Hydraulic Modelling Report

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York Surface Water Management Plan

City of York Council

22 June 2011

Halcrow

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Document history

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1	03/05/11	Draft for discussion	Donald Daly	Laura Baird	-
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Appendices

1 Introduction and Background

1.1 Introduction

The City of York has a long history of exposure to fluvial flood risk from the Ouse and the Foss. City Of York Council (CYC) and other agencies are well informed about the nature of this risk and the long term investments necessary to manage the risk and local actions required before, during and after a flood. Fluvial flood risk has therefore not been the focus of this project.

Surface water flooding is less well understood and more difficult to record and manage. The Flood Regulations (2009) and Flood & Water Management Act (2010) make it the CYC's responsibility to understand surface water flooding and coordinate all partners in reducing the risk if this is unacceptable. Defra have funded the Council to undertake a Surface Water Management Plan (SWMP) which will support these new responsibilities including the preparation of a Preliminary Flood Risk Assessment before June 2011 and a Local Flood Risk Management Strategy following later in the year.

CYC has the capacity to undertake most elements of a SWMP using its own resources. Using their own resources brings significant benefits in terms of ensuring linkages with other Council activities and priorities. An area where the Council have identified the need for some support is in the preparation of surface water flood models and mapping to confirm surface water flood risk areas.

Figure 1 shows the Defra SWMP process diagram. CYC has successfully completed Phase 1 (Preparation) by collating historical data, engaging with other partners and investigating 'hot spot' areas. This report documents the work done by Halcrow to support the Council in completing Phase 2 (Risk Assessment) activities, notably the preparation of detailed surface water flooding maps.

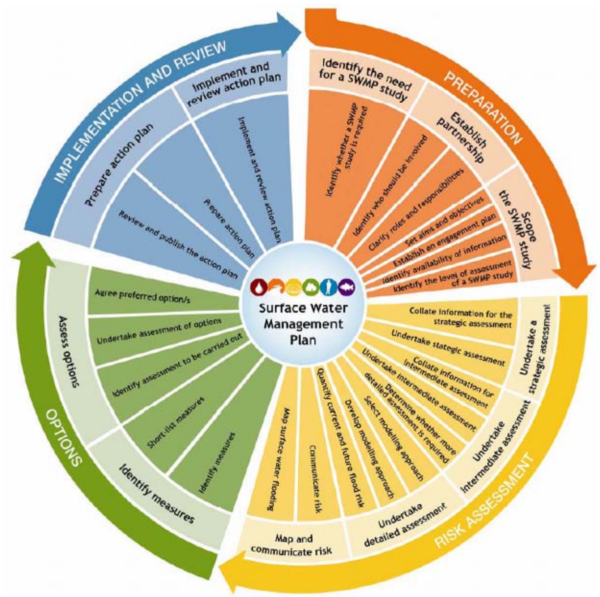


Figure 1: Defra SWMP process

1.2 Background

Funding has been gained by CYC from Defra to produce a SWMP for an identified study area comprising twelve flooding hotspots within the City. CYC hold historic records of road/property flooding from the 2007 event and these data have been the basis of investigation work by the Council in the intervening time.

It was agreed with CYC that this Halcrow study should focus on identifying the priority issues, workable solutions and quick wins, particularly simple solutions such as gully cleaning and maintenance. The study would cover flooding hotspots within the entire City of York area as this had been established as a sound course of action in the strategic study.

2 Flooding Hotspots

2.1 Identification

Areas of surface water flooding concern (flooding hotspots) were identified by CYC based on known historic flooding, Yorkshire Water's sewer flooding record, and the Environment Agency's surface water flood maps.

The 12 hotspots identified are listed in Table 1 below, and shown on a plan in Appendix A1.

Area	Hotspot Name
1	Strensall
2	Wigginton / Haxby
3	Rawcliffe
4	Clifton Without
5	Clifton
6	Heworth
7	Burnholme
8	Acomb
9	Holgate
10	a. Westfield b. Woodthorpe
11	Bishopthorpe
12	Rufforth

Table 1: Initial List of Hotspots

2.2 Filtering

Each of the 12 hotspots was reviewed by Halcrow together with CYC, to understand better the existing flood risk and sources and causes of flooding. The review of the hotspots is summarised in Table 2 below.

Where the reasons for flooding were well understood in a particular hotspot, or solutions had already been identified or implemented, hotspots were removed from the scope of further work.

Area	Summary of review	Conclusions	Hydraulic modelling ?
1	The key area of concern is that centred on York Rd where the EA mapping shows deep flood risk. More detailed modelling should be carried out here.	Hydraulic modelling required. CYC to consider a culvert survey of Strensall Drain d/s of this area.	Y
2	The key area of concern is The Village, in the vicinity of the property flooded in 2007.	Hydraulic modelling required. CYC to consider a flooding questionnaire for properties in this area.	Y
3	The key areas of concern are Howard Drive and Rawcliffe Croft.	Hydraulic modelling required. CYC to consider a flooding questionnaire for properties in this area.	Y
4	The key area of concern is in St Phillip's Grove area. Other areas of flood risk appear to be as a result of culvert capacity on Birdike.	Hydraulic modelling required. CYC to consider a flooding questionnaire for properties in this area. Birdike culvert may benefit from CYC culvert survey.	Y
5	Two key areas of concern are in Shipton St and Field View. The sewer system appears to be under capacity in Shipton St area, and there are vulnerable people at risk of flooding (elderly care home shown within EA flood risk area).	Hydraulic modelling required. CYC to consider a flooding questionnaire for properties in this area.	Y
6	The three key areas (in Straylands Grove, Elm Park Way and Elmfield Ave appear to be due to under capacity of existing drainage.	Hydraulic modelling required. CYC to consider a flooding questionnaire for properties in this area.	Y
7	Only key issue is at junction of Badbargain Lane and Gerard Avenue, due to known gully issues.	Hotspot removed from the scope of this study.	N

Area	Summary of review	Conclusions	Hydraulic modelling ?
8	Two key areas are junction of Carr Lane and Boroughbridge Rd, and Ouse Acres.	Hydraulic modelling required. CYC to consider a flooding questionnaire for properties in this area. CYC to consider survey to determine capacity and condition of Ings Cliff Drain, as EA flood risk map show this area at risk, although no flooding reported here in June 2007.	Y
9	The area around Beech Ave appears to be an issue. Likely main cause is a sewer capacity issue.	Hotspot removed from the scope of this study.	N
10a	The key flood risk areas are around Huntsman Walk.	Hydraulic modelling required. CYC to consider a flooding questionnaire for properties in this area. There is a known DG5 issue with a property on Foxwood Lane. CYC to follow this up with YWS.	Y
10b	Key flood risk areas here are around Acombwood Dr and Alness Dr. Likely main cause is a sewer / land drain capacity issue.	Hotspot removed from the scope of this study.	N
11	It was agreed that the flooding issues here would not benefit from additional surface water modelling.	Hotspot removed from the scope of this study.	N
12	It was agreed that the flooding issues here would not benefit from additional surface water modelling.	Hotspot removed from the scope of this study.	N

Table 2: Review of hotspots

2.3 Final hotspot list

Following the review of hotspots, focus areas within 8 hotspots were taken forward for hydraulic modelling and further assessment. These focus areas are shown in Appendix A2. The complete list is included in Table 3 below.

Area	Hotspot Name	Focus Area Name
1	Strensall	York Rd
2	Wigginton / Haxby	The Village
3	Rawcliffe	Howard Drive Rawcliffe Croft
4	Clifton Without	St Phillip's Grove
5	Clifton	Shipton St Field View
6	Heworth	Straylands Grove Elm Park Way Elmfield Ave
8	Acomb	Junction of Carr Lane and Boroughbridge Rd Ouse Acres
10a	Westfield	Huntsman Walk

Table 3: Final hotspots and focus areas

3 Data collection

3.1 Sources of Data

Data for this study was obtained from three key sources: CYC, Environment Agency and Yorkshire Water.

3.2 City of York Council

CYC provided the following information:

- Digital Terrain Model (DTM) for the City of York area
- Information on flooded properties and roads during the 2007 flood event
- Locations of gullies

Plans showing the 2007 flooded roads and properties are included in Appendix B.1.

3.3 Environment Agency

The Environment Agency provided the following information for the study:

- Surface Water Flood Maps, showing deep and shallow flooding extents for 1 in 30yr and 1 in 200yr return period event.
- Areas Susceptible to Surface Water Flooding (AStSWF) mapping – although this was available, it was not used as it was not considered representative for the York area.

These plans are included in Appendix B.2.

3.4 Yorkshire Water

Yorkshire Water provided the following information for the study, under the data sharing agreement in place between CYC and YWS:

- Sewer plans, showing the location of sewers within York
- Information on the proportion of combined and foul sewers within the sewer system in each hotspot
- Flood exceedance plots (RPA or X-Y plots) for the sewer system in each hotspot – these indicate the capacity of the sewer system by noting the return period of the most frequent event that would lead to inundation of the sewer system by flood water.
- DG5 register detailing all incidents of sewer flooding

Due to the sensitive nature of much of this information, only the sewer plans are included in Appendix B.3, at the request of Yorkshire Water.

4 Hydraulic Modelling

4.1 Purpose and main assumptions

The purpose of the pluvial modelling was to provide quick and simple modelling of pluvial flows to identify the broad surface water risk areas. By applying rainfall directly onto a 2D mesh using TUFLOW software flood extent and depths was determined for eight hot spot areas. Allowance for storage capacity available within the below ground drainage network for each hot spot has been included. Further simulations to investigate the impact of blocked or insufficient gullies on flood extents and depths were also undertaken.

The conceptual approach adopted was to assume that rainfall falling within each modelled hotspot area was the primary source of flooding in that area. Inflows generated by rainfall falling outside each area being secondary either because these flows are very small, or because their time-of-arrival at each study area would be much later than the occurrence of more severe flooding due to the local rainfall). This assumption was considered acceptable due to the very small size of the urban hotspots being investigated.

Rainfall was computed using the Flood Estimation Handbook methodology with losses computed using the FEH rainfall-runoff model. Losses represent hydrological processes which do not directly contribute to surface flooding such as infiltration and interception. Rainfall depths were computed for a range of return period between 1 in 1 yr and 1 in 1000 yr. Allowance for the below ground drainage network capacity was made by subtracting the net rainfall for the estimated sewer standard of service from the specified return periods.

Resultant net rainfall was distributed onto a 2-D terrain model and routed using the TUFLOW hydrodynamic modelling package. A separate 2-D model was developed for each of the eight flooding hot spots. Maximum flood extents for depths greater than 0.1 m and 0.3 m were plotted for specified return periods.

4.2 Hydrological analysis

Rainfall depths were estimated for the 1 in 1 yr to 1 in 1000 yr return period events using the Flood Estimation Handbook (FEH) rainfall frequency and net rainfall hyetograph methods. Details of the computation of net rainfall are provided in Appendix C.1. The FEH losses method generates a net rainfall profile which separates rainfall generating primary flooding from that contributing to slower catchment responses such as infiltration and interception. For this study, following the FEH methodology, 36 to 41% of the initial rainfall remained after losses to slower catchment responses were taken into account (varying according to return period). The total net rainfall for each return period is listed in Table 4 below. The rainfall depths were distributed using the standard FEH summer profile.

Net rainfall for the 1 in 100yr+CC are slightly more severe than the 1 in 200 yr.

Return Period	Total rainfall (mm) for 1 hour storm
1 yr	2.4
2 yr	4.6
5 yr	6.4
8 yr	7.4
10 yr	8.0
20 yr	9.8
30 yr	11.1
50 yr	12.9
75 yr	14.5
100 yr	16.2
100 yr + 30%	21.0
200 yr	20.5
1000 yr	85.3

Table 4: Total net rainfall estimates (mm) for a 1 hour storm for the study areas. The 100 yr + 30% scenario represents the potential impacts of future climate change and urbanisation.

4.3 Hydraulic Modelling

A separate 2-D TUFLOW model was constructed for each of the eight hot spots. Inflows into the TUFLOW model were generated using net rainfall after allowance for the below ground drainage network storage. The models were constructed using a DTM supplied by the Environment Agency with modifications undertaken to improve representation of small features such a kerbs and walls. Buildings were represented using a high roughness value. A 1m grid resolution was adopted as providing a high level of detail in the model results. However, due to excessive simulation times, resolution for Hotspot 2 (Wigginton / Haxby) and Hotspot 10a (Westfield) was relaxed to 2 m. A 2 m grid resolution is considered acceptable for simulation of surface water flooding.

Further details of the Hydraulic Modelling approach are provided in Appendix C.

5 Modelling Outputs

5.1 Introduction

From the hydraulic modelling carried out, flood depth maps have been produced for each of the flooding hotspots. Flood depth maps have been produced for the following rainfall return periods: 30 yr, 75 yr, 100 yr, 100 yr plus 30% to allow for future urbanisation and climate change, and 200 yr.

The maps showing the flood extents are included in Appendix D.

From the initial review of the possible flooding causes in each hotspot, see Section 2, it was considered that blocked gullies in some of the hotspots could exacerbate flood risk. The areas where gullies were considered to be regularly blocked, or where there were thought to be insufficient gullies, were identified in discussion with CYC. Four hot spots where blocked or insufficient gullies could be an issue were identified as hot spots: 1 (Strensall), 5 (Clifton), 8 (Acomb) and 10a (Westfield). The locations of identified gully issues are shown in Figure 3 in Appendix A.

Modelling for the scenario with blocked or insufficient gullies was carried out for three return periods: 75 yr, 100 yr and 200 yr. These three return periods were selected to enable comparison with evidence from the 2007 flood event and the Environment Agency surface flooding maps. Maps showing the flood extents for blocked gully simulations are included in Appendix D.

5.2 Analysis of results

5.2.1 General observations

The flood extents for all return period events in all eight hot-spots are less extensive than the Environment Agency Surface Water Flood Maps. These differences in flood extents are most likely to be attributable to different assumptions in the hydrologic methodology.

Key differences in the hydrological methodology adopted here in comparison with that adopted for the Environment Agency surface maps are:

- Losses (difference between total and net rainfall): The Environment Agency approach calculates losses according to whether an area is predominately urban or rural. For urban areas, such as York, net rainfall is assumed to be 70 % of total rainfall. In the current study, losses are computed according to the FEH methodology using the URBAN and SPR characteristics specific to York; these values being extracted from the FEH CDROM. For the current study, net rainfall is 36 to 41% of total rainfall.

- Below ground drainage capacity: The Environment Agency approach assumes a capacity of 12 mm/hr. In the approach adopted here capacity has been determined from indicative Yorkshire Water standards of service which vary between 2 and 8 mm/hr. For the majority of hot-spots a capacity of 6 mm/hr is assumed.

The adoption of a lower runoff coefficient in the current study provides an explanation for the less extensive flooding than shown in the Environment Agency Surface Water flood maps. Adoption of a 70 % runoff coefficient is a conservative assumption, with such runoff values typically only achieved for paved areas. Urban areas comprise paved and extensive unpaved areas including gardens, parks and verges with average runoff values therefore notably lower.

In the remaining sections, modelled results are compared with the recorded flood history for each of the eight hot spots. For six of the hotspots, model results replicate the evidence from the 2007 event closely, providing confidence that model results are reliable. For Hotspots 2 (Wigginton / Haxby) and 5 (Clifton), model results indicate less flooding than the 2007 event; confidence in results in these two hotspots is therefore lower.

5.2.2 Hotspot 1 (Strensall)

The flood evidence from the 2007 event indicates flooding of the Kirklands highway adjacent to the junction with Hallard Way. The Environment Agency Surface Water Flooding maps indicate flooding in a very similar area with deep water around Kirklands and an adjacent area between Kirklands and Oak Tree Close.

Results from the model are consistent with the 2007 and Environment Agency results. Shallow flooding in the 1 in 30 yr and 1in 75 yr occurs along Kirklands with limited property flooding commencing at 1 in 100 yrs. Results for the 1 100 yr + CC are very similar to the 1 in 200 yr. Confidence in model results is therefore good.

The extents and depth of predicted flooding for the gully blocked scenarios are more extensive than the baselines simulations, indicating that gulley maintenance is important in this area.

5.2.3 Hotspot 2 (Wigginton / Haxby)

Records indicate flooding at the junction of The Village and York Road in 2007. The Environment Agency Surface Water Maps indicate shallow flooding around Hall Rise and the Ambulance Station and to in the gardens between The Village and North Lane.

Output from the model indicates less extensive flooding than the Environment Agency surface flooding maps. The model 1 in 100yr + CC extent is very similar to the 1 in 200 yr, with very limited predicted flooding of property and limited flooding of highways within the hotspot area. For the 1 in 200 yr event, flooding is predicted of the roadway cul-de-sac in Hall Rise and adjacent to the Ambulance Station. The recorded 2007 flooding along highways of The Village and York Road is not replicated by the model.

A key difference between the Environment Agency Surface Water flooding maps and approach adopted here is explicit allowance for storage capacity in the below-ground drainage system. For this hotspot, it is assumed that the below-ground drainage network provides a 1 in 5 yr standard of service, which is represented through a reduction in net rainfall. The reduction in the 1in 200 yr rainfall is from 20.5 mm to 14 mm (equivalent to a 1 in 75 yr event).

The event severity of the 2007 event is recorded, in a report to the Council's Executive Member dated 10 December 2007, to vary across the city from 1 in 20 yr to 1 in 100yr. On basis of this event severity, even when taking into account drainage, the model results seem to under-estimate flooding.

It is plausible that flooding in 2007 was caused by localised blockages in the below-ground drainage system which are not replicated in the model. Similarly it is plausible that localised flow routes that cannot be defined at the scale of the model could also have contributed to flooding.

Due to poor replication of evidence from the 2007 event, confidence in model results for this hotspot is lower than other hotspots.

5.2.4 Hotspot 3 (Rawcliffe)

Two focus areas within this hotspot are identified, located at along Rawcliffe Croft and at the intersection of Howard Drive and Manor Park. Records from the 2007 event indicate localised flooding of the highways in Rawcliffe Croft, Howard Drive and Manor Park. Environment Agency Surface Flooding maps replicate shallow flooding along a localised length of Rawcliffe Croft highway and adjacent properties. The Environment Agency maps show shallow flooding adjacent to Howard Drive but not along Manor Park. .

The results from the latest model replicate the 2007 flooding well. Shallow flooding in Rawcliffe Croft commences at 1 in 30 yr although flooding of adjacent properties is not indicated even in the 1in 200 yr and/or 1in 100yr + CC. Flooding at Howard Drive/Manor Park is less well predicted by the model with very minor flooding predicted in the 1 in 200yr event.

Confidence in model results is therefore considered good.

5.2.5 Hotspot 4 (Clifton Without)

Records from the 2007 event indicate flooding of the highway along Water Lane, Rainsborough Way and St Philip’s Grove. The Environment Agency Surface Flooding maps indicate similar flooding along Water Lane and St Philip’s Grove with a small number of adjacent properties affected. The localised flooding in Rainsborough Way is not indicated in the Environment Agency maps.

Results from the latest modelling indicate flooding consistent with the 2007 event for the 1 in 30yr event along Water Lane. Flooding along St Philip’s Grove is also predicted but concentrated at a central low point rather than the more extensive flooding indicated by the 2007 records. Localised flooding in Rainsborough Way is predicted in the 1 in 200 yr and 1in 100yr+CC event. Flooding of adjacent properties is not indicated.

Confidence in model results is therefore considered good.

5.2.6 Hotspot 5 (Clifton)

Records from the 2007 event indicate flooding of the highways at

- Field View to the west of the railway
- Haughton Road
- Baker Street
- Pembroke Street
- Shipton Street.

Flood extents from the Environment Agency Surface Water flooding maps are broadly consistent with the 2007 event although do not replicate the full extent of flooding on Baker Street.

Results from the baseline model results indicate much less extensive flooding than indicated by the 2007 records. For the 1in200 yr and 1 in 100yr+CC there is some predicted flooding along Field View. Results from the blocked gully simulations indicate some further flooding but again less than indicated from the 2007 records.

For modelling this hotspot, it was assumed that the below ground drainage capacity provided approximately a 1 in 5 yr standard of service. This below ground capacity was represented by a commensurate reduction in the net rainfall. For the 1 in 200 yr event, net rainfall was reduced from 20.5 mm to 14 mm, equivalent to a 1 in 75 yr event. The inclusion of the below ground drainage capacity contributes, but does not fully explain the apparent under prediction of flooding in the model results.

The extents and depth of flooding are more extensive in the outputs from the modelling with blocked gullies, indicating that gulley maintenance is important in this area. For example, flooding of the area around the care home for the elderly, is predicted with blocked gullies during the 1 in 200yr event. .

Due to less replication of flooding evidence from the 2007 event, confidence in model results is lower than other hotspots.

5.2.7 Hotspot 6 (Heworth)

Records from the 2007 event indicate flooding of the highway along Straylands Grove and localised areas of flooding in Elmpark View/Way junction. Additionally localised highway flooding is indicated to the west of Malton Road on Elmsfield Avenue. The Environment Agency Surface Water flooding maps indicate more extensive shallow flooding along Elmpark View and Elmpark Way but less extensive flooding along Straylands Grove. Localised flooding on Elmsfield Avenue is replicated well in the Environment Agency maps.

Results from the model indicate commencement of highway flooding in Elmsfield Avenue in the 1in 30 yr event. Model results indicate extensive highway flooding along Straylands, Elmpark View and Elmpark Way during the 1in 75 yr event. Results from the 1 in 200 yr results indicate significant numbers of properties at risk.

Confidence in model results is considered good.

The flooding in this area is localised in natural low points, exacerbated by the underlying clay preventing infiltration. Infiltration measures are therefore unlikely to prove suitable for this area. One approach which could contribute significantly to the reduction of surface water flooding would be to reduce the amount of run-off entering the existing drainage system. By retrofitting source control attenuation and storage SUDS we can interrupt run-off and delay its entry into the underground drainage system, helping to manage peaks in flow. Pathway SUDS such as swales could potentially help to slow run-off as well, although these may be more difficult to design into the existing urban landscape. Source control SUDS measures appropriate for retrofitting are explained in more detail in the table in Appendix F.

Given that we are dealing with an existing urban area with limited available land, it is likely that property scale measures such as water butts, rainwater harvesting, permeable driveways and disconnection of downpipes will prove the most achievable and best value for money (based on research, including: Environment Agency science report SC060024, Cost Benefit of SUDS Retrofit in Urban Areas, SNIFFER report: Retrofitting Sustainable Urban Water Solutions" and "Stovin and Swan (2007)").

Depending on site specifics, however, there may be potential for other measures such as green roofs, community rainwater harvesting and street scale permeable paving to be considered.

5.2.8 Hotspot 8 (Acomb)

Records from the 2007 flood event indicate highway flooding along Ouse Acres. The Environment Agency Surface Water maps indicate deep flooding at the northerly end of Ouse Acres but additionally localised flooding along Carr Lane. The area at risk at the northerly end of Ouse Acres is considered to be at risk from fluvial flood risk rather than surface flooding and is therefore excluded from the hot spot area.

Results from the modelling study indicate commencement of highway flooding along Carr Lane in the 1in 30 yr event. Flooding along the southerly end of Ouse Acres is not replicated even for higher order events. The 1 in 200 yr event indicates some property flooding.

Comparison of blocked gully scenarios with baseline simulations indicates that flooded areas and depths are similar.

Confidence in model results is considered good.

5.2.9 Hotspot 10a (Westfield)

Records from the 2007 event indicates flooding of the highway along Huntman's Walk. The Environment Agency Surface Water maps indicate flooding centred around a similar area with deep flooding of Thornwood Covert and Huntman's Walk. Shallow flooding of property is predicted.

Results from the modelling indicate commencement of highway flooding in the 1 in 75 yr with more extensive highway flooding in the 1in 200 yr event along Huntman's

Walk and Thornwood Covert. Baseline simulations are less extensive than Environment Agency outlines, and very limited property flooding is indicated. Comparison of baseline and blocked gully simulations, indicate blocked simulation show more consistent flooding with areas of flooding/not flooding combining along the highway. Differences between blocked and unblocked scenarios are relatively small.

Confidence in model results is considered good.

5.3 Flood Viewer

FloodViewer shows flood information in an interactive way, enabling better decision making and more effective engagement with stakeholders. Outputs from models and existing flood maps can be viewed turning modelling information into user-friendly illustrations of the risk of flooding in a particular area. It enables easy viewing of a range of flooding scenarios, such as different return-period events, climate scenarios or defence options.

No expensive GIS software is needed and FloodViewer can be run off most digital media, such as a CD or DVD, USB drive, intranet or website.

As added value and at no additional cost for CYC we have provided flood maps generated by the modelling study in electronic FloodViewer format. To switch between model results users simply use the slide bar located towards the lower left hand side of the screen. Separate FloodViewer files are provided for each of the eight hot spots.

A brochure providing further details and example uses of FloodViewer is provided in Appendix E.

6 Recommendations

6.1 General recommendations

The results from the modelling have shown that flood extents and depths are generally less than those indicated in the Environment Agency Surface Water Maps. The difference in flood outlines is likely to be primarily associated with the overly conservative runoff coefficient adopted in the Environment Agency study.

Sensitivity analysis carried out has confirmed that flood extents are impacted by assumptions on gully blockage and capacity in all four tested hotspots. Differences between baseline and blocked gully scenario are most evident for the more intense rainfall events ie 1in 100 yr + CC. Given the consistency in sensitivity to blocked gullies in all four tested hotspots it would be reasonable to assume that other hotspots would be similarly sensitive. In critical areas, the Council should carry out a programme of inspection and maintenance to ensure gullies are clear and can be opened for maintenance. The Council should also consider whether additional gulley capacity could be provided in some areas. Details are included in the following sections.

6.2 Hotspot-specific recommendations

6.2.1 Hotspot 1 (Strensall)

The Council should consider investigating the capacity, sufficiency and maintenance of gullies in the York Rd area.

6.2.2 Hotspot 2 (Wigginton / Haxby)

The Council should consider investigating the capacity, sufficiency and maintenance of gullies at the junction of The Village and York Road.

6.2.3 Hotspot 3 (Rawcliffe)

The Council should consider investigating the capacity, sufficiency and maintenance of gullies at Rawcliffe Croft, and at the intersection of Howard Drive with Manor Park.

6.2.4 Hotspot 4 (Clifton Without)

The Council should consider investigating the capacity, sufficiency and maintenance of gullies at St Philip's Grove.

The Council should consider inspecting the culvert on Burdike to determine whether there are issues regarding its capacity.

6.2.5 Hotspot 5 (Clifton)

The Council should consider investigating the capacity, sufficiency and maintenance of gullies around the care home on Shipton Street.

6.2.6 Hotspot 6 (Heworth)

The Council should give consideration to retro-fitting SUDs to control surface water at source. This would reduce the volume of surface water entering the below-ground system, reducing the instances of sewer inundation, in addition to providing environmental benefits.

One of the simplest and efficient methods of retro-fitting SUDs would be to fit water-butts to individual properties in this area. Recent national research, as well as recent studies in Hull, indicates that retro-fitting water butts to an area could reduce the volume of surface water entering the below-ground drainage system by around 5%.

Further details of SUDs retro-fitting solutions, and their benefits, are included in Appendix F.

6.2.7 Hotspot 8 (Acomb)

The Council may wish to consider investigating the capacity, sufficiency and maintenance of gullies around the junction of Carr Lane and Boroughbridge Rd, and at Ouse Acres, although our modelling does not predict there to be significant flood risk in these areas.

6.2.8 Hotspot 10a (Westfield)

The Council may wish to consider investigating the capacity, sufficiency and maintenance of gullies at Huntsman Walk, although our modelling predicts that the flood risk is primarily limited to the local roads.

Appendix A

Figures

Appendix A Figures

A.1 Initial Hotspots

A.2 Filtered Hotspots

A.3 Locations of assumed blocked or insufficient gullies

Appendix B

Key data collected

Appendix B Key Data Collected

B.1 Data from City of York Council

B.2 Data from Environment Agency

B.3 Data from Yorkshire Water

Appendix C

Modelling calculations

Appendix C Modelling calculations

C.1 Hydrological analysis

Catchment descriptors for each hotspot were extracted from the FEH CD-Rom version 2.0. Catchment descriptors associated with design rainfall were found to be very similar, and were therefore averaged to obtain one set for rainfall generation. Design rainfall depths vary gradually in areas of modestly varying topography such as the Ouse basin. By adopting a single design rainfall parameter set a proliferation of very similar rainfall profiles was avoided. The most conservative URBEXT value was adopted, and updated to 2011. The key descriptors used for rainfall generation are summarised in Table C.1 below.

Descriptor	Value
SAAR	610.75
SPRHOST	35.75
URBEXT1990	0.363
C	-0.0224
D1	0.3208
D2	0.3260
D3	0.2736
E	0.2916
F	2.4208

Table C.1: Key catchment descriptors and rainfall DDF parameters used for rainfall generation.

Catchment descriptors were entered into a FEH Rainfall-Runoff unit in ISIS software with storm parameters set as follows:

a. Storm duration set to 1.05 hrs, with data interval of 0.05 hrs.

b. Areal reduction factor set to 1, due to the small size of the study areas.

c. Storm profile set to FEH 50% summer profile, due to the urbanised nature of catchments.

Net rainfall is computed using the FEH rainfall-runoff methodology which is summarised in Table C.2. Readers unfamiliar with the methodology are recommended to read Chapter 3, Volume 4 of the FEH manuals. Total rainfall is converted to net rainfall through application of a percentage runoff (PR), which in turn is calculated firstly for rural catchments and then an urban adjustment is applied. Within the urban areas, 61.5% are assumed to be paved with a runoff coefficient of 70% for paved areas.

PRRURAL = SPR + DPRCWI + DPRRAIN	Equation 2.13
DPRCWI = 0.25 (CWI -125)	Equation 2.14
DPRRAIN = 0 for P ≤ 40 mm	Equation 2.15
DPRRAIN = 0.45 (P – 40) 0.7 for P > 40 mm	Equation 2.15
PR = PRRURAL (1.0 – 0.615 URBEXT) + 70 (0.615 URBEXT)	Equation 2.12
CWI = 125 + API5 – SMD	Equation A.1

Table C.2: Summary of runoff estimation methodology

The resulting net rainfall profiles generated by the ISIS software are listed in Table C.3 and shown in Figure C.1.

Time (hrs)	1yr	2yr	5yr	8yr	10yr	20yr	30yr	50yr	75yr	100yr	100yr + 30%	200yr	1000yr
0.00	0.03	0.05	0.07	0.09	0.09	0.11	0.13	0.15	0.17	0.18	0.24	0.23	0.97
0.05	0.03	0.06	0.09	0.10	0.11	0.14	0.15	0.18	0.20	0.23	0.29	0.29	1.19
0.10	0.04	0.08	0.11	0.13	0.14	0.17	0.19	0.22	0.25	0.28	0.36	0.35	1.46
0.15	0.05	0.10	0.14	0.16	0.17	0.21	0.24	0.27	0.31	0.34	0.45	0.43	1.81
0.20	0.06	0.12	0.17	0.20	0.21	0.26	0.29	0.34	0.39	0.43	0.56	0.54	2.26
0.25	0.08	0.15	0.22	0.25	0.27	0.33	0.37	0.43	0.49	0.54	0.70	0.69	2.86
0.30	0.10	0.20	0.28	0.32	0.34	0.42	0.48	0.55	0.63	0.70	0.90	0.88	3.67
0.35	0.13	0.26	0.36	0.42	0.45	0.55	0.62	0.73	0.82	0.91	1.18	1.15	4.80
0.40	0.18	0.35	0.49	0.57	0.61	0.75	0.85	0.99	1.11	1.24	1.61	1.57	6.53
0.45	0.26	0.51	0.71	0.83	0.89	1.10	1.24	1.44	1.62	1.80	2.34	2.28	9.52
0.50	0.42	0.82	1.14	1.32	1.42	1.75	1.97	2.29	2.58	2.87	3.73	3.64	15.16
0.55	0.26	0.51	0.71	0.83	0.89	1.10	1.24	1.44	1.62	1.80	2.34	2.28	9.52
0.60	0.18	0.35	0.49	0.57	0.61	0.75	0.85	0.99	1.11	1.24	1.61	1.57	6.53
0.65	0.13	0.26	0.36	0.42	0.45	0.55	0.62	0.73	0.82	0.91	1.18	1.15	4.80
0.70	0.10	0.20	0.28	0.32	0.34	0.42	0.48	0.55	0.63	0.70	0.90	0.88	3.67
0.75	0.08	0.15	0.22	0.25	0.27	0.33	0.37	0.43	0.49	0.54	0.70	0.69	2.86
0.80	0.06	0.12	0.17	0.20	0.21	0.26	0.29	0.34	0.39	0.43	0.56	0.54	2.26
0.85	0.05	0.10	0.14	0.16	0.17	0.21	0.24	0.27	0.31	0.34	0.45	0.43	1.81
0.90	0.04	0.08	0.11	0.13	0.14	0.17	0.19	0.22	0.25	0.28	0.36	0.35	1.46
0.95	0.03	0.06	0.09	0.10	0.11	0.14	0.15	0.18	0.20	0.23	0.29	0.29	1.19
1.00	0.03	0.05	0.07	0.09	0.09	0.11	0.13	0.15	0.17	0.18	0.24	0.23	0.97

Table C.3: Rainfall profiles

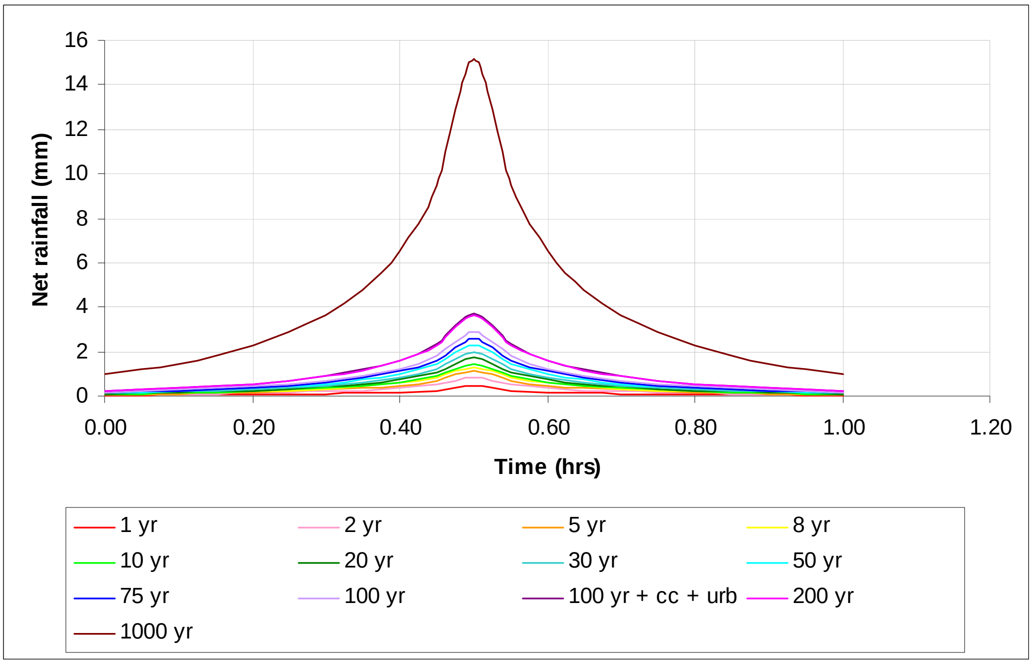


Figure C.1: Rainfall profiles

Allowance for surface drainage network capacity was completed by subtracting the assumed sewer capacity from the net rainfall hyetograph. The sewer capacity in each hotspot area was estimated from the Return Period Analysis (RPA) plans provided by Yorkshire Water. The adopted sewer capacities for each area are:

- Area 4: 1 in 1 yr capacity
- Areas 1, 2, 3, 5, 8 and 10a: 1 in 5 yr capacity
- Area 6: 1 in 10 yr capacity

The resultant surface flow rainfall hyetographs were them input into the 2-D hydraulic models for each of the eight hot spots.

C.2 Hydraulic modelling

C.2.1 Model extent

Eight separate 2D models have been constructed to investigate the pluvial flooding within the study area, one for each hotspot. A default grid resolution of 1m was selected as providing detailed representation of flooding pathways through the urban areas. In the case of Area 2 and Area 10a, the model simulation run times were found to be long and hence inefficient using a 1m grid and therefore a 2m was adopted. A 2m grid is still considered to provide more than sufficient resolution for urban flood risk mapping.

Figures C.2 to C.9 show the extent of eight individual 2D model domains.

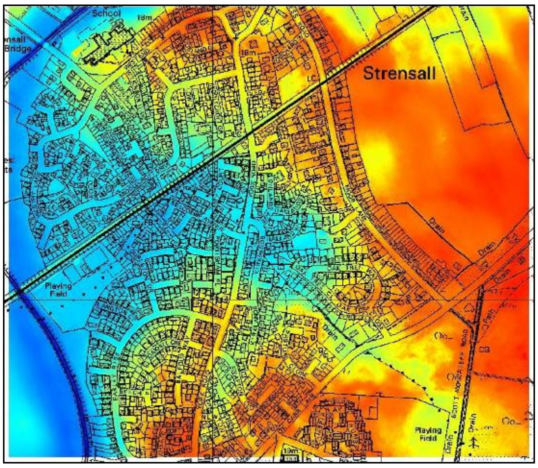


Figure C.2 - Area 1

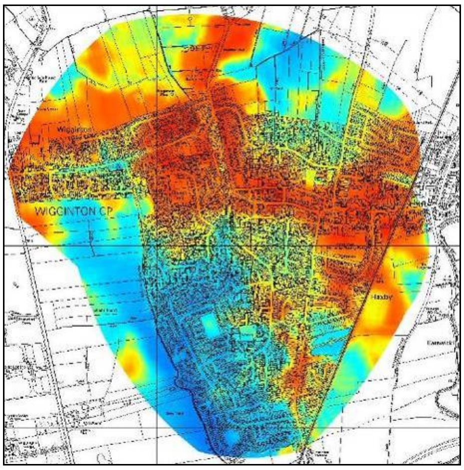


Figure C.3 - Area 2

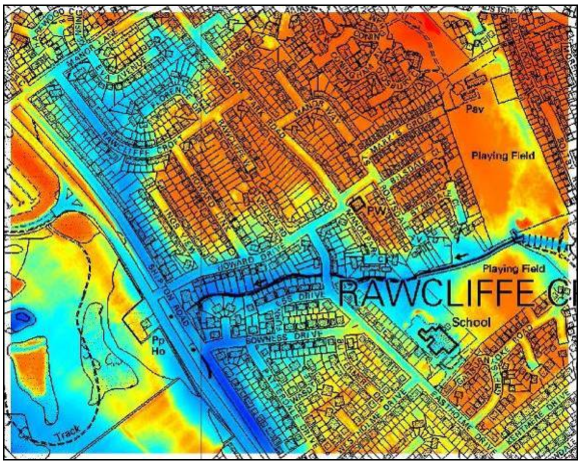


Figure C.4 - Area 3

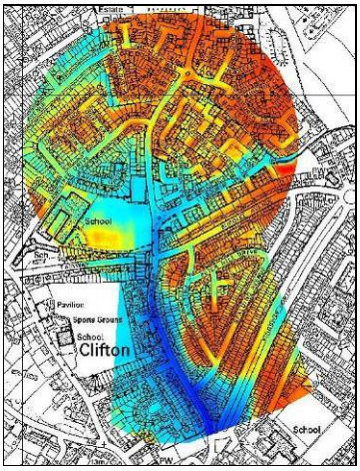


Figure C.5 - Area 4

Figure C.6 - Area 5

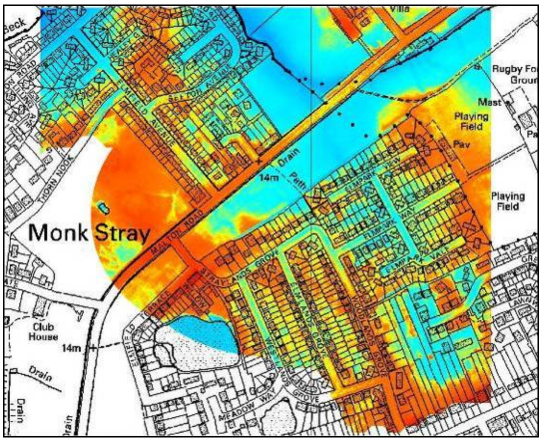


Figure C.7 - Area 6

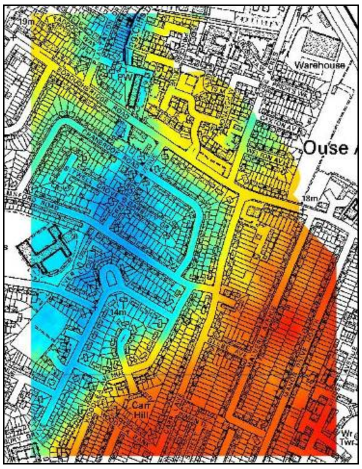


Figure C.8 - Area 8

Figure C.9 - Area 10a

C.2.2 Model construction

Construction of a TUFLOW model involves:

- development of the model computational grid of ground-surface elevations covering the area of interest
- specification of roughness parameters through inclusion of a material layer
- specification of boundary conditions,
- selection of appropriate computational time step and mathematical convergence criterion.

It is sometimes necessary for modifications to be made to the ground surface elevations to smooth out abrupt or unrealistic changes in ground terrain. Abrupt or unrealistic changes can arise due to the filtering of the underlying source data, typically LiDAR or SAR data sources. Modifications to the ground surface elevations are usually entered as an additional 'layer' in the TUFLOW model. Model construction therefore comprises generation of a series of layers which modify the base layer data. Using this layered approach, future users are readily able to follow the model generation process.

C.2.3 Topographic data

Topographic data for the 2d models were provided by the Environment Agency in the form of LiDAR data. The British National Grid was selected as a standard coordinate system. The accuracy of the DTM is assumed to be generally within ±0.15m.

The height of each grid within the model is extracted from the LiDAR. In cases where the grid cell size was too coarse to pick up the correct height of specific structures, they were manually incorporated into the model geometry using polylines and regions with specified elevations as additional model layers. These modifications provided additional detail sufficient to accurately define topographic features such as kerbs and boundary walls.

Environment Agency guidance suggest a range of alternative methods for the representation of buildings relying on the modeller to select the most appropriate approach for each study. For the York study, buildings were represented using a high Manning roughness (see Table C.4 below). Using a high roughness value, allow flow into and through buildings, thus ensuring that floodplain storage is taken into account.

C.2.4 Materials

TUFLOW requires roughness values to be associated with each of the 2D model cells; these roughness values being specified in the model materials layer. Roughness values were derived using Mastermap landuse layers and comparison with reference to established literature. The adopted values being listed in Table C.4.

Material	Manning's n
Residential yards	0.040
Grass, parkland	0.035
Roads and paths	0.020
Buildings	0.500
Rail	0.050
Inland water	0.200
Roadside structures	0.030

Table C.4 – Applied Roughness values

C.2.5 Boundary Conditions

Two boundary conditions have been applied to each of the eight models: a direct rainfall boundary and a stage-flow condition at the most downstream boundary .

Direct Rainfall Boundary

The direct rainfall boundary acts as an inflow boundary for the whole hot spot area. This type of boundary condition uses the resultant surface runoff rainfall profiles derived from FEH (as described in Section C.1).

Stage-flow Boundary

The stage-flow boundary was used to avoid the glass wall effect at the downstream edge of 2D domains. The stage-flow hydrographs were internally calculated by TUFLOW using the slope of ground surface.

C.2.6 Model Parameters

To enable future model users to reproduce model results, an audit trial of the mathematical model parameters used in the model is provided in Table C-5. A one-second time step was adopted, this time step met the required Courant, Friedrichs and Lewy (CFL) stability condition given the wave speed and adopted grid size..

Feature	Parameter value
Wetting and Drying	ON
Cell Wet/Dry Depth (m)	0.0002
Cell Side Wet/Dry Depth (m)	0.0001
Cell Side Checks	METHOD B
Supercritical	ON
Froude Check	1.
Free Overfall	ON
Free Overfall Factor	0.6
Global Weir Factor	1.
Shallow Depth Weir Factor Multiplier	1.
Shallow Depth Weir Factor Cut Off Depth (m)	0.0001
Shallow Depth Stability Approach	METHOD B
Shallow Depth Stability Factor	0.
Shallow Depth Stability Cutoff (m)	0.
Negative Depths In Water Level Output	INCLUDE
Negative Depth Approach	METHOD B
Viscosity Formulation	SMAGORINSKY

Feature	Parameter value
Viscosity coefficients	0.2, 0.1
Viscosity Approach	METHOD B
Boundary Treatment	METHOD A
HQ Boundary Approach	METHOD B
Rainfall Boundaries	STEPPED
Line Cell Selection	METHOD D
Inside Region	METHOD B

Table C.5 – Applied TUFLOW parameter values

C.2.7 Representation of Blocked Gullies

In this study a simple and effective method was used to take into account blockage of gullies. As mentioned above, the net rainfall has been decreased by the sub-surface sewer capacity for the hot spot area which gives a resultant surface runoff. For the blocked gully scenarios, the sewer capacity was not subtracted from the net rainfall hyetograph. The unamended rainfall hyetograph was applied for the area of blocked gullies using an extra polygon in the TUFLOW boundary condition database.

Appendix D

Modelling Outputs

Appendix D Modelling Outputs

D.1 Hotspot 1 (Strensall)

D.2 Hotspot 2 (Wigginton / Haxby)

D.3 Hotspot 3 (Rawcliffe)

D.4 Hotspot 4 (Clifton Without)

D.5 Hotspot 5 (Clifton)

D.6 Hotspot 6 (Heworth)

D.7 Hotspot 8 (Acomb)

D.8 Hotspot 10a (Westfield)

Printed copies of the report contain plans showing only 100y and 200y flood extents for each Hotspot.

Plans showing all modelled flood extents are included on the digital copy of the report.

GIS files are also contained on the digital copy of the report.

Appendix E

Flood Viewer

Appendix E Flood Viewer

FloodViewer files are located on a separate disk.

Instant insight into flood risk

Interactive flood visualisation

FloodViewer shows flood information in an interactive way, enabling better decision making and more effective engagement with stakeholders.

FloodViewer is an interactive tool for flood risk management. Outputs from models and existing flood maps can be viewed using FloodViewer, turning modelling information into user-friendly illustrations of the risk of flooding in a particular area.

It enables easy viewing of a range of flooding scenarios, such as different return-period events, climate scenarios or defence options.

No expensive GIS software is needed to run FloodViewer. It can be run off most digital media, such as a CD or DVD, USB drive, intranet or website, it's easy to set up and you can use your existing data. This, combined with the clear illustrations it produces, make it ideal for sharing information quickly, saving you time and money.

When used over the intranet or website it can be linked to live flood warning alerts and river level data enabling you to effectively monitor and respond to flood events.

Key features

FloodViewer enables users to view information about potential flooding in an area, using interactive tools to interrogate the data and show different scenarios.

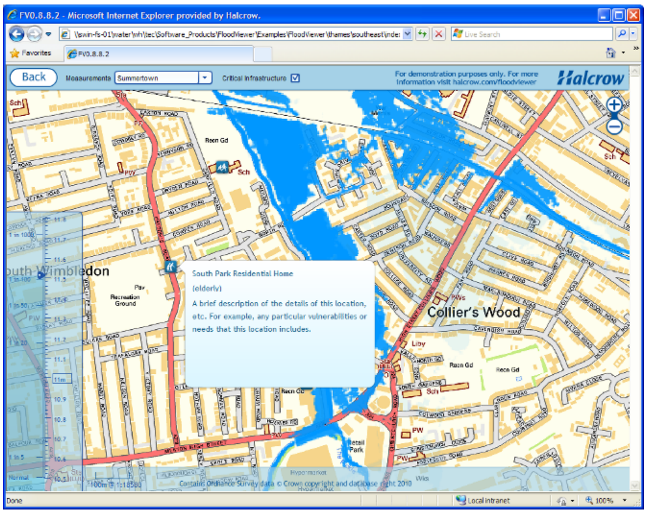
Easy navigation

The interface is designed for easy navigation, enabling you to quickly view and interact with the data. An optional landing page allows easy selection of areas of interest. Panning and zooming tools allow intuitive movement around the information displayed.

Customisable display

Users can integrate data or show only the information required for their needs or relating to particular assets:

- layers can be turned on and off
- toggle between aerial photography and OS maps
- mapping changes dynamically as you zoom



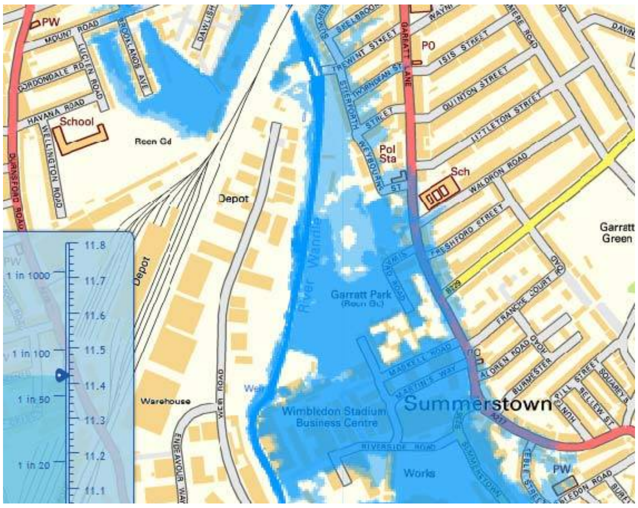
FloodViewer has a GIS-like interface where layers can be turned on and off and users can interact with data sources to help them make decisions.

Intuitive interaction with data

The display of flood information changes as the water-level slider bar is moved to a new water level, return period or key structure height at a given location.

This is of particular benefit when there is an immediate threat of flooding. Forecast flood levels can be used to illustrate the likely extent of flooding associated with a peak water level.

This tool is also used to assess the uncertainty around and effects of predicted and potential water levels.



FloodViewer has a water-level slider (on the left) to allow users to interact with the flood information.

Automatic hypothesising between data sets

FloodViewer automatically hypothesises flood information between model results to give a visual interpretation of flood progression and the onset of flooding. This helps users to make operational decisions without an in-depth understanding of the underlying data.

Improved communication between organisations

FloodViewer can be run from virtually anywhere, so partner organisations can have universal access to the same information, to allow joint decision making.

By using the layer which features important infrastructure, decision makers can see which pieces of infrastructure might be affected by flooding and contact those concerned. To support this, the system provides key details, such as contact names and telephone numbers, vulnerabilities and threshold levels.

In the longer term, this kind of information helps bring focus to where demountable defences should be deployed and how the emergency services might need to be deployed.

Live flood alerts and river and sea levels

Live flood alerts and river and sea levels from the Environment Agency, can be integrated to FloodViewer helping users to understand the current status of flooding and make operational decisions.

Applications for FloodViewer

FloodViewer can help:

- users share information between people in different organisations
- decision making in emergency situations
- keep flood information readily accessible
- allow users to get more from their data
- reduce the need for access to paper and GIS-based systems

Delivering value – case studies

- Flood visualisation for the Midlands

The Environment Agency's is using FloodViewer to help gold and silver-level commands to make decisions in flooding situations in the Midlands region.

FloodViewer helps them see how a set water level translates into a flood event and which critical infrastructure and roads will be affected. It allows them to focus on where to deploy demountable defences and emergency services.

- Flood visualisation for emergency planning

FloodViewer is being considered as a tool to support planning for a large flood exercise. The benefits of using FloodViewer for this project include:

- the ability to display and scroll through hour-by-hour progress of flood water
- the ability to view data with background mapping at a variety of scales and across large parts of England and Wales
- no need for installation of proprietary software or training; viewing is via the web or from a DVD

For more information about FloodViewer visit our website at halcrow.com/floodviewer.

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Appendix F

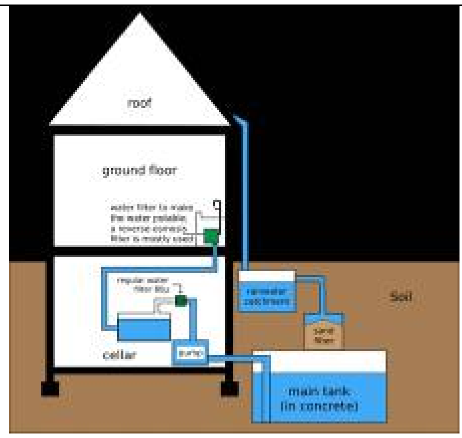
SUDs Retrofit Examples

Appendix F SUDs Retrofit Examples

Appendix F – types of retrofit SuDS measures for 'normal' events

Retrofit SuDS relate to the practice of using single plot or wider area SuDS measures to replace and /or improve existing combined or separate drainage systems in built up areas. Retrofitting of appropriate SuDS is needed because incorporation of SuDS in new developments and areas of urban regeneration is not likely to be enough to deal with increasing surface water runoff and associated water quality problems resulting from issues such as climate change and urban creep.

There are many SUDS measures that are potentially suitable for retrofitting, although which measures can realistically be used depends on issues such as on the amount of physical space, the support of land and property owners and existing infrastructure. There is a great deal of detailed guidance (published by CIRIA, Environment Agency and other private, public and academic organisations) on different types of retrofit SuDS, their benefits, performance and design guidance. The table below summarises some of the main types of SuDS that are suitable for retrofitting, to deal with 'normal' events (1 in 30 year events).

Retrofit SUDS measures	**Description**	**Photos** Photo sources: **http://sudsnet.abertay.ac.uk/sudsphotos.htm (1); http://commons.wikimedia.org/wiki/Main_Page (2)**	***NON-TANGIBLE BENEFITS (CIRIA, 2007, 2010)*** **✓✓ Clear benefits; ✓ possible or limited benefit**					
			Increased air and/or water quality	**Increased green infrastructure**	**Enhanced landscape/ urban design**	**Enhanced amenity**	**Biodiversity & wildlife enhancements**	**Lessening the Urban Heat Island Effect (UHIE)**
Disconnection of down pipes	Direction of roof runoff to local green space for infiltration to the ground or water storage unit (e.g. water butt) for infiltration to the ground. Hard paving and roofed areas can be drained onto unpaved areas or into storage tanks. Driveways and footpaths can be drained onto surrounding lawns.				✓✓	✓		
Water butts	Tanks and drums that can be used to store runoff from roof tops, and can thus provide online attenuation. These are the most common means of harvesting rainwater for garden use. They usually collect water directly from disconnected down pipes.	*Photo source: (2)* Creative Commons Attribution 2.5 Generic license.	✓		✓✓	✓	✓	
Rain Water Harvesting (RWH)	Disconnection of premises from the drainage system to provide an "in-house" collection and storage system for rainwater that can be used for non-potable water use.	 *Photo source: (2)*			✓✓			

Retrofit SUDS measures	Description	Photos Photo sources: http://sudsnet.abertay.ac.uk/sudsphotos.htm (1); http://commons.wikimedia.org/wiki/Main_Page (2)	***NON-TANGIBLE BENEFITS (CIRIA, 2007, 2010)*** **✓✓ Clear benefits; ✓ possible or limited benefit**					
			Increased air and/or water quality	**Increased green infrastructure**	**Enhanced landscape/ urban design**	**Enhanced amenity**	**Biodiversity & wildlife enhancements**	**Lessening the Urban Heat Island Effect (UHIE)**
Green roofs	A source control component which is a roof surface capable of supporting soil and vegetation. They are laid over a drainage area, with other layers providing protection, waterproofing and insulation. Green roofs provide some retention, attenuation and treatment of runoff. They can be intensive or extensive.	 *Photo source: (1)*	✓✓	✓✓	✓✓	✓	✓✓	✓✓
Permeable surfaces	High porosity surfaces which allow rainwater to infiltrate through the surface into an underlying storage area. From here water can be infiltrated to ground, reused or released to surface water drainage system.	 *Photo source: (1)*	✓✓		✓✓	✓	✓	
Bio-retention cells / rain gardens	Small bio-retention cells in which stormwater is cleaned and reduced in volume. Gardens contain engineered soils and specially selected plants to take advantage of rainfall and stormwater run off. Nitrogen, phosphorus and sediment in the stormwater are reduced by the action of plants and growing media. Water can either be infiltrated or returned to the system, depending on prevailing ground conditions. Multiple rain gardens over an area have a cumulative effect in reducing both the volume and quality of stormwater run off.	 *Photo source (2)* Creative Commons Attribution 2.5 Generic license.  *Photo source (2)*	✓✓	✓	✓✓	✓✓	✓✓	✓

Retrofit SUDS measures	Description	Photos Photo sources: http://sudsnet.abertay.ac.uk/sudsphotos.htm (1); http://commons.wikimedia.org/wiki/Main_Page (2)	*NON-TANGIBLE BENEFITS (CIRIA, 2007, 2010)* ✓✓ Clear benefits; ✓ possible or limited benefit					
			Increased air and/or water quality	**Increased green infrastructure**	**Enhanced landscape/ urban design**	**Enhanced amenity**	**Biodiversity & wildlife enhancements**	**Lessening the Urban Heat Island Effect (UHIE)**
Attenuation structures	Storage facilities which store water temporarily to attenuate flows (designed to detain a certain volume, whilst providing water quality treatment). Includes **detention basins.** May allow infiltration of water to the ground, usually having a gravel base to ensure good drain down.	 *Photo source: (1)*	✓	✓✓	✓✓	✓✓	✓	✓
Infiltration structures	Drain water directly into the ground. They include **soakaways** and **infiltration trenches**. They also include permanent pools of water such as **ponds** and **wetlands**, which can provide treatment to the runoff. Ponds have the advantage that they provide amenity benefits for the local residents by way of the open space and habitat creation.	 *Photo source: (1)*	✓✓	✓✓	✓✓	✓✓	✓✓	✓

References

CIRIA (2007). *SUDS Design Manual for England and Wales*.

CIRIA (2010). *Retrofitting surface water management measures – Guidance*. Report RP922

Environment Agency (2007). *Cost-benefit of SUDS retrofit in urban areas.* Science Report – SC060024

Photos:

http://sudsnet.abertay.ac.uk/sudsphotos.htm (1)

http://commons.wikimedia.org/wiki/Main_Page (2)

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