iCASP

Integrated Catchment Solutions Programme

Interoperability

System-based Urban Infrastructure Management (SUIM) for flood risk alleviation in east Leeds, UK

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Date of Issue May 2021

This project was funded by iCASP under NERC Grant: NE/P011160/1

UKRI Natural Environment Research Council

Contents

Executive Summary

More options for urban flood management are available now than ever before (for example, grey built infrastructure, sustainable urban drainage systems). Yet big challenge facing urban flood management is integrate them into existing urban infrastructure systems and to understand how we connect storm water pathways with other urban systems (for example, transport or land use) to expand the capacity of the overall system to cope with future climate uncertainties. This project helps urban flood risk managers by allowing them to identify the sources of flood risk (where flood water comes from) and not just the hazard itself (where the water ends up). The flood source area approach helps us to explore and identify whether existing or new urban development can play more than one role? i.e. be connected with managing excess water and become 'interoperable'? Can a road be used to divert flood water? Can an open green space store it temporarily? We applied a newly developed modelling and spatial analysis approach to an example catchment in the east of Leeds – Wyke Beck. The Wyke Beck case was used as the basis for collaborative work toward developing a user-friendly 'interoperability tool' for future use by Leeds City Council (LCC) in other parts of the city. It could also be used by councils in other cities too. Engagement with the approach concluded the benefits as: a study phase tool for strategic scheme prioritization; improved time saving in partnership funding hunt; earlier negotiations of section 106 contributions & growth funding; derestriction of the prescribed approach to option selection. Further to this three additional schemes were identified that could have been investigated for options in Phase 1, and can be considered in Phase 2: future proofing existing infrastructure; increased green infrastructure storage; public engagement on rainwater storage. Finally, it was identified that the approach supports system flood risk management by supporting three key principles that align directly with the latest government guidance on flood risk management.

1 Introduction & project aim

The aim of this project has been to extend the scope of urban Flood Risk Management (FRM) activities by considering the *sources* of flood risk (where flood water comes from) and not just the hazard itself (where the water ends up). This project, titled: *System-based Urban Infrastructure Management (SUIM),* translated a spatial decision-support framework[1, 2] consisting of hydrodynamic modelling (using unit flood response) and catchment spatial data analysis (post-processing using public data) into FRM practice. Traditional hazard modelling and subsequent planning and appraisal focuses mainly on the receptor/impact aspect of the system, favouring more protective schemes (defences & improved drainage infrastructure at or adjacent to at risk properties) - SUIM considers the full hazard pathway aspect of source to hazard with the catchment system.

The approach was applied to the Wyke Beck catchment (Leeds, UK), which had received funding for a Phase 1 flood scheme (completed 2020), and is currently planning Phase 2 (as of May 2021). SUIM aimed to identify connections, wider catchment opportunities, and funding partnerships beyond the areas of known flood hazard impacts (Figure 1). This report presents a summary of the collaborative project between the University of Leeds' School of Civil Engineering, Leeds City Council, and the Environment Agency. Support for this work was granted by the **Yorkshire Integrated Catchment Solutions Programme (iCASP) through funding from the Natural Environmental Research Council (NERC).**

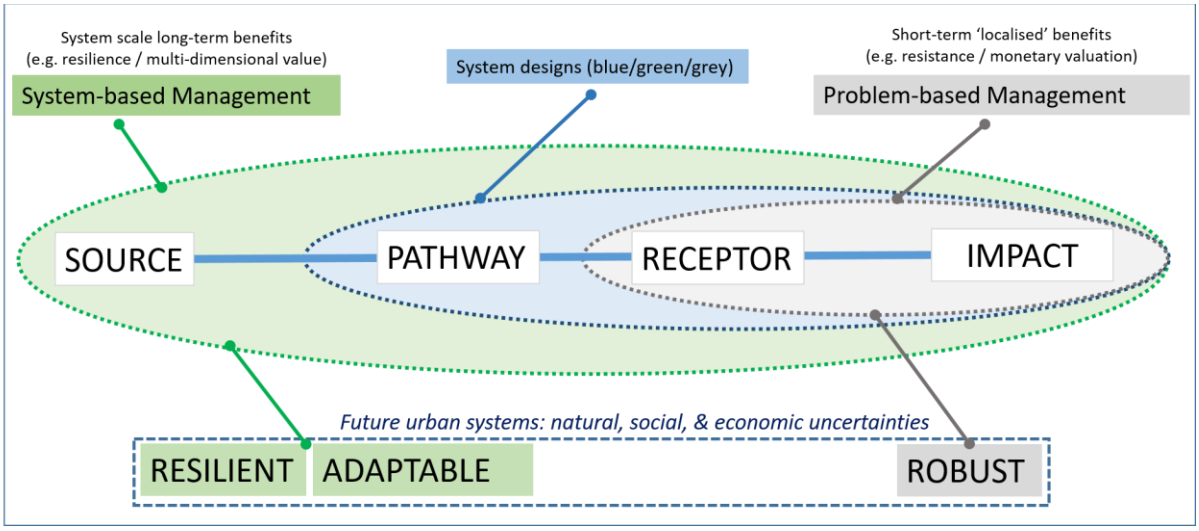

Figure 1. SUIM approach aims to include the full 'system' or model from source to consequence in strategic flood risk planning and infrastructure management

2 System-based Urban Infrastructure Management (SUIM) for flood risk alleviation

The SUIM approach aims to assist the identification of interoperable options, practical collaborative projects, and new funding opportunities through the use of hydrological modelling to consider the *source* of water hazard and interacting systems such as existing infrastructure systems and urban regeneration plans (Figure 1). **The SUIM approach is a 'high-level' or strategic tool** that could be used (in conduction with other data sets) to direct FRM towards opportunities for project connections and

[1] Vercruysse, K. et al. (2019). Developing spatial prioritization criteria for integrated urban flood management based on a source-to-impact flood analysis. Journal of Hydrology v. 578. https://doi.org/10.1016/j.jhydrol.2019.124038
[2] Dawson et al. (2020). A spatial framework to explore needs and opportunities for interoperable urban flood management. Philosophical Transactions of the Royal Society A. https://doi.org/10.1098/rsta.2019.0205

development of shared business cases. It does so by assessing the following information; flood hazard areas, areas contribution to flooding (referred to as flood or hazard source), infrastructure systems (e.g. transport, land use, drainage), and planning data (in this case from LCC regeneration team). In order to identify the key principles and guidelines of how the SUIM approach can be applied we trial the approach in the Wyke Beck catchment in the east of Leeds (see section 3), with the aim of progressing its practical application (into a future tool) and informing future developments.

3 Phase 1 Wyke Beck Flood Alleviation Scheme, Leeds

The following background narrative to the Wyke Beck phase 1 scheme was elicited at a meeting between iCASP and Leeds City Council on March 6th 2020[3]. A partnership approach to funding allocation was used for this scheme, and reflects the type of activity the SUIM approach has been designed to assist. Wyke Beck Phase 1 illustrates that funding for FRM schemes can come from a range of contributors, each with individual metrics (e.g. housing, carbon storage, health & wellbeing, biodiversity, sustainable travel and jobs & growth). An updated Environment Agency formula for allocating funding flood and coastal defenses across England reinforces this trend, where health and environmental benefits will be taken into account.[4] This section provides important background information on the scheme and its successful funding allocation.

3.1 Catchment Overview & Phase 1 Scheme Funding

Wyke Beck is a predominantly urban catchment originating at Waterloo lake in Roundhay Park in the north of Leeds and has a long history of flooding and drainage issues[5] (see Figure 2). Along its course to the confluence with the River Aire in the south east of the city, there are five Local Nature Reserves (LNRs)[6]. In 2018/19 Leeds City Council in partnership with the Environment Agency put forward, received funding and commissioned work to start on Phase 1 of a flood mitigation scheme focusing on 3 of the 5 LNRs. The three sites that make up Phase 1 of the Wyke Beck scheme are designed to have environmental co-benefits and include[7]:

1. Arthur's Rein LNR – removing a culvert and re-profiling the channel
2. Killingbeck LNR – naturalised flood storage
3. Halton Moor LNR – naturalised flood management

Funding for flood risk management in England comes from a variety of sources (see **Error! Reference s ource not found.**). In the case of Wyke Beck phase 1, the scope of the project and funding sources evolved over time to complement brownfield development in the area.

The traditional flood scheme approach: Leeds City Council (LCC) have previously drawn upon Local Levy funding[8] for a study of the Wyke Beck catchment. This study informed plans for "the Wyke Beck Improvements project" - which had been on the Environment Agency's Medium Term Plan for a number of years, the intention being to focus on reducing flood risk to properties in the Dunhill Estate area of Halton (adjacent to Halton Moor). The financing of substantial flood alleviation schemes in the area had previously been attempted by Leeds City Council FRM through the 'traditional' route – focused on leveraging central government funding (see Figure 3). This entails commissioning hydrological modelling of the hazard area and determining the cost/benefit of various options based

[3] Leeds City Council, personal comms, March 6th 2020
[4] Defra (2020). Building flood defences fit for the future - Government announces new formula for allocating funding for flood and coastal defences across England https://www.gov.uk/government/news/building-flood-defences-fit-for-the-future [accessed May 2021]
[5] Leeds City Council – Wyke Beck Valley https://www.leeds.gov.uk/leisure/parks-and-countryside/nature-reserves/wyke-beck-valley [accessed May 2021]
[6] Leeds City Council – Wyke Beck Valley https://www.leeds.gov.uk/leisure/parks-and-countryside/nature-reserves/wyke-beck-valley [accessed May 2021]
[7] West Yorkshire Combined Authority (WYCA) Wyke Beck phase 1 business case (2018) https://westyorkshire.moderngov.co.uk/documents/s4985/Item%208%20-%20Appendix%204%20-BCSummary%20Wyke Beck%20Flood%20Alleviationv1%20FINAL.pdf [accessed May 2021]
[8] Local levy funding is raised through the Council Tax and its level is determined by the Lead Local Flood Authorities (LLFAs) on the Regional Flood & Coastal Committee.

on the number of properties with a reduced risk of flooding, previously referred to as Outcome Measure 2[9]. In this instance the business case did not meet the required standard to be fully funded.

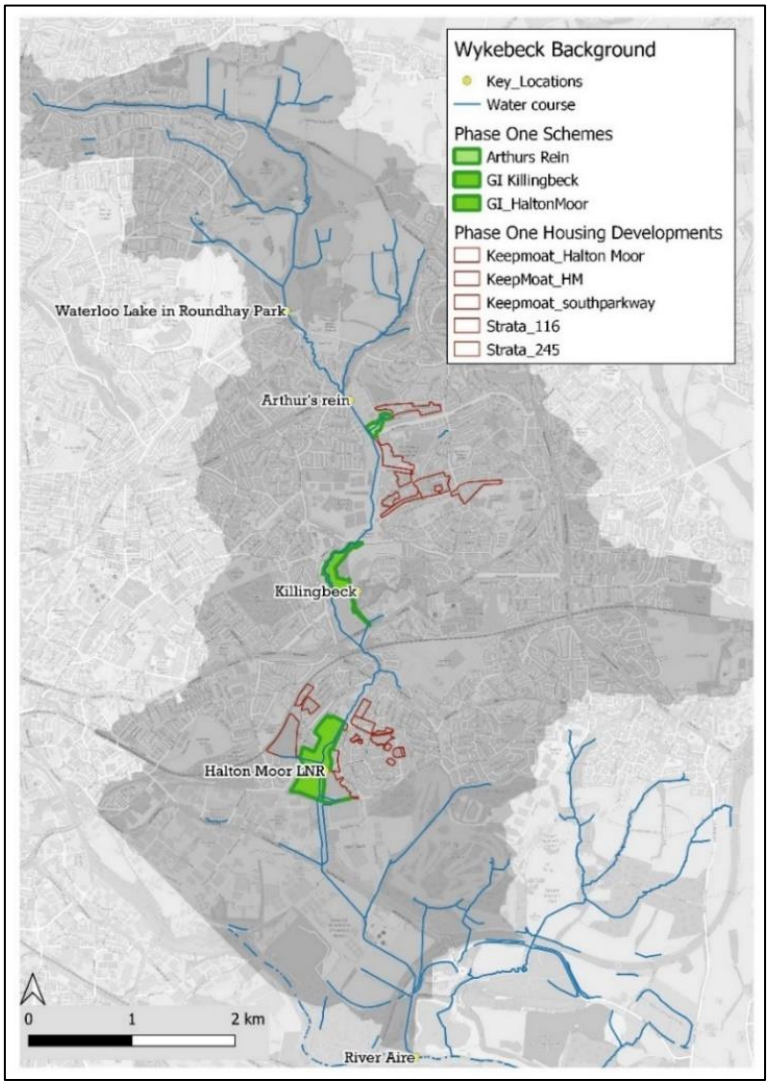

Figure 2. Wyke Beck catchment in Leeds, location of Phase One Flood Alleviation Scheme sites (green areas) and collaborating housing development sites (brown outlines).

Collaborative co-funding with local housing developers: Over time the project grew into a multi-benefit, catchment wide programme of work led by LCC involving environmental and green space improvements as well as looking at flood risk. The programme evolved in response to opportunities to take advantage of Section 106 developer contributions[10] linked to the council's Brownfield Land Programme and an opportunity to obtain £2.6m of Local Growth Funding from the West Yorkshire Combined Authority (WYCA). FCRM Grant-in-Aid (GIA) was also applied for. Developers are bound under Section 106 of the Town and Country Planning Act 1990 to contribute to a Community Infrastructure Levy (CIL) to alleviate the impact of a development if needed.[11] This can include a requirement to off-set the additional burden of surface water drainage. In this instance a business

[9] https://www.gov.uk/government/statistics/flood-and-coastal-erosion-risk-management-outcome-measures
[10] A Section 106 is a legal agreement between developers and the local authority, which is used to mitigate the impact on the local community and infrastructure.
[11] UK Planning Advisory Service (2021). Developer Contributions - CIL & S106 https://www.local.gov.uk/pas/pas-topics/infrastructure/s106-obligations-overview

case was put to the council for the developers' S106 contributions (also known as 'planning gain') to co-fund the flood scheme which would also provide additional capacity for surface water drainage. The payments made by developers (e.g. Strata and Keepmoat) were equal or less than required to put in otherwise required attenuation tanks. LCC worked to secure funding by building a series of business cases from three sources each with different but overlapping funding criteria, namely:

1. £600K from the Environment Agency
2. £2.6M from the West Yorkshire Combined Authority (WYCA) – aligning with the two priority areas of 'clean energy and environmental resilience' and 'infrastructure for growth'.[12]
3. £1.5M from Leeds City Council (CIL/ S109)

Leeds City Council's contribution was made possible by the FRM team working closely with the council's Brownfield Development Scheme (BDS). BDS was initiated in 2013 (and is due to terminate in 2020) to release marginal (e.g. low quality or contaminated land) in packages to developers. The packages were designed to encourage the sale of marginal land in conjunction with more valuable land, in part to help meet the council's annual target of building 2260 homes per year[13].

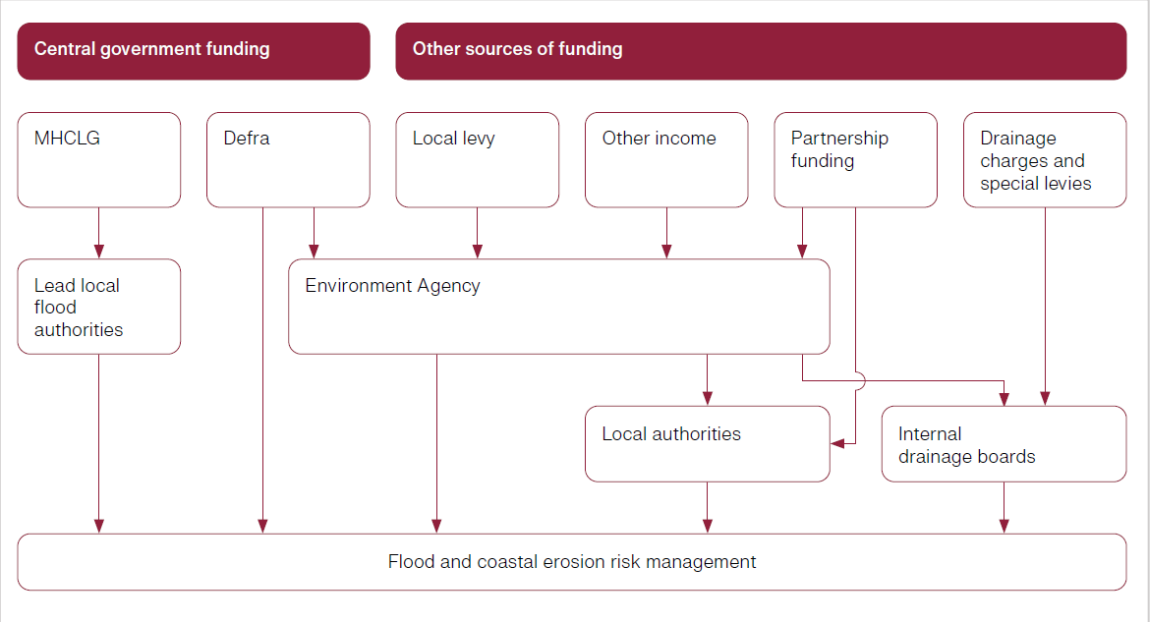

Figure 3. Sources of funding for flood risk management in England. MHCLG: Ministry of Housing, Communities & Local Government. Defra: Department for Environment, Food & Rural Affairs. Source: Department for Environment, Food & Rural Affairs, Central Government Funding for Flood and Coastal Erosion Risk Management in England, September 2019

4 Application of SUIM to Wyke Beck

The SUIM methodology[14] was applied to the Wyke Beck Catchment (Figure 4 a-c). The hazard mapping of both pluvial and fluvial risk is based on a rain on grid two-dimensional LISFLOOD model with modifications to the domain to account for channel conveyance. Rainfall was determined from Flood Estimation Handbook (FEH) catchment characteristics, the flood profile (event) is based on a 1 in 100 year summer storm with a 10 hour duration (1% probability). Drainage and flood loss assumptions calculated in the FEH process are also applied leaving a net rain amount that is applied

[12] https://westyorkshire.moderngov.co.uk/documents/s4985/Item%208%20-%20Appendix%204%20-BCSummary%20Wyke Beck%20Flood%20Alleviationv1%20FINAL.pdf
[13] James Kilroy, personal comms, 20.02.20
[14] https://doi.org/10.1016/j.jhydrol.2019.124038

to the model as the input rainfall. The model is calibrated using the Revitilaised Flood Handbook 2(ReFH2) estimation of flow at the catchment outlet, and FEH catchment characteristics.

The pluvial component has been visually compared with the Environment Agency Surface Water Maps (EASWM), which compare well. However, for our final outputs the pluvial risk outputs contain all surface water from above 1mm. In comparison with the EA, that presents surface water risk above 50mm only, our maps will exaggerate the risk but highlight potential future surface flows**. At this stage, the modeling is designed for strategic analysis rather than site specific accuracy**, and accuracy of the terrain and drainage assets could be improved. We assume that with calibration and comparison with both the ReFH2 and the EASWM maps it is adequate for this strategic level analysis.

The catchment has been divided into equal size grids (1-37 – **Figure 4a**) & the rainfall in each grid has been switched off sequentially and the model re-run to identify the contribution of that grid to flooding across the catchment (an adaptation of the Unit Flood Response technique[15][16]). The flood source contribution area can then be identified (**Figure 4b**), where areas that contribute most to widespread flooding are identified in darker shading. For example, in the north east region of the upper catchment (Red Hall, grid 16), and in the lower catchment (north east of Halton Moor, grid 30). The darkest shades represent contributions to flooding over areas of ~0.15km^2 (or ~15 football pitches).

Figure 4c shows the data available for each grid, and the relative contribution of that grid to catchment flooding including the maximum area flooded, contribution of each grid to the deepest flooding (Depth Flooded), and the grid's contribution to the flooding of: green space, buildings, & roads is shown. For example, **grid 33 causes the deepest flooding, impacting little/no green space, & contributes to some flooding of roads and buildings.**

4.1 Wyke Beck Phase 1 Review

In respect to the Wyke Beck Phase 1 sites (see **Figure 2 & 4a**), the analysis highlights the Halton Moor LNR site as being located within an area of catchment that contributes to the flooding of green space (grids 12,13, 14 – **Figure 4c**), and also the flooding of road network and some buildings (grid 14). The Killingbeck site (north of Halton Moor) is ranked similarly high for contribution to the flooding of green space, and the analysis suggests some contribution to the flooding or roads and buildings. **This confirms that the sites chosen in Phase 1 for green infrastructure development are in an ideal location to retain a high level of water in the catchment.**

4.2 Wyke Beck Phase 1 additional schemes

Figure 4c can be used to identify areas of the catchment where other interventions could complement those carried out in Phase 1, based on their contribution to flooding e.g. flood depth, area, green space, infrastructure (see Figure 4c - **C1-3 & Table 1**). This information becomes particularly useful when viewed in conjunction with spatial plans for upcoming infrastructure developments in the city, three examples are illustrated.

Firstly, **C1: Futureproofing Roundhay lake infrastructure** (C1; Figure 4C, Table 1 & Figure 5) to future climate change (mentioned by FRM team also), and investigating partnerships with the **East Leeds Orbital Route and associated housing developments (see Figure 5).**

Secondly, **C2: East End Park Green Storage** (C2; Figure 4C, Table 1 & Figure 6) to maximize the flooding of green space in the catchment. There are numerous development sites (for example in grid 14, Figure 6) that could be investigated to **receive benefits from interventions or support partnerships in managing surface water in this area.**

[15] Vercruysse, K. et al. (2019). Developing spatial prioritization criteria for integrated urban flood management based on a source-to-impact flood analysis. Journal of Hydrology v. 578. https://doi.org/10.1016/j.jhydrol.2019.124038

[16] Singh et al. 2021 A review of modelling methodologies for flood source area (FSA) identification https://doi.org/10.1007/s11069-021-04672-2

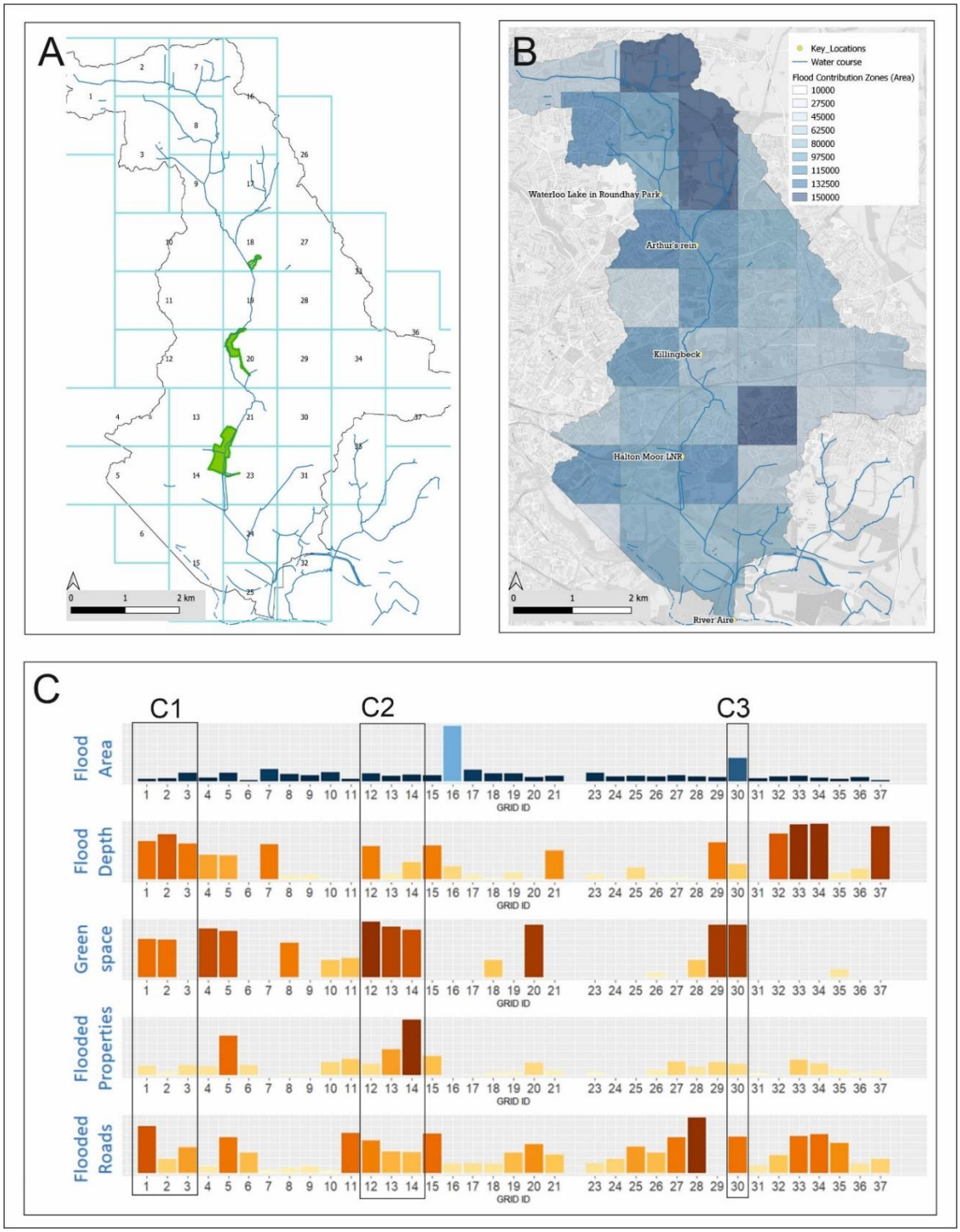

Figure 4A-C: A: *catchment grid ID for unit flood analysis.* ***B:*** *Source to hazard analysis illustrating flood area contributions in the catchment (darker shade = more contribution to flooded area – m2)* ***C:*** *Grid statistics for relative catchment analysis – units are based on area (m2) covered by modelled flows (e.g. flood area, green space flooded, & roads flooded), flood depth represents grid contribution to flood area above 200mm, flooded properties is based on number of building covered by modelled flows. C1-3 examples of areas of interest provided by the SUIM approach (See Table 1 & Figures 5-7)*

Finally, C3: Halton Town Centre Surface Water Scheme (C3; Figure 4C, Table 1 & Figure 7) is also an area that contributes significantly to flooding in the catchment (Grid 30), and presents an **opportunity to adapt the built environment to reduce surface water into the drainage system.** For example, planning was granted to extend a food store and car park, directly on a flow path – making the car

park permeable or increasing the storage of the car park would be an optional improvement (see **Figure 7**), or increasing public participation in home water storage activities to reduce stress on the drainage network.

Table 1. Example source identification opportunities (C1-3) see Figure 4 (above) and Figures 5-7 (at the end of the report).

	Location	Investigation
C1	Upper catchment (Roundhay) (Figure 5)	Future proofing dam infrastructure to climate change. Grids 1-3, 16: Schemes to reduce flow into Roundhay Lake, strengthen dam to reduce overtopping risk.
C2	East End Park (Figure 6)	Increased storage: maximizing flooding of green space & reduce transport flooding: Grids 12-14.
C3	Halton Centre (Figure 7)	Urban area storage improvements. Grid 30 & 29 – high contribution to flooding (area & depth) in catchment. Potential car park alteration is identified (grid 30)

4.3 Stakeholder views on the use of SUIM

The application of SUIM in Wyke Beck has been stakeholder led – with a number of workshops and meetings taking place (see

Table 2).

Some key statements from the project partners:

What are your impressions of SUIMs outputs:	'It is extremely useful to have a graphical representation of the sources of flooding in a map based system it would give us more confidence where the interventions should be' **Leeds City Council**
	'The statistical summary is really useful, can be used to bespoke evidence to metrics of specific funding criteria... WYCA, EA, … steering us towards where collaborative funding could be harnessed' **Environment Agency**
Some traditional modelling does look at flood sources:	'but SUIM looks at it in a slightly different way, including other forms of funding – partnerships from S106 & council capital funds'
	'storage is often thought off but could be used more in the future and SUIM helps identify potential areas to investigate' **Environment Agency**
What could have been done differently in Phase 1 with SUIM:	'We could have identified all developments who could have contributed... [providing more] justification for s1o6 negotiation cost with the developer– costs they could avoid if they don't have to design SUDs - so they can design more houses.'
	'SUIM could have reduced the need for serendipity, and saved time in negotiations'
How do you think SUIM will help FRM in Leeds?:	'[The SUIM approach] allows us to move beyond receptor risk and prioritize the catchment grid by grid and then seek contributions to funding' **Leeds City Council FRM**.
	'[SUIM] can be used as a catchment prioritization tool, allowing for pre-business case optioneering before requesting specific sites for full study'
	'Providing a system perspective for city wide strategic flood risk planning/policy, in the upcoming SFRA'

Overall, it was not possible to quantify the (theoretical) retrospective benefits of using the approach for Wyke Beck Phase 1, although "time saved" was quoted as a likely outcome. The key message was that the SUIM approach allows for **a better alignment between more strategic city level response (top down) and the selection of actual areas of intervention and optioneering (bottom up)** - with the same method applied for both top down and bottom up approaches, it can realistically improve the overall system. In summary of the engagement activities SUIM can:

1. **Identify early opportunities** for interoperable working earlier (partnership approaches, infrastructure interactions etc.) at the catchment scale, and
2. Help support the **strategic evidence** and narratives for partnership approaches (through flood source identification maps)
3. Identify **complimentary interventions** when scheme locations are already decided, and
4. **Identify further areas influencing flooding around existing flood schemes,** again, to help support evidence for wider benefits, and a more strategic approach at a catchment scale.
5. **Provide a richer spatial analysis** of flooding, planning, and existing infrastructure interactions.

Table 2 Stakeholder engagement through the trail application of SUIM in Wyke Beck

Date	Context	Participants
6th March 2020	Kick of Project Meeting – Phase 1 revisit	All team & Partners
26th June 2020	Online SUIM demonstration session	David Dawson and Matt Sherwood (LCC)
22nd July 2020	Workshop: Advancing Wyke Beck Phase 1 practice into Phase 2	All team & Partners
11th Nov 2020	Phase 2 planning meeting	All team & Partners – plus WSP (LCC's flood consultants)
18th Nov 2020	Email exchange of adapted outputs for Phase 2 planning	David Dawson & Matt Sherwood & WSP
19th March 2021	Integrations with existing planning discussion (catchment scale)	David Dawson & Matt Sherwood (LCC)
24th March 2021	Integrations with Strategic Planning (City Scale)	Vanessa Allen (Strategic Flood Risk Assessment)
22nd April 2021	Introduction of SUIM for future Strategic Flood Risk Assessments	10 participants from LCC, Environment Agency, Yorkshire Water & AECOM.

5 Key principles & opportunities for the application of SUIM

Leeds City Council have identified two current opportunities for SUIM to be used for FRM. Firstly, optioneering and business case development for further FRM interventions in Wyke Beck (i.e. Phase 2). Secondly, updating their city-wide Strategic Flood Risk Assessment (SFRA).

The way in which the SUIM information can be used for decision making is flexible. However, the team found that the initial process of reviewing SUIMs outputs was to use the grid by grid chart data (see **Figure 4C**) as the first point of discussion. Then subsequently reviewing the mapping outputs and planning data in turn.

There is a need to quantify and communicate the level of confidence decision makers can put in the information. At present, the data can inform priority areas for further quantitative investigation. LCC have agreed to partner a new project taking this work more into the decision making area.

SUIM must also be capable of **connecting to decision making systems** (e.g. cost benefit analysis) for valuing the benefits of system changes to support **efficiency analysis of schemes and groups of schemes**. This would require further model improvements to provide data to spatially indentify costs and benefits.

Finally, through the collaborative project some principles emerged through applying the SUIM approach to the retrospective case that can be used in future flood schemes – most appropriately Wyke Beck phase 2. Table 3 presents the **three key principles supported by SUIM,** which also directly related to the latest EA guidance on flood scheme funding (Table 3).

Table 3 3 key principles supported by SUIM and how they relate to the latest EA guidance on flood scheme funding

Principle	SUIM support	Environment Agency Guidance (2020)
Embedding water risk in urban regeneration	Reviewing flood source maps with site allocation plans to prioritize intervention & catchment scale strategic plans	**The principles & SUIM approach support the following EA guidance:** • Clearer scheme/programme objective setting across sectors • Assisting the development of the stakeholder engagement plan: e.g. defining scope and business case opportunities • Providing a stronger narrative for the appraisal need – for example in the 'strategic report' or Strategic Outline Case of the Five Business Case Model[17] **Improving management through:** • Clearer descriptions of the source of the opportunity for schemes • The timeliness of the opportunity (through the connection of existing planning timelines and potential sources of co-funding). **Identify wider opportunities through**: • Supporting plans for economic regeneration & biodiversity using natural management techniques • Identifying opportunities for multiple functions in a new infrastructure. • Community enhancements such as recreation and landscaping
Sustainable & resilient growth through project co-development	Earlier identification & engagement with partners/funding & the development shared objectives (outcome measures).	
Building city-wide strategic resilience portfolios	Evidence for improving strategic business cases from multiple sources of funding. Identification of programmes and portfolios of schemes connected using SUIM outputs as evidence	

The SUIM approach also compliments the findings of a related iCASP project - *"Rethinking the value of green and blue infrastructure (GBI)"*[18]. Table 4 summarises how SUIM output could be used to support overcoming the many barriers to the effective valuation and implementation of GBI.

[17] HM Treasury 2018: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/749086/Project_Business_Case_2018.pdf
[18] iCASP (2020). GBI Business Cases project. https://icasp.org.uk/projects-2-2/gbi-business-cases/

*Table 4 Key principles for r*ethinking the value of green and blue infrastructure (GBI) and how the SUIM approach can support

iCASP "Rethinking the value of green and blue infrastructure" principles	SUIM method and output support
Greater strategic emphasis	Using multiple scheme collaboration to demonstrate wider significance of flood scheme.
Building Resilience Programs	Wider visualization of the hazard source and interoperability will enable multiple schemes to combine into a single 'programme' ; avoiding the loss of project value apparent in project by project appraisal.
Integrated provisioning across the catchment	Through the SUIM approach, and multi-agency scheme/catchment workshops, support the provisioning of value/benefits more widely and efficiently.

6 Additional Scheme Maps (C1-3)

Below the related maps to Table 1 and descriptions in section 4.2.

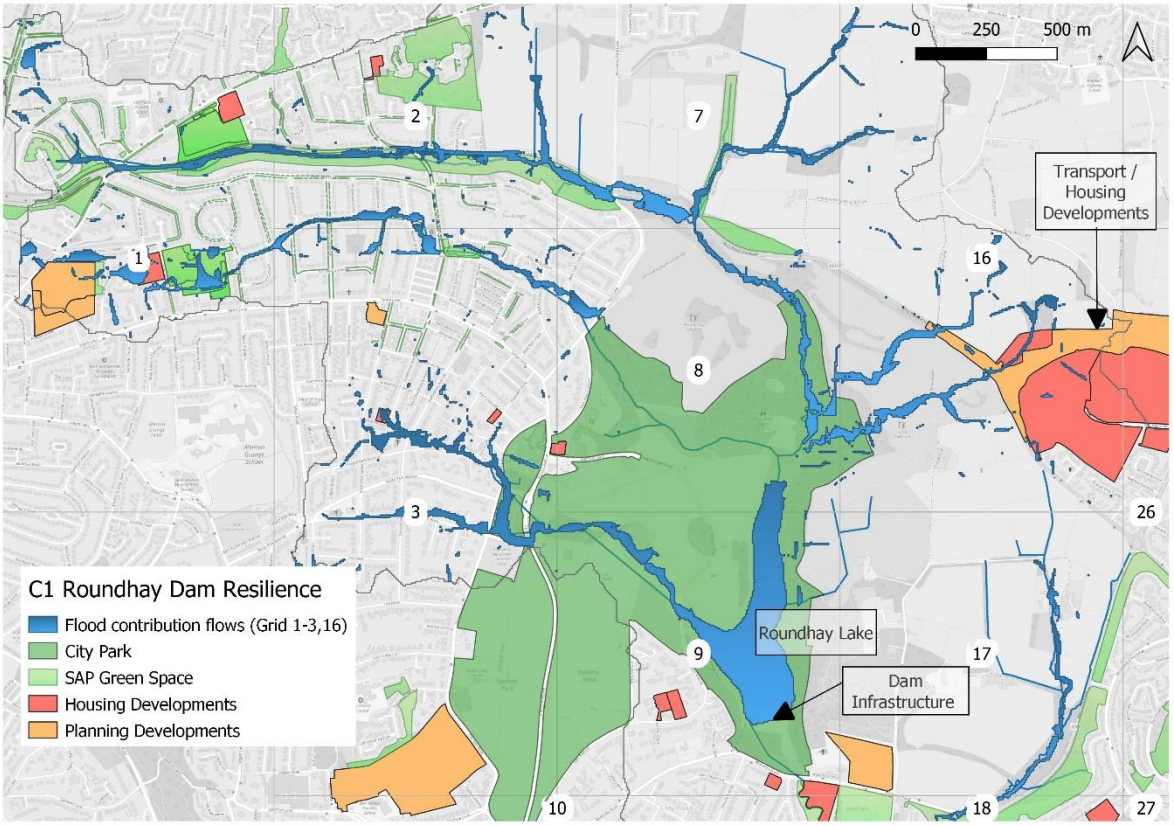

Figure 5. Upper catchment area of interest (C1). Future proofing Roundhay Lake Infrastructure. Flood contribution flows show contributions from grids 1-3 & 16. Site Allocation Plan (SAP) data (2014-2019) illustrated, including major developments in the east (housing & transport), and SAP identified green space that could be adapted to manage flows.

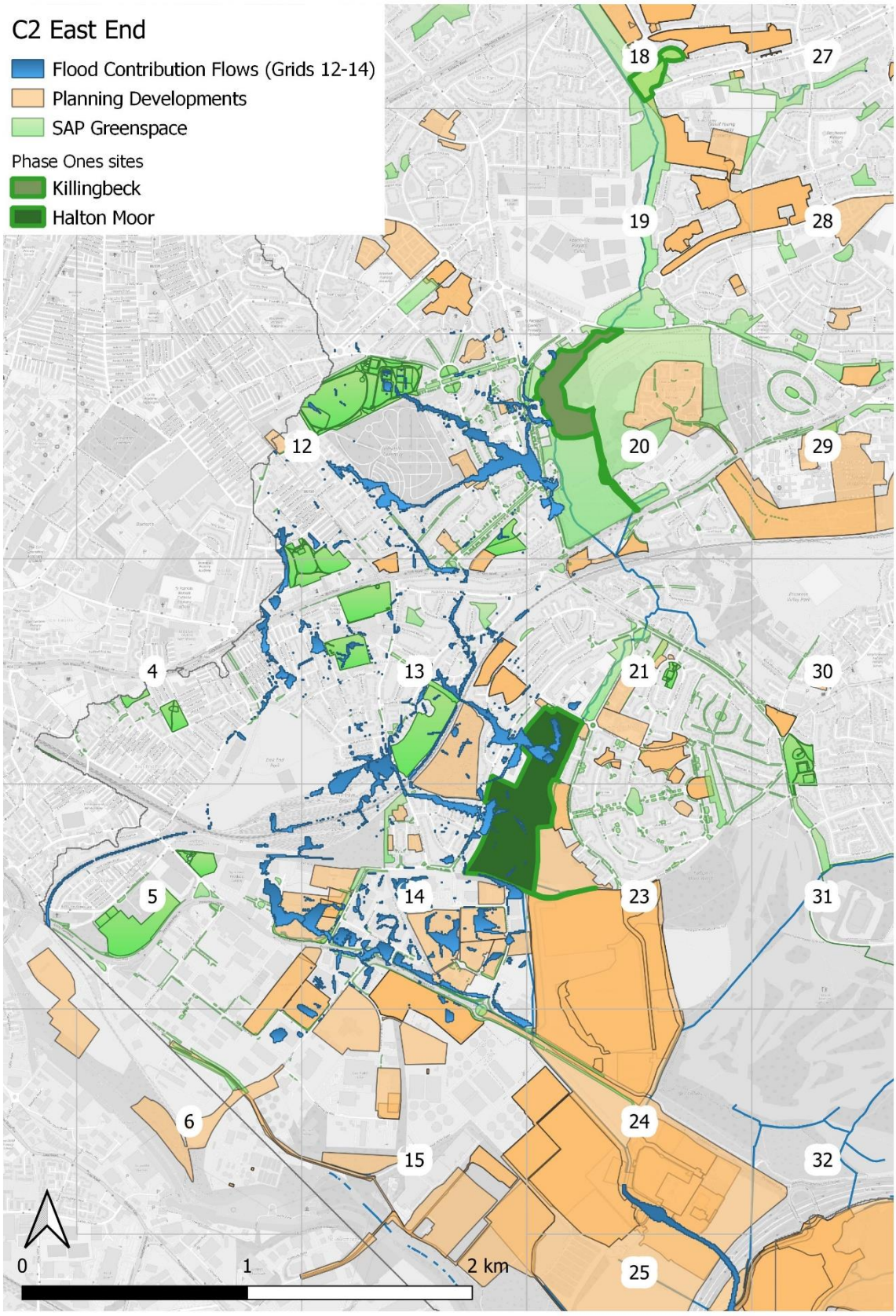

Figure 6. Mid catchment area of interest (C2). Flow contributions from grids 12-14 (see Figure 4 also). Site allocation Planning (SAP) data showing greenspace & major planning applications (developments) that can be considered in water pathway management. Phase One sites also illustrated.

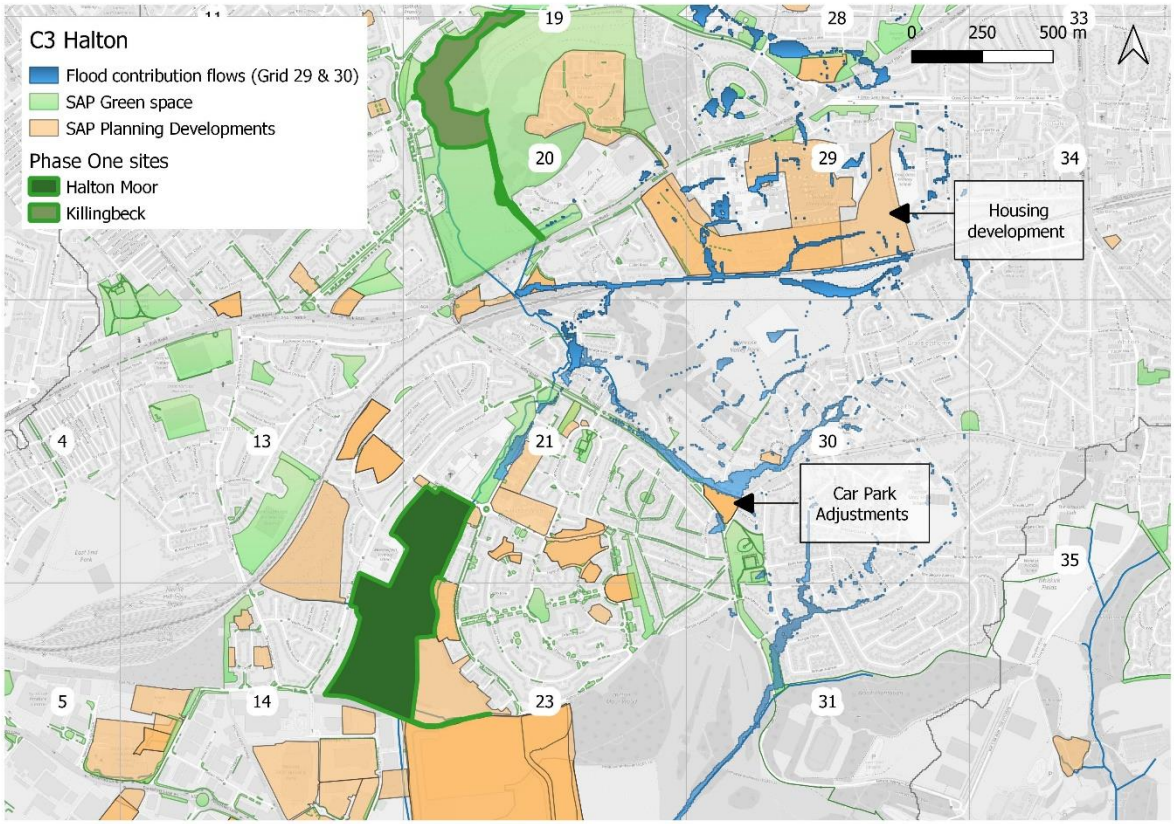

Figure 7. Lower catchment area of interest (C3). Halton Centre (grid 30 & 29) has the highest contribution to flooding (depth & area). Site allocation Planning (SAP) data showing greenspace & major planning applications (developments). Planning of car park adaptations on grid 30 contribution flow could be investigated (southwest area of grid 30), along with housing development (grid 29). .

Acknowledgements

The original research for this project was developed as part of the project "Urban Flood Resilience in an Uncertain Future" (EP/P004261/1), http://www.urbanfloodresilience.ac.uk/.

With thanks to the iCASP project team:

- Tom Willis (University of Leeds), Jonathan Moxon, David Parish (now retired), Matt Sherwood (Leeds City Council), Luke Williams (Environment Agency)

Thanks also to those organisations & individuals who kindly participated in interviews, surveys and workshops:

- Leeds City Council FRM team and Umar Usman & James Kilroy,
- Environment Agency
- WSP Group Leeds