200325	330200448	330200385

The analysis undertaken also focused on the central scenario for Climate Change and the default assumption for the development scenario which relates to a hybrid development of 23,000 properties per annum (see chapter 4 above for more information).

6.3 Results

6.3.1 Baseline damages

The baseline level of damages assumes that no further interventions will be undertaken and that existing interventions will be maintained. The total damages in the absence of any new interventions is shown in **Figure 6.1** below split between fluvial and surface water:

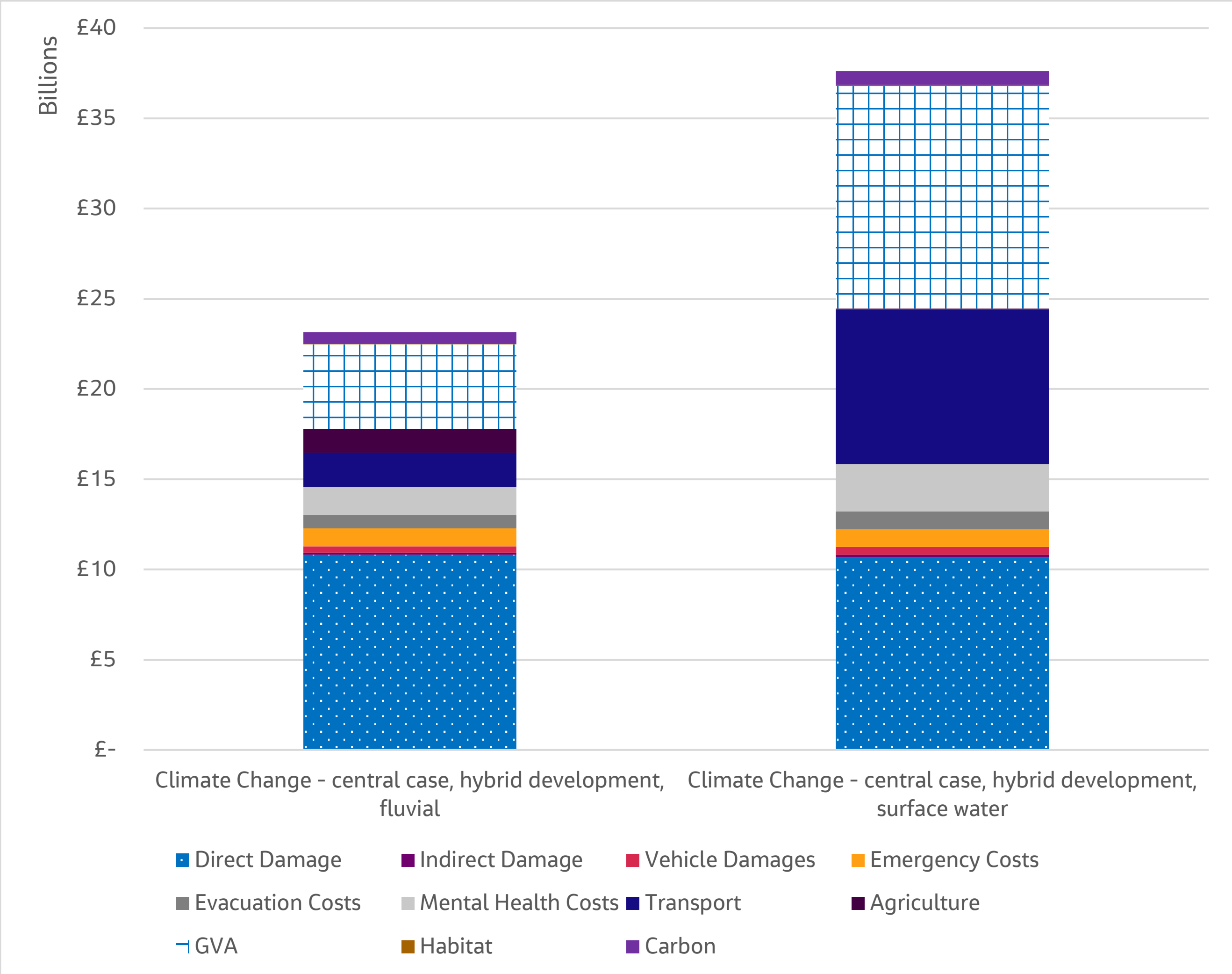

Figure 6.1. Total damages due to fluvial and surface water events by category without any new investments, Present Value with no new investment, Oxcam

6.3.2 Intervention types

The interventions presented below are applied without any switching or adding of other interventions.

6.3.2.1 Fluvial Interventions

Winslow

For Winslow the impact of the fluvial options are set out below. This shows the benefit in billions of pounds. As can be seen the greatest benefits would come from Large Storage and Large Linear Defences. Smaller storage provides the least amount of benefit at £0.06 billion.

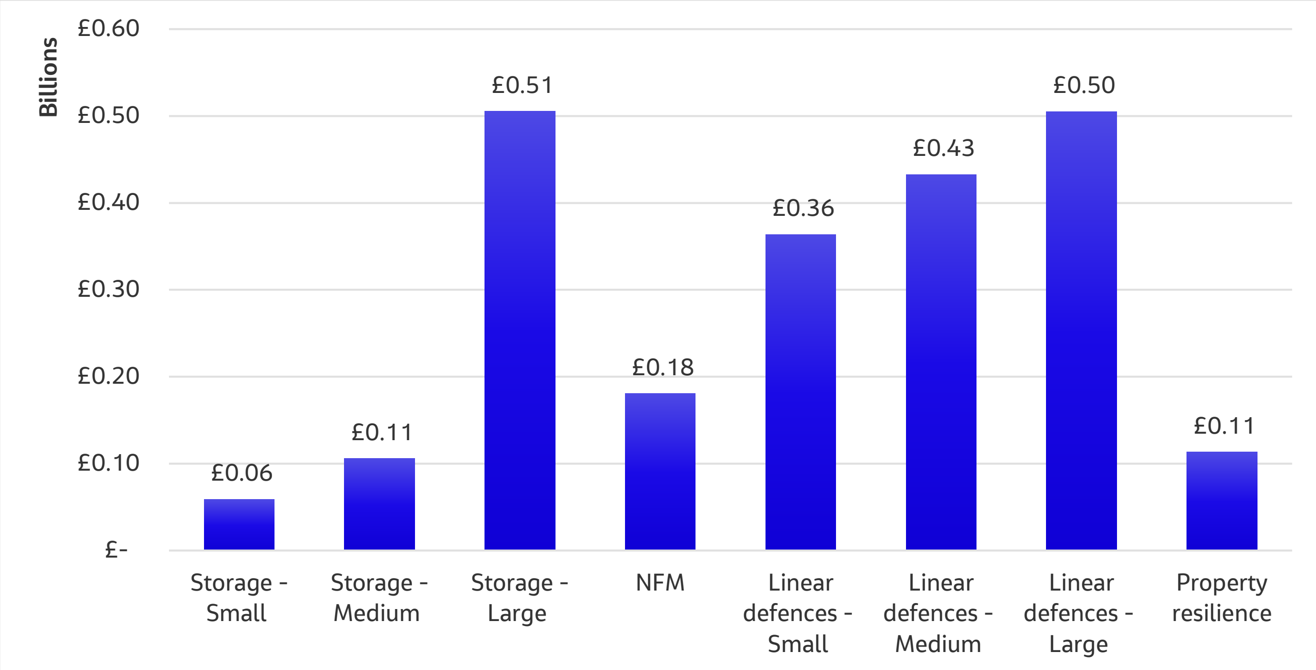

Figure 6.2. Total Benefits by Intervention Type - Fluvial Winslow

The split of benefit by individual category for Fluvial is set out below:

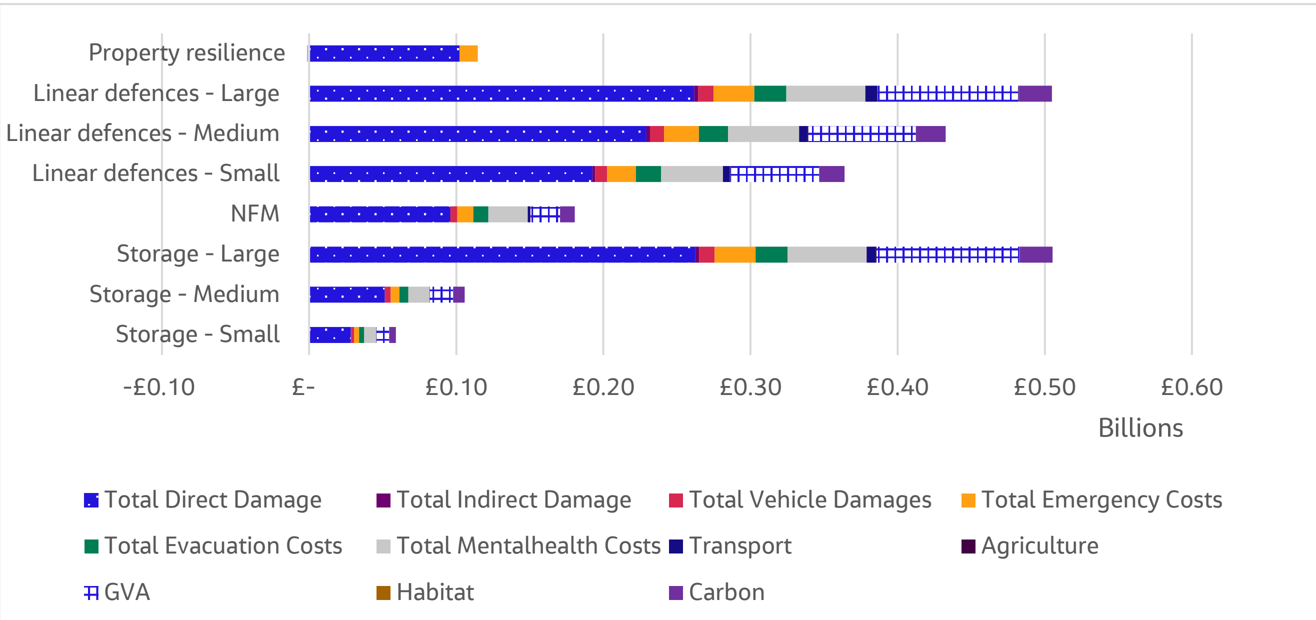

Figure 6.3. Total Benefits by Benefit Type and Intervention Type - Fluvial Winslow

As expected, the largest benefits for all interventions relate to direct damages. Other categories of benefits that are material include Mental Health costs avoided, emergency costs avoided, and GVA benefits from avoided flooding impacts. Non direct damages on average account for 46% of the benefits for fluvial interventions.

Oxcam

The benefits for the Oxcam geography for fluvial interventions are shown below:

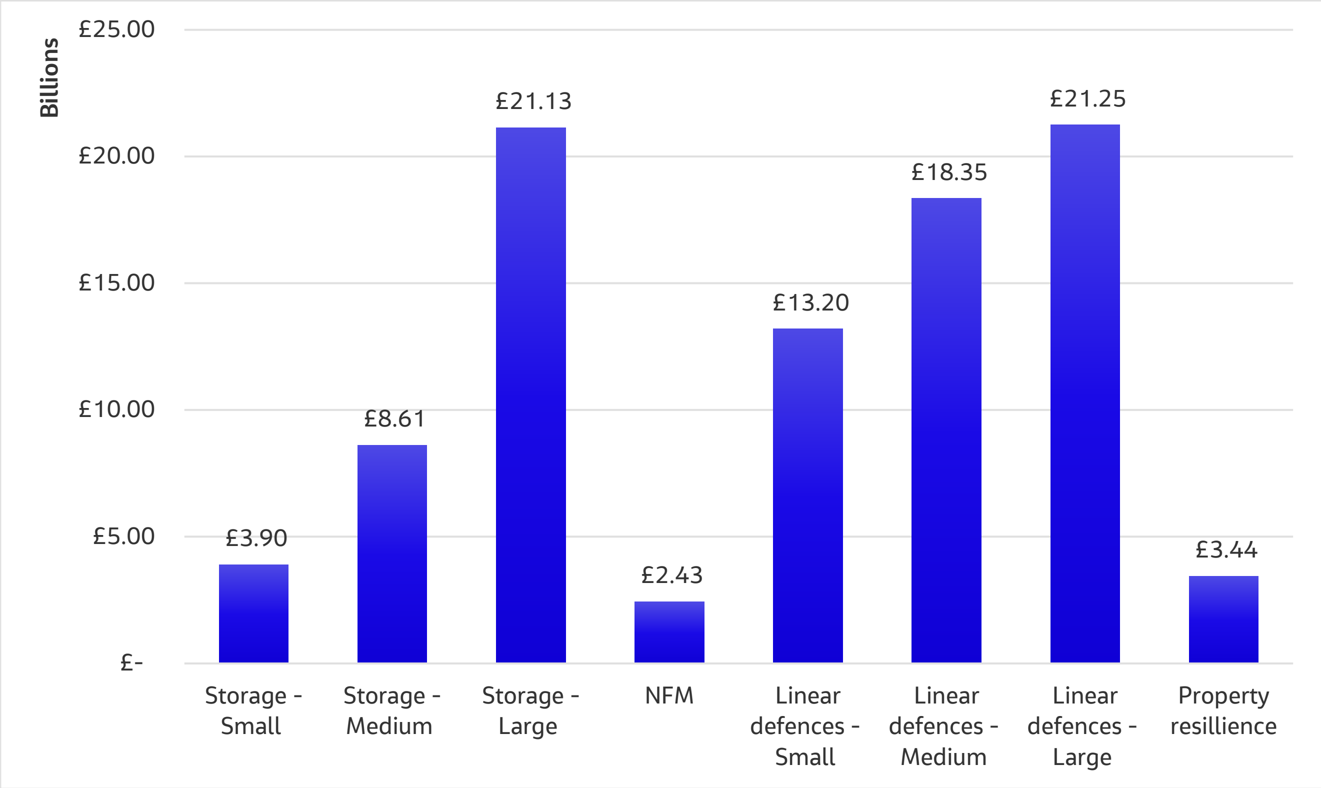

Figure 6.4. Total Benefits by Intervention Type - Fluvial Oxcam

For Oxcam the largest benefit values relate to £21.13 billion for Storage – Large and £21.25 billion for Linear defences – Large. The split by individual category of benefits for fluvial is set out below:

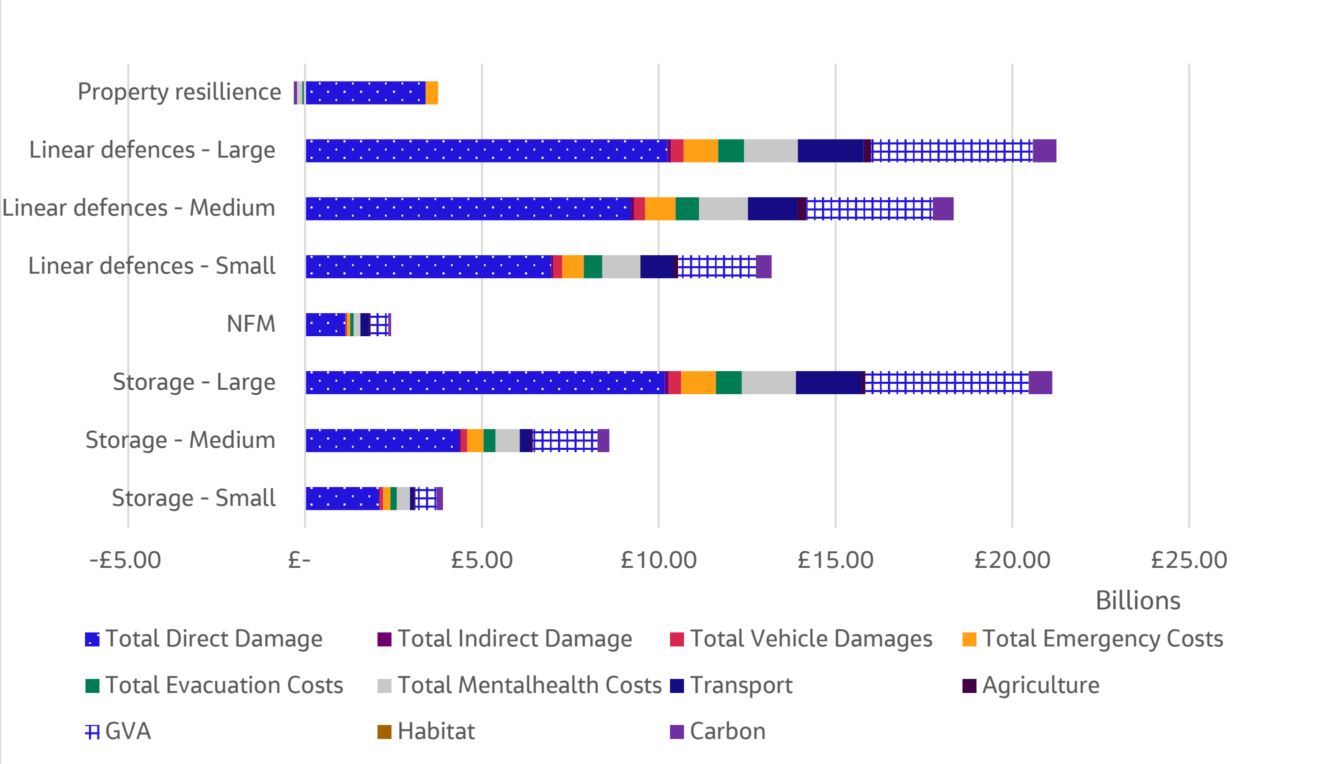

Figure 6.5. Total Benefits by Benefit Type Intervention Type - Fluvial Oxcam

The greatest benefits for fluvial relate to direct damages benefits. Other large benefit categories again include GVA benefits, mental health and avoided emergency costs. Proportionally transportation benefits are much larger at the Oxcam level, representing on average 7% of benefits across interventions, whilst for Winslow they represented only 1% of benefits.

Some minor negative benefits exist related to vehicle damages, mental health costs, evacuation costs and carbon as for fluvial. These exist due to properties that would otherwise have been written off continuing to be occupied for a longer period of time (in some cases indefinitely) due to the additional property resilience protection.

6.3.2.2 Surface Water Interventions

Winslow

For Winslow, the impacts of the surface water options are set out below.

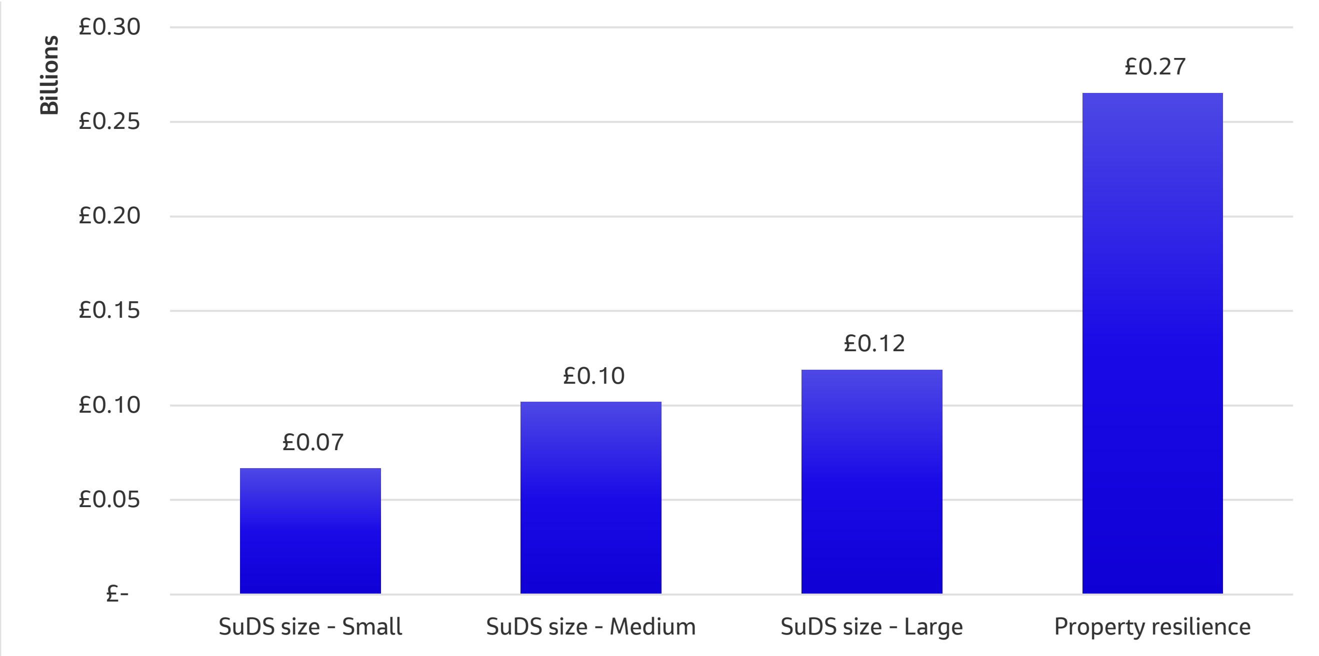

Figure 6.6. Total Benefits by Intervention Type - Surface Water

These relate to SuDS and small property interventions. Increased SuDS provide increased benefits as would be expected. Property resilience provide proportionally greater benefits than the SuDS impacts.

The split of benefit by individual category for Surface Water is set out below:

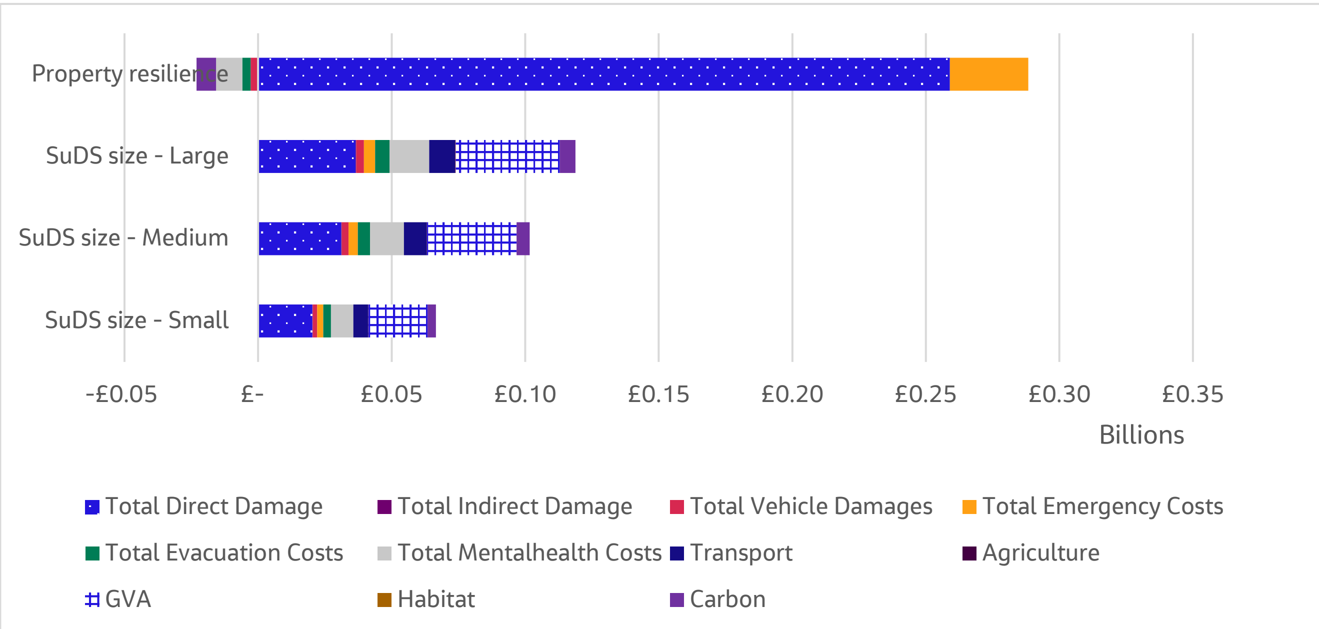

Figure 6.7. Total Benefits by Benefit Type and Intervention Type - Surface Water

For surface water interventions the largest benefits are from property interventions. As expected, these benefits relate mostly to direct damages. In this case more than 90%. Note there are some minor negative benefits related to vehicle damages, mental health costs, evacuation costs and carbon as for fluvial. These exist due to properties that would otherwise have been written off continuing to be occupied for a longer period of time (in some cases indefinitely) due to the additional property resilience protection.

For the SuDS there is a more even split of benefits, with non-direct damages benefits making up 68% of the benefits, with the largest other category being GVA benefits.

Oxcam

The benefits for the Oxcam geography for surface water interventions are shown below:

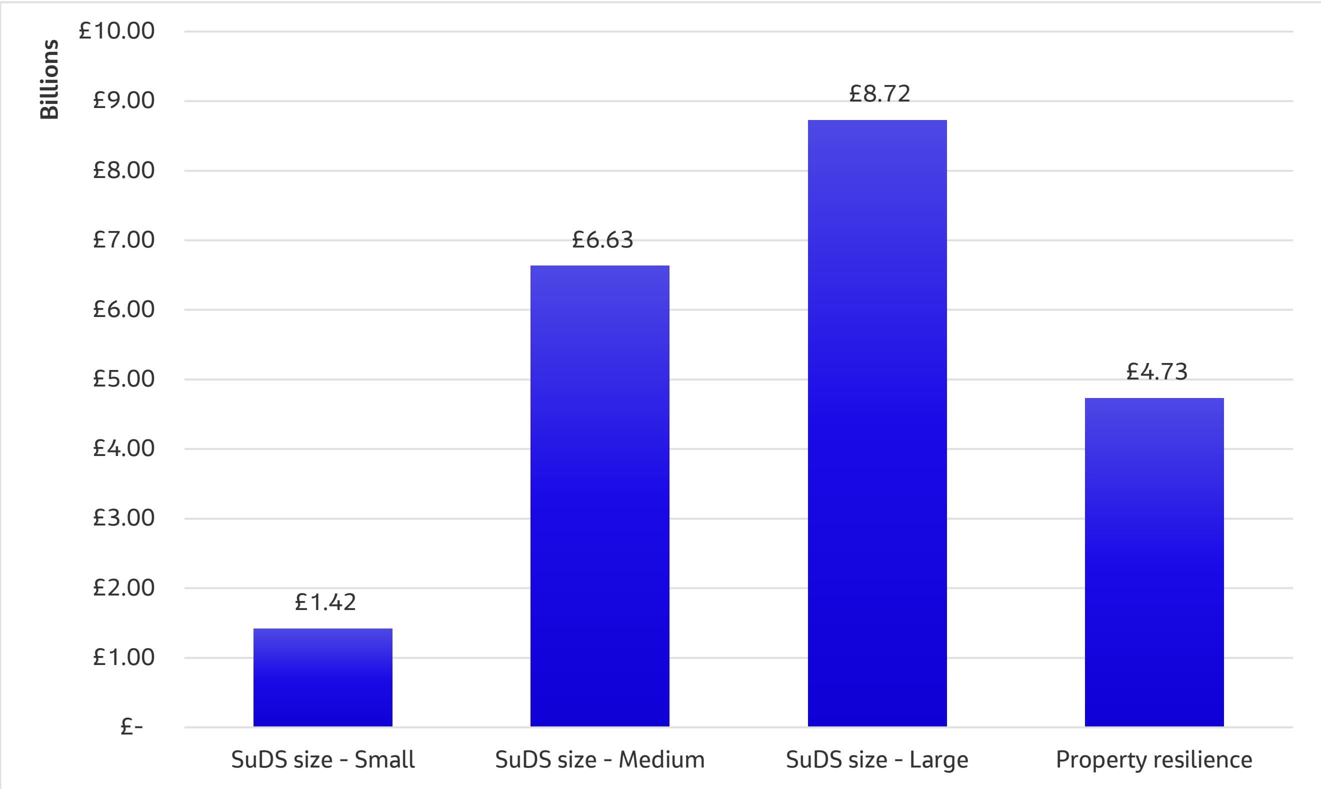

Figure 6.8. Total Benefits by Intervention Type - Surface Water

The distribution of benefits for Oxcam are greatest for SuDS – Large followed by SuDS – Medium and then small property intervention, which in this case is the third highest benefit category.

The split by individual category of benefits is set out below:

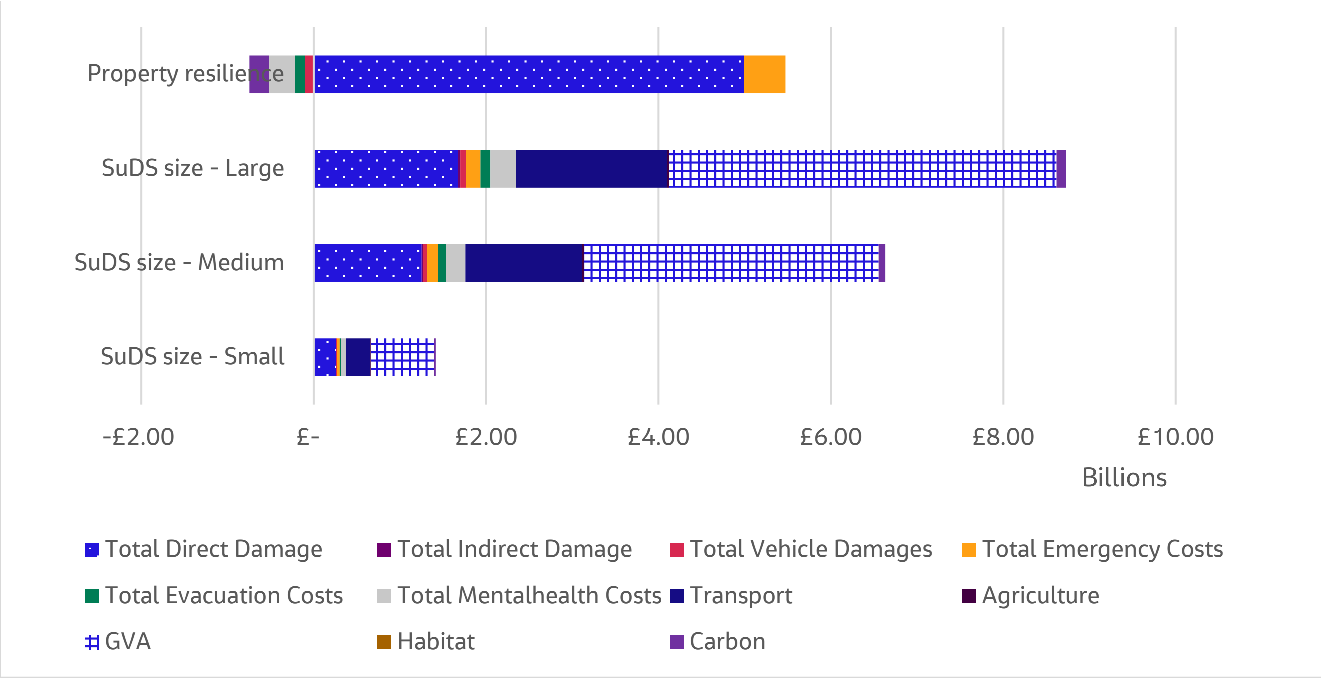

Figure 6.9. Total Benefits by Benefit Type Intervention Type - Surface Water

Benefits from property interventions relate mostly to direct damages, which again represent more than 90% of benefits.

For the SuDS at the Oxcam level, non-Direct Damage benefits account for more than 80% of benefits with the largest category of benefits relating to GVA which accounts for more than 50% of total benefits in these categories.

6.4 Summary of Benefit Contribution

The split of the benefits on average between interventions is set out below for fluvial interventions for Oxcam. This shows that across interventions, reduction in total direct damages provides the greatest benefits. This is followed by GVA benefits[5]. Mental health, transportation costs, evacuation and emergency avoided costs form material categories of benefits.

[5] Note the GVA benefits are a conservative assessment as they do not include benefits from land value uplift or GVA costs avoided due to new land becoming available from flood defence.

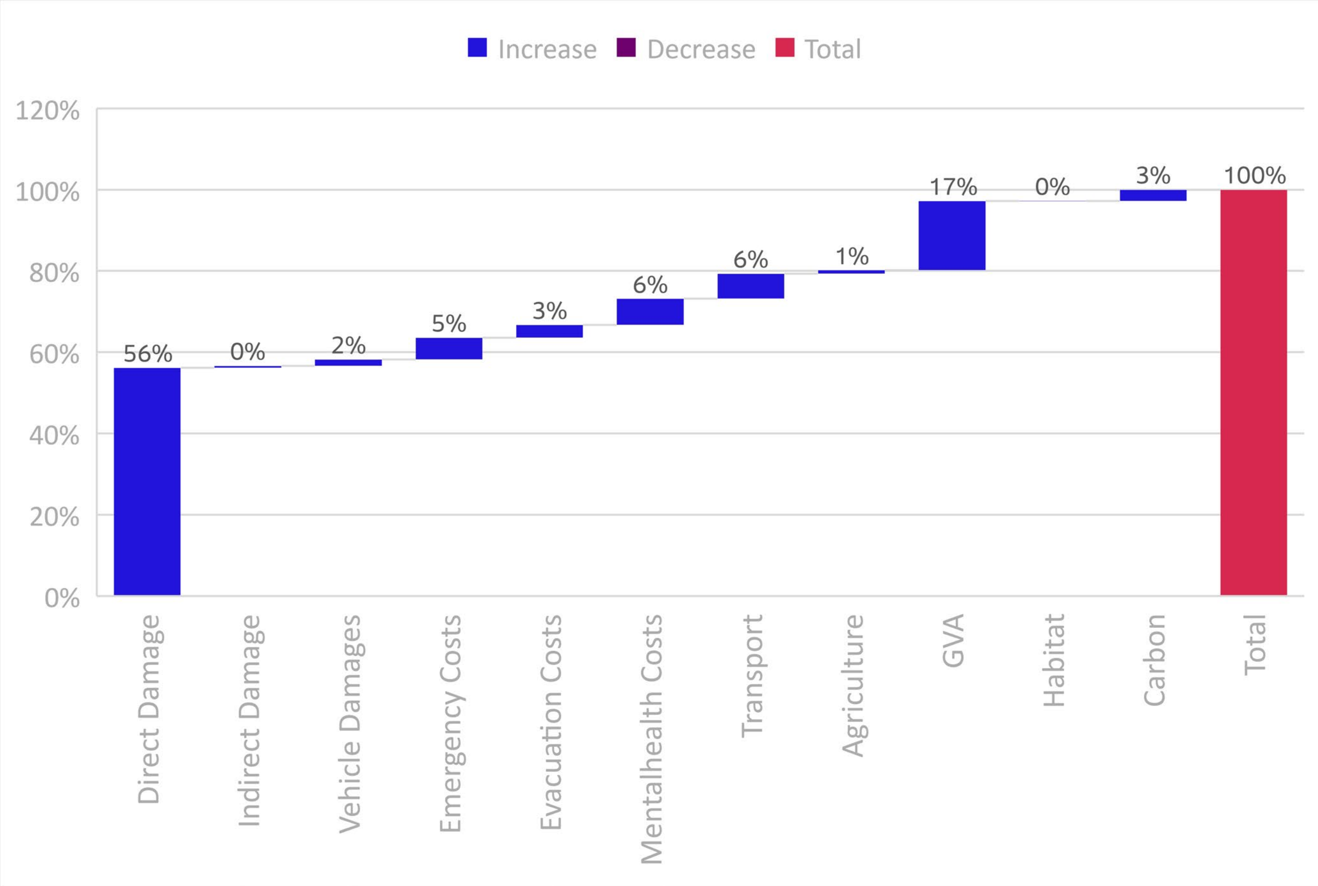

Figure 6.10. Average benefit contribution across fluvial interventions with central CC and hybrid development

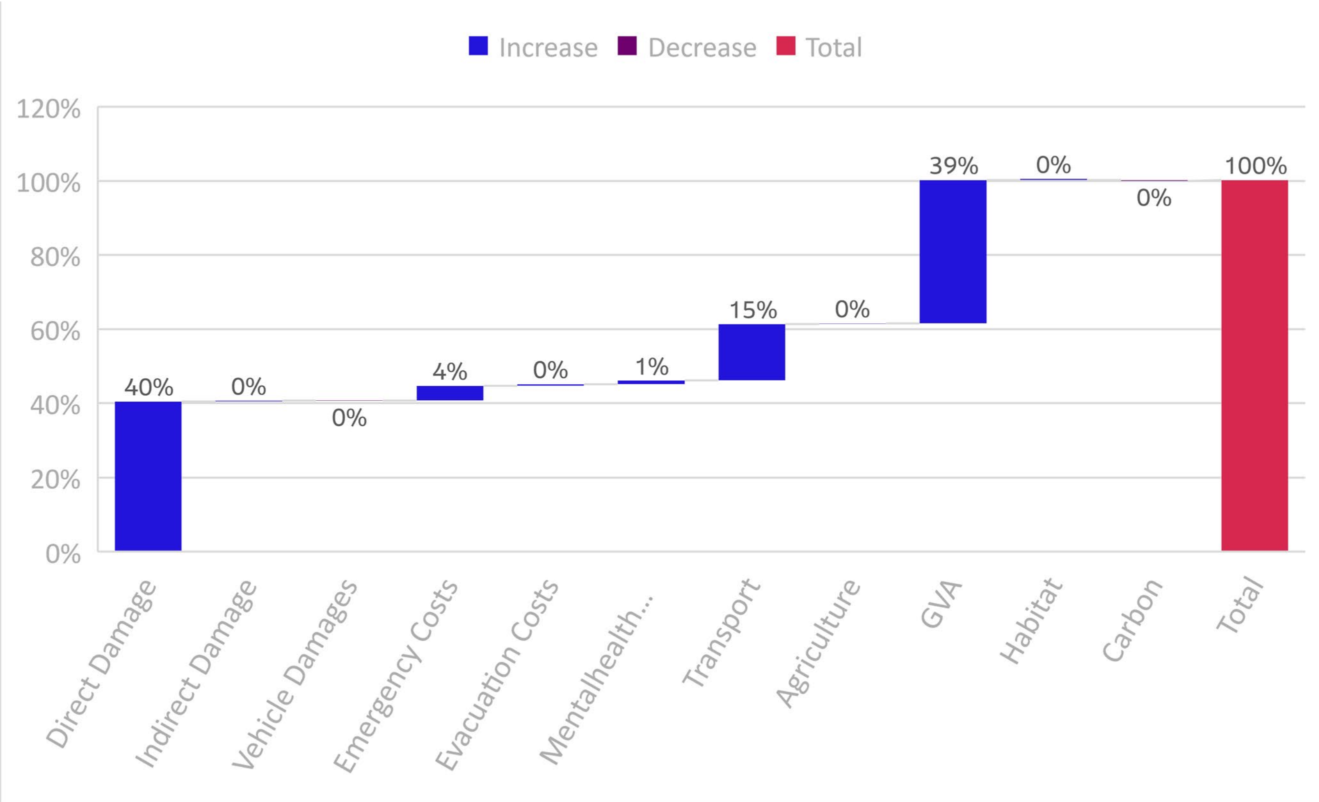

Figure 6.11. Average benefit contribution across surface water interventions with central CC and hybrid development

In this case, there is a significantly greater proportion of benefits being driven by GVA and transport compared to the fluvial interventions. Total direct damages avoided are 40% compared with 53% for fluvial and largely relate to property interventions.

6.5 Damages by different scenarios

The sections above describe the total value of benefits across various interventions for fluvial and surface water, both specific for Winslow and the OxCam region. These assume no specific economic optimisation strategy and do not reflect the interaction between flood risk management interventions. They simply reflect the maximum benefits that would occur should any particular option be implemented independent of any other option. Different interventions might be combined which would illustrate the dynamic nature of the scheme selection. This would impact on both costs and benefits from different baskets of interventions. The optimisation report sets out what an optimised investment strategy would look like and accounts for the interactions between options.

In addition a number of climate change scenarios have been modelled. This report only presents the economic analysis for the Central Baseline Climate Change scenario. Other climate change scenarios have also been modelled. The level of baseline damages is illustrated below for each of the other climate change scenarios, split between fluvial and service water.

6.5.1 Fluvial

The level of baseline total damages due to flooding events across the four climate change scenarios are shown below:

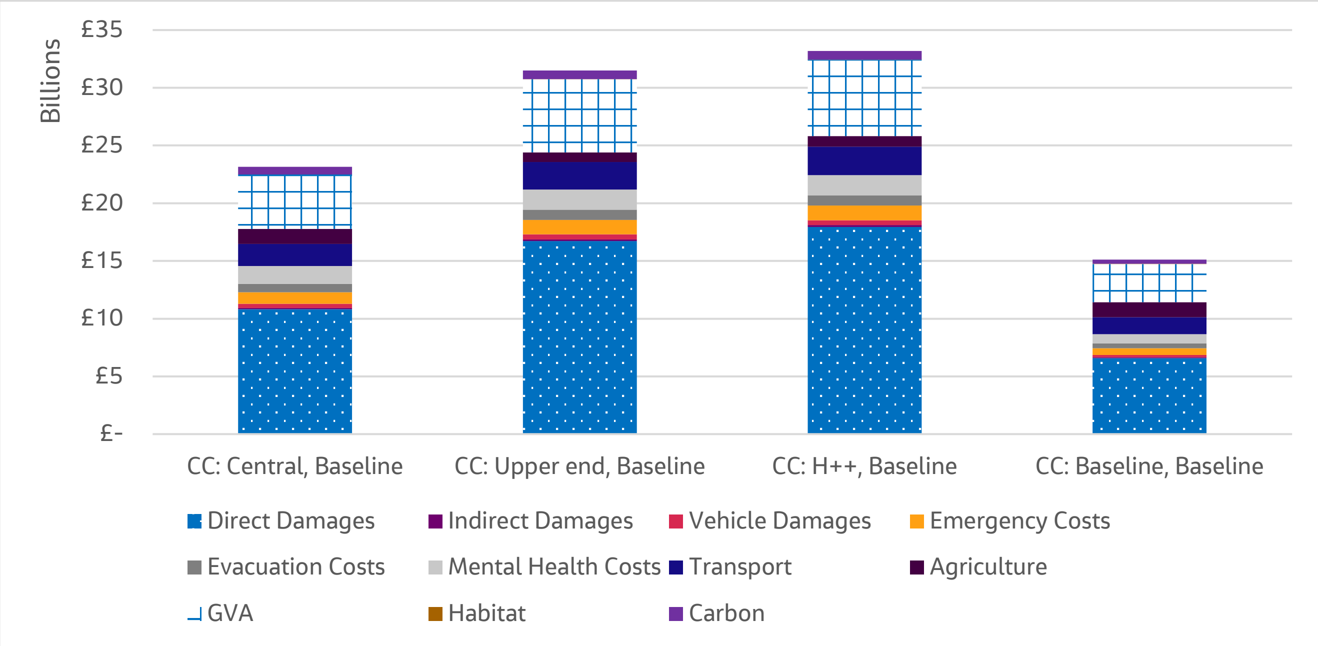

Figure 6.12. Total damages due to fluvial events by category without any new investments, Present Value with no new investment, Oxcam

This confirms that the greatest damages without new interventions for fluvial flooding will occur with the H++ scenario. In this case, damages are expected to amount to more than £32billion over the appraisal period. The least damaging impact will occur with the baseline Climate Change scenario.

6.5.2 Surface water

For surface water, all scenarios have an impact of between £35billion and £40billion of damages, with the upper end and the H++ scenarios producing the greatest damage.

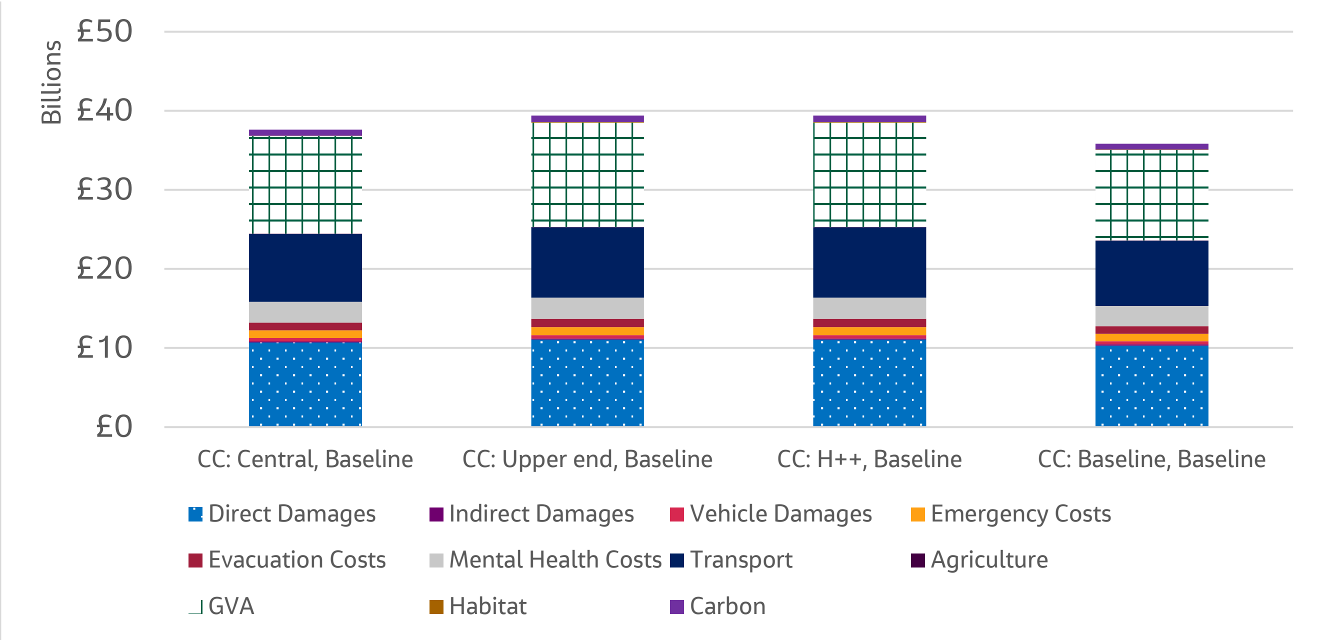

Figure 6.13. Total damages due to surface water events by category without any new investments, Present Value with no new investment

7 Consideration of funding: Partnership funding

Partnership funding may be considered to fall outside the realm of a pure economic analysis – the economic study informs us how much 'should' be invested in flood resilience, outside the constraints of current funding rules. This is particularly relevant to a longer-term study, in which it cannot be reasonably assumed that existing current funding constraints continue in their current form. To that end, LTIS explicitly excludes consideration of partnership funding: *"LTIS does not suggest who should pay. It includes investment from central and local government alongside partnership funding contributions."* (Environment Agency, 2019).

However, it is also useful to understand the extent to which the optimum investment might be funded through FDGiA funding and the extent to which third party contributions would be needed to invest optimally. Calculating partnership funding scores of each intervention also allows for a constrained analysis to find the optimal investment in a scenario where third-party contributions could not be obtained, and the change in risk that would result.

During the project, we agreed that while the optimisation should be led by **economics** (and we would therefore not optimise based on 'fundability'), calculating the partnership funding score(s) of the optimum investment pathway(s) to indicate the fundability of that optimum might be an enhancement that could be done at a later stage.

8 Limitations and lessons learned

A number of limitations were present in our analysis. These included:

- **Insufficient data on Infrastructure (utilities) impacts:** We found that there was insufficient data to sensibly model the impact and avoided damages on utilities. This means that the benefit impact is likely to be understated.

- **Insufficient data on dependency of new developments of flood defences:** There are critical unknowns around the dependency of new developments on flood defences and an absence of research to support defensible assumptions

- **Insufficient data on property value Impacts:** The research on the impact on property values from flood events is inconclusive and could usefully be supplemented.
- **Improved datasets could result in improved calculations:** This would require an EA wide assessment on what data might be updated to better reflect overall economic impact calculations, including where data from other sectors (such as transport and WebTAG data) might usefully be used to completement existing data sources.

- **Data granularity is limited and data between sources is not always consistent:** The National Receptor Dataset (NRD) forms a crucial part of the analysis undertaken when considering local economic impacts. We assume the recent NRD has improved consistency between the NRD dataset and other datasets and regional government level and LSOAs. Improved NRD consistency and increase granularity would provide more accurate estimates of economic impacts.

- **Limitations to the computational complexity mean that is has not been possible to apply capping and write-off across sources**. i.e. total PV impacts for a property would not be capped based on the combined fluvial and surface water impacts, and the fluvial analysis may not pick up that the surface water analysis has written off a property (or vice versa). Thus the analysis required Capping and write-off to be applied as part of the analysis process for fluvial and surface water independently.

- **The approach to forecasting future development has some limitations.** These are described in chapter 4 and include, Static relationship between flood risk and development, lack of forecast of non-residential properties requiring a simplified approach, simplification around land available for development and lack of reflection of local development plans (i.e. any forecast is based on existing developments)

A number of lessons have been learned as part of the economic analysis undertaken. The key lessons are set out below:

- **Economic benefits outside of the traditional benefits multicoloured manual can be useful to support economic analysis:** Using a wider array of benefits provides greater granularity allowing for a better view of total benefits from interventions and also where those benefits might sit in relation to different benefit categories, providing decision makers with better information to make more informed choices.

- **Complexity of analysis supported by database driven approach:** Increased economic parameters do make the analysis substantially more complicated. However, using a database driven approach has illustrated the viability of processing significant data to assess an economic impacts over a wider range of schemes.

9 References

5th studio. (2018, Feb). *Cambridge, Milton Keynes and Oxford future planning options project - final report.* Retrieved from https://nic.org.uk/app/uploads/NIC-FinalReport-February-2018-Rev-A-optimised.pdf

Beltrán, A., Maddison, D., & Elliot, R. (2019). The impact of flooding on property prices: A repeat-sales approach. *Journal of Environmental Economics and Management, 95*, 62-86.

Beltrán, A., Maddison, D., & Elliot, R. J. (2018). Assessing the Economic Benefits of Flood Defenses: A Repeat-Sales Approach. *Risk Analysis, 38*, 2340-2367.

Burgess-Gamble, L., Ngai, R., Wilkinson, M., Nisbet, T., Pontee, N., Harvey, R., . . . Quinn, P. (2018, February). *Working with Natural Processes - Evidence Directory (SC150005).* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/681411/Working_with_natural_processes_evidence_directory.pdf

Clarke, J. (2019). *Long Term Investment Scenarios: Additional Analysis. Topic 5 technical report: Property level resistance and resilience.* Environment Agency.

Clarke, J., Hardwick, S., Old, G., & Kay, A. (2018). *Long Term Investment Scenarios: Additional Analysis. Topic 7 technical report: Natural Flood Management.* Environment Agency.

Department for Business, Energy and Industrial Strategy. (2019, April). *Valuation of energy use and greenhouse gas: Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794737/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal-2018.pdf

Department for Transport. (2018, September). *Road Traffic Forecasts 2018.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/873929/road-traffic-forecasts-2018-document.pdf

Department for Transport. (2020, Oct). *GB Road Traffic Counts.* Retrieved from https://data.gov.uk/dataset/208c0e7b-353f-4e2d-8b7a-1a7118467acc/gb-road-traffic-counts

Environment Agency. (2009). *Achieving more: operational flood storage areas and biodiversity.* Bristol: Envrionment Agency.

Environment Agency. (2010, March). *Flood and Coastal Erosion Risk Management appraisal guidance.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/481768/LIT_4909.pdf

Environment Agency. (2014, February). *Calculate Grant in Aid funding for flood and coastal erosion risk management projects: Guidance for risk management authorities.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/297377/LIT_9142_dd8bbe.pdf

Environment Agency. (2016, October). *Carbon planning tool.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/571707/LIT_7067.pdf

Environment Agency. (2019). *Long-term investment scenarios (LTIS) 2019*. Retrieved October 1, 2020, from https://www.gov.uk/government/publications/flood-and-coastal-risk-management-in-england-long-term-investment/long-term-investment-scenarios-ltis-2019#different-ways-to-manage-risk

Environment Agency. (2020, April 17). *Calculate grant-in-aid funding for flood and coastal erosion risk management projects.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/881099/Calculate_GiA_funding_for_FCERM_projects_2020.pdf

Environment Agency. (2020, April 17). *Operational principles to follow when setting up funding partnerships to tackle flood and coastal erosion.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/879973/Operational_Principles_for_FCERM_funding_partnerships.pdf

Environment Agency. (2020). *Partnership funding calculator 2020 for FCERM Grant-in-Aid.* Retrieved from https://www.gov.uk/government/publications/partnership-funding-supporting-documents

Environment Agency. (2020, April). *Partnership funding: Supporting guidance.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/895861/Partnership_funding_supporting_guidance_for_OM4.pdf

Frontier Economics. (2014). *Flood and coastal erosion risk management and the local economy.* Joint Defra/EA FCERM R&D Programme FD2662.

HM Treasury. (2018). *The Green Book: Central government guidance on appraisal and evaluation.* Retrieved from https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

JBA Consulting. (2015). *Long term costing tool for flood and coastal risk management: Summary (SC080039/S).* Environment Agency.

Keating, K., Keeble, H., Pettit, A., & Stark, D. (2015, March). *Cost estimation for SUDS - summary of evidence (SC080039/R9).* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/411509/Cost_estimation_for_SUDS.pdf

Keating, K., Pettit, A., & Santa-Clara, J. (2015, March). *Cost estimation for flood storage - summary of evidence (SC080039/R6).* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/411176/Cost_estimation_for_flood_storage.pdf

Ministry of Housing, Communities and Local Government. (2019, February). *National Planning Policy Framework.* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/810197/NPPF_Feb_2019_revised.pdf

National Infrastructure Commission. (2017). *Partnering for prosperity: A new deal for the Cambridge-Milton Keynes-Oxford Arc.* Retrieved from https://nic.org.uk/app/uploads/Partnering-for-Prosperty.pdf

Natural England. (2020, November 23). *Priority Habitat Inventory.* Retrieved from data.gov.uk: https://data.gov.uk/dataset/4b6ddab7-6c0f-4407-946e-d6499f19fcde/priority-habitat-inventory-england

Natural England. (2020, May 20). *Provisional Agricultural Land Classification (ALC).* Retrieved from data.gov.uk: https://data.gov.uk/dataset/952421ec-da63-4569-817d-4d6399df40a1/provisional-agricultural-land-classification-alc

Office for Budget Responsibility. (2020). *The economy forecast: Inflation*. Retrieved October 5, 2020, from http://obr.uk/forecasts-in-depth/the-economy-forecast/inflation/#CPI

Penning-Rowsell, E., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., . . . Owen, D. (2013). *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal.* Oxford: Routledge.

Penning-Rowsell, E., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., . . . Owen, D. (2020). *Flood and Coastal Erosion Risk Management: Handbook for Economic Appraisal.* Flood Hazard Research Centre, Middlesex University.

Priest, S., & Viavattene, C. (2020, June). *A method for monetising the mental health costs of flooding (SC1500017).* Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/890296/A_method_for_monetising_the_mental_health_costs_of_flooding_-_report.pdf

Savills. (2016, Nov 4). *The property market within the Cambridge - Milton Keynes - Oxford corridor.* Retrieved from Savills report to NIC: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/601167/Property-market-analysis-Savills-report-for-NIC.pdf

Savills. (2020). *Rural Land Values*. Retrieved from Savills.co.uk: https://www.savills.co.uk/property-values/rural-land-values.aspx

A. Appendix: Development scenario details

A.1 Introduction

The approach to producing development scenarios is described in Section 4. This appendix provides more detail about the parameters applied in the underlying UDM model.

A.2 Constraints

Constraints are areas in the region where new development is not allowed to occur in the model. Table 9.1 shows the set of spatial datasets applied as constraints – as the table shows, these are largely consistent across all the development scenarios, apart from the additional greenbelt areas applied in the new settlement scenarios. Figure 9.1 shows the areas affected by these constraints.

Table 9.1. Constraints applied to the development scenarios.

Constraint	Expansion scenarios	New settlements scenarios
Greenbelt areas	✗	✓
Battlefields (Historic England)	✓	✓
Scheduled Ancient Monuments (Historic England)	✓	✓
SSSI (Natural England)	✓	✓
Priority Habitats (Natural England)	✓	✓
Local Nature Reserves	✓	✓
National Nature Reserves	✓	✓
World Heritage Sites	✓	✓
EA Flood Zone 3 (Environment Agency)	✓	✓
Currently developed areas (from OS MasterMap)	✓	✓
Water bodies (from OS MasterMap)	✓	✓
Natural Capital constraints – grey growth CORE network	✓	✓

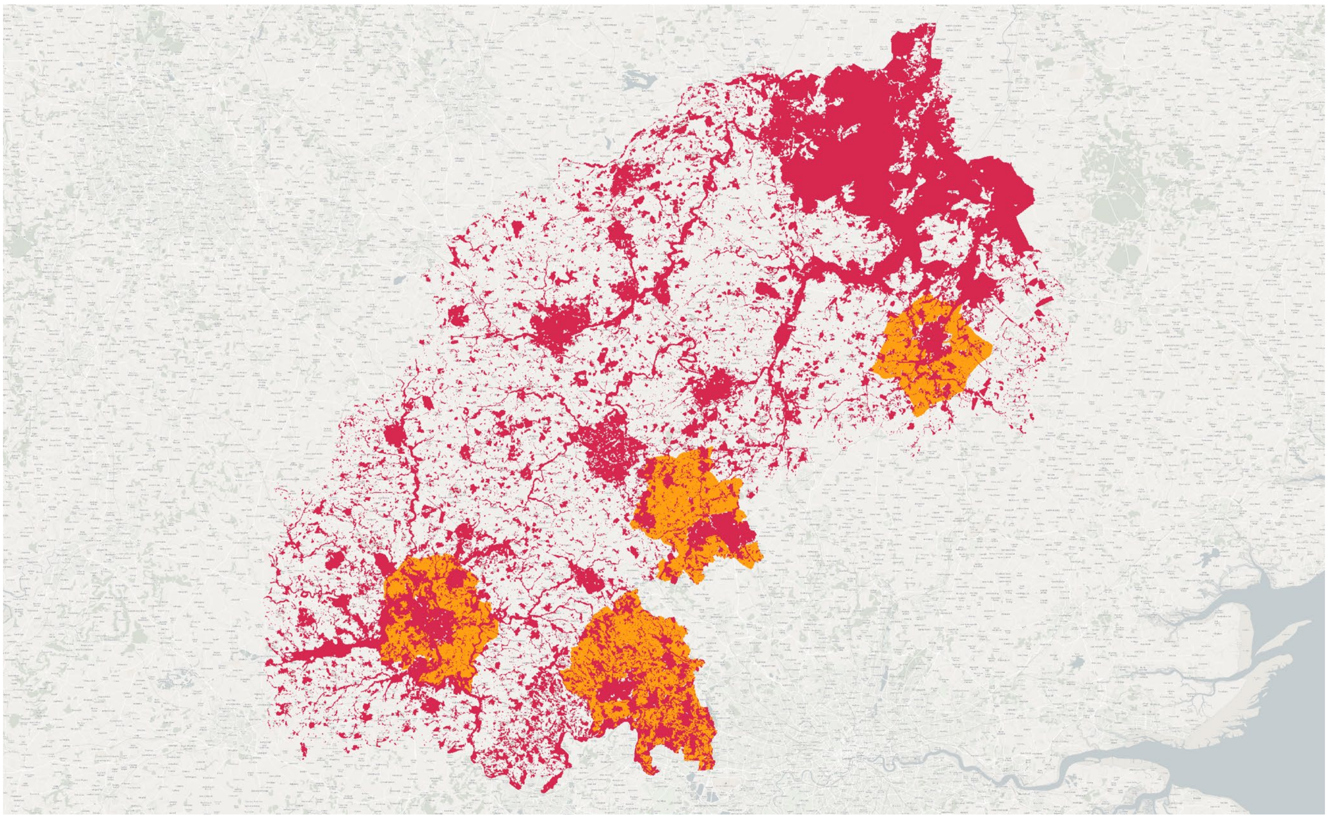

Figure 9.1. Areas where development is excluded (expansion and new settlement scenarios in pink, and additional areas for settlement scenarios in yellow).

A.3 Densities

Housing density in a given cell is defined by:

- Proximity to **existing** urban centres (distance decay – linear or Gaussian) in the expansion scenarios.
- Proximity to **new** urban centres (distance decay – linear or Gaussian) in the new settlement scenarios.

The distribution of housing densities is shown in Figure 9.2.

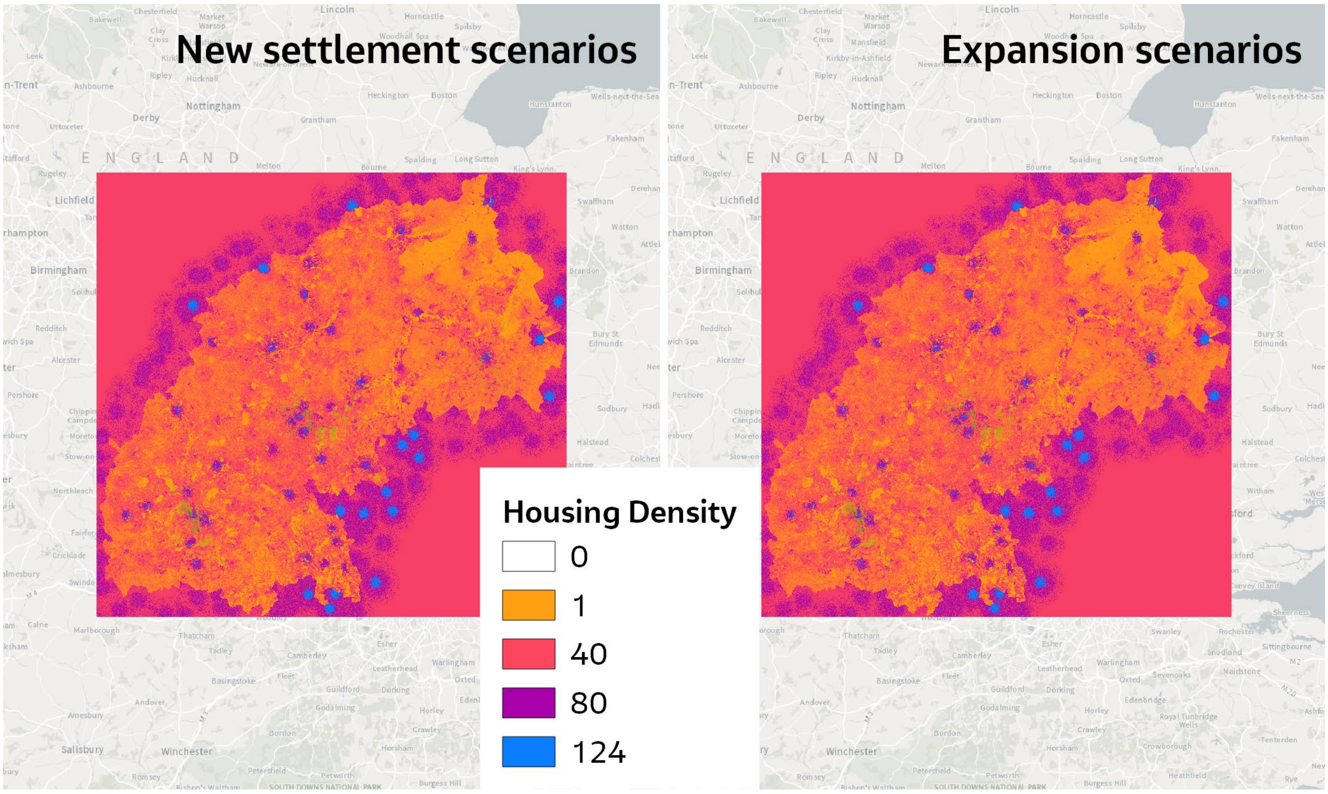

Figure 9.2. Distribution of housing densities.

A.4 Attractors

Attractors define the location and order in which development is distributed across the grid cells that make up the region. Table 9.2 shows the weightings applied to the development scenarios, and Figure 9.3 shows how they translate to a distribution of attractor weightings across the study area.

Table 9.2. Attractor weightings applied to the development scenarios.

Attractor	Expansion scenarios	New settlements scenarios
Current Development Proximity	0.5	0.7
Road Proximity	0.15	0.15
Rail Proximity	0.05	0.05
Employment Access by Road	0.15	-
Employment Access by Rail	0.05	-
Natural Capital Minimum Score	0.1	0.1

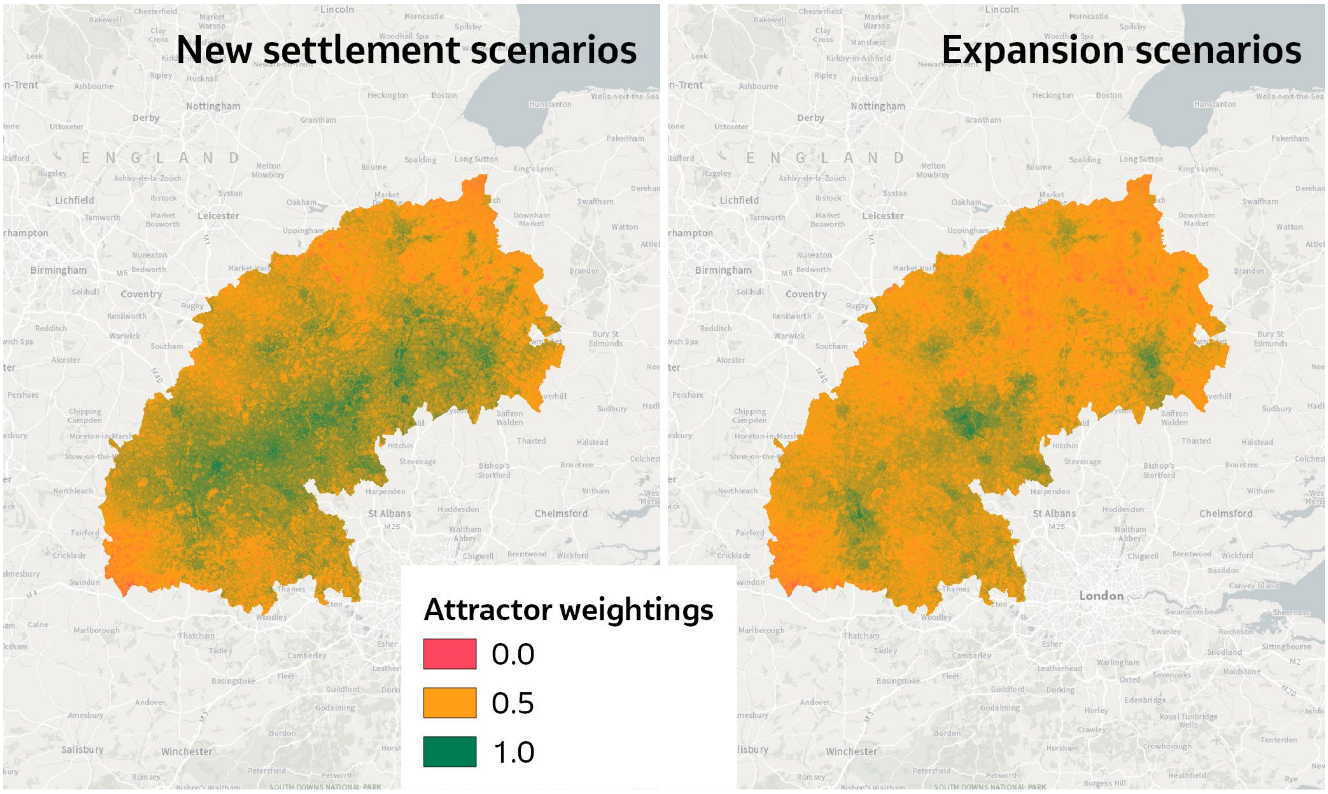

Figure 9.3. Distribution of attractor weightings.

B. Appendix: Model Summary

A.5 Model Summary

References				Capital and construction costs										Cost multipliers		Carbon: Capital emissions (A1 to A5)				
Type	In scope	Price base	LTCT reference	Units	Yard stick	Comments	Form	a	b	Lower limit of Yardstick use	Upper limit of Yardstick use	Estimated design life do nothing	Annual Maintenance cost £ per Unit	Indexing assumes base year is 2015	Optimism bias multiplier	Form	a	b	Units	Comments
Linear Defence	Earth Embankment	2015	Cost_estimation_for_fluvial_defences.pdf	£ per metre	Height (m)	All types using average cost of fill	Power	1.6042	605.9	0.5	5	60	52.5	1.132	1.35	Power	1.604	0.4987	Tonnes of Co2e	Tonnes of co2e per m of height x
Linear Defence	High Ground	2015	Cost_estimation_for_fluvial_defences.pdf	£ per metre	Height (m)	Use Embankment	Power	1.6042	605.9	2	5	60	52.5	1.132	1.35	Power	1.604	0.4987	Tonnes of Co2e	Use embankments. Tonnes of co2e per m of height x.
Linear Defence	Sheet pile wall	2015	Cost_estimation_for_fluvial_defences.pdf	£ per metre	Height (m)	Use All types of wall equation	linear	1358.8	147.3	0.2	2	100	27.5	1.132	1.35	Linear	0.161	0	Tonnes of Co2e	Tonnes of co2e per m of height x
Linear Defence	Vertical Wall	2015	Cost_estimation_for_fluvial_defences.pdf	£ per metre	Height (m)	Use All types of wall equation	linear	1358.8	147.3	0.2	2	100	55	1.132	1.35	Linear	0.527	0	Tonnes of Co2e	Tonnes of co2e per m of height x. Assumes concrete.
Linear Defence	Vertical Wall Raising	2015	Cost_estimation_for_fluvial_defences.pdf	£ per metre	Initial height of wall (m). The raising is treated as an event - so could assume the raise add 0.3 to 0.5 (average of 0.4) metres each event.	Use All types of wall equation	linear	1093	373	0.2	2	100	55	1.132	1.35	Linear	1.462	0	Tonnes of Co2e	per additional m raised above existing crest level.
Catchment Storage	Flood Storage_2	2015	Cost_estimation_for_flood_storage.pdf	£ per m^3 of storage provided	m^3 of storage	Equation 2	power	0.426	7188.5	100	10000000	75	1.5% of capital cost	1.132	1.35	Linear	0.020	0	Tonnes of Co2e	per volume in m^3 of storage
Catchment Storage	Flood Storage_2_Including_Land	2015	Cost_estimation_for_flood_storage.pdf	£ per m^3 of storage provided	m^3 of storage	Equation 2 includes land at 30%	power	0.426	9345	100	100000	75	1.5% of capital cost	1.132	1.35	Linear	0.020	0	Tonnes of Co2e	per volume in m^3 of storage
NFM	Ponds and wetland establishment	unknown	Cost_estimation_for_land_use_and_run-off.pdf	£s per m^3 of ponds and wetlands established	m^3 of volume		Linear	15	0	1	none	45	0.0548	1.132	1.35	Linear	0.020	0	Tonnes of Co2e	per volume in m^3 of storage

Property Flood Resilience	Residential flood resilience	2008	Cost_estimation_for_household_flood_resistance_and_resilience_measures.pdf	Per property	Number of properties		Linear	2640	0	1	1	10	0	1.132	1.35	Linear	0.436	n/a	Tonnes of Co2e	Per property
SUDS	Average_SUDS	2007	Average calculated from Cost_estimation_for_SUDS.pdf	£ per m^3	m^3 stored volume		Linear	161	0	1	None	10	0.0548	1.132	1.35	Linear	0.530	0	Tonnes of Co2e	per volume in m^3 of storage

Carbon: Refurbishment emissions (B5)				Carbon: Operational emissions (B1 to B3)			
Form	A	b	Units and comments	Form	a	b	Units and comments
linear	0.000002	0	tones per m length of height x in meters.	Linear	0.0044	0	tones per m length of height x in meters per year.
linear	0.000002	0	tones per m length of height x in meters.	Linear	0.0044	0	tones per m length of height x in meters per year.
linear	0.0012	0	tones per m length of height x in meters.	Linear	2E-08	0	tones per m length of height x in meters per year.
linear	0.000009	0	tones per m length of height x in meters.	Linear	0.0017	0	tones per m length of height x in meters per year.

l i n e a r	0.291	0	tonnes per m per raise amount x in meters. However, suggest use of the refurbishment assumption from the full height of the wall for more consistent results.	Linear	0.0027	0	tonnes per m per raise amount x in meters. However, suggest use of the refurbishment assumption from the full height of the wall for more consistent results.
L i n e a r	0.0002	0	tonnes per m^3	linear	0.00002		tones per m^3 per year.
l i n e a r	0.0002	0	tonnes per m^3	linear	0.00002		tones per m^3 per year.
L i n e a r	0.00024589 7	0	Tonnes of Co2 e per m^3 at the same time as refurbishment activities	Linear	-0.00039	0	Tonnes per m^3 of storage per year. Assumes that carbon is sequestered at average annual rate of native mixed woodland and hedge rows. A negative indicates that sequestering is greater than any annual emissions from operation on balance
L i n e a r	0.43597427 5	n/a	tonnes per property (use equation for new provision)	n/a	0	0	tones per property per year.
L i n e a r	0.00423350 7	0	Tonnes of co2e per m^3 of refurbishment	Linear	0.037883	0	tonnes of co2 e per m^3 per year