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Climate vulnerability assessment

The risks identified in Section 4 were analysed through a two-stage structured risk assessment for the Square Mile and City Corporation asset portfolio. A summary is provided below; the full technical background is available in Appendix B.

1. A full assessment of climatic changes for the Square Mile using the Met Office UK Climate Projections 2018 was undertaken. This had two components:
 - a. An analysis of average temperatures and rainfall under low and high emissions pathways (RCP 2.6 and 8.5) using probabilistic data for the 5 km square in which the Square Mile lies. Results are presented using the percentile range method, showing the levels under which 25% and 75% of model results lay, as well as the 50th percentile line for the purpose of reporting. This indicates broad climatic patterns for the area with an indication of uncertainty in the modelling.
 - b. An analysis of worst-case weather patterns using the Regional and Local Met Office models for the high emissions scenario (RCP 8.5). Weather patterns like days and intensity of drought, heatwaves, snowfall, thermal comfort and wind speed are analysed. Since average results from the models were used for analysis, it is important to stress that these are indicative only, and real patterns could be worse or better than those found.
2. A literature review and desktop study into the influence of the risks on the Square Mile and City Corporation assets was undertaken. This was informed by analysis of publicly available datasets, relevant City Corporation datasets, peer reviewed journals and publications, and engagement with City Corporation officers. The intention of this exercise was to understand how the six main risk areas would impact City Corporation activities, and to highlight key considerations, opportunities, existing initiatives, and constraints.

Stakeholder engagement

Stakeholder engagement was used to inform the adaptive pathway design. Input was gathered through a structured 3.5 hour workshop led by Buro Happold and attended by City Corporation Officers as well as a selection of external technical experts (21st April 2020). Attendees included the Met Office, Environment Agency, London Climate Change Partnership, Committee on Climate Change, Transport for London, and more.

The attendees were organised into focus groups based around the six risks, and allocated based on their expertise. Following a briefing on the Climate vulnerability assessment and the key risks to be considered, a series of exercises were carried out:

1. Attendees were asked to provide feedback on different risk impacts and the level at which they thought actions should be required to mitigate or alleviate these effects as a group.
2. Attendees were asked to rank risks based on their perceived severity.
3. Attendees were asked to individually rank the efficacy and necessity of a longlist of measures to tackle their risk (identified in the literature review), with group discussions following.
4. Attendees were asked to contribute ideas for additional measures not included on the longlist.

These results fed into the pathways design and threshold identification exercises discussed in the following sections and main body of the report.

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Multi-criteria tool

A longlist of measures was drawn up through a literature review of climate risk assessments and resilience strategies, international guidance and other studies. This was supplemented with results from the stakeholder workshop, the initial climate vulnerability assessment and existing City Corporation activities.

All measures were categorised and labelled, then subsequently analysed against a broad range of evaluation criteria. The selected evaluation criteria are summarised below and were developed based upon a review of range of resources (such as those produced by the International Panel on Climate Change and UKCIP) and tailored for the City Corporation:

- Stakeholder perceptions of impact and importance – based on the workshop outcomes.
- City Corporation influence – ability to influence decision making and implementation.
- Effectiveness – option reduces impact of climate events or increases resilience.
- Equity – potential positive/negative distributional social impacts on vulnerable groups.
- Flexibility – how easily can adjustments be made in response to evolving conditions.
- Robustness – does the option perform well under a wide range of possible climate futures.
- Cost (CAPEX)¹ – what is the CAPEX associated with the adaptation option.
- Cost (OPEX) – what is the OPEX associated with the adaptation option (cost per annum).
- Feasibility – is the option technically feasible and practical to implement in terms of the potential capacity and resources required for delivery.
- Legitimacy – is the adaptation option politically and socially acceptable.
- Unintended consequences – to what extent are there disbenefits or other unintended negative consequences associated with the adaptation option.
- Co-benefits – to what extent might an adaptation option provide valuable co-benefits? Categories for mitigation, sequestration, economic, environmental and social co-benefits.

These aimed to give detailed insight into the strengths of each measure against considerations linked to effectiveness, cost, ease of delivery and co-benefits delivered. The final results of the assessment were put through a sensitivity test for different measure weightings within groupings of criteria based on cost, delivery, effectiveness and co-benefits.

Within the multi-criteria tool, measures were also categorised based on a range of other considerations. For example:

- Primary and secondary risks addressed.
- Measure type (Structural/Physical (Engineered and built environment, Technological, Ecosystem-based, Services), Social (Educational, Informational, Behavioural), or Institutional (Economic, laws and regulations, government policies and programs).
- Measure sub-type (preparatory, management, capital or mainstreaming).
- Project lead times.
- Appropriateness to the Square Mile and/or City Corporation assets that sit beyond this.

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Pathway design and development

The results of the multi-criteria assessment were used to exclude poorly scoring measures, and to check that high scoring measures were prioritised and considered appropriately in the pathway design exercise. A number of the measures were 'bundled' into a single measure; these are illustrated in risk specific pathways (Appendix C) and further explained in the write up of the proposed measures (Appendix D). The design of pathways was an iterative process, it drew on the findings from the climate risk assessment (Appendix B), stakeholder engagement outcomes and was informed by continuous engagement with the City Corporation officers and resilience working group.

While a number of the measures (notably mainstreaming, management and preparatory actions) it is recommended that these are begun today, the adaptive measures (typically capital programmes) are based on thresholds. Thresholds were identified using the outcomes of the Climate Risk Assessment and the addition of further desktop reviews to establish a suitable and robust threshold. For example, the climate risk assessment highlights that overheating of internal spaces creates risk of heat related ill-health and mortality, this in turn has informed this objective. The further desktop review was used to identify the threshold at which actions need to be completed by to avoid unacceptable risk, in this example this was based on daily average outdoor temperatures. The MET Office UKCP18 was then used to establish when this threshold may be reached under a low and high emissions scenario.

Thresholds for adaptive measures have been developed based on best available evidence at this time. Consideration has been given when setting thresholds to identify indicators that the City Corporation can readily track. It is noted that given the complexity and relatively low understanding of some risks, that thresholds should continue to be reviewed and updated in line with best available evidence as this emerges. Similarly, as the City Corporation rolls out its Climate Action Strategy the resources available to monitor performance may evolve and as such more accurate thresholds may become available.

By identifying lead times and thresholds for each measure as appropriate, this allowed all measures to be plotted against time for future decades on a risk by risk basis. Subsequently, risk specific pathways could be reviewed against one another: measures were bundled and scheduled according to points of interdependency and overlaps, with cross-cutting measures pulled into their own pathway and a few additional measures excluded through review of previous stakeholder feedback and criteria results. This narrowed down the final pathway to a distinct group of final measures to be used to build City Corporation climatic resilience.

Preliminary costing

The cost assessment presents:

1. An estimated total cost of all proposed resilience and adaptation measures, attributable to the City Corporation, is presented derived from top down estimates of likely budget requirements. All costs are nominal and do not account for inflation.
2. The majority of measures have been costed using broad cost bandings and the proportion of costs attributable to the City Corporation for each measure has been assumed.
3. Further feasibility and appraisal work is required to assess the intervention options for measures and quantify the direct and indirect economic, social and environmental costs and benefits so that the wider benefits are understood. The outcomes of this work will inform decision making around which options go forward.
4. The total cost is presented over the UK National Adaptation Program periods for both a low and high emissions scenario (based on the pathways presented elsewhere in this study).
5. Total costs exclude costs which may be attributable to others but may be necessary for the successful implementation of proposed resilience and adaptation measures.
6. Costs presented in this study are high level and have been provided for illustrative purposes only. They have been developed with limited input from the City Corporation and others undertaking studies as part of the Climate Action Strategy. Costs have not been based on actual scheme and budget benchmarks from previous and planned projects based on the availability of data and timeframes for the project.

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7. The cost estimate information may include a degree of overlap and double counting for some measures rather than reflecting the incremental cost of climate adaptation and resilience action. A further detailed cost assessment of each measure will be required during subsequent stages. Cost presented at this stage should be treated with caution and will be subject to future changes.

Key assumptions include:

1. Assessment of costs have been done based on the assumptions set out below and are intended as illustrative costs only. These illustrative costs are underpinned by broad assumptions which will require further refinement through programme appraisal and design. These should be treated with caution and may be subject to future changes.
2. Costs have been developed with limited engagement from the City Corporation and without engagement from others undertaking studies as part of the Climate Action Strategy. There is risk as such that costs between projects within the Climate Action Strategy are double counted. The costs presented have also not been informed by actual current levels of spending by the City Corporation. The costs presented are illustrative and should be treated with caution.

3. The level of action taken will be determined based upon the level of risk deemed to be acceptable by the City Corporation and the stakeholders to which the City Corporation is accountable. The two scenario's presented are based on leading research for how the climate may change under a low and high emission scenarios. As such, they present an indication of the measures that may be required under either pathway. Forecasts of change in future climate are however highly uncertain, in turn the actual pathway followed may be different to the high or low emission scenario presented. As part of the project, a robust set of monitoring criteria will be required to monitor change in climate and identify trigger points for action. The high and low emission scenarios are based on RCP 8.5 and 2.6 respectively.

The majority of items have been costed using general bands for both CAPEX (capital costs) and OPEX (operational costs). The table below provides a summary of costing bands adopted. In order to provide an indication of the cost attributable to the City Corporation, the level of influence the City Corporation has over each measure has been identified (or 'scored'). Based on this, an indicative proportion of the total measure cost (CAPEX and OPEX) that may be attributable to the City Corporation has been determined. This is illustrated in the table below.

Within the cost assessment, it has also been assumed that a proportion of the costs for some measures may align with existing expenditure and committed budgets of the City Corporation. In order to account for this, in addition to total costs a total cost minus anticipated existing expenditure is presented. To do this, an assumed percentage of the total measure cost already committed by the City Corporation has been identified for each measure.

Though cost bandings are generally applied, a cost validation exercise has been undertaken for a number of the higher cost measures proposed. These and the key assumptions made in costing them are summarised below.

Score	CoL influence % to pay	Cost assessment references			
		CAPEX (low)	CAPEX high	OPEX low	OPEX high
1	0%	£50,000,000	£75,000,000	£5,000,000	£50,000,000
2	25%	£10,000,000	£50,000,000	£1,000,000	£5,000,000
3	50%	£1,000,000	£10,000,000	£500,000	£1,000,000
4	75%	£200,000	£1,000,000	£200,000	£500,000
5	100%	£0	£200,000	£0	£200,000

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Flood defence assets maintenance and management regimes

The Environment Agency has developed a set of maintenance standards, and associated costs, for routine maintenance activities on flood risk management assets. Costs included in the Maintenance Standards Manual have been used as proxy for this specific measure.²

Total CAPEX (whole programme):

- Min: £2,500,000
- Max: £12,500,000

Total OPEX (whole programme):

- Min: £54,600
- Max: £397,000

Costs have not been based on actual data provided by the City Corporation.

Key assumptions (OPEX):

OPEX has been calculated using guidelines from Section 2 (Maintain Defences) which assess costs for embankments, concrete walls, steel walls, and brick walls. Maintenance unit cost ranges selected refer to a set of activities directed to target condition grade 2 (good) assets. Target condition grade 2 (Good) assets are assumed to have minor defects that will not reduce performance of the asset. The table below provides unit costs by defence type.

The total unit costs represent the sum of embankments maintenance and the average of steel and brick walls costs, An average of manual and mechanical clearance costs gives the final unit cost used. A minimum benchmark of £1655 (£/km/year) and a maximum benchmark of £12031 (£/ m/year) have been assumed. Based on information provided by the City Corporation, the whole length of flood defence in the City is 2.7km. Approximately 1.1km is owned by the City Corporation.³ The programme is expected to run for 30 years and it is assumed that 100% of the cost is already budgeted for.

Costs have not been based on actual data provided by the City Corporation.

Defence type	Maintenance Activity	Manual Clearance (£/km/year)	Mechanical Clearance (£/km/year)
Embankments	Grass Cutting, Tree work, Vermin	2,770 – 17,225	80 – 5,430
Steel Walls	Vegetation, Wall repair works	160 – 530	105 – 390
Brick walls	Vegetation, Wall repair works	355 – 1020	300 – 875
Total* *calculated as maintenance cost for embankments + average of maintenance cost for steel and brick walls.	Grass Cutting, Tree work, Vermin, Vegetation, Wall repair works	3027-18000	283 – 6062

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Building Retrofit Programme

Total capex (whole programme):

- Estimated: £54,590,500

Key assumptions (CAPEX Office):

To align with the Net Zero Carbon study being produced by ARUP as part of the Climate Action Strategy, an office retrofit cost 150£/sqm has been assumed. This is based on data from the Better Building partnership (refer to specific study for further detail) and it is assumed that a number of the interventions included within this benchmark will support resilience and adaptation outcomes. A cost uplift of 9£/sqm has been included to account for further interventions;⁴ this has been based on the retrofit of rainwater harvesting into buildings and a 'high' value has been assumed to account for additional measures which may be introduced. To align with the Net Zero Carbon study being produced by ARUP as part of the Climate Action Strategy, it has been assumed that a total 250,000 sqm of office space owned/managed by the City Corporation will be retrofitted.

Key assumptions (CAPEX Residential):

A benchmark of 1133£/dwelling has been assumed for residential retrofit. ⁵These figures are based on energy retrofit and have been selected to serve as a proxy. An uplift of 45£/sqm has been included to account for additional measures; this has been based on the retrofit of rainwater harvesting into buildings and a 'high' value has been assumed to account for additional measures which may be introduced.³ London space standards have been used to convert the uplift benchmark to a per dwelling cost⁶; the minimum space standards for a two bedroom, four person two storey dwelling has been assumed (81 sqm). Based on information provided by the City Corporation costs are based on the retrofit of 3106 dwellings.

Total OPEX (whole programme):

OPEX are not included.

It is acknowledged that there is a further range of asset types owned and managed by the City Corporation, within the Square Mile and beyond. Based on the assumption above these are excluded and as such the costs should be seen as conservative.

Costs have not been based on actual data provided by the City Corporation.

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Cool street programme

Total CAPEX (whole programme):

- Estimated: £58,443,000

Key assumption (CAPEX):

A benchmark of 35.42 £/sqm have been assumed for urban green spaces.⁷ This accounts for costs associated with preliminaries, renewal of pathways, renewal of planted areas, renewal of grass, and trees, and as such serves as a good proxy for the measure. According to the City of London Transport Strategy⁸, the total street length through the Square Mile is 110 km. It is assumed that the average width of a residential street is 15 metres.⁹ It is assumed that CAPEX will cover initial investment and is treated as a single cost.

Total OPEX (whole programme):

- Estimated: £544,665,000

Key assumption (OPEX):

A benchmark of £33.01/sqm/annum have been assumed for maintenance costs.¹⁰ Area assumptions match those set out above. It is assumed that maintenance costs is based on a 10 years commuted sum. It is assumed that 30% of the costs for this measure is already budgeted for.

Costs have not been based on actual data provided by the City Corporation.

The requirements for cool streets intervention has not been assessed to account for streets which are already performing well or have already been suitably adapted.

Climate-ready healthcare programme

Total CAPEX (whole programme):

- Estimated: £10,764,000

Key assumption (CAPEX):

Data provided by City Corporation suggest that in 2019-2020 around £299,000 were spent supporting city-based core commissioning and delivery of public health initiatives. An additional 20% uplift has been included to account for additional climate resilience and adaptation measures. Based on this, it is assumed that the City Corporation will support a cost of £358,800 for 30 years

Total OPEX (whole programme):

- Estimated: £4,890,000

Key assumption (OPEX):

Data provided by City Corporation suggests that in 2019-2020 around £163,000 were spent for City employed public health staff. It is assumed that 80% of the measure is already budgeted for.

Heat resilient road/highway surfaces programme

Total CAPEX and OPEX (whole programme):

- Estimated: £77,847,000

Data provided by City Corporation suggests that 2020/21 highways repairs and maintenance budget is £2,359,000. This does not include maintenance payments contributed by developers through S106 agreements. An additional 10% uplift have been included to account for additional climate resilience and adaptation measures. It is assumed that every year the Corporation will support a cost of £2,594,900 for 30 years. It is assumed that 90% of the measure is already budgeted for.

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Informing future prioritisation of measures proposed

A multi-criteria assessment was used to analyse different resilience measures that may be adopted. The outcomes of this analysis were used as part of the iterative design process used to create the pathways – for example, low scoring measures were excluded, and patterns in the data used to bundle measures and refine their purpose.

As set out within the main study document, the pathways incorporate 39 measures. These measures may wish to be further refined by the City Corporation, it is anticipated that through this process some measures may not be taken forward. In order to help inform future decisions regarding which measures are taken forward, the following section sets out a high-level analysis of the performance of measures within the multi-criteria assessment.

This assessment presents a simple analysis of the multi-criteria tool outcomes, with results split into quartiles. These results have been overlaid on the pathways and key observations made. This provides a simple assessment of key trends and demonstrates clearly how the multi-criteria results sit in the final pathways.

Distribution of overall scores

The figure below shows the range of scores in for each ranking. These show that the overall scores have a fairly narrow range, with most measures scoring between 3.0-3.5. Scores for co-benefits were more variable, and on average measures scored low on these criteria at less than 3.0. Cost measure scoring showed the highest range, and on average scored more highly than other types of criteria, with some receiving on average a maximum score.

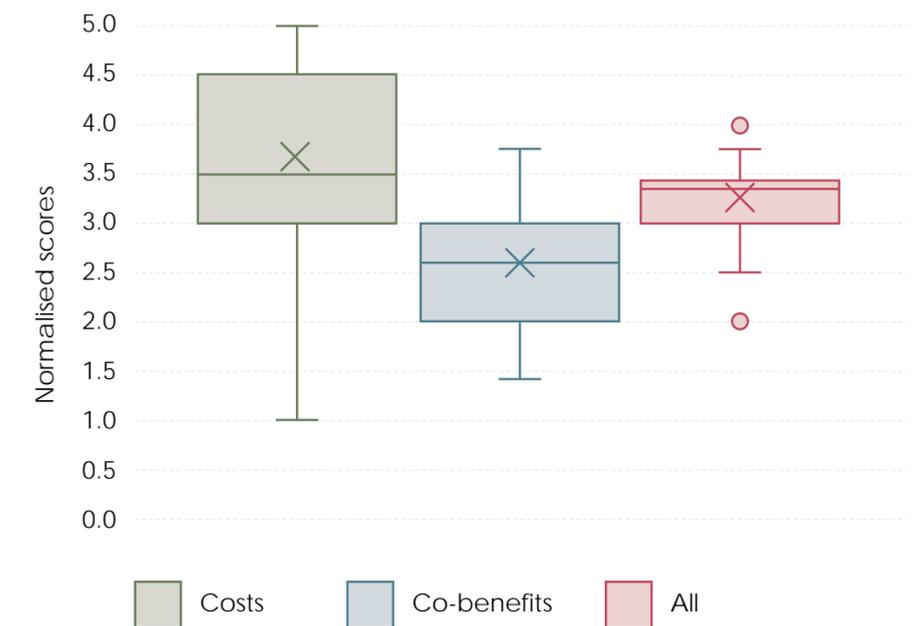
Range of results for the three rankings

Scores by measure type

All measures were mapped onto the pathways according to whether they were a rolling measure (ongoing, frequent updates), a preparatory measure (a one-off measure to be started imminently) or adaptive (to consider implementing in future, based on climatic thresholds). See more in the final report.

The figure below shows key trends in results based on these criteria. These included observations that the cross-cutting, rolling measures scored highly overall. Other rolling measures (risk-specific) scored well, but lower on co-benefits. Adaptive measures were found to be high cost but have high co-benefits, while preparatory measure scores were more mixed. Such findings are perhaps expected, as through the design of the pathway the intention has been to focus on facilitating early action through the identification of no-regret actions. No-regret actions can be considered lower cost and higher co-benefit. Low-regret and flexible actions (i.e. typified by higher cost and lower co-benefit) will form a vital part of the strategy, but in latter years.

Range of results



Range of results for the three rankings

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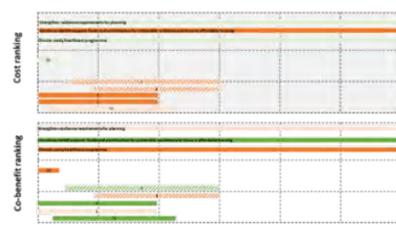
Key trends by measure type

Scores by risk

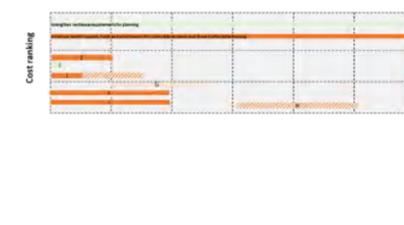
Scores were also broken down by risk type. Key trends are shown below. Crucially, it was found that overall flood risk measures were ranked lower, while natural capital measures ranked higher. In terms of costs, low scores were recorded for flooding, overheating and water stress; high scores were recorded for food and pests. For co-benefits, overheating measures scored highly, as did natural capital measures. Pest measures scored poorly on co-benefits.



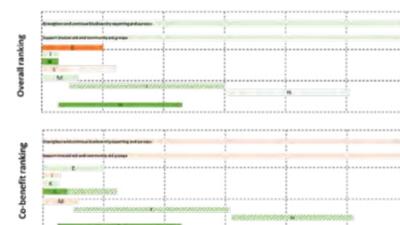
Flooding has low overall rankings, and low rankings for costs



Overheating measures score well on co-benefits but low on cost



Water stress measures score low on cost



Natural capital measures score highly on co-benefits and overall

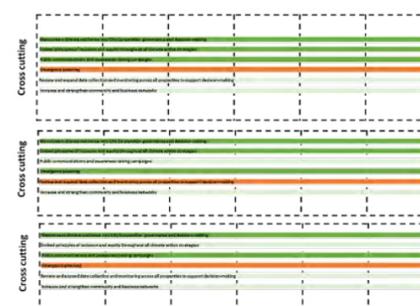


Food measures score relatively well on costs

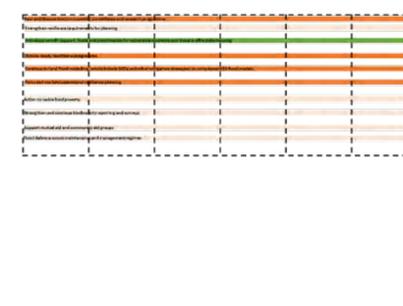


Pest/disease measures score relatively well on costs but badly on co-benefits

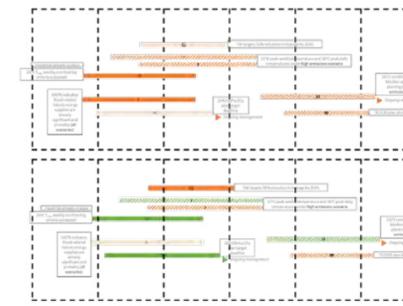
1st Quartile (least expensive, most co-benefits, highest rankings)
 2nd Quartile
 3rd Quartile
 4th Quartile (most expensive least well scoring)



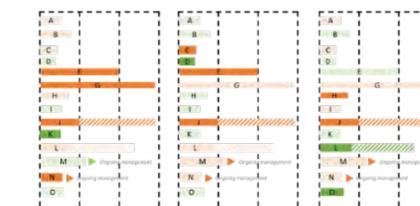
Cross-cutting, rolling measures score well on all three areas: overall, costs and co-benefits



Other rolling measures score fairly well overall, but poorly on co-benefits



Adaptive measures score poorly on costs, but better on co-benefits



Scores for preparatory measures score were mixed

1st Quartile (least expensive, most co-benefits, highest rankings)
 2nd Quartile
 3rd Quartile
 4th Quartile (most expensive least well scoring)

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Key trends by risk type

The Tables below show the top ranked and bottom ranked measures on the pathway. Top and bottom ranked measures were defined based on measures that sat in the top or bottom 50th percentile for all rankings. Of the high-ranking measures, half were cross-cutting, rolling measures. The other half were preparatory. Of low-ranking measures, the majority were preparatory or adaptive.

Top ranking measures on the Adaptive Pathways (lower cost, higher co-benefit)

Adaptation Option Name – high ranking	Score Quartile		
	Cost	Co-benefits	Overall
Increase and strengthen community and business networks	2	2	2
Public communications and awareness raising campaigns	2	1	1
Model food supply networks through the Square Mile to inform future planning	2	1	2
Research, planning and reviews to strengthen natural capital management strategy	2	2	1
Mainstream climate resilience into City Corporation governance and decision-making	1	1	1
Embed principles of inclusion and equity throughout all climate action strategies	1	2	1
Develop financial package and programme to manage resilience actions	1	2	2

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Balance and spread of measures in the pathway:

- There are a good breadth of costs amongst measures, weighted towards cheaper measures.
- Co-benefits tended to be scored low. This is perhaps to be expected since this covers a diversity of areas that few measures would be likely to universally achieve, and the qualitative, conservative nature of the assessment.
- Overall scores were concentrated around 3.0-3.5, suggesting that the design of the pathway has incorporated measures that are effective.
- As previously illustrated, a number of those actions within the pathways that are proposed over the short term have been identified as lower cost, and higher co-benefit. This is to be expected as the pathways focus on facilitating early, no-regret actions, while allowing for careful planning of flexible future measures.

Key measures:

- There are some areas and measures which score consistently highly, these could be considered a core stream of resilience planning. These are largely cross-cutting, rolling measures that look at integrating resilience into City Corporation and communications with the public. They are typically preparatory and mainstreaming.
- Measures around natural capital scored well overall, and were particularly strong in terms of co-benefits. This is to be expected and is supported by a broad evidence base that highlights the critical role of nature in climate action.
- 7 measures scored in the 50th percentile for all rankings. These included measures to mainstream and fill knowledge gaps – such as food supply modelling and coordinating resilience budgets – and work to communicate new actions and guidance to the public.

Costs and future planning:

- It should be acknowledged that the outcomes of the analysis show the value of early action, with those lower cost and higher co-benefit measures typically being measures proposed to commence over the short term. That said, it should be kept in mind that once implemented and in future decades tougher decisions on low-regret and flexible measures will be required to adapt to the impacts of climate change.
- Adaptive measures are typically expensive, which may need to be factored in City Corporation planning. However, they have important additional benefits – such as co-benefits – meaning that they should not be overlooked.
- Food infrastructure and pests and diseases measures scored well on costs, but this may be due to the fact that they involve more planning and research measures, since Task One highlighted that there are more research gaps in these areas. It may be the case that this research highlights additional measures and actions that should be undertaken which may introduce more costs
- Flooding, overheating and water stress measures are typically expensive. This is largely because they involve major infrastructural changes, and in reality costs would be shared with other stakeholders in many of these cases. These costs may also be inevitable in the face of rapidly changing physical conditions. Flood and water measures also tended to score low overall, however several of these are ongoing or required under local governance – such as leak management and flood defence upkeep.
- Natural capital measures score highly on co-benefits, a reminder of their key role in mitigating diverse risks and challenges.

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City Corporation Climate Action Strategy Survey for Square Mile businesses

In June 2020, the City Corporation surveyed businesses in the Square Mile to gain further information on risk perception, areas of progress and ideas for City Corporation actions in the context of the wider Climate Action Strategy. While there were only 9 respondents, the exercise provided some useful feedback and insight into stakeholder priorities and perceptions.

- Perception of risks and preparedness: in general, respondents indicate a perception of high risk for all the 6 areas covered in the project. In particular, Overheating and Pests & Diseases were considered the highest areas of risk (by weighted average) – perhaps reflective of common climate change messaging and the COVID-19 crisis at the time of survey. In contrast, participants suggested that, while in general their preparedness was 'good' for all risks, it was slightly less strong (by weighted average) for natural capital risks and food infrastructure. This may be reflective of the fact these risks are perceived to be less closely linked to professional services (which was the background for 2/3rds of respondents), and so are areas less well covered by business continuity action plans. This is suggestive that the Adaptive Pathways' balanced focus on all areas will suitably allay concerns about the perceived worst risks while supporting businesses to bolster areas they feel less equipped to handle
- Resilience overlap areas & missing areas: organisations indicated that they had taken some actions around resilience to date, but that these were focussed on COVID-19 and loss of capacity to work in office spaces. Though these will have some parallels in other situations, it appeared that few organisations had full resilience strategies. This reflection is validated by the suggestions made by organisations for the City Corporation. These largely focussed on educational materials ('Provide guidance on best practice and incentivise preparedness'; Sharing a set of tools and resources to help sustainability professionals discuss climate risk with senior leadership), communication ('Better communication to support a collective response') and facilitating networking and collaboration ('Link businesses for economies of scale, deliveries, logistics'). These are all key areas of the Adaptive Pathways, suggesting there will be good business engagement with these strategies.

The survey confirmed that the Adaptive Pathways do well to capture the key considerations and suggestions made by respondents, and highlight the importance of the City Corporation as a central body to support businesses to develop resilience and to work collaboratively.

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