Jacobs

Oxford to Cambridge Arc Flood Risk Investment Study Sensitivity Analysis

Revision no: 1

Environment Agency

Oxford to Cambridge Arc Flood Risk Investment Study
4 April 2022

Oxford to Cambridge Arc Flood Risk Investment Study Sensitivity Analysis

Client name:	Environment Agency		
Project name:	Oxford to Cambridge Arc Flood Risk Investment Study		
Revision no:	1	**Project no:**	B550C033
Date:	4 April 2022	**Project manager:**	Daniel Boyd
File name:	Sensitivity testing report.docx	**Prepared by:**	Joe Clarke

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
1	04/04/2022		J Clarke	S Hardwick	S Hardwick	D Boyd

Distribution of copies

Revision	Issue approved	Date issued	Issued to	Comments

Jacobs U.K. Limited

The West Wing
1 Glass Wharf
Bristol, BS2 0EL
United Kingdom

T +44 (0)117 457 2500
www.jacobs.com

Contents

1.   Introduction

The purpose of the sensitivity analysis in the Oxford to Cambridge Arc Flood Risk Investment Study is to understand how changes in parameters affect the key outputs – i.e. the optimum level of investment. A holistic sensitivity analysis would look to explore the effect of all relevant variables to test the relative importance and propagation of uncertainty through the calculation, and – coupled with a comprehensive representation of the uncertainty in those variables – could be used to produce a complete picture of confidence. With the time and cost constraints of this project, we have adopted a more targeted approach to sensitivity testing.

In general, variables fall into one of these categories, based on how many steps are required between the variable and the end result:

1. Variables which would require re-modelling, impact analysis and optimisation.
2. Variables which would require re-running impact analysis and optimisation.
3. Variables which would 'extract' information from the results in different ways, possibly through adjustments to methods, and generally re-running the optimization.

To maximise the value derived from the sensitivity analysis, we have focussed on (3).

Each sensitivity test uses a single future scenario (23,000 homes per year hybrid development scenario, upper central climate scenario) to avoid the unnecessary computation time introduced by multi-future analysis, aside from sensitivity testing which explicitly explores how results change across futures, which uses the full 18-future analysis. The sensitivity analysis has been run for a single catchment – the same catchment across the sensitivity analysis (with the exception of Section 2, which draws on the full OxCam results from the core analysis).

The following sections describe our approach to and the results of the sensitivity analysis:

- Section 2: Understanding sensitivity through core results.
- Section 3: Sensitivity to impacts.
- Section 4: Sensitivity to costs.
- Section 5: Sensitivity to different weightings of future scenarios.
- Section 6: Sensitivity to the level and timing of investment.

This is followed by a brief conclusions section that looks at the key messages from across the sensitivity analyses (Section **Error! Reference source not found.**).

2.   Understanding sensitivity through core results

The summary report demonstrates how the core results support an understanding of sensitivity – in particular the extent to which investment is sensitive to future scenarios:

1. The impact of climate change on the optimum level of investment and Net Present Value (NPV) (Section 4.6 in the summary report).
2. The impact of different development scenarios on the optimum level of investment and NPV – both the development rate and the shape of development (Section 4.7 in the summary report).

This section presents the full set of results which the summary report draws from. Section 2.1 describes the sensitivity of **baseline risk** to climate change and development scenarios, and Section 2.2 describes the sensitivity of **optimum investment** to climate change and development scenarios.

2.1   Baseline

Table 2.1 shows the baseline risk under different futures, grouped by climate change scenarios. It shows that average risk under climate change scenarios ranges from £58.10 billion (central climate change) to £68.91 billion (H++ climate change), a range of £10.81 billion. This is compared with a mean overall baseline risk of £63.5 billion (as reported in Section 3.1.3 of the summary report).

Table 2.1. Sensitivity of baseline risk to climate change.

Climate change:	Central	Upper end	H++	Highest	Lowest
Settlement expansion 23k homes per year	£55.96 b	£60.92 b	£66.43 b	H++	Central
Settlement expansion 30k homes per year	£57.48 b	£66.66 b	£68.11 b	H++	Central
Settlement expansion 43k homes per year	£60.13 b	£69.60 b	£71.08 b	H++	Central
New settlements 23k homes per year	£56.27 b	£65.48 b	£66.96 b	H++	Central
New settlements 30k homes per year	£57.78 b	£67.16 b	£68.67 b	H++	Central
New settlements 43k homes per year	£60.95 b	£70.60 b	£72.13 b	H++	Central
Hybrid development 23k homes per year	£56.23 b	£65.33 b	£66.79 b	H++	Central
Hybrid development 30k homes per year	£57.56 b	£66.83 b	£68.32 b	H++	Central
Hybrid development 43k homes per year	£60.57 b	£70.15 b	£71.68 b	H++	Central
Minimum	£55.96 b	£60.92 b	£66.43 b		
Mean	£58.10 b	£66.97 b	£68.91 b		
Maximum	£60.95 b	£70.60 b	£72.13 b		

Table 2.2 shows the baseline risk under different futures, grouped by development rates. It shows that average risk under development rates ranges from £62.26 billion (23k homes per year) to £67.43 billion (43k homes per year). The range of baseline risk is narrower than for climate change - £5.17 billion – indicating that there is a greater degree of sensitivity to climate change than to rate of development – at least within the constraints of this analysis.

Table 2.2. Sensitivity of baseline risk to development rate.

Homes per year:	23k	30k	43k	Highest	Lowest
Settlement expansion Central	£56.27 b	£57.78 b	£60.95 b	43k	23k
Settlement expansion Upper end	£65.48 b	£67.16 b	£70.60 b	43k	23k
Settlement expansion H++	£66.96 b	£68.67 b	£72.13 b	43k	23k
New settlements Central	£55.96 b	£57.48 b	£60.13 b	43k	23k
New settlements Upper end	£60.92 b	£66.66 b	£69.60 b	43k	23k
New settlements H++	£66.43 b	£68.11 b	£71.08 b	43k	23k
Hybrid development Central	£56.23 b	£57.56 b	£60.57 b	43k	23k
Hybrid development Upper end	£65.33 b	£66.83 b	£70.15 b	43k	23k
Hybrid development H++	£66.79 b	£68.32 b	£71.68 b	43k	23k
Minimum	£55.96 b	£57.48 b	£60.13 b		
Mean	£62.26 b	£64.29 b	£67.43 b		
Maximum	£66.96 b	£68.67 b	£72.13 b		

Table 2.3 shows the baseline risk under different futures, grouped by development shapes. It shows that average risk under development ranges from £64.04 billion (settlement expansion) to £65.11 billion (new settlements), indicating that risk is not sensitive to the shape of development (a range of £1.07 billion) – at least within the constraints of this analysis.

Table 2.3. Sensitivity of baseline risk to development shape.

Shape of development:	New settlements	Settlement expansion	Hybrid development	Highest	Lowest
23k Central	£56.27 b	£55.96 b	£56.23 b	New settlements	Settlement expansion
23k Upper end	£65.48 b	£60.92 b	£65.33 b	New settlements	Settlement expansion
23k H++	£66.96 b	£66.43 b	£66.79 b	New settlements	Settlement expansion
30k Central	£57.78 b	£57.48 b	£57.56 b	New settlements	Settlement expansion
30k Upper end	£67.16 b	£66.66 b	£66.83 b	New settlements	Settlement expansion
30k H++	£68.67 b	£68.11 b	£68.32 b	New settlements	Settlement expansion
43k Central	£60.95 b	£60.13 b	£60.57 b	New settlements	Settlement expansion

Shape of development:	New settlements	Settlement expansion	Hybrid development	Highest	Lowest
43k Upper end	£70.60 b	£69.60 b	£70.15 b	New settlements	Settlement expansion
43k H++	£72.13 b	£71.08 b	£71.68 b	New settlements	Settlement expansion
Minimum	£56.27 b	£55.96 b	£56.23 b		
Mean	£65.11 b	£64.04 b	£64.83 b		
Maximum	£72.13 b	£71.08 b	£71.68 b		

2.2 Optimum investment

Table 2.4 shows the optimum investment under different futures, grouped by climate change scenario. It shows that average optimum investment under each climate change scenario ranges from £4.74 billion (central) to £6.12 billion (H++), a range of £1.38 billion.

Table 2.4. Sensitivity of optimum investment to climate change.

Climate change:	Central	Upper end	H++	Highest	Lowest
Settlement expansion 23k homes per year	£4.75 b	£6.02 b	£6.11 b	H++	Central
Settlement expansion 30k homes per year	£4.78 b	£6.08 b	£6.13 b	H++	Central
Settlement expansion 43k homes per year	£4.89 b	£6.25 b	£6.38 b	H++	Central
New settlements 23k homes per year	£4.63 b	£5.94 b	£6.04 b	H++	Central
New settlements 30k homes per year	£4.63 b	£5.94 b	£6.04 b	H++	Central
New settlements 43k homes per year	£4.76 b	£6.04 b	£6.15 b	H++	Central
Hybrid development 23k homes per year	£4.73 b	£5.95 b	£6.04 b	H++	Central
Hybrid development 30k homes per year	£4.73 b	£5.95 b	£6.04 b	H++	Central
Hybrid development 43k homes per year	£4.76 b	£6.02 b	£6.11 b	H++	Central
Minimum	£4.63 b	£5.94 b	£6.04 b		
Mean	£4.74 b	£6.02 b	£6.12 b		
Maximum	£4.89 b	£6.25 b	£6.38 b		

Table 2.5 shows the optimum investment under different futures, grouped by development rate. It shows that average optimum investment under each rate of development ranges from £5.58 billion (23k homes per year) to £5.71 billion (43k homes per year). The range of baseline risk is narrower than for climate change – £0.13 billion – mirroring the baseline risk analysis in suggesting that (within the constraints of this analysis) there is a greater degree of sensitivity to climate change than to rate of development.

Table 2.5. Sensitivity of optimum investment development rate.

Homes per year:	23k	30k	43k	Highest	Lowest
Settlement expansion Central	£4.63 b	£4.63 b	£4.76 b	43k	23k
Settlement expansion Upper end	£5.94 b	£5.94 b	£6.04 b	43k	23k
Settlement expansion H++	£6.04 b	£6.04 b	£6.15 b	43k	23k
New settlements Central	£4.75 b	£4.78 b	£4.89 b	43k	23k
New settlements Upper end	£6.02 b	£6.08 b	£6.25 b	43k	23k
New settlements H++	£6.11 b	£6.13 b	£6.38 b	43k	23k
Hybrid development Central	£4.73 b	£4.73 b	£4.76 b	43k	23k
Hybrid development Upper end	£5.95 b	£5.95 b	£6.02 b	43k	23k
Hybrid development H++	£6.04 b	£6.04 b	£6.11 b	43k	23k
Minimum	£4.63 b	£4.63 b	£4.76 b		
Mean	£5.58 b	£5.59 b	£5.71 b		
Maximum	£6.11 b	£6.13 b	£6.38 b		

Table 2.6 shows the optimum investment under different futures, grouped by development shape. It shows that average optimum investment under each shape ranges from £5.57 billion (new settlements) to £5.71 billion (settlement expansion), a range of £0.14 billion – again showing that within the constraints of this analysis, optimum investment is much less sensitive to development than to climate change.

Table 2.6. Sensitivity of optimum investment to development shape.

Shape of development:	New settlements	Settlement expansion	Hybrid development	Highest	Lowest
23k Central	£4.63 b	£4.75 b	£4.73 b	Settlement expansion	New settlements
23k Upper end	£5.94 b	£6.02 b	£5.95 b	Settlement expansion	New settlements
23k H++	£6.04 b	£6.11 b	£6.04 b	Settlement expansion	Hybrid development
30k Central	£4.63 b	£4.78 b	£4.73 b	Settlement expansion	New settlements
30k Upper end	£5.94 b	£6.08 b	£5.95 b	Settlement expansion	New settlements
30k H++	£6.04 b	£6.13 b	£6.04 b	Settlement expansion	Hybrid development
43k Central	£4.76 b	£4.89 b	£4.76 b	Settlement expansion	New settlements

Oxford to Cambridge Arc Flood Risk Investment Study Sensitivity Analysis

Shape of development:	New settlements	Settlement expansion	Hybrid development	Highest	Lowest
43k Upper end	£6.04 b	£6.25 b	£6.02 b	Settlement expansion	Hybrid development
43k H++	£6.15 b	£6.38 b	£6.11 b	Settlement expansion	Hybrid development
Minimum	£4.63 b	£4.75 b	£4.73 b		
Mean	£5.57 b	£5.71 b	£5.59 b		
Maximum	£6.15 b	£6.38 b	£6.11 b		

3. Sensitivity to impacts

3.1 Approach

The early stages of analysis (collating and generating water levels to represent baseline, climate change and catchment interventions, running 2D simulations – including simulations representing linear interventions) are complex, and there are many variables and assumptions that form that analysis. A comprehensive sensitivity analysis would explore all these variables and the effect they could have on the optimum level of investment. Through previous discussions, as described above, we have agreed to focus on the 'final stages' of analysis. Sensitivity to impacts is therefore reflective of sensitivity to variables in earlier stages of the analysis, which cannot be represented explicitly in this sensitivity analysis.

1. The key aspiration of this sensitivity analysis is to understand the overall sensitivity to changes in impacts, through a 5-point estimate of total impacts. Data of reasonable upper and lower estimates is limited for impact data, so instead we have explored 50%, 75%, 100% (i.e. the best estimate), 150% and 200% impact adjustments, and re-run the optimisation with these modifications. This gives us an indication of the sensitivity not just of impacts themselves, but also an indication of the importance of earlier stages in the analysis.
2. Given uncertainty in some categories of impacts (and their status as being non-standard for economic appraisals), we have also re-run the optimisation with the following types of impacts removed:

   a. Gross value added (of present and future properties)
   b. The carbon costs of flood recovery.

3.2 Results

Table 3.1 shows the sensitivity of results to different impact multipliers. It shows that that while present value benefits mirror the impact multipliers directly, they do not have a substantive effect on the present value cost – this indicates that the optimum level of investment is **not** sensitive to impacts. Table 3.2 shows similar results with different impact categories removed – again showing that there is no impact on the present value investment.

Table 3.1. Sensitivity to impacts.

Impact multiplier	Present value cost		Present value benefit		Net present value	
50%	£223,338,417	-0.2%	£1,526,023,800	-50%	£1,302,685,382	-54%
75%	£223,726,962	0.0%	£2,289,526,257	-25%	£2,065,799,294	-27%
100%	£223,761,095	0.0%	£3,052,738,922	0%	£2,828,977,828	0%
150%	£225,241,066	0.7%	£4,580,051,304	50%	£4,354,810,238	54%
200%	£225,865,948	0.9%	£6,107,521,817	100%	£5,881,655,869	108%

Table 3.2. Sensitivity to specific impact categories.

Impact categories	Present value cost		Present value benefit		Net present value	
All impacts	£223,761,095	0.0%	£3,052,738,922	0%	£2,828,977,828	0%
No Carbon	£223,761,095	0.0%	£3,052,738,922	0%	£2,828,977,828	0%
No GVA	£223,761,095	0.0%	£2,550,485,284	-16%	£2,326,724,190	-18%

4. Sensitivity to costs

4.1 Approach

The costing of interventions is based on unit cost functions built up using available cost data from the **long term costing tool for flood and coastal risk management** (JBA Consulting, 2015) and storage cost data available from the Thames Valley flood scheme. For example, the capital cost function for an earth embankment is:

$£\ per\ metre\ cost = 605.9h^{1.6042}$ (where h is the height of the embankment)

These equations form the 'central estimate' of our cost analysis. We have explored sensitivity to this cost information by applying a 5-point estimate of 50%, 75%, 100% (central estimate), 150% and 200%. While it would be possible to develop upper and lower cost estimates from the available cost data, adopting a simple range enables us to more directly compare sensitivity to impacts with sensitivity to costs. The optimisation has been re-run with these modified costs.

4.2 Results

Table 4.1 shows the sensitivity of results to different cost multipliers. It shows that the optimum level of investment – as would be expected – closely (but not exactly) mirrors the cost multiplier. However, interestingly, the present value benefit remains largely unaffected – meaning that despite the changes in costs, it does not affect the interventions which are selected.

Table 4.1. Sensitivity to costs.

Cost multiplier	Present value cost		Present value benefit		Net present value	
50%	£112,932,974	-49.5%	£3,053,760,908	0.0%	£2,940,827,934	4.0%
75%	£168,913,746	-24.5%	£3,053,351,858	0.0%	£2,884,438,112	2.0%
100%	£223,761,095	0.0%	£3,052,738,922	0.0%	£2,828,977,828	0.0%
150%	£335,553,065	50.0%	£3,052,660,667	0.0%	£2,717,107,602	-4.0%
200%	£446,676,835	99.6%	£3,052,047,600	0.0%	£2,605,370,765	-7.9%

5. Sensitivity to different weightings of future scenarios

5.1 Approach

We have produced data for 27 different future scenarios (3 climate change × 3 development rates × 3 development shapes), with individual optimisation runs for each of the 27. Of these, 18 (excluding the most extreme development rate) form the core 'all-futures' analysis which evaluates robust investment choices across the futures, rather than optimising under a single future. A key assumption of the 'all-futures' analysis is the relative likelihood of these different scenarios, with our core analysis treating them as equally likely. To understand the implication of adopting equal probabilities, we have considered two scenarios in which probabilities are modified:

- **Middle estimate**. We assume that 30,000 homes per year and upper central climate change represent a middle and more likely estimate, so increase the probability of these, and decrease the probability of others.
- **Extreme climate change**. We increase the probability of the more severe climate change scenarios, and decrease the probability of the less severe climate change scenarios.

The individual optimisation runs – included in Section 2 of this report – also serve as extreme cases (i.e. where 1 scenario is weighted at 100% and all others at 0%). To enable more direct comparison in this sensitivity analysis, we have extracted the results for the individual catchment in Table 5.3.

5.2 Scenarios

For the core analysis, each of the 18 futures is assumed to have an equal weighting, so each scenario has a 1/18 chance of occurring, and therefore contributes 1/18 to the total 'real options analysis' weighted net present value and present value investment.

For the other scenarios, the probability of each future is based on a weighting, divided by the total number of 'points'. A future with a weighting of 4 will therefore have a probability 4× a future with a weighting of 1. The specific weightings are somewhat subjective – for the purpose of this sensitivity analysis, they are designed simply to test the effect of changing weightings.

For the middle estimate, we have assigned weightings based on the 'middle' future having the highest probability, and other futures having a lower probability the more they deviate from the middle. They are calculated as:

- 23k homes per year and either upper end or H++ climate change are assigned a weighting of 1.
- 30k homes per year **or** central climate change are assigned a weighting of 2.
- 30k homes per year **and** central climate change are assigned a weighting of 3.
- 30k homes per year, central climate change and hybrid development are assigned a weighting of 4.

The sum of the weighting points is 34 points, so the probability of each future is calculated as the weighting divided by 34. For example, 30k homes per year, central climate change and hybrid development has a probability of 4/34, or 11.8%.

For the extreme climate scenario, weightings are calculated as:

- Central climate change scenarios are assigned a weighting of 1.
- Upper end are assigned a score of 2.
- H++ are assigned a score of 4.

This adds up to a sum of 42 points, so weightings are calculated as the score divided by 42.

The full set of weightings are defined in Table 5.1.

Table 5.1. Scenario weighting definitions.

Scenario	Equal weighting	Middle estimate	Extreme climate
Central Settlement expansion 23k homes per year	1/18 (5.6%)	2/34 (5.9%)	1/42 (2.4%)

Oxford to Cambridge Arc Flood Risk Investment Study Sensitivity Analysis

Scenario	Equal weighting	Middle estimate	Extreme climate
Upper end Settlement expansion 23k homes per year	1/18 (5.6%)	1/34 (2.9%)	2/42 (4.8%)
H++ Settlement expansion 23k homes per year	1/18 (5.6%)	1/34 (2.9%)	4/42 (9.5%)
Central Settlement expansion 30k homes per year	1/18 (5.6%)	3/34 (8.8%)	1/42 (2.4%)
Upper end Settlement expansion 30k homes per year	1/18 (5.6%)	2/34 (5.9%)	2/42 (4.8%)
H++ Settlement expansion 30k homes per year	1/18 (5.6%)	2/34 (5.9%)	4/42 (9.5%)
Central New settlements 23k homes per year	1/18 (5.6%)	2/34 (5.9%)	1/42 (2.4%)
Upper end New settlements 23k homes per year	1/18 (5.6%)	1/34 (2.9%)	2/42 (4.8%)
H++ New settlements 23k homes per year	1/18 (5.6%)	1/34 (2.9%)	4/42 (9.5%)
Central New settlements 30k homes per year	1/18 (5.6%)	3/34 (8.8%)	1/42 (2.4%)
Upper end New settlements 30k homes per year	1/18 (5.6%)	2/34 (5.9%)	2/42 (4.8%)
H++ New settlements 30k homes per year	1/18 (5.6%)	2/34 (5.9%)	4/42 (9.5%)
Central Hybrid development 23k homes per year	1/18 (5.6%)	2/34 (5.9%)	1/42 (2.4%)
Upper end Hybrid development 23k homes per year	1/18 (5.6%)	1/34 (2.9%)	2/42 (4.8%)
H++ Hybrid development 23k homes per year	1/18 (5.6%)	1/34 (2.9%)	4/42 (9.5%)
Central Hybrid development 30k homes per year	1/18 (5.6%)	4/34 (11.8%)	1/42 (2.4%)
Upper end Hybrid development 30k homes per year	1/18 (5.6%)	2/34 (5.9%)	2/42 (4.8%)
H++ Hybrid development 30k homes per year	1/18 (5.6%)	2/34 (5.9%)	4/42 (9.5%)

5.3   Results

Table 5.2 shows the effect of modified future scenario weightings on the results. It shows some degree of variation in present value benefits, but very little change in the optimum level of investment. When compared with the individual future results shown in Table 5.3 – which show as much as 31% increase in optimum investment under the most extreme climate change scenarios – it indicates that even with modified probabilities, the extremities of certain futures are dampened by the need for robust investment under the full breadth of futures.

Table 5.2. Sensitivity to different weightings of future scenarios.

Weighting	Present value cost		Present value benefit		Net present value	
Equal weighting (core analysis)	£224,059,823	0.0%	£2,779,127,798	0.0%	£2,555,067,975	0.0%
Middle Estimate	£223,710,799	-0.2%	£2,638,537,804	-5.1%	£2,414,827,006	-5.5%
Extreme Climate	£224,728,308	0.3%	£2,969,376,608	6.8%	£2,744,648,300	7.4%

Table 5.3. Core analysis results for individual futures.

Scenario	Present value cost		Present value benefit		Net present value	
Core analysis	£224,059,823	0.0%	£2,779,127,798	0.0%	£2,555,067,975	0.0%
Central-exp_23	£222,957,182	-0.5%	£2,050,409,685	-26.2%	£1,827,452,504	-28.5%
Upper end-exp_23	£226,898,418	1.3%	£3,067,569,631	10.4%	£2,840,671,213	11.2%
H++-exp_23	£241,407,099	7.7%	£3,270,121,786	17.7%	£3,028,714,687	18.5%
Central-exp_30	£222,957,723	-0.5%	£2,146,720,814	-22.8%	£1,923,763,091	-24.7%
Upper end-exp_30	£226,908,688	1.3%	£3,189,902,123	14.8%	£2,962,993,436	16.0%
H++-exp_30	£241,425,752	7.8%	£3,394,680,431	22.1%	£3,153,254,679	23.4%
Central-exp_43	£222,957,723	-0.5%	£2,264,099,127	-18.5%	£2,041,141,404	-20.1%
Upper end-exp_43	£228,996,380	2.2%	£3,368,802,342	21.2%	£3,139,805,962	22.9%
H++-exp_43	£241,480,622	7.8%	£3,577,124,843	28.7%	£3,335,644,220	30.6%
Central-set_23	£222,959,030	-0.5%	£1,919,565,723	-30.9%	£1,696,606,693	-33.6%
Upper end-set_23	£226,833,018	1.2%	£2,886,671,614	3.9%	£2,659,838,596	4.1%
H++-set_23	£238,116,696	6.3%	£3,072,380,280	10.6%	£2,834,263,583	10.9%
Central-set_30	£223,896,552	-0.1%	£1,977,165,304	-28.9%	£1,753,268,753	-31.4%
Upper end-set_30	£226,833,018	1.2%	£2,955,419,419	6.3%	£2,728,586,401	6.8%
H++-set_30	£238,605,247	6.5%	£3,135,833,625	12.8%	£2,897,228,377	13.4%
Central-set_43	£224,222,530	0.1%	£2,106,370,055	-24.2%	£1,882,147,525	-26.3%
Upper end-set_43	£265,976,402	18.7%	£3,165,643,729	13.9%	£2,899,667,328	13.5%
H++-set_43	£293,674,467	31.1%	£3,401,717,508	22.4%	£3,108,043,041	21.6%
Central-hyb_23	£222,959,030	-0.5%	£1,951,937,507	-29.8%	£1,728,978,477	-32.3%
Upper end-hyb_23	£226,873,989	1.3%	£2,937,723,376	5.7%	£2,710,849,387	6.1%
H++-hyb_23	£240,265,470	7.2%	£3,133,732,347	12.8%	£2,893,466,877	13.2%
Central-hyb_30	£222,958,777	-0.5%	£2,004,306,175	-27.9%	£1,781,347,398	-30.3%
Upper end-hyb_30	£226,876,040	1.3%	£3,004,328,490	8.1%	£2,777,452,451	8.7%
H++-hyb_30	£241,918,173	8.0%	£3,203,134,196	15.3%	£2,961,216,023	15.9%
Central-hyb_43	£222,959,030	-0.5%	£2,122,830,633	-23.6%	£1,899,871,603	-25.6%
Upper end-hyb_43	£226,882,499	1.3%	£3,144,038,012	13.1%	£2,917,155,513	14.2%

Oxford to Cambridge Arc Flood Risk Investment Study Sensitivity Analysis

Scenario	Present value cost		Present value benefit		Net present value	
Maximum	£293,674,467	31.1%	£3,577,124,843	28.7%	£3,335,644,220	30.6%
Minimum	£222,957,182	-0.5%	£1,919,565,723	-30.9%	£1,696,606,693	-33.6%

6. Sensitivity to the level and timing of investment

6.1 Approach

While the sensitivity analyses described in the previous sections re-run the optimisation process with modified variables, this analysis instead explores how sensitive the identified maximum net present value pathway is to adjustments of the level and timing of investment.

Specifically:

1. Shifting each investment (other than investment in year 0) forward by 1 decision point, across the study area.
2. Shifting each investment backwards by 1 decision point, across the study area.
3. Increasing each intervention 'level' by 1 (other than those already at the maximum level), across the study area.

   a. For interventions in year 0.
   b. For interventions in future years, leaving year 0 investment unaffected.

4. Decreasing each intervention 'level' by 1 (other than those on the lowest investment level greater than do nothing), across the study area.

   a. For interventions in year 0.
   b. For interventions in future years, only affecting year 0 investment if a reduction in future investment would lead to a downward step in investment.

These explorations will give us an indication of how steeply the net present value decreases either side of the optimum, and therefore of the sensitivity to the computation approach of the optimisation itself.

6.2 Results

in the specific balance of investment between the portfolio of interventions – in particular for catchment-scale storage. However, we believe this is unlikely to have a significant effect on the level of confidence in the overall optimum level of investment, because the results indicate that the portfolio of available interventions enables the analysis to redistribute investment accordingly – for example, if the ideal investment in storage were between 'medium' and 'large', we would see the analysis selecting 'medium' and applying more localised investment (such as in linear defences) to provide additional protection. However, it does indicate that we need to be careful in drawing conclusions from the balance of investment across the portfolio of interventions.

The timing of investment provides 10 possible points of intervening, so we are able to see a relatively nuanced picture of how investment which is too early or too late could affect the present value costs – increasing by 4.6% if 10 years too early, or decreasing by 1.6% if 10 years too late.

Table 6.1 shows the sensitivity of results to the timing of investment, and to the level of intervention.

The results show a significant increase in investment when raising the level of intervention adopted in year 0 or in future years, and a distinct reduction when the level is reduced. It is difficult to draw much meaning from this – with such large catchment-scale interventions included in the analysis, increasing or decreasing the level of investment by just 1 step has a dramatic effect on costs.

The conclusion we could draw from this is that the optimum level of investment **in each intervention** is likely to be sensitive to the available range of intervention options – and that providing steps 'in between' could lead to results which provide more confidence in the specific balance of investment between the portfolio of interventions – in particular for catchment-scale storage. However, we believe this is unlikely to have a significant effect on the level of confidence in the overall optimum level of investment, because the results indicate that the portfolio of available interventions enables the analysis to redistribute investment accordingly – for example, if the ideal investment in storage were between 'medium' and 'large', we would see the analysis selecting 'medium' and applying more localised investment (such as in linear defences) to provide additional protection. However, it does indicate that we need to be careful in drawing conclusions from the balance of investment across the portfolio of interventions.

The timing of investment provides 10 possible points of intervening, so we are able to see a relatively nuanced picture of how investment which is too early or too late could affect the present value costs – increasing by 4.6% if 10 years too early, or decreasing by 1.6% if 10 years too late.

Table 6.1. Sensitivity to the level and timing of investment.

Scenario	Present value cost		Present value benefit		Net present value	
Core analysis	£224,059,823	0.0%	£2,779,127,798	0.0%	£2,555,067,975	0.0%
Shift forward by 1 decision point	£234,268,810	4.6%	£2,739,795,333	-1.4%	£2,505,526,523	-1.9%
Shift backward by 1 decision point	£227,590,913	1.6%	£2,737,968,969	-1.5%	£2,510,378,056	-1.7%
Increase year 0 investment by 1 level	£3,561,396,352	1489.5%	£2,776,426,507	-0.1%	-£784,969,845	-130.7%
Decrease year 0 investment by 1 level	£163,237,001	-27.1%	£2,515,940,889	-9.5%	£2,352,703,888	-7.9%
Increase future year investment by 1 level	£1,438,081,285	541.8%	£2,772,760,167	-0.2%	£1,334,678,882	-47.8%
Decrease future year investment by 1 level	£130,672,674	-41.7%	£2,272,796,186	-18.2%	£2,142,123,512	-16.2%

Table 6.2 shows how the sensitivity described above translates to the sensitivity of residual risk to the level and timing of investment.

Table 6.2. Sensitivity of residual risk to the level and timing of investment.

Scenario	Present value residual risk	
Core analysis	£48,092,780	0.0%
Shift forward by 1 decision point	£47,269,399	-1.7%
Shift backward by 1 decision point	£49,095,763	2.1%
Increase year 0 investment by 1 level	£10,638,225	-77.9%
Decrease year 0 investment by 1 level	£271,123,842	463.8%
Increase future year investment by 1 level	£14,304,564	-70.3%
Decrease future year investment by 1 level	£514,268,545	969.3%

7.   Conclusions

The key messages we can draw from the sensitivity analysis are:

1. Investment is more sensitive to climate change than development – although we can only say with confidence that this is the case within the constraints of our project, as it is possible that this is a by-product of the scenario definitions.
2. The optimum level of investment does not appear to be sensitive to the impacts. This is likely to be because the benefit-cost ratio is high enough (5:1 for the overall OxCam analysis) that even a halving of benefits does not dramatically shift which interventions are cost-beneficial.
3. Similarly, the intervention options adopted in the analysis are not sensitive to the costs. This is likely to be for the same reason as for insensitivity to changes in impacts. However, the overall level of investment required to implement those interventions is directly linked to costs – so the optimum investment level is highly sensitive to the cost data (i.e. if costs were doubled, the optimum investment would be doubled). Given that the level of investment is the core output of this project, this sensitivity is key. We would recommend that further work is needed to improve the cost models available for studies like OxCam (and, for example, the long-term investment scenarios project).
4. The core analysis applied equal probabilities to future scenarios. We found that the results do not change significantly when adopting different weightings (+/-0.3% of the optimum investment). However, if investment were optimised for a **single** future, the optimum investment could be much higher (e.g. a worst case of 31% higher under extreme climate change and extreme development) – this indicates that if we knew with absolute confidence that climate change and development would be extreme, we should invest more earlier to mitigate the changing risk, but that given the uncertainty, the present value investment is lower because we **defer** investment until we know more. This doesn't mean that the overall cash costs would be much different, but the effect of deferring investment is to reduce present value investment because of discounting.