Cambridgeshire Flood Risk Management Partnership

Cambridge and Milton Surface Water Management Plan

Detailed Assessment and Options Appraisal Report

Final

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Appendices

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Glossary

ArcView	Software package used for spatial mapping and analysis of data
Annual Exceedance Probability	Annual chance of an event (rain storm) of a given magnitude occurring in any given year e.g. 1% AEP has a 1 in 100 annual chance of occurring in any given year.
Area Action Plan	An optional Development Plan Document forming part of a Local Development Framework. It is aimed at establishing a set of proposals and policies for the development of a specific area, such as an urban extension.
Areas Susceptible to Surface Water Flooding	Environment Agency produced maps showing the outputs of simple surface water flood modelling at a national scale.
Aquifer	Layer of water-bearing permeable rock, sand, or gravel which is capable of providing significant amounts of water.
Awarded Watercourse	Ordinary watercourses that have been awarded to the respective Local Authority by the Enclosure Acts, such that the Local Authority is responsible for the maintenance of the public drain or watercourse.
Catchment Flood Management Plan	Strategic planning tool through which the Environment Agency works with other key decision-makers within a river catchment to identify and agree policies for sustainable flood risk management.
Combined Sewer Overflow	Discharge, during rain storms, of untreated wastewater from a combined sewerage system; diluted sewage is forced to overflow into streams and rivers through CSO outfalls.
Combined Sewer System	Sewer system that carries both sewage and storm water
Community Strategy	Overarching documents, which promote a long term vision for improving the economic, environmental and social wellbeing of an area.
Critical Drainage Area	Defined in the Town and Country Planning act as an area within Flood Zone 1 which has critical drainage problems and which has been notified… [to]…the local planning authority by the Environment Agency
Defacto Defences	Non flood defence infrastructure that can act as flood defence infrastructure e.g. road/rail embankments
DG5 Register	Register of sewer flooding maintained by a sewerage undertaker
Digital Terrain Model	A graphical representation of the Earth's surface with trees, buildings etc removed.
Exception Test	When a development type is not compatible with flood risk in a particular location, the exception test may be applied if there are valid reasons as to why the development should proceed.
Flood and Water Management Act (2010)	Act which aims to improve both flood risk management and the way in which water resources are managed by creating clearer roles and responsibilities and instilling a more risk based approach. It transposes the EC Floods Directive (Directive 2007/60/EC on the assessment and management of flood risks) into domestic law and to implement its requirements. It places duties on the Environment Agency and local authorities to prepare flood risk assessments, flood risk maps and flood risk management plans.
Flood Estimation Handbook	Produced by the Natural Environment Research Council, this provides guidance on rainfall and river flood frequency estimation in the UK.
Flood Maps for Surface Water	An update to the Environment Agency's AStSWF maps, taking account of buildings and the underground drainage system.

Flood Risk Management	Use of a wide range of techniques including hard engineering, development management and education to manage flood risk
Flood Risk Regulations 2009	The Flood Risk Regulations transpose the EU Floods Directive 2007/60/EC into UK law and were introduced on 10 December 2009
Flood Zones	These are a national data set held by the Environment Agency and show the predicted probability of flooding for any given area. They were created following Defra's Making Space for Water pilot study. This was a Government programme that sought to take forward the developing strategy for flood and coastal erosion risk management in England.
Flood Zone 1	Low probability of flooding: Land assessed as having a less than 1-in-1000 year annual probability of river or sea flooding in any given year, as defined fully in PPS25 table D1.
Flood Zone 2	Medium probability of flooding: Land assessed as having between a 1-in-100 and 1-in-1000 year annual probability of river flooding or between a 1-in-200 year and 1-in-1000 year annual probability of sea flooding in any given year, as defined fully in PPS25 table D1.
Flood Zone 3a	High probability of flooding: Land assessed as having a 1-in-100 year or greater annual average probability of river flooding or greater than 1-in-200 year annual average probability of sea flooding, as defined fully in PPS25 table D1.
Flood Zone 3b (Functional Flood Zone)	Land where water has to flow or be stored in times of flood. Local planning authorities have identified areas of functional floodplain, in agreement with the Environment Agency. The identification of functional floodplain takes account of local circumstances and is not defined solely on rigid probability parameters, but land which would flood with an annual probability of 1 in 20 (5%) or greater in any year, or is designed to flood in an extreme (0.1%) flood, provides a starting point to identify the functional floodplain, as defined fully in PPS25 table D1.
Flow to Full Treatment	This is the maximum flow that a Wastewater Treatment Works can effectively treat before excess flows spill to the storm tanks.
Green Roofs	Vegetated roofs, or roofs with vegetated spaces having a wide range of environmental, social and economic benefits.
Greywater	Wastewater generated from domestic activities such as dish washing, laundry and bathing
Habitat Regulations Assessment	Assessment of whether a particular plan or strategy will impact on a European Site. A European Site is any classified SPA, SAC, potential SPA, candidate SAC or listed Ramsar Site.
Hyetograph	A graphical representation of the distribution of rainfall over time
InfoWorks Model	Computer software used to simulate flow through the sewer system in order to identify and solve issues
Integrated Urban Drainage	Philosophy which considers all aspects of urban drainage (surface water, foul water, fluvial flows) in conjunction with one another in order to improve surface water management.
Internal Drainage Boards	Drainage districts have been established in the most drainage sensitive parts of the country; low lying areas constantly at risk from flooding. Drainage boards are responsible for the improvement and maintenance of rivers, drainage channels and pumping stations, as well as consenting, planning advice, adopting SuDS, and emergency response within their Districts.

Lead Local Flood Authority	Lead Local Flood Authorities are unitary authorities or county councils, and were created as part of the Flood and Water Management Act. They are responsible for leading the co-ordination of flood risk management in their areas, but can delegate flood or coastal erosion functions to another risk management authority by agreement.
Local Area Agreements	Local Area Agreements set out the priorities for a local area agreed between central government and a local area (the local authority and Local Strategic Partnership) and other key partners at the local level. LAAs simplify some central funding, help join up public services more effectively and allow greater flexibility for local solutions to local circumstances.
Local Development Framework	A portfolio of Local Development Documents which provides the framework for delivering the spatial planning strategy for the area.
Local development scheme	Plan detailing how all parts of the local development framework will come together; listing the documents to be produced and the timetable for producing them. A local development scheme must be approved by the secretary of state.
Local Plan	Sets out detailed policies and specific proposals for the development and use of land in a district and guides most day-to-day planning decisions. Local development frameworks will gradually replace local plans over the coming years.
Main River	Main Rivers are usually larger streams and rivers, but also include smaller watercourses of strategic drainage importance. A main river is defined as a watercourse shown as such on a main river map, and can include any structure or appliance for controlling or regulating the flow of water in, into or out of a main river. The Environment Agency's powers to carry out flood defence works apply to main rivers only. Main rivers are designated by the Department of Environment, Food and Rural affairs.
Making Space for Water	Government strategy for flood and coastal erosion risk management in England
MapInfo	Software for spatial mapping and data analysis
Multi-Coloured Manual	Common name for the Flood Hazard Research Centre's publication "The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques"
National Flood and Coastal Defence Database	Definitive database for all data on flood and coastal defence assets held by the EA in England and Wales. Use in analysis and decision making on defence investments to help the Government prioritise expenditure for high-risk areas.
Ordinary Watercourses	An ordinary watercourse is every river, stream, ditch, drain, cut, dyke, sluice, sewer (other than a public sewer) and passage through which water flows which does not form part of a Main river as defined by the Environment Agency (EA). These are generally maintained by local authorities and internal drainage boards.
Pitt Review	Report into the summer 2007 flooding. The report examines both how to reduce the risk and impact of floods, and the emergency response to the floods in June and July 2007. The report made 92 recommendations to be addressed by Government.
Planning Policy Statement 25	Sets out Government policy on development and flood risk to ensure that flood risk is taken into account at all stages in the planning process, to avoid inappropriate development in areas at risk of flooding, and to direct development away from areas of highest risk.
Preliminary Flood Risk Assessment	Requirement under the EU Floods Directive / Flood Risk Regulations. The LLFA must complete a preliminary assessment report on past and future flood risk, and identify significant flood risk areas using national datasets.

Ramsar Site	Wetlands of international importance designated under the Ramsar Convention (Convention on Wetlands of International Importance especially as Waterfowl Habitat) of 1971
Revitalised Flood Extent (ReFH)	Runoff model developed to model flood events. Update to existing FEH runoff model.
Regional Flood and Coastal Committee (RFCC)	RFCC's have replaced Regional Flood Defence Committees following the Flood and Water Management Act. They consult with the EA to help develop flood risk management solutions, as well as providing advice on community engagement, coastal erosion, incident management and emergency planning within their regions. They also have responsibility for raising local levies and providing an accountable forum for testing new ideas and ways of working.
River Basin Management Plan	Outline the management of the water environment, provide a framework for more detailed decision making and provide a summary of the programmes of measures required for the River Basin District to achieve Water Framework Directive objectives.
Section 106 Agreement	Section 106 of the Town and Country Planning Act 1990 allows a local planning authority to enter into a legally binding agreement or planning obligation with a landowner in association with the granting of planning permission. These agreements are a way of delivering or addressing matters that are necessary to make a development acceptable in planning terms.
Separate Sewer System	Sewer system where surface water (rainfall) is kept separate from foul flows
Sequential Test	A planning principle that seeks to identify, allocate or develop land in low flood risk zones before land in high flood risk zones.
Source Protection Zone	Zones defined by the EA for 2000 groundwater sources (wells, boreholes and springs used for public drinking water supply) showing the risk of contamination from any activities that might cause pollution in the area.
Stakeholders	Individuals and organizations that are actively involved in a project, or whose interests may be affected as a result of the project's execution
Strategic Flood Risk Assessment	An approach to assessing flood risk which enables Local Planning Authorities to apply the Sequential Test to land allocations
Surface Water Management Plan	Framework through which key local partners with responsibility for surface water and drainage in their area work together to understand the causes of surface water flooding and agree the most cost effective way of managing surface water flood risk
Sustainability Appraisal	Assessment of the environmental, social and economic effects of a plan and appraisal in relation to the aims of sustainable development.
Sustainable Development	Development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs.
Sustainable Drainage Systems	An approach to managing rainwater failing on roofs and other surfaces through a sequence of actions and measures, that manages the flow rate and volume or surface runoff to reduce the risk of flooding and protect and improve water quality.
TUFLOW	TUFLOW is one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software. It simulates the complex hydrodynamics of floods and tides using the full 1D St Venant equations and the full 2D free-surface shallow water equations.
UK Climate Impacts Programme	UKCIP publishes climate change scenarios on behalf of the Government showing how the UK's climate might change in this century. The UKCIP02 climate change scenarios are widely used in research into the impacts of climate change
Unitary Authority	A single tier local authority responsible for all local government functions within its area.

Urban Extension	Planned expansion of a city or town
Water Cycle	The continuous movement of water on, above, and below the surface of the Earth. The urban water cycle is the movement of water through the urban environment, through pipes, rivers
Water Cycle Strategy	Plan for new development in a holistic manner to ensure the sustainable and timely provision of necessary water services infrastructure
Water Framework Directive	EC water legislation designed to improve and integrate the way water bodies are managed throughout Europe It came into force on 22 December 2000. Member States must aim to reach good chemical and ecological status in inland and coastal waters by 2015.
Zero Carbon Development	A development that achieves zero net carbon emissions from energy use on site, on an annual basis.

AA	Appropriate Assessment
AAP	Area Action Plan
ABI	Association of British Insurers
AEP	Annual Exceedance Probability
AStSWF	Areas Susceptible to Surface Water Flooding
AWS	Anglian Water Services Ltd
BGS	British Geological Society
CCC	Cambridgeshire County Council
CFMP	Catchment Flood Management Plan
CFRMP	Cambridgeshire Flood Risk Management Partnership
CIRIA	Construction Industry Research and Information Association
CLG	Communities and Local Government
CSO	Combined Sewer Overflow
CWS	County Wildlife Site
DAP	Drainage Area Plan
DDF	Depth Duration Frequency
DEFRA	Department for Environment, Food and Rural Affairs
DPD	Development Plan Document
DTM	Digital Terrain Model
EA	Environment Agency
EVY	Edenvale Young Associates Ltd
FEH	Flood Estimation Handbook
FMfSW	Flood Maps for Surface Water
FRA	Flood Risk Assessment
FRM	Flood Risk Management
FRR	Flood Risk Regulations
GIS	Geographical Information Systems
HCL	Hyder Consulting (UK) Limited
HRA	Habitat Regulations Assessment
IDB	Internal Drainage Board
IUD	Integrated Urban Drainage
LDD	Local Development Documents
LDF	Local Development Framework
LiDAR	Light Detecting and Radar
LPA	Local Planning Authority
MCM	Multi-Coloured Manual

NFCDD	National Flood Coastal Defence Database
NNP	Natural Networks Partnership
NNR	National Nature Reserve
PE	Population Equivalent
PPS25	Planning Policy Statement 25: Development and Flood Risk
RBD	River Basin District
RBMP	River Basin Management Plan
ReFH	Revitalised Flood Hydrograph
SAC	Special Area of Conservation
SFRA	Strategic Flood Risk Assessment
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SPG	Supplementary Planning Guidance
SPS	Sewage Pumping Station
SPZ	Source Protection Zone
SuDS	Sustainable Drainage Systems
SWMP	Surface Water Management Plan
UKCIP	UK Climate Impacts Programme
WCS	Water Cycle Strategy
WFD	Water Framework Directive
WTW	Water Treatment Works
WwTW	Wastewater Treatment Works

1 Introduction

1.1 Terms of Reference

Cambridge City Council obtained a grant from Defra to undertake a Surface Water Management Plan for Cambridge and Milton. At the same time Cambridgeshire County Council was planning a Surface Water Management Plan for the whole county, initially starting with a Countywide Strategic Assessment. A partnership approach was considered the most effective way of bringing these potentially disparate studies into a cohesive piece of work. The Cambridgeshire Flood Risk Management Partnership (CFRMP) was used as the delivery body of these studies. A joint procurement exercise was undertaken to ensure best value for the Local Authorities.

Hyder Consulting (UK) Limited (HCL) was appointed to produce the Surface Water Management Plan (SWMP) for the entire county, which is to be completed by April 2015. The first phase of work was the Countywide Strategic Assessment report and was completed in April 2011. Hyder were also appointed to undertake the detailed surface water management assessment of Cambridge and Milton. This SWMP is formed from the outputs of all the stages of the study, from a strategic assessment of the overall study area through to optioneering of the prioritised wetspots. The options assessed at this stage provide a theoretical assessment of how best to mitigate against flood risk in the wetspot. This provides an analysis of where investment could be directed in the future if finance is available.

As part of the same commission, a Preliminary Flood Risk Assessment (PFRA) was also required to be produced by March 2011 on behalf of CCC to satisfy the requirements of Flood Risk Regulations 2009.In addition, a detailed assessment of the Cambridge and Milton area was required, as identified and funded by Defra and in conjunction with Cambridge City Council. This report forms the outputs from the all stages of the study from a strategic assessment of the overall study area through to optioneering of the prioritised wetspots.

The Cambridge and Milton Detailed SWMP was completed in April 2011, and the findings are detailed in this report. It is recommended that this report be read alongside the Countywide Strategic Assessment report mentioned above.

The Cambridge and Milton study area was defined by Defra as a settlement at high risk of surface water flooding, and hence was subject to this detailed SWMP assessment. There are 53,518 domestic properties in the study area (based on the Environment Agency's National Receptor Database). The following table details the numbers of domestic properties predicted to be at risk of surface water flooding in the study area.

Data Source	Extent	No. of Properties Predicted to be Affected
Areas Susceptible to Surface Water Flooding	More	43
	Intermediate	2,763
	Less	7,523
Flood Maps for Surface Water	Deep	611
	Shallow	4,432
SWMP Modelling	Flood Depth over 0.3m	1,607
	Flood Depth 0.1 – 0.3m	9,454

Table 1.1 Properties Predicted to be at risk of Surface Water Flooding

As part of the same commission, a Preliminary Flood Risk Assessment (PFRA) is also required to be produced by March 2011 on behalf of CCC to satisfy the requirements of Flood Risk Regulations 2009.

1.2 Surface Water Management Plans

The wide scale flooding experienced during 2007 precipitated the publication of the Pitt Review[1] which contained a large number of recommendations for Government to consider. The key recommendation in the Pitt Review with respect to surface water management is Recommendation 18, reproduced below, which in turn refers to Planning Policy Statement 25 Development and Flood Risk (PPS25)[2].

> *Recommendation 18: "Local Surface Water Management Plans, as set out in PPS25 and coordinated by local authorities, should provide the basis for managing all local flood risk."*
>
> *Surface Water Management Plans (SWMPs) are referred to in Planning Policy Statement 25 (PPS25) as a tool to manage surface water flood risk on a local basis by improving and optimising coordination between relevant stakeholders. SWMPs will build on Strategic Flood Risk Assessments (SFRAs) and provide the vehicle for local organisations to develop a shared understanding of local flood risk, including setting out priorities for action, maintenance needs and links into local development frameworks and emergency plans.*

Guidance on the production of SWMPs was published in March 2010[3] informed by the Integrated Urban Drainage (IUD) Pilot Studies carried out under the Government's Making Space for Water (MSfW)[4] strategy.

A SWMP outlines the preferred strategy for the management of surface water in a given location and the associated study is carried out in consultation with local partners having responsibility for surface water management and drainage in that area. The goal of a SWMP is to establish a long term action plan and to influence future strategy development for maintenance, investment, planning and engagement.

The framework for undertaking a SWMP is illustrated using a wheel diagram, reproduced from the Defra Guidance[3] as shown in Figure 1-1.

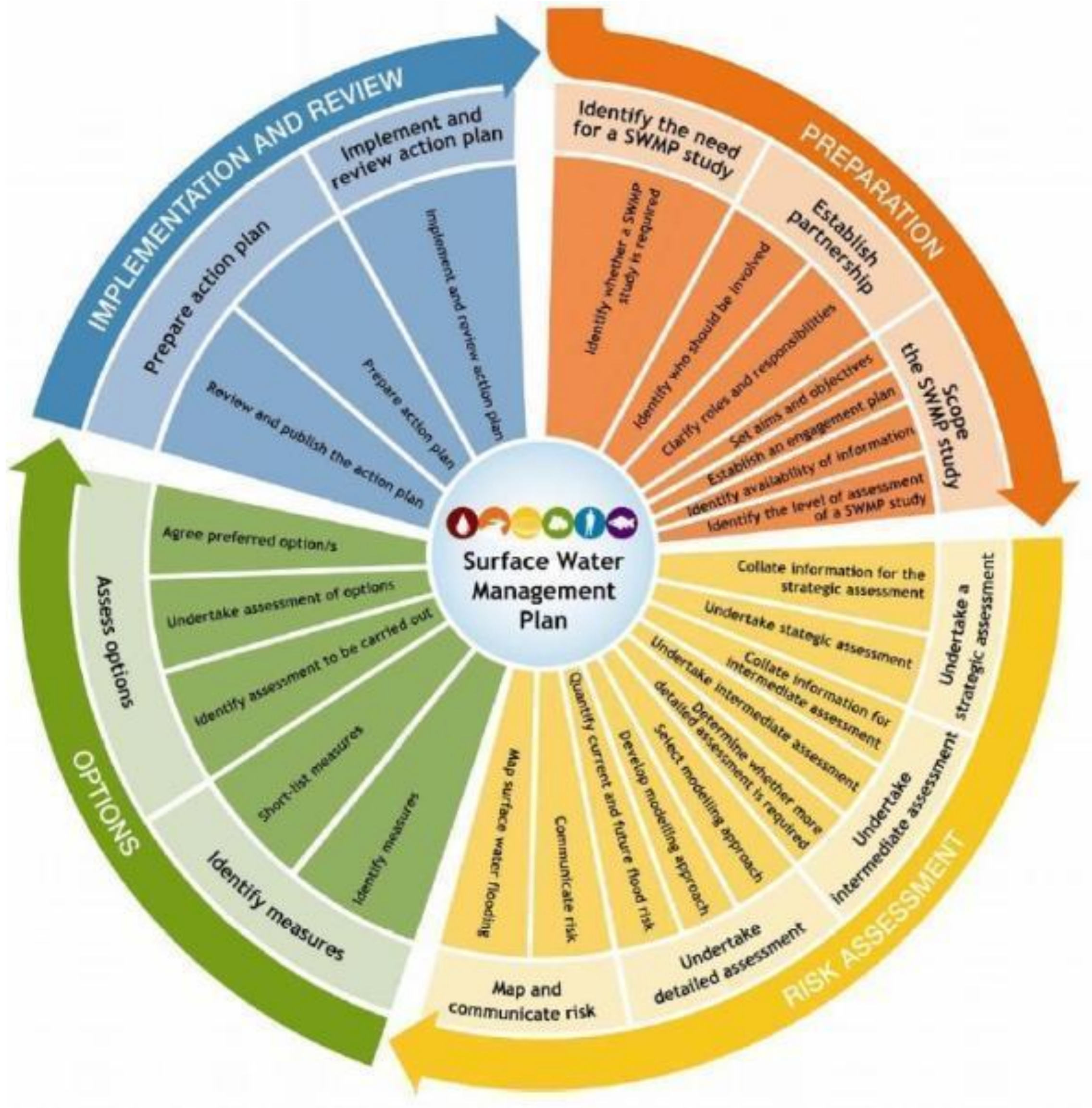


Figure 1-1 SWMP Wheel (source Defra Guidance[3])

The SWMP process is formed of four principal phases;

- preparation,
- risk assessment,
- options, and
- implementation and review.

This report contains the findings from the preparation stage and the strategic and intermediation elements of the risk assessment phase. Text boxes at the start of each chapter summarise the elements of the guidance addressed within the subsequent text.

1.3 Surface Water Flooding

In the context of SWMPs, the technical guidance[3] defines surface water flooding as:

- Surface water runoff; runoff as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity, thus causing flooding (known as pluvial flooding);
- Flooding from groundwater where groundwater is defined as all water which is below the surface of the ground and in direct contact with the ground or subsoil;
- Sewer flooding; flooding which occurs when the capacity of underground systems is exceeded due to heavy rainfall, resulting in flooding inside and outside of buildings. Note that the normal discharge of sewers and drains through outfalls may be impeded by high water levels in receiving waters as a result of wet weather or tidal conditions;
- Flooding from any watercourse not designated a “Main River”, including culverted watercourses which receive most of their flow from inside an urban area and perform an urban drainage function;
- Overland flows from the urban/rural fringe entering the built-up area; and
- Overland flows resulting from groundwater sources.

This report aims to consider surface water flooding issues in Cambridge & Milton as above but it does not address sewer flooding where it is occurring as a result of operational issues, i.e. blockages and equipment failure. It should also be noted that the compilation of all historical flooding within the county area does include some flooding due to main rivers, although further investigation of these occurrences is outside the remit of this report.

Information on Main River Flooding is covered under other strategic planning documents such as Strategic Flood Risk Assessments, produced by district councils.

1.4 Policy Framework

1.4.1 Flood Risk Regulations 2009

The Flood Risk Regulations 2009 (FRR) transpose the European Floods Directive 2007/60/EC into English and Welsh law and bring together key partners to manage flood risk from all sources and in doing so reduced the consequences of flooding on key receptors. Local authorities are assigned responsibility for management of surface water flooding.

As part of the ongoing cycle of assessments, mapping and planning, the FRR requires the undertaking of a PFRA. National guidance was published by the Environment Agency (EA) in December 20105. The requirements of the FRR have also been used to shape this report and to inform the content of the Council’s PFRA report to the Government produced by HCL. Where links between the SWMP and the requirements for a PFRA can be made, these are highlighted in the text boxes at the beginning of the relevant report section for ease of transfer in the future. However, this report does not form a PFRA report in its own right.

1.4.2 Flood and Water Management Act 2010

The Flood and Water Management Act places the responsibility for managing the risk of local floods on the Upper Tier or unitary authorities, as their role as Lead Local Flood Authorities (LLFAs), but allows for the delegation of flood risk management functions to other statutory authorities. The Act also seeks to encourage the uptake of Sustainable Drainage Systems (SuDS) by agreeing new approaches to the management of drainage systems and allowing, where delegated, for district councils and Internal Drainage Boards (IDBs) to adopt SuDS for new developments and redevelopments.

1.4.3 Planning Policy Statement 25

Planning Policy Statement 25 (PPS25) requires that new development should not increase flood risk, and requires developers to design, build and fund the maintenance of SuDS; a SWMP will support this by informing the Local Planning Authority (LPA) of areas at risk of surface water flooding 'and by providing an evidence base to aid the consideration of future development options.

1.5 Sustainable Drainage Systems (SuDS)

Sustainable drainage systems are used to manage rainfall run-off from impermeable surfaces. SuDS encompass a range of techniques which aim to mimic the natural processes of runoff and infiltration as closely as possible. These techniques can include green roofs, ponds, permeable paving and soakaways. Any SuDS scheme should integrate with existing drainage systems and be easily maintainable.

SuDS schemes should be based on a hierarchy of methods termed the 'SuDS treatment train' as illustrated in Figure 1-2.

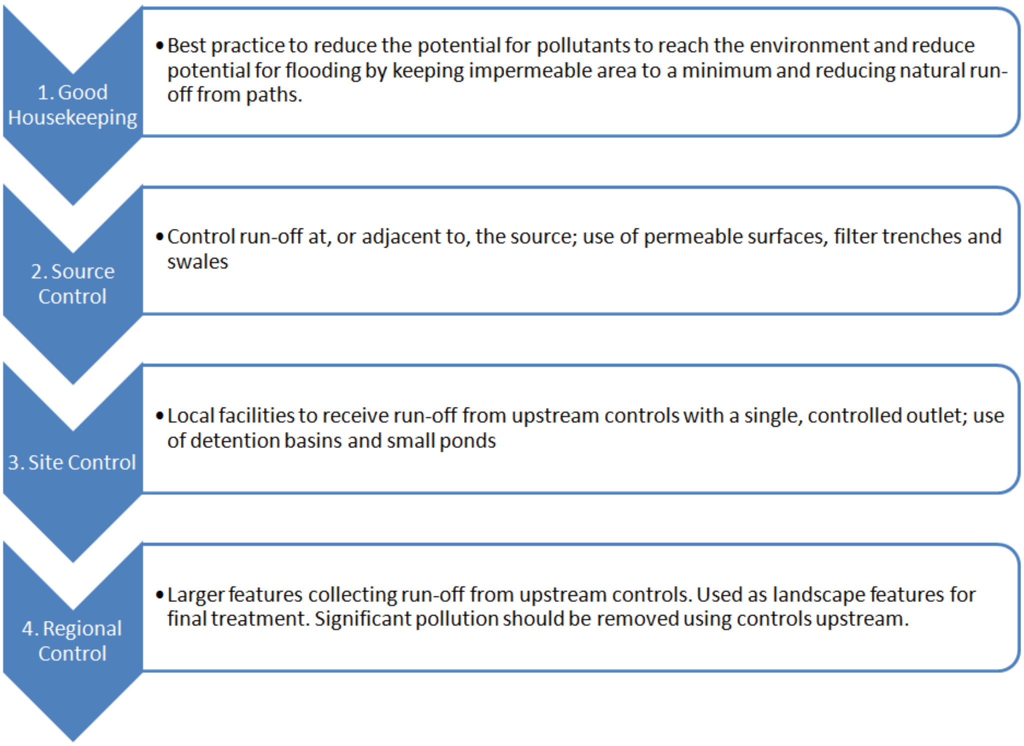


Figure 1-2 SuDS Treatment Train

Guidance recommends that the management of surface water runoff should use a combination of site specific and strategic SuDS measures, encouraging source control where possible to reduce flood risk and improve water quality. Table 1-1 describes some of the SuDS techniques that will be considered in the development of the Cambridge and Milton SWMP.

Type	Description
Balancing Pond	A pond designed to attenuate flows by storing runoff during the peak flow and releasing it at a controlled rate during and after the peak flow has passed. The pond always contains water. Also known as wet detention pond.
Brown Roof	A roof covered with a locally sourced material, its main aim is to partly mitigate any loss of habitat when new developments are constructed.
Detention Basin	A vegetated depression, normally dry except after storm events constructed to store water temporarily to attenuate flows. May allow infiltration of water to the ground
Filter Strip	A vegetated area of gently sloping ground designed to drain water evenly off impermeable areas and filter out silt and other particulates.
Green Roof	A roof with plants growing on its surface, which contributes to local biodiversity. The vegetated surface provides a degree of retention, attenuation and treatment of rainwater, and promotes evapotranspiration. Sometimes referred to as a “living” roof.
Infiltration Basin	A dry basin designed to promote infiltration of surface water to the ground.
Road Side Rain Gardens	Where space allows, these can be constructed alongside roads to allow run-off from roads or pavements to filter slowly through the root system of plants, rather than entering underground drainage systems.
Permeable Surface	A surface formed of material that is itself impervious to water but, by virtue of voids formed through the surface, allows infiltration of water to the sub-base through the pattern of voids, e.g. concrete block paving.
Rainwater Harvesting	A system that collects rainwater from where it falls rather than allowing it to drain away. It includes water that is collected within the boundaries of a property, from roofs and surrounding surfaces. The harvested water is then re-used in applications where potable water is not essential.
Swale	A shallow vegetated channel designed to conduct and retain water, but may also permit infiltration; the vegetation filters particulate matter.

Table 1-1 SuDS Techniques (source Ciria[6])

SuDS techniques can be divided into two main groups; infiltration based or attenuation based. Infiltration based SuDS facilitate the discharge of water directly into the ground through soil and rocks; this is only possible where the underlying geology is permeable enough to allow the passage of water downwards. Attenuation based SuDS retain water on a site and allow it to discharge at a prescribed and controlled rate into a watercourse or sewer.

The feasibility for the use of any SuDS technique should be investigated prior to their installation.

2 Scope of the Cambridge and Milton SWMP

Flood Risk Regulations 2009
Define the aims, objectives and purpose of the report
Describe the overall approach and methodology applied

2.1 Aims and Objectives

2.1.1 Study

The final aim of the SWMP study is to produce a long term surface water management Action Plan for Cambridge and Milton, once in place this Action Plan will be reviewed every 6 years at a minimum.

The objectives of this study are to:

- Map historical flood incident data
- Engage with partners and stakeholders
- Map surface water influenced flooding locations
- Identify surface water flooding wetspot areas
- Assess, compare and prioritise wetspot areas for detailed assessment
- Identify measures, assess options and confirm preferred options for the prioritised 'wetspots'
- Make recommendations for next steps

A wetspot is defined as being an area susceptible to Surface Water flooding following analysis of Modelled Surface Water outputs or historical records.

These objectives will be met following the progression of a number of project stages. The first stage is data collection, involving contact with the varying partner organisations to obtain all relevant information. During this stage the collation of historical and future flooding along with information on flood receptors and flood consequences will take place.

Once the data collection stage is complete, the surface water flooding information will be analysed to identify wetspots that have a history of flooding incidents or potentially could be at risk of future flooding. Those wetspots identified as being at higher risk or priority through agreed local assessment criteria will then progress forward to the next stages, detailed assessment and optioneering.

Following the optioneering stage, recommendations for flood alleviation or mitigation will be considered.

2.1.2 Partnership Working

The Cambridgeshire Flood Risk Management Partnership comprises all the flood risk authorities in Cambridgeshire, including Cambridgeshire County Council, Cambridge City Council, South Cambridgeshire District Council, the Environment Agency and Anglian Water. A SWMP Project Management Board was formed as a sub group of CRMP to steer the production of SWMPs, and they are discussed in more detail in Section 3.1.

The CFRMP has developed a Stakeholder Engagement Plan, which will aid in communicating the work of the partnership to the key stakeholders, and is discussed in further detail in Section 2.4. It is of great importance that collaborative working of this nature is undertaken in order to share experience and expertise.

2.2 Geographic Extent

Flood Risk Regulations 2009
Define the geographic extent of the report and relate to the relevant river basin district and relevant maps

This SWMP has been undertaken for the Cambridge and Milton study area as shown in Figure 2-1. The study area is equal to the Cambridge and Milton settlement defined by Defra for the Early Action Grant.

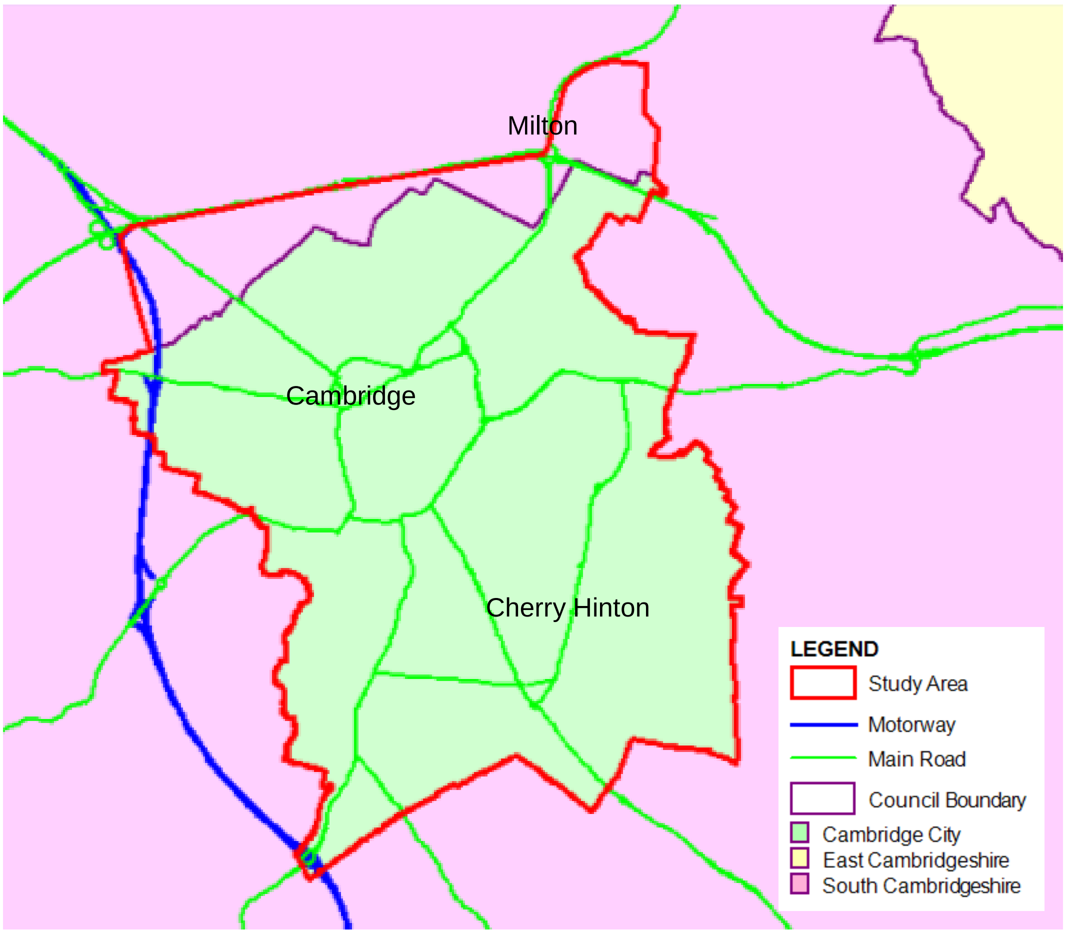


Figure 2-1 Cambridge and Milton SWMP Study Area

The Cambridge and Milton study area is located within the Anglian River Basin District and the River Great Ouse catchment. It incorporates all of the Cambridge City Council area and a small portion of South Cambridgeshire District in the north, where Milton village is located.

2.3 Methodology

The methodology used to carry out this SWMP follows the advice set out in the Defra SWMP guidance3 for the preparation stage and the strategic risk assessment phase. Figure 2-2 illustrates the process carried out to inform this detailed assessment and options appraisal report, a key output of Cambridge and Milton SWMP. It should be noted that this figure only shows the steps subsequent to the formal identification of the Cambridge and Milton settlement as a priority wetspot by Defra.

Further details on the methodology are discussed throughout the report in the relevant sections. The work undertaken for the study is also informed by the EA's PFRA guidance[5] in order to assist in meeting the obligations of CCC as the Lead Local Flood Authority (LLFA). Information on the methodology for subsequent phases of the SWMP is set out in Section 14 of this report.

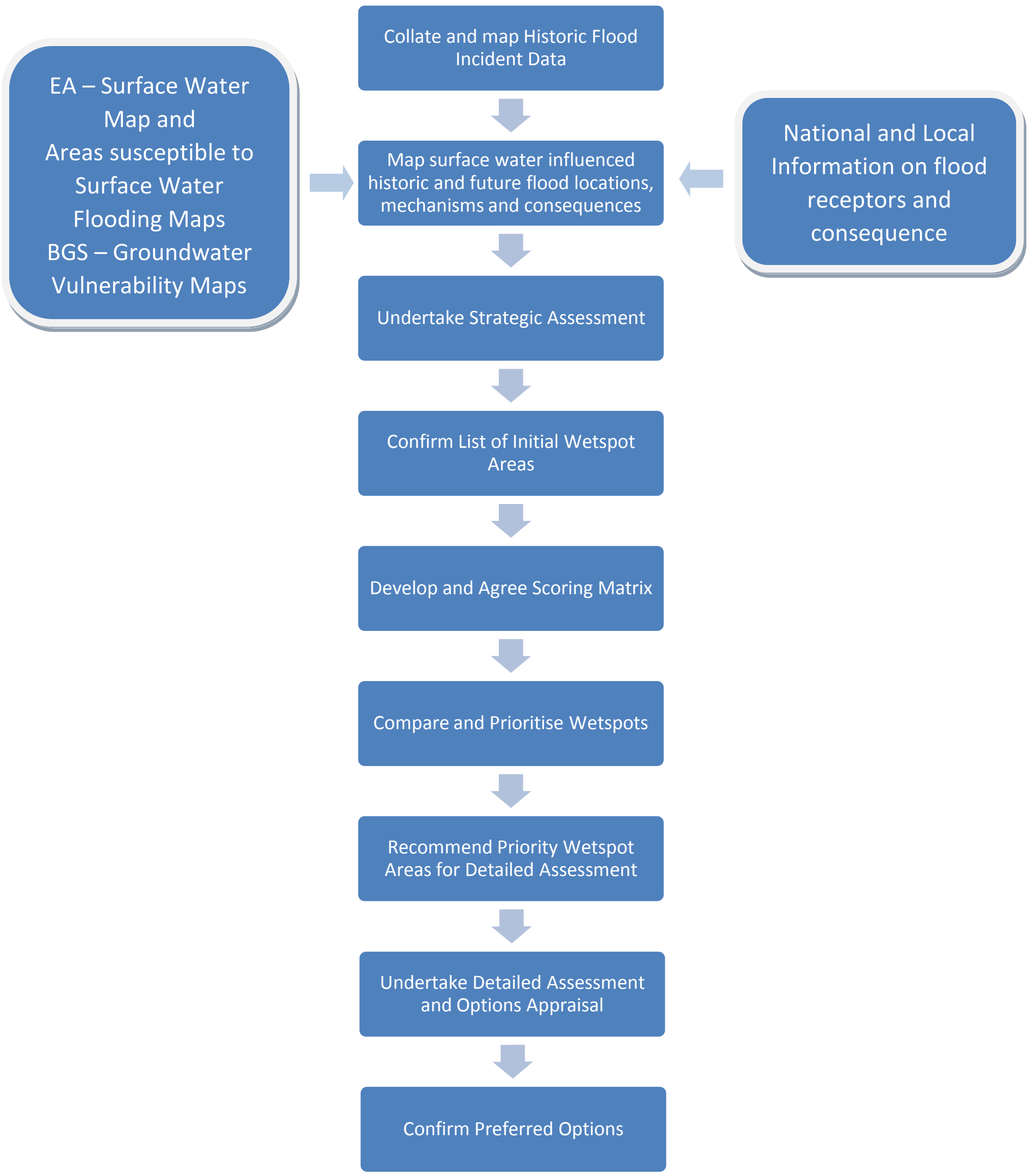


Figure 2-2 Overall Approach to Study Methodology

The specific methodology adapted for the Cambridge and Milton study is further explained in Sections 7 to 13.

2.4 Stakeholder Engagement Plan

> **Flood Risk Regulations 2009**
> Define relevant authorities and partner organisations involved in the assessment of local flood risk.
> Summarise means of stakeholder engagement and composition of local fora and liaison groups

A Stakeholder Engagement Plan[7] has been previously developed by the CFRMP. The purpose of the engagement plan is to improve how the partnership consults and involves citizens and other stakeholders in decision making, and to ensure that their views are used to develop targeted and appropriate flood risk strategies within Cambridgeshire. The strategy sets out clear objectives and principles, along with proposed methods of communication to engage the varying stakeholders.

The objectives and principles of the CFRMP engagement strategy are tabulated below.

	Objective / Principle
Objectives	Raise awareness and provide an understanding about the CFRMP programme of work and its objectives for all key stakeholder groups
	Ensure that the key stakeholders are aware of who they should contact for different flood risk management activities and how
	Provide all key stakeholder groups with an update on the progress of the programme of work, the programme governance arrangements, who the key project representatives are in each area
	Identify the most appropriate communication methods for communicating with each stakeholder group
	Providing keys stakeholders with a mechanism to feedback to the Programme and Project Managers in relation to the work of the partnership
	Ensure communication identifies clear links with other inter-dependent projects/areas of work to avoid confusing and conflicting messages to key stakeholder groups
	Effectively monitor communication activities and use this to influence future planning, messages and communication activities throughout the programme
Principles	Tell stakeholders what they can expect from the work of the Partnership
	Provide clear, accurate and easy to understand information – using plain English and offering a range of formats
	Make sure the communications and messages are consistent with one another
	Get the right balance in relation to the amount and level of communications with each of the stakeholder groups

Table 2.1 Objectives / Principles of the CFRMP Engagement Strategy

During the progression of the SWMP, HCL has contributed to the SEP through various media: meetings and workshops have been held throughout the study, providing an opportunity for all stakeholders to present their opinions on the development of the SWMP.

A Web-GIS portal has been developed allowing the clear visualisation and communication of the outputs of the SWMP; and draft output consultations have been undertaken to explain and discuss the study's findings. The Web-GIS portal is discussed further in Section 5.3.

Cambridgeshire County Council have recently completed the "Flood Memories Project", which invited members of the public to share their flooding experiences, either via a paper or online questionnaire, and via five road shows across the county. Over 250 responses were received and these have been included within this SWMP's Flood Incident Register.

3 Partnership Establishment

The formation of partnerships has an important role in the undertaking of a SWMP, and is required under Defra's SWMP guidance documentation. The SWMP guidance details the identification of those partners / organisations that should be involved and what their roles and responsibilities should be.

It recommends the formation of an engagement plan, which should include objectives for the individual partners, and detail how and at what stages of the SWMP the engagement with stakeholders should take place.

The following sections describe the partners, their roles and responsibilities and their objectives as required by the SWMP guidance.

3.1 Members

Table 3.1 details all those partners or stakeholders who have an interest in flooding within the county area. More details of the CFRMP, SWMP Project Management Board and additional stakeholders are included in the following sections.

Organisation	CFRMP	SWMP Project Board	SWMP Additional Stakeholders
Cambridgeshire County Council	✓	✓	
Cambridge City Council	✓	✓	
East Cambridgeshire District Council	✓	✓	
Fenland District Council	✓	✓	
Huntingdonshire District Council	✓	✓	
South Cambridgeshire District Council	✓	✓	
Cambridgeshire Horizons	✓	✓	
Anglian Water Services	✓	✓	
Environment Agency	✓	✓	
Cambridgeshire County Council Highways Authority	✓	✓	
Middle Level Commissioners and associated IDBs	✓	✓	
Ely Group of Drainage Boards	✓	✓	
Bedford Group of Drainage Boards	✓	✓	
North Level Internal Drainage Board	✓	✓	
Non-Associated Drainage Boards			✓
Natural England	✓		✓
Wildlife Trusts	✓		✓
Town and Parish Councils			✓

Organisation	CFRMP	SWMP Project Board	SWMP Additional Stakeholders
Neighbouring Authorities			✓
Cambridgeshire & Peterborough Local Resilience Forum			✓
Highways Agency			✓
Emergency Services			✓
Elected Members			✓
Landowners / Developers			✓
Utility Companies			✓
General Public			✓

Table 3-1 Organisations Involved

3.1.1 Cambridgeshire Flood Risk Management Partnership (CFRMP)

Anticipating the Floods and Water Act and noting the Government's response to the Pitt review recommendations, Cambridgeshire County Council formed the 'Cambridgeshire's Flood Risk Management Partnership' (CFRMP) in June 2009.

The role of the partnership, made up of the City and District Councils, Environment Agency, Cambridgeshire Horizons, Anglian Water Services and the county's Internal Drainage Boards is to provide a coordinated approach to flood risk management across the County. The partnership will provide a strategic overview to the delivery of actions related to the relevant Pitt Review recommendations, the Flood and Water Management Act (2010) and the Flood Risk Regulations (2009). The partnership will enable Cambridgeshire County Council to fulfil its role as 'Lead Local Flood Authority' (LLFA) in coordinating local flood risk management activities.

3.1.2 SWMP Project Management Board

The SWMP Project Management Board sits within the CFRMP and is responsible for overseeing the production of the SWMP, one of five current projects being overseen by the CFRMP. The Defra guidance defines SWMP partners as those with responsibility for decision or actions regarding surface water management.

3.1.3 Stakeholders

Stakeholders are defined as those affected by, or interested in a problem or solution relating to surface water management.

In addition to those listed in Table 3.1 above, it is possible that, as the SWMP progresses, other stakeholders will be identified and become involved; these organisations will be highlighted in future reports and outputs as required.

3.2 Data Sharing and Licensing

A number of specific agreements have been put in place for the SWMP to facilitate the sharing of data between partners:

- AWS confidentiality agreement setting out the terms under which their data can be used
- GIS licences for mapping and data supplied by CCC and Cambridge City Council
- British Geological Society (BGS) licence for geological data supplied by BGS
- Environment Agency standard data licence
- Environment Agency surface water susceptibility maps licence
- Environment Agency LiDAR licence

4 Need for a Cambridge and Milton SWMP

4.1 Defra Application

Cambridge City Council applied for Defra funding in 2010 under "Early Action Funds" which then identified the need for Cambridge and Milton detailed SWMP.

Defra had previously divided England into 4350 settlements, with Cambridge and Milton considered one settlement. These settlements were then ranked with regard to their possible susceptibility to surface water flooding. Cambridge was ranked 87 out of the 4350 settlements and this indicates that Cambridge may be at a high risk area with regard to surface water flooding.

4.2 Previous Studies

As part of this study, it has been critical to identify the links to other local and regional delivery plans which may influence or be influenced by the SWMP. The SWMP will seek to integrate and align these plans and processes to provide a clear and robust path to delivering flood risk management objectives throughout Cambridge. These studies listed below have already been completed, however the information from the SWMP and future Local Flood Risk Management Strategy can be used to inform any updates to these studies.

4.2.1 Great Ouse CFMP[8]

The Great Ouse Catchment Flood Management Plan (CFMP) was published by the Environment Agency (EA) in July 2010. The catchment covers approximately 8,600 km^2, and is predominantly rural, with the larger population centres of Milton Keynes, Cambridge, Bedford and King's Lynn.

For Cambridge and Milton, the main sources of flood risk were identified as:

- river flooding from the River Cam;
- surface water flooding in Cambridge

A number of flood risk management policy options were identified across the whole catchment, and the policy option covering Cambridge was Policy Option 5 - Areas of moderate to high flood risk where we can generally take further action to reduce flood risk.

4.2.2 South Cambridgeshire and Cambridge City Level 1 SFRA[9]

A Level 1 SFRA covering the Cambridge City and South Cambridgeshire District areas was completed by WSP in September 2010. The main aim of the study was to identify flood risk constraints to development to aid the preparation of the Councils' Local Development Frameworks. The SFRA also includes a toolkit to aid developers in producing site specific Flood Risk Assessments and highlights the importance of using SuDS.

4.2.3 Cambridge Water Cycle Strategy[10]

A Phase 1 Water Cycle Strategy (WCS) for the Major Growth Areas in and around Cambridge was completed in October 2008. This was commissioned by Cambridgeshire Horizons, who brought together a stakeholder steering group including representatives of the local authorities, the EA, water companies, Natural England and other relevant stakeholders. The Phase 1 WCS identified no insurmountable technical constraints to the proposed level of growth for the study area.

A Phase 2 WCS has since been commissioned and will be finalised in 2011. This goes further than the Phase 1 by providing evidence in support of a more aspirational vision for water management. It aims to aspire to water neutrality, improve biodiversity by protecting environmental water quality, and protecting and enhancing the environment through sustainable surface water management.

4.2.4 Clay Farm Groundwater Assessment[11]

Groundwater investigations in South Cambridge were undertaken to the east of Trumpington by AECOM on behalf of Countryside Properties Limited as part of proposed development plans in the area. The report states that "A review of several groundwater hydrographs has confirmed that the groundwater regime is subject to seasonal changes, which affect the groundwater level. However, the principal direction of groundwater flow beneath the site east of Hobsons Brook is relatively consistent and trends towards the west, thus providing intermittent baseflow to the (Hobsons) Brook."

4.2.5 Cambridge Drainage Area Plan[12]

A drainage area plan was undertaken by Atkins in 2004 on behalf of Anglian Water. The main drivers for the DAP were to assess the impact of continuous rainfall on the ability of the foul and surface water systems and wastewater treatment works to handle with increased volumes of water and to see whether this increased flooding susceptibility of properties in the city. The DAP noted that "The Cambridge sewerage system consists of approximately 30% combined and 70% separate system with foul/combined flows discharging to the Cambridge Sewage Treatment Works in the north-east of the catchment. The separate surface water system ultimately drains to the River Cam via numerous tributaries and minor brooks. The combined system sub catchments are clustered in Cottenham and Histon located in the north of Cambridge and Shelford in the south of Cambridge".

In addition to this, as part of the DAP an impermeable area survey (IAS) was undertaken on approximately 30% of the total DAP catchment of Cambridge.

4.3 Drivers for Change

The CFRMP are undertaking this SWMP in order to:

- Better understand the risks and consequences of surface water flooding in Cambridgeshire, including this Cambridge and Milton study;
- To meet or significantly assist in meeting some of the requirements on CCC as Lead Local Flood Authority under the Flood Risk Regulations 2009;
- To meet a number of the requirements of the Flood and Water Management Act specifically in terms of developing an asset register and producing a local flood risk management strategy.

At this point it is worth noting that the developed area of Cambridge has effectively doubled in the past 60 years and as such has had significant impacts on the natural environment, as greener rural areas have been replaced in part by housing, commercial and industrial developments, roads and other forms of community infrastructure.

This is clearly evident in the replacement of natural watercourse systems with concrete drains and channels and the introduction of urban-borne pollutants and sediments to the natural water ecosystems.

The SWMP process allows the opportunity to enhance the condition of these urbanised catchments helping to improve the water quality. Additionally, the implementation of the SWMP and Action Plan can help to provide significant economic and environmental benefits to the community through better preparation against these potential extreme rainfall events, which to a large extent has not occurred since this development has occurred. This key risk in these areas is that such events could be catastrophic in nature across large parts of the County.

4.4 Context

Alongside the legislative requirements discussed above in Section 4.3, and following on from the context described in Section 2.1, this SWMP will support the following initiatives.

4.4.1 Local Flood Risk Management Strategies

Local Flood Risk Management Strategies[13] came into force as part of the Flood and Water Management Act 2010. As LLFA, CCC must develop a strategy for local flood risk management. The strategy must be consistent with the National Flood and Coastal Erosion Risk Management Strategy for England, the regional CFMPs and River Basin Plans, and should be developed and maintained with consultation from other stakeholders, such as the public and other risk management authorities.

The strategy must specify:

- the risk management authorities in the authority's area,
- the flood and coastal erosion risk management functions that may be exercised by those authorities in relation to the area,
- the objectives for managing local flood risk (including any objectives included in the authority's flood risk management plan prepared in accordance with the Flood Risk Regulations 2009),
- the measures proposed to achieve those objectives,
- how and when the measures are expected to be implemented,
- the costs and benefits of those measures, and how they are to be paid for,
- the assessment of local flood risk for the purpose of the strategy,
- how and when the strategy is to be reviewed, and
- how the strategy contributes to the achievement of wider environmental objectives.

4.4.2 Catchment Flood Management Plan (CFMP)

The Cambridge and Milton study area falls within the area covered by the Great Ouse CFMP, as previously discussed in Section 4.1. The Action Plan associated with the Great Ouse CFMP, in conjunction with district wide SFRA’s and this SWMP, will assist in informing the Local Development Framework process and future flood risk management.

5 Data Collection and Collation

5.1 Data Collected for the Study

A full catalogue of data used for the study is contained within Appendix A. The data is flagged as:

- Data held by the Local Authority
- Data held by Partner Organisations
- Environment Agency National Data Set
- Environment Agency Local Data

5.1.1 Sources

Data was provided by:

- Cambridgeshire County Council
- Cambridge City Council
- South Cambridgeshire District Council
- Environment Agency
- Anglian Water
- Natural England
- English Heritage
- Cambridgeshire and Peterborough Environmental Records Centre
- British Hydrological Society
- British Geological Society

5.1.2 Data Quality and Restrictions

The SWMP guidance highlights the importance in understanding the quality of the data in order to inform the later stages of the SWMP. Therefore, data incorporated into the data registers was assigned a quality score between one and four based on a high level assessment:

1. Best Possible
2. Data with known deficiencies
3. Gross assumptions
4. Heroic assumptions

This follows the recommendations in the SWMP guidance but these quality scores will require further assessment as the study is progressed into the next stage. A further review was carried out to define the status of the data in terms of distribution and licensing. This information is also included within the data registers.

5.1.3 Data Format

Existing

Data was supplied for the study in a variety of formats; one objective of the study was to take these disparate data formats and compile them in GIS compatible database formats. Data was obtained in the following formats:

- ArcGIS
- MapInfo
- ASCII
- PDF
- Image
- Word
- Excel

All data was supplied electronically making it easier to collate and store than if it had been provided in hard copy format. Spatial data was, where possible, converted to MapInfo GIS format such that it could be overlaid with other information and to facilitate the use of the data in development and emergency planning.

Data was uploaded onto a secure SharePoint site maintained by Hyder; the capacity of the site allows large quantities of electronic data to be held and accessed by a defined set of personnel making it ideal when data is sensitive or restricted.

Future

The relevant flood risk and incident data will be supplied to CCC as part of the SWMP; it is recommended that CCC remain the custodian of this data and through this role is responsible for coordinating the maintenance of the databases. To ensure that the databases remain current and thus useful, all partners should be assigned the responsibility for providing updates to their assets in GIS format (at least on a yearly basis). There are two main options for keeping these databases current;

1 The data custodian at CCC receives updated data and alters it on the local system

2 All partners have access to a web enabled interface which allows individual organisations to update their data

A similar principle can be applied to the incident database although a web based system would facilitate the entering of event data at the time thus making it a highly useful repository for historical flood information.

5.1.4 Data Gaps and Limitations

A register of outstanding data was maintained throughout the duration of the study.

One key limitation identified is the differing formats of the data received, both between stakeholders and within each individual stakeholder. This was most apparent when data was provided in PDF format, resulting in the need for increased processing to digitise the information into a GIS format.

In addition, the compiling of the Flood Incident Register was made difficult due to the number of different formats that the historical flooding data was received in. Some datasets contained complete addresses and national grid co-ordinates, while other datasets were simply a graphical representation with no information contained within the GIS tables.

In particular, the largest source of historical flooding information, the Customer Complaints database provided by CCC, often had no grid co-ordinates for the flooding incidents, and none had a clear source of flooding listed, making the determination of these a laborious process. This also often compromised the confidence levels of data quality due to the assumptions made based on the limited available information.

5.1.5 LiDAR Issues

LiDAR (Light Detecting and Ranging) is a technique used to map the surface of the Earth's terrain. It works by bouncing light off the surface of the ground and recording the length of time it takes for the light to be reflected. For the purposes of this study, the LiDAR data, provided by the EA, was used to determine overland flow paths during the modelling stages of this detailed assessment.

This section highlights specific issues that arose in terms of the LiDAR provided and steps taken to overcome such issues.

LiDAR was initially received from the Geomatics team, the standard provider of LiDAR to the Environment Agency. This was provided for the majority of Cambridge and Milton at either a 1m or 2m grid resolution. While the majority of the data provided was good, and consistency was evident between LiDAR and spot levels provided, there were a number of issues identified that required corrective measures.

There were a number of areas that had no LiDAR information available as there was insufficient coverage in that area, but additional LiDAR was sourced for these areas.

Subsequent to reviewing these issues, further LiDAR was sourced from Bluesky Systems that provided greater coverage for the rest of Cambridge. There were still areas for which LiDAR could not be sourced – this included areas around Cherry Hinton. For this area, a patch was created that sampled elevations from sewer manhole cover level data provided by Anglian Water. This patch interpolates between known elevations on the LiDAR and known elevations of cover levels in the area where there is no LiDAR information. The result of this patch is to create a smooth surface interpolating between the two known values. This is not a perfect solution; however it is in line with the industry standard guidelines.

Each LiDAR tile was joined together to create a grid that covered Cambridge city. This grid was then inspected through various techniques to ensure consistency and accuracy. These include using numerous cross sections drawn over the map to check the consistency between tiles that had been stitched together. During this checking procedure, numerous errors were found in the LiDAR.

Standard practice for TUFLOW modelling is to use filtered LiDAR as it removes interference and distortion caused by buildings and trees. Figure 5.1 shows that buildings have been poorly filtered leaving anomalous terrain, which would adversely affect the model results. These errors were subsequently corrected when the issues were raised with the EA and they re-filtered the LiDAR. The example in Figure 5.1 shows that the pointed roof of the Grafton Shopping Centre has not been filtered from the LiDAR information.

Figure 5-1 LiDAR filtering errors for buildings

Figure 5.2 shows that in areas where there are errors between flight paths of LiDAR anomalous model results occur. Here, an error in the filtering process used on adjacent flight paths was erroneous, leading to abnormal model results.

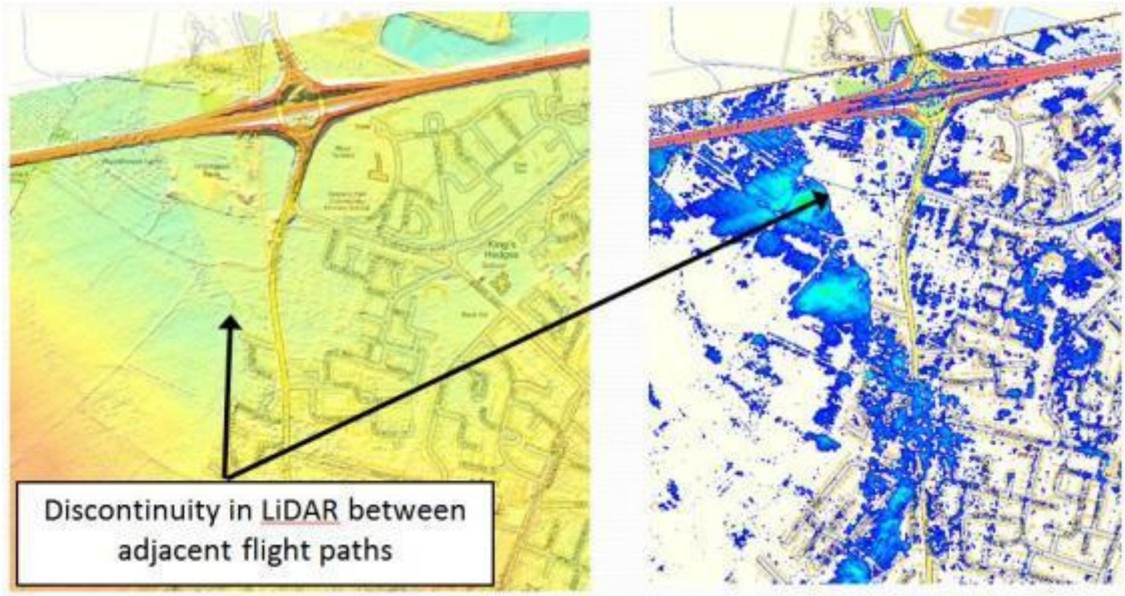


Figure 5-2 Flight path errors

Subsequent to having the LiDAR corrected, the model shows a more realistic distribution of flooding.

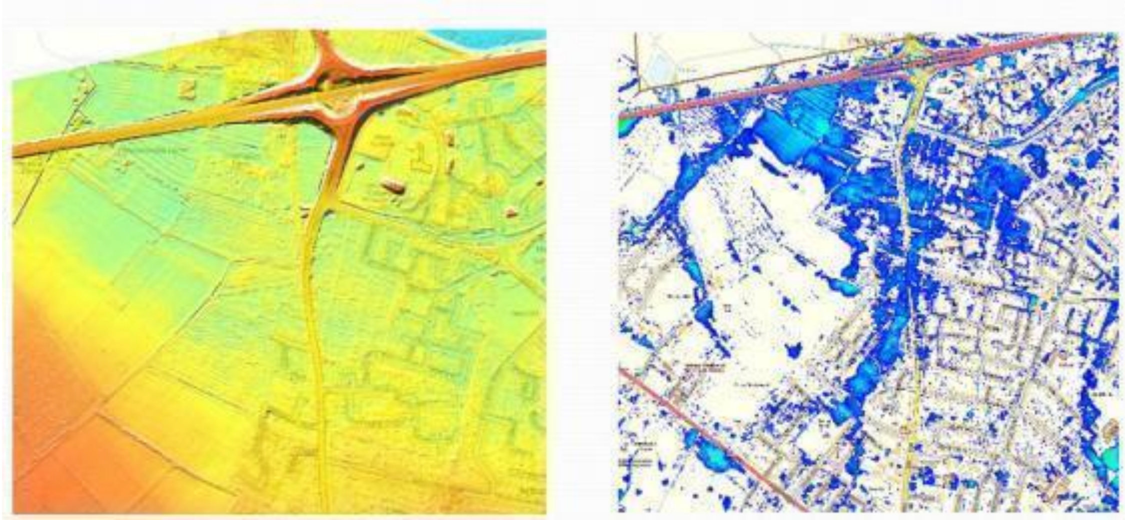


Figure 5-3 LiDAR following corrections

Errors in the LiDAR were corrected internally to begin with but were subsequently completed by the EA Geomatics team. The work that the EA undertook was compared against internal fixes and it was found that there were very few differences in the results of the work. It was decided to use the EA results going forwards because of the added benefits that the additional filtering had on the representation of buildings in key areas.

5.2 Flood Incident Register

A sub task within the data assimilation stage, as part of the countywide SWMP, was the development of a flood incident register to show all the historical surface water flooding incidents in Cambridgeshire, which included those occurring within the Cambridge and Milton study area. For each event the location of each flood incident was registered and an approximate easting and northing for the incident was also recorded where this was readily available or could be estimated within the available project timescale and resources. Each flooding incident was assigned a unique flood incident reference number. The flood incident register for the Cambridge and Milton area is included in Appendix B.

For many incidents the exact location of flooding was not reported, for example “flooding occurred on High Street”. Where the exact location was not known, an indicative location was picked at a central point on the street. Where known, the house number, incident date and time of incident was recorded. It should be noted therefore, that the flood incident register contains approximate grid co-ordinate locations that may not be the exact location of the historical flooding incident. It should also note that grid co-ordinates are missing for several incidents at present.

A crucial component of the incident register is recording the confidence in the source of the information. Some flood events were well reported, with a high level of detail regarding the source, pathway and receptor and other reports did not provide such details. The criteria in Table 5-1 were used to assess the confidence in the flood source. It is recommended that this practice is continued for all new flooding incidents added to the register along with more accurate information on incident location and flood consequence.

Flood Source	Confidence in Flood Source
Little or no evidence to support flood source in incident report	Low - Source assumed

Flood source provided by residents or non technical experts with high level of detail in the incident report	Medium - Some evidence
Flood source provided by ‘technical experts’ e.g. IDB staff or residents with compelling evidence i.e. photos	High - Compelling evidence

Table 5-1 Confidence in flood report sources

5.3 Web based GIS Database

Edenvale Young and HCL, in conjunction with web designers Plan B, have developed a web-based GIS database that allows the user to store and assess information on historic and future flooding and to facilitate prioritisation of wetspots within Cambridgeshire through Multi-Criteria Analysis.

Information relating to property types, critical services, statutory environmental areas and transport routes can be uploaded to the website and assigned scores based on flood susceptibility and Property/ Land Use Multi Criteria weighting agreed with the SWMP Project Management Board. Section 7 provides further information on Multi Criteria Assessment undertaken for wetspots prioritisation purpose.

Figure 5.3 shows a screen shot of the database, with the Castle School wetspot shown in red. Properties at a medium risk of flooding are shown in blue, and those at a high risk in pink.

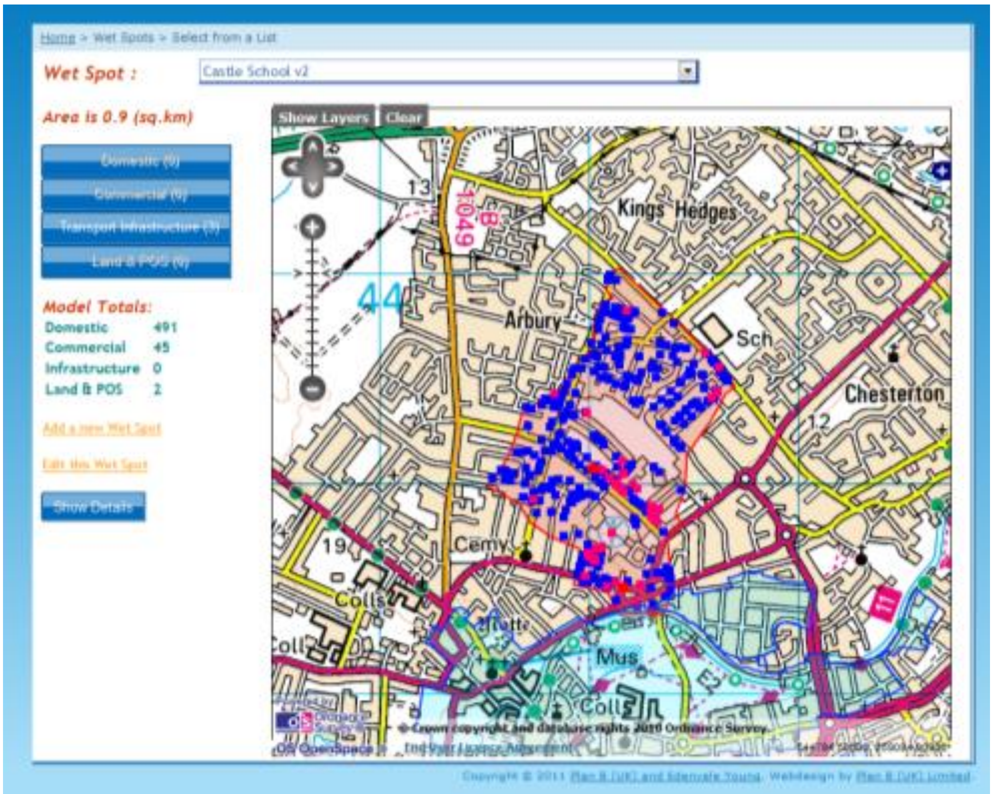


Figure 5-3 Screen Shot of Web-based GIS Database

In addition to showing modelled results, the website also allows information regarding historical flooding to be uploaded. Therefore, if decided by CCC, this GIS Database tool can be used in maintaining a “live” flooding register that can be updated whenever flooding occurs in future.

6 Evidence Base

6.1 Historical Flooding in Cambridge and Milton

Flood Risk Regulations
Introduce the local sources of flood risk being considered for past floods and possible future floods.
Assess past floods which had significant harmful consequences for human health, economic activity, cultural heritage and the environment.

The following sections outline the historical flooding recorded within the Cambridge and Milton study area specifically within the context of the definition given in Section 1.3. This text should be read in conjunction with the Countywide Flood Incident Register shown in Appendix B of the Cambridgeshire Strategic Assessment report. It is highlighted that this report is based on the information supplied by partners up to January 2011; the occurrence of flooding is not static and thus this represents an understanding of the situation as of this date.

The most extensive database is Cambridge City Council's Flooding Database which recorded major flooding events in:

- April to June 1905 (Mainly Fluvial: 15 Records);
- May 1978 (Fluvial, Pluvial and Sewer Flooding: 13 Records)
- July 1982 (Foul / Combined Flooding: 75 Records)
- October 2001 (Surface Water, Sewer, Fluvial and pluvial (108 Records)

Cambridge City Council's Flooding Database and the EA's historic flood information seek to attribute the source (or cause) of the flooding for the majority of the records (e.g. pluvial, fluvial, sewer, groundwater, multiple etc). However, there is a lack consistency in the application of terminology particularly in the distinction between pluvial, surface water and sewer flooding. It should also be recognised that the databases do not include some important flood events. For example, the flooding on Campkin Road in 1970 shown in Figure 6.1 is not recorded within any of the databases. The following photographs were provided by Cambridge City Council.

Figure 6-1 Historical Flooding on Campkin Road in 1970

Figure 6-2 Arbury Estate assumed to be 1970 (location not stated within source material)

Accordingly, there is a high probability that flooding within Cambridge and Milton is under-reported. In general, the historical information associated with flooding in Cambridge and Milton is comparatively poor with few records in relation to the spatial extent of flooding and the frequency of inundation to properties. As discussed this is possibly due to under reporting of problems with flooding by the general public to the Local Authority / Environment Agency. Figure 6.3 shows the location of historical flood events in Cambridge based upon the above data. This information has been extracted from the Web GIS.

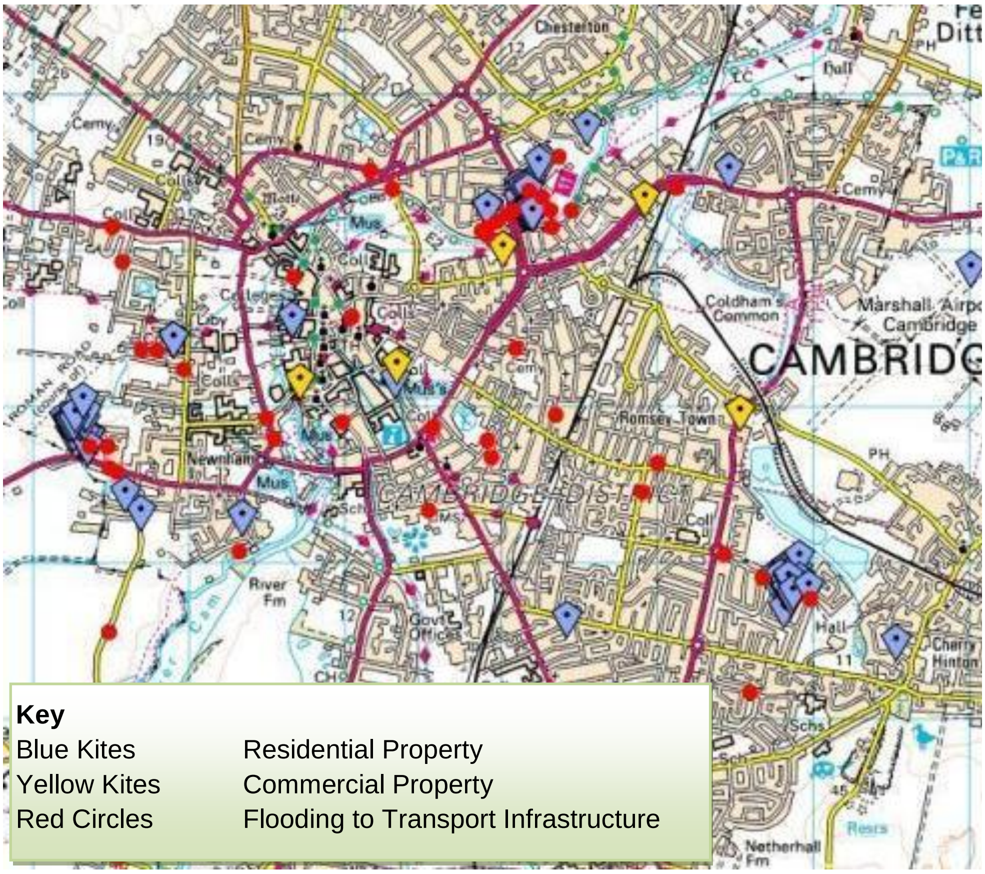


Figure 6-3 Historical Flooding in Cambridge and Milton

Figure 6.3 shows three areas where there is some grouping of flooding and these locations are shown in more detail in Figure 6.4. These latter figures relate to historical flooding at:

- The Riverside area adjacent to the Cam (Main River Fluvial Flooding)
- Newnham adjacent to Bin Brook (Main River Fluvial & Surface Water Flooding)
- St Thomas Square, Cherry Hinton (Surface Water Flooding)

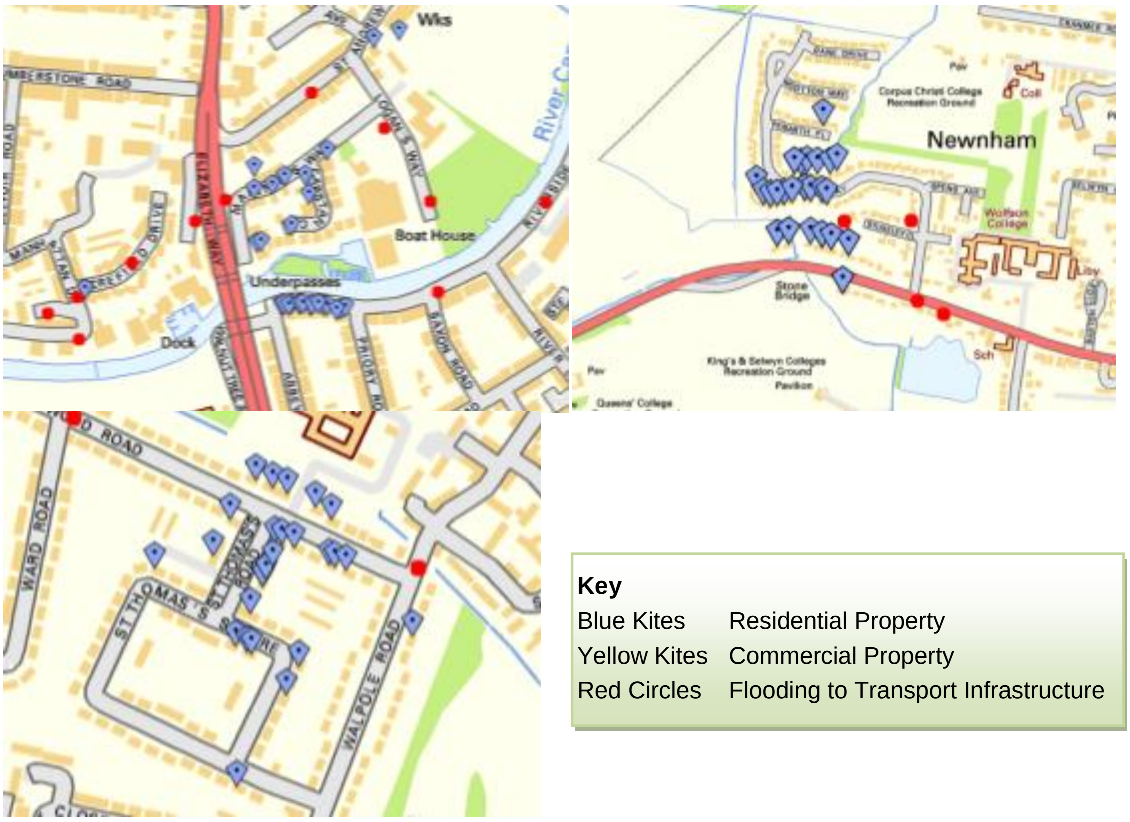


Figure 6-4 Historical Flooding in Cambridge

Accordingly, whilst every effort has been made to analyse the data there is a high probability that there are deficiencies in quantity and the attribution of historical information. It is considered that the majority of the information pertinent to the SWMP falls within the Low to Medium Confidence categories (see Table 5.1). In addition, there is limited correlation between the historical flooding and latest version of the Environment Agency's Surface Water Maps. Caution has therefore been exercised within this section of the report in interpreting the historical record.

6.2 Sources of Recorded Flooding

The following sections summarise the occurrences of recorded flooding for various sources of flooding.

6.2.1 Surface Water Runoff / Pluvial Flooding

Surface water runoff occurs as a result of high intensity rainfall causing water to pond or flow over the ground surface before entering the underground drainage network or watercourse, or when water cannot enter the network due to insufficient capacity.

Locations of historical surface water runoff occurrences were provided by a number of sources, including the county and district councils and Environment Agency.

Pluvial flooding is defined as flooding that result from rainfall-generated overland flow. The historical records include a significant number of descriptive records of flooding which imply that there are issues with pluvial flooding. The records clearly demonstrate that there are problems with pluvial flooding but it should also be recognised that flooding will be the result of numerous factors rather than solely rainfall intensity or duration. This is particularly true of the October 2001 event which includes references which can be reliably interpreted as pluvial flooding.

However, the same database also includes records of pluvial / sewer flooding to the St Thomas Square / Birdwood Road area of Cherry Hinton and fluvial flooding from Bin Brook and the River Cam. The Strategic Flood Risk Assessment (SFRA)[9] prepared in 2006 identifies a number of locations which have, or are subject to pluvial flooding. These are:

- Nuffield Road
- Stratfield Close, Tavistock Road, Woodlark Road
- Bell School Playing Fields
- Chesterton High Street
- Junction of Queens Road/ Sidgwick Avenue

6.2.2 Watercourses

The watercourses in the Cambridge and Milton study area are shown in Figure 6.5 below. Further details on their categorisation and those responsible for their upkeep are given in the following sections.

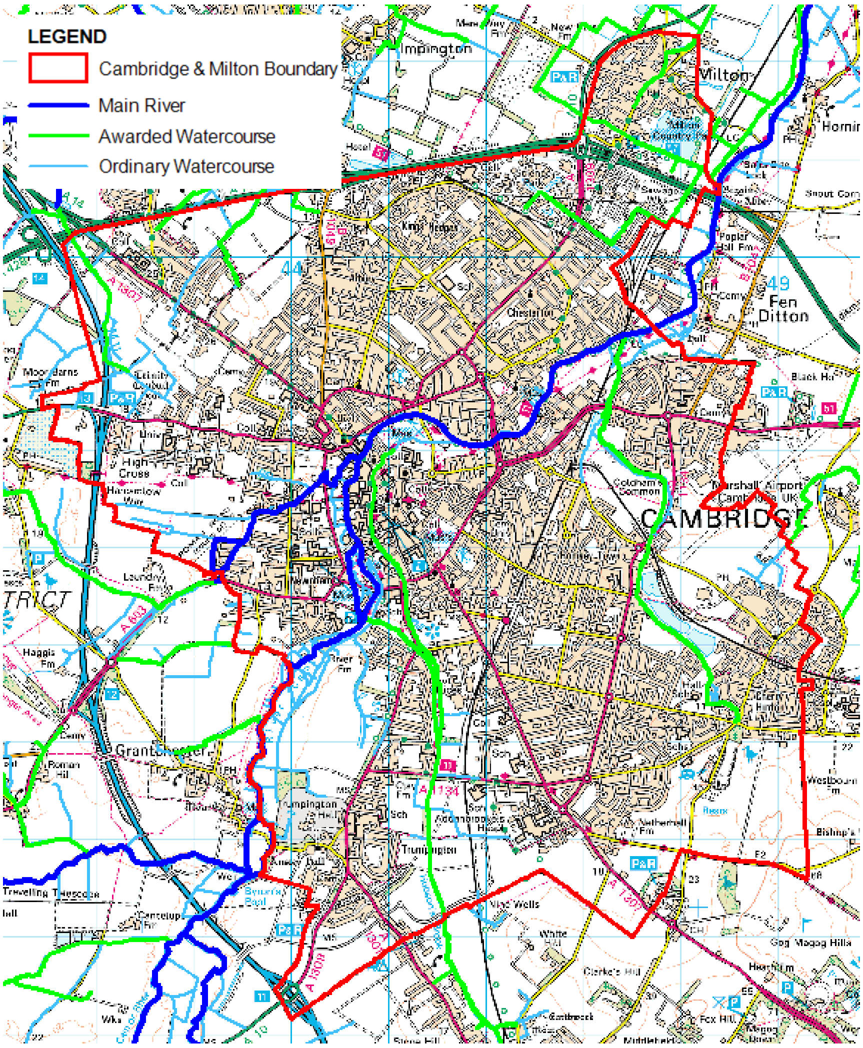


Figure 6-5 Watercourses in Study Area

Main Rivers

Under the Water Resources Act 1991, the EA has powers to maintain and improve designated main rivers for the efficient passage of flood flow and the management of water levels for flood defence purposes. These powers are permissive only and there is no obligation on the Agency to carry out such works. The current maintenance regime for designated main rivers uses a risk based approach and government funding via Defra. The ultimate responsibility for maintaining the bed and banks of any watercourse, including its vegetation, rests with the riparian owner(s).

The EA offers a flood warning service to areas covered by main rivers and some ordinary watercourse tributaries. We also provide protection to certain areas at risk from Main River flooding in the form of strategic flood defences.

The main rivers in the Cambridge and Milton study area are the River Cam and Bin Brook, and these are shown in Figure 6.5. Information on the main rivers in the county area was provided by CCC and the EA.

Ordinary Watercourses

Ordinary watercourses are all rivers, streams, ditches and drains that have not been designated as main rivers. The main responsibility for all watercourses lies with the riparian owners; however the internal drainage boards do have permissive powers to carry out Land Drainage schemes on ordinary watercourses. Local authorities are responsible for any ordinary watercourses that fall within areas where they are the land owner, or if the watercourse is awarded.

Details of ordinary watercourses were provided by the local authorities.

Awarded Watercourses

Awarded watercourses are any watercourses for which responsibility has been transferred to the Council under Enclosure Acts.

They include Hobson's Brook (Conduit), Vicars Brook and Cherry Hinton Brook (ordinary watercourses), the main drainage routes that impact on surface water conveyance in the south of Cambridge. Hobson's Brook has significant lengths of culvert and was laid to convey water from the Nine Wells Spring, located East of Trumpington.

There are also a number of Public Award Drains which facilitate the channelling of surface water. The 1st Public Drain conveys flows from drainage within North Cambridge including King's Hedges, Arbury and Chesterton. Unlike private "riparian" drains they are maintained by Cambridge City Council and South Cambridgeshire District Council who clear the drain regularly and cut back the vegetation.

Details of awarded watercourses were provided by the local authorities.

The historical record within Cambridge and Milton does not include any records directly associated with flooding from ordinary watercourses or Award drains. However, it is considered that flooding to the St Thomas Square area of Cambridge could be influenced by high water levels in Cherry Hinton Brook and the Dawes Lane culvert. These features are illustrated in Section 9.1.

6.2.3 Sewers

Sewer flooding occurs when the capacity of underground systems is exceeded due to heavy rainfall, resulting in flooding inside and outside of buildings. Water companies, in this case Anglian Water Services Ltd (AWS), are obliged under the Water Industry Act[14] to facilitate drainage of surface water up to a 1 in 20 year return period event.

The sewerage system within Cambridge comprises a combined sewer system in the historic heart of the city, with suburban areas comprised of separate foul and storm water sewer systems.

The following figure shows the Anglian Water sewer network and assets.

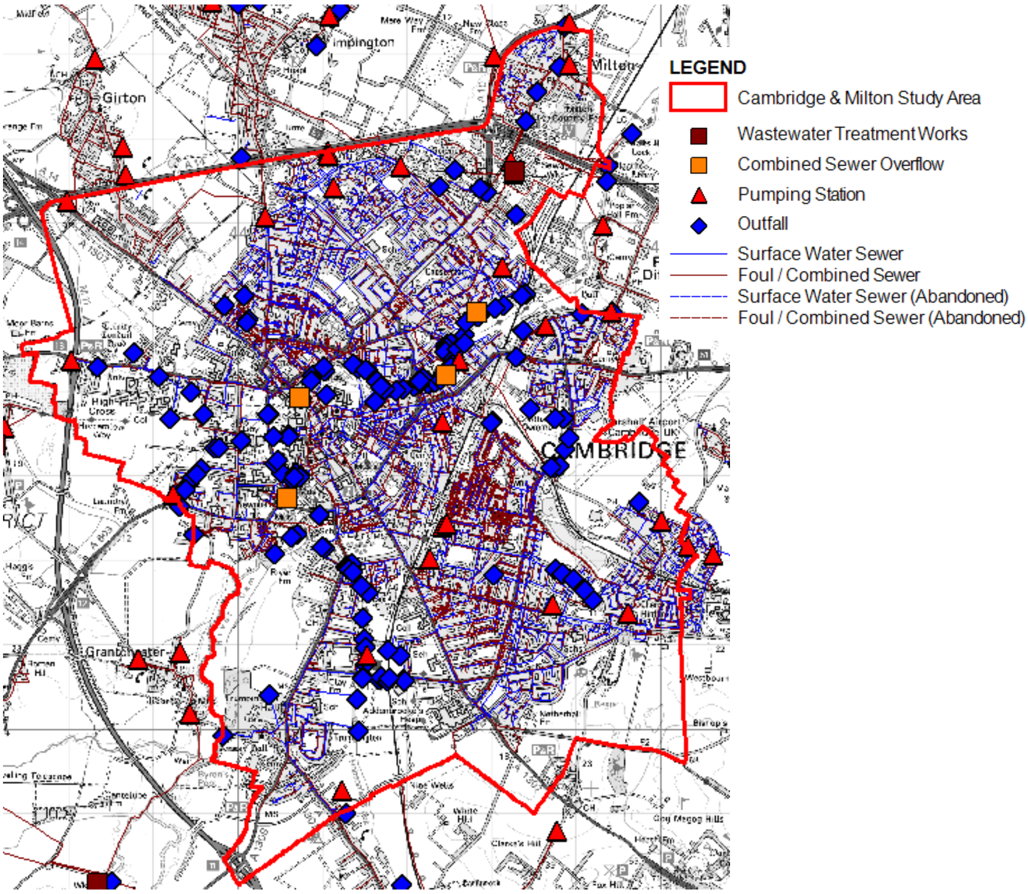


Figure 6-5 Cambridge and Milton Sewer Network

Cambridge Waste Water Treatment Works (WwTW) is situated to the north-east of Cambridge. The majority of flows arrive at the works though a 2.1m diameter gravity sewer, with the remainder arriving via a smaller diameter sewer from Arbury and rising mains.

All gravity flow and some pumped flow enters the works via the Tunnel Terminal Pumping Station (TPS) at the WwTW. Additional pumped flow enters the WwTW directly at the inlet works. No flow measurement for flow to full treatment was available to inform the SWMP study. However, operational staff from AWS has indicated that 3 x DWF (Dry Weather Flow) was the maximum flow to full treatment. This means that the treatment works is capable of treating three times the average daily dry weather sewerage flow, before excess flows spill over a weir into two storm tanks. The capacity of each storm tank is 4,165 m^3. Spill flows will be returned to the inlet works for treatment once incoming flows have reduced sufficiently.

DG5 Flooding Register

AWS maintains a register of flooding as a result of surcharging of the foul and combined sewer network. This is referred to as the DG5 Register. This register records incidents of flooding locations and likely causes. It is noted that as of February 2011 there are three remaining incidents of flooding that remain active on the register. It should be noted that previous DG5 listings have been removed from the register as a result of remedial work, or the implementation of system improvements. AWS considers that the foul system therefore operates very well up to a return period of 30 years, higher than that required by OFWAT.

Historical Flooding Record – Sewer Flooding

The historical record, particularly the Cambridge City Council Customer Reports of Flooding, includes a significant number of descriptive records of flooding tagged with general descriptions such as: blocked drains, foul sewer emissions, road drainage, foul sewer backup and drains silted up. The records clearly demonstrate that there are problems with sewer flooding. However, and in general, there is insufficient information to identify whether flooding is attributable to highway, foul or storm sewer flooding. Moreover, it is frequently not possible to determine the frequency and precise cause of the flooding. It is considered that the quality of historical flooding information falls within the low to medium confidence categories.

AWS has prepared an InfoWorks Hydraulic model of the foul sewerage system as indicated in Table 6.1.

Asset Type	Description
Foul	The foul system is maintained and operated by AWS, who also maintains an Infoworks model of the network which contains asset data, sewer network data and manhole locations
Surface Water	The surface water system is maintained and operated by AWS; however no model exists of the system. They maintain a GIS database, which lists the locations of the manholes and the sewer network
Combined	The combined system operates only in central Cambridge and is owned and operated by AWS. A model of this system is integrated within the foul network model. In practice, the combined system is represented as a foul only network, but an allowance of 30% infiltration from storm water has been made.

Table 6.1 Hydraulic Modelling of Cambridge Sewer System

6.3 Potential Indicators of Surface Water Flood Risk

6.3.1 EA Areas Susceptible to Surface Water Flooding (AStSWF) Maps

The Environment Agency have produced the outputs of a simple surface water flood modelling at a national scale. The modelling did not take into account underground sewerage and drainage systems or smaller over ground drainage systems. No buildings were included and a single rainfall event was applied. The model parameters used to produce the maps were:

- 1 in 200 year return period
- 240 minute storm duration
- 1km^2 resolution

- No allowance for underground pipe network
- No allowance for infiltration

The AStSWF map gives three bandings indicating areas which are 'less', 'intermediate' and 'more' susceptible to surface water flooding. The map is not suitable for identifying individual properties at risk of surface water flooding.

These maps were updated and republished in January 2009.

6.3.2 EA Flood Maps for Surface Water (FMfSW)

Following on from the release of the Areas Susceptible to Surface Water Flooding, The EA updated the original mapping in order to produce the Flood Maps for Surface Water (FMfSW), which were released in October 2010. The existing maps were updated to take account of buildings and the underground drainage system, and more storm events were analysed. It should be noted that these maps do not take into account artificial drainage regimes. The model parameters used to create these new maps were:

- External Publication Scale 1:25,000
- 1 in 30 and 1 in 200 year return periods
- 66 minute storm duration
- 5m^2 resolution with country split into 5km squares
- In rural areas, rainfall was reduced to 39% to represent infiltration
- In urban areas, rainfall was reduced to 70% to represent infiltration
- Global use of Manning's 'n' of 0.1 for rural and 0.03 urban areas

The new maps have two bandings of "deep" or "shallow" and are produced for both 30 year and 200 year return periods.

6.3.3 British Geological Survey Groundwater Flooding Susceptibility Maps

Groundwater flood risk has been assessed by the British Geological Survey (BGS) for the whole country via national flood hazard maps. The groundwater flooding susceptibility data shows the degree to which areas of England, Scotland and Wales are susceptible to groundwater flooding on the basis of geological and hydro-geological conditions.

The dataset provided does not show the likelihood of groundwater flooding occurring, i.e. it is a hazard not risk-based dataset. The risks have been derived using set 'rules' in order to identify areas "based on geological considerations, where groundwater flooding could not occur, i.e. areas where non-aquifers are present at the ground surface" (BGS).

Areas susceptible to groundwater accumulation are passed through a second set of rules in order to create a groundwater level surface (this was taken from groundwater contours, inferred river levels, borehole data and other BGS datasets). The final groundwater level was then compared to a DTM, and the resulting modelled depths of groundwater level above the surface were translated into associated risk categories 'Very High', 'High', 'Moderate', 'Low' and 'Very Low'.

BGS note that "The susceptibility data is suitable…to establish relative, but not absolute, risk of groundwater flooding at a resolution of greater than a few hundred metres. In all cases it is strongly recommended that the confidence data is used in conjunction with the groundwater flooding susceptibility data". In addition, "the susceptibility data should not be used on its own to make planning decisions at any scale, and, in particular, should not be used to inform planning decisions at the site scale. The susceptibility data cannot be used on its own to indicate risk of groundwater flooding".

At this stage of the SWMP, these maps have been used only in a limited capacity, however, it is expected that during future stages, these maps will be used more extensively to inform the optioneering process.

6.3.4 Anglian Water Records

As part of the stakeholder participation, AWS provided HCL with extracts from the foul network model for Cambridge and Milton. While AWS maintains a foul network model for the whole of Cambridge, it does not model the surface water system. For the purposes of a SWMP both types of system must be considered as sources and receptors of flooding.

AWS provided manhole locations, names and cover levels for the foul and combined systems. Using this information and maximum depth output from a series of modelled storm duration's information was extracted for a range of storm durations and return periods as shown in Table 6.2.

Storm Durations (mins)	Return Periods (years)
30, 60, 120, 240, 360, 480, 960, 1140	1 in 5, 1 in 10 , 1 in 20, 1 in 30 and 1 in 100

Table 6.2 Foul / Combined InfoWorks Modelling Parameters

This allowed for an evaluation of the capacity and critical storm duration for the combined network. The maximum water depth at each node was compared to its cover level and where this depth was exceeded, the manhole was highlighted as surcharged.

The review confirmed that for 1 in 30 year rainfall event there was no surcharging to the foul and combined system across the city.

6.4 Maintenance Regimes

Maintenance regimes are critical to ensuring the continued and effective functioning of assets to manage surface water flood risk. Existing maintenance tasks/ responsibilities have been reviewed as part of the SWMP where information is currently available and these are listed below. The SWMP will also assist in identifying and focussing needs in terms of future maintenance and it is recommended that all partners and stakeholders provide the relevant information for inclusion in the final version of this report as appropriate.

Cambridgeshire County Council Highways Authority

The CCC Highways Authority has the over-riding responsibility for all highways and highway structures throughout the council area (with the exception of motorways and some major trunk roads, such as the A11), and operates programmes of inspection and maintenance for bridges and gullies within the county area.

Cambridge City Council

Cambridge City Council is the Land Drainage Authority for the City of Cambridge and undertakes maintenance to the Ordinary Watercourses and Award Drains. The 1st Public Drain, which falls outside the authority's boundary, is also maintained by the City of Cambridge as it conveys water from the northern suburban areas of the city including Chesterton, Arbury and Kings Hedges estates.

In total, Cambridge City Council maintains 16 miles of awarded watercourses and a large number of watercourses that fall within its riparian responsibilities. It carries out annual weed cutting and de-silting when required, and also undertakes regular inspections of assets, including those that it is responsible for, as well as private assets.

South Cambridgeshire District Council

South Cambridgeshire District Council has responsibility for 175 miles of award drains. It has a routine annual vegetation removal programme and an 'as required' silt removal programme.

Anglian Water

Maintenance regimes are critical to ensuring the continued and effective functioning of assets. For the surface water network, Anglian Water assumes that the self-cleansing velocity design standard is sufficient to clear any blockages. As a result they do not have any listed expenditure for maintenance of surface water systems.

For foul and combined systems, Anglian Water follows a reactive approach to maintenance. Therefore maintenance costs vary between years dependent on any reported flooding incidents.

Maintenance regimes are critical to ensuring the continued and effective functioning of assets to manage surface water flood risk. Existing maintenance tasks/ responsibilities has been reviewed as part of the SWMP where information is currently available and these are listed below. The SWMP will also assist in identifying and focussing needs in terms of future maintenance and it is recommended that all partners and stakeholders provide the relevant information for the inclusion in the final version of this report as appropriate.

Environment Agency

The Environment Agency carries out maintenance on those rivers or streams designated as main rivers. The Environment Agency's annual maintenance programme can be viewed by using their website[15].

River Cam Conservancy

The River Cam Conservators are the statutory navigation authority for the River Cam between Silver Street, Cambridge and Bottisham Lock.

They have duties under the Wildlife and Countryside Act 1981 to maintain a diverse aquatic habitat within their area. The Conservancy maintains the River Cam and its banks to allow for its continued navigation use. Maintenance works include bank side vegetation clearance and de-silting.

7 Model Development

7.1 Model Evolution

As discussed in Section 6, there are a number of factors influencing surface water flooding as a result of localised heavy rainfall event in Cambridge. These include:

- Surface water runoff from surrounding recreational / agricultural land towards residential and commercial
- A relatively flat topography providing an increased array of flow paths
- Highway and building surface water runoff
- The capacity of the sewer network
- Infiltration and depression storage

Recent advances in hydrological and hydraulic modelling techniques have allowed for a gradual improvement in assessing sources of flooding and flood risks. Of particular note for this study, advances in direct rainfall modelling allow representation of storms that are not purely fluvial. This technique allows analysis of surface water runoff, infiltration, depression storage and rainfall distribution and its effects on flooding. This is particularly important in meeting the requirements of a SWMP in an environment such as Cambridge, where historical data has shown that flooding from the River Cam and other watercourses is not the only significant source of flooding.

This method of 'raining' on the model domain allows sites at risk of surface water flooding to be identified and also illustrates the main flood pathways by which flooding occurs. In doing so the model represents a means of identifying areas at risk of flooding; from which multi-criteria analysis scores and financial damages can be calculated. Once the baseline flood risk has been identified, the model then provides a useful tool to assess the viability of potential flood alleviation measures.

The use of 1D - 2-D TUFLOW modelling is designed to ensure that the flooding mechanisms are appropriately represented by the model. This approach enables the effect of the topography on overland flood routes to be simulated by direct application of a rainfall profile to a 2D hydraulic model domain. TUFLOW's 2D solution is based on the Stelling solution scheme. It is a finite difference, fixed grid, alternating direction implicit (ADI) scheme solving the full 2D free surface shallow water flow equations. TUFLOW is suited to modelling flooding in major rivers through to complex overland and piped urban flows, and estuarine and coastal hydraulics.

TUFLOW utilises standard GIS packages to manage, manipulate and present input and output data. In order to model surface flows, TUFLOW requires terrain data. This can be from any source (GPS, LiDAR, photogrammetry etc.) but the more detailed and accurate the source of the data, the more accurate and reliable the solution is likely to be. For this study, terrain used by TUFLOW has been generated from 1 and 2 metre resolution LiDAR data (see Section 5.1.4).

In order to address the specific issues relating to the Cambridge and Milton SWMP, a three stage modelling strategy was developed for this study.

- Stage 1 - Hydrological Analysis and development of broad scale, bare earth, models of North and South Cambridge and sensitivity testing to determine the hydrological / infiltration response of the catchment. (see Section 7.2).
- Stage 2 – Identification and evaluation of wetspots using the bare earth model developed in Stage 1 and Prioritisation using Multi Criteria Analysis (MCA) (see Section 8).
- Stage 3 - Detailed modelling assessment of specific wet-spots within Cambridge and Milton. This included the development and testing of engineering options and economic analysis (see Sections 9 to 12).

The three stages are also associated with increasing refinement of the model. As noted above the Stage 1 and 2 modelling was based upon bare earth modelling with infiltration rates appropriate to the catchment areas. South Cambridge is a highly permeable catchment whereas the infiltration characteristics of northern Cambridge are substantially different. This section also includes discussion on the common principles used through the study including the selection of grid size, roughness, the representation of buildings and the analysis of the results.

7.2 Hydraulic Modelling - Common Principles

7.2.1 Roughness

Material layers were applied to the model domain to cover areas of houses, trees and roads. These surfaces were then assigned appropriate Manning's Roughness Coefficient values (n) to reflect differences in hydraulic roughness. The 2D model representation of roughness includes depth varying Manning's coefficients. Roughness is defined at two depths as shown in Table 7.1.

No.	Material Type	d_1 (m)	n_1	d_2 (m)	n_2
1	Grazed Fields / Short Grass	0.1	0.3	0.2	0.05
2	Roads	-	-	-	0.02
3	Kept Fields	0.05	0.3	0.1	0.04
4	Urban	0.05	0.1	0.1	0.065
5	Scrubland	0.1	0.3	0.3	0.06
6	Trees / Wooded	0.1	0.3	0.2	0.1
9	Buildings	-	-	-	1

Table 7.1 TUFLOW Material Roughness Values

For example for kept fields the Manning's roughness for depths of flow less than 0.05m (= d1) is 0.3 (= n1). Similarly for depths greater than 0.1m (= d2) the Manning's roughness is 0.04 (= n2). Between 0.05m and 0.1m the value of roughness varies linearly. This was specifically introduced to account for shallow depths associated with the flow across surfaces in direct rainfall conditions.

The materials layer used to assign roughness to the model was derived from Mastermap data provided under the project data request. Within this dataset, different land use types are identified using land use codes and detailed descriptions of land use type. An example is shown in Table 7.2.

Code	Theme	Description	Make
10172	Roads	Track	-
10111	Land	Natural Environment	Rough Grassland

Table 7.2 Mastermap Code Allocation

The Mastermap data was trimmed to the boundaries of the Cambridge study area in order to remove land uses that were irrelevant to the study. Using a filtering process, unique land use codes that appear within the model limits were identified. Each of the land use descriptions were interrogated against Manning's coefficient that would be appropriate for that land use. A materials file was created utilising the land use code and appropriate roughness. This allowed roughness to be applied in detail to the whole city.

7.2.2 Representation of Buildings

Buildings have been represented by applying a high manning's roughness of 1.0 to a buildings footprint. This encourages water to flow around buildings where the roughness values are lower.

7.2.3 Use of Plot Output (PO) lines

In order to analyse the model results at points of interest, a series of Plot Output (PO) lines were drawn within the TUFLOW model to record integral flows, water levels and velocities throughout the simulation. These lines were generally placed perpendicular to main flow routes such as Bin Brook, Cherry Hinton Brook and Vicars Brook. The PO lines can be analysed to determine the total volume of flow passing through it over the simulation.

7.3 Stage 1 - Hydrological Analysis / Bare Earth Modelling

7.3.1 Stage 1 - Bare Earth Model Construction

In order to maximise efficiency and reduce model run times to an acceptable level Cambridge was divided into two bare earth models to the north and south of the Cam, as shown in Figures 7.1 and 7.2.

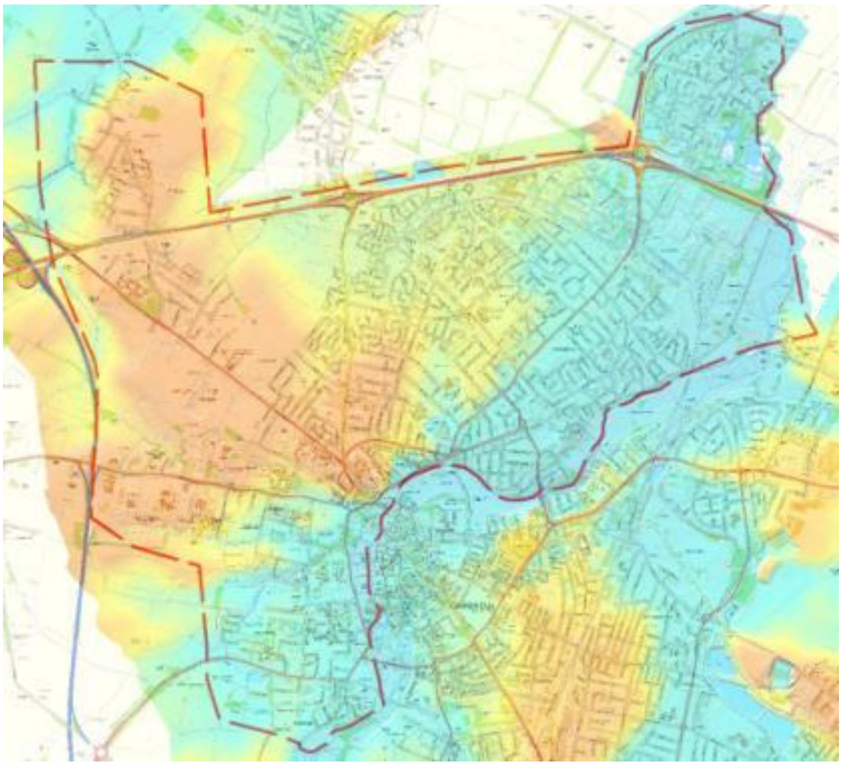


Figure 7-1 North Cambridge Direct Rainfall Model- Extents of TUFLOW Domain (5.0m grid)

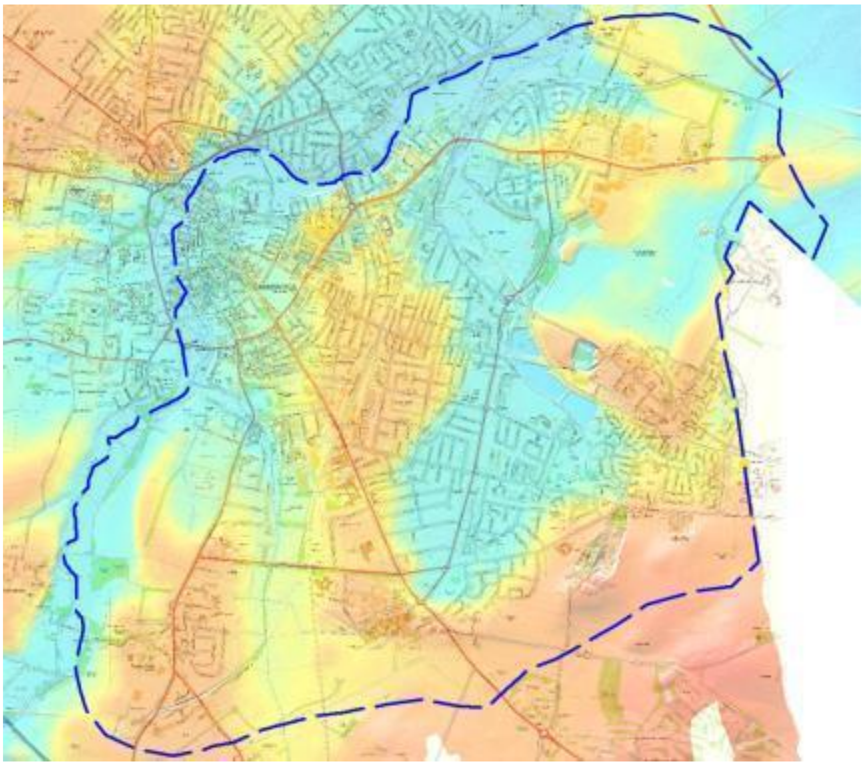


Figure 7-2 South Cambridge Direct Rainfall Model - Extents of TUFLOW Domain (5.0m grid)

The division line represented by the River Cam reflects a geological divide with highly permeable chalk catchments to the south and less permeable and mixed surface geology in the north. This approach separated areas with substantially different infiltration rates ensuring that each unique area could be treated separately and appropriately. The analysis associated with establishing infiltration rates for North and South Cambridge have been described in Section 7.3.4. Dividing the model at the River Cam also had the advantage that it substantially reduced model run times ensuring that multiple model scenarios could be tested.

The Cambridge City domain was established using a code polygon, which was drawn around the surface water catchment, allowing a reasonable extra distance as a buffer. This buffer was to ensure that all the surface water catchment had been encompassed. The downstream boundary for the model is a HQ line, which has been snapped around the entire perimeter of the domain code region. TUFLOW assigns a water level to cells selected by this line, based on a stage-discharge curve. This curve was automatically generated by TUFLOW, using a slope ('b' value) of 0.001. This value was chosen to give a suitably steep slope, based on its use in other rainfall models.

It was not necessary to be too precise in assigning a value to the HQ line, as its only purpose is to remove water from the domain as it reaches the edges and drains away from the modelled region. This prevents ponding of water at the edge of the model domain and therefore reduces instabilities and erroneous results. As a buffer was included around the catchment, it was decided that the HQ line is sufficiently far from any point of interest as to not affect the results.

For the broad scale investigation that is required under Stage 1, a grid size of 5 m was chosen for the TUFLOW domain as noted in Table 7.3. This grid size is considered to be representative of the wide area of the initial modelling because it is approximate to street width (understood to be the dominant flow paths through urban environments).

Model Parameters	
Grid Size	5 m
Time Step	1 second
Bare Earth Storm Durations	30, 60, 120, 240, 480 minutes
Bare Earth Model Return Periods	1 in 200 years
Modelling Return Periods	1 in 30, 50, 75, 100, 200 years
Storm Duration	4 hours
Total Run Time	8 hours

Table 7.3 Stage 1 Model Parameters

The refinement of grid sizing is specified for the detailed wet-spot modelling (Section 9). To allow for an accurate assessment of flow paths caused by direct rainfall, a runtime allowing for an additional 4 hours whereby no additional rainfall enters the model domain was specified.

The results for a 200 year (0.5% AEP) 60 minute storm over Cambridge with infiltration rates in the south equal to 50% and infiltration rates in the north equivalent to 15% (see Section 7.3.4 for discussions associated with infiltration) are shown in Figure 7.3. Depths above 0.1m but below 0.3 m are shown in blue; depths above 0.3 m are shown in red. This model output shows a clear problem associated with flooding around Cherry Hinton, but also that surface water flooding is apparent throughout the City. The north of the city (as divided by The Cam) shows that there is widespread surface water resulting from the storm.

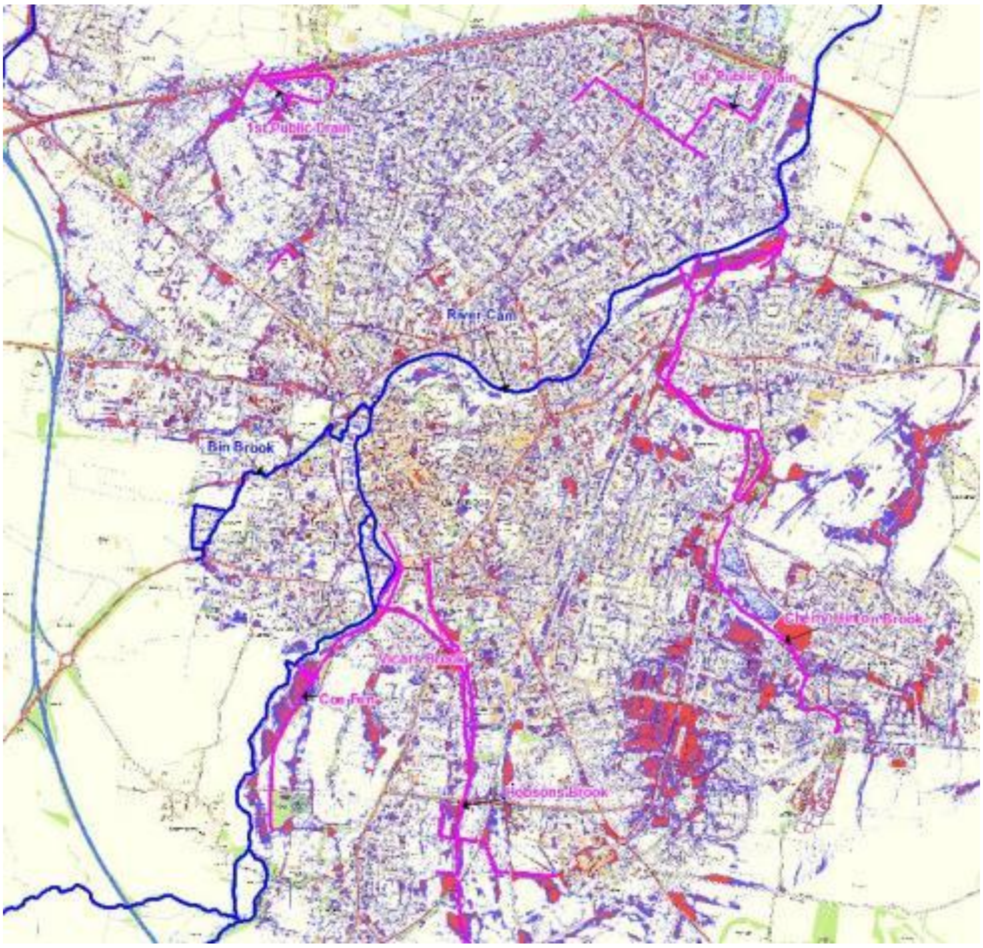


Figure 7-3 Combined Model Results for 200 year (0.5% AEP) North & South Cambridge Bare Earth Models

7.3.2 Hydrological Analysis

As noted above the purpose of developing a TUFLOW model of Cambridge was to analyse the effects of rainfall on the city by looking at flow paths, velocities and catchment response. This was achieved by applying Depth Duration Frequency (DDF) rainfall derived from the FEH CD Rom over the model area. The application of direct rainfall to a 2D model domain is a fairly novel approach to assess flood risk. One advantage of the approach is that the model does not require estimation of flow at discrete locations since flow is automatically generated from the incident rainfall according to the way in which it is channelled by the modelled topography.

Whilst the direct rainfall model explicitly simulates the channelling and pooling of surface water, losses to the ground through infiltration are not immediately accounted for. Such a scenario – in which no infiltration losses are represented – could be assumed to be indicative of a frozen or highly saturated catchment response. However this is a very conservative assumption and hence it is desirable to include a measure of infiltration losses in the model to make it more representative.

The role of the hydrological analysis, therefore, was primarily to inform the scale of infiltration losses to be incorporated in to the hydraulic model. To do this, the 2D model was run iteratively for a number of estimated infiltration losses before comparing the model output with fluvial flow estimates determined by Flood Estimation Handbook (FEH) techniques on specific sub-catchments. The FEH techniques account for infiltration losses either implicitly (in the case of the statistical method) or explicitly (using ReFH) and hence were considered to provide an indicative estimate of the infiltration loss that was yet to be included within the 2D model.

By undertaking this exercise, the hydrological analysis indirectly took on a secondary purpose of ensuring that the catchment response simulated by the direct rainfall model was comparable to design flood estimates obtained from FEH methodology. This secondary objective was not insignificant given that the FEH suite of techniques are recommended by the Environment Agency and represent the current best practice guidance for undertaking flood estimates on catchments within the UK. It was therefore felt that agreement with FEH estimates for the specific sub-catchments where the comparative analysis was undertaken would serve to improve the credibility of the modelling approach and provide added confidence to the results determined by the study. The objectives of the hydrological analysis are therefore summarised as follows:

- To estimate the scale of infiltration losses within the extent of the study area to be incorporated within the direct rainfall model,
- To ensure the direct rainfall model output is consistent with FEH estimates of fluvial peak flows.

7.3.3 TUFLOW Rainfall Boundary

The TUFLOW model was designed to simulate the effects of rainwater induced flooding to Cambridge. As such, the only inflow for the TUFLOW model was a rainfall hyetograph that was applied over the catchment through a TUFLOW rainfall boundary region. The hyetograph defines point rainfall and duration and is applied homogeneously over the entire extent of the model. Figure 7.4 shows an example hyetograph used in the modelling for a 1 in 200 year rainfall event for a storm duration of 4 hours equivalent to the FEH DDF rainfall of 62mm. No internal boundaries were defined within the TUFLOW domain.

This rainfall event was chosen for Stage 1 modelling after a suite of return periods and durations were run and considered. For the initial assessment it was necessary to create flooding throughout the whole of Cambridge in order to get an idea of the areas most susceptible to flooding. This rainfall storm was finally chosen because it tied in with the AStSWF mapping and also met the criteria for producing sufficient flooding to allow analysis.

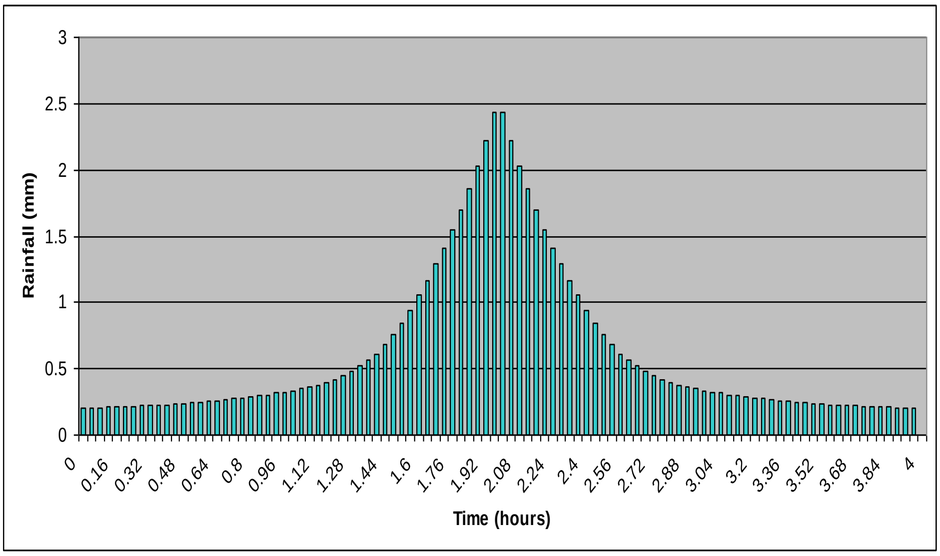


Figure 7-4 Example Hyetograph

7.3.4 Derivation of Infiltration Parameters

A detailed description of the derivation of infiltration parameters for the north and south of Cambridge is provided in Appendix C. However, in summary, land use across the 2D domain was defined using Mastermap classification data. From this dataset, impermeable surfaces such as land occupied by buildings or roads could be identified. For the direct rainfall model simulations, infiltration losses were applied to those areas of the 2D domain which were not occupied by impermeable surfaces, such as gardens, parks and agricultural land.

The infiltration losses were then represented within the direct rainfall model by applying a constant percentage reduction to the depth of incident rainfall at each time-step during the 1-in-200 year four hour storm. The simulated output hydrographs from the direct rainfall model using sensitivity testing of infiltration losses of between 10% and 80%.

Using the input rainfall boundary model, the total volume of rainfall falling on the Bin Brook catchment in the north and the Vicar's Brook catchment in the south was calculated for each infiltration scenario. This volume was then compared to the volume of water that passed through Plot Output (PO) lines within the TUFLOW model at the confluence with the Cam to assess the percentage run-off from the catchment for a 1 in 200 year event with a storm duration of 240 minutes. The use of PO lines within the model domain allows for further analysis and comparison of flow, velocity and water volume at specific locations between different scenarios and return periods.

The peak flow and shape of the resultant hydrograph derived from the PO line was then compared to hydrological estimates of flood flow using the FEH Statistical method for Vicar's Brook and the ReFH method for Bin Brook. Figure 7.5 shows the results of this analysis for Bin Brook to the north of the Cam and Figure 7.6 shows the results for Vicar's Brook which is on the highly permeable catchment on the south of the River Cam. Based upon this analysis infiltration rates for north and south Cambridge of 15% and 50% were adopted respectively for use through the SWMP modelling.

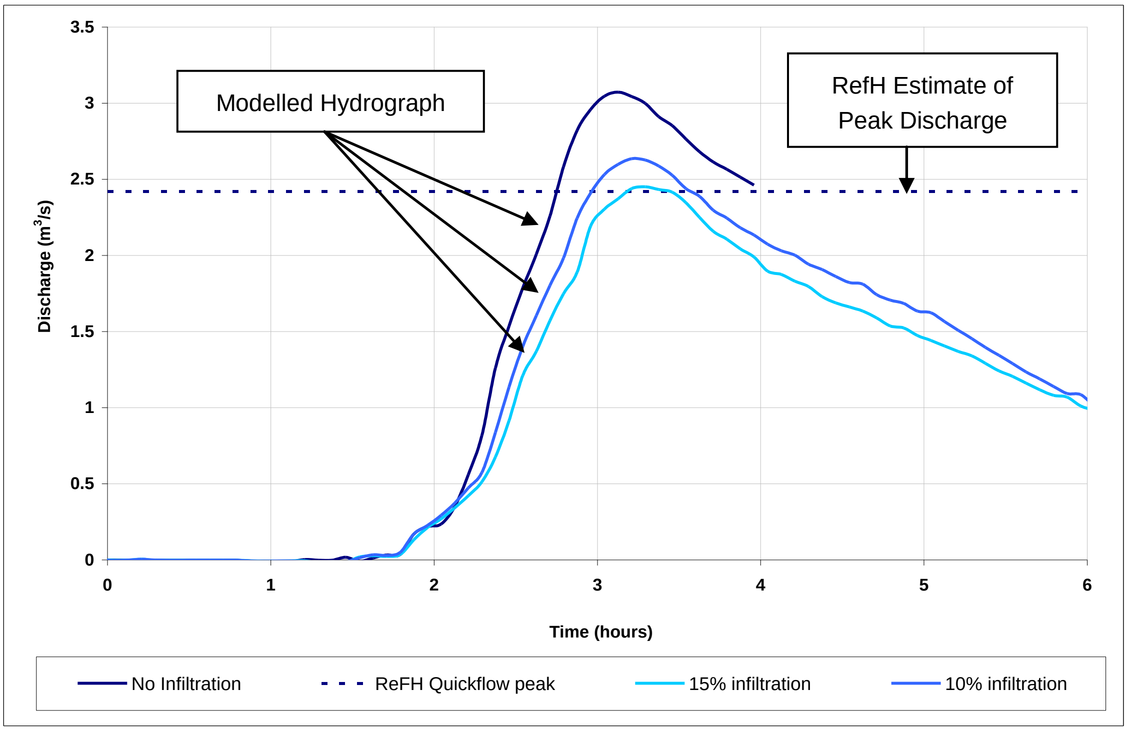


Figure 7-3 TUFLOW Model Sensitivity to Infiltration – Bin Brook

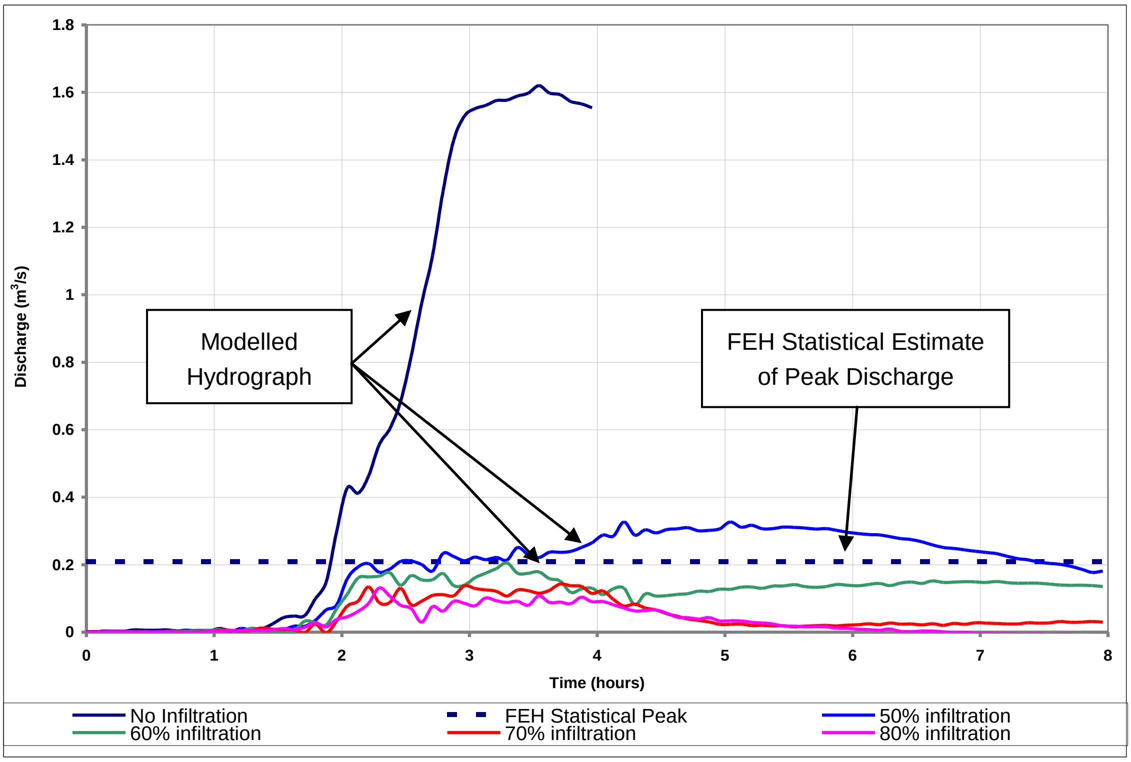


Figure 7-4 TUFLOW Model Sensitivity to Infiltration – Vicar's Brook

8 Wetspot Selection and Prioritisation

Flood Risk Regulations
The assessment of the possible harmful consequences of future floods from local sources of flood risk

8.1 Approach

The principal purpose of a strategic assessment is to identify broad locations which are considered more or less vulnerable to surface water flooding. These are then taken through an intermediate assessment. This chapter describes the selection and prioritisation of areas in line with the strategic and intermediate risk assessment phases. This section is divided into three sub-sections to facilitate the above objective. These are:

- Identification of Potential Wetspot Areas within Cambridge and Milton using the results of the bare earth modelling described in Section 7. This is referred to as Stage 2 of the modelling strategy
- Multi-Criteria Assessment (MCA) Methodology. This describes the agreed MCA approach agreed with the SWMP Project Board.
- Prioritisation of Wetspots within Cambridge and Milton using the MCA methodology.

The objective of the MCA assessment and prioritisation is the identification of two agreed wetspots to be taken forward to the intermediate assessment stage. The workflow to establish the prioritisation is shown in Figure 2.2

8.2 Stage 2 - Identification of Potential Wetspot Areas

A wetspot is an area deemed to be at significant risk of surface water flooding. This risk is identified using either historical flooding reports and / or the Environment Agency's Flood Maps and localised modelling. A number of principles were established in relation to identifying wetspot areas within the Cambridge and Milton SWMP. These were:

- The wetspots were initially identified by depth using the Stage 1 bare earth modelling of north and south Cambridge, historical data and supporting information from Cambridge City Council.
- The wetspots must include all of the upstream contributing areas to ensure that flood flows to the area where water accumulates are considered by the detailed assessment. In order to meet this criterion the velocity and flow outputs from the Stage 1 bare earth model were interrogated to delineate the wetspot, sub-catchment areas.

Figure 8.1 shows the results of the Stage 1 bare earth modelling for a 1 in 200 year (0.5% AEP) return period for Cambridge. Areas of inundation shown in blue are equivalent to a flood depth of between 0.1m and 0.3m. Areas of inundation shown red are equivalent to flood depths greater than 0.3m. The figures allow a preliminary delineation of the wetspot catchments. In particular, there is clearly a well defined accumulation area on the axis of Perne Road and Cherry Hinton Road. There is also evidence of historical flooding within the St Thomas Square area to support the modelling.

Based solely on depth the distinction between various wetspots is less clear to the north of the Cam where there appears to be several separate areas of accumulation. In order to address this uncertainty the velocity vectors associated with the model were interrogated. Figure 8.1 shows the peak velocity vectors for the King's Hedges and Arbury area of north Cambridge.

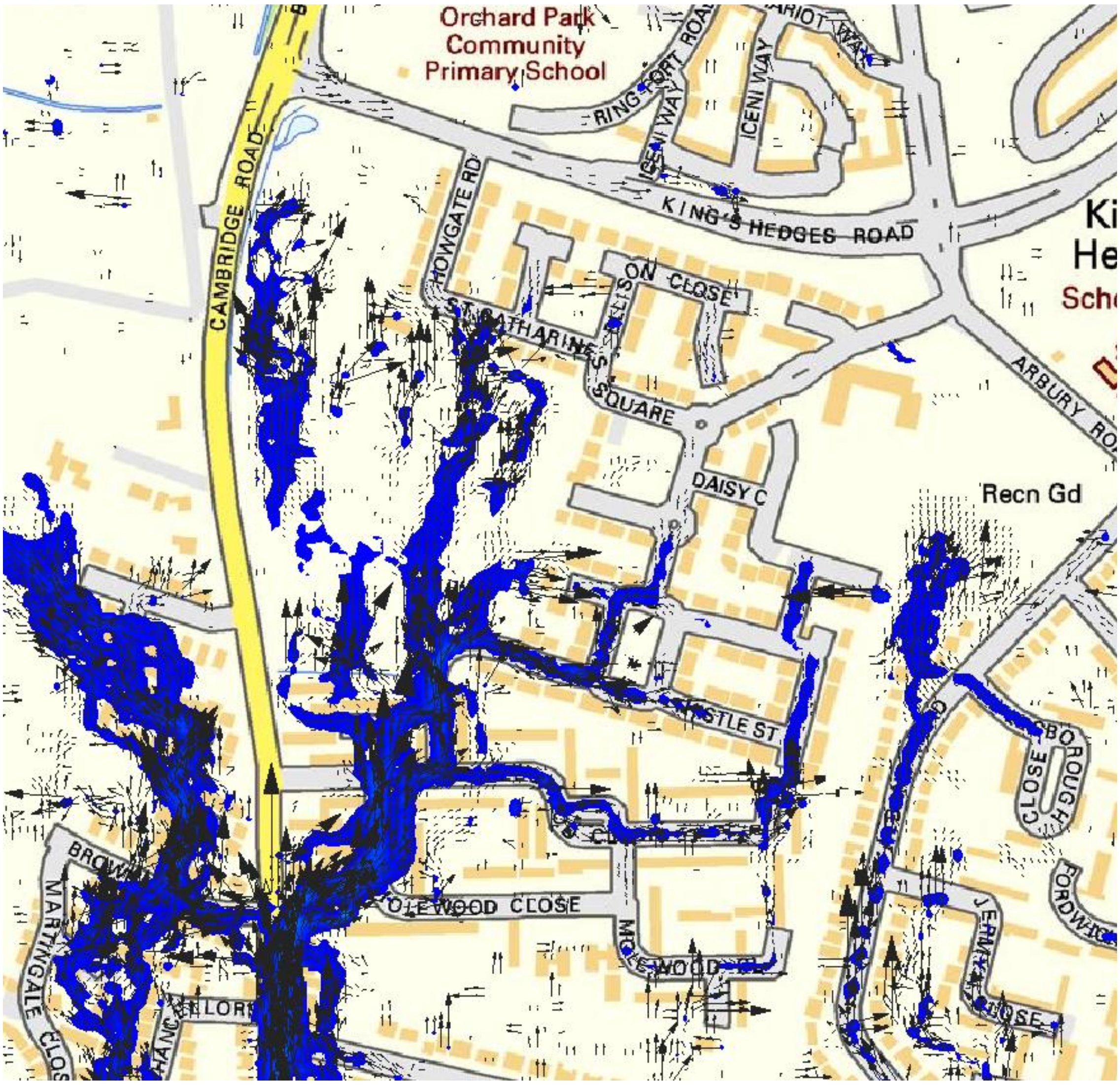


Figure 8-1 Results of Stage 1, Bare Earth Modelling (1 in 200 years – 0.5% AEP) Flow Vectors for King's Hedges & Arbury

In the case of the King's Hedges and Arbury area of Cambridge the wetspot is defined by the principal flow paths as shown in Figure 8.2.

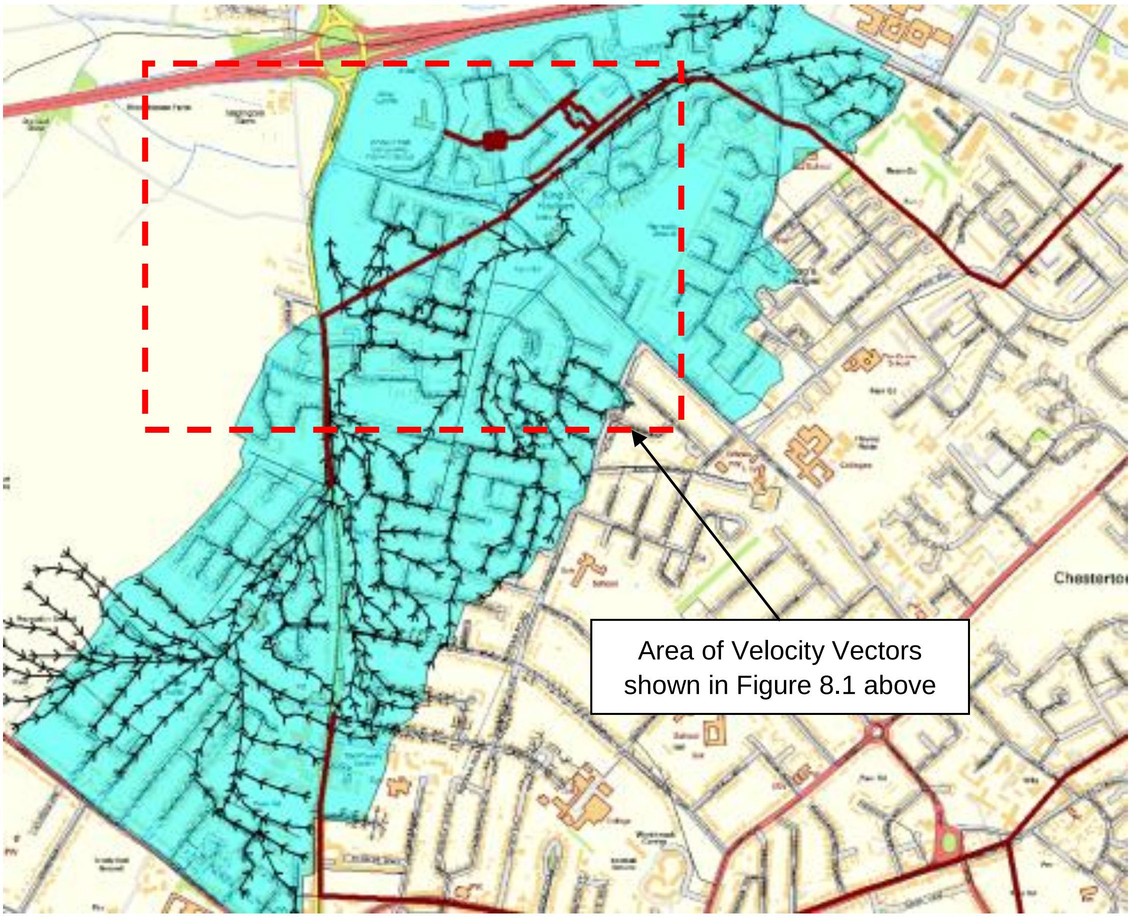


Figure 8-2 Delineation of King's Hedges & Arbury Wetspot (highlighted blue) showing principal flow paths.

For the King's Hedges and Arbury wetspot it is evident that there is a depression to the east of the Cambridge / Cherry Hinton Road and to the south of King's Hedges Road. In this manner eleven wetspots have been identified in Cambridge and Milton. These are listed in Table 8.1 and delineated on Figures 8.3 to 8.13 showing the flood susceptibility output from the WebGIS.

Figure Ref	Wetspot
8.3	Bin Brook
8.4	Vicar's Brook / Hobson's Conduit
8.5	Cherry Hinton
8.6	Cherry Hinton Village
8.7	Coldham's Common
8.8	Milton Village
8.9	North Chesterton
8.10	South Chesterton
8.11	Castle School
8.12	King's Hedges and Arbury
8.13	Cambridge City Centre

Table 8.1 Stage 2 Wetspots for Cambridge and Milton and their associated figure numbers

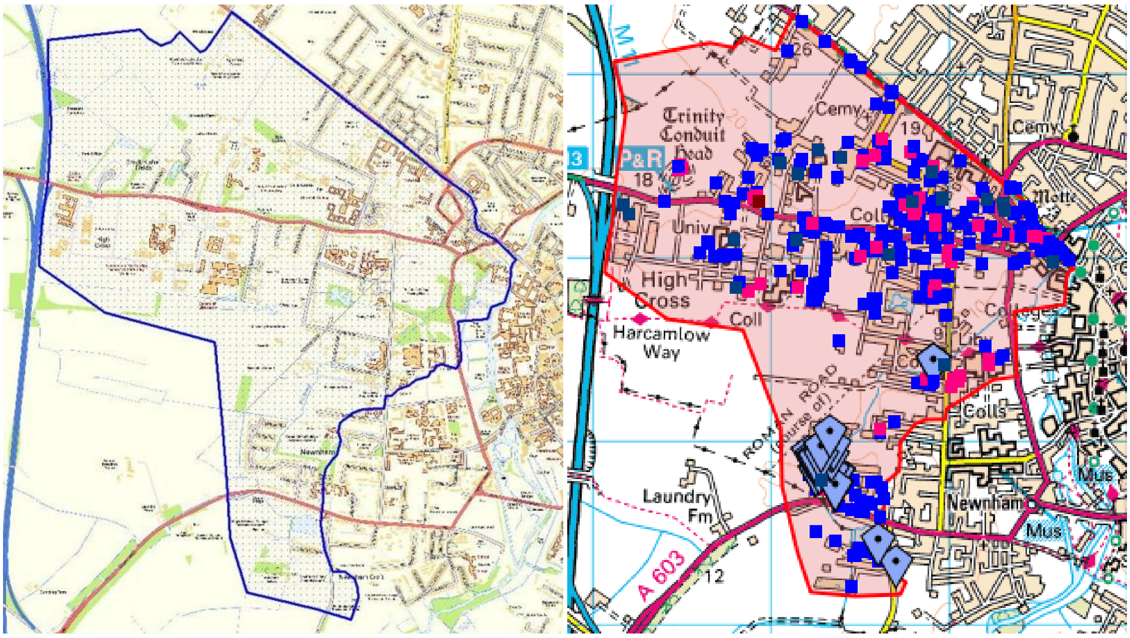


Figure 8-3 Location of Bin Brook wetspot

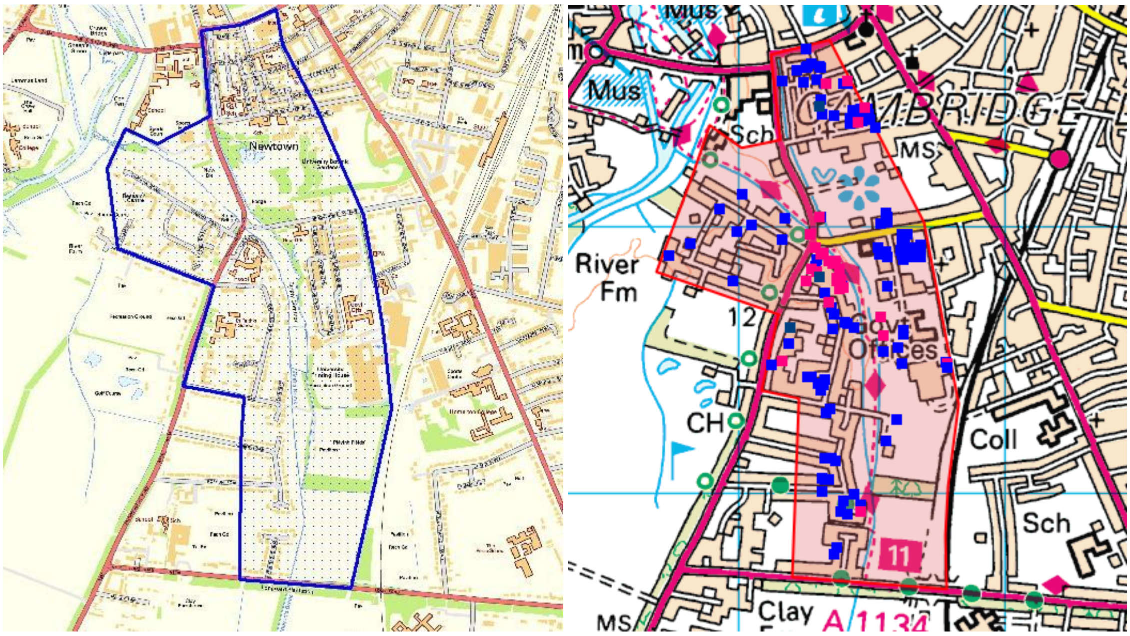


Figure 8-4   Location of Vicar's Brook / Hobson's Conduit wetspot

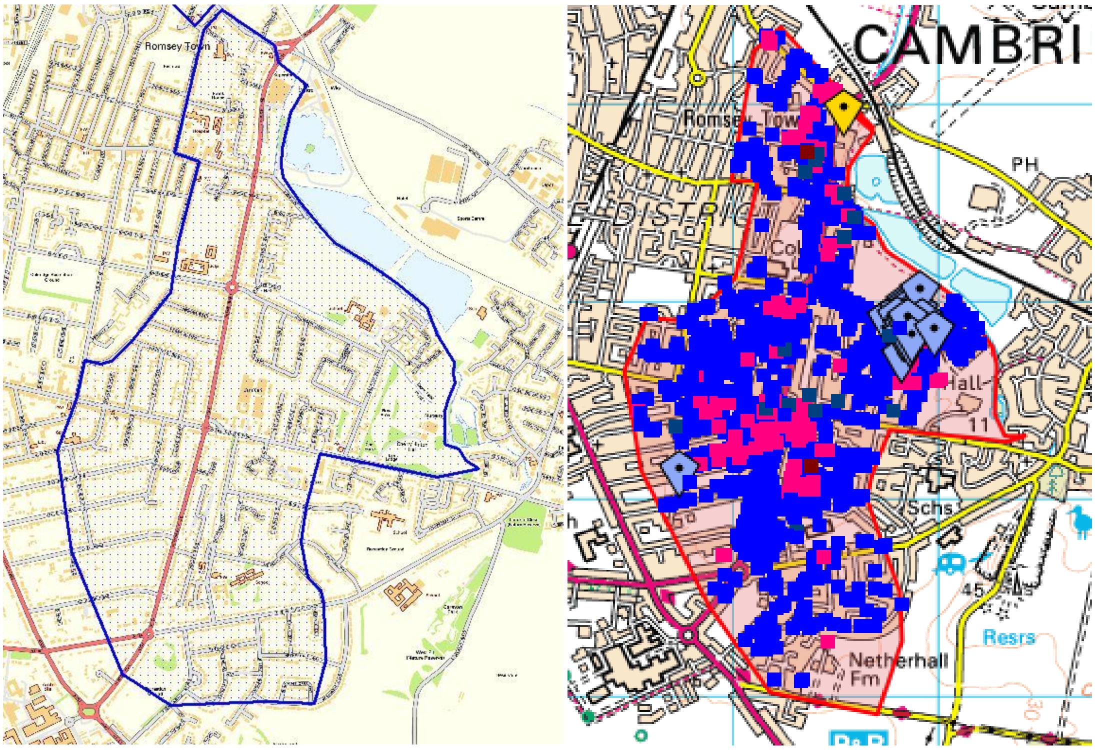


Figure 8-5   Location of Cherry Hinton wetspot

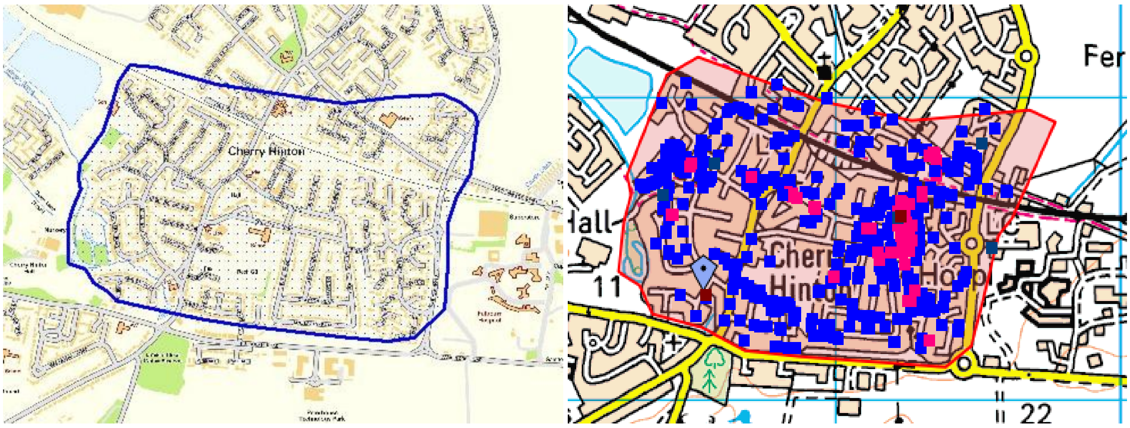


Figure 8-5 Location of Cherry Hinton Village wetspot

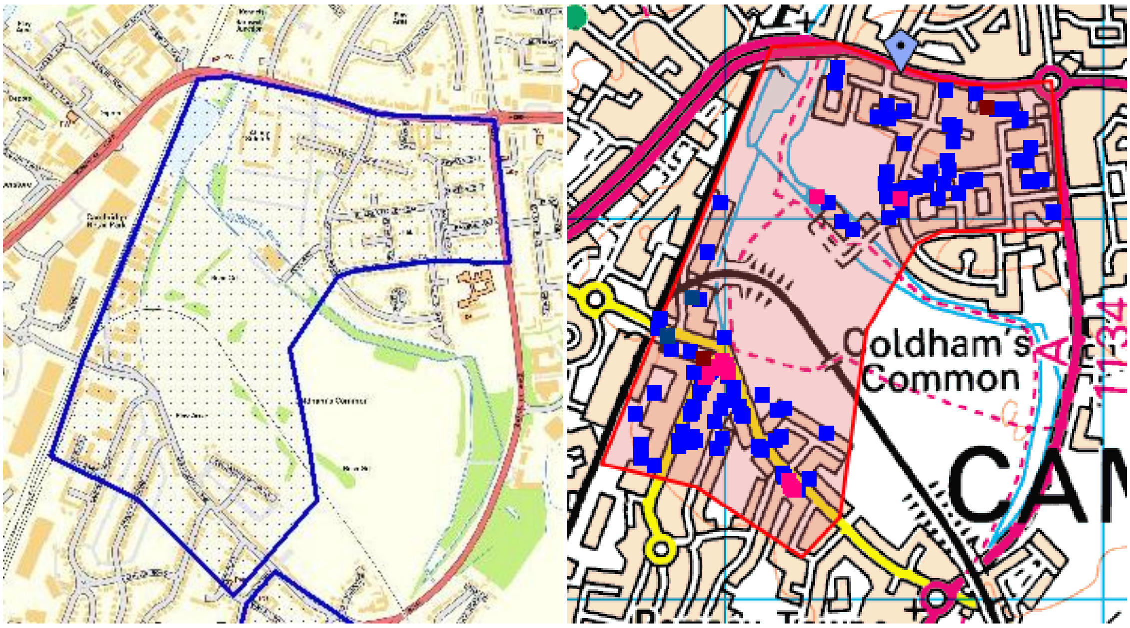


Figure 8-6 Location of Coldham's Common wetspot

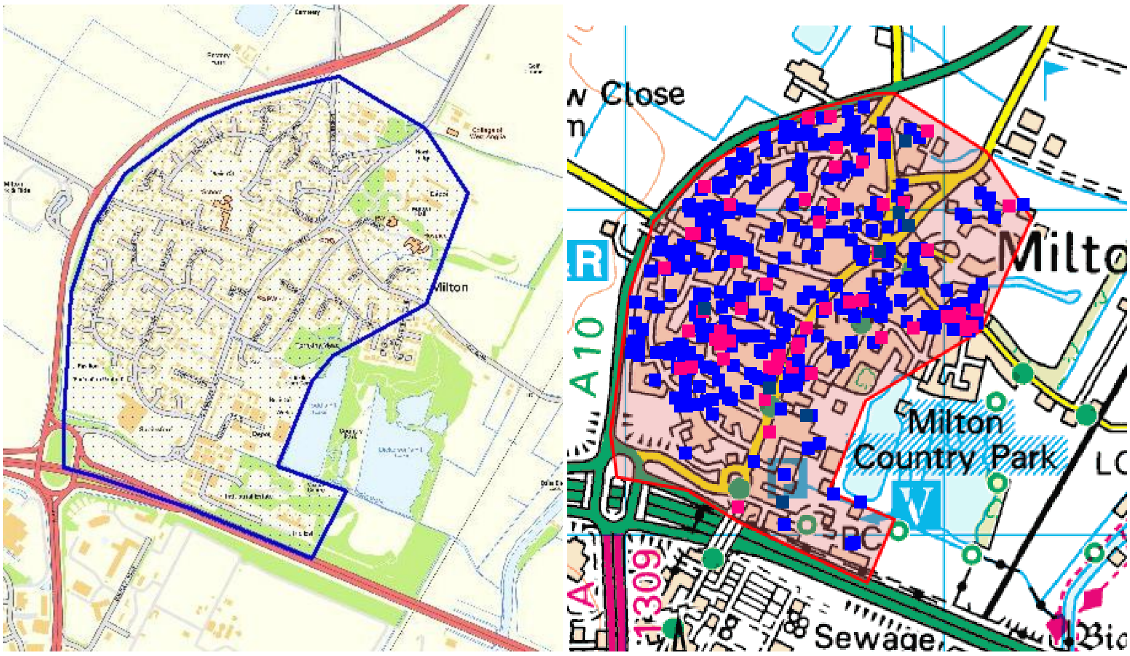


Figure 8-7 Location of Milton Village wetspot

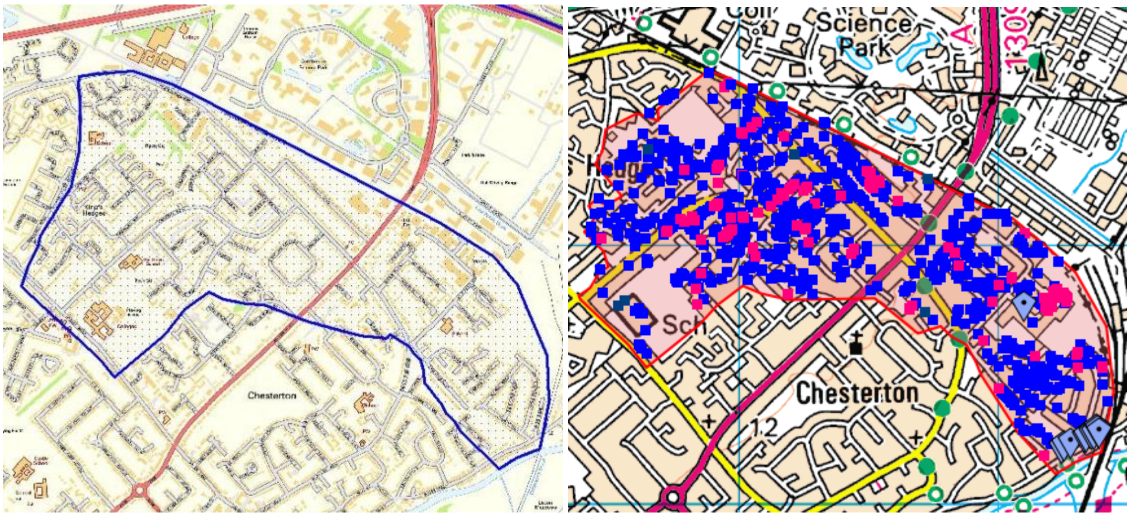


Figure 8-8 Location of North Chesterton wetspot

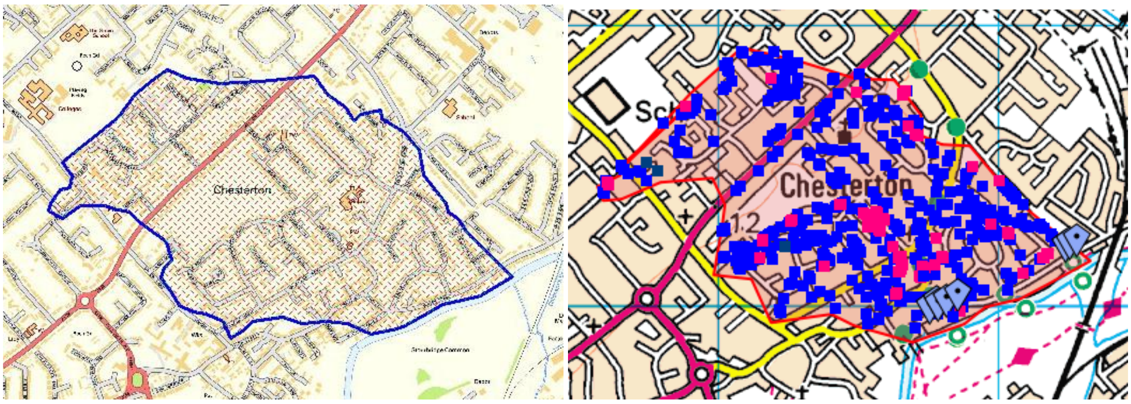


Figure 8-9 Location of South Chesterton wetspot

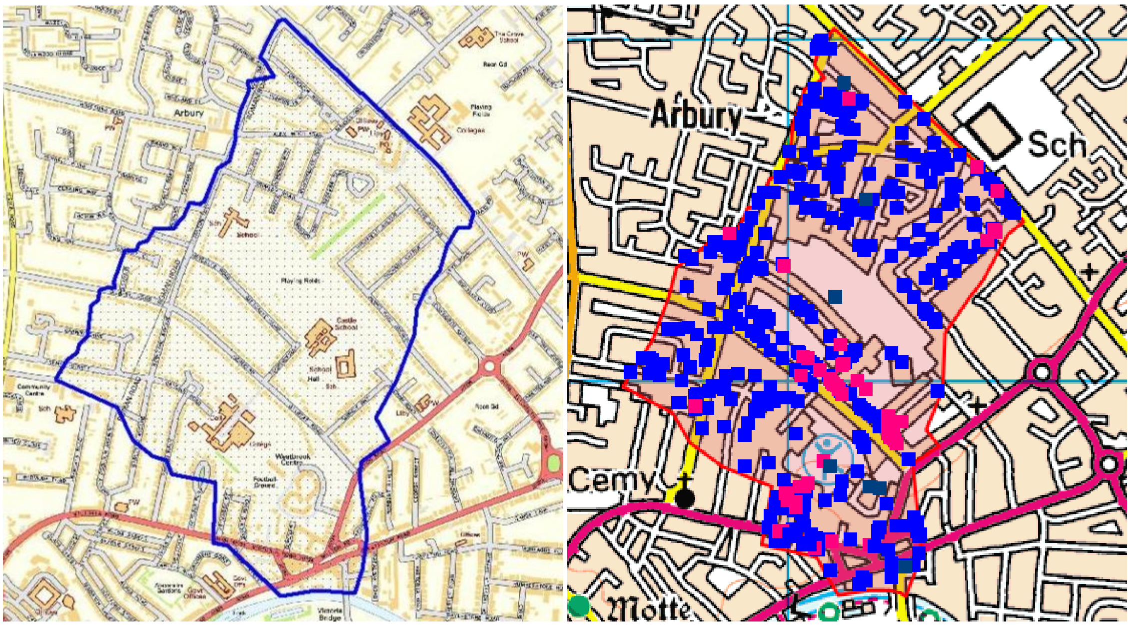


Figure 8-10 Location of Castle School wetspot

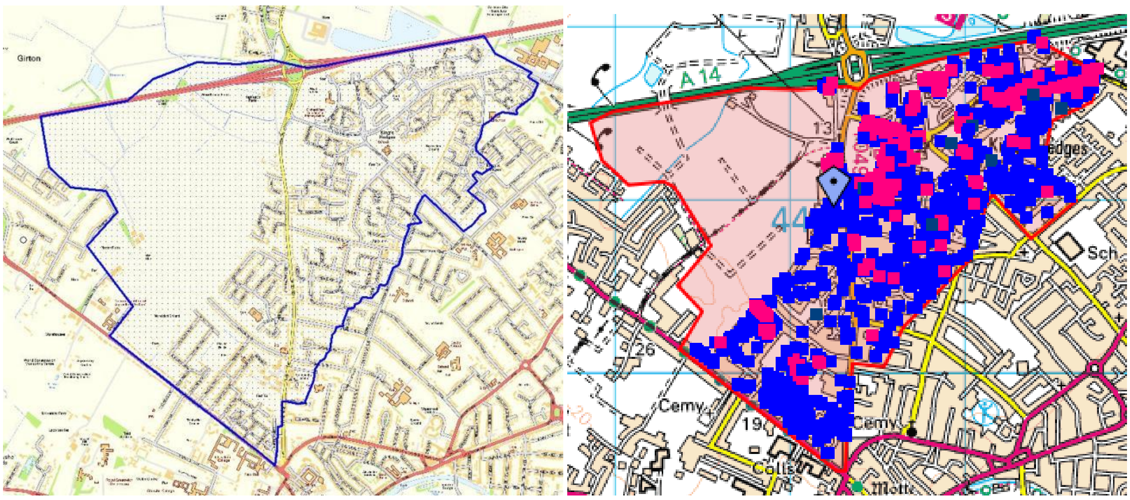


Figure 8-11 Location of King's Hedges and Arbury wetspot

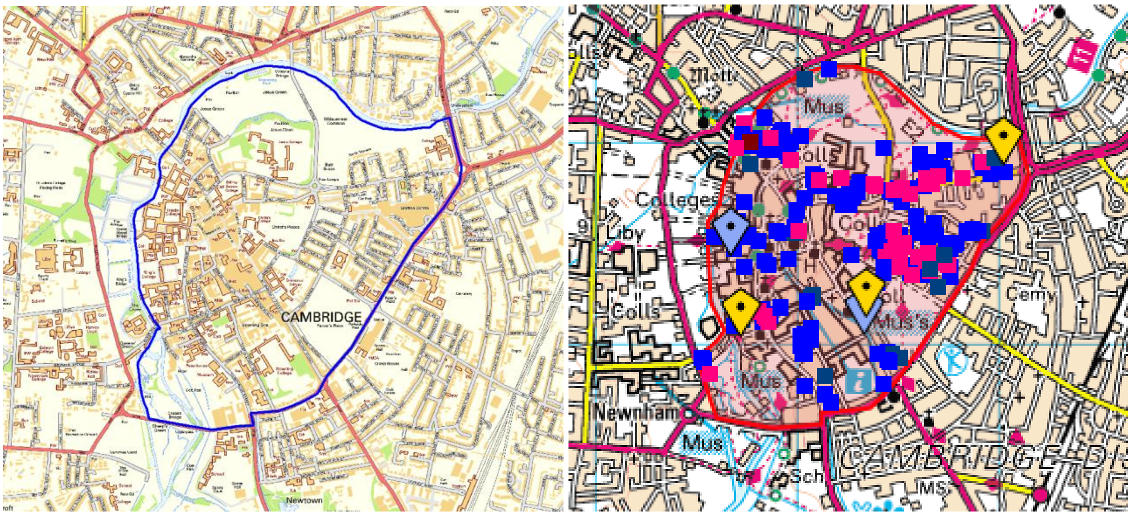


Figure 8-12 Location of Cambridge City wetspot

8.3 Multi-Criteria Assessment Methodology

8.3.1 Introduction

Multi Criteria Analysis is a scoring and weighting methodology by which the impact of flooding on a wide range of receptors can be evaluated. It is frequently used in conjunction with benefit cost analysis to prioritise and determine investment strategies to mitigate the risk of flooding. MCA allows for comparison of severity of flooding between regions based upon the perceived value of buildings, infrastructure, commercial enterprise and services. Five receptors types have been used within the MCA and are listed below. They will be discussed in more detail later in the following sections.

- Domestic Properties
- Critical Infrastructure
- Non-Domestic Properties
- Transportation
- Land and Public Open Space
- Cultural

Multi-Criteria can be adapted through the adjustment of weightings to reflect the needs and concerns of society. This is particularly where there is social, amenity or environmental factors which are considered to be important but where it is difficult to assign an economic value. Within the Cambridge and Milton SWMP Multi Criteria Analysis has been used as a high level decision making tool to compare and prioritise wetspots. The surface water MCA calculations are based on a flood depth weighting multiplied by a weighting for each receptor type (see Section 8.3.2 for more details). The general format of the formulae used for the Cambridge and Milton SWMP is shown in Figure 8.14.

The weightings for all receptors used for the Cambridge and Milton SWMP were discussed with the Project Board during a workshop in December 2010 and then agreed following further consultation with CCC's emergency planning team and Natural England

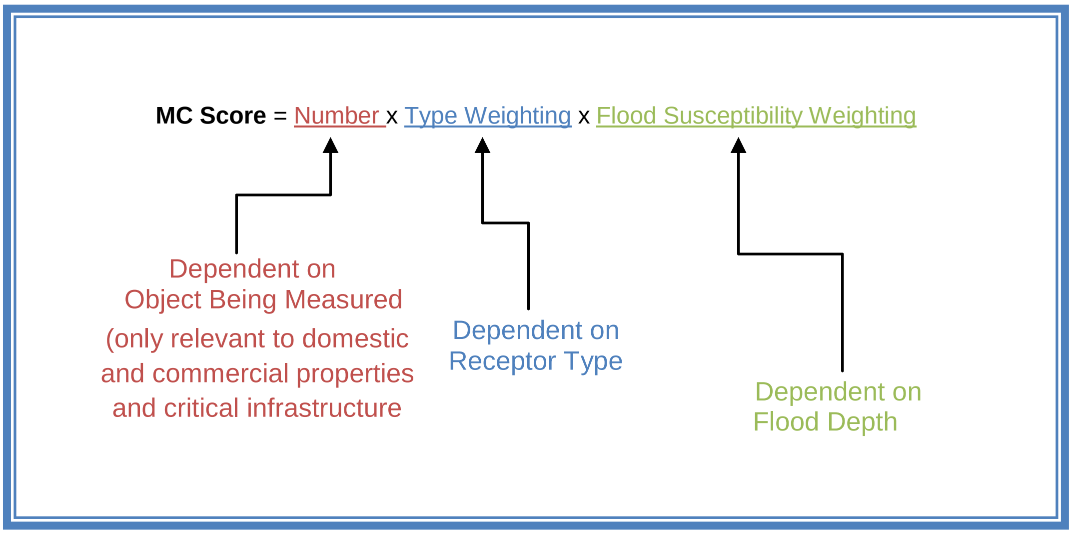


Figure 8-14 MCA Scoring (General Format)

8.3.2 Flood Susceptibility Weighting

The flood susceptibility weighting is common to all receptors and is based upon the flooded depth. Flood depths for Cambridge and Milton have been extracted from the bare earth modelling and uploaded to the Web GIS for all receptor types within the Cambridge and Milton area. The flood susceptibility weighting has been based upon assigning the weightings shown in Table 8.2.

Susceptibility	Flood Depth (mm)	Weighting Applied
High	300 and above	2
Medium	100 – 300	1
Low	Less than 100	0

Table 8.2 MCA Flood Susceptibility Weightings

Figure 8.15 shows an extract from the Web GIS showing an area within the King's Hedges and Arbury wetspot.

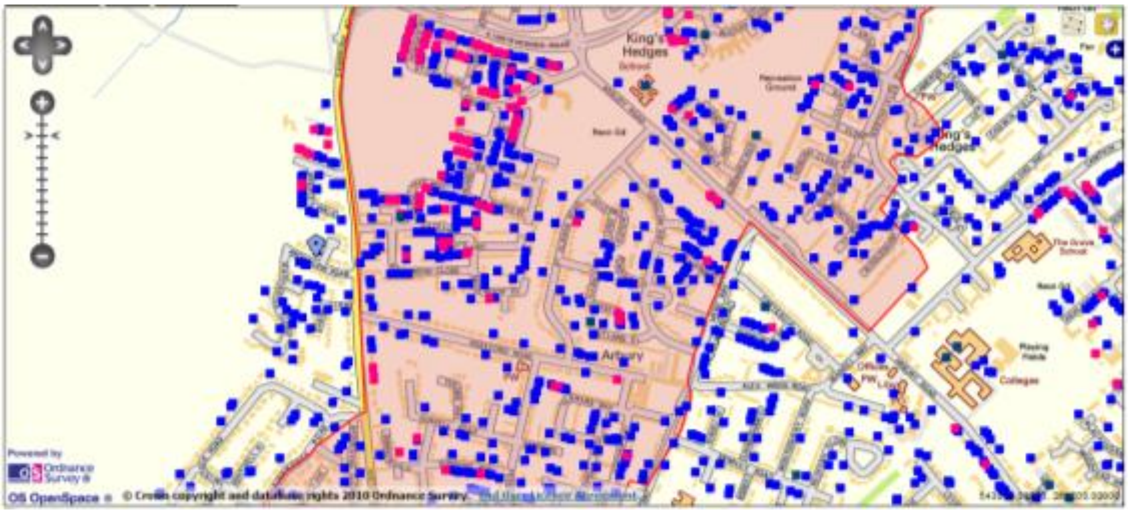


Figure 8-15 Susceptibility Weightings for Kings Hedges and Arbury Wetspot

All property shown in blue would be subject to between 0.1m and 0.3m depth of flooding based upon the stage 1 bare earth modelling for a 1 in 200 year rainfall event. Similarly property shown in red would be flooded to a depth greater that 0.3m in the same event.

8.3.3 Type Weighting

Domestic Properties

The multi-criteria scoring system for domestic properties is shown in Figure 8.16. The SWMP Project Board has agreed that the Type weighting should be set to 2.34 (based on the average national occupancy rate), in line with the EA's guidance. The MCA in this case reflects the number of people affected by flooding. In addition the SWMP Project Board agreed that the social class weighting should not be applied to each property individually but as a lumped weighting for each wetspot. More discussion on this issue is given later in this section.

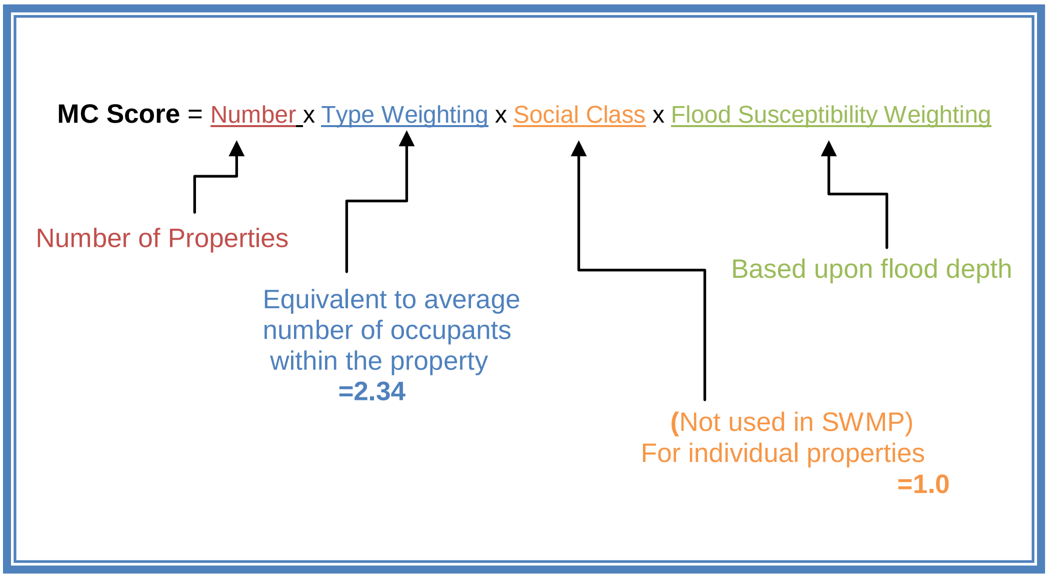


Figure 8-16 MCA Scoring for Domestic Properties

Social Class Categorisation

The Social Class Categorisation is a correction factor that can be applied to the MCA which takes into account social status of occupants for domestic property. Table 8.3 details the four social classes.

Social Class	Description
AB	Upper middle and middle class; higher and intermediate managerial, administrative or professional
C1	Lower middle class; supervisory or clerical and junior managerial, administrative or professional
C2	Skilled working class; skilled manual workers
DE	Working class and those at the lowest level of subsistence; semi-skilled and unskilled manual workers. Unemployed and those with no other earnings (e.g. state pensioners)

Table 8.3 Social Class Weightings and Descriptions

These are from the 2001 Census and can be found on the NOMIS website[16]. The values used in the MCA for each wetspot are listed in Section 8.5.

Commercial Properties

The multi-criteria scoring system for commercial properties is shown in Figure 8.14. The property types are based upon the Multi-Coloured Manual (MCM) and include a range of commercial categories. The categories including the MCM land use code and weightings are shown in Appendix D.

Critical Infrastructure

The multi-criteria scoring system for critical infrastructure is shown in Figure 8.14. The type weightings include a range of categories. The categories including the MCM land use code and weightings are shown in Appendix D. MCA weightings for critical infrastructure was agreed with the project board, following consultation with CCC Emergency Planners.

Transport Infrastructure

The multi-criteria scoring system for transport infrastructure is shown in Figure 8.14. The SWMP Project Board decided to derive the Type Weighting for the impacted roads on the traffic flow information. Transport information and associated traffic flows were provided by CCC's Highways Department. This information included the National Street Gazetteer for the county area and the 2009 Traffic Monitoring Report. The type weightings include a range of categories. The categories including weightings are shown in Appendix D.

Land and Public Open Space

The multi-criteria scoring system for Land and Public Open Space is shown in Figure 8.14. These categories were agreed with Natural England and the SWMP Project Board. The type weightings include a range of categories. The categories including weightings are shown in Appendix D.

Cultural Receptors

Information about listed buildings and conservation areas were obtained from the County and District Councils and English Heritage.

8.4 Prioritisation of Wetspot Areas

8.4.1 Example Calculation

As noted in the previous section depth information from the model scenarios was uploaded to the Web GIS tool for analysis and the use of the Web GIS is illustrated below with an example. St Thomas Square is an area of Cambridge which has historically been affected by flooding (see Figure 8.17). The blue kites indicate properties which have been historically flooded with the blue and red squares are the bare earth model results.

Figure 8-17 St Thomas Square Wetspot

The wetspot for St Thomas Square was enclosed by drawing a polygon directly on the Web GIS and within the wetspot are 158 domestic properties and 1 high school vulnerable to inundation in a 1 in 200 year event. In addition, it is understood that 26 domestic properties and the school were flooded in 2001. The return period for this event based upon the rainfall record is understood to be in the order of 1 in 50 years (equivalent to an Annual Equivalent Probability (AEP) of 2%).

Figure 8.18 shows the calculation used by the WebGIS to calculate the MCA score for both the modelled and historical information. The analysis presented in the report gives the modelled and historical MCA score which are 2.1 and 2.7 respectively and the sum of the modelled and historical which is 4.8 adjusted for social categorisation and the annual probability of flooding.

Multi-Criteria Analysis (Based on Modelled Flood Depths)

Domestic (Houses)

MC Score = Number x Type Weighting x Social Class x Flood Susceptibility Weighting

MC Score = 137 x 2.34 x 1 x 1 = **321** (Medium flood susceptibility)

MC Score = 21 x 2.34 x 1 x 2 = **49** (High flood susceptibility)

Critical infrastructure (School)

MC Score = Number x Type Weighting x Flood Susceptibility Weighting

MC Score = 1 x 50 x 1 x 1 = **50** (Medium flood susceptibility)

Total Domestic & Critical Infrastructure = 420

Allowances for Return Period and Social Categorisation

Modelled Return Period (1 in 200 years) = 0.005 (as probability)

Social Categorisation Weighting = 1.051

Multi Criteria Score (Modelled) = 420 x 0.005 x 1.051 = 2.2

Multi-Criteria Analysis (Based on Historical Information)

Domestic (Houses)

MC Score = Number x Type Weighting x Social Class x Flood Susceptibility Weighting

MC Score = 19 x 2.34 x 1 x 1 = **44** (Medium flood susceptibility)

MC Score = 7 x 2.34 x 1 x 2 = **33** (High flood susceptibility)

Critical infrastructure (School)

MC Score = Number x Type Weighting x Flood Susceptibility Weighting

MC Score = 1 x 50 x 1 x 1 = **50** (Medium flood susceptibility)

Total Domestic & Critical Infrastructure = 127

Allowances for Return Period and Social Categorisation

Historical Return Period (1 in 50 years) = 0.02 AEP

Social Categorisation Weighting = 1.051

Multi Criteria Score (Historical) = 127 x 0.02 x 1.051 = 2.7

Figure 8-18 MCA Example Scoring St Thomas Square (Modelled & Historical Data)

8.5 Locations for Detailed Assessment

The Web GIS has been used to undertake the prioritisation based upon the methodology described above. Table 8.4 shows the results of the modelled MCA Scores and Table 8.5 shows the historical MCA scores.

Web-GIS ID	Wetspot	Web-GIS MCA Score	AEP Weighting	Social Weighting	MCA Score
34	King's Hedges & Arbury	5,848	0.005	1.196	34.1
3 + 36	Cherry Hinton (North & South)	6,042	0.005	1.051	31.3
30	North Chesterton	3,760	0.005	1.196	22.3
35	Bin Brook	3,678	0.005	1.140	20.3
32	South Chesterton	3,072	0.005	1.058	16.1
6	Milton	2,199	0.005	1.196	12.4
33	Castle School	1,806	0.005	1.196	10.5
38	Cambridge City	1,709	0.005	1.114	8.9
37	Cherry Hinton Village	1,449	0.005	1.000	7.2
4	Vicar's Brook	938	0.005	1.600	6.4
5	Coldham's Common	594	0.005	1.201	3.4

Table 8.4 Multi-Criteria Analysis Summary (Modelled Data Scores)

Web-GIS ID	Wetspot	Web-GIS MCA Score	AEP Weighting	Social Weighting	MCA Score
35	Bin Brook	102	0.020	1.140	2.3
3 + 36	Cherry Hinton (North & South)	147	0.020	1.051	1.7
32	South Chesterton	42	0.020	1.058	0.9
30	North Chesterton	29	0.020	1.196	0.7
38	Cambridge City	8	0.020	1.114	0.2
5	Coldham's Common	3	0.020	1.201	0.1
4	Vicar's Brook	0	0.020	1.600	0.0
6	Milton	0	0.020	1.196	0.0
33	Castle School	0	0.020	1.196	0.0
34	King's Hedges & Arbury	0	0.020	1.196	0.0
37	Cherry Hinton Village	0	0.020	1.000	0.0

Table 8.5 Multi-Criteria Analysis Summary (Historical Scores)

Table 8.6 shows the combined modelled and historical data. The King’s Hedges & Arbury and Cherry Hinton (North & South) wetspots obtain the highest score for both the modelled and combined approaches by some margin to the third placed wetspot of North Chesterton. Bin Brook and South Chesterton are the highest scorers in terms of the historical information. However it is recognised that under-reporting of flooding may be mis-representing the historical scores.

Web-GIS ID	Wetspot	Total Web-GIS Score	Total MCA Score
34	King's Hedges & Arbury	5848	34.1
3 + 36	Cherry Hinton (North & South)	6189	33.0
30	North Chesterton	3789	23.0
35	Bin Brook	3780	22.7
32	South Chesterton	3114	17.0
6	Milton	2199	12.4
33	Castle School	1806	10.5
38	Cambridge City	1718	9.1
37	Cherry Hinton Village	1449	7.2
4	Vicar's Brook	938	6.4
5	Coldham's Common	596	3.4

Table 8.6 Combined Modelled and Historical MCA Scores

On the basis of the combined historical and modelled MCA scores it was recommended that the Cherry Hinton and King’s Hedges & Arbury wetspots should be progressed to detailed analysis within this phase of work. This was agreed with the SWMP Project Management Board. The remaining nine wetspots should continue to be monitored, particularly with a view to using any future development in these areas to help to mitigate the flood risk.

9 Detailed Assessment

9.1 Stage 3 - Detailed Model Development

Following the identification of the Cherry Hinton and King's Hedges / Arbury Estate as 'Priority Wetspots', further detailed modelling has been undertaken to refine the existing Stage 2 model to a geographically smaller region. Accordingly, direct rainfall models have been developed for the Cherry Hinton and King's Hedges / Arbury wetspots. These models have been developed to enable a greater level of detail to be incorporated into the TUFLOW domain (e.g. storm sewer network, existing SuDS schemes and engineering options) whilst at the same time reducing the grid size to give better resolution to the output and maintaining reasonable model run-times.

The common principles discussed in Section 7.2 associated with roughness, representation of buildings, including the use of PO lines discussed in Section 7.2.3 are applicable to the Stage 3 modelling. In addition, the rainfall boundary hyetograph used for the Stage 3 bare earth models has also been applied to the Stage 3 models. Specific details associated with the Cherry Hinton and King's Hedges / Arbury Estate models are discussed in the following sections.

The objective of Stage 3 modelling is to understand and quantify the effects of surface water flooding and to model the effectiveness of any proposed engineering option elements to mitigate for the effects of surface water flooding for doing nothing, doing the minimum and doing something options. The following sections include discussion on the development of the doing nothing and doing the minimum models which form the basis of the economic assessment. The configuration of engineering options and their incorporation within the models is discussed in Section 11.

9.1.1 Cherry Hinton Wetspot

Following Stage 2 the surface water sub-catchment was defined and determined the model boundary for Stage 3. The extent of the model domain is shown in Figure 9.1.

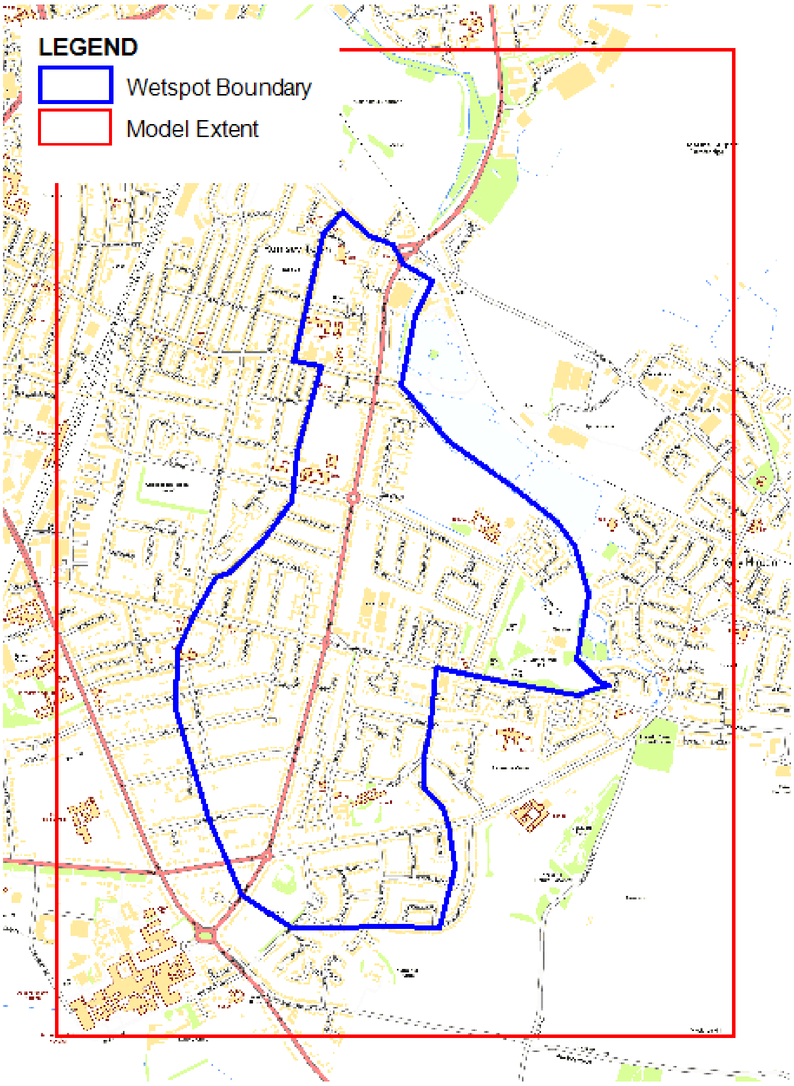


Figure 9-1 Cherry Hinton Wetspot

The model extent was chosen based on the Stage 2 modelling results and analysis of the 2D domain for this sub-catchment. It is possible that areas to the North-West of the domain and South East of the domain do not drain toward the Cherry Hinton study area. The model extent to the East was extended to ensure that the area of Cherry Hinton Village that drained towards Cherry Hinton was included within the rainfall model.

Model Parameters

Grid Size	3 m
Time Step	1 sec
Bare Earth Storm Durations	240
Infiltration	15%
Modelling Return Periods	1 in 30, 50, 75, 100, 200 years
Storm Duration	4 hours
Total Run Time	8 hours

Table 9.1 Cherry Hinton Model Parameters

The main progressions between the Stage 1 and Stage 3 assessment was the refinement of the grid size and the inclusion of the sewer network system provided by Anglian Water apart from the doing nothing scenario (shown in Figure 9-2).

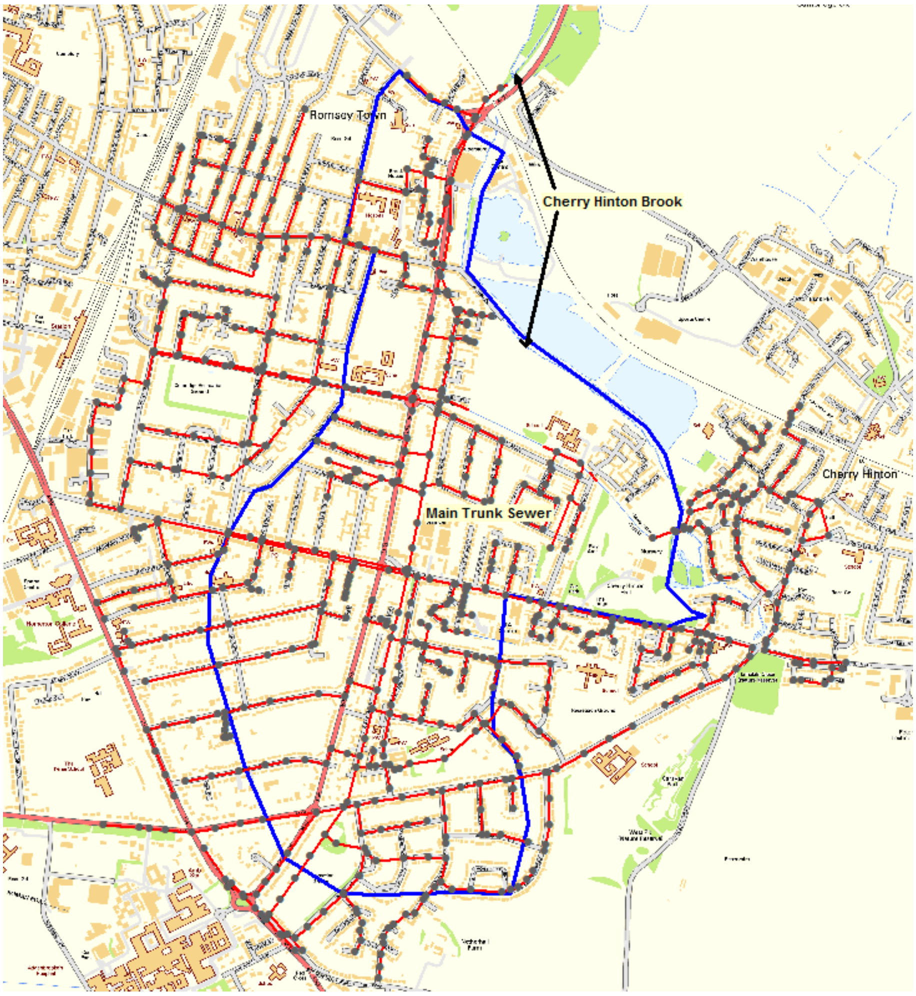


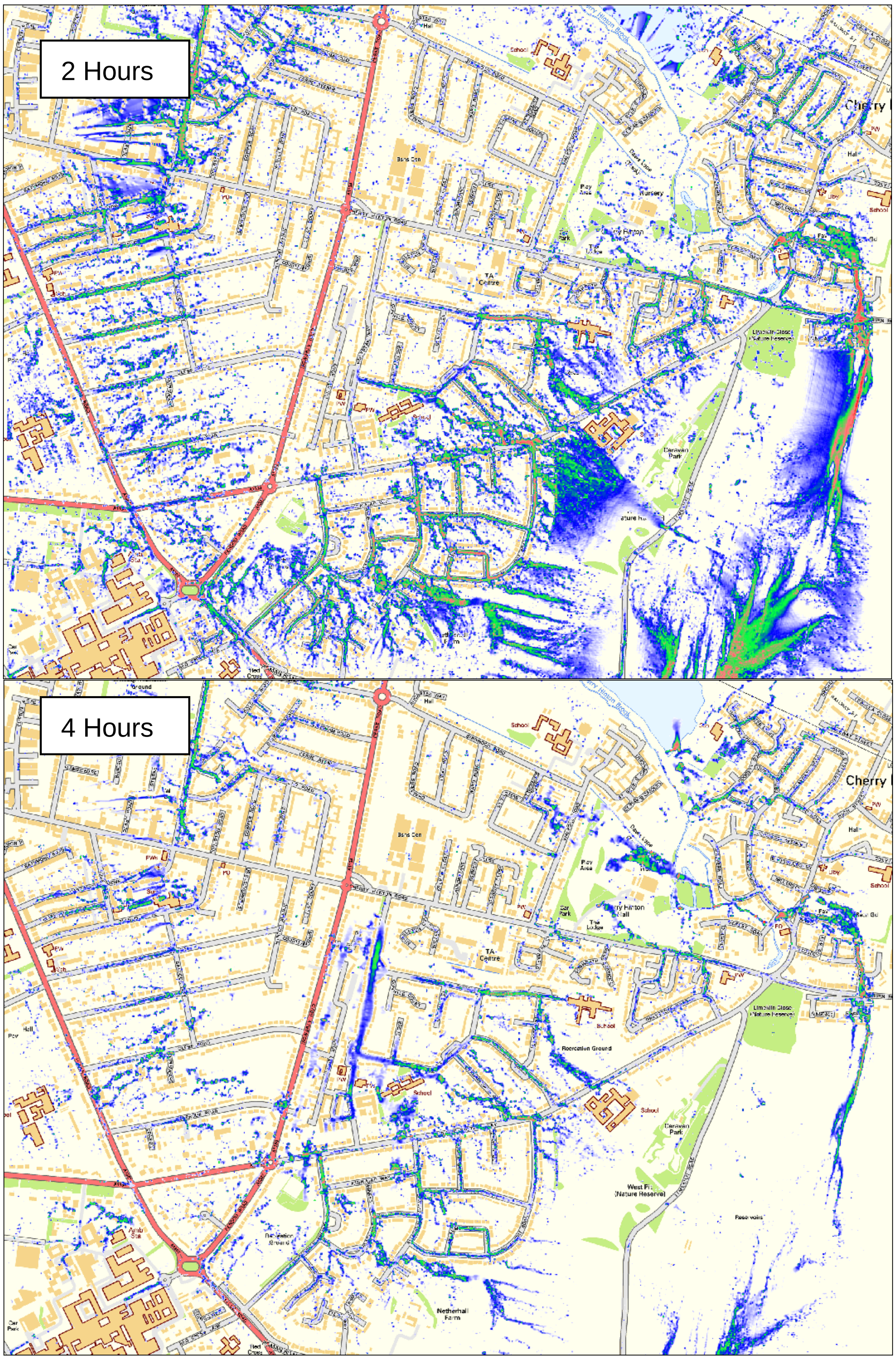
Figure 9-2 Cherry Hinton Wetspot boundary and storm sewer network

Figure 9-3 to Figure 9-XX summarise some of the key flow routes, and surface water flooding issues in the Cherry Hinton wetspot. The images are taken from the 1 in 200 year rainfall event, do nothing model scenario (does not take in to account any drainage network).

Figure 9-3 shows flow velocities at 2 hours and 4 hours. The majority of flows through the Cherry Hinton area occur in the first 4 hours of the rainfall event. Water flows from the periphery of the catchment, where land is relatively steeper and routes through the urban area, predominantly flowing along roads.

As flows diminish during the latter part of the rainfall event ponding can be seen particularly south of Cherry Hinton Road around Mander Way (See Figure 9-4). The ponding in this area is possibly due to the Cherry Hinton Road acting as a barrier to flows.

Figure 9-5 summarises the max depths across the study catchment for this event. Ponding to the south of Cherry Hinton road is again noticeable, as is an area of flood depths between 0.1-0.3m in the St Thomas Square area.



Key

Velocity (m/s)

(white)	0-0.05
(blue)	0.05-0.15
(green)	0.15-0.25
(pink)	0.25-0.5
(red)	0.5+

Figure 9-4 – Velocities in Cherry Hinton During the 1 in 200 year rainfall event at 2 and 4 hours (Do Nothing Scenario)

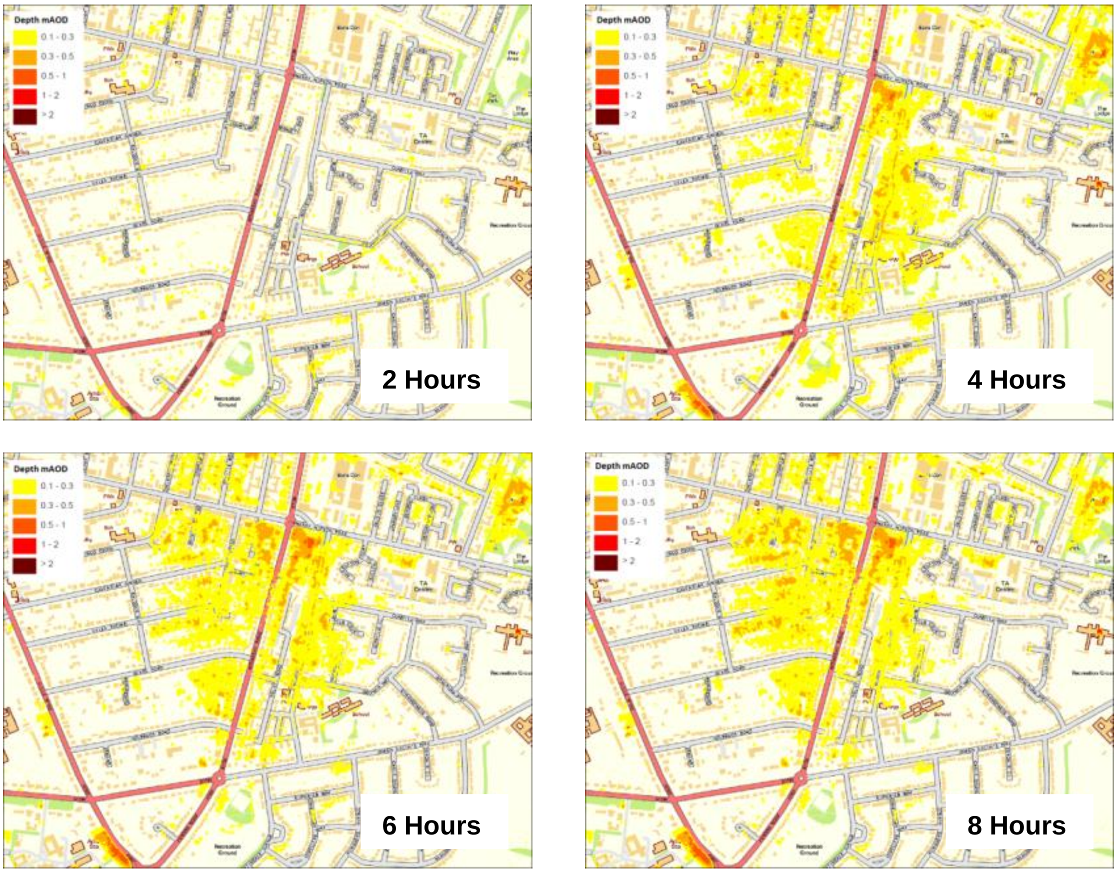


Figure 9-3 – Cherry Hinton TUFLOW Model Results Depth (0.5% AEP) at varying times during the Do Nothing Scenario

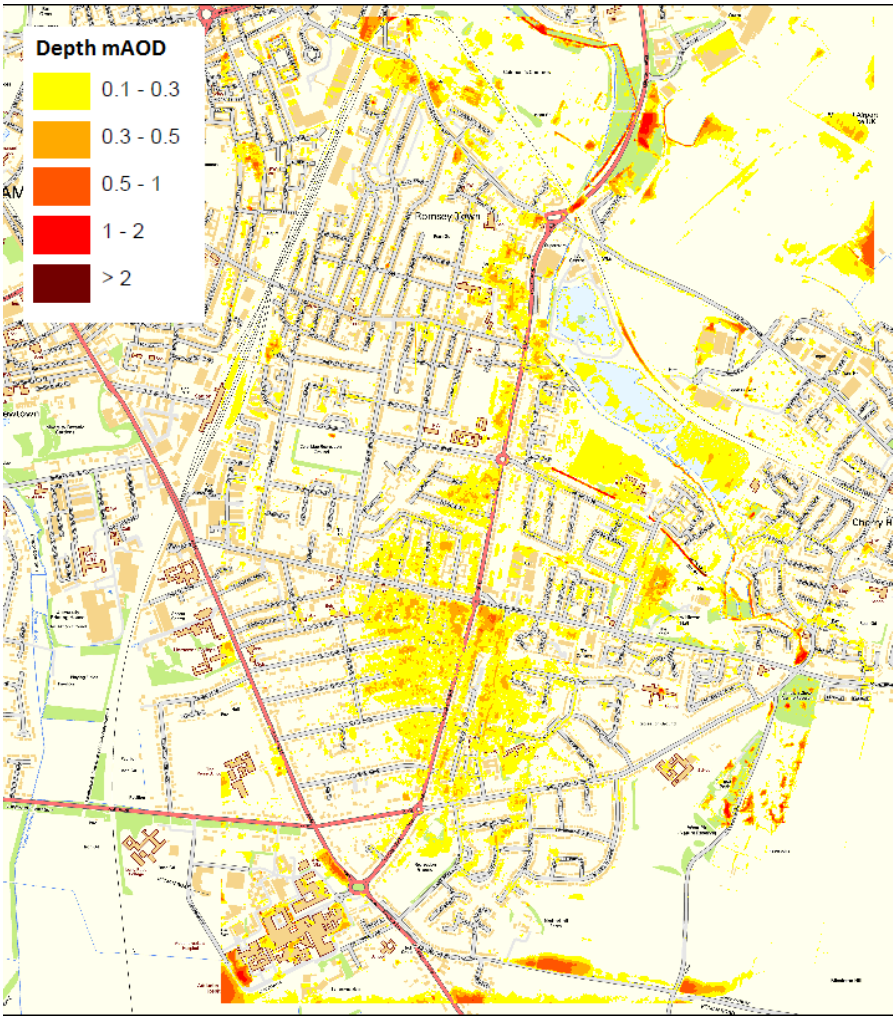


Figure 9-4 – Cherry Hinton TUFLOW Model Results (0.5% AEP) – Maximum Depth (Do Nothing Scenario)

9.1.2 King's Hedges and Arbury Wetspot

Following Stage 2 the surface water sub-catchment was defined and determined the model boundary for Stage 3. The extent of the model domain is shown in Figure 9.6.

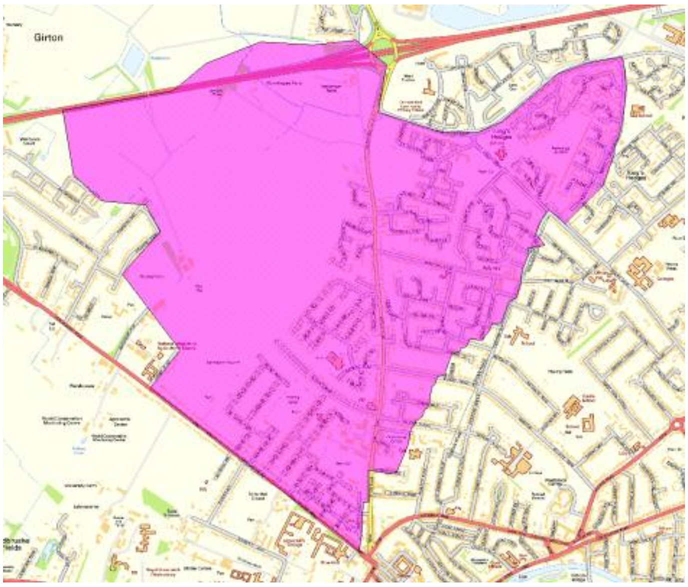


Figure 9-6 King's Hedges and Arbury Wetspot (TUFLOW Model Domain Boundary)

It should be noted that the model domain shown above is geographically larger than the wetspot boundary. This ensures that the NIAB housing development and its drainage is explicitly included within the model. The approach adopted within Stage 1 for the rainfall boundary, rate of infiltration, LiDAR, roughness and representation buildings remained unchanged for the detailed modelling within Stage 3 with the model parameters shown in Table 9.2.

Model Parameters	
Grid Size	2 m
Time Step	1 sec
Bare Earth Storm Durations	240
Infiltration	15%
Modelling Return Periods	1 in 30, 50, 75, 100, 200 years
Storm Duration	4 hours
Total Run Time	8 hours

Table 9.2 Stage 3 Model Parameters

The main progressions between the Stage 1 and Stage 3 assessment was the refinement of the grid size and the inclusion of the sewer network system provided by Anglian Water (shown in Figure 9.7). The 1D representation of the existing stormwater sewer was included in all Stage 3 runs apart from the doing nothing scenario.

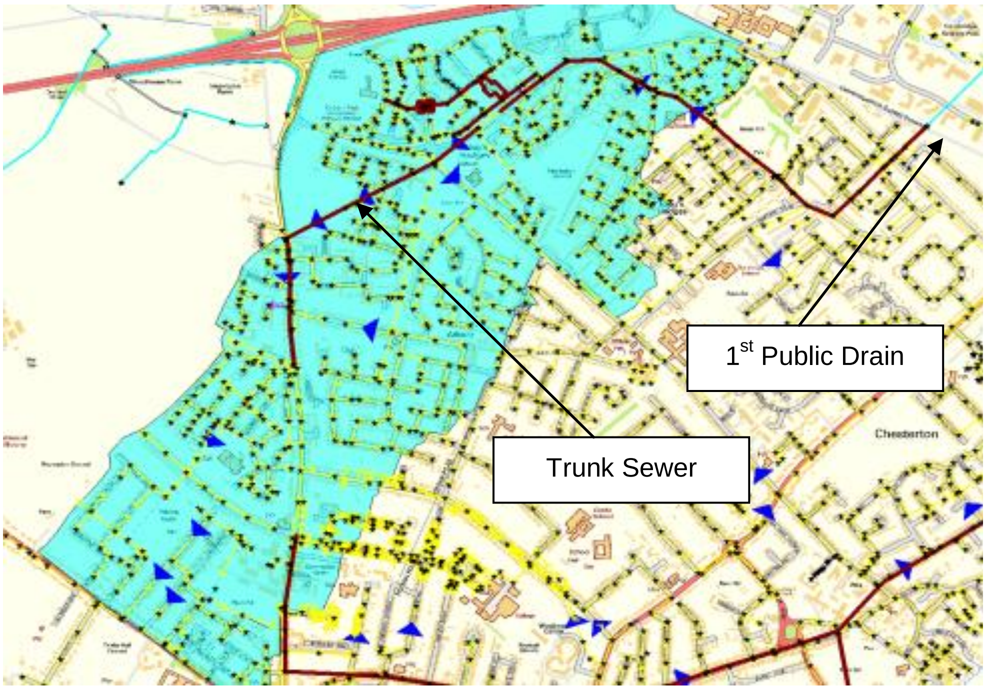


Figure 9-7 King's Hedges & Arbury Wetspot (including Storm Sewer network)

The following figure shows the progression of flooding for a 0.5% AEP event with an allowance for climate change. Figure 9.8 shows flood depth at varying hours during the simulation.

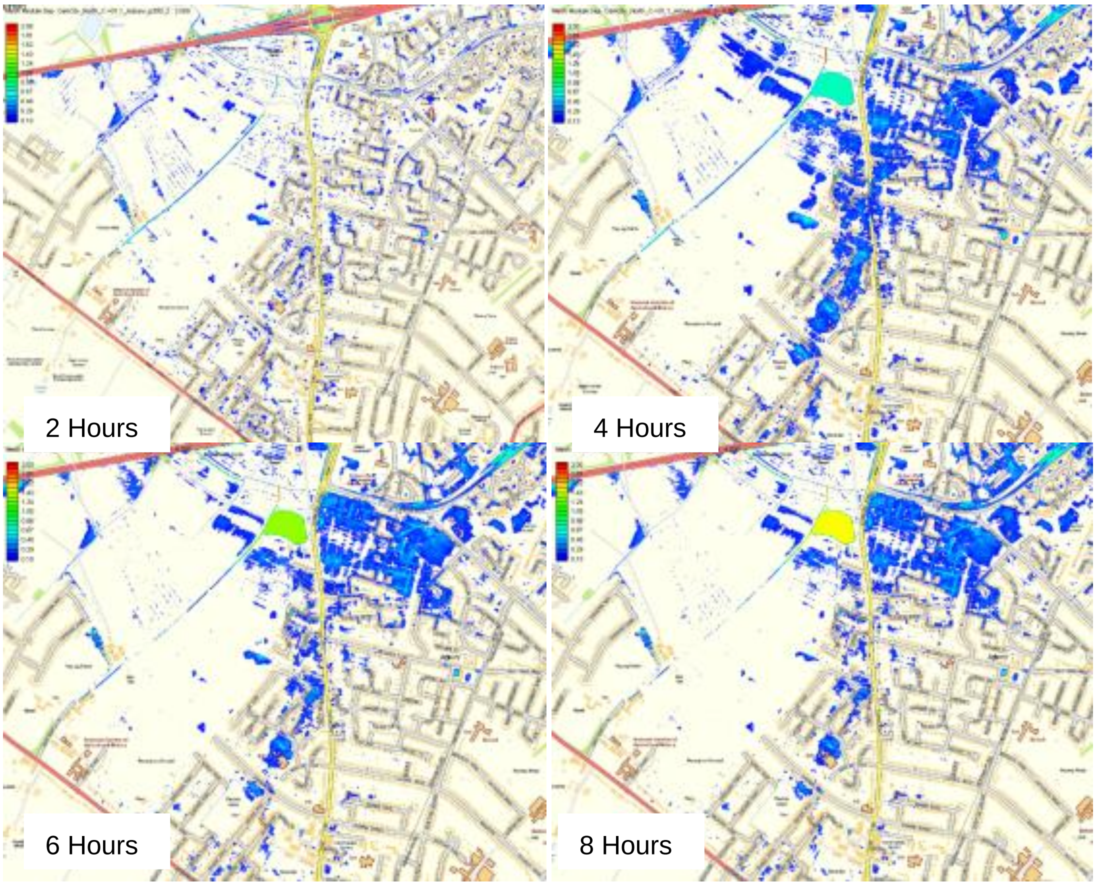


Figure 9-8 Kings Hedges and Arbury TUFLOW Results (0.5%AEP) for varying durations – Depths

Figure 9.9 shows the maximum flood depths during the simulation.

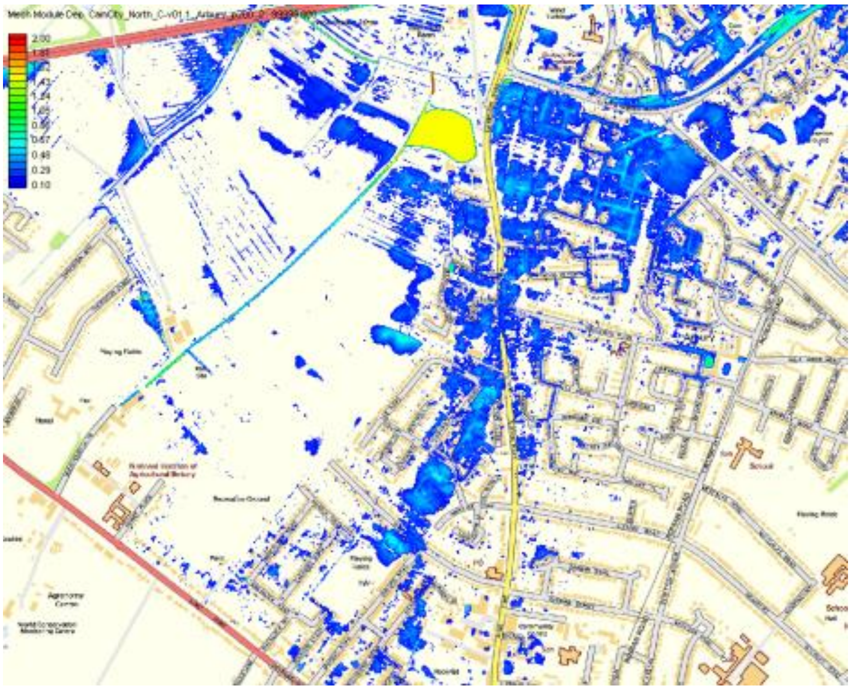


Figure 9-9 Kings Hedges and Arbury TUFLOW Results (0.5%AEP) – Maximum Depth

Similarly Figure 9.10 shows flow at 2, 4 and 6 hours.

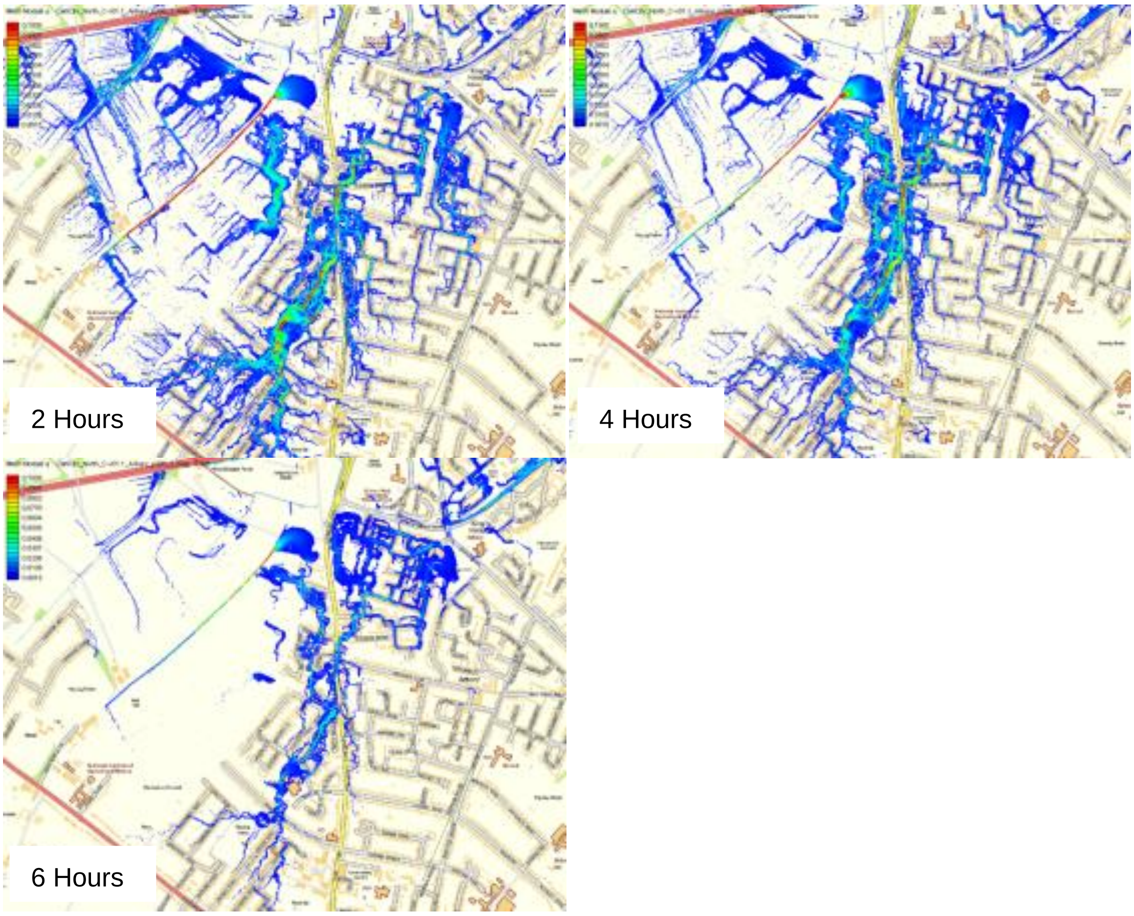


Figure 9-10 TUFLOW Model Results (1 in 100 years cc) for varying durations - Flows

The general progression of flooding is from the south west to the north east with the depression formed by the King's Hedges Road and Milton Road being particularly vulnerable in the latter stages of the flood event.

9.2 Model Verification

Unfortunately, there is currently no information in the form of historical evidence or flow monitoring to verify the TUFLOW model for both the King's Hedges and Arbury and Cherry Hinton wetspot other than the records of historic flooding. Nevertheless, it is considered that these models are representative of the conditions within these wetspots.

10 Flood Hazard and Risk Mapping

10.1 Flood Risk Regulations Requirement

Under Flood Risk Regulation 19-1 a lead local flood authority must prepare a flood hazard map and a flood risk map in relation to each relevant Flood Risk Area (FRA), if identified by the PFRA process.

No significant FRA has been identified by neither the EA nationally, nor the first cycle of the Cambridgeshire PFRA at a local level[17]. However, depth, velocity and hazard maps have been prepared for the Cambridge and Milton SWMP study area as they will inform further local Flood Risk Management Strategy developments and the second cycle of the PFRA process in six years time.

The flood hazard map should include the likely extent (including water level or depth) of possible floods, the likely direction and speed of flow of possible floods, and whether the probability of each possible flood occurring is low, medium or high (in the opinion of the person preparing the map).

A flood risk map is a map showing in relation to each flood risk;

- The number of people living in the area who are likely to be affected in the event of flooding
- The type of economic activity likely to be affected in the event of flooding
- Any industrial activities in the area that may increase the risk of pollution in the event of flooding
- Any relevant protected areas that may be affected in the event of flooding
- Any areas of water subject to specified measures or protection for the purpose of maintaining the water quality that may be affected in the event of flooding
- Any other effect on human health, economic activity or the environment.

10.2 Role in the SWMP

The outputs of the Surface Water Management Plan meet the requirements of the above Flood Risk Regulation.

Modelling carried out for Stage 1-3 of the SWMP will produce Hazard outputs in the modelled areas. The return periods run in the modelling allow for determination of probability for medium and high probability flooding.

The Multi-criteria analysis and the reporting of the results of this analysis will meet the Flood Risk Map requirement of the Flood Risk Regulations. The Web-GIS contains information on the extent of flooding to Key Flood Receptors. The Web-GIS programme also allows editing of existing and creation of new Wetspot boundaries and extensive analysis of flood risk in Cambridge.

10.3 Flood Depth, Velocity and Hazard Maps

Flood depth, velocity and flood hazard mapping has been produced based upon the TUFLOW bare earth models for Cambridge north and south for 1 in 30 (3.33% AEP), 1 in 75 (1.33% AEP) and 1 in 200 year (0.5% AEP) return periods using a storm duration of 240 minutes. The mapping is included within Appendix E. In addition, Appendix F and Appendix G include additional maps associated with the various options discussed in subsequent sections.

Flood hazard are important factors in the assessment of flood risk and evacuation of the general public. Three categories of flood hazard have been identified in the DEFRA / Environment Agency Documents: Flood Risk Assessment Guidance for New Development[18], (DEFRA Report FD2320) and Flood Risks to People Methodology[19] (DEFRA Report FD2321). These are “Danger for All”, “Danger for Most” and “Danger to Some”. The equation below gives the relationship between hazard, depth, velocity and debris:

$H = (v+0.5) \times d + Df$ Where

H = hazard

v = velocity

d = depth

Df = debris factor

$Df = 0.5$ for $d < 0.25$m

$Df = 1.0$ for $d > 0.25$m

The mapping presented in the SWMP has been based upon the following thresholds, taken from DEFRA Report FD2320. However it should be noted that DEFRA Report FD2321 places a different hazard rating of the transition to Category 3. The FD2320 indicates that the change occurs at 2.0 whereas the FD2321 report indicates that this happens at 2.5. This has a significant impact on the interpretation of the results for the SWMP which are discussed below but it should be noted that the results are presented conservatively as set out below.

Danger to Some	Category 1	$H > 0.75$
Danger to Most	Category 2	$H > 1.25$
Danger to All	Category 3	$H > 2.00$

The colouring of the flood hazard mapping is commensurate with the hazard categorisation given in Figure 10.1. Areas coloured red are considered dangerous for all; areas in dark yellow are dangerous to most; light yellow is dangerous to some and blue areas are inundated areas mainly on the margins of the flood plain which are considered to hold little hazard. The time series graphs show the depth (left axis) and hazard category (right axis) for specific control point locations as discussed above.

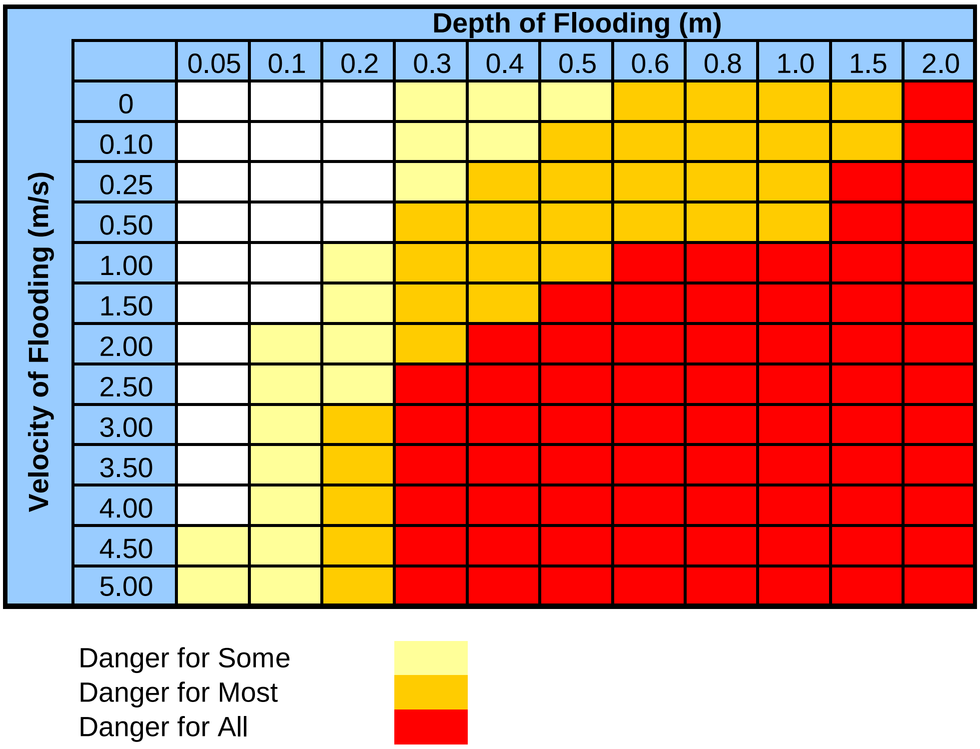


Figure 10.1 Hazard Categorisation

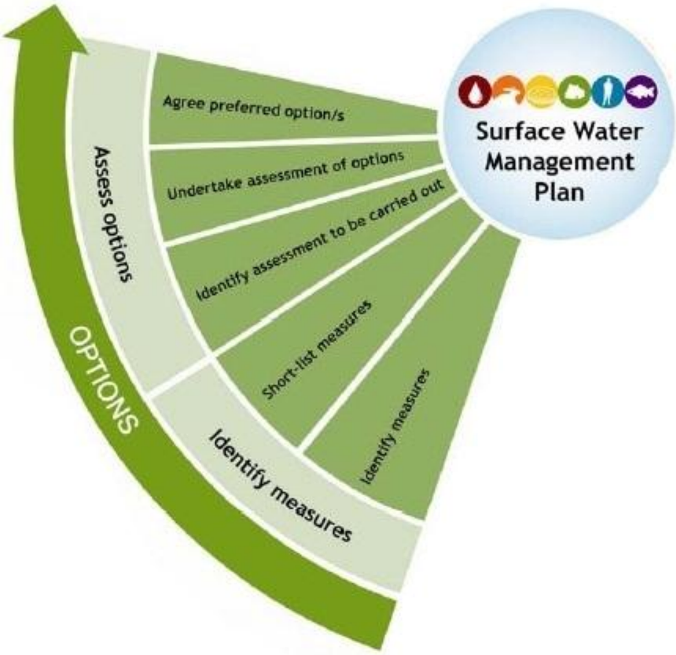
Appendices F and G provide flood depth, velocity and flood hazard mapping for the 0.5% AEP event for Kings Hedges and Arbury and Cherry Hinton wetspots, respectively. The following sections provide further details of these prioritised wetspots.

In addition to the above maps, additional datasets such as the EA's National Receptor Database (NRD) along with local information collated as part of the SWMP have been assessed to undertake the MCA as previously described in Section 8.3:

- Domestic
- Commercial
- Critical Infrastructure (e.g. Hospitals / Water Treatment Works)
- Transportation Infrastructure (roads / railways)
- Land & Public Open Space (Statutory conservation areas)
- Cultural

The above flood risk receptors impacted by the surface water flooding have been uploaded to Web-GIS, which indicate the scale of flood risk across Cambridgeshire along with the MCA results for specific wetspots within the Cambridge and Milton study area.

11 Engineering Options Identification and Assessment



11.1 Measures Identification

As noted above the engineering elements evaluated in this section are based upon employing the most appropriate techniques for the various sites. The engineering elements proposed within this section fall into a range of categories as shown in Figure 11.1 and where possible and economical the use of sustainable drainage systems (SuDS) and surface water reduction strategies has been promoted over hard infrastructure alternatives such as the upgrading of existing sewers.

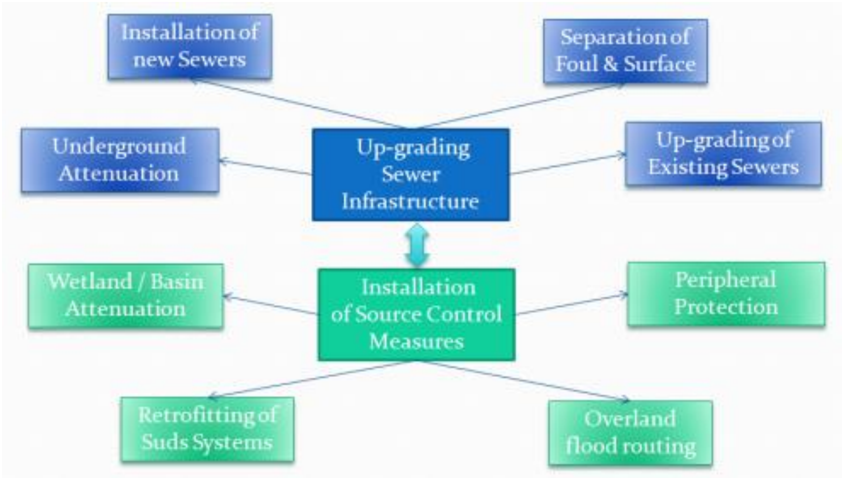


Figure 11-1 Surface Water Flood Mitigation Options

The key constraints (see Figure 11.2) associated with the implementation of all of the options are space and cost.

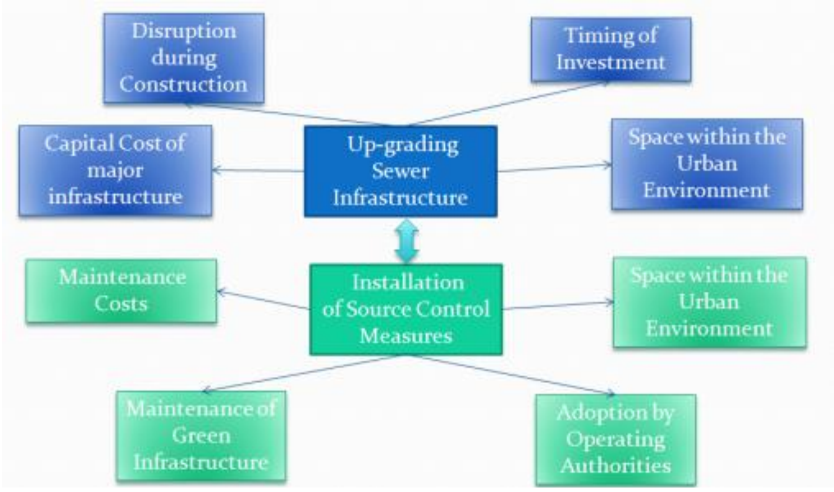


Figure 11-2 Engineering Options Constraints

Accordingly, the engineering options proposed within the report have been designed to be accommodated within the urban environment.

It should be noted that the engineering options proposed are potential solutions to current issues and priorities. During the course of the SWMP time frame, it is possible that these issues or priorities may change and new constraints and priorities may present themselves. The options may, therefore, be difficult to implement, and it should be borne in mind that the engineering works for some options are proposed over a long period.

In both Cherry Hinton and Kings Hedges & Arbury, there are several open spaces which can be utilised for attenuation but in general the surface area is dominated by roads and sub-urban housing. Nevertheless attenuation has been explored at several locations with the introduction of attenuation basins, wetlands and ponds and there has been consideration of the use of swales where possible.

In Cherry Hinton, for example, open spaces at a number of schools have been investigated as potential sites for attenuation structures. It should be noted however that other pressures such as the need to expand and improve existing school sites may be contrary to using school open spaces in flood mitigation works. New developments may however offer alternative opportunities for partnership working, such as utilising green roofs in new school developments.

The street environment is also a significant constraint in the installation of drainage infrastructure. Within these areas techniques including permeable paving, filter drains, Road side rain gardens are discussed in detail in the following sections.

11.2 Source Control Measures within highways

The installation or retrofitting of source control measures within highways is an important consideration for two main reasons which are:-

- Roads and highways form an important conveyance route for flood waters
- The majority of roads and highways are within the public domain reducing potential land ownership problems with access and construction.

A range of source control measures have been considered for the purposes of the SWMP and this includes:-

- The installation of permeable paving

- The use of road side rain gardens
- Filter drains
- Swales
- Infiltration basins

Space within the urban environment is a key issue in retro-fitting SuDS solutions. Figure 11.3 shows a typical street scene within a 1930s residential area of Cambridge. In these locations the verges, footpaths and road itself give good opportunities to incorporate source control measures.

Figure 11-3 Typical Cambridge Street Scene

Figure 11.4 shows a possible way that the street scene could be changed through the introduction of permeable paving and the use of road side rain gardens (see also Figure 11.5). It also shows how traffic control measures can be used to assist storm water drainage within the highway.

Permeable paving provides significant benefits in relation to rainfall interception as well an option for removal of surface water volume. Permeable paving systems are designed to allow water to infiltrate to the underlying granular sub-grade material and eventually provide local groundwater recharge.

The feasibility for the installation of permeable paving should be considered at every site where this SuDS measure is proposed. To work most effectively, they should be installed in areas with permeable soils and a low risk of groundwater flooding, as this would indicate relatively low levels of groundwater. As with all SuDS, it is essential that they are maintained effectively to prevent blockage by silt and gravel, which will reduce their effectiveness. If not maintained regularly, the ability of permeable paving to remove surface run-off will decrease until they become, in effect, impermeable surfaces.

Figure 11-4 Permeable paving and road side rain gardens

The purpose of the road side rain gardens system is to create a chain of surface water storage areas each connected with a filter / French drain. Surface water is temporarily stored in the soil and granular layer at the base of the structure before being gradually released into the groundwater through infiltration into the ground below. Intentionally situated in roadside verges, this will provide areas of storm water infiltration and planting into the smallest of places. Road side rain gardens typically contain hydrophilic flowers, grasses, shrubs and trees and a generic example is shown in Figure 11.5.

Figure 11-5 Typical example of a road side rain garden

11.3 Cherry Hinton

11.3.1 Engineering Measures and Options

This section of the report considers the engineering elements and the option combinations for the mitigation of surface water flooding in Cherry Hinton. The engineering elements and option combinations considered in this document have been developed from work undertaken during the course of the project. The hydrological and hydraulic, and risk analyses has allowed the options to be developed further in order to compare the schemes in terms of cost and technical suitability.

Cambridgeshire County Council, the Lead Local Flood Authority under the Floods and Water Management Act, has powers to carry out works for the management of surface water run-off, ordinary watercourses and groundwater.

Table 11-1 gives a summary description of the engineering elements and Figures 11-6 to 11-18 provides the location of each element. The nature, feasibility and benefits associated with each of the engineering elements are discussed in Section 12. The engineering elements have been combined to form the option combinations which have been modelled and analysed to evaluate their technical suitability and economic benefits to select a preferred engineering option. The Option Combinations and a description of each Engineering Option is included in Section 12.

Option	Engineering Element Name	Description
CH-A	Maintain existing system to a better standard	Implementation of an effective maintenance regime to all existing drain and culverted systems in order to reduce the potential for blockages by vegetation or deposition to reduce the hydraulic capacity of flow routes. Maintenance would include regular inspection, tree works and clearance of debris as required.
CH-B	St Bedes School – Attenuation Basin	Construction of an attenuation basin at St Bede School, Birdwood Road.
CH-C	Daw's Lane Allotments – Attenuation Basin	Construction of an attenuation basin on Daws Lane Ditch (Right Bank).
CH-D	Cherry Hinton Hall – Attenuation Basin	Construction of an attenuation basin in the grounds of Cherry Hinton Hall.
CH-E	Netherhall Lower School – Attenuation Basin	Construction of an attenuation basin in the playing fields of Netherhall Lower School
CH-F	Netherhall School & Sixth Form College - Swale, Attenuation Basin, Bunding	Construction of a swale, attenuation basin and bunding in the playing fields of Netherhall School and Sixth Form College.
CH-G	Netherhall Farm – Swale, Attenuation Basin, Bunding	Construction of a swale, attenuation basin and bunding in the grounds of Netherhall Farm.
CH-H	Nightingale Avenue Recreation Ground – Attenuation Basin	Construction of a swale and attenuation basin at Nightingale Avenue Recreation Ground
CH-I	Queen Edith's School – Infiltration Basin	Construction of an Infiltration Basin in the playing fields of Queen Edith's school.
CH-J	Highway source control on all estate roads (non-major highways).	Installation of highway source control (Permeable Paving) on all non-major estate roads within the model boundary of Cherry Hinton.
CH-K	Wulfstan Road – Road side rain gardens	Construction of highway source control (Road side rain gardens) in the existing road verges.
CH-L	Gunhild Road – Road side rain gardens	Construction of highway source control (Road side rain gardens) in the existing road verges.
CH-M	Hartington Grove - Highway source control	Installation of highway source control (Permeable Paving) on Hartington Grove.

Option	Engineering Element Name	Description
CH-N	Blinco Grove - Highway source control	Installation of highway source control (Permeable Paving) on Blinco Grove
CH-O	St Margaret's Square – Highway source control	Installation of highway source control (Permeable Paving) on St Margaret's Square
CH-P	Hinton Avenue – Highway Source Control	Installation of highway source control (Permeable Paving) on Hinton Avenue
CH-Q	Lilac Court – Highway Source Control	Installation of highway source control (Permeable Paving) on Lilac Court
CH-R	Wulfstan Way, Godwin Way and Gunhild Court – Highway Source Control	Installation of highway source control (Permeable Paving) on Wulfstan Way, Godwin Way and Gunhild Court.
CH-S	Missleton Court – Highway source control	Installation of highway source control (Permeable Paving) on Missleton Court
CH-T	Kelvin Close – Highway Source Control	Installation of highway source control (Permeable Paving) on Kelvin Close
CH-U	Laundry Lane – Highway Source Control	Installation of highway source control (Permeable Paving) on Laundry Lane
CH-V	Derwent Close – Highway Source Control	Installation of highway source control (Permeable Paving) on Derwent Close
CH-W	St Thomas's Square and Walpole Road – Highway Source Control	Installation of highway source control (Permeable Paving) on St Thomas's Square and Walpole Road.
CH-X	Chalmers Road, Gray Road, Ward Road – Highway Source Control	Installation of highway source control (Permeable Paving on Chalmers Road, Gray Road & Ward Road
CH-Y	Ancaster Way, Tiverton Way & Budleigh Close – Highway Source Control	Installation of highway source control (Permeable Paving) on Ancaster Way, Tiverton Way & Budleigh Close
CH-Z	Cambridge Airport – Attenuation Pond	Construction of two attenuation basins in the grounds of Cambridge Airport.
CH-AA	Drainage Network Improvements	Drainage network improvements in targeted locations across the network.
CH- AB	Drainage Network Improvements	Drainage network alterations at Brooks Road.
CH-AC	St Bedes School – Attenuation Basin	Construction of an attenuation basin at St Bede School, Birdwood Road (Amended dimensions from **CH-B**)
CH-AD	Cherry Hinton Hall – Attenuation Basin	Construction of an attenuation basin in the grounds of Cherry Hinton Hall (Amended dimensions from **CH-D**)
CH-AE	St Thomas's Square – Highway Source Control	Installation of highway source control (Permeable Paving) on St Thomas's Square.
CH-AF	Netherhall School & Sixth Form College - Swale, Attenuation Basin, Bunding	Construction of a swale, attenuation basin and bunding in the playing fields of Netherhall School and Sixth Form College (Amended dimensions of attenuation basin from CH-F).
CH-AG	Netherhall Farm – Swale, Attenuation Basin, Bunding	Construction of a swale, in the grounds of Netherhall Farm.
CH-AH	Nightingale Avenue Recreation Ground – Attenuation Basin	Construction of an attenuation basin at Nightingale Avenue Recreation Ground (Amended dimensions of attenuation basin from CH-H).

Table 11.1 Cherry Hinton engineering elements

Maintain existing system to a better standard

Engineering element CH-A is based upon the implementation of an effective maintenance regime to ensure that blockage by vegetation or deposition will not reduce the hydraulic capacity of the existing drainage infrastructure including the public drains, ordinary watercourses, highway gullies, storm and foul sewers. Maintenance would include regular inspection, treeworks, jetting and clearance of debris, gravel and siltation where required.

In the context of blockage by trees, maintaining to a better standard would entail implementing good arboricultural practice which includes surveys for root-plate stability of the larger specimens, selective thinning and coppicing of the developing scrub to increase vigour, thinning for better specimens, removal of non-native species and improvement of the stand for amenity, bank stability and biodiversity purposes. Removal of major fallen dead-wood, obstacles and other debris are desirable. The objective of these works would be to reduce the amount of woody debris liberated in flood conditions which could accumulate on the bridges or sewers.

Maintenance also assumes enforcement of notices served under the Land Drainage Act[20]. The objective of this engineering element would be to reduce the amount of debris liberated in flood conditions which could accumulate and in a flood event block culverts and drainage channels. The advantages and disadvantages of providing an effective maintenance regime are as follows.

	Advantage / Disadvantage
Advantage	Clearance of drains and swale networks will ensure that water drains freely and to the best of its design capacity.
	Regular and effective maintenance and record keeping could help to support flood defence funding decisions.
Disadvantage	Inspection of the flood defence systems and assets should take place prior to and after potential significant rainfall events, representing a burden on the asset owners, both in terms of cost and time

Table 11.2 Advantages / Disadvantages of engineering element CH-A

St Bede's School & Daws Lane Ditch (Right Bank)

Engineering element CH-B is based on the construction of an attenuation basin in the grounds of St Bede's school and in allotment areas on the right bank of Daw's Lane. The purpose of this storage structure is not to intercept overland flows, but act as an offline storage structure when water level in the Daw's Lane ditch is high. This would alleviate pressure on the drainage network elsewhere in the catchment.

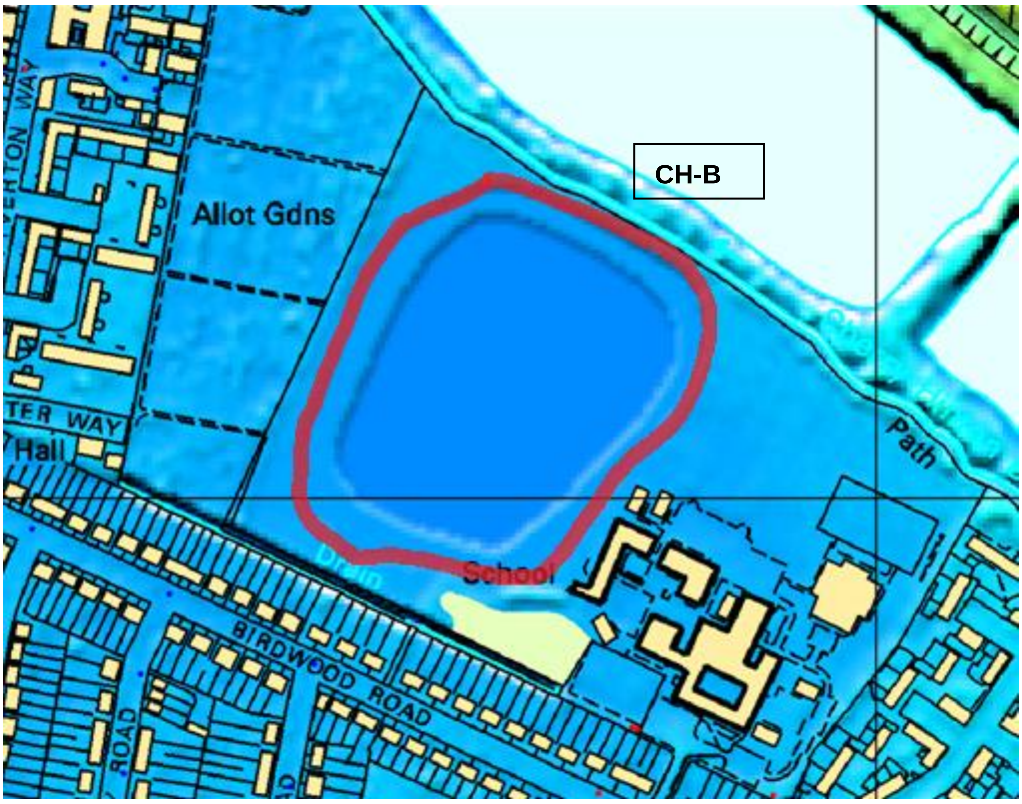


Figure 11-6 Possible location / geometry for St Bede's attenuation structure – CH-B

Figure 11-7 Example of an offline storage structure

Figure 11.7 above shows the construction of an offline storage structure in Leicester. The photograph on the left shows the depression of the basin and two incoming pipes, while the photograph on the right shows the receiving watercourse and outfall structure from the basin.

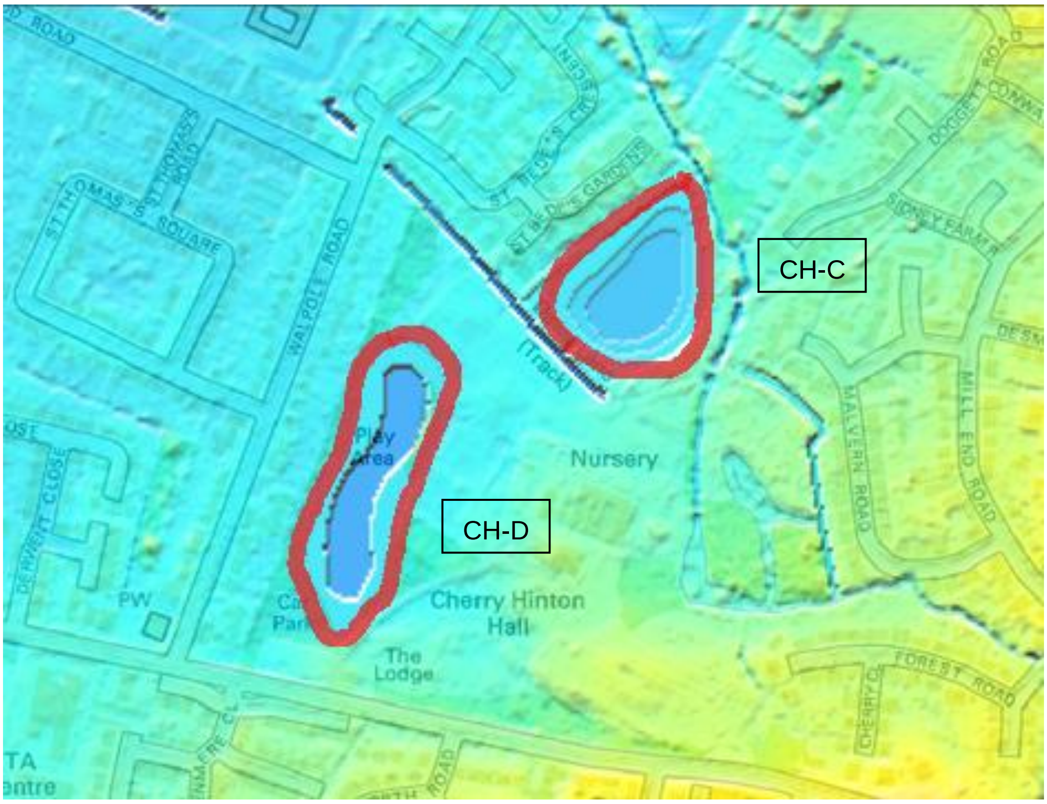
The advantages and disadvantages of providing this form of flood mitigation measure are as follows: -

	Advantage / Disadvantage
Advantage	Attenuation of storage of flood water when water levels are high in the Daw's Lane ditch
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Encourage natural groundwater recharge
Disadvantage	Potential health and safety implications of adding flood storage areas in and around schools without significant costs associated with education and warning requirements
	Temporary closure of the parkland during construction and when water levels in the Ditch are high.
	Additional land drainage may be required to prevent water logging of sports pitches
	May require new siting of allotment gardens
	Burnsite allotments are not managed by the council, making utilisation of this area for an attenuation basin more problematic

Table 11.3 Advantages / Disadvantages of engineering element – CH-B & CH-C

Cherry Hinton Hall Attenuation

The Cherry Hinton Hall attenuation structure is designed to intercept surface water flowing down Cherry Hinton Road, in to the grounds of Cherry Hinton Hall and onto Walpole Road.



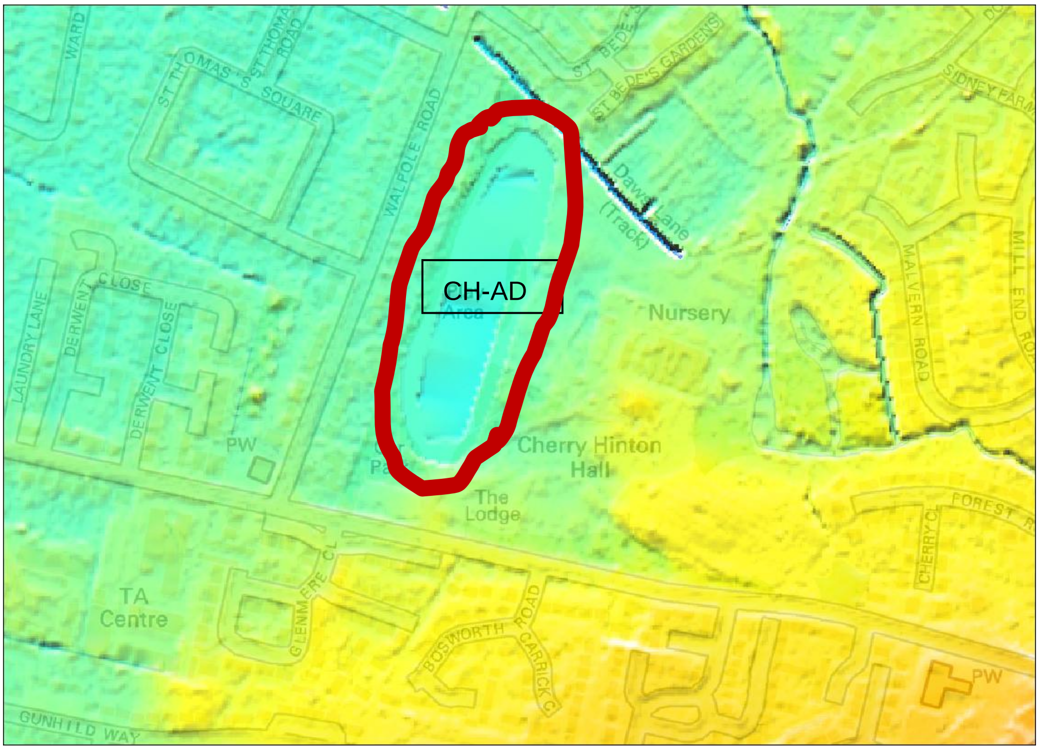


Figure 11-8 Possible location/geometry of Cherry Hinton Hall attenuation basin – CH-C & CH-D

	Advantage / Disadvantage
Advantage	A decreased conveyance of overland flow of flood water toward an area with historical records of flooding.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Encourage natural groundwater recharge
Disadvantage	Potential health and safety implications of adding flood storage areas in and around schools without significant costs associated with education and warning requirements
	Temporary closure of the parkland during construction and when water levels in the Ditch are high.
	Loss or partial loss of a Children’s Play area in the grounds of Cherry Hinton Hall.
	Design of Attenuation Basin would need to take account of requirements for Cherry Hinton Folk Festival

Table 11.4 Advantages / Disadvantages of engineering element CH-D

Netherhall Lower School, Netherhall Sixth Form College, Netherhall Farm and Nightingale Avenue Recreation Ground Attenuation

Engineering options CH-E to CH-H are attenuation options designed to reduce overland flows from fields and roads in the south of the catchment with the explicit purpose of reducing the amount of water reaching the area around Wulfstan Road and its junction with Cherry Hinton Road where there has been predicted ponding during the 1 in 200 year flood do nothing and do minimum flood events.

The attenuation structures at Netherhall Sixth Form College and Netherhall Farm have been modelled with swales to route flow into the structure. The surround topography has also meant it was necessary to model these two structures with additional bunding.

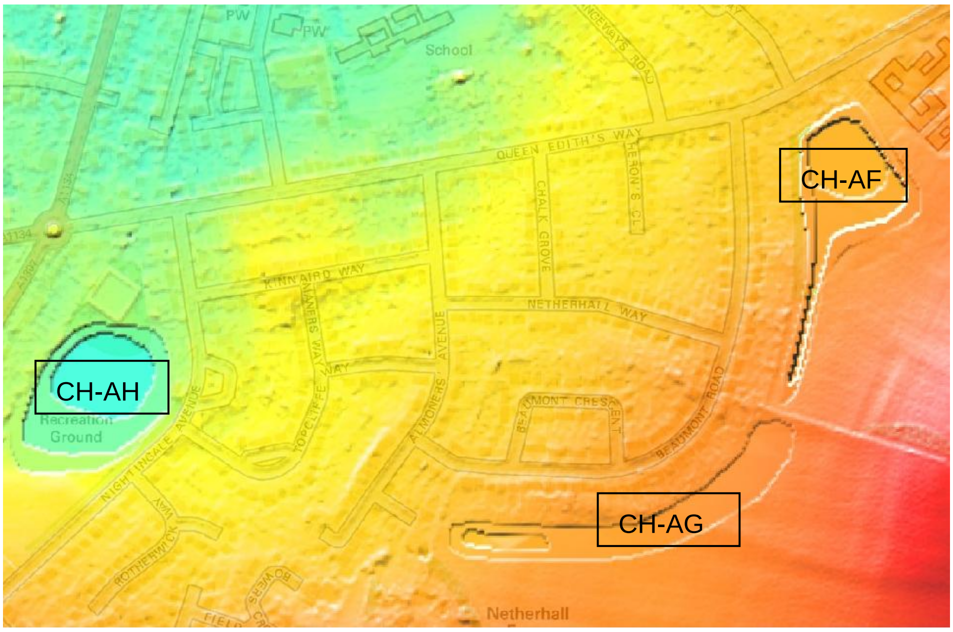


Figure 11-9 Possible locations for attenuation systems in south catchment CH-E to CH-H & CH-AF to CH-AH

	Advantage / Disadvantage
Advantage	A decreased conveyance of overland flow of flood water toward an area with historical records of flooding.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Encourage natural groundwater recharge

Disadvantage	Temporary closure of the areas during construction.
	Swales to route flow in to structures will need regular maintenance.
	Loss or partial loss of two recreation areas.
	Excavation and re-use of materials could have health & safety implications on School Sites.

Table 11.5 Advantages / Disadvantages of engineering elements CH-E – CH-H

Queen Edith's School Infiltration Basin

Further attenuation of overland flows (CH-I) was required from the urban areas around Almoners' Avenue, Netherhall Way and Queen Edith's Way. This was required where attenuation options CH-E to CH-H had been bypassed. The playing fields of Queen Edith's primary school were shown to be a key flow route through the catchment. Attenuation in the form of an infiltration basin was modelled in this location.

Figure 11-10 Queen Edith's School Infiltration Basin – CH-I

	Advantage / Disadvantage
Advantage	A decreased conveyance of overland flow of flood water toward an area with historical records of flooding.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Encourage natural groundwater recharge
Disadvantage	Temporary closure of the areas during construction.
	Swales to route flow in to structures will need regular maintenance.

Table 11.6 Advantages / Disadvantages of engineering element CH-I

Permeable Paving

In order to assess the effectiveness of highway source control measures a “first pass” approach was considered where, despite obvious cost implications, all residential roads in the Cherry Hinton wetspot are fitted with the permeable paving, (with filter drains) to provide the attenuation volume. The extent of roads “fitted” with highway source control measures are shown in green in Figure 11-13. This is engineering element CH-J.

Engineering elements CH-K and CH-L consider the use of Road side rain gardens within the verges of the road and engineering elements. CH-M to CH-Y are based upon the use of permeable paving/filter drains as appropriate applied to a number of estate roads within the Cherry Hinton wetspot. Permeable paving was located in those areas where there was concern over surcharging manholes.

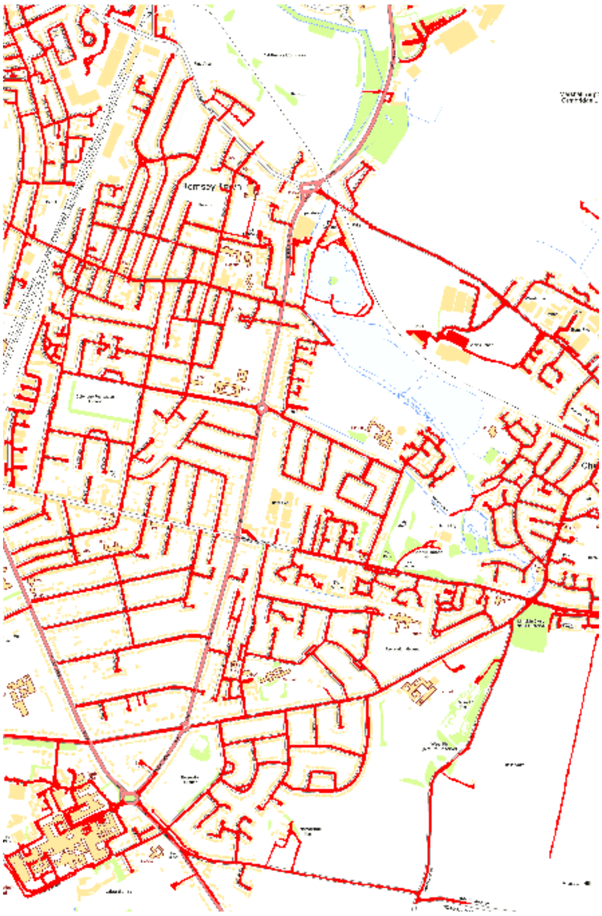


Figure 11-11 Potential locations for retrofitting permeable paving “First Pass” – CH-J

The advantages and disadvantages of permeable paving are shown below.

	Advantage / Disadvantage
Advantage	Permeable paving surfaces have been demonstrated as effective in managing and reducing runoff from paved surfaces.
	Management of potential flooding at the source, ‘upstream’ of any high risk areas.
	Sustainable alternative to creating a larger capacity sewer network.
	Encourage natural groundwater recharge.
	Water treatment by pollutant removal.
	Reduces net volume required by the storm sewer system.
Disadvantage	Construction within the road will lead to temporary road closures.
	High associated construction cost
	Can only be constructed on highways with low traffic volumes where speed restrictions not exceeding 30mph are present.
	Annual inspection of permeable pavement will be required.
	Need to ensure utilities in area are still accessible and not subject to increased stress
	Regular maintenance required to maintain effectiveness

Table 11.7 Advantages / Disadvantages of permeable paving – CH-J

The locations of potential areas where permeable paving could be installed are shown in Figures 11-12 to 11-15.

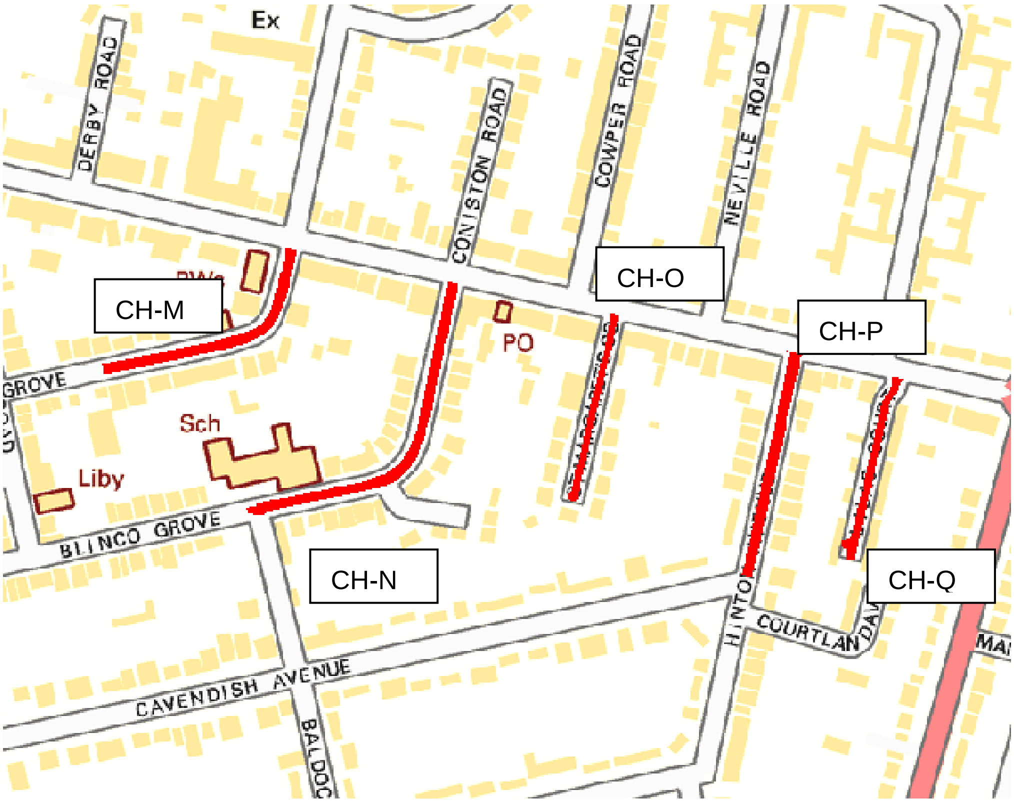


Figure 11-12 – Potential locations for permeable paving options - CH-M to CH-Q

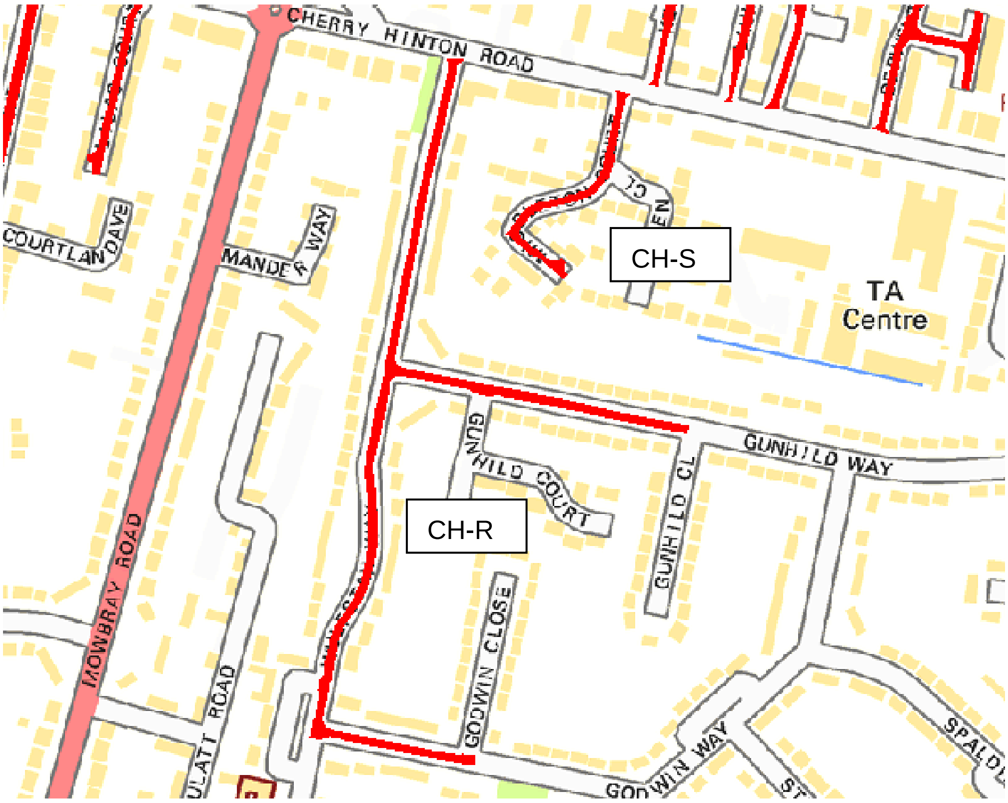


Figure 11-13 – Potential locations for permeable paving options CH-R and CH-S

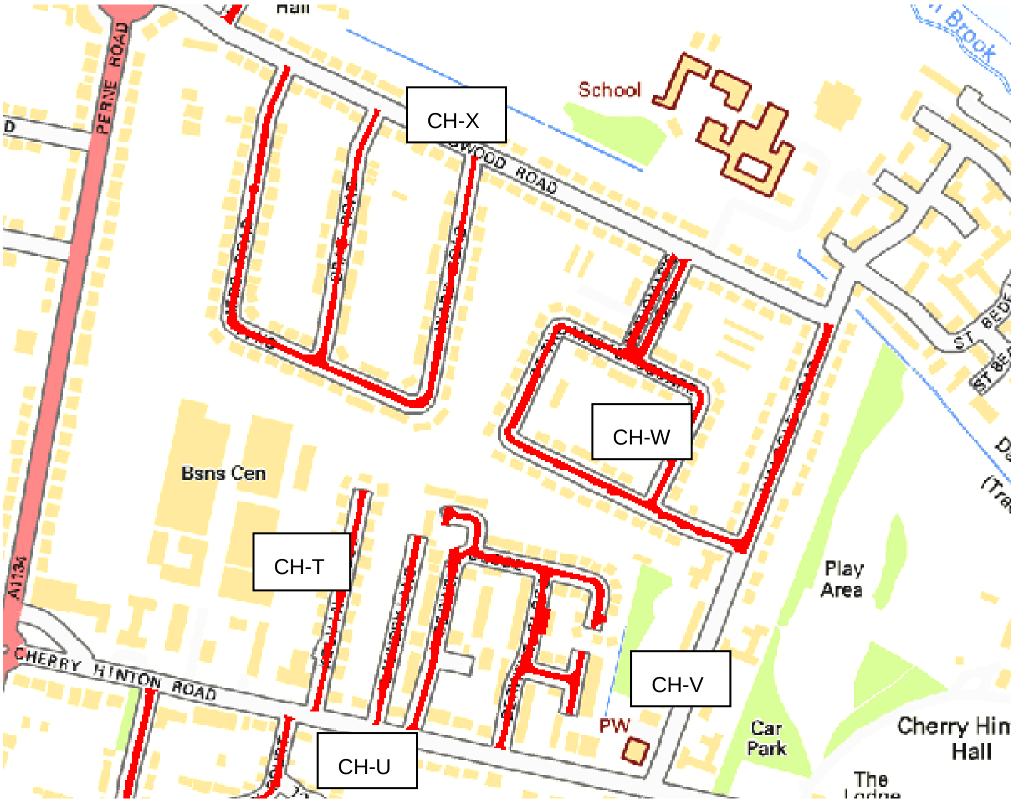


Figure 11-14 – Potential locations for permeable paving options CH-T to CH-X

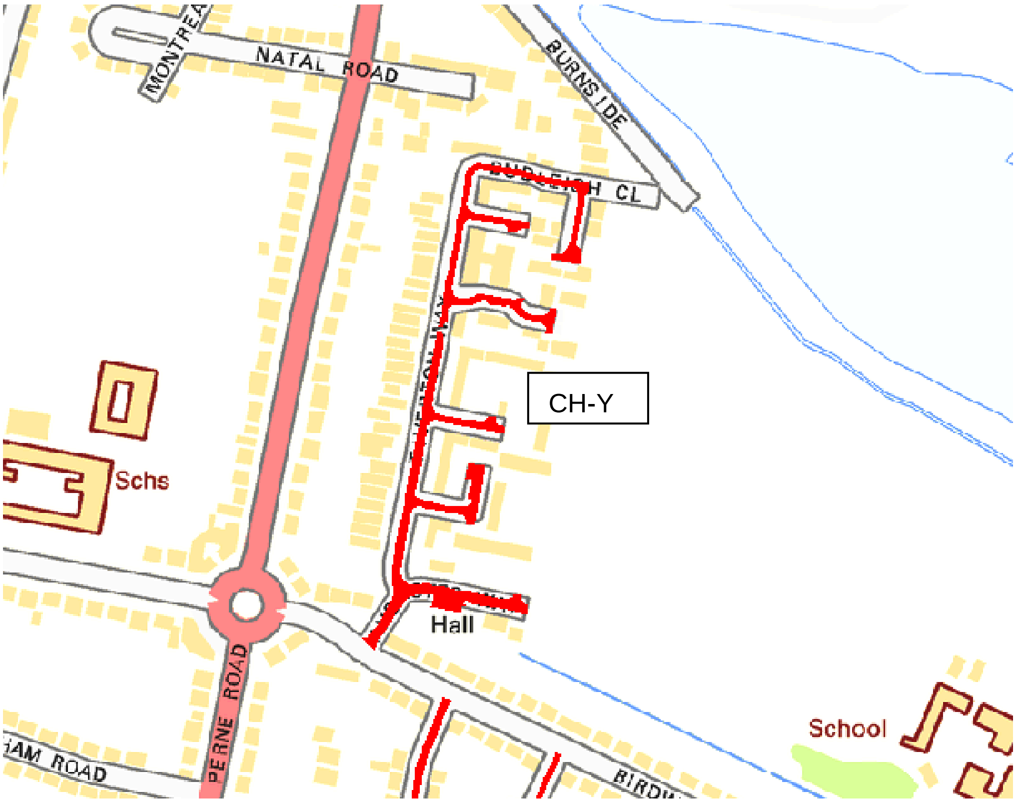


Figure 11-15 – Potential locations for permeable paving options CH-Y

Road side rain gardens

Road side rain gardens are designed to filter run-off from roads or pavements slowly through the root system of plants, rather than entering underground drainage systems. The advantages and disadvantages of using road side rain gardens are shown in the table below.

	Advantage / Disadvantage
Advantage	Effective in managing and reducing runoff conveyed by highway surfaces.
	Sustainable alternative to creating a larger capacity sewer network.
	Encourage natural groundwater recharge.
	Reduces net volume required by the storm sewer system.
	Contribution to aesthetic appeal and habitat in urbanised areas.
	Flexible for use in areas of various shapes and sizes.
Disadvantage	Regular maintenance of vegetation, such as weeding, soil replacement and watering during dry periods.
	Inspection following large rainfall events. This includes clearing of the access channel from the road to the soil.
	Periodic replacement of planting is required.
	Usage is dependent on width of road
	Loss of on-road parking space

Table 11.8 Advantages / Disadvantages of road side rain gardens – CH-K & CH-L

The locations of road side rain gardens are shown in Figure 11-14

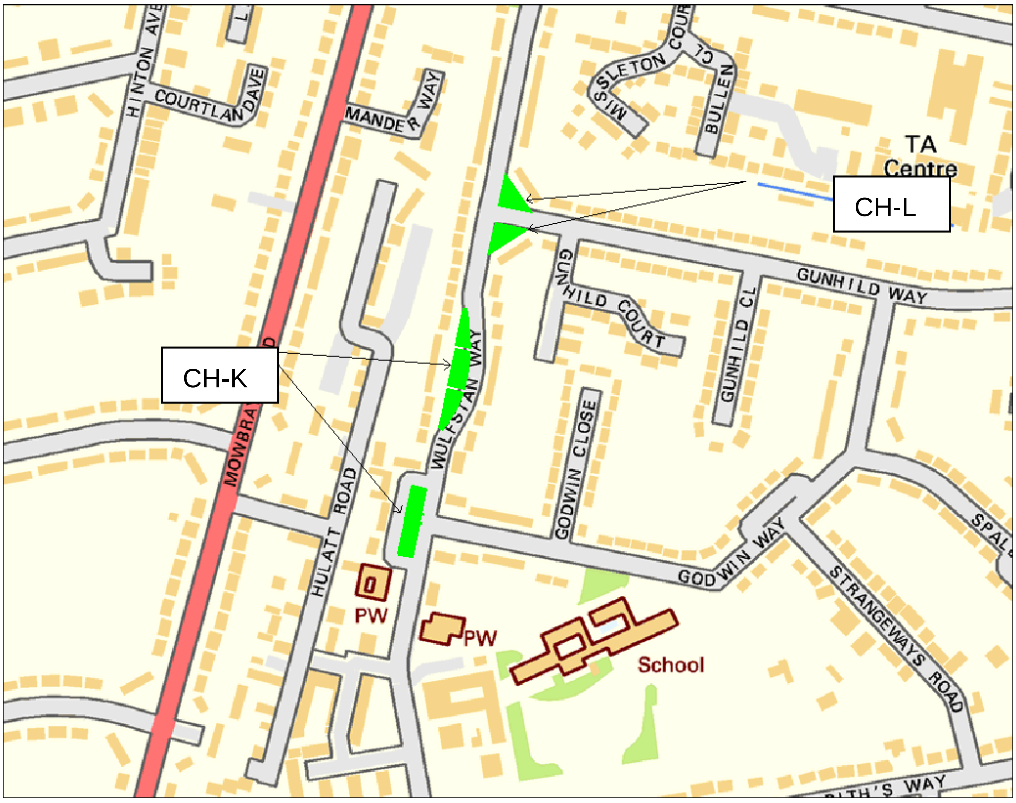


Figure 11-16 – Potential locations for road side rain gardens – CH-K – CH-L

Attenuation Structure in the Grounds of Cambridge Airport

Further attenuation options were considered in the very north of the study area. Whilst this area is outside of the Wetspot boundary, the preliminary damages analysis from the 'Do Nothing' and 'Do Something' Scenario showed this to be an area of high damages and as such this area was identified where there could be a large reduction in costs for little expenditure.

Potential attenuation ponds within the grounds of the Cambridge airport (See Figure 11-19).

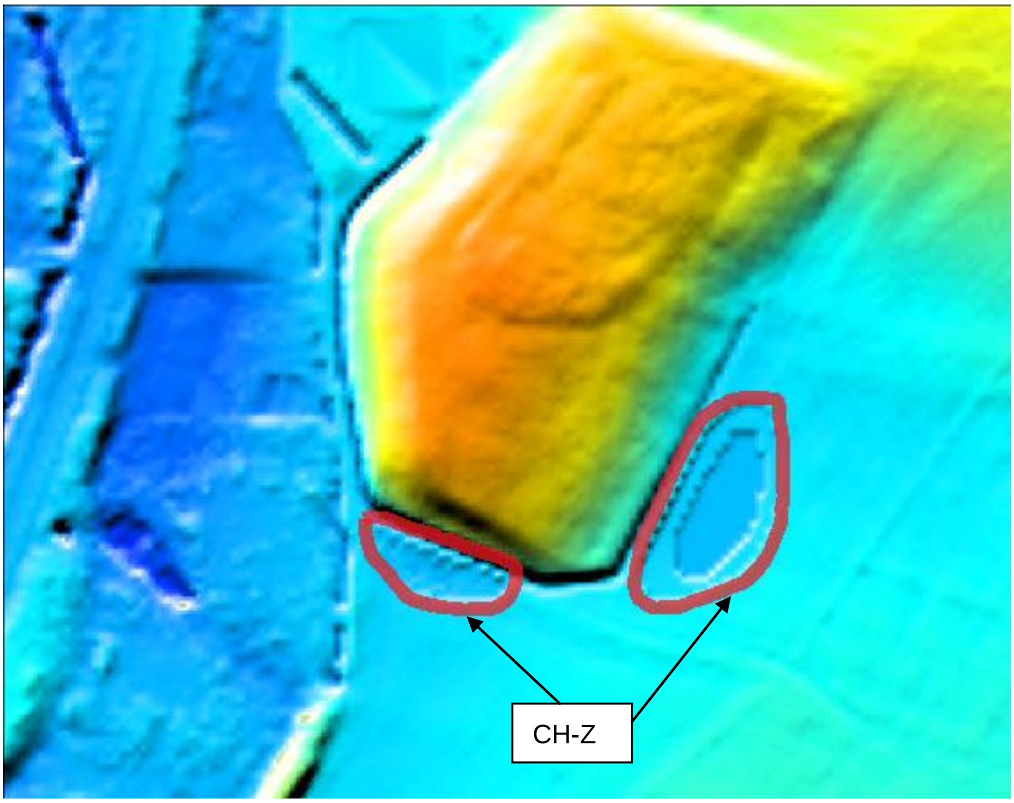


Figure 11-17 – Cambridge Airport Attenuation Ponds – CH-Z

Drainage Network Improvements

1D model results were interrogated along with data on historical flooding to identify areas where network drainage improvements may reduce flood risk.

The locations of network drainage improvements, though increasing pipe capacity are shown in red on Figure 11-20.

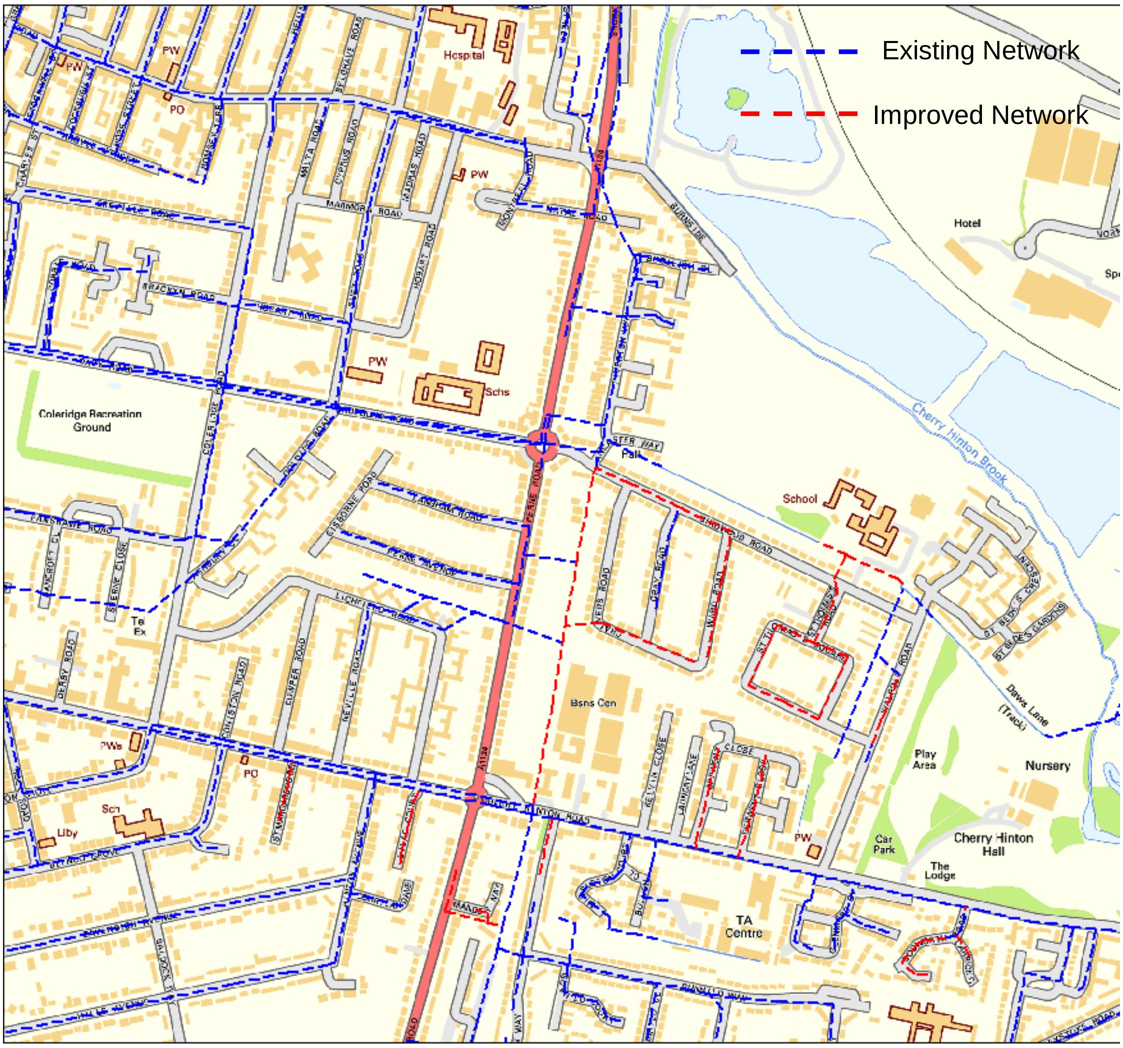


Figure 11-18 Network Drainage Improvements – Option CH-AA

	Advantage / Disadvantage
Advantage	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Reduce the risk of manhole surcharging.
Disadvantage	Temporary closure of the roads during construction causing disruption.
	Network improvements are generally expensive to carry out.

Table 11.9 Advantages / Disadvantages of Network Drainage Improvements

Drainage Network Improvements and Discharge into the Cherry Hinton Brook

To alleviate pressure elsewhere in the drainage network a pipe was modelled in the drainage network that would take water from the surface water drain when the water level is high within the system, in to the Cherry Hinton Brook via an attenuation area at Brooks Road Recreation Ground (See Figure 11-21).

Not included in the list of disadvantages of the proposed drainage network improvements, is the impact of increasing flows into the Cherry Hinton Brook at this point. Any engineering option taken forward for detailed should give consideration to not increasing flow risk elsewhere. The Environment Agency has highlighted that the Cherry Hinton Brook has it's own flood risk issues. Engineering option CH-AB would rely on being able to outfall in to the Cherry Hinton Brook. As such this engineering option has been considered with other engineering options that may also reduce flows in to the Brook. However if such an option were to be pursued it would require more detailed modelling, particularly of the Brook itself. For such modelling work to be completed, more detailed survey information of the brook would be required.

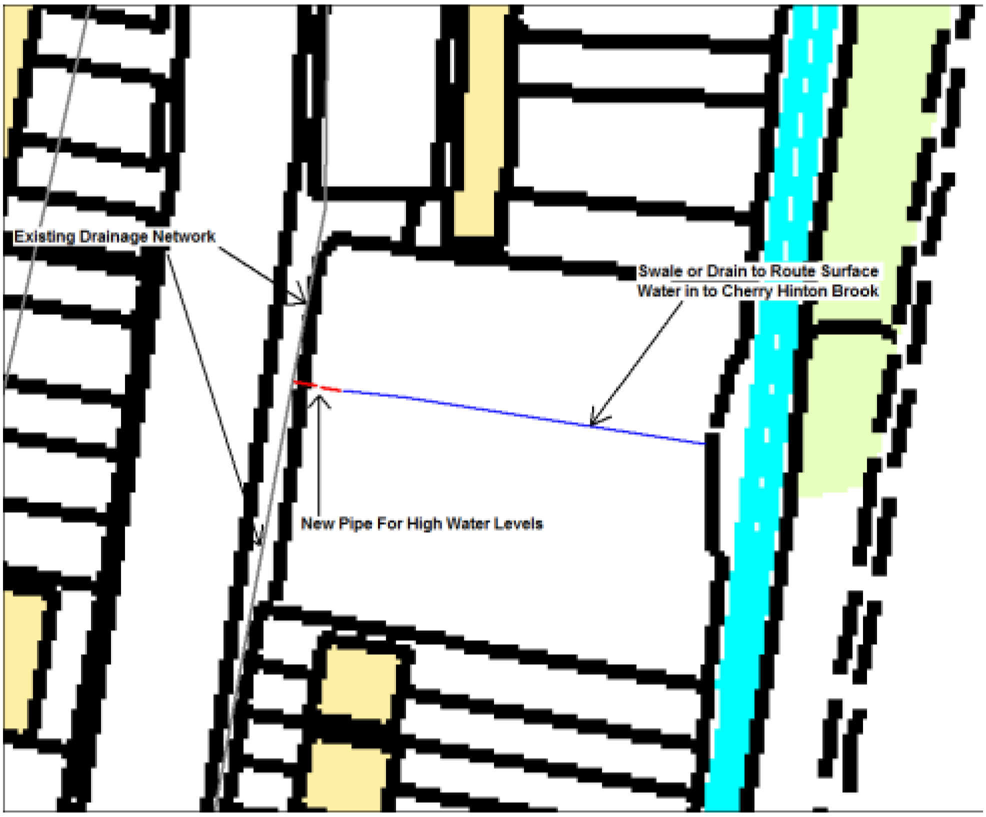


Figure 11-19 – Drainage Improvements

	Advantage / Disadvantage
Advantage	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Reduce the risk of manhole surcharging.

Disadvantage	Temporary closure of the roads during construction causing disruption.
	Network improvements are generally expensive to carry out.
	Control of any pollution in to the Cherry Hinton Brook will be required

Table 11.10 Advantages / Disadvantages of Network Drainage Improvements to Cherry Hinton Brook

11.4 Kings Hedges and Arbury

11.4.1 Engineering Measures and Options

This section of the report considers the engineering elements and the option combinations for the mitigation of surface water flooding in King's Hedges and Arbury. Cambridgeshire County Council as the lead local flood authority has under the Floods and Water Management Act, powers to carry out works for the management of surface water run-off, groundwater. The engineering elements and option combinations considered in this document have been developed from work undertaken during the course of the project. The hydrological and hydraulic, and risk analyses has allowed the options to be developed further in order to compare the schemes in terms of cost and technical suitability. Table 11.12 gives a summary description of the engineering elements.

Option	Engineering Element Name	Description
KH&A-A	Maintain existing system to a better standard	Implementation of an effective maintenance regime to all existing drain and culverted systems in order to reduce the potential for blockages by vegetation or deposition to reduce the hydraulic capacity of flow routes. Maintenance would include regular inspection, tree works and clearance of debris as required.
KH&A-B	Histon Recreational Ground – Attenuation Basin and Swale	Construction of a swale connected to an attenuation basin at Histon Recreational Ground.
KH&A-C	Extension to existing swale network at NIAB	Extension to existing swale network at National Institute of Agricultural Botany Estate (NIAB)
KH&A-D	Fitzwilliam Playing Fields Attenuation Basin	Existing drain to be converted into an attenuation basin.
KH&A-E	Cambridge Road Allotment – Attenuation Swale, Basin and Overflow	Construction of a swale connected to an attenuation basin at the Cambridge Road allotment site. This includes for a drain connection to the swale from Walnut Tree Way and an overflow pipe culvert at the attenuation basin underneath Cambridge Road. The overflow pipe will lead towards an existing swale network on the western side of Cambridge Road.
KH&A-F	St Albans Road Recreation Ground – Swale and Attenuation Basin	Construction of a swale connected to an attenuation basin at St Albans Road Recreational Ground.
KH&A-G	Highway source control on all estate roads (non-major highways).	Installation of highway source control on all non-major estate roads within the model boundary of King's Hedges and Arbury.
KH&A-H	Windsor Road – Road side rain gardens	Construction of Road side rain gardens in the existing road verges.
KH&A-I	Gilbert Road – Road side rain gardens	Construction of Road side rain gardens in the existing road verges.
KH&A-J	Tavistock Road and Warwick Road – Road side rain gardens and Attenuation Basin	Construction of an attenuation basin and Road side rain gardens in the existing road verges.
KH&A-K	St. Albans Road – Road side rain gardens and Attenuation Basins	Construction of an attenuation basin and Road side rain gardens in the existing road verges.
KH&A-L	Histon Road – Road side rain gardens	Installation of SUD's Road side rain gardens and filter drains in the existing road verges.

KH&A-M	Roseford Road – Road side rain gardens	Installation of SUD's Road side rain gardens and filter drains in the existing road verges.
KH&A-N	Chatsworth Avenue - Highway source control	Installation of highway source control measures
KH&A-O	Windsor Road – Highway source control	Installation of highway source control measures
KH&A-P	Hurrell Road – Highway source control	Installation of highway source control measures
KH&A-Q	Harding Way – Highway source control	Installation of highway source control measures
KH&A-R	Molewood Close – Highway source control	Installation of highway source control measures
KH&A-S	Hazelwood Close – Highway source control	Installation of highway source control measures
KH&A-T	Buchan Street – Highway source control	Installation of highway source control measures
KH&A-U	Roxburgh Road – Highway source control	Installation of highway source control measures
KH&A-V	Minerva Way – Highway source control	Installation of highway source control measures
KH&A-W	Borrowdale Road – Attenuation	Construction of a attenuation basin
KH&A-X	Tavistock Road – Attenuation and Road side rain gardens	Construction of an attenuation basin and Road side rain gardens in the existing road verges.
KH&A-Y	Carisbrooke Road – Road side rain gardens	Construction of Road side rain gardens in the existing road verges.
KH&A-Z	Mayfield Primary School - Swale	Construction of a swale and small raised embankment around the perimeter of the site leading toward the attenuation basin at Tavistock Road (KH&A-X)
KH&A-AA	Gilbert Close – Raised Pavement	Construction of a raised pavement in Gilbert Close and the connecting area of Histon Road
KH&A-AB	Cambridge Road – Piped Culvert leading to Allotment Swale	Piped culvert from Cambridge Road opposite to the entrance to Chancellors Road. Piped culvert leading to the Cambridge Road Allotment Swale (KH&A-E)
KH&A-AC	Overflow pipe on trunk main sewer parallel	Overflow pipe on trunk main sewer parallel to Cambridge Road connected to the Allotment swale network

Table 11.12 Engineering Elements

The nature, feasibility and benefits associated with each of the engineering elements are discussed in Section 12. The engineering elements have been combined to form the option combinations which have been analysed to evaluate the economic benefits of the combinations and to select a preferred engineering option. These Option Combinations are discussed in Section 12.

Maintain existing system to a better standard

Engineering element KH&A-A is based upon the implementation of an effective maintenance regime to ensure that blockage by vegetation or deposition will not reduce the hydraulic capacity of the existing drainage infrastructure including the public drains, ordinary watercourses, highway gullies, storm and foul sewers. Maintenance would include regular inspection, treeworks, jetting and clearance of debris, gravel and siltation where required.

In the context of blockage by trees, maintaining to a better standard would entail implementing good arboricultural practice which includes surveys for root-plate stability of the larger specimens, selective thinning and coppicing of the developing scrub to increase vigour, thinning for better specimens, removal of non-native species and improvement of the stand for amenity, bank stability and biodiversity purposes. Removal of major fallen dead-wood, obstacles and other debris are desirable. The objective of these works would be to reduce the amount of woody debris liberated in flood conditions which could accumulate on the bridges or sewers.

Maintenance also assumes enforcement of notices served under the Land Drainage Act. The objective of this engineering element would be to reduce the amount of debris liberated in flood conditions which could accumulate and in a flood event block culverts and drainage channels. The advantages and disadvantages of providing an effective maintenance regime are shown below.

	Advantage / Disadvantage
Advantage	Clearance of drains and swale networks will ensure that water drains freely and to the best of its design capacity.
	Regular and effective maintenance and record keeping could help to support flood defence funding decisions.
Disadvantage	Maintenance will have limited impact on the frequency and depth of flooding experienced by properties currently vulnerable to flooding due to blockage during a flood event.
	Inspection of the flood defence systems and assets should take place following any significant rainfall events.

Table 11.13 Advantages / Disadvantages of engineering element KH&A-A

Histon Recreational Ground

Engineering element KH&A-B is based on the construction of a swale and attenuation basin at Histon Recreational Ground. As a primary overland flow route to the confluence on Windsor Road, the topography of Histon Recreational Ground provides an area where surface water is conveyed through the parkland and travels towards the north western corner of the site.

Through installing a swale network around the parkland and an attenuation basin at the north western corner this will provide an attenuation of flood water which would otherwise enter local domestic properties. The attenuation basin would be connected to the local sewer network via a flow control device (e.g. orifice pipe or hydro-brake) and attenuate flood water back into the system or infiltrate into the surrounding soil.

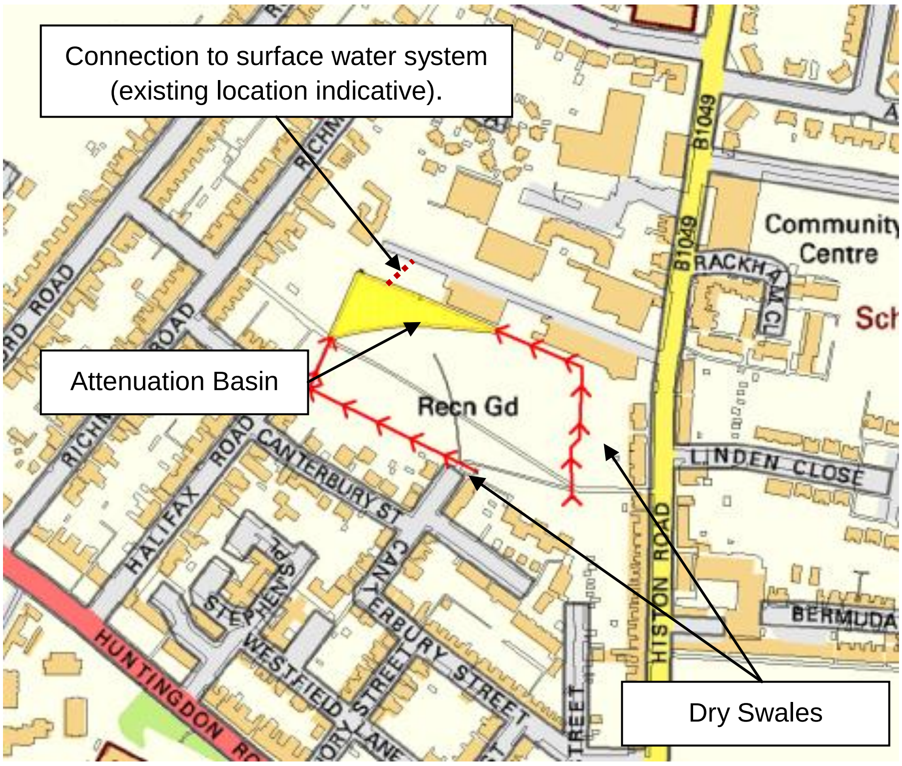


Figure 11-20 Location of Histon Recreation Ground Swale & Attenuation Basin - KH&A-B

The advantages and disadvantages of providing this form of flood mitigation measure are as follows.

	Advantage / Disadvantage
Advantage	Attenuation of storage of flood water that enters a natural conveyance route through Histon Recreation Ground towards domestic properties.
	Utilising an already existing connection to the sewer network.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Encourage natural groundwater recharge.
Disadvantage	Maintenance will have limited impact on the frequency and depth of flooding experienced by properties currently vulnerable to flooding due to blockage during a flood event.
	Temporary closure of the parkland during construction

Table 11.14 Advantages / Disadvantages of engineering element KH&A-B

NIAB Estate

Engineering element KH&A-C is based on extending of the proposed swale network on the soon to be developed land previously owned by the NIAB. The modelling indicates that there are advantages in intercepting surface water run-off which would otherwise miss the system. As noted in the advantages and disadvantages widening the existing swale system may be problematical and could be subject to space constraints within the proposed estate.

Third party impacts associated with the extension to the swale system and any widening would also have to be considered during the design stage including the impact on the proposed attenuation basis at the downstream end of the swale system. Nevertheless it presents a significant opportunity to reduce surface water run-off to the wetspot particularly where the extension to the system is proposed. The advantages and disadvantages of providing this form of defence are shown below.

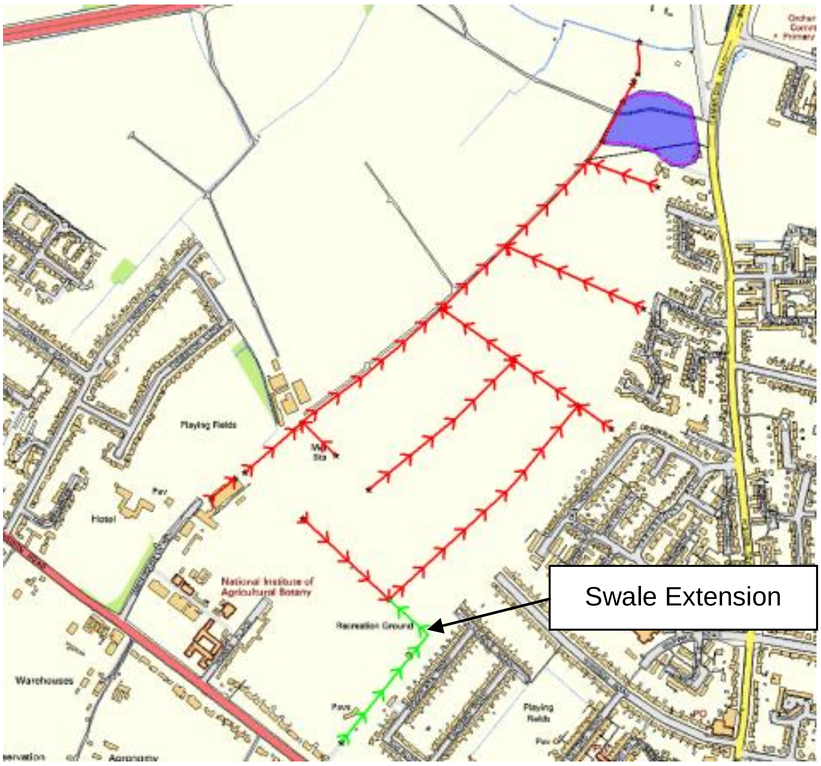


Figure 11-21 Location of Proposed Swale network - KH&A-C

	Advantage / Disadvantage
Advantage	A decreased conveyance of overland flood water from agricultural land will reduce the effects of what would otherwise be one of the largest contributors of flood water to the wetspot.
	Reduction of flood water conveyed by the existing sewer network.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Encourage natural ground water recharge.
Disadvantage	The proposed swale system will require routine maintenance.
	Access to the site required for large plant during the construction stage and hauling of material through estate roads.
	Proposed width of swales may meet resistance from the developer's plan which already has been granted planning permission.

Table 11.15 Advantages / Disadvantages of engineering element KH&A-C

Fitzwilliam Playing Fields

The location for an engineering element KH&A-D was selected primarily due to its location near to the surface water confluence on Windsor Road. Flow enters the playing field from the adjacent housing estate and flows in a north easterly direction towards Windsor Road. This engineering element includes improvements to the existing drain to form a dry swale (a swale with a filter drain below) and the development of an area for stormwater attenuation ‘upstream’ of a major surface water confluence on Windsor Road and to provide an opportunity to attenuate surface water into the storm sewer network. The advantages and disadvantages of providing this form of defence are shown below.

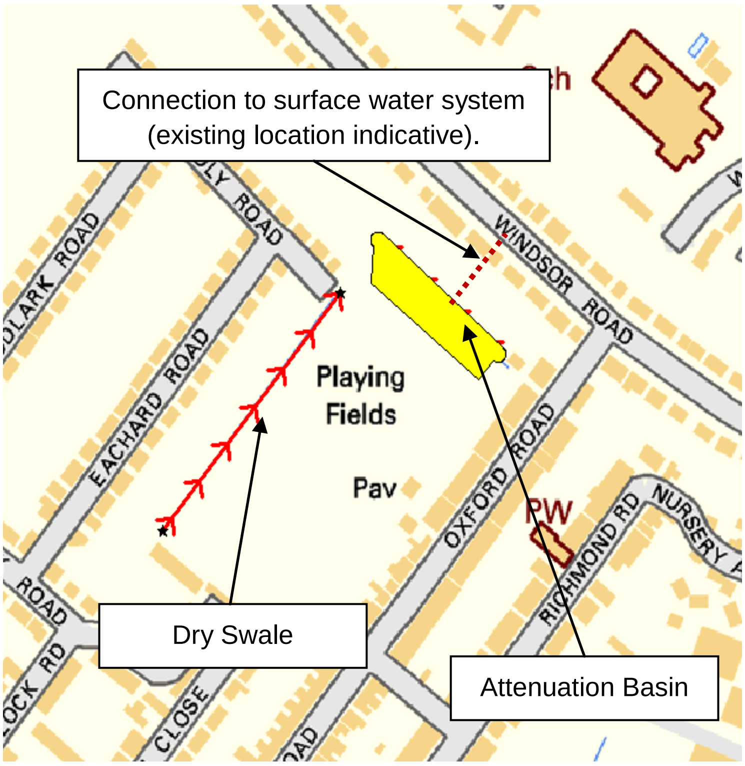


Figure 11-22 Fitzwilliam Playing Fields Attenuation Basin – KH&A-D

	Advantage / Disadvantage
Advantage	A large volume of flow from within the wetspot estate will be attenuated in an already existing ‘green space’.
Advantage	A large attenuation basin will significantly reduce the total volume of water entering residential areas downstream of this location.
Advantage	Managing the rate of runoff will reduce flooding caused by urbanisation.
Advantage	Encourage natural ground water recharge.
Disadvantage	Connection to the sewer system will require maintenance to ensure that the connection is not impeded.
Disadvantage	Access to the site required for large plant during the construction stage and hauling of material through estate roads.
Disadvantage	Potential closure of the playing fields during construction.
Disadvantage	Site is situated on University property and may be difficult to obtain permissions required to proceed with the works.

Table 11.16 Advantages / Disadvantages of engineering element KH&A-D

Mayfield Primary School, Tavistock and Warwick Roads

The Mayfield Primary School and Tavistock Road area is situated within the primary surface water flow route and surface water flood mitigation measures will provide an increased protection to the school and residential properties on Carisbrooke Road and Chatsworth Road. In particular open green space and verges of Tavistock Road north of Mayfield Primary School, can be converted to provide a series of attenuation basins. Accordingly a number of engineering elements have been considered to mitigate the effects of surface water flooding in this area. These engineering elements are described below and shown below.

Engineering element KH&A-J

- The introduction of attenuation basins within green space outside the perimeter of Mayfield School with a depth of 0.9m.
- The development of a storm water planter system of interconnected drainage.

Engineering element KH&A-X

- The introduction of attenuation basins within green space outside the perimeter of Mayfield School with a depth of 2.0m.
- The development of a storm water planter system of interconnected drainage

Engineering element KH&A-Z

- The construction of a swale to redirect flood water away from the school.

These engineering elements have been modelled individually and where appropriate collectively to determine the most effective mitigation measures in this area.

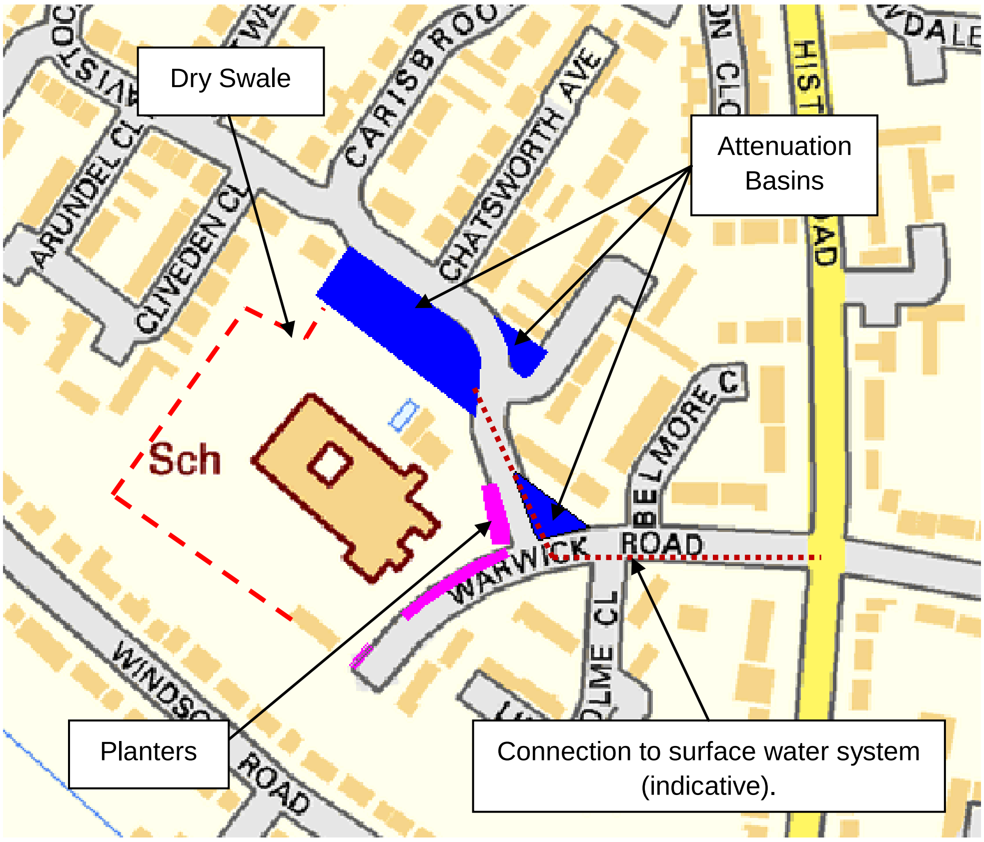


Figure 11-23 Mayfield school, Tavistock Road and Windsor Road - KH&A-J, KH&A-X and KH&A-Z

	Advantage / Disadvantage
Advantage	A large volume of flow from within the wetspot will be diverted from a residential estate and attenuated.
	Flood risk mitigation to Mayfield Primary School.
	Reduction of surface flood water conveyed by the existing sewer network.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Access and egress to the site for construction can be achieved using major road connections.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Encourage natural ground water recharge.
Disadvantage	Engineering Element KH&A-X may require fencing and safety precautions to protect members of the public from entering the attenuation basin area.
	Temporary closure of highways may be caused during construction.
	Access to the site required for large plant during the construction stage and hauling of material through estate roads.

Table 11.17 Advantages / Disadvantages of Engineering Elements KH&A-J, KH&A-X and KH&A-Z

Cambridge Road/ Histon Road

Six engineering elements have been considered alongside the Cambridge / Histon Road. The road runs in a northerly direction bisecting the King's Hedges & Arbury wetspot and has an important function in relation to flood conveyance within the wetspot. The engineering elements include:-

Engineering Element KH&A - E

- The development of an attenuation area in the north westerly corner of the allotments with discharge to the watercourse on the western side of the highway.
- Construction of a dry swale to convey surface water run-off to the attenuation basin.

Engineering Element KH&A-AB

- Construction of a storm water culvert along Cambridge Road to intercept floodwater crossing the Cambridge road and convey surface water from Chancellors to the swale within the allotment.

Engineering Element KH&A-W

- Construction of an attenuation area adjacent to Borrowdale Road

Engineering Element KH&A-AA

- Construction of raised footpaths adjacent to Gilbert Close to mitigate flooding

The objective of engineering element KH&A - E and KH&A-AB is to mitigate the effects of surface water flooding to the eastern side of Cambridge / Histon Road by intercepting flows crossing Cambridge Road from the west. The redirection of flood water into the swale network from Walnut Tree Way also provides an interception point for surface water entering and inundating domestic properties on the nearby estate (Figure 11.26). Water is routed along the Cambridge Road perimeter towards the attenuation basin in the north western corner of the allotment.

The position of the attenuation basin was located to provide a suitable piped overflow to an existing swale network on the opposite side of the Cambridge Road. In addition, this engineering element could also be linked with the construction of a new culvert (or swale if possible) which conveys flood water from the junction of Badminton Close and Histon Road to the attenuation basin. The objective of constructing a raised footpath on Gilbert Close and an attenuation basin at Borrowdale Road (engineering elements KH&A-W and KH&A-AA) is to mitigate the risk of localised flooding in this area.

Engineering Element KH&A-AC

- Construction of an overflow pipe between the Trunk Sewer and Cambridge Road Allotment Swale.
- The objective of engineering element KH&A-AC (in conjunction with KH&A-E) will provide an opportunity for storm water to leave the storm sewer network when capacity has been reached. Water leaving the storm sewer enters the Allotment swale network.

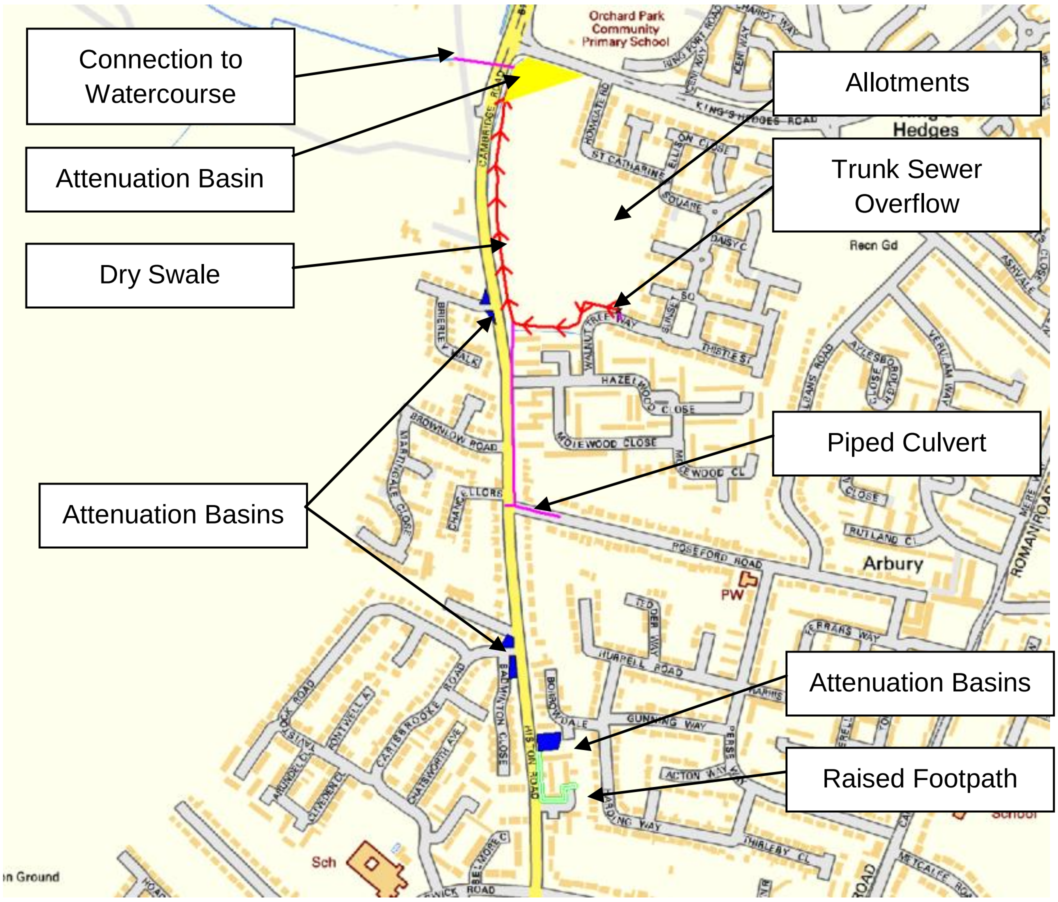


Figure 11-24 Cambridge / Histon Road - KH&A-E, KH&A-AB, KH&A-W, KH&A-AA and KH&A-AC

The advantages and disadvantages of providing this form of defence are as follows.

	Advantage / Disadvantage
Advantage	A large volume of flow from within the wetspot will be diverted from a residential estate and attenuated towards the attenuation basin.
	Reduction of surface flood water conveyed by the existing sewer network.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Flood protection to properties of Gilbert Close
	Encourage natural ground water recharge.
	Upon reaching capacity the storm sewer is provided with an overflow relief outlet at the Cambridge Road Allotment. This will allow for a greater utilisation of existing drainage capacity under large storm event conditions.
Disadvantage	Construction may require fencing and safety precautions to protect members of the public from entering the attenuation basin area.
	Potential closure and interruption of allotment activities during periods of construction.
	Temporary lane closure of the Cambridge Road could lead to an increase in congestion along other major access and egress routes in Cambridge.
	Raised pavement areas may increase the volume of flood water on the Histon Road.
	The trunk sewer overflow pipe will increase pressure on the soakaway system in the Cambridge Road Allotment.

Table 11.18 Advantages / Disadvantages of Engineering Elements KH&A-E, KH&A-W, KH&A-AA, KH&A-AB and KH&A-AC

St. Albans Recreational Ground & Surrounding Roads

Anecdotal evidence that the St. Albans Recreational ground experiences frequent periods of water logging during the winter months supports the findings of this study. The recreation ground is particularly vulnerable to flooding at higher return periods. In order to mitigate the effects of surface water flooding, the recreational ground to the north west of St. Albans Road and the adjacent roads provides a large area where a storm water planter, swale and attenuation network has been considered. Surface water would be collected in the swale and planter network located and routed towards the attenuation basin in the south western corner (see Figure 11.27).

A number of engineering elements have been considered to mitigate the effects of surface water flooding in this area. These engineering elements are described below.

Engineering Element KH&A-F

- The introduction of an attenuation basin within the St Albans Road Recreation Ground.
- The construction of a swale to redirect flood water around the recreation ground

Engineering Element KH&A-X

- The introduction of an attenuation basin within the Aylesborough Close.
- The development of a storm water planter system of interconnected drainage

These engineering elements have been modelled individually and where appropriate collectively to determine the most effective mitigation measures in this area.

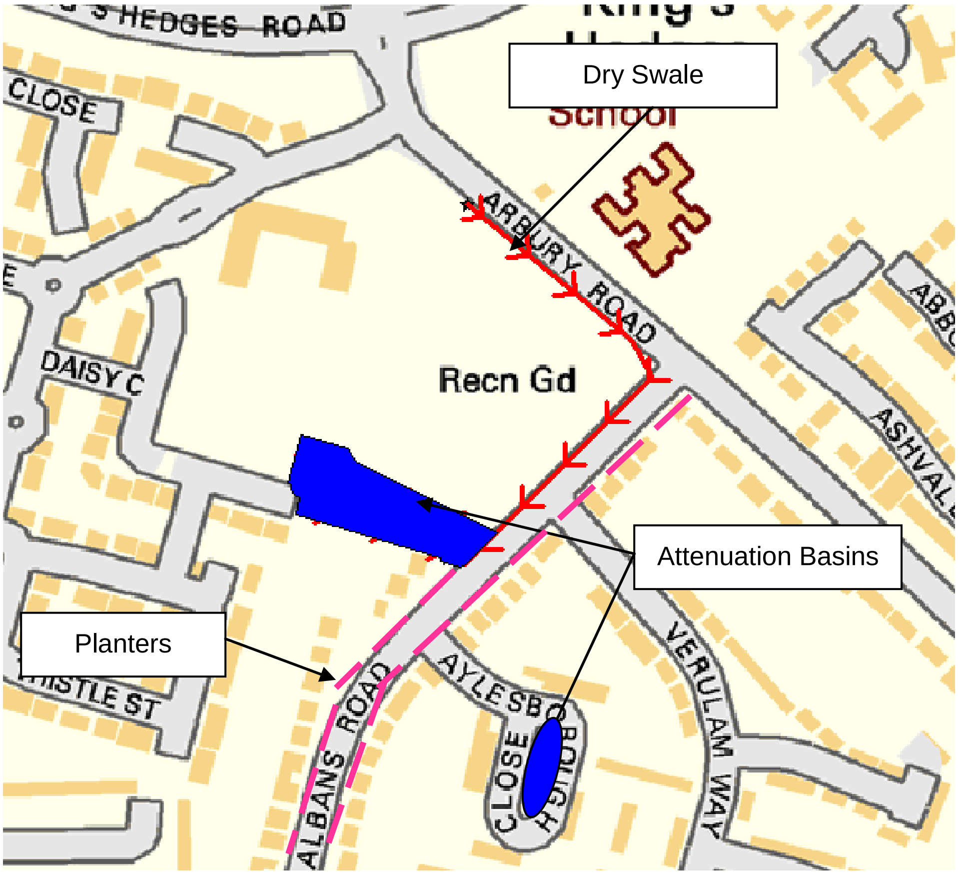


Figure 11-25 Location of Engineering elements KH&A-F and KH&A-X

	Advantage / Disadvantage
Advantage	A large volume of flow from within the wetspot will be diverted from a residential estate and attenuated.
	Reduction of surface flood water conveyed by the existing sewer network.
	Access and egress to the site for construction can be achieved using major road connections.
	Manage the rate of runoff and reduce flooding caused by urbanisation.
	Encourage natural ground water recharge.
Disadvantage	Potential restrictions on access to the recreational ground during construction.
	Temporary closure of highways may be caused during construction.

Table 11.19 Advantages / Disadvantages of Engineering Elements KH&A-F and KH&A-X

Permeable paving / Road side rain gardens

In order to assess the effectiveness of highway source control measures a “first pass” approach was considered where, despite obvious cost implications, all residential roads in the Kings Hedges and Arbury wetspot are fitted with the most cost effective combination of permeable paving, road side rain gardens and filter drains to provide the attenuation volume. The extent of roads “fitted” with highway source control measures is shown in Figure 11.28. This is engineering element KH&A-G.

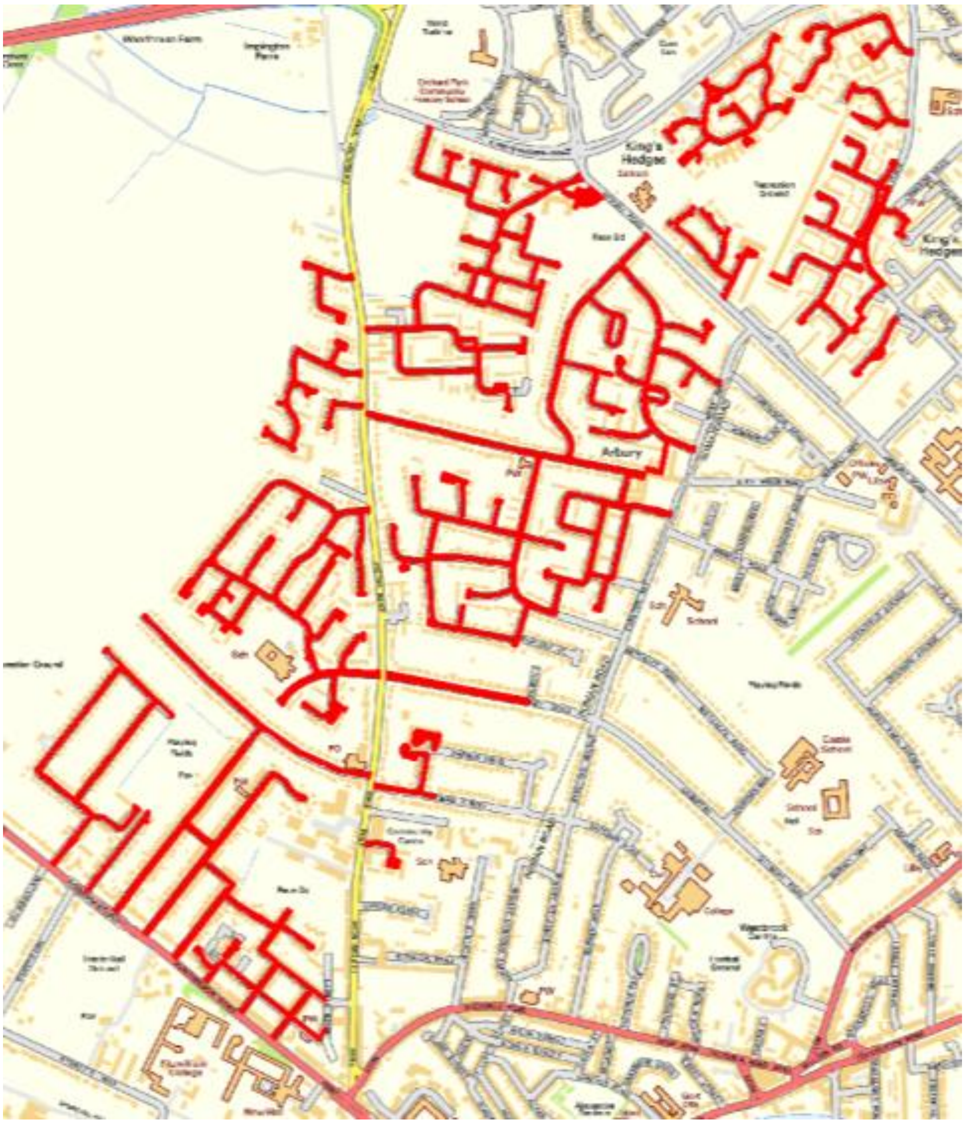


Figure 11-26 Potential Permeable Paving Locations KH&A-G

Engineering elements KH&A-H, KH&A-I, KH&A-L, KH&A-M, KH&A-Y consider the use of Road side rain gardens within the verges of the road and engineering elements KH&A-N, KH&A-O, KH&A-P, KH&A-Q, KH&A-R, KH&A-S, KH&A-T, KH&A-U, and KH&A-V are based upon the use of permeable paving / planters / filter drains as appropriate applied to a number of estate roads within the King’s Hedges and Arbury estates. These engineering elements have been combined to form the Option Combinations to determine the impact of highway source control on the economic assessment (see Section 13).

Figures 11-29 to 11-42 show the potential locations of the engineering elements mentioned above.

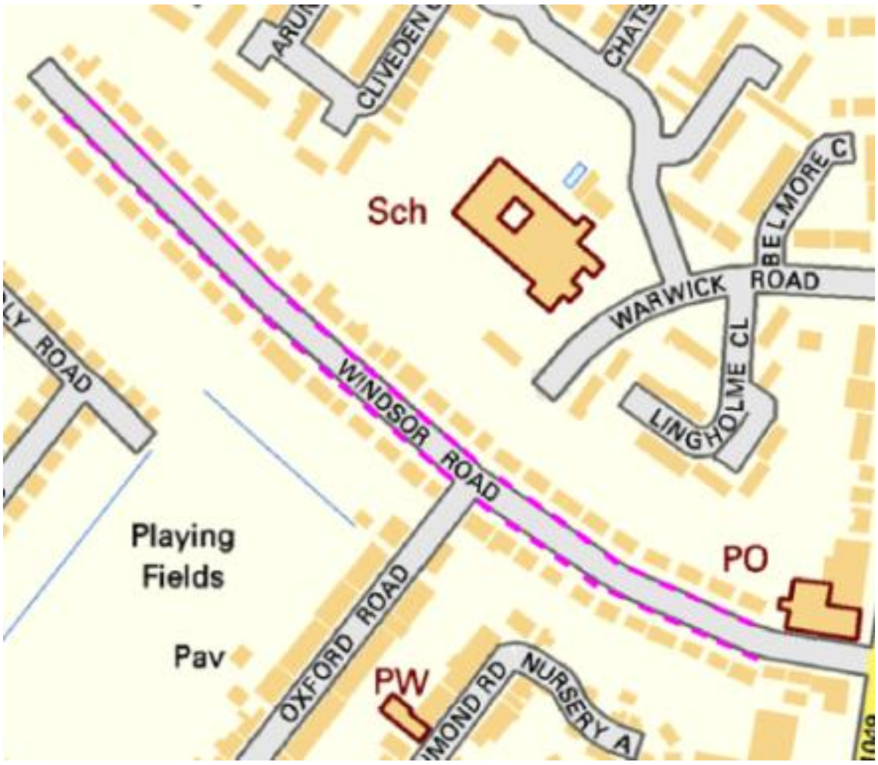


Figure 11-27 Windsor Road Roadside Road side rain gardens KH&A-H

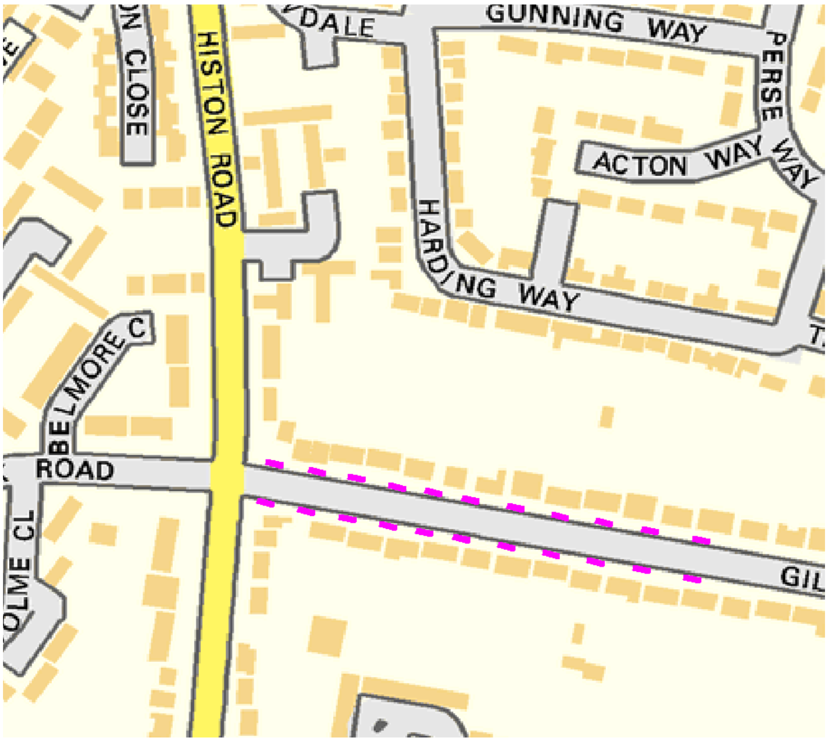


Figure 11-28 Gilbert Road – Roadside Road side rain gardens KH&A-I

Figure 11-29 Histon Road – Roadside Road side rain gardens KH&A-L

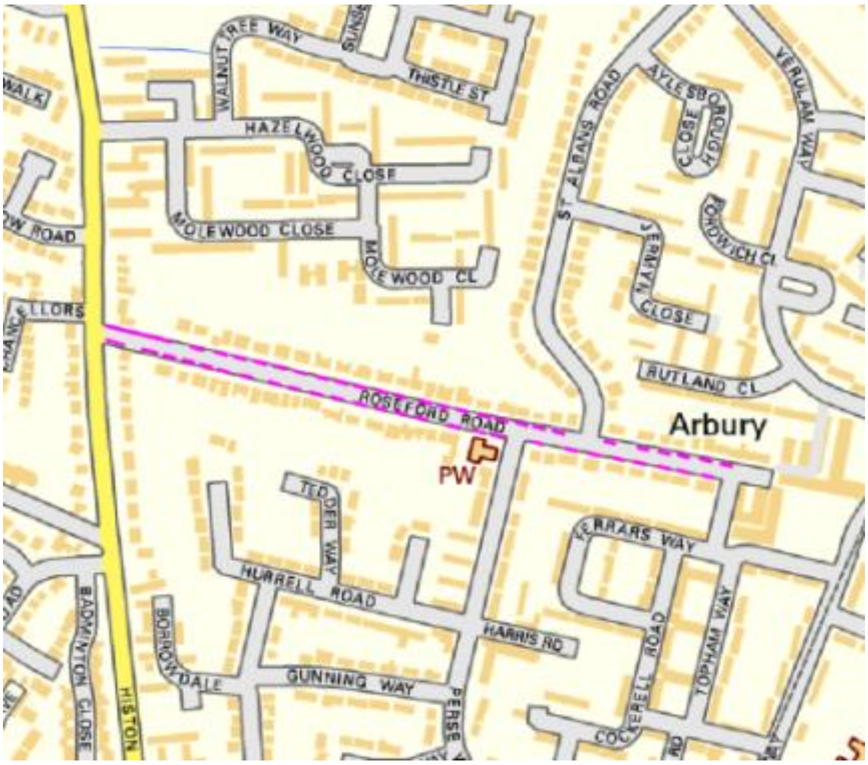


Figure 11-30 Roseford Road –Road side rain gardens KH&A-M

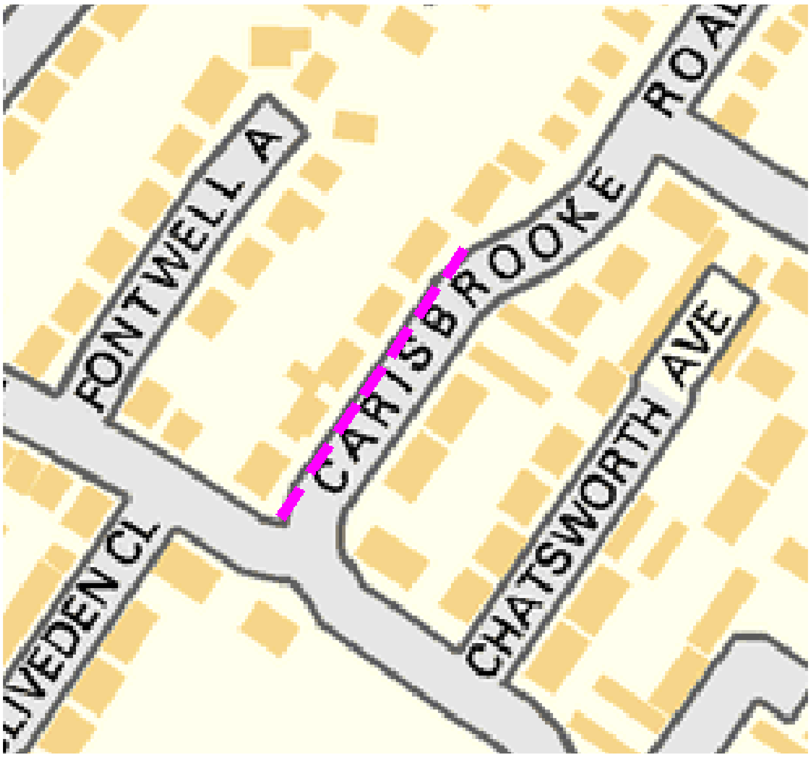


Figure 11-31 Carisbrooke Road –Road side rain gardens KH&A-Y

Figure 11-32 Potential locations for permeable paving options - KH&A-N

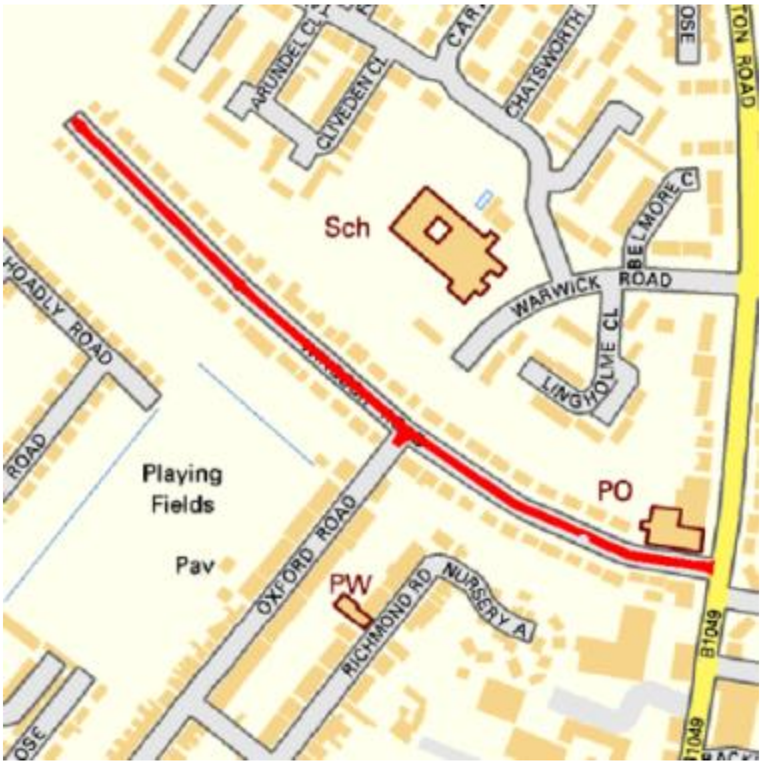


Figure 11-33 Potential locations for permeable paving options - KH&A-O

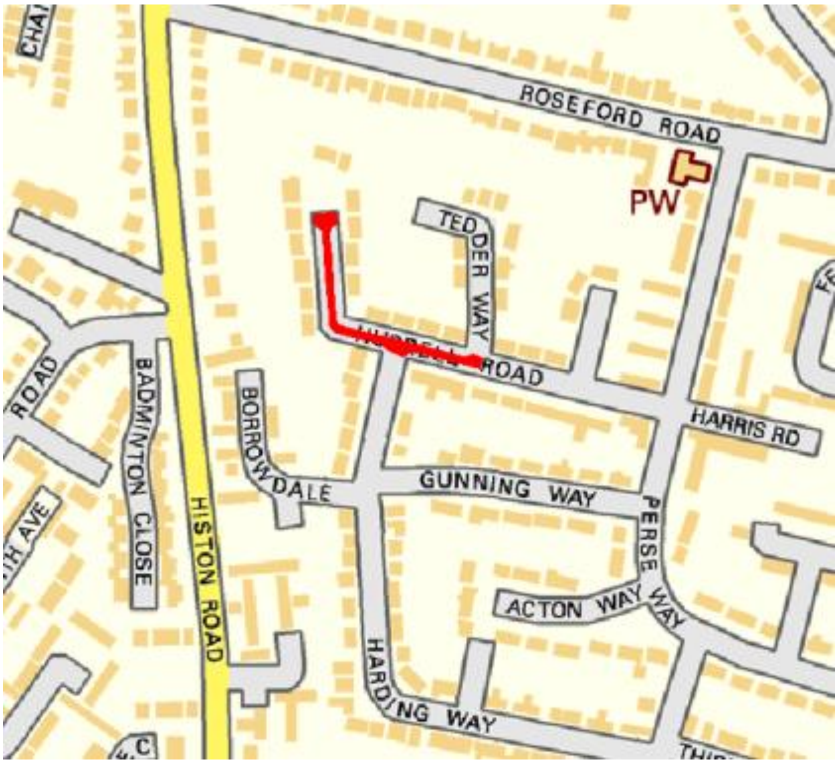


Figure 11-34 Potential locations for permeable paving options - KH&A-P

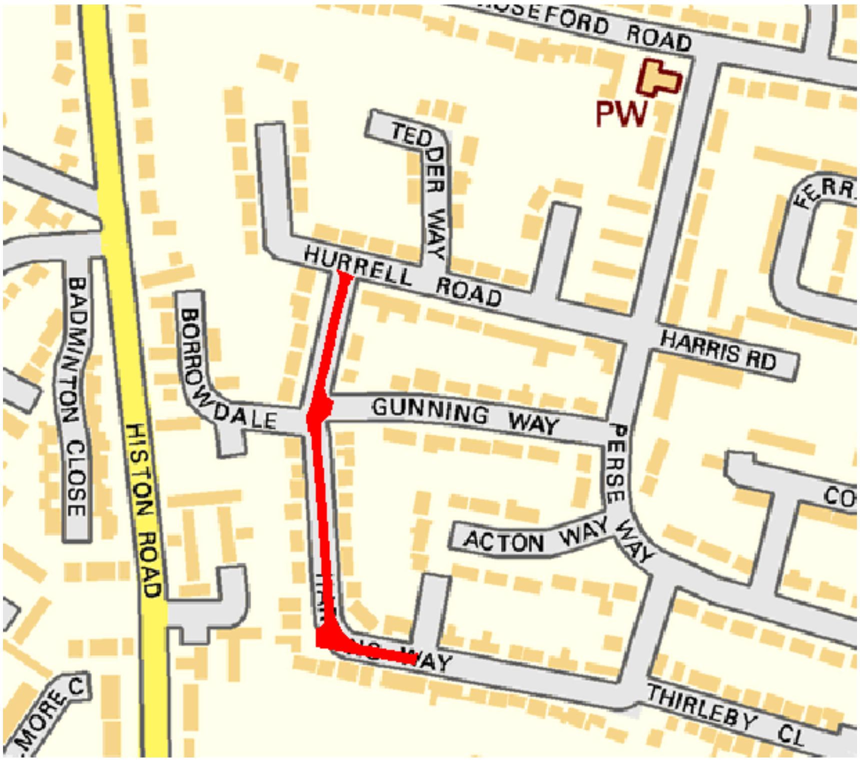


Figure 11-35 Potential locations for permeable paving options - KH&A-Q

Figure 11-36 Potential locations for permeable paving options - KH&A-R

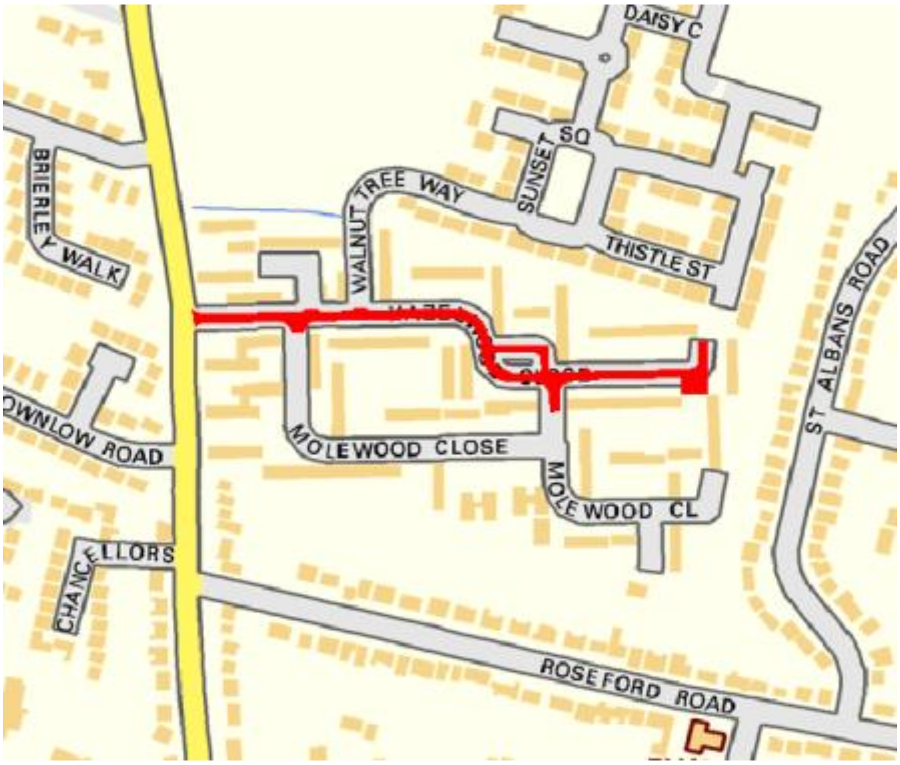


Figure 11-37 Potential locations for permeable paving options - KH&A-S

Figure 11-38 Potential locations for permeable paving options - KH&A-T

Figure 11-39 Potential locations for permeable paving options - KH&A-U

Figure 11-40 Potential locations for permeable paving options - KH&A-V

11.5 Preferred Options Identification

In order to address flooding within the Cherry Hinton and Kings Hedges wetspots and for the purposes of the SWMP, combinations of options have been developed. These have been tested for their effectiveness of reducing flooding in each wetspot.

The engineering elements described in Section 11.3.1 and Section 11.4.1 have been combined into Option Combinations which have been evaluated for the purposes of the SWMP. These combinations reflect the flooding mechanisms described above with the objective of determining their technical suitability and whether there is an economic case for the mitigation of surface water flooding in both wetspots. Descriptions for the options are presented in Section 12.2.1 and Section 12.3.1 below for Cherry Hinton (Option Combinations C1 to C8) and Kings Hedges (Option Combinations C1 to C8) respectively.

12 Economic Appraisal

12.1 Introduction

The engineering elements described in Section 11 have been combined to form the Option Combinations as shown in Table 12.1 and 12.5. These Option Combinations have been assessed in relation to whole life costs, flood damages and residual damages in accordance with the methodology contained in the following documents.

- Flood and Coastal Erosion Project Appraisal Guidance (FCERM-AG Manual)[21].
- The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques[22]

The latter document is also known as the Multi-Coloured Manual (MCM, 2010). The evaluation of the residual risk of flooding has been discussed in the relevant sections associated with the Option Combinations. The residual flood risk damages relating to the “Do Something” options have been discounted annually to enable a direct comparison with other options. A discount rate of 3.5% has been adopted for the cost benefit analysis.

The economic analysis assumes an investment profile in flood mitigation infrastructure over an 80 year period. The investment profile was introduced to reflect the likely degree of investment in flood mitigation infrastructure available to the CFRMP. For option combinations which incorporate attenuation basins \ wetlands the investment profile is structured to assume that one basin is constructed every two years until the attenuation schemes have been completed. Following the completion of the attenuation basin / wetland phase of work it is then assumed that highway source control measures are progressively installed based upon the scope of the option combination. Structuring the works in this manner ensures that there is an ongoing even distribution of work in terms of flood mitigation. In addition, this structure also has a positive effect on benefit cost ratios.

It should also be noted that a value engineering exercise was undertaken to evaluate the Option Combinations indicated that a significant factor in the costs associated with the works were associated with the excavation and disposal to landfill of materials for the formation of attenuation basins and other flood mitigation infrastructure. Accordingly the economic analysis assumes that all excavated materials will be re-used on site to avoid the cost of disposal of the material. This could include the formation of embankments and other landscaping features. This avoids costs associated with disposal including land fill tax. It also promotes the sustainable credentials of the project by reducing the carbon footprint associated with the transportation of materials for disposal.

Whilst an optimism bias of 60 % has been applied to all of the cost estimates (as per the current guidance applicable for a strategy of this nature) there are a number of economic risks or uncertainties associated with the development of the cost estimates.

12.1.1 Methodology – Damages Assessment

The assessment of cost associated with flood damage of properties in Cambridge has been assessed using the DEFRA and Environment Agency approved approach outlined in the Multi-Coloured Manual. The MCM method for assessing damages refer to depth/damage curves based on property type, age and social class of the dwellings occupants, in order to evaluate the overall damage avoided in a flood risk area.

For each Option Combination, flood depth results for each return period were extracted for all properties within the modelled region. With respect to the flood depth, damages result from the physical contact of flood water with damageable property.

Using the address data provided by the National Property Dataset (NPD) the land use data is derived to form the basis of the cost of the damages assessment. This data includes:

- The land use category
- The floor area
- The property threshold
- The most appropriate level of detail for depth/damage data

The dataset used for this study did not provide the property threshold level therefore LiDAR inclusive of an additional 0.1m was used to determine the threshold level of each address point. Through calculating the flood damages associated with the 'Do Nothing', 'Do Minimum' and 'Do Something' options the Annual Average Damages are calculated.

Depending on the size or severity of each flooding event, each flood event will cause a different amount of flood damage. The Average Annual Damage (AAD) is the average damage per year in monetary terms that would occur at each specific address point, within the modelled domain, from flooding over 100 years. In many years there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there may be major flood damage (caused by large, rare flood events). Estimation of the AAD provides a basis for comparing the effectiveness of different flood alleviation and management measures (i.e. through measuring the reduction in AAD).

The methodology for assessing the benefits of flood alleviation combines:

- An assessment of risk, in terms of the probability or likelihood of future floods to be averted, and
- A vulnerability assessment in terms of the damage that would be caused by those floods and therefore the economic saving to be gained by their reduction.

Through assessment of the associated damage values and the benefits incurred through Engineering Options, proposed schemes are compared against each other using their benefit-cost ratio (BCR).

Within the appraisal of engineering options, a comparison between the consequences of 'Do Something' are assessed against the baseline 'Do Nothing' option. The cost of each Option Combination and the relative damages incurred are combined to create a benefit cost ratio. This ratio is used to assess the viability of each Option Combination to determine the viability of each option and also the levels of effectiveness for how capital can be spent to protect and alleviate from the effects of flooding. The BCR is the ratio of benefits produced through introduction of flood alleviation options, expressed in monetary terms, relative to its cost, identifying the greatest 'value for money'.

The Multi-Coloured Manual[22] states that;

'Projects are only viable if the benefits exceed the costs (i.e. the ratio of benefits to costs is greater than 1.0).Where benefits marginally exceed costs, there is often high uncertainty as to whether an option is justified, because only a small change or error in either the benefits or costs would tilt the balance the other way. So when comparing a 'Do Something' option to the baseline option, confidence is needed that a 'Do Something' option is clearly preferable.

In this regard, the decision process explored whether the best value for money is provided while achieving the most appropriate standard of risk management defence. This is undertaken by assessing the incremental benefit-cost ratio of each economically viable option.'

12.1.2 Economic Risks

The principal economic risks are associated with the construction of all Engineering Options are:-

- Cost of possible diversion of utilities;
- Cost of land negotiations
- Compensation for disruption
- Buildability

It is recommended that the project lead should approach utility companies to obtain agreements for the relocation of services as necessary. In addition the project lead should engage with all landowners and stakeholders at the earliest opportunity during the design process to ensure their collaboration.

12.1.3 Cost Estimates

Each of the proposed Option Elements has been costed in accordance with information on maintenance expenditure obtained from Cambridge City Council and Cambridgeshire County Council and SPON's Civil Engineering and Highways Price Book[23]. In terms of developing the discounted capital costs of construction works each Option Element was assigned into an investment profile to simulate the implementation of expenditure, spread over a number of years. The final capital costs for each Option Combination are therefore subject to a specific pattern of spending.

12.2 Cherry Hinton

12.2.1 Engineering Option Combinations

The Option Combination Elements were combined into 'Do Something', which includes 'Do Minimum' and Option Combinations C1, to C8, as shown in Table 12.1. The 'Do Something' Option Combinations are listed below:-

- **Do Nothing** – The "Do Nothing" option assumes that no maintenance, clearance or other intervention is made to interfere with the natural fluvial processes or sewer network. The evaluation of the "Do Nothing" option is a technical requirement required by the Treasury in order to enable comparisons to be made between the "Do Minimum" and "Do Something" options. The flood loss damages associated with the "Do Nothing" option are the benefits of the economic assessment. A bare earth model for this analysis will provide the 'Baseline' model for this study.

- **Do Minimum** – Maintenance of the existing storm sewer, ordinary watercourse and highway drainage including, gully cleaning, jetting, removal of debris / vegetation; treeworks and periodic removal of deposition and sediments.

- **Option Combination C1** - This combination comprised the installation of attenuation ponds and swales. The investment profile assumes that one swale or basin element is constructed every two years over a period of 6 years, and the maintenance costs are staggered according to when that particular element was completed.

- **Option Combination C2** - Option combination is based upon the distribution of source control measures in the public highway on all estate roads (e.g. the most cost effective combination of permeable paving, road side rain gardens and filter drains). The capital cost of undertaking this work has been divided into a year-by-year spend over a 60 year period, representing a steady conversion of roads throughout Cambridge. The profiling also assumes no significant increase in the highway maintenance costs for these replacement roads, although in reality it is likely that there would be a saving due to the removal of a number of road gullies which would no longer require clearing and maintenance.
- **Option Combination C3** – This combination comprised the installation of attenuation ponds and swales alongside highway source control (a combination of permeable paving and filter drains) at targeted locations within the catchment.
- **Option Combination C4** - This option consisted mainly of improvements to the existing surface water drainage network where previous modelling had identified problems with surcharging manholes.
- **Option Combination C5** - This combination comprised the installation of attenuation ponds and swales alongside highway source control (a combination of permeable paving and filter drains) at targeted locations within the catchment alongside routing of flow from the surface water drainage network in to the Cherry Hinton Brook.
- **Option Combination C6 –** This option looks exclusively at optimising existing attenuation structures, and focusing on the St Thomas Square area of the wetspot. It also utilises short lengths of permeable paving.
- **Option Combination C7 –** This combination includes the optimised attenuation structure at Cherry Hinton Hall, whilst including amended versions of the attenuation structures at Nightingale Avenue, and Netherhall Sixth Form College and Netherhall Farm. It utilises permeable paving in strategic locations across the wetspot.
- **Option Combination C8 –** This combination option is an amendment of Option C7, with the exception of removing any permeable paving mitigation strategies in the area.

Engineering Element	C1	C2	C3	C4	C5	C6	C7	C8
CH-A	✓	✓	✓	✓	✓	✓	✓	✓
CH-B	✓		✓		✓			
CH-C	✓		✓		✓			
CH-D	✓		✓		✓			
CH-E	✓		✓		✓			
CH-F	✓		✓		✓			
CH-G	✓		✓		✓			
CH-H	✓		✓		✓			
CH-I	✓		✓		✓			
CH-J		✓						
CH-K			✓		✓			
CH-L			✓		✓			
CH-M			✓		✓			

Engineering Element	C1	C2	C3	C4	C5	C6	C7	C8
CH-N			✓		✓			
CH-O			✓		✓		✓	
CH-P			✓		✓		✓	
CH-Q			✓		✓		✓	
CH-R			✓		✓			
CH-S			✓		✓			
CH-T			✓		✓			
CH-U			✓		✓			
CH-V			✓		✓			
CH-W			✓		✓			
CH-X			✓		✓			
CH-Y			✓		✓			
CH-Z					✓			
CH-AA				✓	✓			
CH- AB					✓			
CH-AC						✓		
CH-AD						✓	✓	✓
CH-AE						✓	✓	
CH-AF							✓	✓
CH-AG							✓	✓
CH-AH							✓	✓

Table 12.1 Option Combinations – Cherry Hinton

12.2.2 Benefit Cost Analysis

Table 12.2 summarises the Average Annual Damages and Present Value Damages associated with the 'Do Nothing' and 'Do Something' Option Combinations. Based upon the assessment of damages and the cost estimates given for each option combination, the present value damages have been combined with the whole life cost estimates within Table 12.2. This table summarises the costs, benefits and residual damages associated with each option.

Option Combination	Average Annual Damage (£)	Present Value Damages (£)
Do Nothing	2,103,033	44,405,140
Do Minimum	1,866,839	38,595,519
C1	1,779,009	35,371,413
C2	1,608,320	30,267,809

C3	1,755,881	34,679,886
C4	1,875,614	38,259,890
C5	1,784,220	35,527,218
C6	1,855,110	41,847,010
C7	1,827,933	41,034,411
C8	1,815,448	40,661,107

Table 12.2 Flood and Residual Flood Damages – Cherry Hinton

12.2.3 Non Engineering Measures

A range of policy lead measures have been considered as discussed in Sections 13 to 15 below in addition to the engineering options above.

Costs and Benefits £	No Scheme	Do Minimum	C1	C2	C3	C4	C5	C6	C7	C8
PV costs from estimate		1,329,885	3,034,442	45,010,458	5,499,939	2,938,493	6,331,813	2,513,168	3,132,571	2,228,003
Optimism bias adjustment		797,931	1820,665	27,006,275	3,299,963	1,242,675	3,799,088	1,507,901	1,879,543	1,335,802
Total PV Costs from appraisal (PVc)		2,127,816	4,855,108	72,016,733	8,799,903	4,181,168	10,130,900	4,021,070	5,012,114	3,564,805
PV damage (Pvd *)	44,405,140	38,595,519	35,371,413	30,267,809	34,679,886	38,259,890	35,527,218	41,847,010	41,034,411	40,661,107
PV damage avoided		5,809,621	9,033,727	14,137,331	9,725,254	6,145,250	8,877,922	7,412,899	8,225,498	8,598,802
Total PV benefits (PVb)		5,809,621	9,033,727	14,137,331	9,725,254	6,145,250	8,877,922	7,412,899	8,225,498	8,598,802
Net Present Value (NPV)		3,681,805	4,178,619	-57,879,402	925,352	1,964,082	-1,252,978	3,391,829	3,213,384	5,033,997
Average benefit cost ratio		2.73	1.86	0.20	1.11	1.47	0.88	1.84	1.64	2.41

Table 12.3 Summary of Costs and Damages – Cherry Hinton

Year	C1	C2	C3	C4	C5	C6	C7	C8
1	CH-A, CH-E	CH-A, CH-J	CH-A, CH-E	CH-A , CH-AA (10%)	CH-A, CH-E	CH-A, CH-AC	CH-A, CH-AD	CH-A, CH-AD
2		CH-J (1.2%)		CH-AA (20%)				
3	CH-C	CH-J (1.8%)	CH-C	CH-AA (30%)	CH-C	CH-AD	CH-AF	CH-AF
4		CH-J (2.4%)		CH-AA (40%)				
5	CH-I	CH-J (3.0%)	CH-I	CH-AA (50%)	CH-I	CH-AE	CH-AG	CH-AG
6		CH-J (3.6%)		CH-AA (60%)				
7	CH-H	CH-J (4.2%)	CH-H	CH-AA (70%)	CH-H		CH-AH	CH-AH
8		CH-J (4.8%)		CH-AA (80%)				
9	CH-B	CH-J (5.4%)	CH-B	CH-AA (90%)	CH-B		CH-AI	
10		CH-J (6.0%)		CH-AA (100%)				
11	CH-D	CH-J (6.6%)	CH-D		CH-D		CH-AE	
12		CH-J (7.2%)						
13	CH-F, CH-G	CH-J (7.8%)	CH-F, CH-G		CH-F, CH-G			
14		CH-J (8.4%)						
15		CH-J (9.2%)	CH-M through Y (4%)		CH-M through Y (4%)			
16		CH-J (9.8%)	CH-M through Y (8%)		CH-M through Y (8%)			
17			CH-M through Y (12%), CH-K		CH-M through Y (12%), CH-Z			
18			CH-M through Y (16%)		CH-M through Y (16%)			
19			CH-M through Y (20%), CH-L		CH-M through Y (20%), CH-AB			
20			CH-M through Y (24%)		CH-M through Y (24%)			
21			CH-M through Y (28%)		CH-M through Y (28%), CH-K			
22			CH-M through Y		CH-M through Y			

		(32%)	(32%)
23		CH-M through Y (36%)	CH-M through Y (36%), CH-L
24		CH-M through Y (40%)	CH-M through Y (40%)
25			CH-M through Y (44%), CH-AA (10%)
26			CH-M through Y (48%), CH-AA (20%)
27			
…			
35			CH-M through Y (84%), CH-AA (100%)
40		CH-M through Y (100%)	CH-M through Y (100%)
60	CH-J (100%)		

Table 12.4 Spending Patterns: Engineering Options Combinations – Cherry Hinton

12.3 Kings Hedges and Arbury

12.3.1 Engineering Option Combinations

The Option Combination Elements were then combined into 'Do Something', which includes 'Do Minimum' and Option Combinations C1 to C8, as shown in Table 12.5. The 'Do Something' Option Combinations are listed below:-

- **Do Nothing** – The "Do Nothing" option assumes that no maintenance, clearance or other intervention is made to interfere with the natural fluvial processes or sewer network. The evaluation of the "Do Nothing" option is a technical requirement required by the Treasury in order to enable comparisons to be made between the "Do Minimum" and "Do Something" options. The flood loss damages associated with the "Do Nothing" option are the benefits of the economic assessment. A bare earth model for this analysis will provide the 'Baseline' model for this study.

- **Do Minimum** – Maintenance of the existing storm sewer, ordinary watercourse and highway drainage including, gully cleaning, jetting, removal of debris / vegetation; treeworks and periodic removal of deposition and sediments.
- **Option Combination C1** - This combination comprised the installation of attenuation ponds and swales. The investment profile assumes that one swale or basin element is constructed every two years over a period of 6 years, and the maintenance costs are staggered according to when that particular element was completed.
- **Option Combination C2** - Option combination is based upon the distribution of source control measures in the public highway on all estate roads (e.g. the most cost effective combination of permeable paving, road side rain gardens and filter drains). The capital cost of undertaking this work has been divided into a year-by-year spend over a 60 year period, representing a steady conversion of roads throughout Cambridge. The profiling also assumes no significant increase in the highway maintenance costs for these replacement roads, although in reality it is likely that there would be a saving due to the removal of a number of road gullies which would no longer require clearing and maintenance.
- **Option Combination C3** - This option combination includes the large scale source control measures in the public highway in combination with the installation of attenuation ponds and swales and, similarly, this cost is spread over a 60-year period; although this time source control measures in the public highway on all estate roads are not implemented until year 20. This option also includes attenuation basins and swales with the investment occurring at 2-year intervals. This represents an alternative investment profile to Option Combination C2.
- **Option Combination C4** - This option consisted mainly of the installation of small-scale storm water planter options, as well as a number of targeted source control measures in the public highway schemes selected for their effectiveness.
- **Option Combination C5** - This option combination selected a number of the better performing attenuation basins and swales, included some of the best performing source control measures in the public highway schemes, and also included some specifically targeted defences for individual groups of properties.
- **Option Combination C6** - This option combination selected a number of the better performing attenuation basins and swales, and also included some specifically targeted defences for individual groups of properties

- **Option Combination C7** – This option combination utilises a variety of the most effective attenuation basins and swales. Most notably is the inclusion of a swale around Mayfield Primary School redirecting flow, which would previously enter the school, into the proposed attenuation basin on Tavistock Road.
- **Option Combination C8** – This option combination uses the specification of C7 with the addition of a storm sewer overflow pipe connected to the swale network of the Cambridge Road Allotment. The inclusion of this element will provide an additional measure to increase conveyance of storm water using the existing sewer network during large return period events.

Option Element	C1	C2	C3	C4	C5	C6	C7	C8
KH&A-A	✓	✓	✓	✓	✓	✓	✓	✓
KH&A-B	✓		✓		✓	✓	✓	✓
KH&A-C	✓	✓	✓	✓	✓	✓	✓	✓
KH&A-D	✓		✓		✓	✓	✓	✓
KH&A-E	✓		✓		✓	✓	✓	✓
KH&A-F	✓		✓		✓	✓		
KH&A-G		✓	✓					
KH&A-H			✓	✓				
KH&A-I			✓	✓				
KH&A-J			✓	✓				
KH&A-K			✓	✓				
KH&A-L			✓		✓			
KH&A-M			✓	✓				
KH&A-N				✓				
KH&A-O				✓				
KH&A-P				✓				
KH&A-Q				✓				
KH&A-R				✓	✓			
KH&A-S				✓	✓			
KH&A-T				✓				
KH&A-U				✓				
KH&A-V				✓				
KH&A-W					✓	✓		
KH&A-X					✓	✓		✓
KH&A-Y					✓			
KH&A-Z						✓		✓
KH&A-AA						✓		
KH&A-AB						✓		
KH&A-AC								✓

Table 12.5 Option Combinations - Kings Hedges and Arbury

12.3.2 Benefit Cost Analysis

Table 12.6 summarises the Average Annual Damages and Present Value Damages associated with the Doing Nothing and Doing Something Option Combinations. Based upon the assessment of damages and the cost estimates given for each option combination, the present value damages have been combined with the whole life cost estimates within Table 12.6. This table summarises the costs, benefits and residual damages associated with each option.

Option Combination	Average Annual Damage (£)	Present Value Damages (£)
Doing Nothing	640,666	19,155,927
Doing Minimum	432,522	12,932,435
C1	337,418	10,088,828
C2	324,199	9,693,555
C3	263,538	7,879,799
C4	367,607	10,991,478
C5	324,313	9.696,962
C6	296,558	8,867,099
C7	351,262	10,502,731
C8	344,821	10,310,139

Table 12.6 Flood and Residual Flood Damages - Kings Hedges and Arbury

12.3.3 Non Engineering Measures

A range of policy lead measures have been considered as discussed in Sections 13 to 15 below in addition to the engineering options above.

Costs and Benefits £	No Scheme	Do the Minimum	C1	C2	C3	C4	C5	C6	C7	C8
PV costs from estimate	787,613	787,613	1,430,417	12,738,907	9,151,713	3,387,033	2,218,950	2,087,406	1,398,950	1,428,421
Optimism bias adjustment		472,568	858,250	7,643,344	5,706,183	2,032,220	1,331,370	1,252,444	839,370	857,053
Total PV Costs from appraisal PVc		1,260,181	2,288,668	20,382,251	14,857,896	5,419,252	3,550,320	3,339,850	2,238,320	2,285,474
PV damage Pvd *	19,155,927	12,932,435	10,088,828	9,693,555	7,879,799	10,991,478	9.696,962	8,867,099	10,502,731	10,310,139
PV damage avoided		6,223,492	9,067,100	9,462,373	11,276,128	8.164,449	9,458,965	10, 288,828	8,653,196	8,935,229
Total PV benefits PVb		6,223,492	9,067,100	9,462,373	11,276,128	8.164,449	9,458,965	10, 288,828	8,653,196	8,395,229
Net Present Value NPV		4,963,311	6,778,432	10,919,878	3,581,768	2,745,197	5,908,645	6,948,678	6,414,876	6,649,755
Average benefit cost ratio		4.94	3.96	0.46	0.76	1.51	2.66	3.08	3.87	3.91

Table 12.7 Summary of Costs and Damages - Kings Hedges and Arbury

Year	C1	C2	C3	C4	C5	C6	C7	C8
1	KH&A - D, KH&A-A, KH&A-C	KH&A-A, KH&A-C, KH&A-G	KH&A-A, KH&A-B, KH&A-C	KH&A - A, KH&A - C, KH&A - H	KH&A - A, KH&A-B, KH&A - C,	KH&A - A, KH&A - B, KH&A - C,	KH&A - A, KH&A - B, KH&A - C,	KH&A - A, KH&A - B, KH&A - C,
2		KH&A-G (1.2%)						
3	KH&A - B	KH&A-G (1.8%)	KH&A-D	KH&A - I	KH&A - D	KH&A - D	KH&A - D	KH&A - D
4		KH&A-G (2.4%)						
5	KH&A - F	KH&A-G (3.0%)	KH&A-E	KH&A - J	KH&A - E	KH&A - E	KH&A - E	KH&A - E
6		KH&A-G (3.6%)						
7	KH&A - E	KH&A-G (4.2%)	KH&A-F	KH&A - K	KH&A - F	KH&A - F	KH&A - X	KH&A - X
8		KH&A-G (4.8%)						
9		KH&A-G (5.4%)	KH&A - H	KH&A - M	KH&A - L	KH&A - W	KH&A - Z	KH&A - Z
10		KH&A-G (6.0%)						
11		KH&A-G (6.6%)	KH&A - I	KH&A - N	KH&A - R	KH&A - X		KH&A - AC
12		KH&A-G (7.2%)						
13		KH&A-G (7.8%)	KH&A - J	KH&A - O	KH&A - S	KH&A - Z		
14		KH&A-G (8.4%)						
15		KH&A-G (9.2%)	KH&A - K	KH&A - P	KH&A - W	KH&A - AA		
16		KH&A-G (9.8%) ↓						
17		↓	KH&A - L	KH&A - Q	KH&A - X	KH&A - AB		
18		↓						
19		↓	KH&A - M	KH&A - R	KH&A - Y			
20		↓						
21		↓	KH&A-G (1.2%)	KH&A - S				
22		↓	KH&A-G (1.8%)					

23		KH&A-G (2.4%)	KH&A - T
24		KH&A-G (3.0%)	
25		KH&A-G (3.6%)	KH&A - U
26		KH&A-G (4.2%)	
27		KH&A-G (4.8%)	KH&A - V
…			
60	KH&A-G (100%)		
80		KH&A-G (100%)	

Table 12.8 Spending Patterns: Engineering Options Combinations – Kings Hedges and Arbury

13 Summary

In order to address the specific issues relating to the Cambridge and Milton SWMP, a three stage modelling strategy was developed and implemented:

- Stage 1 - Hydrological Analysis and development of broad scale, bare earth, models of North and South Cambridge and sensitivity testing to determine the hydrological / infiltration response of the catchment.
- Stage 2 – Identification and evaluation of wetspots using the bare earth model developed in Stage 1 and Prioritisation using Multi Criteria Analysis (MCA).
- Stage 3 - Detailed modelling assessment of specific wet-spots within Cambridge and Milton. This included the development and testing of engineering options and economic analysis.

The SWMP direct rainfall analysis and review of historical data have improved the understanding of future surface water flood risk within the Cambridge and Milton wetspot at a strategic level.

The detailed modelling has defined the surface water flood risk to Cherry Hinton and the Kings Hedges and Arbury estate in Cambridge. The model results have substantially refined the extent of surface water flooding from the Environment Agency AStSWF and FRM4SWF and been verified where possible by the available historical data.

Multi-criteria analysis confirmed Cherry Hinton and the Kings Hedges & Arbury estate as two key wetspots out of the twelve identified where the risk of surface water flooding required more detailed modelling, including the development of potential engineering options to reduce flood risk in the wetspot.

A range of potential engineering measures and options have been identified, modelled and costed for Cherry Hinton and Kings Hedges and Arbury, which highlight the need and benefit of reducing the future flood risk. These engineering options should be considered along with non engineering policy measures in order to maximise benefits. Funding constraints and stakeholder buy-in are likely to be a key obstacle to implement catchment wide solutions at both wetspots, highlighting the need for further stakeholder consultation and prioritisation of viable measures.

Following Cost-Benefit analysis, the 'Do Minimum' option that involves continuation of current maintenance arrangements of the existing drainage system is proving to be the most financially cost effective option at both Wetspots. This is almost certainly due to the fact that the surface water sewer systems in Cambridge have a significant impact at mitigating the risk of flooding at lower return periods which is an important factor in the economic analysis. However, it should be noted that Option Combinations C6, C7 and C8 within the Arbury & King's Hedges wetspot return good benefit cost ratios of 3.08, 3.87 and 3.91, respectively, which is commensurate with other similar locations in the UK affected by fluvial and surface water flooding.

It should also be recognised that the 'Do Minimum' option does not deliver any reduction in the number of properties vulnerable to flooding and will not address increasing flood risk associated with climate change and this is a critical factor in relation to adopting a strategy to deal with climate change within the city.

The suitability of the 'Do Minimum' option is also questionable in terms of new duties imposed by the Flood and Water Management Act, social and environmental acceptance and future uncertainty. This clearly highlights the need for further consideration and implementation of a broad strategy, including the refinement of engineering associated with Option Combinations (to optimise the benefit cost ratios), Quick Wins and Policy Initiatives.

13.1 Key Surface Water Flooding Issues in Cherry Hinton

Flooding within Cherry Hinton is exacerbated by limitations in the hydraulic capacity of the storm water sewer. At higher return period floods where the sewer network is surcharged, water can pond to the south of Cherry Hinton Road. Cherry Hinton road also acts as a barrier to overland flow of water, resulting in relatively large depths of flooding in these areas during the higher return period floods.

The main trunk sewer that runs from south to north through the catchment before discharging into the Cherry Hinton Brook can exacerbate problems in the northern sub-catchment. At higher return periods, despite the large pipe size (approximately 1.8m in diameter in some places), the network can still surcharge as a result of the shallow falls of the pipe network.

In the St Thomas Square area of the catchment, the interaction between the sewer network and the local drains can also cause surface water flooding issues.

Detailed modelling of the Cherry Hinton Wetspot identified a series of potential issues in the study area.

- Ponding of water at the Cherry Hinton Road can result in noticeable flood depths and hazards.
- The interaction between the surface water pipe network and Birdwood Road Drain can cause flooding in the St Thomas Square/Walpole Road area of Cherry Hinton.
- Water in the main trunk network is susceptible to throttling in the North of the study area due to shallow falls in the pipe network. This can result in surcharging manholes during the higher return period events causing flooding and can also reduce the movement of water from the south of the study area.

13.2 Key Surface Water Flooding Issues for Kings Hedges & Arbury

As with the Cherry Hinton wetspot, flooding within the Kings Hedges & Arbury wetspot is exacerbated by limitations in the hydraulic capacity of storm water sewer system. The areas to the north of the wetspot are drained by the storm water system to the 1st Public Drain to the east. The existing trunk sewer which runs in an arc through north Cambridge varies between 1.35m and 1.5m (at the downstream end) and is approximately 3.5km long with a fall of 8.5m representing a gradient of approximately 1 in 400. The trunk sewer serves a catchment area of approximately 2.4km^2. Hydraulic modelling indicates that the sewer is at full capacity during a 1 in 30 year event (storm duration of 240 minutes). Accordingly the trunk sewer has a limited beneficial impact on flooding at higher return periods.

At present flood risk within the King's Hedges and Arbury wetspot is increased when the existing agricultural land and sports pitches to the west of the wetspot are saturated during periods of long rainfall. This will be mitigated by the construction of the NIAB development which incorporates extensive SuDS features which captures potential flood water at source and directs flow away from the wetspot areas.

It should also be recognised that past, proposed and ongoing urban development has led to an increase in impermeable surfaces, causing a relative reduction in overall permeable surface area and capacity for infiltration within the King's Hedges and Arbury wetspot. This is particularly true of property in the north of the wetspot including the areas around Minerva Way and Buchan Street where relatively dense development in the 1980s / 1990s which incorporated limited green space has led to the a reduction the overall permeability of the wetspot.

Unfortunately, these developments were undertaken at a time when Sustainable Drainage Systems were not common practice in the UK and the development was been connected to the storm water system described above.

13.3 Preferred Options For Further Investigation

The Preferred Options for Cherry Hinton are:

1. Increased maintenance of ordinary watercourses and surface water drains within the wetspot:
2. Engineering Option Combination **C8**
3. Policy Recommendations (See Section 15.3)

The Preferred Options for Kings Hedges & Arbury are:

1. Increased maintenance of ordinary watercourses and surface water drains within the wetspot:
2. Engineering Option Combination **C8**
3. Policy Recommendations (See Section 15.3)

As previously described in Section 12, the economic analysis assumes an investment profile in flood mitigation infrastructure over an 60 year period. The investment profile was introduced to reflect the likely degree of investment in flood mitigation infrastructure available to the CFRMP, CCC and Cambridge City Council.

A value engineering exercise was undertaken to evaluate the Option Combinations indicated that a significant factor in the costs associated with the works were associated with the excavation and disposal to landfill of materials for the formation of attenuation basins and other flood mitigation infrastructure. Accordingly the economic analysis assumes that all excavated materials will be re-used on site to avoid the cost of disposal of the material. This could include the formation of embankments and other landscaping features. This avoids costs associated with disposal including land fill tax. It also promotes the sustainable credentials of the project by reducing the carbon footprint associated with the transportation of materials for disposal.

Whilst an optimism bias of 60 % has also been applied to all of the cost estimates (as per the current guidance applicable for a strategy of this nature) there are a number of economic risks or uncertainties associated with the development of the cost estimates. The principal economic risks associated with all of the option combinations are:

- The availability of land to form the attenuation storage areas
- Cost associated with dealing with utilities which have not been itemised with the cost estimates.
- The cost of land negotiations and compensation for disruption

It is therefore considered that significant effort should be placed into obtaining agreements with landowners and stakeholders to undertake the proposed works. In order to mitigate this risk it is recommended that CCC/Cambridge City Council and the Cambridgeshire Flood Risk Management Partnership enter into discussion with all landowners and stakeholders at the earliest opportunity during the design process to ensure their collaboration.

Recommendations on preferred flood mitigation strategies for the two Wetspots are further discussed in the following sections. The implementation of the engineering option combination described in the report will have significant beneficial impact on flooding but it should also be recognised that there will be additional benefits streaming from the implementation of flood mitigation strategies. This includes:

- Beneficial impacts on bio-diversity associated with wetland options
- Beneficial impacts on bio-diversity associated with the implementation of greener highway source control measures which includes planting in verges
- Improvements in the design of the urban realm through the shift from grey to green infrastructure. This includes retro-fitting and incorporation of green infrastructure with highways design and other areas of urban design
- Potential benefits in integration of investment with targets associated with bio-diversity
- Potential benefits in amenity function and connectivity across the two Cambridge wetspots

13.4 Key Mitigation Strategies For Cherry Hinton

Whilst the engineering options proposed at this stage are at a strategic level, the modelling work carried out gives a clear indication to the approaches that could be taken during detailed design of surface water mitigation strategies in Cherry Hinton. These include;

1. Continuing maintenance of the existing surface water sewer system which provides significant benefits in mitigating flooding at lower return periods.
2. Development of Engineering Option C8 in further detail which includes the installation of attenuation features and swales within the catchment. This particular Option Combination includes specific measures to address flooding to the St Thomas Square area.
3. Policy measures discussed in Section 15

As the modelling undertaken at this stage is at a strategic level, it is not possible to state where targeted maintenance of drainage ditches would need to take place.

Issues for further consideration at Detailed Design stage are listed below:

1. Lower return periods for inclusion in cost-benefit analysis – detailed design of surface water flood risk mitigation measures should include an assessment of the damages associated with the depth of flooding at lower return periods i.e. return periods below 1 in 30 year. Engineering option combination C1 and Engineering option combination C8 were modelled with an additional return period of 1 in 20 year. The cost benefit score for Option Combination C1 was **2.5** and for Engineering Option Combination C8 was **3.11** when the 20 year result was included in the cost benefit analysis. This shows that careful consideration should be given to lower return periods at detailed design stage.

2. Targeted drainage network improvements in Cherry Hinton - this investigation will need to include a survey check of manhole invert levels the study area.

3. Targeted Permeable Paving - large scale retrofitting of permeable paving on existing estate roads is not feasible as a surface water management strategy for Cherry Hinton. Option C3, which was a derivation of Option C1, but with approximately £4,178,202 of permeable paving in certain existing roads included was not a feasible option. Further attempts to optimise the use of permeable paving in engineering options C6 & C7 proved unsuccessful in increasing the cost benefit scores. As such it may appear that retro-fitting permeable paving at present is prohibitive in cost. However the use of permeable paving in new developments does require further investigation.

13.5 Key Mitigation Strategies For Kings Hedges & Arbury

Whilst surface water flooding within the King's Hedges and Arbury wetspot is widely distributed because of the nature of the catchment topography the hydraulic modelling and economic analysis has identified a number of areas of particular vulnerability in relation to surface water flooding. The proposed engineering option includes intervention in the form of the construction of attenuation and highway source control measures. However, using source control measures is a significant challenge in mitigating the risk of flooding.

Limited open space within the urban environment within the Kings Hedges and Arbury wetspot means that it is not always possible to place attenuation features in the optimum position to mitigate flood risk. Similarly mitigation of flood risk through highway source control measures can be complicated by the presence of utilities within the highway and the attendant costs. Accordingly, the residual flood risk associated with the use of source control measures for distributed flooding is significant.

This is reflected in the results of the economic analysis which has returned benefit cost ratios for Engineering Combination C1 to C8 which are slightly less than the Doing Minimum. Despite this, the economic case for intervention within the King's Hedges and Arbury wetspot is considered strong. It is considered that a pro-active position should be adopted in relation to mitigating flood risk to the King's Hedges and Arbury wetspot to reduce the number of properties vulnerable to flooding, reduce the current risk of flooding and prepare for climate change. Accordingly, it is considered that the strategy should include:-

1. Continuing maintenance of the existing surface water sewer system which provides significant benefits in mitigating flooding at lower return periods.

2. Development of Engineering Option C8 in further detail which includes the installation of attenuation features and swales within the catchment. This particular Option Combination includes specific measures to address flooding to the Mayfield Primary School.

3. The categorisation of the attenuation basins and swales adjacent to the Mayfield Primary School as a potential "Quick Win". It is considered that the implementation of works in the vicinity of the school will have a significant positive impact in relation to mitigating flood risk to the school.

4. The possible categorisation of works to the Allotments Attenuation basin as a "Quick Win". It is envisaged that the attenuation basin at this location will be in the form of a combined wetland and flood storage basin. The configuration of storage attenuation in the form of a wetland means that there could be significant environmental benefits associated with bio-diversity in implementing this particular Engineering Element.

Policy measures are discussed in Section 15 and in Chapter 8 of the Countywide Surface Water Management Plan.

13.6 Benefits of Cambridge and Milton SWMP

The modelling results, assessments and maps created during this Detailed SWMP, with emphasis on the eleven identified wetspots, can be used as follows:

- Indication of potential development constraints and opportunities to reduce the predicted flood risk
- Identification of which stakeholders should be consulted with regard to new development
- Highlights broad scale risk and indication as to whether a developer is required to undertake further investigation
- Evidence as to why Developers should undertake further investigation and develop appropriate mitigation measures
- The CCC Highways Department can see where highways flooding has occurred in the past and during times of high rainfall focus maintenance and emergency response efforts in these areas
- The Emergency Planning team can use historical flooding data, updated flood receptors, MCA findings and broad wetspot areas to identify more vulnerable areas and prepare suitable emergency planning measures
- Development of future planning policies and local flood risk management policies as part of Cambridge City Council's and South Cambridgeshire District Council's future Local Development Documents and CCC's Local Flood Risk Management Strategy. In particular, with regard to the consideration of surface runoff from any infill development between the two prioritised wetspots.

14 Next Steps

14.1 Surface Water Management Action Plan – Preparation, Implementation and Monitoring

The next stage of the SWMP will be the Implementation and Review Stage as illustrated above. It will involve the review of evidence and recommendations from the previous stages of Cambridge and Milton SWMP and parallel countywide broad brush SWMP in order to prepare, implement and monitor an appropriate Action Plan for the two detailed wetspots:

- Cherry Hinton
- Kings Hedges and Arbury

Consideration could also be given for combining implementation of the engineering elements across both Cherry Hinton and Kings Hedges & Arbury Wetspots so that the areas may be prioritised to formulate the preferred option or strategy where the greatest cost-benefit can be achieved within both areas in a combined Action Plan.

This combined approach may potentially provide a greater justification for capital investment and stakeholder support; in particular, within the short to medium term period where the impact of current economic climate is even greater rather than trying to solve the predicted flooding issues in isolation.

Other key considerations for detailed design to take in to account are:

- Limited extents of open land in the study area to create attenuation features require careful planning and negotiations with the impacted land owners. Location of attenuation structures should be carefully balanced against economic, social and environmental needs.

- Resolution and description of features in the urban realm should be improved within the hydraulic model for the purposes of the detailed design. For example there is limited representation of smaller linear features (e.g. garden walls and kerbs) which may have a localised impact on flood routing within the urban environment.
- Implementation, construction and maintenance costs, if applicable, for any designs that are progressed to the detailed stage, along with the source of any required funding.

The Action Plan will collate all the information from the earlier phases to enable the implementation of the preferred structural and non-structural options according to an agreed and coordinated delivery programme. In summary, it should outline:

- The preferred options
- The actions required by each partner and stakeholder
- Who should lead in developing the actions, and
- The timetable for implementation and monitoring

The action plan will also inform CCC's Local Flood Risk Management Strategy described in Section 15.6, as the LLFA, under the FWMA by providing information on where surface water flooding may occur within the Cambridge & Milton study area and the rest of county allowing members of the public to prepare for flooding from surface water and other local sources accordingly.

A monitoring strategy should be incorporated within the Action Plan and Local Flood Risk Management Strategy in order to monitor the effectiveness of the implemented options and to keep them up to date. This SWMP will be reviewed and updated every 6 years; ideally this should be undertaken in conjunction with related Countywide SWMP review process in order to coordinate the process and avoid a potential piecemeal approach to surface water management needs across the county. The Cambridgeshire Flood Risk Management Partnership (CFRMP) Stakeholder Engagement Plan measures effectiveness by gauging key contact from the different stakeholder groups to gain feedback levels of understanding of messages that have been communicated.

It is proposed that the following publication of this SWMP all key contacts are consulted accordingly to agree the way forward. However, the exact timescale for the preparation, implementation and monitoring of the Action Plan is yet to be decided by the CFRMP, subject to the availability of necessary funding.

14.2 Engage with Stakeholders

One of the key objectives of the SWMP process is to engage with partners and stakeholders. There may be opportunity to utilise and refine the CFRMP Stakeholder Engagement Strategy to engage stakeholders on the preferred options and development of Action Plan. The CFRMP Stakeholder Engagement Strategy Plan is discussed in more detail in Section 2.4.

15 Recommendations

15.1 SWMP Action Plan and Monitoring

The key conclusions, preferred options and flood risk management strategies presented in Section 13 should be factored in the development of the Surface Water Action Plan and methods for communicating and monitoring the Action Plan as detailed in Section 14 above.

Cambridge and Milton SWMP can also be used as a framework for the development of detailed assessments for the remaining wetspots within the Cambridge and Milton study area.

As part of this study, optioneering has only been undertaken for two of the identified eleven wetspots within the Cambridge and Milton study area. These two, Cherry Hinton and King's Hedges and Arbury were chosen due to their high scores following the Multi-Criteria Assessment stage. However, the North Chesterton and Bin Brook wetspots also scored highly. It is recommended that these wetspots be included in the Action Plan and monitored to determine if any betterment to flood risk can be obtained through future development plans. It should also be possible to build an integrated model of Bin Brook and carry out a detailed assessment as described in this report.

Next steps have been set out in the Countywide Surface Water Management Plan, and the majority of these next steps will also apply to the Cambridge & Milton area. In addition, next steps specific to the Cam & Milton area are detailed in the Table 15-1.

Next Step	Indicative Timescale	Lead Responsibility
Communication of new surface water to members of the public and how this affects them.	6-12 Months	Cambridge City & Cambridgeshire County Council
Regular Review including review of other Cambridge & Milton wetspots.	Every 6 years/Ongoing	CFRMP Stakeholders

Table 15-1 Next Steps Timetable

15.2 Data Management

The Countywide SWMP report highlights the need for improved data management across Cambridgeshire and these recommendations are also applicable to the Cambridge and Milton study area.

It is recommended that the data register development is led by the CFRMP as this will allow the capture of all data specific to the different and varying areas of Cambridgeshire.

15.3 Quick Win Measures

The 'quick win' measures recommended are:

- CCC, Cambridge City Council, South Cambridgeshire District Council, utility companies, emergency services and their planning teams to undertake assessments of key assets in the areas of Cambridge and Milton SWMP.

- Use of the flood incident register alongside Multi-Criteria Assessment results for Cambridge and Milton wetspots to guide future maintenance and inspection investment
- Campaigns to increase the uptake of water butts and other SuDS whilst minimising impermeable areas in existing residential areas (this is in line with the Cambridge Sustainable Drainage Design And Adoption Guide [24])
- The SWMP modelling outputs and EA's FMfSW can be used to identify where the risks are critical to their operation, so that suitable steps including contingency planning can be taken. The MCA assessment results undertaken to date and Web-GIS for Cambridge and Milton can also inform this process.

15.4 Role of the SWMP Report in the Planning Process

The Countywide Surface Water Management Plan has included as a next step the production of a planning guidance document, that will assist planners in the use of additional surface water information as an evidence base in the planning process. Consideration should be given to this Planning Guidance document, and the comments in the Surface Water Management Plan.

However the modelling of the Cherry Hinton & Kings Hedges & Arbury Wetspot has provided additional information & evidence for use in the planning process. Recommendations for planners dealing with planning applications in the Cambridge & Milton wetspots are detailed below in Table 15-2.

Wetspot	Recommendation	Evidence
All Cam & Milton Wetspots	Development of a specific SPD for Cambridge & Milton to integrate the evidence identified during the Detailed Assessment to help redress the balance of urbanisation in the area and to help mitigate for future climactic uncertainties, improve water quality and provide opportunities for slowing the flow.	Several areas with Cam & Milton are shown to have suffered surface water flooding in the past and are shown to be at risk of potential flooding.
All Cam & Milton Wetspots	Sensitivity testing of proposed surface water attenuation structures in new developments to account for increasing impermeability (urban creep) over the lifetime of the development. Over-design of such structures may also provide a measured and temporary reduction in flood risk elsewhere.	Historical trends of increasing impermeability have reduced the performance standard for the above and below ground surface water systems.
All Cam & Milton Wetspots	Where key flow paths through a site can be identified from the mapping provided, these flow paths should be integrated into the design of the surface water attenuation structures within a new catchment.	From velocity mapping within modelled outputs.
Cherry Hinton and Kings Hedges & Arbury	Careful consideration of the use of architectural designs such as drop kerbs in new developments within the wetspots.	A number of significant flow paths through the wetspot are along roads and these should be treated as preferential flowpaths.
Cherry Hinton	Limit, and where possible better, the rate of discharge from new development sites that contribute to the Cherry Hinton wetspot area.	Ponding of water at the Cherry Hinton road as a result of flows surface runoff from the south of the catchment.
King's Hedges & Arbury	Careful consideration with regards to installation of additional attenuation and soakaway basins. Provide a suitable storage capacity to reduce negative impacts such as increased localised inundation of nearby dwellings and commercial properties near to attenuation locations.	Attenuation and soakaway catchments are increased due to dry swales within this study. The surplus in catchment of these sites through a dry swale network must also be accounted for in any additional attenuation locations.

Table 15-2 Recommendations for Planners in Cambridge & Milton

15.4.1 Emergency Planning

Review of Council Emergency Plans

The Emergency Planning team at Cambridgeshire County and Cambridge City Councils should use historical data, updated flood receptors, MCA findings and broad wetspot areas to identify more vulnerable areas and prepare for suitable emergency planning measures.

Review of Asset Vulnerability

All CFRMP partners and utility companies to undertake assessments of their key assets in the areas of surface water flood risk.

The sources of data should include the most detailed flood risk information available for the area of interest. This will allow identification of where the risks are critical to their operation so that suitable steps including contingency planning can be taken.

15.4.2 Sustainable Development & Rainwater Harvesting

Generally planning policies covering the Cambridge and Milton area encourage the use of SuDS. Developers need to consider the most appropriate SuDS measures for their site. As well as SuDS measures providing mitigation against flood risk, they can also provide environmental and amenity benefits to an area. As well as larger scale SuDS measures on development sites, individual homeowners can provide surface water attenuation through Rainwater Harvesting.

Domestic Level Incentives

Householders should be encouraged to use water butts; either by working with existing schemes or through new initiatives. Whilst developers should not consider water butts as a method for reducing surface water run-off from a development site, water butts are a component part of SuDS measures.

They should be encouraged across the area as a preventative measure as per CIRIA Interim Code of Practice for SuDS.

15.5 Local Flood Risk Management Strategy (LFRMS)

A LFRMS should be one which meets the key elements of Flood Risk Management outlined in Figure 13-1.

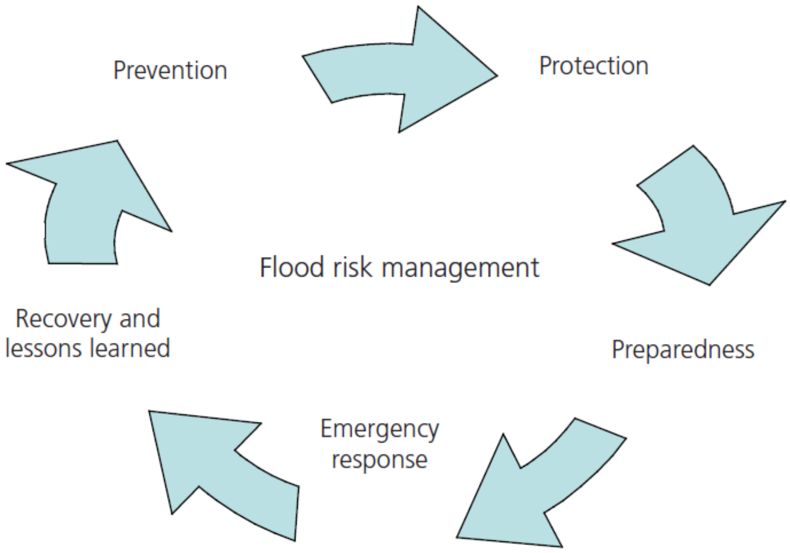


Figure 13-1 European Model For Flood Risk Management

The preparation of LFRMS should be informed by the Living Draft Preliminary Framework published by the Local Government Group in February 2011, this SWMP report and associated Countywide SWMP and PFRA. It should be informed ongoing programme reviews, economic impact assessment, and information from real flood events and systematic approach to assessing flood risk.

The Cambridge and Milton SWMP allows identification of where Prevention measures are required. The mapping outputs and report allow for targeted protection measures to help reduce risk to the impacted properties and communities. These measures involve the implementation of strategies involving retrofitting of existing buildings, implementation of Sustainable Drainage Systems and promotion of wider sustainable water and environmental management practices.

Non structural measures such as better data management, stronger flood risk management partnerships, and policy guidance also play a vital part in this process. Therefore, the SWMP should significantly help developing CCC and CFRMP members to provide a wide range of measures to manage local flooding in a coordinated way that balances the need for communities, the economy and the environment as expected by a LFRMS.

Two of the 12 wetspots identified by Cambridge and Milton SWMP have been modelled in detail and the results are discussed in this report. Information on areas at risk of surface water flooding has also been refined through the Stage 1 bare earth direct rainfall modelling undertaken across the study area.

These studies should be used as starting point, along with historic flooding data, to identify any areas where 'quick wins' can be easily implemented. Additionally, the identification of these areas can help direct action towards the formulation of plans to develop Community Flood Risk partnerships, who should be supported to help increase local preparedness and resilience to these events. One action that should be promoted in these areas is the identification of suitable Flood Wardens or flood action groups, who should be empowered to prepare suitable Emergency Plans, with CFRMP support. LFRMS should have due consideration to the specific flood risk management strategies discussed in Section 13 for Cherry Hinton and Kings Hedges and Arbury Wetspots.

16 References

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