West Yorkshire Flood Innovation Programme Accelerator Project

Work Package 4: Develop and embed system-based Flood Risk Management to prepare for climate change Feasibility Study Report

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Executive summary

Observing the source of flooding (i.e. its origin) within an urban catchment is important to understand the range of potential solutions to reduce flood hazard. An approach to map the flood source area (FSA), allows hazard models to be used to indicate the source of the hazard and potential flows across a catchment. In previous work the FSA approach has been identified as a potentially useful tool for identifying and negotiating partnership contributions to flood schemes (pre-scheme developments). The exact utility and practitioner perspective of the approach for managing urban flood risk is, however, unknown. We utilised a modelling and spatial analysis approach from a catchment in the east of Leeds - Wyke Beck - to scope a practical approach. 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 and for broader application by local authorities across West Yorkshire. We conducted a survey on the approach and have connected the FSA mapping to economic damage data to illustrate the spatial distribution of economic benefits of tackling flooding at source. Partnership engagement and area prioritisation were identified as the key benefits of using the approach. We have identified monetary values for improving water storage in three locations (using different potential methods). Finally, it was shown 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. Recommendations include more stakeholder-led discussion on the direction of future work in this area to benefit research and application.

Background and rationale

Flood frequency and magnitude is highly likely to increase as climate change progresses. Flood source maps identify areas within a catchment which contribute most towards flooding and assess flow pathways and areas within the catchment most at risk from flooding. These maps enable assessment of priority areas for catchment management and/or land-use change which maintains or lowers flood risk. Two examples of potential uses are:

Example 1. Potential locations for a new housing development may be considered based on the extent to which that location contributes to downstream flooding. If the chosen location is likely to increase downstream flood risk, additional flood mitigation measures may be required which should be accounted for at the planning stage.

Example 2. Where locations have high contribution to flood risk downstream, flood mitigation measures may be concentrated on those areas and flow pathways stemming from those areas.

During a previous project (System-based urban infrastructure management (SUIM) – Yorkshire Integrated Catchment Solutions Programme (iCASP)), it was estimated that the completed Wyke Beck Flood Alleviation Scheme had £4.1M in initial costs and around ~£1.5M from section 106 contributions (from housing developers). Flood source maps in Wyke Beck may have been able to support negotiations, and in this case could have unlocked an additional £40k-£800k from developer contributions. This was a primary motivation for exploring the use of FSA in catchment scheme development.

This WYFLIP Accelerator scoping study explored the use of flood source mapping, identified strategic areas for future mapping, and created a new framework (pathway to decision making) for flood source (system)-based flood risk management. The following objectives were set out in April 2023, to be completed by March 2025.

1. Identify strategic areas for flood source (system) mapping across West Yorkshire, and connect flood source maps to impact estimation (e.g. properties & roads)
2. Evaluate current use of flood source maps within West Yorkshire, including for economic, technical, environmental, and social impact.
3. Engage with other WYFLIP Accelerator scoping studies on spatial data requirements and collection to help identify opportunities for use of flood source mapping.
4. Integrate a new framework with current practice to a) identify opportunities to manage flood risk at source, and b) evaluate the co-benefits of such activities in business case portfolios for climate ready planning (and prioritisation).

Research methodology

The project utilised previous research methods from a research and impact translation project, System-based urban infrastructure management (SUIM), which used FSA approaches and spatial observations in GIS to identify three key FSAs in the Wyke Beck catchment (Figure 1A).

Firstly, the FSA output maps were linked to damage repair or insurance costs (therefore potential benefits through costs avoidance) using the Treasury Green Book guidance (HM Government, 2022). This enabled FSA to be reviewed in terms of monetary damage reduction (**objective 1**).

Second, through a workshop in 2024, a low-cost participatory GIS method (connected to the WP5 scoping study – **objective 3**) was used to validate the FSA and identified water (flood) extent areas via stakeholder observation and knowledge. A GIS 'heat map' layer was created, using inputs from stakeholders with active knowledge of the Wyke Beck catchment, which showed stakeholder-identified flood source and hazard areas (Figure 1B).

A survey was designed and distributed requesting feedback on usability of the FSA method and outputs (using examples from the SUIM project), and on how future FSA maps could be better designed for utilisation in planning new flood schemes & partnership working (**objectives 2 and 4)**. Continued discussion & meetings were held with members of the Wyke Beck Flood Alleviation Scheme. Post process maps were produced to address the survey-identified challenges (**objectives 1 & 2**).

The results and outputs from this scoping study were presented to the WYFLIP Board in December 2024 to support knowledge sharing.

Findings

Our findings have been divided into three categories: 1. Connecting flood source maps to economic impacts; 2. Engaging with other WYFLIP work packages / scoping studies - validation of FSA maps; and 3. Evaluating use of flood source mapping.

Connecting flood source maps to economic impacts

Wyke Beck Phase One Flood Alleviation Scheme had £4M initial scheme costs and around ~£1.5M from section 106 contributions. With FSA maps to support new negotiations, Phase One could have unlocked and additional £40k-£800k from developer contributions in the Wyke Beck subcatchment. These values were calculated from a review of the Flood Alleviation Scheme reports (WYCA, 2024)

Following comments received from survey respondents, we explored the economic analysis associated with the FSA approach. This used the locations identified in SUIM project (C1-3, Figure 1A, Table 1), associated with future proofing existing infrastructure (C1), increased green infrastructure storage (C2), and public engagement on rainwater storage (C3). The monetary impact analysis carried out (Tables 2 and 3; Appendix 1) demonstrates the potential cost[1] of damage to roads[2] (Table 1) or buildings[3] (Table 2) due to flooding[4] from each FSA individually.

For example, improving water storage in C1 FSA1 could save between £262,738 and £875,795 in damages. In total, improved flood defences in C1-3 could equate a total economic value of >£12M (Table 2). Similarly, the analysis can examine buildings impacted by FSAs (Table 3); reducing the flow of water from source areas within zones C1-3 could have potential economic value of >£13M. Although values cannot be used directly in scheme business cases, they provide evidence for strategic cases that look to include interventions in multiple locations across the catchment.

The values given in Tables 1 and 2 may be used as an estimate of savings, should flood risk reduction measures be implemented. However, it should be noted that costs are calculated per FSA. Some hazard areas will receive water from multiple FSAs. When planning flood mitigation measures, consideration should be given as to whether the hazard area has one or multiple source areas using all available FSA maps. Hazards with few source areas, and high associated costs, will have greatest economic return for flood mitigation.

[1] Costs adjusted for inflation using the Bank of England inflation calculator (November 2024)

[2] Costs calculated using 'unit reconstruction for resurfacing a local road' only, comparing 'quiet' and 'busy' categories (Flood and Coastal Erosion Risk Management Manual for Economic Appraisal). Further analysis is required to calculate costs associated with flooding to major roads.

[3] Costs calculated using The Green Book (2021) based on typical damage per property per flood event for a) <0.1m depth; b) >1.2m depth; c) no flood protection and no warning service; and d) existing protection against a 1-in-200 chance and a flood warning of >8 hours.

[4] The FSA maps show water extent, not the depth of water. Cost analysis has assumed flood occurrence.

Table 1 Flood Source Area opportunities (C1-3) see Figure 1.

	Location	Investigation
C1	Upper catchment (Roundhay)	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	Increased storage: maximizing flooding of green space & reduce transport flooding: Grids 12-14.
C3	Halton Centre	Urban area storage improvements. Grid 30 & 29 – high contribution to flooding (area & depth) in catchment. Potential car park alteration is identified (grid 30)

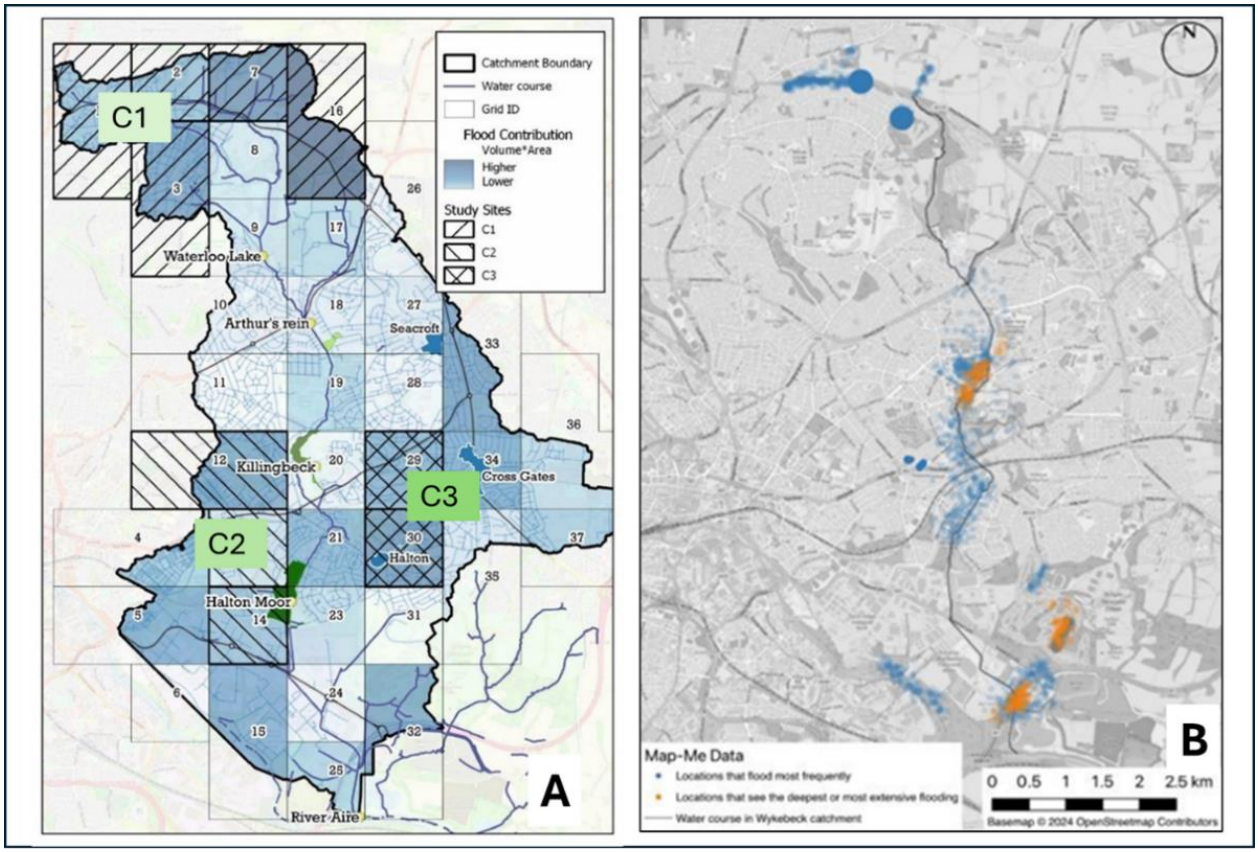

Figure 1: A: Flood source area (FSA) map of Wyke Beck Catchment. Colours indicate areas that contribute the most to flooding within the catchment (the source of hazard, i.e. not always locations of flood hazard) through flows in and around the grids (numbered). Locations of Phase One green infrastructure schemes are shown along with study sites C1-C3 identified in a previous project. These sites were used to examine the monetary impact of interventions in the source areas. B: Results from an interactive Map-Me exercise with stakeholders asked to identify sources of flooding in the Wyke Beck catchment. Observations suggest stakeholder engagement can be used for scheme identification (and partnership development) in locations where detailed hydrological mapping does not yet exist.

Table 2. Grid ID monetary impact analysis from transport damage (excludes disruption to travel/services). These can indicate the economic benefit of retaining water with each grid id.

FSA Grid ID.		Damage to all road types from flood source (see grid id.)	
		Lower estimate (direct damage, £)	Upper estimate (direct damage, £)
C1	1	262,738	875,796
	2	108,405	361,353
	3	192,739	642,464.
	16	53,552	177,616
C2	13	306,210	1,020,071
	14	188,605	628,688
	15	136,974	489,912
C3	29	210,431	701,438
	30	274,088	913,632

Table 3. Grid ID monetary impact analysis from building damage (properties only). These can indicate the economic benefit of retaining water with each grid id.

FSA Grid ID		Total number of buildings within the FSA flow pathway	Typical damage per property per flood event (<0.1m depth, £)
C1	1	61	711,327
	2	43	501,427
	3	148	1,725,8430
	16	9	2,915,275
C2	12	250	559,733
	13	48	81,628
	14	7	104,950
C3	29	182	2,122,321
	30	190	2,215,609

Engaging with other WYFLIP work packages - validation of FSA maps

During interactions with other work packages (scoping studies), it was identified that the Map-Me 'spray-can' tool approach used for Work Package 5 would be useful for examining stakeholder understanding of the hydrological hazard and sources within the Wyke Beck catchment. In a workshop attended by Yorkshire regional flood managers and practitioners, participants were asked to identify areas of deep flooding and areas of widespread flooding on a map of the Wyke Beck catchment (Figure 1B). Comparing Figures 1A and 1B, FSA maps and stakeholder 'insight' are reasonability well aligned. This provides a level of validation of the FSA approach and suggests that stakeholder insight can be used where computational models do not currently exist.

Evaluating use of flood source mapping

Previous engagement with the FSA approach (SUIM study) 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 and growth funding
- Derestriction of the prescribed approach to option selection.

The survey responses we received were detailed and knowledgeable viewpoints from Local Authority and Environment Agency staff. Overall, there was general agreement on the utility of the approach - for example, looking at interventions in areas away from the hazard impacts (e.g. up-stream). It was also suggested that the FSA maps would be useful for working with project partners in workshops (e.g. supporting negotiations). The utility would suit pre-scheme development (optioneering) and higher-level strategic flood risk assessments.

Based on the survey responses, further improvements to the FSA approach included:

- Examining benefit areas across catchments (e.g. from damage reduction): this was carried out partially during the project (see previous economic section). The simulation of scheme benefits in the mapping process (e.g. feedback loops) would be useful, however, technically this is a challenge and would take some computational resource and skill in a future study.
- Scale of mapping: suggestions of being able to expand the scale of the maps for transparency was also suggested and moving the idea towards a user tool to allow users to scan areas for flood source information. This would be possible in a future study if funding became available.
- Extension of data sets of use for scheme identification: The map outputs would be more useful with additional data: Land Drainage Plans, Sewer Network Plans, Highway Drainage Plans, Land Uses.

Recommendations and proposed next steps

Roll out of the approach: there is clear potential of the approach scoped out in this study. We strongly recommend it is adopted and applied in a development scheme to demonstrate the value explicitly. Through that approach the interaction with site allocation planning data can be scrutinised and reviewed against water management approaches.

Partnership engagement: future projects should use Map-Me and FSA data to engage with multiple stakeholder sectors on water management opportunities to develop strategies for climate ready planning. This would require an assessment of more catchments (pluvial and fluvial flood dominated systems) with new FSA modelling, also with consideration of broadening the scale of modelling to examine wider regional analysis of flood source (e.g. at a sub catchment scale). This would enable sub catchments to be graded in terms of their contribution to flooding across the region. Recent University of Leeds research has used the FSA approach to investigate sub-catchment contributions to flood risk at the regional scale and so it is recommended that this work is expanded). This would help prioritisation of funding allocation to areas with the most widespread benefits.

Area prioritisation: the approach will allow future examination of the type of flood source e.g. grid-to-grid flooding, where one source area floods itself or one other source area, compared to grid-to-grids flooding, where one source area floods multiple other source areas. Similarly, further analysis of whether there is one contributing area or multiple contributing areas to specific flood hazards could be useful to determine how well flood management in specific FSAs may influence flooding.

Appendix 1: Cost and inundation area results for C1, C2 and C3

Roads

FSA		Area of water covering road due to source area (m^2)						Total area of water covering road due to source area (m^2)
		A Road	Classified Unnumbered	Motorway	Not Classified	Unclassified	Unknown	
C1	1	6344.09	580.54		447.87	5443.80	112.85	12929.14
	2	3415.16				1919.40		5334.57
	3				245.77	9034.60	204.15	9484.52
	16	916.68		379.85		488.29	837.27	2622.10
C2	13	889.90	69.25	379.85	317.89	12548.97	862.50	15068.36
	14	111.81		379.85		7349.73	1439.77	9281.17
	15	741.03		379.85	99.29	2983.78	3028.49	7232.45
C3	29	290.22		379.85	413.74	7078.53	2192.81	10355.14
	30		2751.36	379.85	886.27	8725.16	745.07	13487.71

FSA		Total area of water covering roads due to source area (m^2)	MCM2013 *Calculation based on costs for *local* roads, applied to *all* road types		Adjusted cost estimate Adjusted from 2013 for inflation to April 2024 *correct 30.05.2024	
			Lower cost estimate (direct damage, £)	Upper cost estimate (direct damage, £)	Lower cost estimate (direct damage, £)	Upper cost estimate (direct damage, £)
C1	1	12929.14	193,937.17	646,457.24	262,738.59	875,795.76
	2	5334.57	80,018.50	266,728.34	108,405.39	361,353.11
	3	9484.52	142,267.84	474,226.14	192,739.36	642,463.64
	16	2622.10	39,331.55	131,105.17	3552.19	177,616.15
C2	13	15068.36	226,025.38	753,417.94	306,210.21	1,020,071.16
	14	9281.17	139,217.48	464,058.26	188,605.98	628,688.41
	15	7232.45	108,486.68	361,622.26	136,974.13	489,911.95
C3	29	10355.14	155,327.16	517,757.19	210,431.21	701,437.81
	30	13487.71	202,315.60	674,385.33	274,088.79	913,631.56

Green Spaces

FSA		Area of water covering green space due to source area (m^2)														Total area of water covering green space from source area (m^2)
		Allotments Or Community Growing Spaces	Amenity: Residential or Business	Amenity: Transport	Cemetery	Golf Course	Institutional Grounds	Land Use Changing	Natural	Play Space	Playing Field	Private Garden	Public Park or Garden	Religious Grounds	School Grounds	
C1	1		12336.55	11365.21			1112.55		13923.40		8115.22	20572.45	601.99	51.13	230.17	68308.67
	2		11827.40	2650.54		25.00	1180.27		14329.03	6.84		9732.91				39751.99
	3	378.31	11602.42	3024.68		114.55	1112.55		120839.45	6.84	10214.42	32677.61	9943.41	1049.20		190963.45
	16	582.05	9362.87	439.93			1308.31	889.46			14453.53	27462.40	44.45	0.21	3329.71	57872.91
C2	13		20016.02	3377.21				2978.84	1396.65			5740.28				33509.00
	14		31766.68	272.85				1351.57	47211.83			1248.86				81851.80
	15		43868.73	1759.98		28029.58			136555.27			435.85				210649.42
C3	29		13845.86	6438.42	149.87		7837.13	4128.67	92.26			22872.07	10533.80		2503.69	68401.78
	30		27091.44	2786.30		147.20	107.78	3960.15	11807.91		465.92	23624.06	43003.32	168.60	2148.89	115311.58

A lack of appropriate data meant that damage costs could not be associated with green spaces.

Buildings

Building type	Area of water covering buildings (ground floor & *NA* only) due to source area (m^2)									Total
	C1				C2			C3		
	1	2	3	16	13	14	15	29	30	
Ancillary Building						1518.5	1070.0	1192.1		3780.5
Bus Shelter				0.1						0.1
Care / Nursing Home	318.3									318.3
Children / Nursery					137.3					137.3
Chimney / Flue					488.9					488.9
Commercial									762.7	762.7
Dentist	10.0									10.0
Detached	2378.0	865.0	5950.8	163.1	144.5			774.5	2460.6	12736.6
Dwelling			0.0					1085.2		1085.3
Education									128.3	128.3
Electricity Distribution Facility							236.1			236.1
Electricity Production Facility					10289.1	13064.8				23353.9
Electricity Sub-Station	7.0	7.8	11.7			234.8				261.2
Factory/Manufacturing						5480.4	818.7			6299.1
Fast Food Outlet / Takeaway (Hot / Cold)					25.0				2344.7	2369.7
Fire Station								390.1		390.1
Food Processing						646.5				646.5
Health Care Services								267.9	94.4	362.3
HMO Bedsit / Other Non Self Contained Accommodation									337.7	337.7
HMO Not Further Divided					57.1	35.8		0.1	269.1	362.1
Hospital								9610.1		9610.1
Hospital / Hospice								2609.0		2609.0
Incinerator / Waste Transfer Station					3311.3	4013.6				7324.9
Indoor / Outdoor Leisure / Sporting Activity / Centre	232.5		11.7	11.7						255.9
Job Centre					25.0					25.0
Library									247.8	247.8
Licensed Private Members Club					253.4					253.4
Local Government Service						1029.9				1029.9
Office / Work Studio			75.1		25.0			1284.2	11.1	1395.4
Other Licensed Premise / Vendor					25.0				159.6	184.6
Place Of Worship	34.8	34.8	1102.0		25.0				0.2	1196.8
Primary School					1350.2			3862.9	3417.9	8631.0
Professional Medical Service									2931.8	2931.8
Property Shell	27.9	416.1	1944.9	575.7	251.4			1208.7	1973.1	6397.8

Public / Village Hall / Other Community Facility					0.5			25.0		25.5
Public House / Bar / Nightclub					25.0				109.0	134.0
Railway Asset					8851.6					8851.6
Restaurant / Cafeteria			344.1	19.0					10327.4	10690.5
Retail Service Agent								14.7	2931.8	2946.5
Secondary School									63.2	63.2
Self Contained Flat (Includes Maisonette / Apartment)	2666.1	1500.8	14630.2	1727.2	2951.1			7315.4	3136.4	33927.2
Semi-Detached	5283.9	2626.3	7036.1	128.1	12412.0	1501.8		10186.3	11442.9	50617.4
Shop / Showroom	60.0				162.8	1149.0	1070.0	444.1	17109.7	19995.6
Telecommunication					488.9			91.8	762.7	1343.3
Terraced	10.0	1406.6	7496.9	1617.2	12993.0	354.1		4401.6	7203.0	35482.5
Unknown	4558.7	179.7	1979.6	520.0	25261.0	48773.1	18108.3	5209.6	12286.9	116876.9
Vet / Animal Medical Treatment									762.7	762.7
Warehouse / Store / Storage Depot					9367.1	35798.5	6873.3		1333.1	53372.0
Workshop / Light Industrial					1746.3	2872.9	1642.9	31.2	0.1	6293.5
Total	**15587.2**	**7037.1**	**40583.1**	**4762.2**	**90667.6**	**116473.6**	**29819.4**	**50004.5**	**82607.9**	**437542.5**

Building type	Number of buildings (ground floor & *NA* only) within the FSA flow pathway									Total
	C1				C2			C3		
	1	2	3	16	13	14	15	29	30	
Ancillary Building			1			1		2		4
Care / Nursing Home	1									1
Channel / Conveyor / Conduit / Pipe							1			1
Children / Nursery					1					1
Church Hall / Religious Meeting Place / Hall			1							1
Detached	19	6	36	1	2			8	23	95
Electricity Production Facility					2	2				4
Electricity Sub-Station			1						1	2
Factory/Manufacturing						1				1
Fast Food Outlet / Takeaway (Hot / Cold)									1	1
Fire Station								1		1
Food Processing						1				1
Health Care Services								1		1
Hospital / Hospice								1		1
Incinerator / Waste Transfer Station					1	1				2
Indoor / Outdoor Leisure / Sporting Activity / Centre			1	1						2
Land					2				1	3
Library									1	1
Licensed Private Members Club					1					1
Lock-Up Garage / Garage Court					1					1
Office / Work Studio			2							2
Other Licensed Premise / Vendor									1	1
Primary School								2	2	4
Property Shell		2	10		3			3	4	22
Public / Village Hall / Other Community Facility								1		1
Restaurant / Cafeteria			1							1
Retail Service Agent								1		1
Self Contained Flat (Includes Maisonette / Apartment)			1		4				1	6
Semi-Detached	41	27	74	1	134	24		129	117	547
Shop / Showroom								1	7	8
Terraced		8	20	6	91	5		32	31	193
Warehouse / Store / Storage Depot					6	10	4			20
Workshop / Light Industrial					2	3	2			7
Total	**61**	**43**	**148**	**9**	**250**	**48**	**7**	**182**	**190**	**938**

FSA		Total number of buildings within the FSA flow pathway	Adjusted* cost estimate (£) relating to buildings *Corrected to 2024 prices from 2020/21 prices as per The Green Book			
			A: Typical damage per property per flood event (<0.1m depth); **£11,661.10 per property (2020 cost = £9,500)**	**B: Typical damage per property per flood event (>1.2m depth)** **£52,168.11 per property (2020 cost = £42,500)**	**C: A property with no flood protection and no warning service** **£6,682.43 per property per annum (2020 cost = £5,444)**	**D: A property with existing protection against a 1-in-200 chance and a flood warning service of >8 hours** **£51.55 per property per annum (2020 cost = £42)**
C1	**1**	61	£711,327.10	£3,182,254.71	£407,628.23	£3,144.55
	2	43	£501,427.30	£2,243,228.73	£287,344.49	£2,216.65
	3	148	£1,725,842.80	£7,720,880.28	£988,999.64	£7,629.40
	16	9	£2,915,275.00	£13,042,027.50	£1,670,607.50	£12,887.50
C2	**13**	250	£559,732.80	£2,504,069.28	£320,756.64	£2,474.40
	14	48	£81,627.70	£365,176.77	£46,777.01	£360.85
	15	7	£104,949.90	£469,512.99	£60,141.87	£463.95
C3	**29**	182	£2,122,320.20	£9,494,596.02	£1,216,202.26	£9,382.10
	30	190	£2,215,609.00	£9,911,940.90	£1,269,661.70	£9,794.50