North West Cambridge Development: Climate Change Adaptation Strategy

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North West Cambridge Development: Climate Change Adaptation Strategy.

Stage 1 report

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Executive Summary

Introduction

The North West Cambridge (NWC) Climate Change Adaptation strategy project has been supported by the Technology Strategy Board (TSB) competition Design for Future Climate: Adapting Buildings. The purpose of the study is to investigate the projected climate change impacts upon this development and subsequently put forward recommendations for remedial and mitigation measures. This final report, in combination with the technical Appendices, describes the NWC project, the climate change risks, and proposed adaptation strategies. Although specific proposals may not apply to other schemes on different sites, the principles applied will apply to many. As part of the Design for Future Climate project, it is important that this work provides guidance for other schemes and lessons learnt. Therefore a strong emphasis is placed on processes which can be applied to future projects.

Initial masterplanning of NWC took place during the 2000s to develop an outline masterplan to act as the basis for the development of the Area Action Plan (AAP - specific planning policy for the development). Following adoption of the AAP in January 2009, further masterplanning commenced which challenged the original concept ideas, and led to the development of the proposals for Outline Planning submission. The commencement of this Design For Future Climate study in 1006 CRD1 LIB DFFC 23159 was after the main principles of the masterplan had been set, but still at a point where the analysis could influence the design of the site.

The site is being developed by the University of Cambridge to provide a significant addition to the city in terms of housing, employment, research accommodation, public amenities, and open space. The development provides a number of unique opportunities for creating a sustainable development. Most importantly, half of the homes will be for University Staff and remain under the ownership of the University and a large proportion of the research buildings will be for University academic purposes. NWC will therefore have a lifetime guardian providing opportunities to introduce, implement and maintain measures throughout the duration of the development, and who will benefit from the adaptation measures in the future. Due to the strategic nature of the development and client, exemplar sustainability standards are required of the site through specific planning policy, including Code for Sustainable Homes level 5 for all 3000 dwellings (the largest development known at this level), and BREEAM Excellent for all non domestic buildings. In addition, the reputation and profile of the University requires the scheme to be a leading example of sustainable development.

Scoping

This report examines the overall climate change risks for the development. Largely guided by the United Kingdom Climate Projections (UKCP09) climatic data, the future projections for the years 2050 and 2080 have been assessed based on high emissions and the 50th percentile scenario. As expected the analysis has principally identified temperature rises and consequent increases in ‘heat waves’ in summer months, and in precipitation terms, drier winters followed by potentially some wetter summers. In general, it was found that the climate projections (as the name suggests) provide an idea of broad patterns and risks, but they, and the associated derived weather files, are insufficient for detailed modelling of extremes which is important when understanding building design limits. For some assessments such as flooding or overheating, it was felt that simple descriptions of expected extreme events would be more useful than derived weather files as the majority of the year is not of interest.

Subsequent to the climate change projection analyses, a number of key risks have been identified for the NWC Site. These are:

- Summertime overheating: The East of England is one of the warmest regions of England and one of the most likely to suffer extreme summers such as the one experienced in 2003. The temperatures are projected to increase, exasperating the currently occurring problem. A consequence of higher summer temperatures may be overheating in buildings in NWC.

- The Urban Heat Island (UHI) effect: The development of a greenfield site into a relatively high density development will undoubtedly have some impact on external temperatures. Although the effect of the UHI effect is expected to be minor the risk at NWC Site has been assessed as medium. This is because the rise in external temperature may not in itself have a large impact. However an increase in external temperature will have a consequential impact on internal temperatures, and therefore limiting rises in external temperatures will help to reduce internal overheating.
- Water conservation: The East of England is the driest region in the UK. Water supply remains a risk for the site, and the site as a whole remains vulnerable to an extended regional drought. There are options that could be taken to provide further adaptation beyond ensuring that the water demands of the buildings are low. For this reason the issue has been appraised as high risk and will be analysed further.
- Water management and preventing flood risk: With a change from agriculture and open space making use of natural infiltration and run off, to a relatively dense development, the site is at risk of surface water runoff and flooding both on site and in neighbouring areas. Therefore this issue has high importance and will be studied further.

Whilst other risks exist, they are either very low risk, or more suited for assessment at the detailed design stage with negligible impact on the masterplan.

Analysis and results

This report and appendices provides details of the analysis of each of the four risk areas, and the results. In summary:

- **Water management and flooding.** Four scenarios of water management were examined including business as usual (conventional surface water drainage), the development of ponds and wetlands, the inclusion of swales and ‘green fingers’, and finally the addition of green roofs. Under the baseline scenario, the 1 in 100 year peak run off rates from the green field site were exceeded in at least one simulation suggesting that flooding may be increased downstream with the development of the site. The inclusion of the wetlands provided the largest benefit with a reduction in 25% of peak run off and no exceedance of the 1 in 100 year event. Swales provided a further small improvement, but green roofs provided no discernible improvement. The SuDS (Sustainable Drainage System) measures proposed offer additional amenity benefits to the site and are required for planning and Code / BREEAM assessment purposes. Therefore it is not possible to provide a simple cost-benefit analysis for this scheme due to the multiple uses. The strategy taken forwards includes an intensive SuDS system of ponds, wetlands, swales, and potentially green roofs (where other benefits are also gained).
- **Water conservation.** The dry conditions in the East of England mean that water is already a stressed resource, and will continue to be so with increased population and potential reductions in total rainfall. This study examines a number of conservation measures which form four scenarios. These range from a combination of rainwater collection and grey water recycling at a plot level, to site wide recycling of black water to non-potable, and storm water to potable. The Code requires a target of 80 litres potable per person per day to be met, and the baseline solution (as used on other developments) represents the highest capital cost solution at £19m. The site wide solutions range from £5m to £8m and have potential revenue associated with the sale of recycled water. They therefore offer more cost effective solutions. There are a number of barriers and risks associated with each of the alternative solutions, not least the current water regulations. All of the options are being considered further and there is a continued collaboration with local

water companies including discussions with Ofwat. However this analysis shows the potential benefit of incorporating water conservation measures at a masterplanning scale where the cost of implementation may be less overall than applying to every building.

- **External temperatures.** The change of use from Greenfield to medium density urban development will mean that external temperatures are likely to rise, and the masterplan may offer opportunities to limit this increase, benefitting external and internal areas. An AECOM developed Computation Fluid Dynamics (CFD) model has been used to assess four scenarios of external overheating with different measures applied. The results demonstrate that different measures can impact on external temperatures differently, some resulting in lower localised temperatures (for example shading), whilst others providing smaller reductions over larger areas including neighbouring areas. Overall, green infrastructure including the use of green landscaping and trees were found to provide the largest benefit to local residents in terms of reduced air temperatures, with additional amenity benefits. The use of high albedo (high reflectance) façades was found to have a benefit but with variable results. Where the reflected radiation is reflected to the ground, surface / pedestrian height temperatures may increase, however where the radiation is reflected upwards, there are temperature reductions. This suggests that high reflectance materials are more suited for the higher buildings and roofs.
- **Internal overheating.** Overheating modelling on sample flats and houses demonstrates that there is some overheating predicted in bedrooms in current conditions, in particular for an east-west orientated flat. In the 2050 and 2080 conditions, overheating occurs in most places, in particular with a significant increase in bedrooms. Measures were examined including solar control glazing, shading, thermal mass, ventilation, and orientation. Solar control glass, especially when combined with external shading, was found to be the most cost effective method for minimising overheating. The next most cost effective method was incorporating high ventilation rates, resulting in the large reductions with no rooms overheating. The provision of ventilation through secure design needs to be considered along with suitable acoustic mitigation. Increased thermal mass, contrary to popular belief, was found to increase overheating in bedrooms, due to preventing the room cooling at night as quickly as a lightweight structure. One issue to consider is how the mass is insulated, and the ability to expose thermal mass will allow greater cooling at night with adequate ventilation to provide cooling the following day.

Proposed Adaptation Strategy

Table 1 provides a summary of the strategy being taken forward for each risk area.

Table 1: Summary of the risks and strategies being taken forwards.

Risk	Summary of risk	Summary of strategy adopted
Water management and flooding (section 3.2)	With a change from agriculture and open space to a relatively dense development, the site is at risk of surface water runoff and flooding both on site and in neighbouring areas. Therefore this issue has high importance and an extensive sustainable urban drainage regime is required to prevent any additional run off.	An extensive strategy of SUDs consisting of "green fingers" linked to ponds in the western edge was proposed for the scheme as part of the outline planning application. This DFC has assessed these components alongside more and less extensive systems to demonstrate the effectiveness of the proposed soluition. The study has also been used to refine the scheme, including for it's potential use as part of a water conservation measures.
Water conservation (section 3.3)	The East of England is the driest region in the UK. Water supply remains a risk for the site and the site as a whole remains vulnerable to an extended regional drought. The scale of development will provide a large additional burden on local water supplies and therefore this is a high risk.	This study has identified four options for the scheme ranging from a business as usual scenario of on-plot rainwater collection and greywater recycling, to a site wide rainwater-to-potable, and blackwater-to-nonpotable scheme. An assessment of the four scenarios shows that scenario B (consisting of a site wide rainwater capture and recycling scheme) has the lowest risk and potentially highest chance of implementation. All four options will continue to be pursued with water company partners to identify the most suitable solution for taking forwards. This decision is likely to be heavily influenced by the water company appetite and risk profile.
External overheating (section 3.4)	The development of a greenfield site into a relatively high density development will have some impact on external temperatures. Although the effect of the UHI effect is perceived to be minor, the risk at NWC Site has been assessed as medium. This is because the raise in external temperature may not in itself have a large impact, but an increase in external temperature will have a consequential impact on internal	The external overheatin study shows that there are a range of measures which can be deployed and which may have an impact on external temperatures. Extensive green infrastrucute in the form of trees and open spaces will be provided to reduce the area of hard landscaping where suitable. Consideration of facades and hard landscaping will also be made in the subsequent design, but will need to be carefully implemented so as not to

	temperatures, and therefore limiting raises in external temperatures will help to reduce internal overheating.	simply reflect the heat elsewhere. Green roofs are not proposed as a key measure, partially due to the high relative cost, and also due to the extensive requirements for roofs to be covered in PV.
Internal overheating (section 3.5)	The East of England is one of the warmest regions of England and one of the most likely to suffer extreme summers such as the one experienced in 2003. The temperatures are projected to increase, exasperating the currently occurring problem. The consequence of higher temperatures certainly results in the prediction of overheating in buildings in NWC.	The analysis has highlighted a number of principles which will be taken forward in the detailed design. These include: - minimisation of single aspect dwellings, - careful control of solar gains, in particular on western facades, and the use of solar control glass and shutters. - Designs to incorporate large openings to allow large air change for purge ventilation in summer. - Exposure of thermal mass in living areas and kitchens.

Table 2 provides a summary of the implementation timescales and investment triggers for each of the adaptation strategy items, alongside a summary of the cost benefit analysis. Due to the nature of this study, where the analysis is concentrating on masterplanning elements, the adaptation measures are by and large developed as part of the initial development and infrastructure works, and are not triggered by future events.

Table 2: Summary of implementation timescales and cost benefit analysis for each adaptation strategy item.

Adaptation strategy	**Timescales for implementation and investment triggers**	**Cost benefit analysis**
Sustainable Urban Drainage	All of the sustainable urban drainage infrastructure will be constructed as part of the site infrastructure works. This will commence in 2013 and be constructed on a phase by phase basis as the development is built out. The phasing of the site means that the phase 1 infrastructure works will include a large fraction of the Western Edge, to which the green fingers from future phases will connect. Source control measures in the form of	The total cost of the proposed SUDs system is circa £2.2M which is broadly comparable with a conventional surface water drainage scheme. However elements of the latter will remain in some areas to collect and transfer water into the main SUDs network where infiltration measures are not suitable. A direct cost benefit analysis of the SUDs scheme is not simple, since the SUDs features are required as part of the planning permission, and provide a range of other services including walking and

	infiltration and minor SUDs features will be designed on a plot-by-plot basis to join the main site system. (see section 3.2.5)	cycling paths, recreation areas, noise buffers, and general amenity improvement. Assigning costs specifically to drainage functions is therefore difficult. (see section 3.2.6)
Water conservation (section 3.3)	At present, the final water conservation scheme is unknown. Any plot-based systems (scenario A) will be installed during the development of individual plots. A site-wide system (scenarios B, C, and D) will be developed on a phased basis as the scheme is built out. Some degree of modularity may be required in central treatment plant, and the infrastructure design will need to be designed to allow for future additions to be made whilst being maintained operable. (see section 3.3.6)	Cost benefit analysis of the water conservation measure shows that a baseline solution of on-plot capture and recycling has the highest capital cost at circa £19M. The alternative scenarios B – D produce savings of between £8M and £14M depending on which option is examined. Therefore all of the site-wide options are more cost effective and therefore potentially commercially attractive to an external partner. (see section 3.3.7)
External overheating (section 3.4)	The measures proposed including open green spaces, trees, and potential facade and hard landscaping treatment will be implemented during the development of the site. (see section 3.4.6)	Cost benefit analysis considers the volume of air reduced by 1°C or more per unit of mitigation measure. On this basis, trees are slightly less cost effective than other measures when considering temperature reduction alone. However they have a relatively low overall capital cost. As with the SUDs analysis, it is difficult to allocate the cost of measure to external temperature reduction only, as they all provide a wealth of other functions. The temperature reduction offered by green infrastructure could effectively be seen as a free added benefit. (see section 3.4.7)
Internal overheating (section 3.5)	The key measures identified of solar control glazing, orientation, and suitable ventilation will be implemented during detailed design of the buildings and will help inform the masterplanning of each	The cost analysis demonstrates that solar glazing has the lowest cost at circa £5 - £8 per m2 of development per 100 hours reduction in overheating. Ventilation openings have a higher cost at up to

	plot. Further solar control measures such as shutters and awnings may provide benefit in the future, but have not been analysis as part of this work. (see section 3.5.3)	circa £230 / m2 whilst thermal mass has an extremely high cost benefit due to the very small overheating benefit. (see section 3.5.4)

Following the analysis and reporting stage of this D4FC study, the University has decided to proceed with a site-wide rainwater capture and recycling system and is currently developing this scheme with a water utilities company. This decision has been made on the basis of the work carried out in this D4FC study and additional work and will be the first scheme of its type in the UK at this scale.

Lessons learnt and recommendations

The study of Climate Change Adaptation and the development of strategies is a relatively new field, especially when applied to 'real' development projects. The conducting of this study on NWC demonstrated many of the challenges associated with conducting a study on a project. These include:

- The masterplanning process. There are a number of drivers for the masterplanning process and timescales and the majority of these take precedence over the adaptation study. To be beneficial, the adaptation study needs to be conducted by the same team members as working on the main project, but this means that time conflicts will occur, and the project design takes precedence. Consideration also needs to be made of skills availability, and it is possible that certain consultants required for the adaptation work will not be engaged with the design team at the required time.
- Integration into the programme. The pressures on the design team mean that the adaptation work may not take priority and its programme and scope need to fit within the other responsibilities. Therefore it is important that the adaptation analysis commences as early as possible, even where sufficient data is not available, to allow later updating, and that resource within the team is used when available, even if this is not optimal in terms of timing.

The reporting of adaptation strategies also needs consideration. On a large masterplan, many of the measures are relatively complex and may cover a number of adaptation issues or design approaches. These measures may also provide other functions or benefits for the site (for example green infrastructure can provide amenity space) and therefore it is impossible to separate out their costs and benefits. Setting a baseline in terms of cost and performance is therefore challenging.

The analysis in this report makes use of a number of resources, techniques and models, most of which are in their infancy and subject to error. As work in adaptation continues on other projects, it is likely that over time, these will all become more refined and accurate. However until there is some form of standardisation or guidance, a large number of alternative analysis methods will remain in use, potentially causing inconsistency.

One important area for investigation is the use of the UKCP climatic data and associated derived weather files. The probabilistic and scenario driven nature of the climate projections means that a range of results may be generated depending on the scenario selected, and this is unsatisfactory if clients are to have confidence in the analysis and make investment decisions based on it. Perhaps most importantly a number of adaptation issues are around extremes of weather rather than annual weather patterns. Therefore it may be useful if more emphasis is placed on determining reasonable extreme weather descriptions alongside annual weather files.

Extended Adaptation of Other Buildings

There are very many new Urban Extensions being considered at present, to address housing needs. The issues of this project will apply to very many of these, although clearly the circumstances of each may be different. In particular the degree of water stress or flood risk will vary greatly with location; however the majority of housing pressure is in the South-East of England, where water stress is greatest. Therefore the approaches outlined to sustainable urban drainage and reducing potable water demands will be relevant to many schemes.

Similarly for the thermal environment, although the local climate will be different by location, and building solutions will also vary from site to site, the principles and ideas discussed will be of general relevance to most masterplanning projects.

0 Introduction

0.1 The context of this study

In June 2010, the Technology Strategy Board (TSB) launched a competition, Design for Future Climate: Adapting Buildings, to fund the development of strategies to adapt UK buildings to a changing climate. The ultimate aim of this competition is to develop the UK's capability for adapting buildings to the challenges posed by the future climate. AECOM has been awarded funding to develop an adaptation strategy for four current building or development projects, of which the North West Cambridge (NWC) Development, by the University of Cambridge, is one.

This Climate Change Adaptation (CCA) strategy has been carried out in parallel to a separate commission where AECOM are providing masterplanning, sustainability, energy and design advice which will present a number of options for NWC Development. In practice, this adaptation strategy involves carrying out additional design work to develop strategies for resilience to climate change over the lifetime of the site. While the client is not obliged to implement the options put forward by this strategy, AECOM is contractually obliged to inform TSB if the client has implemented or intends to implement recommendations in the report. This information will be used to establish the impact of the competition funding on the design and to provide best practice information for future developments.

The emphasis of the analysis within this report is around the climate change issues which may affect the masterplanning of the development. These include site wide infrastructure, layout and massing, and landscaping. The nature and stage of the NWC project allows these to be investigated in more detail, whereas the analysis on many of the other TSB adaptation projects may be limited more to the technical design and specification of individual or groups of buildings. This approach means that there will be limited overlap with the analysis from other TSB projects, and maximum benefit obtained from a large scale masterplan.

0.2 What is the aim of this adaptation strategy?

The main aim of this study is to investigate the extent to which projected climate change will impact upon the development in terms of risk to both the NWC Development and its occupants, and subsequently put forward recommendations for remedial and mitigation measures. By fully making use of this adaptation strategy as far as practicable the site will be able to cope better with the impacts of a changing climate, whilst ensuring uninterrupted operation and continuing comfort and safety for its occupants.

0.3 This report

This final report is a non-technical summary of the adaptation work conducted on the NWC development. In addition to this non-technical report, a number of separate technical appendices are provided giving detail in relevant areas. It is intended that this non-technical summary is read first, followed by relevant appendices where required. The technical appendices include:

- Appendix 1: Description of the Site
- Appendix 2: Climate Change Risks
- Appendix 3.1: Adaptation Strategy – Water Management and Flooding
- Appendix 3.2: Adaptation Strategy – Water Efficiency
- Appendix 3.3: Adaptation Strategy – External Overheating
- Appendix 3.4: Adaptation Strategy – Internal Overheating
- Appendix 4: Project team

1 North West Cambridge Development

1.1 Description of the Development

The NWC development is being bought forward by the University of Cambridge to provide a significant addition to the city in terms of housing, employment, research accommodation, public amenities, and open space.

The University's vision is to transform the site into a vibrant urban community, a place for working, living and recreation. This will be achieved not only by integrating the Site with the existing city and adjacent occupiers, but also by thinking about provision of a range of amenities and facilities within the Site that will meet the needs of this community long into the future.

The University is committed to sustainable development and the first policy of the NWC Area Action Plan1 sets out the vision for the Proposed Development:

> *"North West Cambridge will create a new University quarter, which will contribute to meeting the needs of the wider city community, and which will embody best practice in environmental sustainability."* (Policy NW1, AAP)

In particular, policy NW24 supports the development of a low carbon site, promoting the use of low carbon and renewable forms of energy supply and distribution infrastructure. The first part of this policy also sets requirements for addressing the impacts of future climate change:

> *"Development will be required to demonstrate that it has been designed to adapt to the predicted effects of climate change"* (Policy NW24, AAP)

The 140 hectare site is a triangular area on the edge of Cambridge, bounded by Huntingdon Road (A1307), Madingley Road (A1303) and the M11. The site is owned by the University of Cambridge and is predominantly green belt land; currently a mix of farmland and university buildings. Only about 90 hectares will be developed and around 50 hectares - over one third of the site - will remain open space.

The development proposals submitted as part of the application are as follows:

- Up to 3,000 dwellings (Class C3 and C4);
- Up to 2,000 student bed spaces (Class C2);
- Up to 40,000 sq.m. commercial employment floor space (Class B1(b));
- Up to 60,000 sq.m. academic employment floor space (Class D1/suigeneris);
- 4,300 sq.m. retail floor space (Use Class A1/A2/A3/A4/A5) (of which the food store is 2,000 sq.m. trading floor space);

[1] Due to the strategic nature of the development and the fact that the site extends into two Local Authorities (Cambridge City Council, and South Cambridgeshire District Council), an Area Action Plan (AAP) was adopted to provide policy for the site.

- Senior living (75 rooms) (Class C1/C2);
- Community centre (Class D1);
- Primary Health Care (Class D1);
- Primary School (Class D1);
- Hotel (150 rooms) (Class C1) and conference facilities;
- Access roads;
- Pedestrian, cycle and vehicle routes;
- Parking;
- Combined Heat & Power Plant (CHP);
- Provision and/or upgrade of services and related service media and apparatus;
- Drainage works (including ground and surface water attenuation and control);
- Open space and landscaping (including parks, play areas, playing fields, allotments, water features and formal/informal open space).

The development provides a number of unique opportunities for creating a sustainable development. Most importantly, half of the homes will be for University Staff and remain under the ownership of the University and a large amount of the research buildings will be for University academic purposes. Alongside the long term ownership of these specific building types, the University wishes to retain control over most of the open space and public areas, providing a long term buy-in to the quality and operation of the development. Unlike most other large developments, NWC will therefore have a lifetime guardian providing the opportunity to introduce measures which have ongoing operation and maintenance requirements but which also provide lifecycle benefits.

1.2 How is NWC placed to respond to the Impacts of Climate Change?

The purpose of this TSB research programme study is to increase the levels of understanding of climate change adaptation using a number of real sites as case studies. The outputs should inform both the site design and proposals, and also develop information which is useful more widely and can be disseminated to provide best practice advice to other development projects. NWC was proposed as a case study to allow examination of the larger scale masterplanning issues for feeding into other similar large masterplans. Whilst many of the building level risks and challenges will exist for buildings on NWC as for many other individual building projects, it is the larger scale masterplanning issues which are of key importance for this study.

We believe that there are three main features of the site which may affect its future resilience to climate change:

- The site is currently predominantly greenfield land and will be developed into a relatively dense mixed use site. This may increase external temperatures, which in itself may not pose a risk, but could cause subsequent overheating problems within buildings.
- With a change from agriculture and open space making use of natural infiltration and run off, to a relatively dense development, the mitigation of surface run off will be important to help limit flooding on the site and in neighbouring areas down-stream.
- Location in the East of England. The region currently suffers from water shortages and is likely to do so more frequently in the future. A large new development will increase demand on local water suppliers, but may also offer opportunities for on-site water collection and distribution.

Despite the potential risks associated with future climate change, there are a large number of opportunities presented by large scale developments, and in particular NWC, for example:

- Commitment to sustainability by the University: high levels of sustainability and basic adaptation measures are integrated into the baseline site proposals;
- Large development: the size and scale of development could allow the integration of large scale site wide systems which are not feasible for smaller developments. A large scale and centralised grey/rain water recycling system would be an example;
- Mixed development: the mixed nature of the development combining domestic and non-domestic uses may provide opportunities for the sharing of services and resources in an efficient manner;
- Absence of existing infrastructure: the Proposed Development is currently greenfield land free from the constraints of an existing infrastructure where introducing certain measures can be very difficult or unfeasible and therefore opportunities cannot be realised;
- Long term ownership: the majority of the development will be retained by the University and will be operated and maintained by them. This allows any lifecycle benefits of CCA measures to be gained by the University;
- Flexibility: whilst the masterplan is well progressed, the design process is long, and there is a degree of flexibility in the parameter plans submitted as part of the Outline Planning Application, allowing the future incorporation of climate change adaptation measures;
- Political support: many of the drivers for a sustainable development originated from the two local councils and the resulting AAP. There remains a very strong support for sustainable design proposals, and most importantly, the addressing of future climate change and the associated risks;
- The University is heavily committed to the design process to ensure that the final development will be truly sustainable for the University in the long term. The development process will be strictly controlled by the University through design codes and developer contracts, to ensure that all the sustainability and adaptation measures are incorporated;
- The masterplan already incorporates certain elements of adaptation measures to mitigate the effects of future climate change on the site. This is also acknowledged in Area Action Plan; for example the Site is required to be adaptable to higher summertime temperatures as a result of climate change. Overall a statement in masterplan summarises the aspirations in adaptation to the future climates:

  > *"New development will need to be adaptable for unavoidable changes in climate without further increasing emissions with active heating and cooling systems. There is much that can be achieved through 'passive measures' such as the location, layout, orientation, aspect and external design of buildings and landscaping around buildings that can help occupants to cope more easily with the effects of climate change."* (NWC AAP Policy NW24)

The rest of this report examines the risks in more detail, and assesses the potential for the currently proposed and alternative measures to aid mitigation for the effects of potential future climates.

2 Climate Change Risks

2.1 Determining Climate Change Risks

A risk assessment has been carried out to investigate the extent of the projected climate change impact upon the Proposed Development in terms of risk to both the site and its occupants. Full details of this risk assessment are provided in Appendix 2, and this section aims to provide a high level overview of the analysis. The assessment uses UKCP09 data to assess risk, but also takes into account other factors which are site specific and which may impact the adaptation strategy.

In his report developed for the TSB, Bill Gething groups the key climate impacts and risks into a number of distinct categories which form the contract agreement and which we have been requested to use as the basis for the studies into climate change adaptation. The categories are shown in Table 3 below. Clearly many of these items will only apply to certain types of buildings and sites, and are also more relevant at different stages of design. In particular many of the design issues consider detailed building design measures, and this report is examining masterplanning scale issues. In this study each of these issues were considered initially, and then a shorter list of key issues selected for detailed consideration in section 3.

Table 3: List of design challenges[2]

Designing for comfort	
	Keeping cool – building design
	Keeping cool – external spaces
	Keeping warm at less cost
Construction	
	Structural stability – below ground
	Structural stability – above ground
	Fixing and weatherproofing, detailing
	Materials behaviour
	Construction work on site
Managing Water	
	Water conservation
	Drainage external and building related
	Flooding – avoidance
	Flooding – resistance and resilience
Landscape	
	Plant selection and changes to ecology
	Irrigation Techniques
	Failsafe design for extremes – water
	Firebreaks

[2] Bill Gething Report, “Design for Future Climate An Adaptation Agenda for the Future Climate” 2010

Whilst the list above presents the broad range of challenges facing the built environment in the UK, assessment of design challenges specific to NWC Development requires understanding of the consequences of climate change within the region of the Development Site. For this reason an impact analysis has been carried out and future climate projections have been considered for the area.

2.2 Projected climate change impact and risk

The primary source of information on the climatic changes that we might expect in the UK is the United Kingdom Climate Projections (UKCP09) published by the UK Climate Impacts Programme (UKCIP).

The projected climatic conditions have been assessed for Cambridge to examine how the local climate may change. This assessment covers temperature (both peak and average temperatures, and frequency of events), rainfall, wind (both magnitude and orientation), and solar radiation. Full details of the assessment are provided in Appendix 2.

Having identified the likely climate change impacts for the NWC Development, the key risks were examined which may be caused by the projected climate changes on the phase 1 masterplan and constituent buildings.

In an idealised situation, it will be possible to use a two stage assessment of risk, where in the first instance the scale of the risk is considered to focus work onto key areas where the risks are most significant. In the second stage a more detailed risk assessment approach can be conducted as described here where sufficient information is available to allow assessment of the different levels. This approach can be used where risk is easily quantified, but in many of the adaptation areas, risk may be relatively subjective and it can be difficult to compare one with another. In this report, we use a simple two stage assessment:

- During the scoping process, the first stage of this risk assessment process is used to inform where the detailed analysis of risk and mitigation should be focussed.
- In the later stages of detailed assessment for the baseline and adaptation scenarios, the second stage of risk assessment will be used where possible.

In this study, the following risk matrix has been applied during the scoping stage (see Appendix 2) where possible:

- *Risk = Likelihood x Consequence*

Likelihood \ Consequence	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
A (almost certain)	L	M	H	X	X
B (likely)	L	M	M	H	X
C (moderate)	L	L	M	H	X
D (unlikely)	L	L	M	M	H
E (very unlikely)	L	L	L	M	M

Where:

- X – Extreme risk, requiring immediate action

- H – High risk issue requiring detailed research and planning at senior management level
- M – Moderate risk issue requiring change to design standards and maintenance of asses
- L – Low risk issue requiring action through routine maintenance of assets

The likelihood is the frequency of the weather events that drive the risk, and these likelihoods are predicted to fluctuate with the changing climate. So for example for the case of fluvial flooding, it is clearly driven by the amount of rainfall in a catchment area over a given period of time. These rainfall events are described through their return periods, i.e. a 1 in 5 year flood is expected to occur once every 5 years. For overheating the driving influence is a period of time above a given temperature and the sunshine levels.

Further details on the risk assessment are provided in Appendix 2, including use of the risk assessment matrix where relevant.

2.3 Summary of risks

The risks posed to the North West Cambridge Site due to the projected climate change impacts have been investigated. Data has been assessed for the 2050 and 2080 projections for the 50th percentile probability. Where required, the Prometheus [3] Design Summer Year (DSY) weather files are used for the analysis to assess the potential impact on Cambridge weather conditions. Full details are provided in Appendix 2 which provides an analysis of the following potential climate change conditions using the UKCP09 climatic data:

- Temperature change. The data demonstrates that average temperatures will rise slightly, but with a significant increase in the number of days which experience average temperatures of 22° or more.
- Solar radiation. In general there is unlikely to be a significant change in solar radiation or cloud cover, and this is therefore unlikely to be a key factor in temperature changes.
- Precipitation. The data suggests that overall annual rainfall levels are unlikely to significantly change, but there will be a shift to drier summers and wetter winters, causing the potential for summer droughts. The data suggests that summer rainfall could be up to 53% less than present conditions. UKCP09 only assesses average rainfall, and therefore the data does not support more detailed analysis of peak rainfall conditions and flooding. For these the Environment Agency provides simple guidance of a +30% increase in peak rainfall in the 2080s. Reducing run-off is critical on the development due to the clay aspect sloping to Washpit brook, which currently floods Girton Village downstream.
- Wind speed and orientation. The UKCPO9 data and Prometheus weather files suggest no significant change in wind speed and orientation.

The analysis demonstrates the limitations of the UKCP09 data which is based around averages, whereas many risks associated with climate change are associated with extremes of weather.

Following the analysis of potential climate change impacts, a risk analysis of the design challenges listed in Table 3 has been made. Where possible the analysis is quantitative, but the scoping nature of this section means that many factors are treated qualitatively. The assessment of risks has also mostly concentrated on the challenges which may need addressing during the masterplanning process to maximise the use of project resources.

The table below is a summary of the risk analysis of the design challenges assessed and decided to be taken forward in this study.

[3] http://centres.exeter.ac.uk/cee/prometheus/downloads.html

Table 4: Summary of risks for the North West Cambridge Development (full details of the assessment can be found in Appendix 2).

Topic	Overall Risk	Taken forward for stage 2 detailed analysis in section 3
Designing for comfort		
Keeping cool – building design	High	Yes. This is fundamental to the design and layout of building blocks and therefore a masterplanning issue.
Keeping cool – external spaces	Medium	Yes. There are opportunities for the masterplanning design to incorporate features which can help reduce external temperatures.
Keeping warm at less cost	Low	No. The buildings will be highly efficient and connected to a CHP / District heating network. Heating costs will therefore be very low.
Construction		
Structural stability – below ground	Low	No. These are new buildings built to the required codes , and structural issues will be addressed at detailed design. In general, wind loads are relatively small and do not govern the structural stability. Wind damage is more likely to occur to roofs and cladding (see below).
Structural stability – above ground	Low	
Fixing and weatherproofing, detailing	Low	No. This requires consideration at detailed design and will be considered at that stage. The design intent for NWC is heavier weight construction with robust materials, rather than lightweight cladding and roofing solutions.
Materials behaviour	Low	
Construction work on site	Low	
Managing Water		
Water conservation	High	Yes. The East of England suffers from water stress, and the masterplan offers opportunities for innovative water saving measures.
Drainage external and building related	High	Yes. The development of the site from Greenfield to dense development may increase run off and result in flooding downstream in Girton. Developing a sustainable drainage strategy will be important to reduce flooding.
Flooding – avoidance	High	
Flooding – resistance and resilience	High	
Landscape		
Plant selection and changes to ecology	Medium	No. It is likely that planting will need to consider future water availability and temperatures and this has been considered at the outline landscape design stages. However a more detailed assessment will need to be made during the detailed landscape design.
Irrigation Techniques	Medium	Yes. This is considered as part of the overall water strategy development.
Failsafe design for extremes – water	Medium	No. This will be considered as part of detailed design.
Firebreaks	Low	No. Firebreaks for landscaping will be considered during the landscape design. It is not anticipated that this will be an issue due to the natural breaks in the site design.

The output from this scoping stage identifies a number of significant risks for NWC Site:

- Summertime overheating: The East of England is one of the warmest regions of England and one of the most likely to suffer extreme summers such as the one experienced in 2003. The temperatures are projected to increase, exasperating the currently occurring problem. The consequence of higher temperatures certainly results in the prediction of overheating in buildings in NWC.
- The Urban Heat Island (UHI) effect: The development of a greenfield site into a relatively high density development will undoubtedly have some impact on external temperatures. Although the effect of the UHI effect is perceived to be minor, the risk at NWC Site has been assessed as medium. This is because the raise in external temperature may not in itself have a large impact, but an increase in external temperature will have a consequential impact on internal temperatures, and therefore limiting raises in external temperatures will help to reduce internal overheating.
- Water conservation: The East of England is the driest region in the UK. Water supply remains a risk for the site and the site as a whole remains vulnerable to an extended regional drought. There are options that could be taken to provide further adaptation beyond ensuring that the water demands of the buildings are low. For this reason the issue has been appraised as high risk and will be analysed further.
- Water management and preventing flood risk: With a change from agriculture and open space to a relatively dense development, the site is at risk of surface water runoff and flooding both on site and in neighbouring areas. Therefore this issue has high importance and will be studied further.

These issues will be investigated at stage 2 in Section 3: Adaptation Strategy which provides a detailed analysis of baseline conditions and adaptation strategies.

3 Adaptation Strategy

3.1 Introduction

This section presents the analysis of a number of design options to define an adaptation strategy for the site, which can help mitigate the risk of the future climate change challenges identified in section 2. The analysis is based around the four identified risks which need assessing and mitigating at the masterplanning stage, and includes the following outline adaptation strategies:

- The need to manage water run off and prevent flooding.
- The need to conserve water.
- The need to reduce external temperatures though careful site layout and design.
- The need to reduce internal overheating to provide healthy comfortable environments.

For each of the issues, mitigation measures and strategies are identified which may improve resilience to climate change. Important aspects considered in this section are:

- The types of measure and technical viability
- The economic benefits of the measure on a lifecycle basis, ensuring the adaptation strategy does not impact the commercial viability of the development.
- The current development programme, and the integration of the measures into this programme.
- Future upgrading and potential for phased deployment of the measures.
- Details of which measures are being implemented and if not, what the barriers to implementation are.

Appendix 3 provides full details of the analysis and should be consulted for further in depth analysis and description of each of the areas.

This section is split into the following parts:

3.2 – Water management and flooding

3.3 – Water conservation

3.4 – External temperatures and overheating

3.5 – Internal overheating

3.6 - Summary

3.2 Water Management and Flooding:

3.2.1 Introduction:

Conventional rainwater management consists of draining rainfall runoff from a site to an underground sewer system before discharging it to a receiving waterway. However, this has contributed to a host of well established issues including increased rates of stormwater runoff, increased flood risk and more polluted receiving waterways. Ecologically, stormwater runoff entering waterways often carries contaminants from the urban environment, such as oil and petrol debris from the roads, which has a deleterious effect on the health of the ecosystem.

There have been great leaps forwards in the championing, incentivising and regulating of more sustainable water management in the UK in recent years. These advances have precipitated a move towards decentralised systems and emerging technologies. The cornerstone of these measures is referred to as sustainable drainage systems (SuDS). Their goal is to replicate natural ecosystems using vegetation and soils to filter and store rainwater before returning it to the water table. The benefit of this process is that it requires little energy, and improves the ecology of the site. Importantly, SuDS can also contribute to a more aesthetically pleasing and resilient environment.

As discussed in the scoping section 2 (and expanded in Appendix 2), the majority of the Northwest Cambridge site is not at risk of flooding. However, the village of Girton, located just north of the site is at risk of flooding due to the confluence of several waterways, including the Washpit Brook that runs through the site. Accordingly, the development of the site has the potential to increase surface water runoff from the area and increase flood risk downstream at Girton. Changes in rainfall patterns and intensity due to climate change could also affect flood risk downstream. Another risk connected to water management is the health of aquatic ecosystems, in Washpit brook and in waterways downstream. The development of the site could increase pollution of waterways via runoff, and equally changes in rainfall pattern could change the pollutant load of stormwater runoff.

As outlined in Appendix 1, the site is approximately 140 hectares in size, and is bounded by the M11 to the west, Huntington Road (A1307) to the east and north and Madingley Road (A1303) to the south. Topographically the site slopes in a northeast-southwest direction, falling from 23-25 m to 13-15 m, flowing in a roughly northwards direction in the depression adjacent to the M11 is the Washpit Brook. This brook will provide one of the major main conveyance routes for surface waters from the site. It has been identified that the deep, canalised form of the brook is an artefact of agricultural modification. Rejuvenation of this feature could play a major part in the realisation of more natural, ecologically diverse and flood risk reducing drainage within and from the site. After passing a small wetland immediately north of the A1307, the brook flows in a northwest direction until its confluence with Beck Brook in northwest Girton.

From the images in Figure 1, it can be seen that the Washpit Brook has been somewhat influenced by agricultural development. The canalisation of the brook not only reduced the ecological carrying capacity of the Brook, but limits its ability to attenuate high flows during heavy rainfall events.

Figure 1: Images along the course of Washpit Brook[4]

Using data obtained from the Environment Agency, the vast majority of the site is in Flood Zone 1 (FZ1), indicating that there is less than a 0.1% probability of flooding occurring in a given year. This equates to a flooding return period 1 in 1000 years or less frequent. In the very northwest corner of the proposed development there is a short stretch of land adjacent to the Washpit Brook that is in FZ2. Land in this envelope is at risk from between a 1% and a 0.1% probability flooding event; the return period of flood likely to affect this area being between 1 in 100 years and 1 in 1000 years.

The site's relatively low flood risk is important, as the underlying geology presents a challenge for effective water management. Bedrock geology data from the British Geological Survey (BGS) shows that the site is predominantly underlain by stiff clay (gault) and some chalk (West Melbury Marly Chalk) deposits. Permeability is important for some SuDS features to attenuate and filter rainwater effectively before returning it to the water table, but both of these geological formations are particularly unsuitable for this purpose. While other SuDS features can still be implemented, much of the site is unsuitable for the use of infiltration-based drainage options. Along the more elevated northwest boundary of the site, there are areas which will be more suitable for infiltration and soakaway drainage options; however, this is likely to be limited by the thickness of these deposits.

3.2.2 Risks of using SuDS

Sustainable drainage practices are known to have multiple benefits for the water cycle on-site as well as within the wider water catchment; however, employing SuDS does require considering risks. Risks associated with the Northwest Cambridge site as well as general SuDS risks need to be considered. The risks identified were: space

[4] images courtesy of Rodney Burton - http://www.geograph.org.uk/profile/2182

requirements, imperfect modelling, lack of expertise, adoption challenges, and timelines. Each of these is discussed in Appendix 3.1.

3.2.3 Potential solutions

Following detailed modelling of likely rainfall on the site, outlined in Appendix 3.1, a number of responses were developed. To understand the options for on-site water management, four surface water management scenarios were created and their performance modelled against predicted future climate rainfall. The four options are discussed below.

Scenario 1: Business as Usual (BAU)

Business as usual represents a scenario where no sustainable drainage systems are employed within the site and conventional piped systems are used connecting to an existing sewer arrangement. This scenario is unlikely to be implemented due to Code for Sustainable Homes requirements and emerging regulations under the Flood and Water Management Act; however, it does offer the opportunity to model the baseline performance of the site if no sustainable strategies were employed to manage surface water runoff. In this scenario, each source node is connected to a series of junctions which drain the site based on current typography to the site outfall at the northern edge of the NWC development. No green roofs or rainwater harvesting tanks are assumed on any plot across the site.

Scenario 2: Western Edge Only (WEO)

The Western Edge Only (WEO) management scenario includes natural hydrological flow and attenuation features, including swales, and interconnecting ponds/wetlands at the base of each of the green fingers (see Figure 2 for an explanation of the location of the Western Edge). As shown in Figure 2, water is to be managed along the Western Edge, and no sustainable drainage systems are assumed within the developed area of site or the green corridors that extend into the site from the Western Edge. An underground pipe network would direct all runoff to the Western Edge.

Scenario 3: Green Fingers (GF)

The Green Fingers (GF) scenario builds on WEO. In this scenario, swales and ponds within the green corridors area included within the surface water management strategy to extend the SuDS ‘treatment train’ and provide more opportunities for attenuation and filtration of runoff. The additional treatment trains within the green corridors that connect development areas to the Western Edge are depicted in Figure 3. The morphology of the swales within the green corridors becomes increasingly natural in nature towards their junction with hydrological features of the Western Edge; starting off as narrow urban canals (rills) within the more developed areas of the site.

Scenario 4: Green Fingers + Green Roofs (GF+GR)

The Green fingers + green roofs scenario includes the features of the GF scenario and the addition of green roofs for source control on non-residential buildings with large roof areas. Green roofs are an added feature to control the surface water runoff where it falls on each parcel. The vegetation and soil are included in green roofs help to reduce runoff from each parcel add to the overall treatment train.

3.2.4 Results

The modelling results suggest there is a general improvement in the performance of each scenario that includes more SuDS components. This is most obvious for peak site run-off. The BAU Scenario shows that peak runoff exceeds the greenfield runoff rates at least once in the 26 years modelled (see figure 30 in Appendix 3.1). As more SuDS are introduced in scenarios 2 and 3 there is a significant drop in the median, peak and spread of runoff from NWC, with the median peak reducing by around 25% or more. This results in none of the modelled flood events exceeding the 1 in 100 year greenfield run off rate. Scenario 4 (GR) has a negligible impact on reducing peak run off further.

Similar trends are also seen in water quality between scenarios 1 and 2 (BAU and WEO). There is quite a dramatic water quality improvement from having large interconnected water features for surface waters to cascade through as they drain from the urban parts of the site. What is interesting, however, is the inclusion of additional swale and pond features within the green corridors (GF – scenario 3) does little more to improve the quality of the water leaving the site. Peak flows are, however, much lower and have a smaller spread.

In the case of scenario 4 (GR) the effect of the introduction of green roofs to commercial, academic and student accommodation buildings is quite unexpected – the quality of surface waters actually decreases when compared to GF and WEO scenarios. This reduction in surface water runoff quality with an increase in water-sensitive management appears quite paradoxical. A potential explanation for this is that the additional green infrastructure included in the GR scenario with retention on roofs acts to further reduce run-off from the site, increasing the amount of time that may pass without significant discharge from the site. This may act to concentrate nutrients and sediments within the swales, ponds and wetlands. Once a large enough rainfall event occurs, saturating the green roofs and generating run-off in the green corridors and along the Western Edge, the accumulated nutrients and sediments are flushed through the system. Due to the further increase in attenuation in this scenario however, the peak flows are significantly reduced and therefore the nutrients are relatively more enriched.

Appendix 3.1 shows the more detailed results of modelling the four scenarios.

Figure 2: Western Edge with envisioned type of large scale SuDS design.

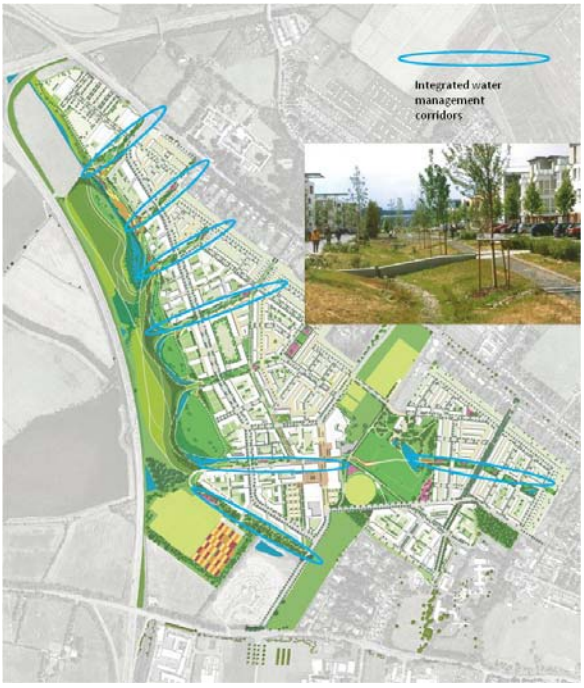

Figure 3: Envisioned Green Fingers from Western Edge

3.2.5 Timescale for implementation

The SuDS proposals for the site will need to be taken forward in tandem with the development phases as they form an integral part of the site infrastructure. A substantial portion of the Western Edge will need to be built out to take runoff from the initial phase, but this can be linearly expanded as development phases progress north, and additional wetland areas linked to the green fingers can be included with later phases. The design of the masterplan and western edge, which includes crescent shaped bunds (see Figure 3) has been designed to allow this phased approach.

The SuDS features are an integral part of the landscaping and infrastructure and therefore their construction commences at the beginning of each phase.

3.2.6 Costs and benefits assessment

SuDS have been successfully masterplanned in to the site vision from the concept stage, with land allocations including the Western Edge and the green fingers being included. It is difficult to assign costs to these initiatives, as the land utilised for SuDS features is also utilised for a range of other services and benefits, including walking and cycling paths, recreation areas, allotments, open space requirements, noise buffers, and amenity improvement. The following table includes the best-estimate cost of key SuDS initiatives for the masterplan, relating to the four scenarios outlined above.

Table 5: Best-estimate cost of key SuDS initiatives

Scenario	Costs	Benefits
Scenario 1: Business as Usual Assumed to include conventional drainage infrastructure consisting of underground piping to an outfall.	Using benchmarks from other schemes, conventional drainage of highways (pipes and manholes) has been estimated at a cost of £2,245,000. This excludes on-plot storm water drainage. If SuDS were not included on this site, additional costs for pumping and infrastructure would be likely, as the runoff could not be discharged directly to the small watercourse on-site and would be instead linked to the sewer network.	Under the BAU scenario, the 1 in 100 year Greenfield peak run off is exceeded at least once in the 26 model runs, demonstrating the need for an alternative drainage strategy.
Scenario 2: Inclusion of SuDS in the Western Edge Assumed to include wetlands and ponds. Western edge land already included in masterplan for a range of uses and is not included as a cost sacrifice.	The estimated cost of wetlands and ponds in the western edge is £775,000. Under this scenario, conventional drainage of highways would still be required to transfer runoff to the western edge.	The wetlands represent the largest SuDS component, and reduce the median peak run off by around 25% from circa 0.8 m^3 / s to 0.6 m^3 / s. The range of peak run-off is significantly reduced, with the upper bounds reduced by around half, resulting in no occurrences of the 1 in 100 year Greenfield run off being exceeded.
Scenario 3: Inclusion of SuDS in western edge and green fingers Assumed to include swales in green fingers and key street corridors.	The cost of creating the swales, along the primary and secondary roads and some in other locations, is approx. £1,400,000. Under this scenario the conventional drainage costs are likely to	Inclusion of the green fingers provides a further reduction in peak run off to around 0.5 m^3 / s, and further reduces the upper range. The small improvement over scenario 2 requires almost double

	significantly reduce if design can use kerb and channel arrangements to keep water above ground and transfer to swales in the green fingers.	the cost. However the green fingers also provide amenity and aesthetic improvements and help to achieve local planning requirements and Code targets.
Scenario 4: Inclusion of SuDS in western edge, green fingers and inclusion of green roofs on key buildings Assumed that 50% (50,000m^2) of research facilities and student housing buildings will include green roofs. Cost is additional to conventional roof construction.	Building on the cost of scenario 3, the additional cost of 50,000 m^2 of green roofs is estimated to be £2,000,000. The benefits of green roofs are however much wider than runoff management.	The additional cost of circa £2 million provides no measured benefit in peak run off and also incurs a slight reduction in water quality over scenario 2. Therefore green roofs are not cost effective for flood alleviation on NWC. However green roofs can offer additional benefits beyond water management.

3.2.7 Proposed Strategy for NWC Recommendations

The scenarios have demonstrated that peak flows of runoff can be significantly reduced through the implementation of SuDS features. Water quality is also expected to increase, though it is noted that the scenario including green roofs (Scenario 4) could create minor decreases in quality due to build up of nutrients in SuDS features in dry periods. Based on the water management benefits outlined by the modelling, and the wider recreation and urban design benefits created through the design of SuDS in the western edge and green fingers, Scenario 3 appears to provide the most favourable cost-benefit balance. On the basis of water management only (as predicted by the modelling in Appendix 3.1), the addition of green roofs provides little benefit as the land based SuDS proposals already provide a very good level of attenuation and treatment. However, the wider benefits of green roofs, including thermal, ecological and aesthetic benefits as well as a range of external temperature adaptation benefits (as discussed elsewhere in this report) mean that Scenario 4 may be the most favourable based on a holistic analysis of opportunities. Similarly, other source control initiatives such as rainwater harvesting may also be beneficial for water use reduction benefits discussed elsewhere in this report.

3.2.8 Strategy being taken forward

The inclusion of SuDS in the masterplan has been a strong feature since prior to the DFC study. The inclusion was driven by a number of factors:

- Good practice urban design
- The opportunities provided by the large landscaped areas
- The need to meet surface run off targets in the Code for Sustainable Homes and BREEAM.
- The requirement to include SuDs features in the AAP and local planning guidance.
- The added benefits in terms of amenity for local residents.

The development of SuDs in the scheme prior to this study has been a collaborative process with AECOM masterplanners and water experts, and the project's multidisciplinary engineers, URS. The application of the DFC study to the scheme has enabled the more detailed modelling and assessment to be conducted by AECOM SuDS expert, Celeste Morgan, to establish their performance and optimise if necessary. The analysis effectively demonstrated that the initial proposals of infiltration measures, swales, and attenuation ponds performed very well.

Figure 4 provides an illustration of the proposed SuDs strategy submitted as part of the outline planning application. Localised areas will make use of appropriate infiltration measures where suitable to minimise run off. After this first stage, a series of surface water ditches or swales will be created along key routes through the site, in particular the radial route (which is the main road from the south east of the site to the north west, running parallel to the M11), and the orbital route (which runs from Madingley Road to Huntingdon Road). A key feature of the site is the “green fingers” (highlighted in Figure 3) which are pedestrian and cycle routes for transporting people from the centre of the development to the Western Edge green area adjacent to the M11. These routes are landscaped green routes which provide amenity space, biodiversity, transportation, and incorporate the main SuDs swales for transporting surface water from within the development to the Western Edge.

The Western Edge forms the final component of the SuDs strategy, incorporating

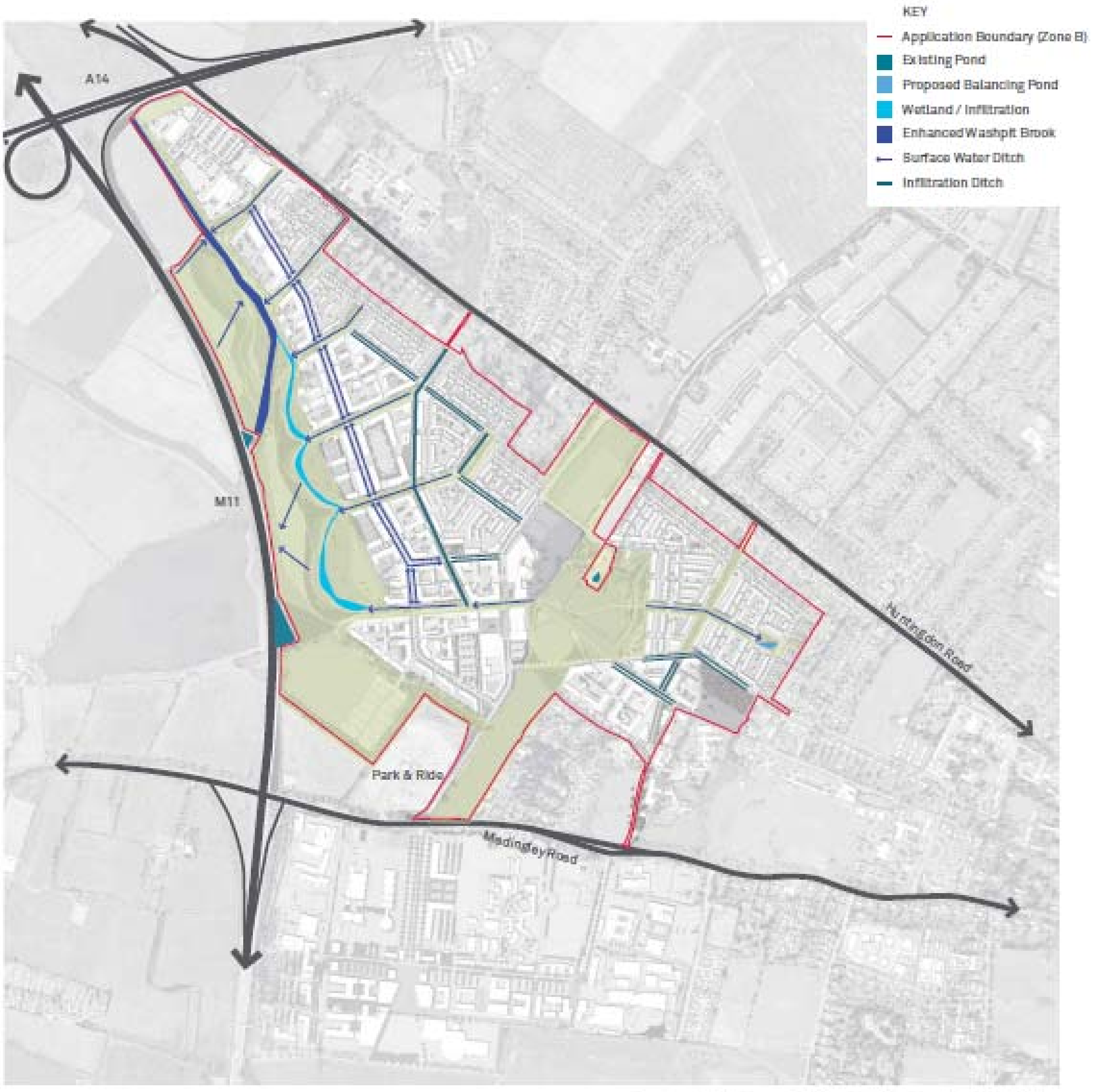

Figure 4: Illustration of proposed SuDS measures proposed for the scheme.

Additional source control measures including the implementation of on-plot source control measures such as green roofs and rainwater harvesting are assumed to be included at concept stage, but are yet to be tested through the detailed design stage.

3.3 Water Conservation

3.3.1 Introduction

While management of 'too much' water and flooding is crucial to adaptation as discussed above, 'too little' water is also a major challenge for the future of the Cambridge area and the East of England generally. With an average annual rainfall of 548 mm/year, Cambridgeshire is one of the drier areas of the UK, and reducing demands on centralised potable water supplies will be particularly important for the area. The changing climate will further exacerbate water stress issues. Overall, rainfall may not change drastically on an annual basis, but the predicted drier summers and wetter winters[5] will require an intelligent solution that responds to more extreme events and which considers how best to handle the varying patterns of precipitation. Cambridge is classified as a water stressed area by the Environment Agency, and is predominantly reliant on groundwater supplies to support its growing population.

Water conservation has been recognised as a key sustainable design issue to address, and the development has committed to meet Code for Sustainable Homes level 5, which requires substantial reductions in potable water use from the mains supply. Aside from the need to reduce use of potable water, there are concerns around the site's ability to handle and treat wastewater efficiently. While capacity exists, connecting into conventional sewer system will require the addition of four pumping stations, which are costly and carbon intensive. For these reasons, an alternative and progressive approach, which incorporates various types of water recycling, is preferable.

The NWC development represents a unique opportunity for integrating progressive water recycling solutions that will reduce the demand for import of potable water to the site, including:

- Achieving Code for sustainable homes level 5 requires meeting the challenging target of 80 litres per person per day compared to the average household water consumption of 150 litres per person per day[6]. Achieving this target will require some level of water recycling in a cost effective manner;
- The network of SuDS features proposed for the site (see previous section) means that there will be an existing supply of treated stormwater to be reused on-site;
- Due to the financial costs and carbon emissions involved in pumping wastewater off-site, the site might benefit from on-site wastewater treatment and reuse;
- Alternative water supplies could create a development which is more resilient in the face of climate change and increasing water stress, and may give more 'freedom' to residents to use available non-potable supplies of water; and
- As the long term land owner, the University's support for innovative solutions, in conjunction with a progressive Council (Cambridge City Council) and local water companies (Cambridge Water and Anglian Water) presents an ideal atmosphere to implement a water sensitive design.

There are a number of options for taking advantage of these auspicious circumstances. The various forms of water recycling that can be considered include rain and stormwater recycling, greywater recycling, and blackwater recycling. Rainwater harvesting collects and stores roof water either above ground or below ground. Greywater recycling is the treatment and reuse of water from showers and hand basins, and blackwater is the treatment and reuse of any water on site. Harvesting stormwater and recycling wastewater not only cleanses polluted waste streams, but can also provide micro-climate and amenity benefits and greater water supply resilience in the future depending on the solution chosen. The ultimate goal is to achieve a balance where the water consumed can be

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[5] UKCP09 (2009) Key Findings. Available: http://ukclimateprojections.defra.gov.uk/21708#key

[6] Chapagain, A. K. and S. Orr (2008) UK Water Footprint: The impact of the UK's food and fibre consumption on global water resources, Volume 1, WWF-UK, Godalming, UK. Available: http://www.waterfootprint.org/?page=files/UnitedKingdom

supplied entirely through water recycling measures. All of the options have advantages and disadvantages as discussed in section 3.3.8 and discussed further in Appendix 3.2.

3.3.2 Risks

While there are many benefits associated with a strategy which incorporates locally recycled water, risks do exist. As a relatively new consideration in planning and designing new developments, there is not the same level of expertise, knowledge and comfort that exists in constructing conventional water infrastructure. Some of the risks associated with alternative water sources include: proper sizing of systems, budgeting for reliability, securing an appropriate amount of space and location within a masterplan, obtaining community buy-in, and effective management and maintenance. These risks are discussed in Appendix 3.2.

3.3.3 Options to reduce potable water demand

Determining an effective solution bespoke to the Northwest Cambridge site first requires understanding the existing opportunities. As each site will have a different profile of outflows and inflows of water, also known as water balance, Appendix 3.2 outlines the water balance modelling undertaken for the NWC site. Once the water balance was understood, options to manage water demand could be developed.

Reusing rainwater and wastewater can be done at both the plot-scale, and the larger site-wide scale. Collecting and managing water on an individual plot scale can be implemented by collecting and reusing rainwater from roofs and the landscape surrounding a building. If rainwater is allowed to flow off the property it is known as stormwater, and can be collected across a larger site, treated, and reused for all plots on the site. Similarly for wastewater, greywater can be captured and treated for individual buildings, while blackwater can be captured and treated at a large site-wide scale. The various options considered in developing a site-wide strategy for Northwest Cambridge are included below.

- Option 1: Building-based rainwater harvesting for garden watering
- Option 2: Rainwater harvesting for non-potable use
- Option 3: Site-wide stormwater harvesting stored in artificial aquifer for potable use
- Option 4: Site-wide stormwater harvesting for non-potable use
- Option 5: Greywater recycling for non-potable use
- Option 6: Site-wide blackwater recycling for potable use
- Option 7: Site-wide blackwater recycling for non-potable use

For on-site stormwater recycling, the major options to be considered involve storage. To provide some security of supply, significant storage is necessary to balance supply and demand over the year as rainfall patterns vary. The advantage of site-wide stormwater collection (as opposed to plot-based) is that there is a wider catchment area to gather water from (public areas and roads as well as roofs) and there is potential for a centralised storage system that can be sized to better accommodate peaks and troughs in supply and demand. The full analysis of storage options on the NWC site is included in Appendix 3.2.

3.3.4 Options Appraisal

Determining which options should be included in the overall assessment required each one to be appraised on how it could deliver a range of benefits. Doing so required establishing the following criteria:

1. **Imported water use reduction**: The scale of contribution it could make towards the achievement of water reduction in buildings and other site uses.

2. **Estimated scale of cost**: For new infrastructure and ongoing operation and management
3. **Masterplan integration and landscape integration**: Size and type of infrastructure and the potential for enhancement/detriment of the scheme aesthetic and land use ambitions
4. **Management responsibilities**: Role of stakeholders and homeowners in maintaining and operating the water management infrastructure
5. **Carbon implications**: Demands from pumping, operation and embodied energy.
6. **Waterway protection**: Of Washpit brook, in terms of both quality and base flow, and potential relief of flood risk downstream
7. **Acceptance Issues**: Political or technical aversion to risk inherent in the option.

The full assessment of these options is included in Table 8 in Appendix 3.2.

3.3.5 Scenario Formation

Following an initial assessment of the seven options based on the above criteria, four scenarios were developed to take forward for more in-depth analysis including cost appraisals and assessments of wider implications for site and off-site infrastructure. The four scenarios that were tested are discussed below.

Scenario A: Either rainwater and greywater recycling systems are installed at plot scale to provide non-potable supply to buildings. This is a combination of options 2 and 5 above, whereby rainwater would be harvested from roofs in combination with site-wide greywater recycling through bio-mechanical treatment tank systems. In this scenario wastewater would be discharged offsite to a conventional wastewater treatment plant using pumping stations.

Scenario B: Site-wide stormwater recycling is implemented to meet non-potable demands. This would rely on a SuDS system to treat the water before pumping it up the western edge to a storage area at the top of the site where it is stored, before being treated and reused for non-potable purposes. Greywater and blackwater are pumped off-site to a conventional wastewater treatment plant.

Scenario C: Site-wide blackwater is recycled to meet non-potable demand. The blackwater recycling would rely on either a mechanical treatment method known as a membrane bio-reactor (MBR), or a natural treatment method before being re-circulated to buildings for non-potable supply. Greywater would be drained with blackwater to be treated and reused. Stormwater would be treated and discharged via a SuDS system to a receiving waterway. This system eschews the need for wastewater drainage to be connected to off-site infrastructure.

Scenario D: This scenario is a combination of scenarios B and C, where stormwater is captured and treated on-site via a SuDS system to supplement potable supply, while wastewater (blackwater and greywater) are treated via MBR system to provide non-potable supply. This would essentially create a closed loop development with little reliance or impact on off-site infrastructure. However, this scenario faces some barriers with respect to requirements for infrastructure needs and identifying an appropriate water management body to maintain water quality

.

3.3.6 Timescale for implementation

Initial site works are planned for mid 2013 on site, followed by an initial phase of development. The delivery of site-wide options in particular can be difficult to implement on a phased basis, but a strong masterplan can help to achieve infrastructure efficiencies based on economies of scale. The development of site wide systems needs to carefully consider phasing and location of plots, to ensure that the infrastructure can be rolled out in line with development, and be operable during the build out. This means that some degree of modularity may be required, and that continuity of operation needs to be considered as the scheme is extended.

Scenario A could be implemented on a plot basis at any time, while the other Scenarios would need to be implemented on a phased basis, where site-wide infrastructure is designed to increase in capacity. Scenario B can be phased alongside the implementation of SuDS features to capture stormwater runoff, with additional capacity being built in as more development (and impermeable area) is delivered. Due to the relatively simple storage and treatment systems in this scenario, timescale is not a major constraint. Scenario C and D however require the development of significant treatment infrastructure which will require planning permission and more detailed technical design. The timescale for these two scenarios is therefore longer and may not be deliverable to provide for the initial phase of development, which will be challenging as in the short term conventional infrastructure will be required.

It may not be possible to have a fully operational system in place when the first homes are sold, as the storage and treatment needs of the site-wide systems need to be put in place. It will be key to invest in a site-wide non-potable pipe network so that alternative water sources can be ‘plugged in’ when they are ready to be supplied. In the mean time, potable water from the mains source can be used. The Code for Sustainable Homes makes an allowance for this situation, and credits will be awarded as long as site-wide infrastructure is operational before 60% of homes in a phase are built.

3.3.7 Costs and benefits assessment

Based on the cost advice from Gardiner and Theobold (G+T) and engineering advice from URS a feasibility assessment for the four scenarios has been developed. The full assessment is outlined in Appendix 3.2 and a summary provided in Table 6.

Table 6: Summary of cost benefit analysis for each water conservation scenario. For a detailed explanation of the costs, see Appendix 3.2).

Scenario A On-plot Recycling		**Scenario B Stormwater to Non-Potable**	
Item	*Cost (£mil)*	*Item*	*Cost (£mil)*
Total with sub option 1 (rainwater and greywater)	**48.50**	**Total with sub option 1 (with aquifer)**	**6.05**
Total with sub option 2 (rainwater or greywater)	**19.45**	**Total with sub option 2 (with lake)**	**8.20**
Scenario C Blackwater to Non-Potable		**Scenario D Closed loop development**	
Item	*Cost (£mil)*	*Item*	*Cost (£mil)*
Total with sub option 1 (Membrane bio-reactor)	**8.20**	**Total**	**10.85**
Total with sub option 2 (living machine)	**6.20**	**Total with off-site infrastructure savings**	**7.85**
Total with sub option 1 and off-site infrastructure saving	**6.90**		
Total with sub option 2 and off-site infrastructure saving	**4.90**		

The cost assessment provides a high level understanding of the capital cost implications for each scenario. Scenario A is substantially more expensive than the other scenarios with a minimum cost of £19M, and can be attributed to implementing stormwater and greywater recycling for each plot as opposed to the other three scenarios, which take advantage of economies of scale inherent in a site-wide response giving savings of between £8M and £14M depending on which scenario is examined and whether off-site infrastructure potential savings are included. Scenarios B and C and D are the most cost-effect means of achieving Code level 5, and all warrant further investigation. In terms of costs, an artificial aquifer in scenario B is best, while a natural system, referred to as a “living machine,” is best in scenario C. While scenario D is the most expensive of the three, it is the most environmentally resilient and removes the need for pumping stations.

3.3.8 Proposed Strategy for NWC Recommendations

One of the scenarios will need to be taken forward to meet both the University's ambitions and the planning requirements to meet Code for Sustainable Homes. The analysis of alternative water supply scenarios has shown that there is significant potential for innovation and good practice in management of the water cycle on the Northwest Cambridge site. The scale and location of the site could support the implementation of site-wide water recycling to supply non-potable or potable water to the residential and non-residential properties on-site. Such an approach would support achievement of external potable water demands, demonstrate best practice in water-scarce Cambridge, protect and enhance local water resources and alleviate pressures on off-site infrastructure. A summary of the overarching assessment of scenarios is provided in Table 4 below, which shows an assessment of impact that each scenario will have on a range of factors (green – positive impact, and red – negative/poor impact). Ths assessment shows that scenario B (stormwater to non potable) is the only scenario to have no major negative impacts (no red items).

The initial assessment of capital costs indicates that the implementation of an alternative approach, i.e. any of scenarios B, C or D, are likely to be more cost-effective than the current 'traditional' on-plot approach to water recycling to meet Code for Sustainable Homes Level 5. On the basis of the overall assessment, Scenarios B, C and D all offer promise and would warrant further investigation. In order to examine the scenarios in further detail and determine deliverability, several aspects require further investigation: consultations with Anglian Water and BRE, spatial and planning implications, detailed design, certainty in costs, and analysis of energy expenditure for each of the water solutions identified. These are discussed in Appendix 3.2.

3.3.9 Strategy being taken forward

At the time of writing, all scenarios are being considered for more detailed assessment. Discussions have been held with several water companies to judge the deliverability of the scenarios. All scenarios are believed to be technically and economically feasible. The selection of the preferred scenario is likely to be made based on timescale implications, such that a practical and feasible scheme can be developed within the current project programme, and delivery partnering opportunities, taking into account the attractiveness of the scheme with water companies, their perceived risks and benefits of each scenario. Through the next stages of the project development, the University will work with a number of water companies to identify a preferred partner for delivering the scheme.

Table 7: Overarching Assessment of Scenarios. This shows the impact of each scenario on a range of factors. Green indicates a positive impact, whilst red indicates a negative impact or low level impact.

Scenario	Water Savings	Operational Costs for UoC	Spatial Impact	Programme Impact	Householder Maintenance Liability	Operator Maintenance Liability	Complexity of Operation Arrangement	Innovation and PR	Technical Risk	Water Resource Health	Capital Costs
A: On-plot water recycling	Portion of non-potable demand met	May be significant for UoC property	On-plot	Baseline scheme	Risk of failure of systems and plumbing	Individual owners	Many owners	Known response	Recycled water	Roof runoff removal	Min £19.45m
B: Stormwater to non-potable	Non-potable demand met	Low-tech	Need to identify aquifer/ small plant	Storage/ Plant may affect planning	Non-potable supply plumping	Non-potable manager	EA approval and supplier	First of its kind	Recycled water	Aquifer recharge Runoff removal	Min £6.05m
C: Blackwater to non-potable	Non-potable demand met	High-tech	Plant (western edge)	Plant may affect planning	Non-potable supply plumping	Non-potable manager	EA approval and supplier	First of its kind in large dev.	Recycled water	Sewage removal	Min £4.90m
D: Closed loop development	Zero water	High-tech	Aquifer and Plant	Plants may affect planning	Non-potable supply plumping	Manage two supplies	EA approval, interact with Cambs W	First closed loop	Recycled water to potable	Aquifer recharge Runoff + Sewage	Min £7.85m

3.4 External Temperatures and Overheating

3.4.1 The Urban Heat Island Effect:

The urban heat island (UHI) effect is where a densely built up, populated area experiences higher temperatures than those experienced in the surrounding rural areas, sometimes as much as 7^{o}C warmer (Greater London Authority, October 2006). This will be exacerbated with the onset of climate change with impacts on both the energy use and the comfort of site users, both internally and externally, and as such, needs to be clearly considered in designing new built environments.

3.4.2 Air Temperature and Thermal Comfort:

Thermal comfort is a subjective measure of a person's psychological response to the heat balance of the human body. The effects of the thermal environment on different people can vary greatly and this makes assessing the thermal comfort of a large group of people a complex issue. The Universal Thermal Comfort Indicator[7] (UTCI) has been selected to assess the thermal comfort within a small zone of the NWC development. This is effectively a perceived temperature, taking into account a number of climatic metrics.

The UTCI is defined as the air temperature in the reference condition (50% humidity, still air and full shade) that causes the same physiological response as the actual observed conditions. The range and classification of UTCI is given in Table 5, below.

Above 46°C	38°C to 46°C	32°C to 38°C	26°C to 32°C	9°C to 26°C	9°C to 0°C	0°C to -13°C	-31°C to -27°C	-27°C to -40°C	Below -40°C
Extreme Heat Stress	Very Strong Heat Stress	Strong Heat Stress	Moderate Heat Stress	No Thermal Stress	Slight Cold Stress	Moderate Cold Stress	Strong Cold Stress	Very Strong Cold Stress	Extreme Cold Stress

Table 8: The UTCI scale

Taking the baseline site input conditions (see Appendix 3.3 for a detailed description of the modelling) and assuming a pedestrian was standing in an open space with concrete paving, the UTCI temperature for NWC would already be within the strong heat stress range (approximately 36°C) and so it is important that the impacts of the UHI are considered in the design to try and reduce external temperatures.

3.4.3 Mitigating and Managing the UHI Effect:

There are a number of strategies for mitigating and managing the UHI effect, each with varying benefits and consequences:

- Urban density, thermal mass and albedo - as a rule, increasing urban density results in an increased impact of the UHI effect. This is due to the increase in thermal mass of materials within a small space. The result is elevated air temperatures at night, which are not only uncomfortable but they increase the baseline temperature so that the site is always warmer, which exacerbates the UHI further the following day.

  To minimize the UHI effect, the surface finishes on all surfaces within an urban environment should be as smooth and light as possible. The relative reflectivity of a material is known as its albedo – the higher the albedo the higher the reflectivity of the material.

[77] Developed by a commission established by the International Society of Biometeorology, 2000.

- Open green space - Green spaces create cooler microclimates through absorbing less heat than built up areas and through the process of evapo-transpiration, where water drawn from the air, soil and water bodies is released through a leaf's pores. When the water evaporates, energy is absorbed from the air, so creating a cooling effect. In green spaces which are greater than 1 hectare in size, the effect can be sufficiently pronounced to develop a distinctive microclimate.

  In addition to the evaporative cooling benefits of green spaces, green roofs have the added benefit of reducing the amount of heat build up within the building fabric, which could in turn impact on the energy performance of the building.

- Shading – Perhaps the most effective way for reducing the UHI is to prevent heat radiation from being absorbed in the first place. Furthermore, thermal comfort is heavily influenced by the solar radiation as air temperature. Shade could come from a range of sources such as, overhanging buildings and awnings. However, shading from trees not only has the benefit of providing shading, but also has the added evapo-transpiration benefits. Quantitative assessment of the benefits of green infrastructure in urban environments by Gill et al[8] found that an additional 10% green cover in high density urban areas could moderate temperatures sufficiently to entirely counteract warming due to climate change until 2050, in Manchester.

3.4.4 Modelling the UHI Effect and Mitigation at North West Cambridge

The change from green field to built development at the North West Cambridge site represents a significant land use change that is likely to result in an increase in external temperature through air temperature increases and radiant heat. This is likely to reduce thermal comfort when compared to the existing site conditions.

Analysis has been undertaken to try and establish what the likely relative temperature increase due to the urbanisation of this region might be, and how this increase could be mitigated by testing a number of measures that are known to reduce the impacts of the UHI.

This is done by using computational fluid dynamics (CFD) techniques that are regularly employed to analyse wind flow patterns around a site and adapting the model to take in to account thermal effects. Due to the complexity of such modelling techniques, the period of analysis is restricted to a particular short period of time, and does therefore not fully represent conditions throughout the year. Because of this, likely worst case conditions are analysed.

Setting the climatic baseline

Adverse impacts of the UHI on thermal comfort are worst felt on hot, sunny days where wind speeds are low. Weather tapes created by the Prometheus project at the University of Exeter have been analysed to determine the conditions that should be used as inputs to the simulation. As this analysis considers the comparative increase or decrease in temperature, it is likely that similar increases or decreases can be expected using future climate weather data. The analysis provided in this study focuses on a single snapshot in time, however simulations are conducted for a full 24 hour period so as to take account of the dynamic physical phenomena that occur in the built environment, such as temperature and solar load variation, solar azimuth and altitude, and the effects of thermal storage and release.

- *External Air Temperature* - Measured air temperature data for the Cambridge area has been analysed to arrive at an average external temperature of 26.5°C, which corresponds to a particularly hot day.

[8] Adapting Cities for Climate Change: The Role of the Green Infrastructure, S.E. GILL, J.F. HANDLEY, A.R. ENNOS and S. PAULEIT (2007)

The UKCP09 climate change scenarios suggest that the number of hours that this temperature is likely to be exceeded will triple by 2030, and as a percentage of the year, this is likely to rise from its current levels of 0.3% to just over 1% of the year.

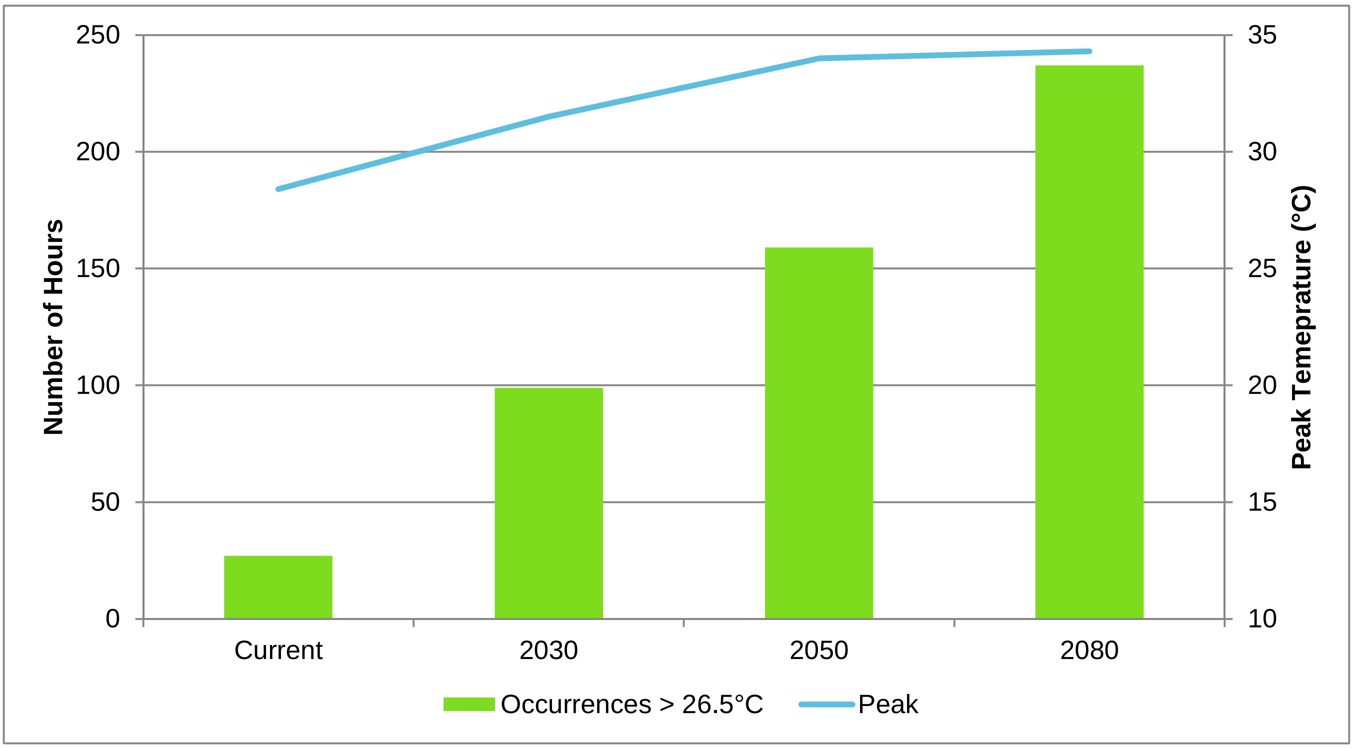

Figure 5: Projected increase in peak temperature and number of hours over 26.5°C

- *Wind* Speed - The UHI effect is at its worst when wind speeds are low. This is because heat that builds up in construction materials locally heats up the air surrounding the buildings and is not dispersed away from the urbanised area. A wind speed of 2 m/s (measured at 10m) is used in the analysis, and blows from a south westerly direction, which is the prevailing wind direction for Cambridge (and the majority of the UK). Further details of wind conditions are provided in Appendix 2.
- *Solar Radiation* - The weather variable that has the highest impact on the UHI is the radiative heat coming from the sun. Because of this, a mid-August day is selected due to its high solar load and transition across the sky on a summer's day.

Testing UHI mitigation measures

To understand the relative impact that the mitigation strategies described above are likely to have on the NWC development, a 3-dimensional model of a small section of the whole development containing each of the mitigation measures has been created. In addition, a baseline case has been simulated as a reference using typical construction materials and master plan strategies.

Each model is summarised below, with only one variable changed in each model to assess the importance of each measure. The first improvement option is a change to the albedo of the buildings, which is not shown in the figure, but labelled as 'improved facade' in the table below, and consisting of white paint on the walls and roves. A section of the site in the centre of Phase 1 has been modelled. This includes the local market square (predominantly hard landscaped), a mixed use block to the North consisting of ground floor shops, office space, and key worker housing, and a key worker housing block the North West. This part of the site is one of the most densely developed and the combination of open space and buildings provides a suitable opportunity for examining a range of adaptation measures.

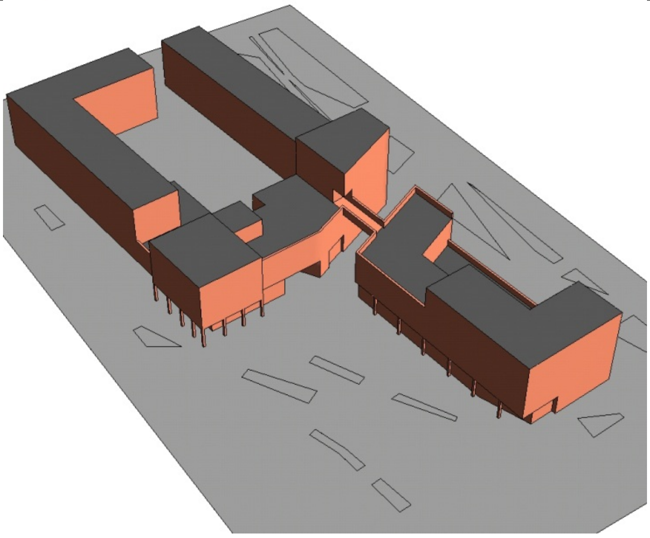	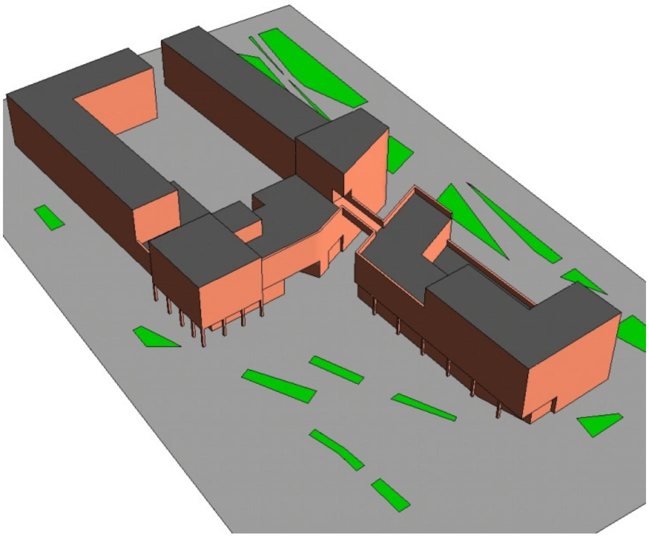
Figure 6: Baseline UHI model	Figure 7: Green infrastructure (grass) UHI model
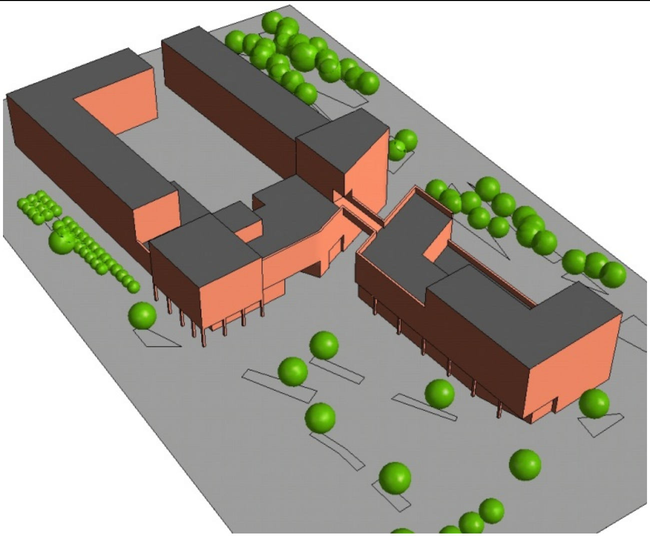	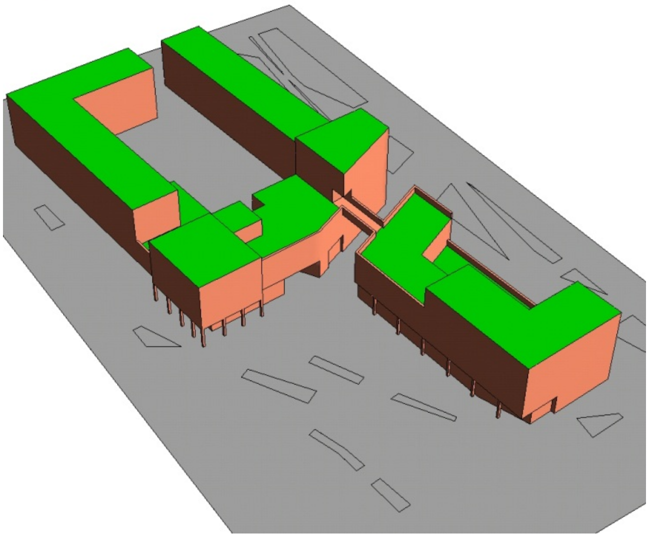
Figure 8: Green infrastructure (trees) UHI model	Figure 9: Green roof UHI model

3.4.5 Summary of Results

The analysis presented shows how different UHI mitigation measures are likely to impact the pedestrian comfort around the NWC site. In order to compare each case, the average UTCI at pedestrian level (1.75m above ground level) is shown in Table 9, as well as air temperature at 1.75m and average air temperature in the volume surrounding the proposed buildings.

Table 9: Comparison of mitigation measures based on the average UTCI and air temperature

	Average UTCI at pedestrian height (°C)	Average air temperature at pedestrian height (°C)	Average air temperature in surrounding volume (°C)
Baseline	34.6	27	26.6
Improved facade	35.2	26.8	26.5
Green infrastructure - grass	34.6	26.9	26.6
Green infrastructure - trees	33.6	27.2	26.7
Green roof	34.5	26.7	26.5
Rural	33.6	24.3	25.8

It is also useful to consider the minimum and maximum values of each variable to understand the range of temperatures that may be experienced under the modelled scenarios. Figure 10 and Figure 11 show how the air and UTCI temperatures could potentially vary across the site for each case modelled. The green band shows the range of temperatures that were observed in the rural green field model, measured at pedestrian height. The bold symbol for each case represents the average air temperature or UTCI temperature, respectively, that has been calculated, with the error bars depicting the upper and lower bounds of each variable across the site, i.e. in the baseline case, the average air temperature is 27°C, which varies between 23.5°C and 32.5°C across the site, depending on location.

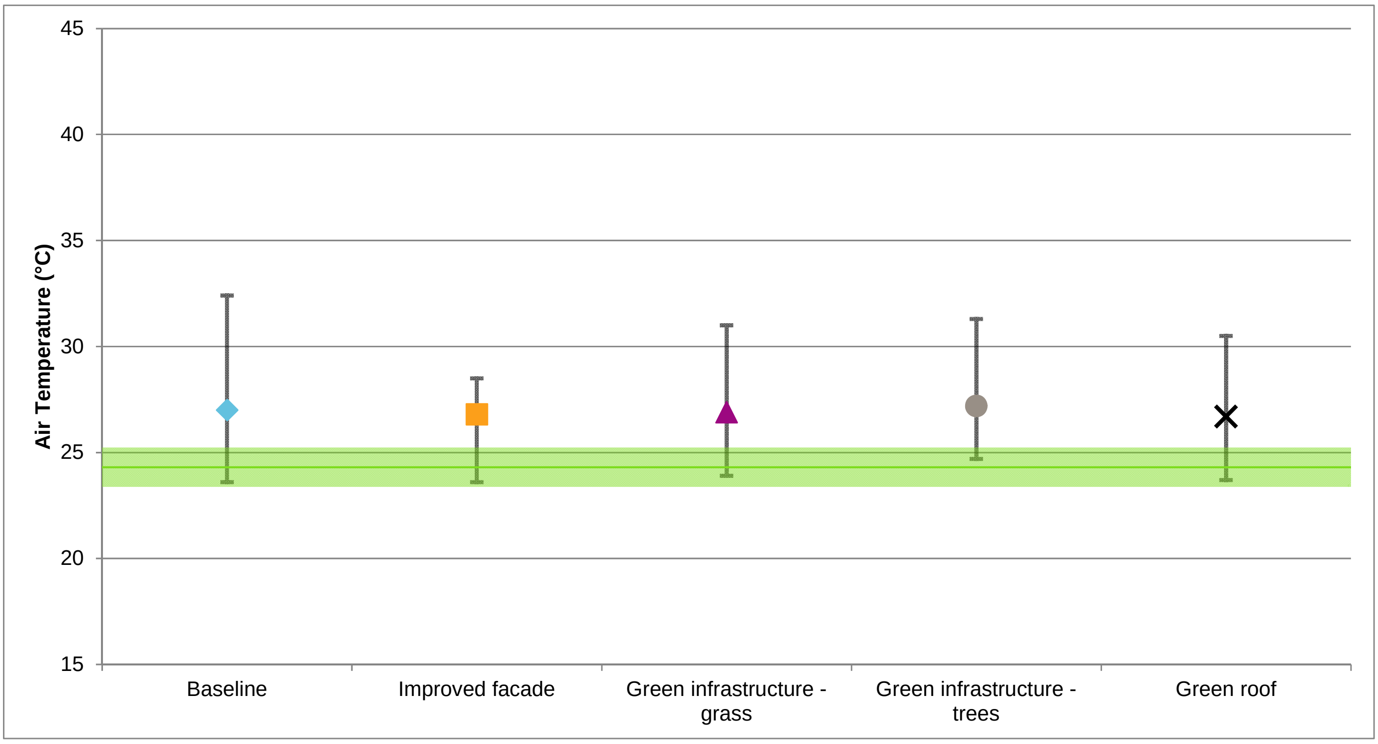

Figure 10: Comparison of minimum, average and maximum air temperatures

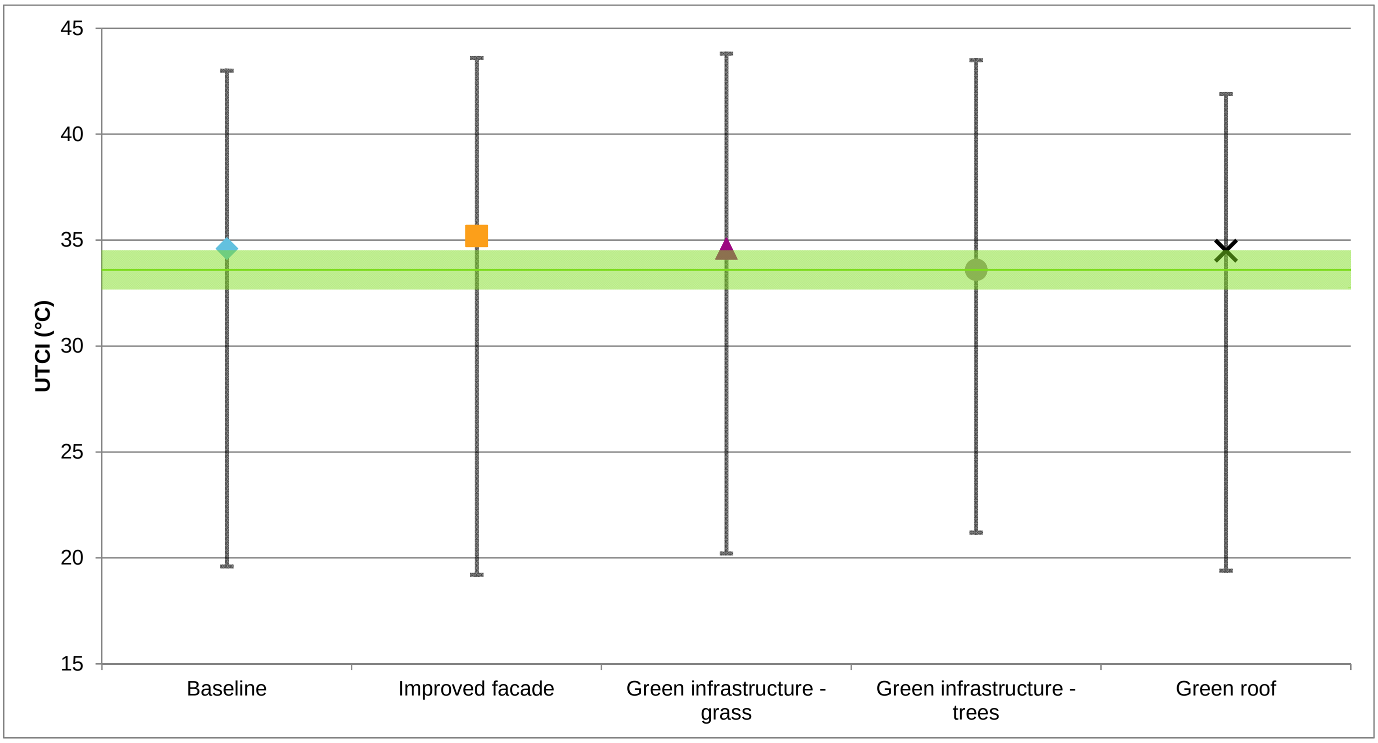

Figure 11: Comparison of minimum, average and maximum UTCI temperatures

The results in the above figures that the air temperatures across a rural green field site are less than those that are likely to be experienced across the developed site (based on data in Appendix 3.3). No single measure alone can effectively reduce the average temperature across the site to green field levels, However the model suggests that improving the façade has the largest impact in reducing the range of temperatures experienced. This is due to the reduction in façade surface temperature that is observed by increasing the reflective properties, i.e. the albedo of the façade covering.

On the other hand the UTCI for the improved façade has the potential to perform worse when compared to the baseline and keeping all other variables constant. This is because the solar radiation that is reflected off the façade is then absorbed in to the ground, resulting in slightly higher ground temperatures. This combined with a higher mean radiant temperature (due to an increased amount of radiation) results in poorer thermal comfort. As such, using a highly reflective façade construction is only really beneficial if the heat radiation reflected is not absorbed by other materials or onto people. Furthermore, this strategy is likely to be more beneficial at reducing the wider UHI effect if deployed on taller buildings, where the radiation can be reflected back safely.

The model also showed that vegetated areas are important for reducing surface temperatures and can help reduce the urban heat island by reducing the amount of heat that is convected into the wider urban environment. This is particularly the case for larger areas of grass or trees, which are likely to create their own microclimate. The Manchester University Studies have shown that unlike surface temperature, globe temperatures were less likely to be affected by surface cover i.e. the globe temperature above grass (and therefore human comfort) is comparable to that above asphalt or concrete. Tree shade, however, greatly reduces globe temperatures by reducing the radiation penetrating onto materials where it can be absorbed and reradiated. Low vegetation such as grass is therefore important for reducing the wider UHI effect, because less heat is convected back into the environment; however the effects of this are unlikely to be felt on site.

Tree cover on the other hand, not only helps to reduce surface temperatures and therefore the urban heat island effect, but is also reduces the solar radiation and therefore increases thermal comfort.

3.4.6 Timescale for implementation

As with many design considerations, the most beneficial time to consider green infrastructure interventions to manage the UHI effect is during the masterplanning phase; setting out the relationship between buildings and open space. As detailed design progresses, a better understanding of where vegetated areas can be located can be developed alongside the design of buildings to support green roofs and reduced albedo surfaces (whether through cladding or finish). As trees take a long time to mature, they can be planted when they are relatively small and inexpensive; delivering their benefit as they mature and the impacts of climate change are more acutely felt. Careful consideration of species will need to be undertaken to use species that can cope with the changing climate i.e. can take periods of inundation and drought. Furthermore, measures should be taken to protect open space assets from future development. The siting of trees needs to be carefully considered to ensure that suitable shading is provided without impacting other requirements such as daylighting for buildings.

3.4.7 Costs and benefits assessment

It is somewhat difficult to assess which measures are likely to be most effective, therefore, an additional metric has been developed. To analyse the effectiveness of each measure, the volume of air that has been reduced by at least 1°C when compared to the baseline case has been calculated, and tabulated against the extent across which each mitigation measure has been applied. This is shown in Table 10.

Table 10: Normalised comparison of each mitigation measure

	Extent of mitigation applied to model	Volume of air that may experience a reduction in air temperature of 1°C or more	Relative volume of air per unit of mitigation measure
Improved facade	Façade = 12,183m^2 Roof = 4,654m^2 Total = 16,837m^2	16,019m^2	0.95m^3 per 1m^2 of façade treatment
Green infrastructure – grass	1274m^2	2,208m^2	1.73m^3 per 1m^2 of grass coverage
Green infrastructure – trees	71 trees (various sizes)	540m^2	7.61m^3 per tree
Green roof	4,654m^2	21,432m^3	4.61m^3 per 1m^2 of green roof

From this normalised comparison and an understanding of the cost for each mitigation measure, an assumption as to the cost per 1°C cooling can be established. The costs are developed further in Appendix 3.3. The table below considers these costs in summarising their overall benefit and priority for adoption (note that costs do not include management and maintenance cost).

Table 11: Cost Benefit Analysis (please see Appendix 3.3 for a full explanation of the costs and assessment)

	Reducing external air temperature	**Improving thermal comfort**	**Capital cost**	**Cost per cooling benefit** (£ per m^3 air reduced by 1°C or more)	**Priority level**
Improved façade	Very good at reducing air temperature which could have benefits on the wider UHI effect.	Care needs to be taken to avoid reflecting heat onto sensitive receptors or where it can be absorbed and re-radiated.	£	£ £variable	Medium
Increased green infrastructure - grass	Evaporative cooling helps reduce the air temperature	Reduces reflected radiant heat to improve thermal comfort at pedestrian level	£	£ £9 / m^3	High
Increased green infrastructure - trees	Evaporative cooling is a pedestrian level	Extra benefits from shading which reduces radiant temperatures	£	£ £ £32 / m^3	High
Green roofs	As with grass, effectively cools the air.	Has the added benefit of reducing the absorption of heat into the building fabric. Radiant temperature benefits are however less likely to be felt by pedestrians, but supports reduction of wider UHI.	£££	£ £9 / m^3	Medium

This discussion relates only to the benefit of green infrastructure in reducing air temperature directly. It should be recalled that the benefit of shading from trees is also significant for thermal comfort, and would be expected to have a larger effect on the external thermal comfort than indicated here from air alone. The opportunity to be outside under shade is recognised as important in heat-wave conditions [9]. However unless the buildings are shaded directly (discussed in the next section) it is the air temperature effect that is most relevant to internal overheating.

3.4.8 Proposed Strategy for NWC

The proposed strategy to manage the UHI and thermal comfort will draw on all of the above mitigation measures during the detailed design process. However, as described above, the drivers to implement these interventions are not just driven by the need to manage the microclimate. Opportunities should be sought to maximise urban greening, particularly with street trees and areas of vegetation at ground level. Where facade treatments are used,

[9] See Department of Health Heatwave Plan for England 2012. http://www.dh.gov.uk/health/2012/05/heatwave-plan/

care must be taken to avoid reflecting the heat back onto sensitive receptors, such as pedestrians, or where it can be absorbed by other materials to be re-radiated at night and reinforcing the UHI effect.

3.5 Internal overheating

3.5.1 Introduction to the Risks of Internal Overheating

Increases in average and peak summer temperatures as a result of climate change may mean that there is a higher likelihood of buildings overheating in the future. This is not only uncomfortable for residents of the development, but can also make building occupiers less productive, and in some cases, the building unusable.

The North West Cambridge Area Action Plan shows a clear requirement for buildings on the North West Cambridge site to be adaptable to higher summertime temperatures as a result of climate change:

> *“New development will need to be adaptable for unavoidable changes in climate without further increasing emissions with active heating and cooling systems. There is much that can be achieved through ‘passive measures’ such as the location, layout, orientation, aspect and external design of buildings and landscaping around buildings that can help occupants to cope more easily with the effects of climate change.” (NWAAP 9.2)*

A number of different dwelling types are proposed at North West Cambridge. Overheating analysis has been carried out on four of these dwelling topologies (two houses and two flats) in order to assess whether a business-as-usual approach is likely to result in overheating using present day and future weather files (2050 and 2080).

The analysis of overheating breaches the gap between masterplanning and detailed design. In this section, design features are considered which fall both in the masterplanning and brief setting area, and also into detailed design. This range of measures is considered to assess the comparative cost benefit, but the outcome from the work will mainly consider the measures which may be appropriate during the masterplanning / brief setting stage.

Features common to all dwellings at North West Cambridge

A window area of approximately 40% of the facade is assumed for all dwellings, according to previous work on daylight standards at North West Cambridge. The fabric insulation and air-tightness standards will be reasonably, but not exceptionally, air tight (5 m^3/m^2/hour assumed); broadly in accordance with the Fabric Energy Efficiency Standard (FEES) required under the proposed definition of zero carbon. The masterplan has not been based consciously on passive solar design principles and therefore the orientation of dwellings is random and it is not anticipated that these dwellings will necessarily feature large south facing glazed facades.

Flat Types

Overheating has been assessed in a 1 bed (type B1) and a 2 bed flat (type B2) as shown in Figure 74 and Figure 75, Appendix 3.4. The flats are to be incorporated into a block of flats, generally no more than 4 storeys high and designed around a courtyard. Flat B1 is orientated East/West and Flat B2 is orientated North/South. Both are mid floor flats. The flats are accessed by an external deck which provides some shading to one of the two facades. Generally single aspect flats are to be avoided at North West Cambridge and therefore all flats are modelled as being capable of cross ventilation.

House Types

Overheating has been assessed in a 2 bed (Type A4) and a 3 bed house (type A5) as shown in Figure 76 and Figure 77, Appendix 3.4. The orientation of the houses was chosen as North West / South East since the majority of houses in phase 1 are orientated in this way.

Business-as-usual / Baseline

In order to provide a baseline from which to measure improvements in overheating performance a proposed standard specification for the dwellings were agreed with the architects. The specifications are detailed in appendix 3.4 along with diagrams of the building layouts.

Definition of overheating risk

Overheating risk in dwellings is currently not well defined. It is only subject to legislation through the Government's Standard Assessment Procedure (SAP) used for compliance with Part L and hence a number of differing criteria are proposed from various organisations.

CIBSE Guide A provides a temperature benchmark against a duration of time as an overheating criterion. For non air-conditioned buildings the overheating criteria is deemed to be not exceeding 1% of the annual occupied hours over an operative temperature of 28°C. For bedrooms it is assumed that night time temperatures are more disruptive of sleep and therefore the overheating temperature is reduced to figures exceeding 26°C. Different occupied hours were therefore assumed for bedrooms as follows:

Table 12: Findings: overheating risk in the baseline specification

	Occupied Hours	**Defined Overheating Criteria**
Bedrooms	Occupancy period assumed to be from 10pm to 8am. Some sensitivity analysis was also carried out to assess overheating risk during the day. This is important for the housebound or for young children/babies that sleep during the day.	1% annual occupied hours (37 hours) at temperatures exceeding 26^{oc}
All other rooms	Occupancy period assumed to be from 8am to 10pm. Note that overheating is assessed throughout the day but internal gains from people/small power are assumed to be not present during the middle of the day	1% annual occupied hours (51 hours) at temperatures exceeding 28^{o}C.

When modelled under the current climate the business-as-usual specification results in some overheating (hours above 26/28°C) according to the definitions outlined above:

a) Bedrooms in house A5 exceed 26°C for an average of 2.7% of occupied hours. The bedroom in flat B1 exceeds 26°C for 3.8% of the occupied hours.

In general, however, overheating does not occur in the majority of spaces and not at all in the living areas and kitchens. As expected overheating becomes much more of a problem with the hotter climate scenarios predicted for 2050 and 2080. In particular:

a) The combined kitchen/living room of house A5 (examined as one space) exceeds 28°C for 1.4% of occupied hours in 2050 and 2% of occupied hours in 2080.

b) The bedrooms of house A4 now begin to overheat in 2050. Temperatures exceed 26°C in these spaces by an average of 4.6% of occupied hours in 2050 and 6.5% in 2080. Temperatures in the bedrooms of house A5 exceed 26°C by an average 10.1% of occupied hours in 2050 and 12.1% in 2080

c) Bedrooms in the flats overheat more extensively from 2050. In flat B1 the bedroom exceeds 26°C for 15.3% of the occupied hours in both 2050 and 2080. In flat B2 the bedrooms exceed 26°C by an average of 2.9% of the occupied hours in both 2050 and 2080.

d) The living spaces of flat B1 also experience higher levels of overheating from 2050. The combined kitchen/living room of flat B1 exceeds 28°C for 5.5% of occupied hours in 2050 and 2080. By contrast the kitchen and living rooms of flat B2 do not exceeds 28°C at all.

Taking this last comment it is interesting to note that flat B1 experiences significantly higher levels of overheating than flat B2. The possible cause of this may be its orientation. Flat B1 is East/West facing whereas flat B2 is North/South facing with prominent shading provided by the external deck access.

The findings suggest that overheating will become more of a problem in later climate scenarios for those who are likely to be at home during the middle of the day, i.e. the elderly, home workers and parents of young children. Overheating risk increases significantly when occupied hours for bedrooms are extended into the day. This is highly relevant to the key worker homes proposed for North West Cambridge where office spaces (desks) may be located in bedrooms and may be used by occupants for home working during the day.

3.5.2 Potential solutions and Costs

A range of solutions to reduce overheating have been tested through thermal modelling as outlined in Table 13 below. Given that the bedrooms of house A5 and Flat B1 experience the highest levels of overheating, results are presented for these 2 buildings in the following analysis.

Table 13: Overheating solutions modelled

	Overheating solutions	**Cost (extra over,(£/m2)**	**Cost (extra over,(£/m2)**	**Comments**
		Flat	House	
Thermal mass	Lightweight	Baseline	Baseline	Timber frame
	Medium weight	40	46	Brick and block (with suspended ceilings and plasterboard on dabs
	heavyweight (3)	139	145	Brick and block (with exposed mass surfaces) (3) respectively.
Shading	Solar-glass – G=35%	16	16	
	Solar-glass in conjunction with: Blinds	24	24	
	Solar-glass in conjunction with: shutters	176	146	Shutters are assumed to result in reduced ventilation though this might be mitigated through separate ventilation louvres (see below).
	Solar-glass in conjunction manual awning	46	50	
Ventilation opening	Increased window area: 50% of window opening	164	90	In practice, window areas are often limited to 10% of window opening due to the need for safety and security. Therefore larger areas will necessitate more complicated, costly and potentially unattractive solutions such as separate louvres, ventilation panels or grilles over windows. For NWC some of the facades require acoustic treatment due to excessive noise levels predominantly from nearby roads. A solution involving an acoustic louvre has therefore been costed but other solutions will be investigated during detailed design.

Orientation	East/West orientation moved to North/South	Not costed	Not Costed	As noted above Flat B1 overheats significantly more than flat B2. A sensitivity run has been tested on flat B1 with a North/South orientation.

3.5.3 Timescale for implementation

The detailed design stage of North West Cambridge began in August 2012 with Stage D+ and detailed planning submissions expected in March 2013. This means that the outputs from this report are timed very well to coincide with the stage of design when decisions on overheating mitigation measures are best made. With the possible exception of orientation (the outline masterplan has already made decisions on orientation) decisions on the thermal mass properties, solar shading and means of ventilation will be made between August 2012 and December 2012.

As discussed in the previous section some mitigation measures (such as blinds and brise-soleil) can be retro-fitted at a later date but, in particular measures such as thermal mass and appropriate means of ventilation require integration from the start.

Assessment of overheating risk has been incorporated into the design briefs for detailed design and it is therefore expected that design teams will carry out similar levels of analysis to those presented in this report on emerging designs. The emerging conclusions of this report are expected to inform early design decisions.

3.5.4 Costs and benefits assessment

Table 14 and Table 15 below show the hours of overheating for a range of mitigation measures together with the cost-efficiency of each of those measures defined as the cost of preventing 100 hours of overheating relative to the baseline scenario. A low positive value for £/m^2 spent suggests that the measure is highly cost effective, whilst a higher value suggests the measure is less cost effective In the case of solar control glazing the baseline is considered to be ordinary low-E double glazing. All other measures assume that solar control glazing has been installed.

Solar Control Glass

Early modelling showed that solar control glass results in the largest reductions in overheating relative to cost. It also produces among the highest gross reductions in overheating. It does not, however, bring the hours of overheating to within 1% occupied hours in the worst rooms analysed and therefore additional measures are required. The remaining measures were tested in conjunction with solar control glass in order to test the synergistic effects of combining measures in this way.

It should be noted that solar control glass will have a clear negative impact on beneficial solar gains in winter and potentially daylight. The cost of the glazing for this study assumes high performance solar control glass with a low G-value (35%) but high light transmission (66%) that will deal with the daylight issue. The negative impact on heating demand is beyond the scope of this study. See note on heating energy use below.

Thermal mass

In disagreement with some overheating studies the effect of thermal mass was found to be small in most of the spaces analysed. Further work should test this assumption on the basis that some occupants of North West Cambridge will be at home during the day.

In agreement with other studies the effect of thermal mass is least effective (and sometimes counterproductive) in bedrooms, particularly when only occupied at night. Increased thermal mass was also found to be expensive and therefore the cost efficiency of this measure was low and in some cases negative.

Concept of insulated thermal mass

Some of the thermal mass findings may seem to contradict evidence from vernacular design. Typically, buildings in Mediterranean climates (more like the climates predicted in the future in the UK) are thermally heavyweight with thick walls and tiled floors. However the key difference is that these vernacular buildings are not blanketed in insulation as is assumed in the models. This insulation reduces the rate at which heat escapes through the fabric of the buildings and allows the thermal mass to become saturated with heat over long spells of warm weather. Again, the effect is more noticeable in flats where thermal mass was found to be less effective. The challenge for design to use thermal mass therefore is to achieve high enough rates of ventilation over the thermal mass to cool it at night to be available as a resource the next day. See also note on heating energy use below.

In the following tables a range of mitigation measures in Flat B1 and the Bedrooms of House A5 have been examined. Measures resulting in overheating reductions below 1% occupied hours shaded in green.

Table 14: Hours of overheating and cost efficiency, **2050**

		Hours Overheating			Cost efficiency of measure			
	Overheating solutions	B1		A5	B1		A5	
		Living Spaces	Bedroom	Bedrooms	Living Spaces	Bedroom	Bedroom	Average across Buildings
		Hrs above 26/28°C			£/m^2 spent / 100 Hrs saved			
Solar Glass	Ordinary Low E glass, G=66%	281	558	371				
	Solar Glass, G=35%	71	253	45	8	5	5	6
Thermal mass	Lightweight, G=35%	71	253	45				
	Medium weight	58	252	41	308	4000	1150	1819
	heavyweight	55	245	37	869	1738	1813	1473
Shading	Blinds	53	15	10	44	3	23	24
	Shutters	0	0	0	183	51	351	195
	Manual awning	66	17	3	600	13	83	232
Ventilation opening	Ventilation louvre allowing 50% equivalent opening	1	0	0	234	65	200	166

*Table 15: Hours of overheating and cost efficiency: **2080***

		Hours Overheating			Cost efficiency of measure			
	Overheating solutions	B1		A5	B1		A5	
		Living Spaces	Bedroom	Bedrooms	Living Spaces	Bedroom	Bedroom	Average across Buildings
		Hrs above 26/28°C			£/m^2 spent / 100 Hrs saved			
Solar Glass	Ordinary Low E glass, G=66%	280	557	442				
	Solar Glass, G=35%	186	384	85	17	9	4	10
Thermal mass	Lightweight, G=35%	186	384	85				
	Medium weight	167	391	86	211	-571*	-4600*	-1654*
	heavyweight	163	391	77	604	-1986*	1813	144
Shading	Blinds	132	42	13	15	2	11	9
	Shutters	0	0	7	95	46	187	109

	Manual awning	175	93	8	418	16	65	166
Ventilation opening	Ventilation louvre allowing 50% equivalent opening	6	0	3	91	43	110	81

(*See footnote[10])

Shading

Notwithstanding the large benefit from solar control glass, other shading measures were found to be effective at reducing overheating overall and did so cost effectively. The next most cost effective measure after solar control glass was internal blinds. The combination of solar control glass and blinds in bedrooms generally brought overheating hours below 1% in 2050 assuming reasonable ventilation rates. Shutters result in the largest overall gross reductions in overheating (to zero in all cases) but are not as cost effective due to their relatively high gross cost.

Ventilation

As with shutters high ventilation rates through secure ventilation louvres were found to result in the highest gross reductions in overheating, in most cases taking the hours above 26/28°C to zero. This was found to have the next highest level of cost effectiveness after solar control shading and internal blinds.

3.5.5 Proposed Strategy for NWC - Recommendations

The analysis suggests that overheating is not likely to be a considerable problem in the sample dwellings during current average Cambridge summers assuming that residents are able to open their windows fully in a safe/secure manner during occupied periods and all dwellings are cross ventilated. Evidently hotter summers such as the one experienced in 2003 are more like the average summers assumed in the later climate models and therefore it is possible that exceptional summers in the near future will see overheating.

As average summers become hotter as a result of climate change the analysis suggests that overheating will become more of a problem, in particular in dwellings that are occupied in the peak of the day. Given the demographics at North West Cambridge it is not inconceivable that a large number of researchers will be working from home or have partners/spouses with young children at home during the day. In addition, the market homes may be occupied by the elderly during the day.

The question that needs to be asked therefore is the extent to which the mitigation measures analysed can easily be implemented in the homes at North West Cambridge. In other words, how adaptable are the homes to climate change? Some measures such as manually operated awnings and blinds can be fitted easily in the future. The following therefore highlights measures that should be incorporated in the base design of dwellings to avoid costly retrofit at a later date.

Solar Control

Solar control glazing is found to result in significant and cost effective reductions in overheating. Assuming that high performance glazing with high light transmission is specified there is a case for solar control glass to be fitted in West facades at least where other forms of solar shading are less effective in the late afternoon. In other facades further work should be carried out to establish the balance between overheating and loss of beneficial solar gains. It is interesting to note that flat B2 overheats significantly less than flat B1 probably due to the fact that flat B2 is south facing and is self-shaded by the deck-access. In the absence of solar control glass self shading window design

[10] All of the measures presented cost more than the baseline solution. Therefore the negative cost efficiency is achieved through an increase in the number of hours overheating, and these measures are therefore extremely non cost effective with no overheating mitigation benefit.

should be employed with deep reveals on east and west facing windows. Large window areas should be avoided. Separate daylighting analysis suggests that adequate daylight can be achieved with window areas around 40% of facade area and therefore further glazing is likely to result in more overheating without significant gains in daylight.

Ventilation

Along with shutters, high ventilation rates were found to result in the highest gross reductions in overheating, in most cases taking the hours above 26/28°C to zero. High ventilation rates were modelled assuming 50% equivalent window area open during occupied hours. However, even the lesser ventilation rate assumed in the base case (10% equivalent window area) will be difficult to achieve in practice due to safety/security constraints. Homes with noisier external conditions will need to seek ways of mitigating noise ingress through the ventilation opening. In addition the analysis assumes that window openings are not obstructed by curtains, therefore it is preferable for the ventilation opening to be separate from the window. Any single aspect dwellings should have means of driving higher ventilation rates through such means as stack chimneys since single sided ventilation will not result in high enough ventilation rates to prevent overheating, particularly where noise prevents large openings. Lastly, dwellings with a ground floor (i.e. all houses and some flats) should have a means of allowing large ventilation openings at night whilst not allowing intruders to get access.

Thermal mass

Thermal mass was found to be of some benefit, though medium thermal mass was generally as beneficial as high thermal mass, and solar control combined with high ventilation rates was found to provide adequate internal comfort levels in low thermal mass dwellings. The thermal mass of the dwellings at North West Cambridge should therefore be driven by other considerations such as cost and buildability.

A note on heating energy use

Because this study has focussed on summertime overheating no analysis has been carried out on the effect of overheating prevention measures on wintertime heating energy consumption. The reduction in solar gain caused by solar protection and the effect of thermal mass may lead to changes in heating demand. The literature has contradictory findings on thermal mass in particular. A report by ARUP on the effect of thermal mass in housing[11] found a 10% *increase* in heating energy demand in high thermal mass dwellings, while a separate ARUP report[12] on lifecycle energy consumption (including embodied carbon) in dwellings of differing thermal mass suggests a 19% *decrease* in heating energy demand.

In both cases the house design was conventional and not passively designed to make use of solar gains (large south facing glazing). The main difference seems therefore to be in the control regime used for the heating system. Intermittent heating (and occupancy) is assumed in the first thermal mass report while continuous heating is assumed in the lifecycle energy report. The energy demand response of a house to thermal mass is very much dependent on occupancy periods and the heating regime.

The findings (both from the literature and the thermal modelling) would suggest that intermittently occupied dwellings (particularly those used mainly for sleeping) would benefit from low thermal mass and intermittent heating. By contrast, family homes that are used 24-hours a day would benefit from high thermal mass and continuous heating. The demographics projected for North West Cambridge suggest the former will occupy the key worker flats while the latter will occupy the terraced houses. This suggests that houses should be thermally heavier-weight while the flats should be thermally lightweight. While yet to be decided a default option for materials at North West Cambridge could be the opposite with timber houses and concrete frame flats.

[11] Bill Dunster Architects, UK Housing and Climate Change, Lightweight vs. Heavyweight construction
[12] Embodied and operational carbon dioxide emissions from housing: A case study on the effects of thermal mass and climate change

An additional factor is embodied energy. While a thermally heavyweight building might demand higher embodied energy, specifically with the use of concrete, this may be mitigated by less use of air-conditioning in summer and therefore lower net energy over the lifetime of the building. This indeed is the finding of the ARUP report. However, this paper suggests that design solutions can be found in lightweight dwellings that result in low levels of overheating which might preclude the installation of air-conditioning.

3.5.6 Strategy being taken forward

Since North West Cambridge has only just begun detailed design no firm decisions on an overheating strategy have been made. However a number of principles have been taken through to detailed design and will be incorporated where possible:

- Minimisation of single aspect dwellings
- Use of stack ventilation where single aspect dwellings are unavoidable
- Careful control of solar gains, in particular on western facades, through the use of solar control glass and possibly shutters
- Design of ventilation openings to allow large air-change rates in a secure and, where required, noise abating manner.
- Exposure of some thermal mass (where used) in living rooms and kitchens. Less emphasis on thermal mass in bedrooms.

3.6 Summary

This section of the report provides a summary of the detailed assessments conducted in the four identified risk areas.

Table 16 provides a summary of the strategy being taken forward for each risk area. This summarises information from this report, and in turn from Appendices 3.1 to 3.4.

Table 16: Summary of the risks and strategies being taken forwards.

Risk	Summary of risk	Summary of strategy adopted
Water management and flooding (section 3.2)	With a change from agriculture and open space to a relatively dense development, the site is at risk of surface water runoff and flooding both on site and in neighbouring areas. Therefore this issue has high importance and an extensive sustainable urban drainage regime is required to prevent any additional run off.	An extensive strategy of SUDs consisting of “green fingers” linked to ponds in the western edge was proposed for the scheme as part of the outline planning application. This DFC has assessed these components alongside more and less extensive systems to demonstrate the effectiveness of the proposed soluition. The study has also been used to refine the scheme, including for it’s potential use as part of a water conservation measures.
Water conservation	The East of England is the driest region	This study has identified four options for

(section 3.3)	in the UK. Water supply remains a risk for the site and the site as a whole remains vulnerable to an extended regional drought. The scale of development will provide a large additional burden on local water supplies and therefore this is a high risk.	the scheme ranging from a business as usual scenario of on-plot rainwater collection and greywater recycling, to a site wide rainwater-to-potable, and blackwater-to-nonpotable scheme. An assessment of the four scenarios shows that scenario B (consisting of a site wide rainwater capture and recycling scheme) has the lowest risk and potentially highest chance of implementation. All four options will continue to be pursued with water company partners to identify the most suitable solution for taking forwards. This decision is likely to be heavily influenced by the water company appetite and risk profile.
External overheating (section 3.4)	The development of a greenfield site into a relatively high density development will have some impact on external temperatures. Although the effect of the UHI effect is perceived to be minor, the risk at NWC Site has been assessed as medium. This is because the raise in external temperature may not in itself have a large impact, but an increase in external temperature will have a consequential impact on internal temperatures, and therefore limiting raises in external temperatures will help to reduce internal overheating.	The external overheatin study shows that there are a range of measures which can be deployed and which may have an impact on external temperatures. Extensive green infrastrucute in the form of trees and open spaces will be provided to reduce the area of hard landscaping where suitable. Consideration of facades and hard landscaping will also be made in the subsequent design, but will need to be carefully implemented so as not to simply reflect the heat elsewhere. Green roofs are not proposed as a key measure, partially due to the high relative cost, and also due to the extensive requirements for roofs to be covered in PV.
Internal overheating (section 3.5)	The East of England is one of the warmest regions of England and one of the most likely to suffer extreme summers such as the one experienced in 2003. The temperatures are projected to increase, exasperating the currently occurring problem. The consequence of higher temperatures certainly results in the prediction of overheating in buildings in NWC.	The analysis has highlighted a number of principles which will be taken forward in the detailed design. These include: - minimisation of single aspect dwellings, - careful control of solar gains, in particular on western facades, and the use of solar control glass and shutters. - Designs to incorporate large openings to allow large air change for purge ventilation in summer. - Exposure of thermal mass in living areas and kitchens.

Table 17 provides a summary of the implementation timescales and investment triggers for each of the adaptation strategy items, alongside a summary of the cost benefit analysis. Due to the nature of this study, where the analysis is concentrating on masterplanning elements, the adaptation measures are by and large developed as part of the initial development and infrastructure works, and are not triggered by future events.

Table 17: Summary of implementation timescales and cost benefit analysis for each adaptation strategy item.

Adaptation strategy	**Timescales for implementation and investment triggers**	**Cost benefit analysis**
Sustainable Urban Drainage	All of the sustainable urban drainage infrastructure will be constructed as part of the site infrastructure works. This will commence in 2013 and be constructed on a phase by phase basis as the development is built out. The phasing of the site means that the phase 1 infrastructure works will include a large fraction of the Western Edge, to which the green fingers from future phases will connect. Source control measures in the form of infiltration and minor SUDs features will be designed on a plot-by-plot basis to join the main site system. (see section 3.2.5)	The total cost of the proposed SUDs system is circa £2.2M which is broadly comparable with a conventional surface water drainage scheme. However elements of the latter will remain in some areas to collect and transfer water into the main SUDs network where infiltration measures are not suitable. A direct cost benefit analysis of the SUDs scheme is not simple, since the SUDs features are required as part of the planning permission, and provide a range of other services including walking and cycling paths, recreation areas, noise buffers, and general amenity improvement. Assigning costs specifically to drainage functions is therefore difficult. (see section 3.2.6)
Water conservation (section 3.3)	At present, the final water conservation scheme is unknown. Any plot-based systems (scenario A) will be installed during the development of individual plots. A site-wide system (scenarios B, C, and D) will be developed on a phased basis as the scheme is built out. Some degree of modularity may be required in central treatment plant, and the infrastructure design will need to be designed to allow for future additions to be made whilst being maintained operable. (see section 3.3.6)	Cost benefit analysis of the water conservation measure shows that a baseline solution of on-plot capture and recycling has the highest capital cost at circa £19M. The alternative scenarios B – D produce savings of between £8M and £14M depending on which option is examined. Therefore all of the site-wide options are more cost effective and therefore potentially commercially attractive to an external partner. (see section 3.3.7)
External overheating (section 3.4)	The measures proposed including open green spaces, trees, and potential facade and hard landscaping treatment will be implemented during the development of the site.	Cost benefit analysis considers the volume of air reduced by 1°C or more per unit of mitigation measure. On this basis, trees are slightly less cost effective than other measures when considering

	(see section 3.4.6)	temperature reduction alone. However they have a relatively low overall capital cost. As with the SUDs analysis, it is difficult to allocate the cost of measure to external temperature reduction only, as they all provide a wealth of other functions. The temperature reduction offered by green infrastructure could effectively be seen as a free added benefit. (see section 3.4.7)
Internal overheating (section 3.5)	The key measures identified of solar control glazing, orientation, and suitable ventilation will be implemented during detailed design of the buildings and will help inform the masterplanning of each plot. Further solar control measures such as shutters and awnings may provide benefit in the future, but have not been analysis as part of this work. (see section 3.5.3)	The cost analysis demonstrates that solar glazing has the lowest cost at circa £5 - £8 per m2 of development per 100 hours reduction in overheating. Ventilation openings have a higher cost at up to circa £230 / m2 whilst thermal mass has an extremely high cost benefit due to the very small overheating benefit. (see section 3.5.4)

4 Learning from work on this contract

Include description of masterplanning process from exec syummary.

4.1 Introduction

Most of the projects in the TSBs "Designing for a Future Climate" programme are based around the design of buildings, either individual or a small grouping. One of the key rationales for AECOM selecting the NWC project for an adaptation study was to investigate how the process can be used on a large masterplan. NWC offered some interesting opportunities:

- The project was beginning the masterplan process when commencing the study. This timing allows large infrastructure issues to be investigated, and where possible, incorporated into the masterplan. Many existing studies concentrate at the building scale, but this project allows the investigation of wider scale issue to see whether adaptation work can be beneficial.
- The client (University of Cambridge) will remain the majority landowner of the scheme with 1,500 homes remaining in the Universities ownership alongside other non-domestic buildings. This ownership structure means that there should be a stronger interest in longer term economic benefits.
- The client has high aspirations for the site to be sustainable, and a globally leading example of sustainable development. This could facilitate greater integration of the adaptation work into the design process and the subsequent integration into the built development.

When reading this report, the reader needs to remember this rationale and understand the stage of the project. At the time of writing this final report (Summer 2012), no project building designs have yet commenced and architects have only just been contracted to commence the design stages. Therefore items of analysis relating to building design, albeit at masterplan scale, are necessarily high level.

4.2 Our approach (a)

AECOM have taken a risk based approach for this study to identify some of the key issues for NWC, and then assessed these in more detail. This risk based approach is detailed in Appendix 2 and takes into account the likelihood of an event (for example a hot summer) occurring, and the consequence of this. The approach has been developed by AECOM for corporate adaptation planning. This risk based approach provides a robust framework for decision making. It involves 7 key steps, as shown in the following diagram, and is essentially what we have followed, through a single cycle rather than more than one.

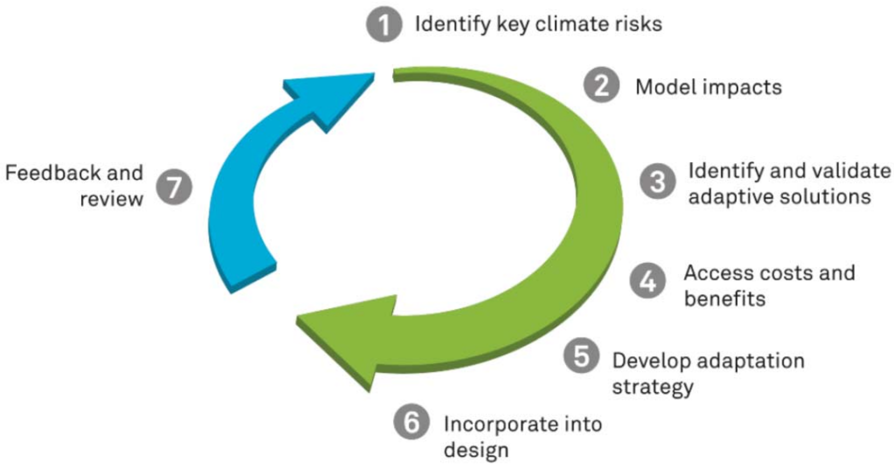

Figure 12: Schematic showing the AECOM approach to climate change adaptation strategy development

As the remainder of this section demonstrates, the masterplanning process is not necessarily straight forward or efficient, and the actual assessments conducted have in some cases gone through a number of iterations to reflect sudden changes to the masterplan or the cost plan. The flexible nature of the masterplanning process also means that the outcomes of this do not all directly influence the final design, but the design process, design briefing, and future work tasks.

4.3 The project team (b)

The diagram below illustrates the structure of the overall NWC project and the climate change adaptation study within this. Further details are provided in Appendix 4 for the key individuals involved.

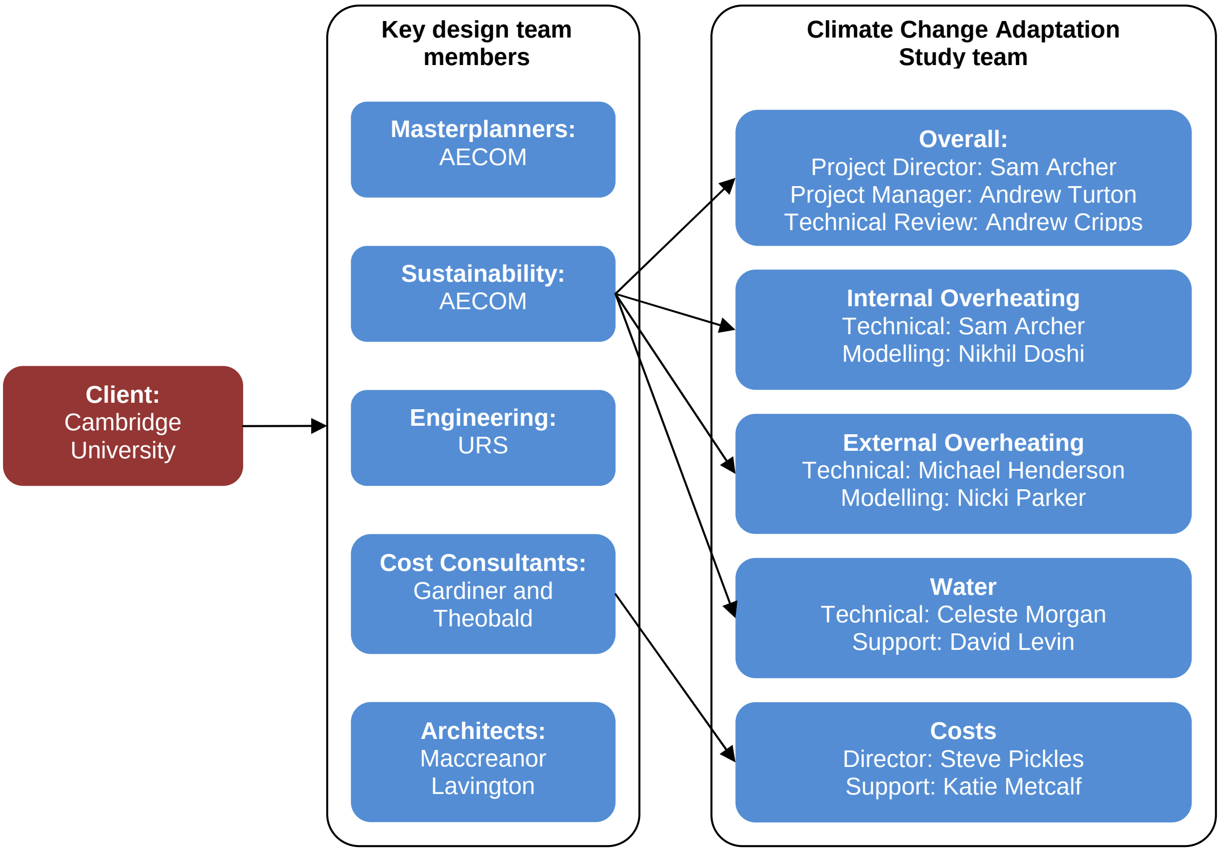

Figure 13: Schematic of team structure and organisation.

As described in section 4.7 of this report, the climate change study has been conducted in parallel with the main masterplanning process. This means that the climate change study team is working in parallel with the masterplanning team, with many members common to both (further information is provided in section 4.7.2). The arrows in Figure 13 show the direct linkages between the masterplanning design team and the climate change adaptation team, primarily with project funding. However there has been coordination with the other main members of the design team including input from the multidisciplinary engineers as part of the masterplanning design, the masterplanners, and architectural input for developing generic dwelling designs for the overheating analysis.

4.4 The project plan (c)

One of the key lessons learnt from working on a masterplan project is around programming. When AECOM submitted a bid for this project in July 2010, consultants had been working with the University of Cambridge for a year helping to form the sustainability and energy strategy for the development. The entire master planning process had also been running for around a year. The following key milestones had been proposed for the project:

- Masterplan fix in early 2010.
- Outline planning application for the entire site by September 2010.
- Reserved matters planning application following a period of design work for phase 1 by early 2011.

In light of these milestones, the original intention of this work was to integrate the adaptation study with the remaining master planning design and phase 1 detailed design with a report complete in August 2011. Figure 14 shows the original project programme.

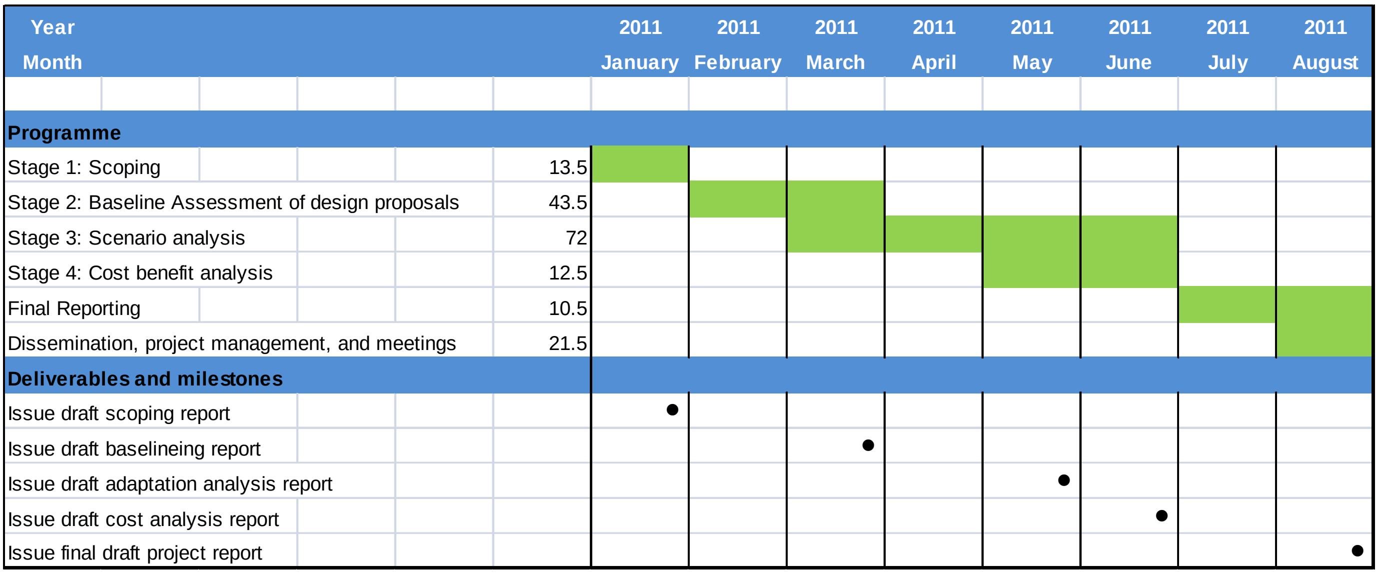

Figure 14: Original programme for conducting the adaptation work

As the project commenced, it became evident that the original programme was ambitious and it was revised accordingly. The complexity of developing a large integrated mixed use masterplan, combined with the number of stakeholders from within and outside the University has meant that delivery and sign off of the masterplan was heavily delayed. The final version of the overall masterplan 'fix' was issued in early 2012 with Phase 1 in Spring 2012. The Outline planning application was submitted in September 2011 and gained approval in summer 2012. Detailed design on Phase 1 is about to commence (August 2012) with reserved matters applications intended for phase 1 in early 2013 (around 2 years later than the initial programme).

These delays are outside the control of the adaptation study, resulting in late conclusion of this work, although certain elements have been able to commence prior to the masterplan fix. For example development of the external overheating work commenced on previous versions of the masterplan to test the methodology and assumptions, although the final analysis has used the final masterplan version. Work on water was also able to commence in advance of the masterplan fix (the water strategy being less dependent on details of the masterplan), but the bulk of the water work has had to be integrated with the design and engineering teams, resulting in an overall delay.

Internal overheating work was only able to commence in March 2012 following the temporary appointment of architects to design indicative houses to test the viability of achieving the Code for Sustainable Homes Level 5.

In connection to overall programme, the detailed programme and integration of adaptation work into the programme is discussed in more detail in section 4.7. These process issues are perhaps the most important area where lessons can be learnt for future adaptation studies.

4.5 Resources and tools used

4.5.1 Water management

A variety of hydraulic modelling tools are available that can be used to simulate rainfall and runoff events for a site. This project utilised MUSIC UK, a tool developed specifically for including SuDS and water management features at a site scale in Australia which has now been adapted for the UK. The tool is very easy to use and also provides an visual desktop that allows you to size and drop SuDS features onto a site and run rainfall scenarios quickly to test both flow and water quality. MUSIC seems to be much more approachable and easily understandable to non-engineering practitioners. It also has the advantage of having very specific typologies for different SuDS features available, so that modeller does not have to specify expected performance, therefore improving consistency of analysis. The ability to use bespoke rainfall data allowed us to run the model using both standard historical data and simulations of future rainfall events using UKCP09 data.

4.5.2 Water efficiency

The masterplanning stage is the crucial stage in which to identify how alternative sources of water can be provided in an efficient manner. Plot-scale solutions can be put in place at any design stage, but there is an opportunity in the easily stages, particularly for large developments, to consider communal supplies of non-potable water to reduce a site's water footprint. A Water Sensitive Urban Design strategy was developed at an early stage to bring all water considerations (water supply, wastewater management and surface water runoff) together within the planning and urban design process.

4.5.3 Tools for External Temperatures and Overheating

The CFD used for this analysis utilises the ANSYS suite of software, with CFX as its solution engine. The methodology used has been developed in house by AECOM and therefore is not available to others. Although the methodology is still in its infancy, studies like this are improving the assumptions and approximations that are made with the aim of developing a toolkit that can be used in the early stages of design to assist in decision making.

4.5.4 Internal Overheating

A variety of thermal modelling tools are available that can simulate internal temperatures in buildings given different climate scenarios. The overheating analysis for North West Cambridge was carried out using the ApacheSim thermal modelling module of IES VE-Pro software. This allows simulation of a building's thermal response to an hourly weather file. Hourly weather files where used based on the current average Cambridge climate and future climates predicted by UKCIP09 data for 2050 and 2080.

As discussed briefly in section 3.5 overheating risk in dwellings is poorly defined in the literature and therefore using software to determine whether a building will overheat involves subjective judgement, both in the inputs to a model and the interpretation of outputs. Overheating is currently regulated under Part L of the Building Regulations using am model in the Government's standard assessment procedure (SAP) for compliance with Part L. The analysis of overheating in SAP is very simplistic and is based on current weather data and therefore does not predict overheating under future, hotter, climates. The zero carbon hub have produced a comprehensive review[13] of available tools for overheating analysis with a view to making recommendations on the most appropriate tool for future overheating legislation. In the interim, industry guidance on appropriate (standard) inputs to a dwelling

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[13] Carbon Compliance for Tomorrow's New Homes: Topic 3: Future Climate Change

overheating model, interpretation of results and a review of overheating thresholds and standards would be welcome.

4.6 Resources recommended to others (g)

4.6.1 Water Management

Based on the results of this study we would recommend the use of MUSIC UK as a design tool at a masterplanning stage to integrate suitable and effective SuDS features to manage surface water runoff under current and future conditions.

4.6.2 Water efficiency

To initiate this process, it is recommended that a Water Sensitive Urban Design strategy to assess the water profile of the site, considering future potable and non-potable demands, water efficiency measures, current infrastructure, contextual water issues, landscape and ecology opportunities and possible alternative supply sources (wastewater, greywater and surface water runoff). All of these should also be considered in the context of future climates to determine an efficient and resilient urban structure and water management solution. The carbon content of water supply should also be considered to deliver an low carbon solution.

4.6.3 Internal overheating

The VE-Pro software is a relatively sophisticated software package for use by a trained operator. It allows assessment of a variety of common overheating mitigation measures and is therefore recommended for use in overheating assessments. It is not likely to be used by say, architects in early concept stage reviews of environmental design, particularly of dwellings that are rarely assessed using this type of dynamic simulation software. Since overheating risk is generally defined in terms of hours of exceedance it is usually assessed using hourly thermal modelling tools that must be operated by trained users (usually thermal modellers). This is one reason why SAP takes a more simple approach. No assessment was made comparing this software with other thermal modelling software however.

4.7 The process of the project (e)

The process of the project is where the main lessons have been learnt. The description below may seem a little pessimistic, but it was the reality on this project and will likely apply to most other schemes of this scale.

4.7.1 The Masterplanning process

Developing a large masterplan like NWC is a very complex process with many drivers and interested parties. The masterplanning development is as much about feasibility work and engaging with other stakeholders as it is about the design of the site. With the University of Cambridge, added complexity is introduced through internal University approvals processes which operate on a monthly, quarterly basis, or even less frequent basis.

This complexity results in the drivers and priorities for the masterplanning process changing over time, reflecting the various deadlines and milestones. For example, a priority one month could be updating a financial appraisal for University approval, whilst in another month, it could be producing development guides for inclusion into architect's contracts. The actual masterplan development is therefore not continuous, but jumps forwards in stages when prioritised.

The development of a masterplan is also expensive and so certain consultants and skills are only bought on board as and when required. This means that certain tasks may not be possible until the relevant consultants are available. One example which delayed the project programme was the availability of architects on the project team to develop housing models for the internal overheating analysis. Despite funding being available to supplement the architects work and look at variations for adaptation measures, no housing designs were developed until March 2012 when some testing work was conducted to assess the viability of achieving the Code for Sustainable Homes Level 5. Prior to this, architects were not appointed to input to the masterplan.

On the surface, the study of masterplanning issues should not depend on architects appointments to generate indicative housing designs. However many of the internal overheating assessment outcomes will influence the design briefs (which have been written as part of the masterplanning process) and may impact on the form and size of dwellings, which in turn influences the overall masterplan. Therefore some early input from architects is desirable.

4.7.2 Integration into the programme

The assessment of climate change adaptation requires a programme which allows for periods of analysis and review, examining the function and performance of different measures and their viability. This process takes time, especially when examining some of the large infrastructure measures on a masterplan like NWC. This process can only commence once a baseline design or set of assumptions is available, and then when complete, recommendations can be made and fed into the design where relevant.

This process is very different to the masterplanning process described above, where the design progresses in jumps. This means that if the baseline design is needed for the adaptation analysis to commence, then further masterplanning work during the adaptation analysis period may supersede any adaptation work. The end result is that conclusions from the adaptation analysis may be too late to influence the eventual design.

Once again a prime cause of this situation is access to resource. The work on NWC has demonstrated that consultants on the project are often working at the limits of resource availability on the project, driven by client demands and commercial drivers. Whilst funding has been provided by the adaptation study to secure additional input, the existing team often does not have the time resource for the adaptation work until their main design and consultancy duties are complete. By this point, the completion of their main duties may mean that the window of time in which the adaptation work can influence the project has passed.

Based on the experience of NWC, we recommend the following measures:

- Commence analysis as early as possible and if suitable, before the availability of baseline data. We found during the course of this project that whilst baseline design data may assist with the analysis, sensible assumptions can often be developed prior to the finalisation of the baseline, which can later be updated.
- Make use of resources when available. The programming of this project meant that much of the adaptation work was conducted during a busy period of the project. We recommend that future adaptation work is more flexible in the programme, making use of the availability of other consultants when available rather than when ideally timed for the adaptation research. However this may not always be possible due to programme issues as outlined above.

4.7.3 Reporting process

The reporting outline developed by the TSB takes a simplistic view of adaptation by breaking the analysis down into stages and separate measures. When looking at technical details of building design (for example, whether to include brise soleil or not), this may be an appropriate route with distinct and additional items of technology or design features being investigated. However at a masterplan level and with the issues being addressed at this scale, there is a greater degree of integration between the measures. One example is the drainage / management of storm water, and the supply of recycled water. These therefore need to be considered as more of a system, and not separate elements.

On a purely practical basis, assessing adaptation on a systems basis is not directly compatible with the strict reporting format and outputs requested by the TSB for the DFC projects, although we have attempted to do so. However from a research perspective, a systems approach requires a more holistic approach to looking at adaptation measure scenarios rather than individual measures. This is complicated by the baselineing issue (see below) where it is challenging to separate out measures, costs, and benefits.

The concept of base-lining proposals is a challenge, and therefore the calculation of additional costs or mitigated impacts also open to interpretation. Firstly with the research being conducted alongside the design, there is an iterative process going on which means that the baseline proposal is not static but constantly changing. This is good in that the adaptation work is influencing the project, but means that effort may not be spent on drawing an initial arbitrary baseline for the purposes of costing.

Secondly, separating out the mitigation measures from the baseline can also be challenging. In the case of NWC, external overheating analysis has examined the impact that increased green infrastructure and water features may have on external temperatures. The baseline site proposals contained extensive green infrastructure to improve the external environment and provide amenity space. An extensive SUDs system was also proposed to meet planning, Code for Suitable Homes, and BREEAM requirements. Therefore whilst these features also help to mitigate future temperature rises, they perform a number of other functions and provide cost benefits elsewhere. The inclusion of these items in the baseline scheme (albeit without optimisation for climate change mitigation), has also meant that a false baseline needs to be considered where these are not included, to allow assessment of their impact. Whilst this does not necessarily enhance knowledge for NWC, it does help examine their effectiveness as measures for other developments.

4.8 Client decision making processes and how to influence them (f)

The issue of adaptation for NWC has featured since the early scheme proposals. Policy within the NWC Area Action Plan (AAP – specific planning policy developed for the site given its strategic nature) sets requirements for assessing the designs and ensuring that they have been developed considering the need for climate change adaptation.

Alongside the policy drivers for adaptation, the University has set up an internal expert panel (the Sustainability Panel) which is used to review the project proposals. This panel is made up from national and international sustainability experts from within the University academic departments and have set high standards for the development to ensure the result is a global exemplar.

The University of Cambridge has a long history of managing and maintaining large sites around Cambridge and takes a long term view in investment decisions. NWC will be no different and the University is keen to ensure that the design proposals represent a high quality development which will maintain a high quality appearance into the future. One aspect of this is the limiting of modifications and additions which are not 'designed in' such as (for example), the retrofit of air conditioning units on houses. The long term view also means that buildings should function well in line with the sustainability principles into the future providing high quality accommodation with low operation costs.

The combination of these drivers has meant that the NWC client team within the University has been strongly engaged with the sustainability agenda in general, including the issue of climate change adaptation, and the requirement to assess measures and mitigate where viable. However despite the range of drivers pushing the agenda, a rational decision process remains and the following aspects need to be examined to ensure viability:

- Cost effectiveness of proposals. As discussed many elements of adaptation incorporated in NWC perform other functions or are required for other reasons or through policy, and therefore may provide zero additional cost mitigation benefits. However other measures (for example a closed cycle water strategy) will incur cost changes from the baseline scheme which need to be assessed in terms of economic viability.

- Impact on plot disposal. Whilst a large proportion of the site will remain in University ownership and be developed by the University, a number of plots will be sold to commercial developers, helping to finance the University components. Alongside the economic viability of the measures (and there direct impact this may have on the plots), the market attractiveness of the measures also needs to be assessed. For example, a complex natural ventilation system which may provide lifetime cost benefits may not be compatible with developers standard designs and act as a disincentive to developers.
- Occupant comfort. In buildings occupied by the University and employees, good levels of comfort will need to be provided to ensure that the accommodation remains attractive compared with other market accommodation, and rental incomes can be maintained. The university will therefore consider the long term mitigation impact of measures on the development and the role these will play in providing a quality place to live and work.
- The phasing of measures. By definition, most of the adaptation measures examined in this report are at masterplan scale and will need to be incorporated into the design at the masterplan and design stages to ensure they can be included in the final development. However it is likely that many of the measures being examined at a building scale can be retrofitted and whilst they may provide benefits in future climatic conditions, they may not be required in the shorter term. Therefore a strategy may need to be developed with the client to ensure that future retrofit is enabled in the design without being included from day 1.

By including discussion around the adaptation measures from early in the project masterplanning process, combined with the range of drivers for the client, the assessment of adaption has been well integrated into the decision making process.

4.9 Dissemination

The timescales for this analysis and the overall NWC project programme have meant that opportunities for external dissemination have been limited up to now. However, the following have been used for dissemination outside of the project:

- Design for a Future Climate Conference 2010
- Design for a Future Climate Conference 2011
- Design for a Future Climate Conference 2012
- 7th International Conference on Water Sensitive Urban Design, Melbourne Australia (2012). Adapting to Climate Change in the UK: A Water Sensitive Urban Design Approach Applied to NW Cambridge. Ashley Woods, AECOM.

Throughout the project, the close link between the adaptation study team and the masterplanning design team, has meant that results and initial ideas coming from this study have been fed into the design of scheme so far where cost effective measures are available. In particular, this process has been supplemented by two important documents which help drive the development:

- Outline Planning Application. The Sustainability Statement issued as part of the Outline Planning application includes a section on climate change adaptation. This proposes how the design of the site will consider water management, water conservation, and the design of dwellings for future climate conditions to prevent overheating or the need for comfort cooling.

- Development briefs. A number of development briefs have been written which act as an instruction manual to the architects working on each of the individual Lots. The development briefs contain information on a number of sustainability issues, including a section describing the requirements to make the site adaptable to future climates. In particular, these set the standards for dwelling modelling to ensure that the designs will not overheat in future climate conditions.

The timing of the adaptation project has coincided well with the detailed design stage of the scheme. Architects have been appointed during August 2012 and the results of this final report are being fed into the individual lot design teams at Stage B and C, ensuring they can be efficiently incorporated into the designs. This is being conducted through the key members of this adaptation study being involved in the further design and design guidance for the project, including acting in a review role in each of the individual project teams.

5 Extending Adaptation to other buildings

5.1 Applicability of the approach to other projects and limitations (a and b)

5.1.1 Water conservation

The approaches developed for this masterplan project should, in general, be possible to use, as developed here, for other, similar masterplan projects. The advanced water cycle strategy options developed for NWC are based partially around generic risks and barriers, and extensive consultation with the water industry. The main difference for the work progressing so far has not been physical aspects of the site, but the University's enthusiastic approach to be innovative. Therefore the approaches can equally well be applied to other large masterplan projects, and work on leading projects such as NWC could pave the way to wider spread adoption.

Many of the risks and barriers are associated with legislation and the water regulations. There is an appetite from the water companies involved to challenge some of these issues for the NWC scheme, which will reduce the size of these barriers for other projects.

There are inevitably many scheme specific factors which need to be considered, in particular the size of plant and locations for the plant and water storage. It is therefore likely that other schemes will also require sufficient space for hosting these. The water balance will also need to be considered for other projects to refine the options, to ensure that that the site water uses and incoming water from rainfall is correctly understood.

The water strategy scenarios identified are relatively generic, and whilst the costs are directly relevant to NWC, the overall scenarios could be applied to other large masterplans without any major limitations apart from the scheme specific factors identified above. One site specific consideration which may impact the cost benefit one way or the other may be requirement for off-site infrastructure reinforcement. On NWC, there may be a cost benefit from avoided reinforcement, but this could be significantly more on other schemes providing additional benefit, but may not apply at all for other schemes.

5.1.2 Water management

The overall results from the water management analysis are applicable to other similar masterplans. In particular, the results demonstrate that large scale SuDS features such as ponds and large wetland areas can significantly reduce peak run off, followed by the smaller scale swales within streets and green fingers. They also show that where the larger scale features are available, the use of green roofs provides a negligible improvement, with possible detriment for water quality. Whilst the overall conclusions can be applied to other masterplans, the analysis is clearly highly dependent on the local ground conditions, and change of use. Therefore the detailed water calculations will always need to be conducted on a site by site basis to assess the peak run off and likelihood of flooding.

A key limitation for other developments will be land availability and density of development. The requirement for NWC to retain a Green Belt separation, and the noise barrier against the M11 means that large areas of land are available for large SUDs features. The aspirations for the University to provide large amounts of amenity space also provide the intermediate green finger structures space. On denser developments, or where more commercial considerations are made, the scope for including these features may be reduced.

5.1.3 External Temperatures and Overheating

The modelling developed for this project highlights that green infrastructure and façade treatments can have a useful impact on the air temperature and thermal comfort within a site. However, the impact from each method of managing the UHI appears relatively minimal. However, the UHI is influenced by wider thermodynamic systems and when considered on a site by site basis may undervalue their ability in reducing the wider UHI effect. This is because the model assumes a snapshot in time with relatively high baseline temperature on site and air temperature coming in from neighbouring sites. Impacts on the UHI are however, cumulative. On site, shading will reduce heat building up in the first place, so stopping re-radiation at night and therefore delivering a lower starting temperature the next day. Similarly, an incremental build up of green infrastructure on neighbouring sites will reduce the air temperature flowing into the site in the first place and it will remain cooler on site before it moves off. As such, the drivers for considering the benefit of green infrastructure in managing the microclimate might be more apparent at a city scale. Furthermore, drivers for including green infrastructure on site are likely to derive from other socio-economic factors such as amenity and recreation. As such, guidance to coordinate onsite green infrastructure with wider strategic UHI management through planning is more likely to have an impact on air temperature and thermal comfort.

As with the water management measures, a limitation on other sites will be the availability of land for green infrastructure measures. The availability of open space for landscaping, combined with the generous street widths on NWC allows for significant investment in green infrastructure, which, due to the Universities long term involvement, will have a robust management strategy. On other sites, these measures may be excluded on the basis of space, and the options available for future maintenance, in particular where local authority adoption is required.

5.1.4 Internal overheating

The models used for overheating are applicable in general to other domestic building projects. The representation of thermal mass can be improved in these models, and a broad agreement on appropriate over-heating targets would also help make the assessment by different engineers more comparable.

Whilst the dwelling types and designs are likely to vary for other projects, the broad conclusions and principles in relation to thermal mass, ventilation, solar control, and orientation will remain the same for other projects with similar climatic conditions.

The internal overheating analysis can be applied to most other development without any specific limitations.

5.2 Applicability of the recommendations to other projects (c)

The nature of the analysis for this project, and the subsequent outputs are applicable to a wide range of other projects. Some aspects such as the extensive site wide water strategy options are more relevant for larger masterplans, whilst other factors such as the internal overheating analysis can be applied to all forms of housing.

Given the location of NWC, the outputs from this work are potentially directly applicable to similar schemes in the Cambridgeshire area, in particular the Southern Fringe developments in the south of Cambridge incorporating Clay Farm and Trumpington Meadows, although the masterplanning for these sites is complete and construction has commenced on many plots. Another scheme of direct relevance is the Northstowe development to the north west of NWC. Whilst phase 1 has obtained outline planning permission, the design is still to commence, and future phases remain to be masterplanned.

Further, and as introduced briefly in Appendix 5, there are proposals for many new Ecotowns and Major Urban Extensions across the UK including Northstowe in South Cambridgeshire, although it is far from clear how many of these will be built. AECOM is working on some of these, and will be able to carry over thinking to these. It is noted that in general adaptation was not obviously considered as part of the previous studies on Ecotowns.

5.2.1 Water

The recommendations for tools and processes are applicable, but the recommendations themselves are context-dependent and are based on site-specific costs and benefits. However the finding that larger schemes can be more cost effective than interventions in every home is likely to be generally applicable for relatively dense sites. This site as a major new development on a green field site has particular benefits in terms of ease of application of measures, and this should be taken into account when considering the applicability of the findings to other existing sites.

5.2.2 External Temperatures and Overheating

Although the balance of facade treatments and green infrastructure assets might vary depending on specific site opportunities and constraints, they should suitable for consideration on most sites.

5.2.3 Internal overheating

The high level results relating to solar shading, orientation, thermal mass and ventilation are likely to be applicable to similar housing types on other developments with similar climatic conditions. These principles can therefore be applied and be used to identify the key measures. However, it will be important to assess the overheating of the specific designs, especially where certain overheating criteria need to be met as the qualitative results will be scheme specific.

5.3 Resources, tools and materials developed through this project (d)

5.3.1 Water Management

This project developed a methodology to sample and manipulate rainfall data based on UKCP09 predictions allowing future rainfall scenarios to be utilised in hydraulic modelling. This methodology could be repeated in future projects. The methodology is described in Appendix 3.1.

5.3.2 External Temperatures and Overheating

The UHI methodology has been further developed in a number of areas as a result of this study. The approach to estimating surface temperatures of buildings has been refined with temperatures estimated over a 24 hour period and is discussed in more detail in the Solar Radiation section of Appendix 3.3. The approach to modelling cooling from green infrastructure has also been improved with the amount of cooling dependant on local variables rather than averages experienced across the solution domain. This is discussed further in the Cooling from green infrastructure section in Appendix 3.3 The improvements to the methodology will allow more accurate comparisons to be undertaken in future studies.

5.4 Further needs to provide adaptation services (e)

5.4.1 Water management and water efficiency

These studies have shown that consideration of adaptation at an early masterplanning stage both drives the consideration of new options and provides new parameters that test and develop ‘traditional approaches’ to design. In most cases, an adaptation approach reinforces best practices in design and provides the opportunity to create successful places that provide multiple benefits and particularly reinforces the need for better integration of natural processes and green infrastructure to manage resources in a way that mimics nature and is ‘naturally resilient’. By nature, adaptation is not an ‘add-on’ but a key design criteria for a range of design decisions. As such, adaptation should become an integral part of design best practice, but it is recognised that initially there is a need to raise awareness amongst disciplines and demonstrate design solutions, and to this end it may be beneficial to develop adaptation strategies through masterplanning to aid a transition period.

5.4.2 Overheating

These studies have shown that facade treatment and green infrastructure can help manage external thermal comfort, however, there is a growing body of evidence, principally from the USA through iTree and the Sacramento Municipal Utility District's 'tree benefit calculator' of the role that green infrastructure plays in supporting the thermal, and in turn, energy performance of buildings i.e. by reducing solar gain and the impact from winter wind. This integration between internal performance and external environment is an emerging field that requires more exploration.

At present, there is no immediate correlation between external temperatures and internal temperatures which can be made. The external temperature modelling, as demonstrated in this report, shows relatively small shifts in temperature, but the complexity of the case combined with relative simplicity of current models means that the results distribution ranges are likely to be relatively large. There is thus an uncertainty on the external temperature change.

In combination with the above, the internal overheating modelling is based on weather files, which are relatively generic and are not based on a specific location. For example the temperature conditions for the edge of Cambridge may have different temperatures to the centre of Cambridge. This variation may be comparable to, or larger than, the variation in external temperatures under the different adaptation scenarios. Therefore it is not possible to say how changes in external temperatures will impact on the temperature profiles for internal overheating modelling. If a quantitative view is taken, then this may not be critical, and a simple assumption can be made that reductions in external temperatures will help reduce internal temperatures. However it is not possible at this stage to quantify this impact.

5.4.3 The design process

The design process and issues associated with this are identified in section 4.7. The successful provision of adaptation services requires them to be included as a requirement in the design process to ensure that they take sufficient priority, and that all the relevant design team members buy in to the approach. For this to happen, the requirement may come from planning, legislation, or other drivers such as environmental assessment methodologies (which in turn may be driven by planning).

A large number of design elements, in particular the design of mechanical and electrical services, and building structures, make extensive use of design codes and compliance guides. It is therefore important that these codes and guides incorporate adaptation issues and design factors for adaptation to be effectively included in projects. Without this, there is a risk that designs which include adaptation features may be seen as non compliant with codes and guides, or simply not addressed.